New Jersey Field Guide
for Energy Auditors and Inspectors of Single Family Housing

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New Jersey Field Guide for Energy Auditors and Inspectors of Single Family Housing

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This *Field Guide* describes procedures used to analyze and improve the performance of existing homes retrofitted under the Department of Energy's Weatherization Assistance Program in the State of New Jersey.

In compiling this publication, the authors have benefited from the experience of many individuals who have reviewed our documents, related their experiences, or published information from which we've gained insight. Though we can't name everyone to whom we're indebted, we acknowledge the specific contributions of the following people: Michael Blasnik, David Butler, Anthony Cox, Bob Davis, Jim Davis, R.W. Davis, Rick Karg, Eric Kjelshus, Rudy Leatherman, Bruce Manclark, Gary Nelson, Russ Shaber, Cal Steiner, Ken Tohinaka, John Tooley, Bill Van Der Meer, and Doug Walter. We take full responsibility, however, for the content and use of this publication.

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Preface

The New Jersey Auditor and Inspector Field Guide outlines a set of best practices for energy audits, in-progress inspections, and final inspections in New Jersey. This guide speaks to the energy auditor or inspector whose main focus is on energy auditing, work scope development, and quality control.

The purpose of this guide is to provide specific guidance on evaluating a home's existing condition of insulation, air sealing, heating, cooling, baseload, and health and safety. This guide incorporates information from the following standards and specifications.

- DOE Standardized Work Specifications (2011)
- DOE Weatherization Job Task Analysis (2011)
- WAP Policy Directives from 2005 to 2011
- Building Performance Institute (BPI) Standards (2012)
- International Residential Code 2009
- International Energy Conservation Code 2009
- National Fuel Gas Code (NFPA 54) 2009
- International Mechanical Code 2009

The National Renewable Energy Laboratory (NREL) completed a review of this guide's content in late 2010 that greatly improved its alignment with DOE and BPI standards along with suggesting many other substantial technical enhancements.

This guide begins with a discussion of energy auditing, inspecting, customer relations, and work-scope development. Then we discuss baseload measures such as water heaters and refrigerators from a weatherization perspective. Following baseload are four chapters that explain energy conservation measures (ECMs) that are applied to the building shell: blower door testing, air-sealing, insulation, and doors and windows. After that is a long and important chapter on heating and cooling. Here we've included more detail than you may need, but we feel that all the content is important to weatherization agencies in New Jersey.

We've included a dedicated chapter on mobile homes where we discuss the ECMs particular to mobile homes. In this chapter we sometimes refer to other sections of the guide that contain information that's relevant to both mobile homes and site-built homes.

We finish with health and safety, an important topic for everyone. There are many DOE directives and long-standing weatherization practices discussed in this chapter. The last part of the chapter covers the most statistically threatening hazards to workers, including driving, falls, back injuries, and respiratory ailments.

We hope you find this guide informative and easy to use, and we welcome all your feedback. Thanks for your hard work on behalf of low-income families in the Department of Energy's Weatherization Assistance Program.

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TABLE OF CONTENTS

1: Energy Audits, Client Relations, and Inspections

Purposes of an Energy Audit 17
Auditing & Inspection: Judgment and Ethics. 18
Recordkeeping for Energy Audits & Inspections 20

Parts of an Energy Audit 22
Visual Inspection 22
Diagnostic Testing 28
SIR Calculations with Energy Software. 29

The Work Order 30
Questions about the Audit and Work Order 31

Work Inspections 32
In-Progress Inspections 32
Final Inspections 32
Quality Control Versus Quality Assurance 33

Client Relations. 34
The Energy Auditor's Client Interview 35
Communication for the Inspector 36
Denial or Deferral of Weatherization Services 36

Understanding Energy Usage 38
Baseload Versus Seasonal Use 38

Client Education. 41
Reducing Heating Consumption 42
Reducing Electric Baseload 43
Reducing Hot Water and Laundry Consumption 43
Reducing Cooling Consumption 44

2: Baseload Measures

Water-Heating Energy Savings 47
Determining the Water Heater's Insulation Level 49
Water Heater Blankets 50
Measuring and Adjusting Hot Water Temperature 51
Water-Heater Pipe Insulation 52
Water-Saving Shower Heads 53
Storage Water Heater Choices 54
Water-Heater Replacement Decisions 54
Comparing Water Heaters 55
Water Heater Installation 57
Alternative Water-Heating Products 58
Refrigerator Evaluation 61
Refrigerator Metering Protocol 62
Lighting Improvements 65
Servicing Clothes Dryers 66

3: Diagnosing Shell Air Leakage

Shell Air-Leakage Fundamentals 69
Goals of Air-Leakage Testing 70
House Airtightness Testing 72
Blower-Door Principles 72
Preparing for a Blower Door Test 74
Blower-Door Test Procedures 76
Approximate Leakage Area 78
Evaluating Home Ventilation Levels 78
Whole-House Ventilation Requirement 79
Local (Spot) Ventilation Requirement 80
The ASHRAE 62.2–2010 Infiltration Credit 81
Verifying Fan Airflows for Ventilation 83
Pollutant Control 84
Pollution-Control Checklist 84

Testing Air Barriers 85
Primary Versus Secondary Air Barriers 87
Simple Pressure Tests. 88
Simple Zone Pressure Testing. 89
Decisions about Basement and Crawl Spaces. 96
Controlling House Pressure 100
Duct-Induced Room Pressures 100

4: Air Sealing Homes

Air Sealing Fundamentals. 103
Air Sealing Strategy. 104
Air Sealing Safety 105
Air Sealing Materials 106
Air Barrier Materials. 106
Stuffing Materials. 108
Caulking and Adhesives 109
Liquid Foam Air Sealant 112
Sealing Major Air Leaks and Bypasses 113
Removing Insulation for Air Sealing 115
Major Air Leak Locations & Treatments 115
Minor Air Sealing 127

5: Installing Insulation

Insulation Material Characteristics. 129
Fibrous Insulation Materials. 130
Foam Insulation Materials 133
Open-Cell Polyurethane Spray and Injectable Foam . . 134
Insulation Safety and Durability 137
Insulation Durability. 138
Attic and Roof Insulation. 140
Preparing for Attic Insulation 140
Safety Preparations for Attic Insulation 142

Attic Ventilation 146
Blowing Attic Insulation 147
Insulating Closed Roof Cavities 149
Installing Attic Batt Insulation 152
Cathedralized Attics 152
Vaulted Attics 153
Finished Knee Wall Attics 154
Walk-Up Stairways and Doors 158

Wall Insulation 160
Wall Insulation: Preparation and Followup 161
Retrofit Closed-Cavity Wall Insulation 164
Insulating Unreinforced Brick Walls 172

Insulating Floors and Foundations 173
Preparing for Foundation or Floor Insulation 174
Installing Floor Insulation 179
Basement Insulation 183

Duct Insulation 186

6: Windows and Doors

Window Replacement Specifications 189
Window Replacement Options 190
Window Energy Specifications 190
Removing Old Windows 191
Installing Replacement Windows 191

Window Safety Specifications 194
Windows Requiring Safety Glass 194
Fire Egress Windows 197

Door Replacement and Repair 198
Door Replacement 198
Door Repair and Improvement 198

7: Evaluating Heating and Cooling Systems

Essential Combustion Safety Tests 203
Leak-Testing Gas Piping 204
Carbon Monoxide (CO) Testing 204
Worst-Case CAZ Depressurization Testing 205
Improving CAZ Depressurization and Draft 210
Zone Isolation Testing for Atmospherically Vented Appliances 212

Heating System Replacement 212
Combustion Furnace Replacement 212
Gas-Fired Heating Installation 215
Combustion Boiler Replacement 217
Oil-Fired Heating Installation 220

Gas Space Heater Replacement 224
Space Heater Operation 225
Unvented Space Heaters 225

Electronic Combustion Analysis 225
Combustion Efficiency Test for Furnaces 228
Critical Combustion-Testing Parameters 233

Inspecting Gas Combustion Systems 234

Oil Burner Safety and Efficiency Service 236
Oil Burner Inspection 236
Oil Burner Testing 238
Oil Burner Adjustment 240
Oil Burner Maintenance and Visual Checks 241

Inspecting Furnace Heat Exchangers 242

Wood Stoves 243
Wood Stove Clearances 243
Wood Stove Inspection 245

Inspecting Venting Systems 248
Vent Connectors 248

Chimneys 251
Masonry Chimneys 252
Manufactured Chimneys. 253
Chimney Terminations 254
Metal Liners for Masonry Chimneys 254

Special Venting Considerations for Gas 256
Venting Fan-Assisted Furnaces. 256

Combustion Air. 259
Un-Confined-Space Combustion Air 260
Confined-Space Combustion Air 260

Ducted Air Distribution 263
Solving Airflow Problems 264
Evaluating Furnace Performance. 268
Improving Forced-Air System Airflow 272

Evaluating Duct Air Leakage 274
Troubleshooting Duct Leakage 274
Measuring House Pressure Caused by Duct Leakage . . 278

Sealing Duct Leaks 280
Sealing Return Ducts 281
Sealing Supply Ducts 282
Duct Boots, Registers, and Chases. 284
Materials for Duct Sealing. 284

Duct Insulation 285

Hot-Water Space-Heating Distribution 286
Boiler Efficiency and Maintenance 286
Distribution System Improvements 287

Steam Heating and Distribution. 290
Steam System Maintenance 290
Steam System Energy Conservation. 292

Programmable Thermostats 293

Electric Heat. 293
Electric Baseboard Heat. 294
Electric Furnaces 295

Central Heat-Pump Energy Efficiency 295
Room Heat Pumps 299
Ductless Minisplit Pumps 301

Evaluating Ducted Central Air-Conditioning Systems . . . 301
Central Air-Conditioner Inspection 303
Air-Conditioner Sizing 304
Duct Leakage and System Airflow 305
Evaluating Air-Conditioner Charge 305

8: Mobile Homes

Mobile Home Air Sealing 308
Shell Air Leakage Locations 309
Duct Leak Locations 311
Belly Pressure Test 312

Mobile Home Heating 314
Furnace Maintenance and Energy Efficiency 316
Furnace Replacement 316

Mobile Home Insulation 319
Insulating Mobile Home Roof Cavities 319
Mobile Home Sidewall Insulation 324
Mobile Home Floor Insulation 326

Mobile Home Windows and Doors 328
Mobile Home Storm Windows 329
Replacing Mobile Home Windows 330
Mobile Home Doors 330

Cool Roofs for Mobile Homes 330

Mobile Home Skirting 332

9: Health and Safety

Carbon Monoxide (CO) 334
Causes of Carbon Monoxide 334
Gas Range and Oven Safety 336

Smoke and Carbon Monoxide Alarms 338
Smoke Alarms 338
CO Alarms. 339

Moisture Problems 340
Symptoms of Moisture Problems. 342
Preventing Moisture Problems 343

Other Pollutants 345
Radon. 345
Asbestos 346

Lead-Safe Procedures. 348
EPA RRP Requirements 348
Lead-Safe Weatherization. 349

Whole-House Ventilation Systems. 351
Exhaust Ventilation 351
Supply Ventilation. 353
Balanced Ventilation 353
Adaptive Ventilation. 355
Electrical Safety 356

Appendices 359

Resources 359
Energy Auditor Prerequisites. 360
Q.C. Inspector Prerequisites 361
Required Diagnostic Equipment 362
R-values for Common Materials 363
Calculating Attic Insulation 364
Calculating Wall Insulation. 368
Calculating Mobile Home Insulation. 371
ASHRAE 62.2 Ventilation 373
Refrigerator Dating Chart 374
Measuring BTU Input on Natural Gas Appliances. 375
DOE Health and Safety Guidance. 378
Index. 389

Chapter 1: Energy Audits, Client Relations, and Inspections

This chapter outlines the operational process of energy audits, work orders, and final inspections as practiced by non-profit agencies and contractors working in the Department of Energy's (DOE) Weatherization Assistance Program (WAP).

The mission of DOE WAP is **"To reduce energy costs for low-income families, particularly for the elderly, people with disabilities, and children, by improving the energy efficiency of their homes while ensuring their health and safety."**

This chapter also discusses ethics, client relations, and client education.

1.1 Purposes of an Energy Audit

An energy audit is a set of procedures that evaluates a home's existing condition and outlines improvements to the energy efficiency, health, safety, and durability of the home.

Depending on the level of the audit, an energy audit includes some or all of the following tasks.

1. Inspect the building and its mechanical systems to gather the information necessary for decision-making.
2. Evaluate the current energy consumption along with the existing condition of the building.
3. Diagnose areas of energy waste, health and safety, and durability problems related to energy conservation and evaluate the health and safety impact of the ECMs to encourage behavioral changes.
4. Recommend energy conservation measures (ECMs).
5. Predict savings expected from ECMs.

6. Estimate labor and materials costs for ECMs.
7. Educate residents about their energy usage and your proposed energy retrofits.
8. Provide written documentation of the energy audit and the recommendations offered.
9. Energy audits justify how program dollars are spent in a unit and/or building.

1.1.1 Auditing & Inspection: Judgment and Ethics

Good decisions are extremely important to your success as an energy auditor or inspector. Good decisions depend on judgment and ethics.

Promote the goals of the WAP program at all times.

1. Save energy and money for the client in a cost-effective manner.
2. Improve health and safety
3. Improve building durability
4. Improve comfort

Weatherization Ethics Basics

5. Know, understand, and comply with the requirements of the WAP program.
6. Develop the inspection, diagnostic, and software skills necessary for WAP energy auditing.
7. Never leave a home less healthy and safe than you found it.
8. Never specify work that is likely to damage a building or to leave the building less durable than you found it.
9. Never disclose confidential information about your organization or your clients.

Choosing Energy Conservation Measures

10. Choose ECMs according to their cost-effectiveness along with DOE and State policy, not personal preference or client preferences.
11. Don't manipulate energy software to select or avoid particular ECMs.

Avoiding Conflict of Interest

12. Don't accept payment for recommending products or services.
13. Avoid personal bias in your influence on purchasing, hiring, and contracting.
14. Don't accept payment or other benefits for consideration in an inspection report.

Representing Yourself and the Profession

15. Communicate honestly with clients, coworkers, contractors, and supervisors including refraining from making promises.
16. Always represent yourself, your organization, and the energy-auditing and quality-control inspection profession in a positive and professional way.
17. Insist that crew leaders and installers working with you conduct themselves in a professional manner.
18. Know the limits of your authority, and ask for guidance when you need it.

Inspecting Weatherization Jobs

19. Perform quality-control inspections as an independent representative of your weatherization agency.
20. Perform "third party" inspections as an individual with no association with either the home owner or the

weatherization agency that performed the weatherization work.

See also New Jersey State Ethics Requirements for DCA employees: http://www.state.nj.us/ethics/docs/ethics/plainlanguage.pdf

1.1.2 Recordkeeping for Energy Audits & Inspections

The client file is the record of a weatherization completion. The client file should contain all of the following items.

1. Intake Section

- Signed and Completed Application
- Income Eligibility Documents
- Copy of Social Security Card
- Proof of Ownership
- Client Energy Consumption Usage Data
- Owner's Permission to Weatherized
- Renovate Right Pamphlet Receipt or Lead Free Certificate
- Landlord/Tenant Agreement or Assurance Statement on Rent Controlled Unit.

2. Audit/Field Paperwork

- Client Sign Off & Agency Final
- Priority Audit List or Energy Audit including Input and Output Information
- Pre and Post Blower Door Numbers
- Copy of HESWAP Install List
- Copies of Invoices or Inventory Form
- Print Out of waptac.org Database recommendation with SIR

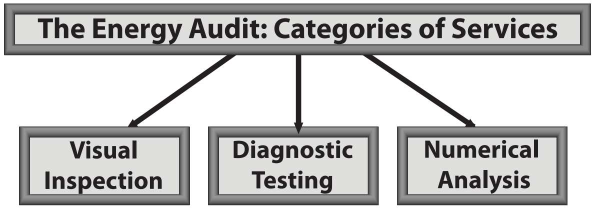
- Refrigerator Order Form and Order Form With Delivery Confirmation
- Appliance/Heating System Evaluation Form
- Bid Documents
- Photographs, if deemed necessary
- Heating System Improvement Survey

3. Heating System Improvement Services

- Heater Checklist
- Bid Request Letters
- Bid Proposals Received
- Copy of Permits
- Installer Certification with test results
- Agency's Final Test Results
- Picture of "Red Tag"
- GAMA/AHRI Certification
- Pre & Post Pictures of Heating System/Hot Water Boiler
- Copies of Invoices
- If required, approval from OLIEC

Why We Care about Health, Safety, and Durability

The health and safety of clients must never be compromised by energy conservation measures. Harm caused by our work would hurt both our clients and our professions. Energy conservation work can change the operation of heating and cooling systems, alter the moisture balance within the home, and reduce a home's natural ventilation rate. Energy auditors and inspectors must take all possible precautions to avoid possible harm from these changes. Our services must improve safety, indoor air quality, and home durability as part of our mission to save energy.



1.2 Parts of an Energy Audit

Visual inspection, diagnostic testing, and SIR analysis are three types of energy auditing procedures we discuss in this section. These procedures should aid you in evaluating all the appropriate ECMs that are cost-effective.

The energy audit must also propose solutions to health and safety problems related to the energy conservation measures.

1.2.1 Visual Inspection

Visual inspection orients the energy auditor to the physical realities of home and home site. Among the areas of inspection are the following:

1. Building interior and exterior
2. Heating and cooling systems
3. Baseload energy uses
4. Health and safety issues
5. The home's physical dimensions: area and volume

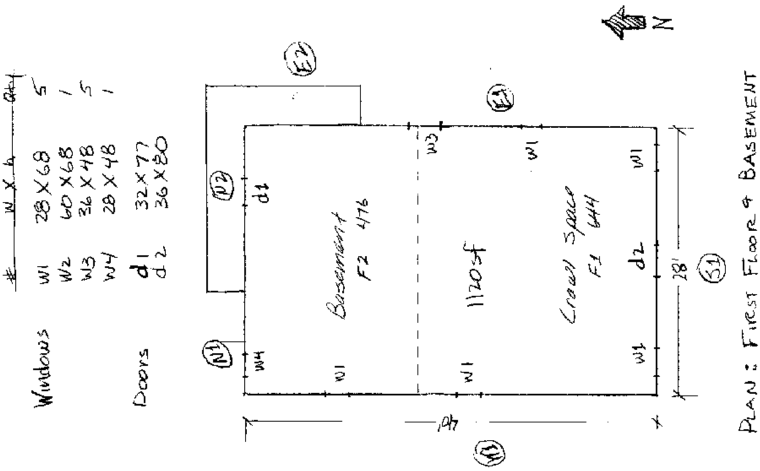
Inspecting the Building Exterior

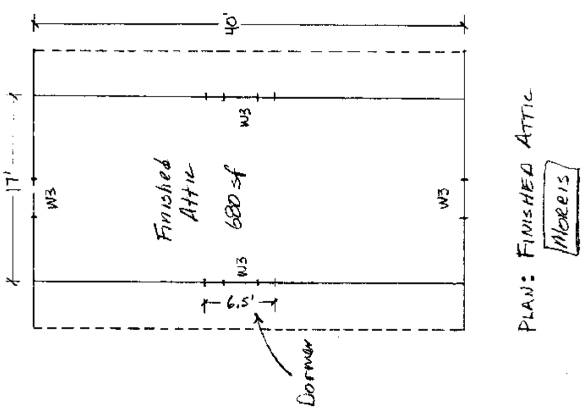
The energy auditor should inspect the home from the exterior first, to understand the home's layout, maintenance condition, site issues, floor plan, and main utilities.

1. Inspect the characteristics and condition of the foundation, roof, siding, windows, doors, and overhangs.

2. Inspect the foundation, and measure the area exposed above grade.
3. Evaluate the site drainage, and look for evidence of moisture accumulation and damage.
4. Note any additions to the dwelling.
5. View the building through an infrared scanner, if available, to identify thermal flaws.
6. Evaluate roof and window shading from trees, awnings, and other buildings.

Visualization: Auditors learn to visualize the home and make simple drawings to aid in communication.





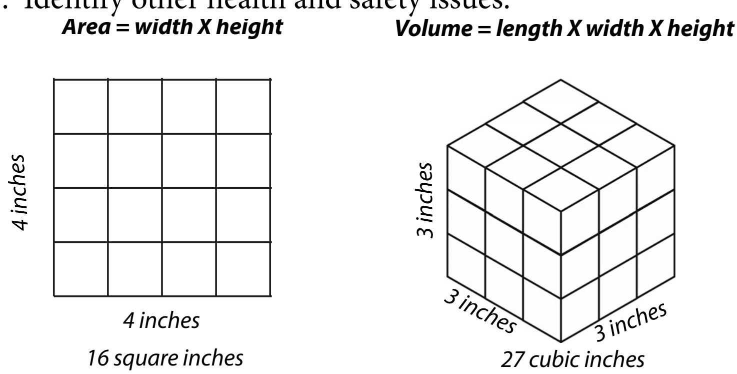
Floor plans: Drawings can help document the home's important characteristics.

7. Determine which compass orientation each side of the home faces to evaluate the effect of solar heat gain. Evaluate the opportunity to use solar energy or to block it as appropriate to the season and climate.
8. Inspect the chimney(s) and exhaust vents. Note their location and condition.

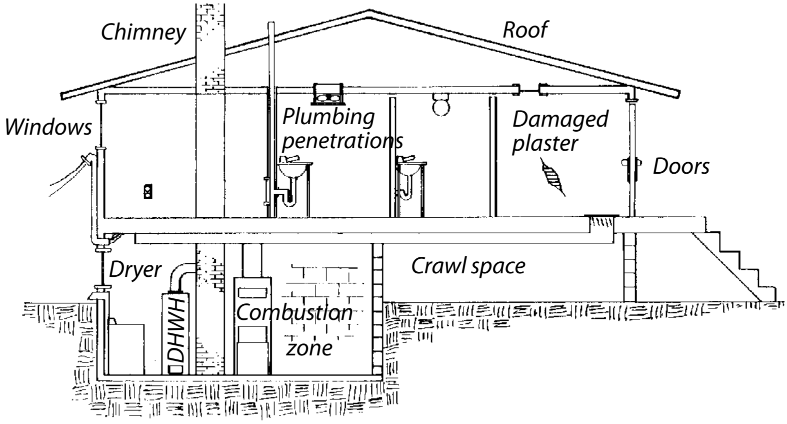
Inspecting Dwelling Interior

Inspect the interior using the mental map you developed from exterior inspection. Consider these activities when you inspect the home's interior.

1. Locate and identify components of the thermal boundary.
2. Evaluate the type, thickness, and condition of insulation in the attic, walls, floors, and foundation.
3. Look for large air leaks.
4. Measure the building's floor space and interior volume.
5. Inspect for evidence of moisture problems such as mold, water stains, or musty smells.
6. Inspect the wiring in the attic or other areas affected by weatherization measures.
7. Identify other health and safety issues.



Area and volume: Energy auditors calculate the area and volume of homes.



Interior and exterior inspection: When combined with testing, the inspection of the home's exterior and interior helps the auditor decide on the energy conservation and repair priorities for the home.

Heating-System Inspection

Inspect the heating-system to identify problems to be solved during weatherization by a heating technician.

1. Look for signs of spillage, backdrafting, and flame roll-out.
2. Measure the clearance between combustibles and chimneys or vent connectors.
3. Compare the size of the venting system with the input rating of the appliances served if you notice spillage or corrosion.
4. Inspect all forced-air heat exchangers for deterioration.
5. Look for signs of water leaks in boilers and water heaters.

Cooling Evaluation

The cooling evaluation includes both the cooling equipment and aspects of the building shell that affect cooling in particular. These evaluations are completed only when medically necessary or when the elements of the cooling system adversely affect the heating system or must be addressed as part of a heating system evaluation.

1. Inspect the roof assembly for shading, insulation, and reflectivity.
2. Inspect the attic for adequate insulation level.
3. Inspect the windows for shading and solar transmittance.
4. Examine the coils of room air conditioners and outdoor condensing units for dirt and other airflow restrictions.
5. Inspect central air conditioners for leaks in the condensate tray and drain.
6. Inspect the central air conditioner's vapor-line insulation.
7. Evaluate the air-conditioning system with professional help as needed.

Baseload Inspection

Baseload energy consumption is comprised of energy uses that remain constant throughout the year, as opposed to seasonal energy consumption such as heating and air conditioning. The water heating system, the refrigerator, lights and the clothes dryer are all important baseload energy consumers and should be evaluated during an energy audit.

1. Check for excessive dust on refrigerator's coil.
2. Measure or estimate refrigerator electricity consumption.
3. Refrigerator temperature should be 36–40°F, and freezer temperature should be 0–5°F.
4. Inspect the water heater and piping for insulation, leakage and safety problems.
5. Water heater temperature should be 120°F.

6. Inspect the dryer and dryer vent for lint and debris.
7. Inspect lighting and recommend compact-fluorescent replacement bulbs as appropriate.

See "Baseload Measures" on page 47.

Health and Safety Inspection

Identify energy-related health and safety deficiencies, which could be created or worsened by weatherization activities. Be very careful and courteous about discussing these problems with clients so you don't alarm them needlessly.

1. Determine the severity of the deficiencies, and whether there is an immediate threat to the health or safety of household members. **Address emergencies immediately in accordance with the NJ Weatherization Program State Plan and policy guidelines.**
2. Check for presence and proper placement of CO detectors and smoke alarms in accordance with policy guidelines, state and local codes.
3. Test for carbon monoxide and depressurization in homes with combustion appliances, tuck under and attached garages, and wood burning stoves.
4. Inspect for moisture and other indoor pollution problems.
5. Interview the homeowner about the family's health.
6. Explain all health and safety problems clearly, and answer questions patiently.

1.2.2 Diagnostic Testing

Measurement instruments provide important information about a building's unknowns, such as air leakage and combustion efficiency. Use these diagnostic tests as appropriate during the energy audit.

1. Blower door testing- Required: Depressurization is required pre and post measure to evaluate the airtightness of a home and parts of its air barrier.
2. Duct airtightness testing- Optional: A variety of tests using a blower door and pressure pan to locate duct leaks.
3. Combustion safety and efficiency testing- Required: Must be performed pre and post measures to sample combustion by-products to evaluate safety and efficiency.
4. Infrared scanning- Optional: Viewing building components through an infrared scanner, shows differences in the temperature of building components inside building cavities.
5. Appliance consumption testing- Required: Refrigerators are monitored with logging watt-hour meters to measure electricity consumption.

1.2.3 SIR Calculations with Energy Software

Energy auditors currently use approved energy-auditing software, to determine which ECMs have the highest Savings-to-Investment Ratio (SIR). Energy auditing software approved for use in New Jersey include these three.

1. NEAT (National Energy Audit Tool) is accepted for use with single-family and multi-family properties (1-4 unit buildings).
2. MHEA (Manufactures Home Energy Audit is accepted for use with mobile and manufactured homes.
3. EAQUIP is accepted for use in large multifamily buildings (5 units or more).

SIR = Lifetime savings ÷ Initial investment

DOE WAP and the New Jersey WAP program require that ECMs have an SIR greater than 1. ECMs with higher SIRs should be installed before or instead of ECMs with lower SIRs.

Regardless of which energy software is used, the auditor must collect information to inform decisions about which ECMs to choose.

1. Measure the home's exterior horizontal dimensions, wall height, floor area, volume, and area of windows and doors.
2. Record year of construction.
3. Measure the current insulation levels.
4. Do a blower door test to evaluate air leakage.
5. Do a combustion efficiency test to evaluate the central heating system.
6. Evaluate energy bills and adjust the job's budget within limits to reflect the potential energy savings.

1.3 The Work Order

The work order is a list of materials and tasks that are recommended as a result of an energy audit. The work order connects the energy audit with the final inspection. The auditor writes the work order, the crew leader executes it, and the inspector compares the work order to the work done. The inspector evaluates the energy audit, the work order, and the finished work. Consider these steps in developing the work order.

1. Evaluate which energy conservation activities have an acceptable savings-to-investment ratio (SIR) using software.
2. Select the most important health and safety problems to correct.

3. Provide detailed specifications so that crews or contractors can clearly understand the materials and procedures necessary to complete the job.
4. Estimate the cost of the materials and labor.
5. Verify that the materials needed are in stock.
6. Inform crews or contractors of any hazards, pending repairs, and important procedures related to their part of the work order.
7. Obtain required permits from the local building jurisdiction.
8. Specify interim testing during air-sealing and heating-system maintenance to provide feedback for workers.
9. Consider in-progress inspections and schedule the final inspection for the job's final day if possible.

1.3.1 Questions about the Audit and Work Order

The inspector is responsible for the quality control of the whole process of weatherizing a home. The inspector asks these questions during the final inspection.

1. Did the auditor find all the opportunities and identify all the hazards?
2. Do the Work Scope ECMs agree with computer analysis (audit) and DOE standards?
3. Did the work order adequately specify the labor and materials, required by the energy audit?
4. Did the crew follow the work order?
5. What changes did the crew leader make to the work order?
6. Did these changes benefit the client and the WAP program?

7. Did the completed weatherization job fulfill the mission of WAP as stated on *page 17*.

1.4 Work Inspections

Good inspections provide a real incentive for workers to follow specifications and maintain good quality. There are two common opportunities for inspections: in-progress inspections and final inspections.

1.4.1 In-Progress Inspections

Many energy conservation procedures are best inspected while the job is in progress. Visiting while the job is in progress demonstrates your commitment to getting the job done correctly. Either the energy auditor or the inspector may conduct an in-progress inspection.

These measures are good candidates for in-progress inspections because of the difficulty of evaluating them after completion.

1. Dense-pack wall insulation
2. Insulating closed roof cavities
3. Furnace installation or tune-up
4. Duct testing and sealing

In-progress inspections are also an excellent way to provide training and technical assistance.

1.4.2 Final Inspections

A certified inspector completes a final inspection before the weatherization job is reported to DOE as a completion. Final inspections ensure that weatherization services were provided as specified in the work order, and that the home is left in a safe condition. The weatherization agency does the final inspection for quality control, which is a term for in-house self evaluation of jobs.

1. Confirm that the crew installed the approved materials in a safe, effective, and neat way.
2. Confirm that the crew matched existing finish materials for measure installation and necessary repairs.
3. Review all completed work with the client. Confirm that the client is satisfied.
4. Verify that combustion appliances operate safely. Do worst-case draft tests and CO tests as appropriate.
5. Do a final blower door test.
6. Use an infrared scanner, if available, to inspect insulation and air sealing quality.
7. Specify corrective actions when the work doesn't meet standards.
8. Verify that the crew used the correct lead-safe procedures if these procedures were necessary in installing ECMs.
9. Verify that all required paperwork, with required signatures is in the client file.

1.4.3 Quality Control Versus Quality Assurance

Quality control is an internal process of a weatherization program. Quality assurance is a third-party inspection performed an inspector employed by the State or by the DOE.

Energy auditors may perform either quality-control or quality-assurance inspections. The following are important elements of these inspections.

1. Verify compliance with specifications, job order, and energy audit.
2. Provide feedback on material quality and worker performance, both good and bad.
3. Issue instructions for correcting errors and omissions.

4. Survey clients for level of satisfaction.
5. Perform energy-conservation monitoring and evaluation, if appropriate.
6. Report to the weatherization agency, the State, or the DOE about the quality of the weatherization work.

Field Monitoring

Field monitoring is the quality assurance visit conducted by the State weatherization program or the DOE. The State or DOE monitor's job is similar to the agency's inspector. However, the quality-assurance monitor is independent of the local weatherization agency and reports his or her inspection results to the State or to the DOE. The monitor describes these inspection results in these ways.

1. Strengths or areas where the agency performs well.
2. Concerns are minor problems with paperwork or job quality that the agency can easily correct.
3. Major findings, which are contract violations, safety violations, or omissions of required procedures.

The monitor issues a report and the agency must respond in writing. Major findings require the agency to tell the State how the agency will correct the problems.

1.5 Client Relations

Client satisfaction depends on the reputation, professional courtesy, and communication ability of the energy auditor or inspector.

Making a good first impression is important for client relations. Friendly, honest, and straightforward communication helps create an atmosphere where problems and solutions can be openly discussed.

Setting priorities for client communication is important for the efficient use of your time. Auditors and inspectors should strive to communicate clearly, directly, and efficiently. Limit your communication with the client to the most important energy, health, safety, and durability issues.

1.5.1 The Energy Auditor's Client Interview

The client interview is an important part of the energy audit. Even if clients have little understanding of energy and buildings, they can provide useful observations that can save you time and help you choose the right ECMs.

1. Make sure that the client understands the WAP program and why you are visiting their home.
2. Listen carefully to your client's reports, complaints, questions, and ideas about their home's energy efficiency.
3. Ask questions to clarify your understanding of your client's concerns.
4. Avoid making promises until you have time to estimate the job and discuss the home with a crew chief or contractor.
5. Make arrangements for additional visits by crews and contractors as appropriate.
6. Ask the client about comfort problems, including zones that are too cold or hot.
7. Ask the client to see their energy bills if you haven't already evaluated them.
8. Ask the client if there is anything relevant they notice about the performance of their mechanical equipment.
9. Ask about family health, especially respiratory problems afflicting one or more family members.

10. Discuss space heaters, fireplaces, attached garages, and other combustion hazards.
11. Discuss drainage issues, wet basements or crawl spaces, leaky plumbing, and mold infestations.
12. Discuss the home's existing condition and how the home will change with proposed retrofits.
13. Identify existing damage to finishes to insure that weatherization workers aren't blamed for existing damage.
14. Before you leave, give the client a quick summary of what you found.

1.5.2 Communication for the Inspector

Even though the work is complete and the client was involved with the energy auditor and crew, don't assume that the client knows who you are or why you're visiting their home.

1. Ask a few questions to determine whether the client knows who performed the work and why.
2. Does the client appreciate the benefits of the weatherization job?
3. Has the client noticed a difference in comfort?
4. Is the client satisfied with the work?
5. Does the client understand how they can save energy through their behavior?

1.5.3 Denial or Deferral of Weatherization Services

When you find major health, safety, or durability problems in a home, sometimes it's necessary to deny the client weatherization services or defer (delay) weatherization until those problems are solved. The problems that are cause for denial or deferral of services include, but are not limited to the following.

1. Major roof leakage
2. Major mold infestation and other moisture deterioration
3. Major foundation damage
4. Major plumbing problems
5. Human or animal waste in the home
6. Major electrical problems or fire hazards
7. The home is vacant or the client is moving

Major behavioral problems may also be a reason to deny services to a client, including but not limited to the following.

1. Illegal activity on the premises
2. Lack of cooperation by the client.

Consult the NJ Weatherization Program State Health and Safety Plan for specific guidance on denials or deferrals.

Matching Funds to Avoid Denials

Energy auditors must be able to refer denied or deferred clients to appropriate programs/agencies to obtain repair funds. Agencies should develop a list of resources which include the following sources whenever possible:

1. Department of Housing and Urban Development (HUD) Emergency Repair Funds
2. HUD Healthy Homes Initiative Funds
3. Department of Agriculture (USDA) Rural Development Funds
4. State and local repair funds
5. Church, charity, and foundation funds

1.6 Understanding Energy Usage

A major purpose of any energy audit is to determine where energy waste occurs. With this information, the energy auditor then allocates resources according to the energy-savings potential of each energy-conservation measure. A solid understanding of how homes use energy should guide both decision-making and post-weatherization evaluation.

Table 1-1: Top Six Energy Uses for U.S. Households

Energy User	Annual kWh	Annual Therms
Heating	2000–10,000	200–1100
Cooling	600–7000	n/a
Water Heating	2000–7000	150–450
Refrigerator	500–2500	n/a
Lighting	500–2000	n/a
Clothes Dryer	500–1500	40–90

Estimates by the authors from a variety of sources.

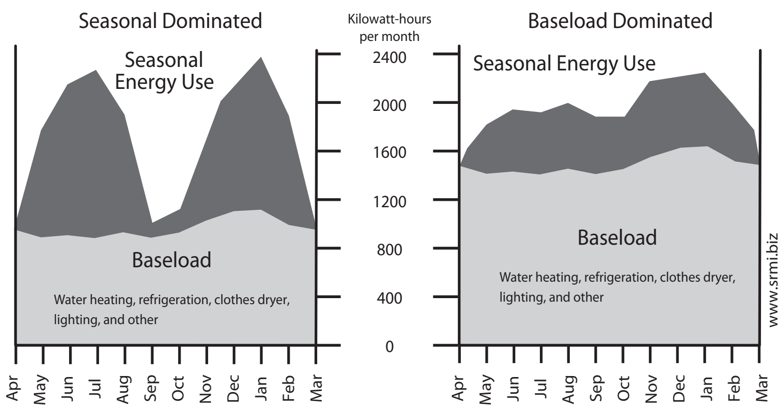
1.6.1 Baseload Versus Seasonal Use

We divide home energy usage into two categories: baseload and seasonal. Baseload includes water heating, lighting, refrigerator, and other appliances. Seasonal energy use includes heating and cooling. You should understand which of the two is dominant as well as which types of baseloads and seasonal loads are the highest energy consumers.

Many homes are supplied with both electricity and at least one source of combustion fuel. Electricity can provide all seasonal and baseload energy, however most often there is a combination of electricity and natural gas, oil, or propane. The auditor must understand whether loads like the heating system, clothes dryer, water heater, and kitchen range are serviced by electricity or by fossil fuel.

Potential energy savings depends on total energy use. The greatest savings are possible in homes with highest initial consumption.

Avoid getting too focused on a single energy-waste category. Consider all the individual energy users that offer measurable energy savings.



Seasonal vs. Baseload Domination of Energy Use: Homes with inefficient shells or in severe climates have large seasonal energy use and smaller baseload. More efficient homes and homes in mild climates are dominated by baseload energy uses.

Separating Baseload and Seasonal Energy Uses

To separate baseload from seasonal energy consumption for a home with monthly gas and electric billing, do these steps.

1. Obtain the client's energy billing for 2 years if possible (one year at a minimum). If the client can't produce these bills, they can usually request a summary from their utility company.
2. Add the 3 lowest bills together.
3. Divide that total by 3.

4. Multiply this three-month low-bill average by 12. This is the approximate annual baseload energy cost.
5. Total all 12 monthly billings.
6. Subtract the annual baseload cost from the total billings. This remainder is the space heating and cooling cost.
7. Heating is separated from cooling by looking at the months where the energy is used — summer for cooling, winter for heating.

Table 1-2: Separating Baseload from Seasonal Energy Use

Factor and Calculation	Result
Annual total gas usage from utility bills	**1087 therms**
Monthly average gas usage for water heating Average of 3 low months gas usage (21 + 21 + 22) ÷ 3 = 21.3 therms per month	21.3 therms per month
Annual gas usage for water heating Monthly average usage multiplied by 12 12 x 21.3 = 256 therms per year	**256 therms** per year
Annual heating gas usage Annual total minus annual water-heating usage 1087 – 256 = 831 therms per year	**831 therms** per year
Annual total electric use from utility bills	**6944 kWh**
Monthly average usage for electric baseload Average of 3 low months electricity usage (375 + 372 + 345) ÷ 3 = 364 kWh per month	364 kWh per month
Annual electric usage for baseload Monthly average usage multiplied by 12 12 x 364 = 4368 kWh per year	**4368 kWh** per year
Annual heating and cooling electrical usage Annual total minus annual baseload usage 6944 – 4368 = 2576 kWh per year	**2576 kWh** per year

1.7 Client Education

Client education is a potent energy conservation measure. A well-designed education program engages clients in household energy management and assures the success of installed energy conservation measures (ECMs).

1.7.1 Reducing Heating Consumption

For many clients, increasing comfort and reducing heating and air conditioning costs are the most important benefits of weatherization.

Building Shell

The following are the most important client-education priorities relating to the building shell.

1. Explain the options for attic, wall, and floor insulation.
2. Explain the options for testing and sealing air leaks in the building shell.
3. Explain how major window upgrades don't fit into the overall home energy package. The installed cost of major window upgrades generally fails to provide an adequate SIR, and so window ECMs aren't usually recommended by the Weatherization Assistant software.

Forced-Air Systems

The following are the most important client-related energy measures for forced-air furnaces:

1. Locate the furnace filter and demonstrate how to change or clean it.
2. Show the client how to clean supply and return grilles periodically.
3. Show the client how to open floor registers. Help them remove obstructions like rugs and furniture from registers.
4. Explain the process used for testing and sealing air leaks in the duct systems.
5. Show the client how to use a programmable thermostat if they have one or if one will be installed. Explain that the energy savings depend on the number of degrees of

temperature-setpoint reduction and the amount of time the setpoint is reduced.

1.7.2 Reducing Electric Baseload

Electric baseload includes the refrigerator, lighting, the clothes dryer and other loads such as computers, TVs, and entertainment equipment. Water heating and baseload ECMs are discussed in *"Baseload Measures" on page 47*.

1. Inspect lighting to determine whether incandescent lighting remains in the home. Recommend replacing incandescent lighting with fluorescent or LED lamps.
2. Recommend lighting controls for lights that are frequently left on.
3. Inspect the clothes dryer and its vent for lint. Advise the client to remove lint from the dryer and vent.
4. Recommend reduction of standby power consumption by using switchable plug strips for entertainment centers, computers, and computer peripherals.
5. Advise the client to buy ENERGY STAR appliances.

1.7.3 Reducing Hot Water and Laundry Consumption

The auditor should explain or demonstrate the following habits for reducing hot water and laundry energy costs.

1. Advise the client to wash clothes in cold water unless warm water is needed to get dirty clothes clean. Also advise them to wash and dry full loads of clothes.
2. Show the client how to clean the dryer lint filter after each load and how to remove lint and outdoor debris from the dryer vent termination.

3. Show the client how to use the electronic or moisture-sensing clothes-dryer cycle. Have them note the dial reading that gets clothes acceptably dry and use that setting consistently.

Modern dryer dials: Somewhere in the middle of the electronic or automatic cycle is the most conservative setting.

4. If the water heater has been recently replaced, educate the client how to drain a gallon or two of water to clean sediment from the bottom of the tank.

1.7.4 Reducing Cooling Consumption

Advise your clients to take these steps that reduce air conditioning costs and improve their comfort.

1. Maximize shading and reflectivity of roofs, walls, and windows.
2. Use circulating fans to improve comfort in occupied rooms.
3. Set the air-conditioner thermostat to the highest thermostat setting that still provides acceptable comfort.
4. Close interior doors to limit the area cooled by room air conditioners.
5. Open interior doors and all registers when operating the central air conditioner.
6. Clean air-conditioner coils as needed.
7. Use a programmable thermostat, or change thermostat settings based on habitual occupancy, such as work and school schedules.
8. Avoid using powered attic ventilators because they use a large amount of electricity and tend to increase the home's summertime air leakage.

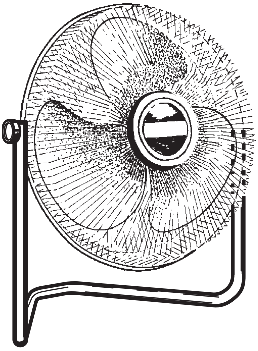
9. Don't operate the air-conditioner blower continuously because blowers use considerable electricity and continuous operation increases both duct leakage and air leakage through the building shell.

10. Turn off lights, appliances, and circulating fans when not in use to reduce their heat output and electricity consumption.

Cooling with Ventilation and Fans

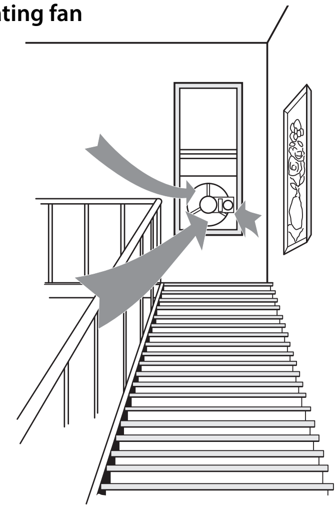
Window fans and whole-house fans are most effective when used at night to remove heat that has collected in the home during the day, except during very humid weather. Set them to exhaust air through a window that is high on the south side of the home, then open a window or door that is low on the north side to admit cool air. Don't use ventilating fans while running an air conditioner. Close windows and draw the drapes or blinds each morning.

Floor fans, table fans, and ceiling fans create a wind-chill effect indoors, which can improve comfort and reduce cooling costs. Since no air is moved out of the home, you can use circulating fans at the same time that an air conditioner is running.



Circulating fan

Ventilating fan



CHAPTER 2: BASELOAD MEASURES

Baseload energy consumption — water heating, refrigeration, lighting, clothes drying, and plug loads — accounts for a large part of the energy use in most homes. In mild climates, baseload consumption may be larger than heating and cooling combined.

Water heating is usually powered by combustion rather than electricity. Gas combustion also sometimes powers ranges and clothes dryers. In many homes, part of the baseload energy use is combustion fuel and part is electricity. In other homes, all the baseload consumption is electricity.

For safety information on combustion water heaters, see *"Spillage and CO Testing" on page 208*.

Table 2-1: Levels of Household Electric Baseload Consumption

Indicator	Low	Medium	High
kWh per Year	<4500	4500–8500	>8500
kWh per Month	<375	375–700	>700
kWh per Day	<12	12–23	>23
kWh per Person (Annual)	<1900	1900–3500	>3500

Doesn't include heating, cooling, or water heating. Assumes 2.4 persons per household and average annual consumption of 6500 kWh per household.

2.1 WATER-HEATING ENERGY SAVINGS

The most important tasks in evaluating hot water energy savings are determining the water heater's insulation level, measuring the shower's flow rate, and measuring the water temperature.

Table 2-2: Water Heating Consumption According to Family Size

Number of Residents	Annual kWh	Annual Therms	Gallons Per Day
1	2700	180	25
2	3500	230	40
3	4900	320	50
4	5400	350	65
5	6300	410	75
6	7000	750	85

Author's interpretation of data from single-family homes with existing water heaters from Energy Information Administration, Lawrence Berkeley Laboratory, *Home Energy Magazine*, and others.

2.1.1 Determining the Water Heater's Insulation Level

Common storage water heaters consist of a tank, insulation surrounding the tank, and an outer shell. There is typically either 1 or 2 inches of insulation surrounding the tank. The insulation is either fiberglass or polyisocyanurate.

Identifying Tank Insulation

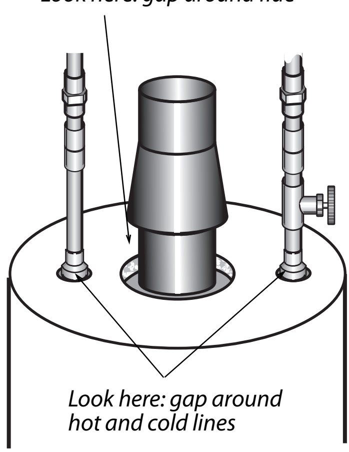


Table 2-3: Insulation R-Values

Insulation/thickness	R
Fiberglass 1 inch	3
Fiberglass 2 inches	6
Isocyanurate 1 inch	6.5
Isocyanurate 2 inches	13
Isocyanurate 3 inches	19.5

Follow this procedure to determine the water heater's insulation level.

1. Look for a listing of R-value on a label on the water heater.
2. Find a hole in the outer shell where the flue pipes emerges or where plumbing connects. Look around the hole for either fiberglass or polyisocyanurate insulation.
3. If the hole isn't large enough to see the insulation level on an electric water heater, try removing the access panel for the heating element after disconnecting power from the unit.
4. You may just be able to see the gap between the tank and outer shell. If you can't see this gap, use a ruler or probe to push through the insulation along side of a pipe connecting to the tank until the probe hits the steel tank to determine thickness. Make sure that the probe

is against the tank and not against a nut welded to the tank.

5. Insulate all water heaters with a minimum of R-6, R-12 is recommended.

2.1.2 Water Heater Blankets

Install an insulation blanket on all water heaters that are outside the heated space, **unless the manufacturer's label prohibits it**. Follow these guidelines to avoid fire hazards and to simplify future service.

Gas Water Heaters

When you install insulation on gas water heaters, use these specifications.

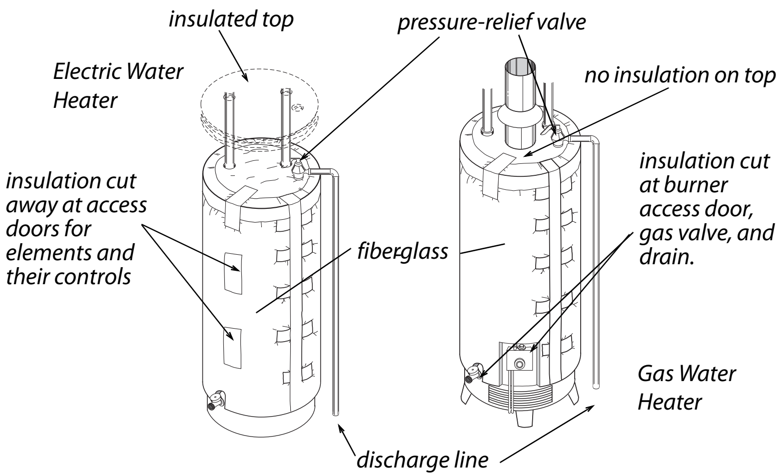
1. Keep insulation at least 2 inches away from the gas valve and the burner access panel. Don't install insulation if the pilot access panel is missing. Don't install insulation below the burner access panel.
2. Don't cover the pressure relief valve and discharge line with insulation.
3. Don't insulate the tops of gas-fired water heaters because the insulation can obstruct the draft diverter.

Electric Water Heaters

When you install insulation on electric water heaters, use these specifications.

1. Mark the blanket to locate the thermostat and heating element access plates or cut the blanket at these locations.
2. When you cut the blanket for the thermostats, cut the bottom and sides but not the top. This creates a hinge that allows the door in the insulation to swing open and closed.

3. Cover the top of the water heater with insulation.
4. Don't cover the pressure relief valve and discharge line with insulation.

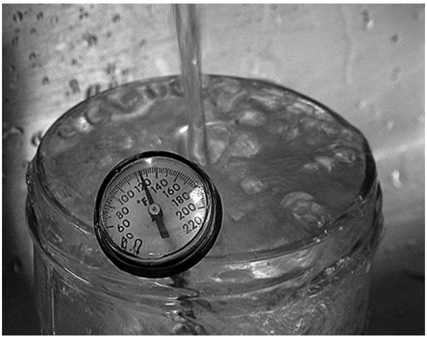


Water heater insulation: Insulation should be installed carefully so it doesn't interfere with the burner, elements, draft diverter, FVIR combustion intake, or pressure relief valve and discharge line. Blanket must be installed with tape and secured with straps

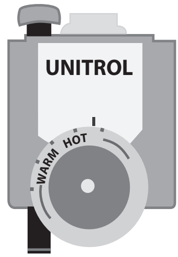
2.1.3 Measuring and Adjusting Hot Water Temperature

Use the following instructions to adjust water.

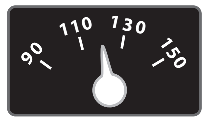
1. Shut off power to an electric water heater before opening thermostat access panels.
2. Measure the water temperature at the nearest faucet to the water heater. Reduce the temperature to 120° F with the customer's permission.
3. On electric water heaters, set both upper and lower thermostats to the same temperature.



Setting hot-water temperature: Getting the temperature correct can take a few measurements and re-adjustments.



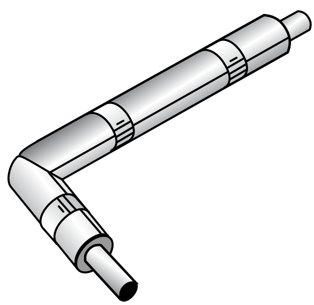
Gas water heater control



Electric water heater control

2.1.4 Water-Heater Pipe Insulation

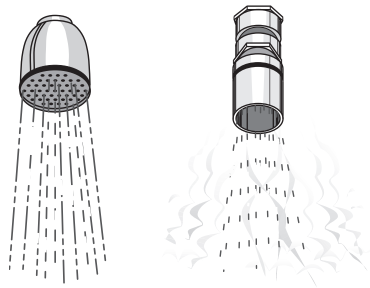
Install pipe insulation to slow convection of hot water into the water lines near the tank.



1. Insulate the first 5 feet of hot and cold water pipe from the water heater.
2. Use pipe wrap with a minimum thickness of 3/4 inch and a minimum R-value of 3.5. Cover elbows, unions and other fittings to the same insulation thickness as the pipe.
3. Keep pipe insulation 6 inches away from single-wall vent pipe and 1 inch away from Type B vent.
4. Interior diameter of pipe sleeve must match exterior diameter of pipe
5. Fasten pipe insulation with zip ties, tape, or other approved method.

2.1.5 Water-Saving Shower Heads

Most families use more hot water in the shower than for any other use. A low-flow shower head reduces this consumption.



Water-saving shower heads: Two styles of water-saving shower heads give consumers a choice between steamy showers and less steamy ones.

Replace high-flow shower heads with a water-saving shower head rated for a flow of 1.5 to 2.0 gallons per minute. Avoid installing low quality shower heads as they often provide a less satisfying shower and are prone to clogging.

Use caution in removing the existing shower head from old, fragile plumbing systems. To be safe, don't attempt to remove the shower arm that connects the shower head to the fitting inside the wall, but replace just the shower head itself.

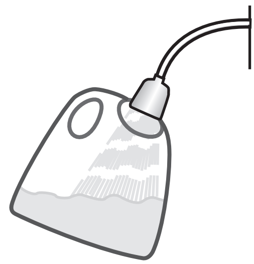
Measuring Shower Flow Rate

You can determine flow rate by measuring the time needed to fill a one-gallon plastic container. If the one-gallon container fills in less than 20 seconds, your flow rate is more than 3 gallons per minute.

1. Start the shower and set it to the maximum showering rate.
2. Start a stopwatch at the same time you move the container underneath the shower, capturing its entire flow.
3. Note the number of seconds and divide 60 by that number to find gallons per minute.

Measuring shower flow rate: If you divide 60 by the number of seconds needed to fill a gallon container, you will calculate flow in gallons per minute.

$$\frac{1\ \text{gal}}{15\ \text{sec}} \times \frac{60\ \text{sec}}{1\ \text{min}} = 4\ \frac{\text{gal}}{\text{min}}$$



2.2 Storage Water Heater Choices

Direct-fired storage water heaters are the most common water heaters found in single-family homes.

Important: All existing and new storage water heaters must have a pressure-and-temperature relief valve and a safety discharge pipe. Install a relief valve and discharge pipe if none exists. The discharge pipe should terminate 6 inches above the floor or outside the dwelling as specified by local codes. The discharge pipe should be made of rigid metal pipe or approved high temperature plastic pipe.

2.2.1 Water-Heater Replacement Decisions

Existing gas water heaters, including propane, typically use 200 to 400 therms per year. New gas water heaters use as little as 175 therms per year, resulting in a savings of around 75 therms per year. Similar savings are possible by replacing electric water heaters. Consider the following recommendations for specifying water heaters.

1. A replacement gas or oil storage water heater should have an energy factor of at least 0.67 and be insulated with at least 2 inches of foam insulation.

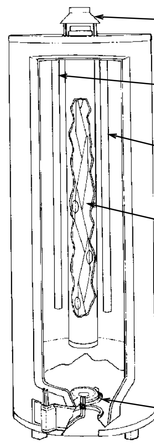
2. A replacement electric water heater should have an energy factor of at least 0.93 and be insulated with at least 2.5 inches of foam insulation.

2.2.2 Comparing Water Heaters

People often ask whether to install a natural-gas fired, propane-fired, oil-fired, or electric water heater. The choice isn't easy and it involves many factors including safety, reliability, efficiency, and installed cost.

Safety Comparison

Conventional direct-fired gas water heaters vent their combustion by-products to a gravity vented chimney. They can spill products of combustion into the living space, especially if the chimney isn't tall enough, warm enough, or sized properly. Sharing of a main chimney with another combustion appliance can also cause venting problems.



Standard gas water heater: These open combustion appliances are often troubled by spillage and backdrafting.

Electric water heaters need no combustion air, which makes them safer for buildings with low natural air leakage, compared to conventional gas storage water heaters.

Electric water heaters have no products of combustion to worry about. However, because the recovery capacity is generally much less than gas water heaters of the same size, there is a greater chance of someone trying to compensate for a cold shower by setting the electric water heater's to an unsafe temperature.

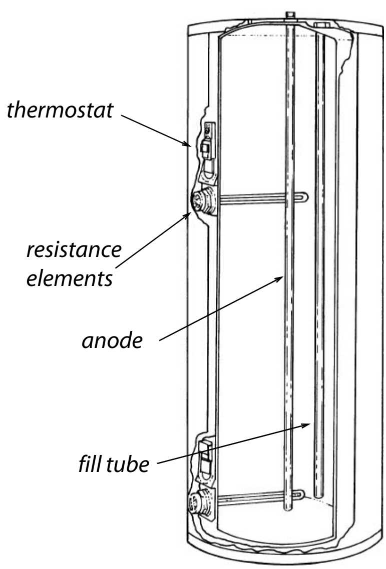
Reliability Comparison

Storage water heaters are popular because they are inexpensive and reliable. Both gas and electric storage water heaters are simpler and more reliable than more expensive and complex water heaters. The lifespan of storage water heaters depends on local water quality and the quality of the water heater's tank.

Most heaters have glass-lined steel tanks which are typically warranted for five years. All types of heaters are available with larger or additional sacrificial anodes, which are pieces of metal that corrode before the tank does, thereby extending the tank life and maybe the warranty. If you buy a ten-year guarantee heater instead of a five-year guarantee heater, this choice might reduce the future cost of replacement and possible water damage from leaks.

Efficiency and Energy Cost Comparison

Conventional gas storage water heaters are rated at about 80% steady-state efficiency. However, whenever a storage water heater isn't firing it is losing heat up the chimney. This happens when cold air flowing through the heater, is warmed by the heater and escapes up the flue. This off-cycle heat loss reduces annual efficiency drastically and may result in the water heater's EF being less than 0.60.



Standard electric storage water heater: Electric water heating is more expensive than gas or oil but safer. Electric water heaters should have at least 2 inches of foam insulation.

The exact energy factor for a particular storage water heater is difficult to estimate because of many factors including: chimney height, chimney diameter; wind; the home's air-tightness; outdoor temperature; and water heater temperature setpoint. With these variables the actual annual efficiency can vary from 60% to 40%

or even lower. Nevertheless, gas storage water heaters cost less to operate than electric water heaters of the same insulation level.

Electricity is approximately 4 times as expensive as natural gas. However, electric water heaters have no flue and therefore no flue losses. They do lose heat through the insulation jacket, which brings the annual efficiency down to around 90%. Heat-pump water heaters have an efficiency of 200% because they heat water with heat from the surrounding air. But because the electricity production and transmission system in the U.S. is about 31% efficient, the overall energy use and cost for heating water with electricity is higher than with gas.

Installed Cost Factors for Storage Water heaters

The cost of purchasing a water heater isn't very different between electric and gas conventional models. The installed cost for gas depends more on the availability of a chimney and a gas pipe. Advanced storage water heaters with more than 2 inches of foam insulation are more costly than standard units with one or two inches of foam insulation. Electric storage water-heater installation depends on the availability of a 240-volt electric circuit.

2.2.3 Water Heater Installation

Follow the manufacturer's installation instructions and state and local codes when installing a water heater.

Follow these procedures when replacing a storage water heater.

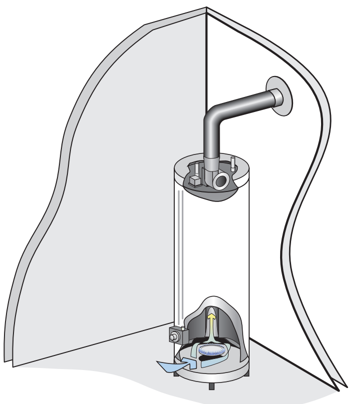
1. Install an emergency drain pan under each replacement water heater that is at least 4 inches deep.
2. Install an expansion tank if required by local code.
3. Install dielectric unions, a pressure-and-temperature relief valve, and a backflow preventer.
4. Adjust water temperature to 120 degrees F or to the lowest setting acceptable to occupants.

2.2.4 Alternative Water-Heating Products

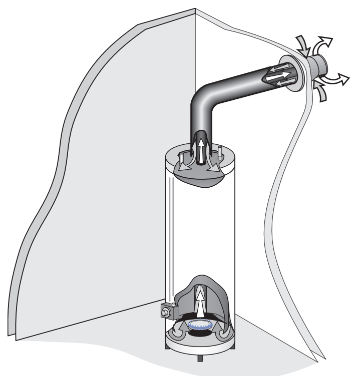
Weatherization programs sometimes choose alternative water-heating products to improve efficiency and/or safety.

Sidewall-Vented Gas Storage Water Heaters

When gas storage waters cause persistent venting problems, the energy auditor may specify a sidewall-venting water heater. Two common types of these water heaters are shown here.



Fan-assisted water heater: The fan allows horizontal venting.



Direct-vent water heater: Moves combustion air and flue gases through a concentric pipe system without a draft fan.

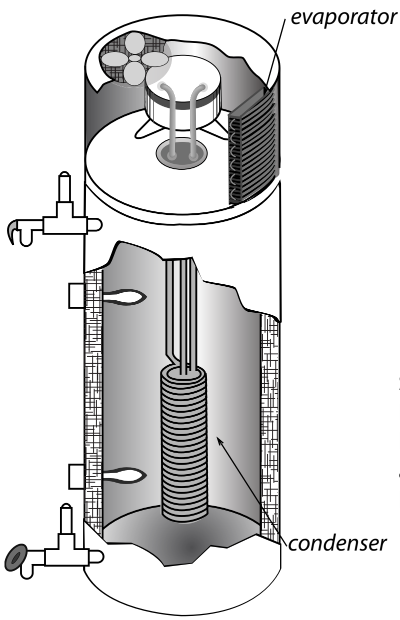
Tankless Instantaneous Gas Water Heaters

Tankless instantaneous gas water heaters are more efficient and cost less to operate compared to conventional gas storage water heaters. However, tankless waters are more expensive to install and may have shorter lifespans compared to storage water heaters.

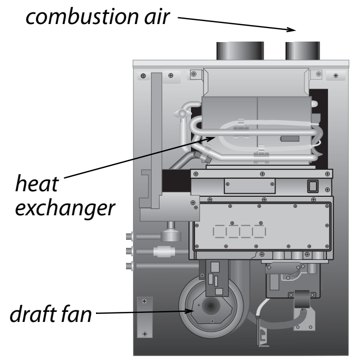
Heat Pump Water Heaters

Heat pump water heaters can heat water at up to 2.3 times more efficient than electric-resistance storage water heaters, based on the manufacturers' specifications listed for both appliances.

Heat pump water heaters use heat from surrounding air to heat water. They cost much more than conventional electric water heaters but are far less costly to operate.



Heat pump water heater: This heat pump water heater has the heating coil (condenser) surrounded by the domestic water.



Sealed-Combustion Tankless Water Heater: These expensive water heaters have a tiny market share and save around one-third of energy used by the best storage water heaters.

Table 2-4: Comparison of Advanced Water Heaters

Advanced Water Heater Type	Energy Savings % and $ Savings*	Expected Lifespan	Major Advantages
High-efficiency storage tank (Oil, gas, electric)	10%–20% ≤$500	8–15 years	Lowest first cost
Instantaneous Tankless (direct fired)	45%–60% ≤$1800	5-15 years	Unlimited hot water
Heat pump	50%–65% ≤$900	5-15 years	Most efficient electric option

From information supplied by ENERGYSTAR.gov by the Environmental Protection Agency. * Lifetime savings compared to conventional water-heater models and same fuel.

Table 2-5: Electrical Consumption of Typical Appliances

Appliance	Annual usage (kWh)	Annual cost
Ten-year-old refrigerator or freezer	1250	$188
New ENERGY STAR refrigerator or freezer	500	$75
Television	100–1000	$15–$150
Clothes dryer	1200	$180
Well pump	500	$75
Furnace fan	500	$75
Computer	50–400	$8–$60
Hot tub, spa	2300	$345
Water bed	1000	$150

Data from Lawrence Berkeley Laboratory and others. Based on 15¢ per kilowatt-hour for electricity.

2.3 Refrigerator Evaluation

There are two common options for evaluating refrigerator energy consumption for replacement. The first option is to use the resources included in the *Refrigerator Guide* on the WAP-TAC web site (www.waptac.org). These resources include a database of refrigerators by model with approximate electricity usage and a refrigerator analysis tool. The second option is to follow the metering procedure presented here.

Refrigerators built after 1993 use less electricity than refrigerators built before that year. Another efficiency increase occurred in 1999 in the refrigerator industry.

Refrigerators that are replaced should be taken to a facility that is licensed to reclaim their refrigerant and recycle the refrigerator's parts. No refrigerator, taken out of service, should be returned to service by sale, barter, or for free.

The use of multiple refrigerators in homes is common and this practice increases electricity usage. Energy auditors should inform customers about the use of more than one refrigerator and suggest consolidating food storage into a large single refrigerator.

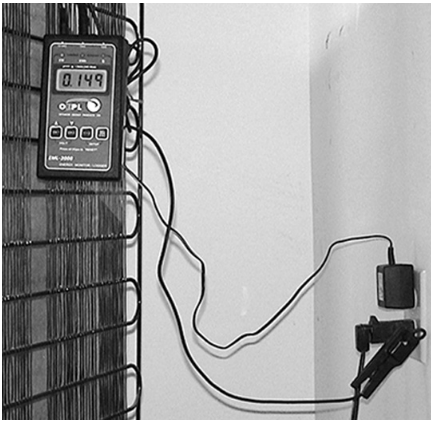
2.3.1 Refrigerator Metering Protocol

Older refrigerators use from 1000 to 2000 kWh per year. Newer ENERGY STAR refrigerators use less than 500 kWh per year. This difference presents a good opportunity to significantly reduce electricity consumption.

You need a minimum of two hours to accurately measure refrigerator energy consumption using a recording watt-hour meter.

A number of unusual circumstances could affect the accuracy of the metering, including the following.

- A quantity of warm food recently placed in the refrigerator.
- Abnormally high or low ambient temperature. For example: refrigerators in garages during the summer or winter; or refrigerators in vacant homes where heating or cooling systems aren't operating.



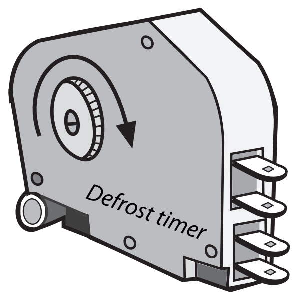
Recording watt-hour meter: Measures energy consumption over time. The better units can also calculate monthly consumption, or record maximum current draw to help identify the defrost cycle.

If the refrigerator is an automatic defrost model, an inaccurate reading could result if the unit goes into the electric defrost mode during the test period. This test protocol includes provisions to prevent the defrost mode from activating.

1. Determine if the refrigerator is equipped with automatic defrost. This is usually stated on the manufacturer's data plate or on the outside of the unit. If the refrigerator is equipped with a manual defrost, proceed to step 3.

2. If the unit is equipped with automatic defrost, follow this sub-procedure.

   a. Locate the defrost timer. This small electrical box is usually located behind the front kick-plate, though you may need to move some wires and use a flashlight to see it. It may also be located on the rear of the unit or inside the main compartment behind the lighting panel.



   b. Open the defrost timer and locate the advance pinion. This shaft usually has a screwdriver slot to allow you to manually advance the timer.

   c. Turn the timer clockwise (you can break the timer if you turn counter-clockwise) until you hear a loud click. This turns the defrost heaters on. Turn it 10-20 degrees further until it clicks loudly again, turning the heaters off.

   d. You can now perform your measurement since the timer won't call for defrost heat again for several hours.

3. Connect the refrigerator to a recording watt-hour meter. Run the test for at least two hours. You don't need to stop at exactly two hours, and a longer mea-

surement is OK. During the test, avoid opening the refrigerator, or do so briefly.

4. At the end of the test, read the kilowatt/hours of consumption measured by the meter. Divide this number by the number of hours in the test. This gives you the number of kilowatts consumed each hour. Multiply this number times the total number of hours in a year (8760 hours per year). The product of this calculation is the annual kilowatt-hours expected to be consumed by the unit.

5. **Plug the refrigerator back into its outlet.**

length of test in hours ↘ ↙ number of hours in a year

$$0.32 \div 2 = 0.16 \times 8760 = 1402$$

↗ kilowatt-hours consumed ↑ hourly consumption in kilowatt-hours ↖ predicted annual consumption in kilowatt-hours

Refrigerator consumption example: In this example, a 2-hour measurement was performed. During this time, the appliance consumed 0.32 kilowatt-hours of electricity, or 0.16 kilowatt-hours for every hour. The annual total of 1402 kilowatt-hours is well beyond the 450 kilowatt-hours per year consumed by today's most efficient refrigerators.

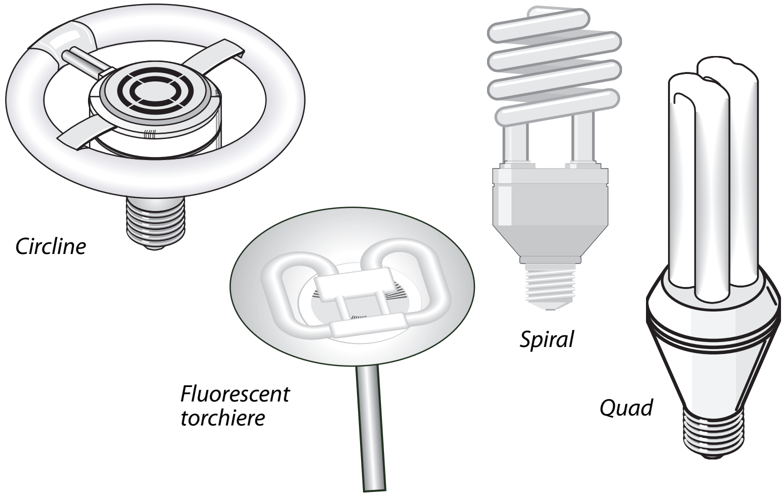
Table 2-6: Kilowatt-Hours per Hour vs. Kilowatt-Hours per Year

kWh/hour	kWh/year	kWh/hour	kWh/year
0.23	2000	0.16	1400
0.22	1900	0.15	1300
0.21	1800	0.14	1200
0.19	1700	0.13	1100
0.18	1600	0.11	1000
0.17	1500	0.10	900

2.4 Lighting Improvements

Most homes have 6 to 12 incandescent lamps that burn for more than two hours per day. These should be considered for retrofit by more-efficient compact fluorescent lamps (CFLs). This easy retrofit has as good an economic return as any weatherization measure.

1. Ask the customer about their lighting usage, and explain the electrical savings potential for switching to compact fluorescent lamps (CFLs).
2. Demonstrate a CFL bulb to the customer if they are unsure about replacing their incandescent light bulbs.
3. Select the type of CFL and its wattage, according to its use and the light level to which the customer is accustomed.
4. Turn on each CFL after installation to ensure that it operates. Make sure that the customer is satisfied with the light level.
5. Replace halogen torchieres with fluorescent torchieres.
6. Inform customers about proper recycling of fluorescent bulbs by stores, municipal waste departments, or other recycling organizations.



Compact fluorescent lamps: These advanced lamps use about one-third of the electricity of the incandescent lamps they usually replace, and they last about ten times as long.

2.5 Servicing Clothes Dryers

The drying time of a load of laundry is determined by the dryer installation and the amount of lint in the dryer, vent piping, and vent termination. After a few years, lint builds up and slows drying time, increasing energy use and cost. The original installation can also cause excessive drying time when flexible vents are excessively long, kinked, or restricted in some other way.

Vinyl flexible dryer vent isn't an approved dryer vent material and should be replaced with metal flexible dryer vent if found as part of an ECM or incidental repair.

Observe the following suggestions when servicing clothes dryers to reduce drying time and improve energy efficiency.

1. Unplug the clothes dryer.
2. Remove the vent pipe and vent termination and clean all lint out of them.

3. Clean lint out of the electric heating elements and the air-way around them.
4. Inspect the airway at the dryer's vent connection and clean lint out of it.
5. Dryer vents longer than 3 feet should be piped in 4-inch-diameter rigid aluminum or galvanized pipe.
6. Avoid using screws to join rigid pipe sections because they collect lint. Join and seal the sections with silicone caulking.
7. Dryer vents longer than 6 feet should use a 5-inch dryer vent termination and 5-inch-diameter rigid vent pipe.
8. Use short, stretched pieces of flexible metal dryer vent to connect the dryer to the rigid vent if needed to allow dryer to be moved in and out.
9. If you find flexible dryer vents that are longer than necessary, stretch the flexible pipe and cut it just long enough to allow the dryer to slide in and out and to connect to its rigid vent pipe.

Chapter 3: Diagnosing Shell Air Leakage

Air leakage is one of the most wasteful and common energy problems. The testing described here allows energy auditors to analyze the existing air barriers and decide whether and where air-sealing is needed. This testing also allows inspectors to evaluate the effectiveness of the crew's air-sealing work.

Ideally the air barrier and insulation are installed together at the building's thermal boundary. The the air barrier's effectiveness has a substantial effect on the performance of the insulation. This chapter focuses on pressure-testing homes to determine airtightness and guide air-sealing.

3.1 Shell Air-Leakage Fundamentals

Controlling shell air leakage is a key concern for successful weatherization. The decisions that the energy auditor makes about specifying air-sealing before weatherization and the inspectors post-weatherization evaluation affect a building throughout its lifespan. Air leakage has these impacts.

1. Air leakage accounts for a significant percentage of a building's heat loss.
2. Air leakage through insulated assemblies reduces the R-value of insulation.
3. Air leakage moves moisture in and out of the house, wetting and/or drying the building.
4. Air leakage causes house pressures that can interfere with the venting of combustion appliances.

Air Leakage and Ventilation

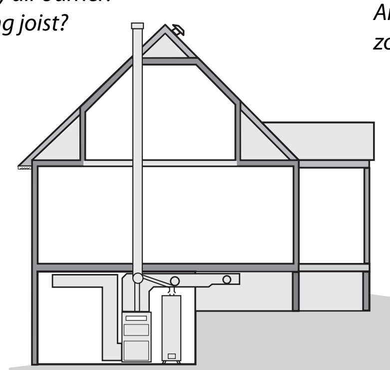
Most homes depend on air leakage to provide outdoor air for diluting pollutants and admitting fresh air. However, air leaks can also bring pollutants into the home. Mechanical ventilation is a more reliable and efficient way to provide fresh air. See *"Evaluating Home Ventilation Levels" on page 78* and *"Lead-Safe Procedures" on page 348*.

3.1.1 Goals of Air-Leakage Testing

Air-leakage testing accomplishes a variety of purposes.

1. Air-leakage and pressure testing measures the home's air-tightness level.
2. It evaluates the home's ventilation requirements.
3. It helps you to decide how much time and effort is required to achieve cost-effective air-leakage and duct-leakage rates.
4. It helps to compare the air-tightness of the air barriers on either side of an intermediate zone, such as an attic or crawl space. For example, comparing the ceiling with the ventilated roof gives the auditor an idea of how leaky the ceiling is.
5. It evaluates the leakiness of individual air barriers like ceilings.
6. It helps decide the best place to establish the air barrier in an area that has no obvious thermal boundary such as an uninsulated crawl space.

The reason for the complexity of air-leakage testing is that there is so much uncertainty about air leakage. Testing is needed because there simply is no accurate prescriptive method for determining the severity and location of leaks, especially in complex homes. Depending on the complexity of a home, you may need to perform varying levels of testing to evaluate shell air leakage.



Questions to ask during an air-leakage evaluation: Your answers help determine the most efficient and cost-effective location for the air barrier.

Air-Sealing with Air-Leakage Testing

Dedicate most of your effort to seal the large air leaks that pass directly through the thermal boundary first. Chasing small leaks or leaks that connect to the outdoors through interior walls or floors isn't worth as much effort if the budget is limited.

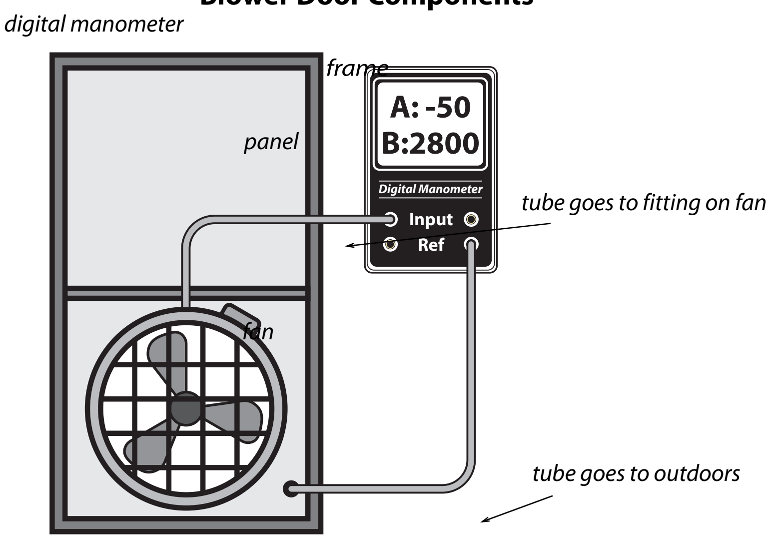
1. Perform blower door testing.
2. Analyze the test results to determine if air sealing is cost-effective.
3. Locate and seal the air leaks.
4. During air-sealing, monitor your progress with blower door testing.
5. Stop air sealing when air-sealing goals have been achieved or the budget limit has been reached.

3.2 House Airtightness Testing

House airtightness testing was made possible by the development of the blower door. The blower door measures a home's leakage rate at a standard pressure of 50 pascals. This leakage measurement can be used to compare homes with one another and to established air-leakage standards.

The blower door also allows the auditor to test parts of the home's air barrier to locate air leaks. Sometimes air leaks are obvious. More often, the leaks are hidden, and you need to find their location. This section outlines the basics of blower door measurement along with some techniques for gathering clues about the location of air leaks.

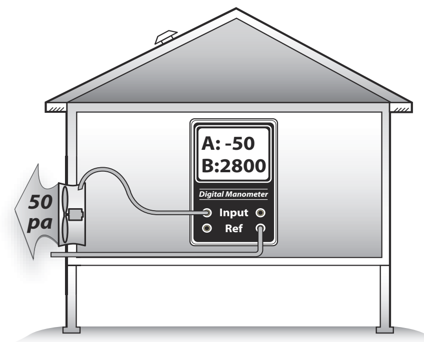
Blower Door Components



3.2.1 Blower-Door Principles

The blower door creates a 50-pascal pressure difference across the building shell and measures airflow in cubic feet per minute (CFM_{50}), in order to measure the leakiness of homes. The blower door also creates pressure differences between rooms in the house and intermediate zones like attics and crawl spaces. These pressure differences can give clues about the location and combined size of a home's hidden air leaks.

Blower door test: Air barriers are tested during a blower-door test, with the house at a pressure of 50 pascals negative with reference to outdoors. This house has 2800 CFM_{50} of air leakage. Further diagnostic tests can help determine where that leakage is coming from.

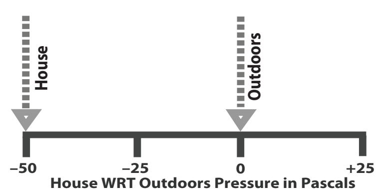


Blower-Door Terminology

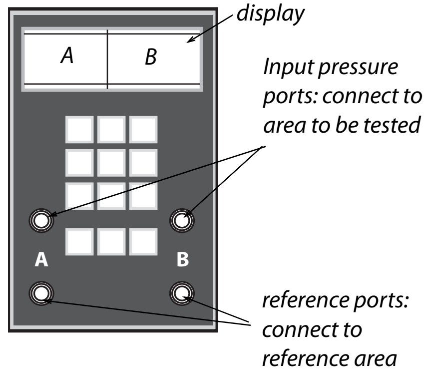
Connecting the digital manometer's hoses correctly is essential for accurate testing.

This method uses the phrase *with-reference-to (WRT)*, to distinguish between the input zone and reference zone for a particular measurement. The outdoors is the most commonly used reference zone for blower door testing. The reference zone is considered to be the zero point on the pressure scale.

For example, *house WRT outdoors* = –50 pascals means that the house (input) is 50 pascals negative compared to the outdoors (reference or zero-point). This pressure reading is called the house pressure.



Digital manometers: Used to diagnose house and duct pressures quickly and accurately.



Low-Flow Rings

During the blower door test, the manometer measures airflow through the fan. This airflow (CFM_{50}) is the primary measurement of a home's airtightness and is directly proportional to the surface area of the home's air leaks. For the blower door to measure airflow accurately, the air must be flowing at an adequate speed. Tighter buildings and smaller buildings don't have enough air leakage to create an adequate airspeed to create the minimum fan pressure. This low-flow condition requires using one or two low-flow rings, to reduce the blower-door fan's opening and to increase air speed, fan pressure, and measurement accuracy.

When the air speed is too low, the DG-700 displays "LO" in the Channel B display. After installing one of the low-flow rings, follow the manufacturer's instructions for selecting the proper range or configuration on the digital manometer.

3.2.2 Preparing for a Blower Door Test

Preparing the house for a blower door test involves putting the house in its normal heating-season operation with all conditioned zones open to the blower door. Try to anticipate safety problems that the blower door test could cause, particularly with combustion appliances. Check the chimney damper (when applicable). If there is no damper, the chimney should be blocked to shut off air flow. Window air conditioners should either be removed or wrapped with plastic (a large garbage bag will do) and the perimeters sealed with masking tape. If possible, sashes should be locked.

1. Identify the location of the thermal boundary and determine which house zones are conditioned.
2. Identify large air leaks that could prevent the blower door from achieving adequate pressure, such as a pet-door.
3. Put the house into its heating-season operation with windows, storm windows, doors, and vents closed and air registers open.
4. Turn off combustion appliances temporarily.
5. Open interior doors so that all indoor areas inside the thermal boundary are connected to the blower door. This could include the basement, conditioned kneewall areas, and closets.

Avoiding Risky Situations

Don't perform a blower door test in risky situations like the following until you remove the risk or perform an acceptable building repair.

1. A wood stove is burning.
2. Holes in the ceiling that could lead to dust pollution during a blower door test.
3. Extremely weak building components, like a poorly installed suspended ceiling or loose wood wall paneling.
4. When there is a floor furnace that cannot be disarmed or a common chimney where there is no access to the other unit.

3.2.3 Blower-Door Test Procedures

Follow this general procedure when performing a blower-door test.

1. Set up the house for winter conditions with exterior doors, primary windows and storm windows closed. The door to the basement should be either open or closed, according to whether or not the basement is considered to be within the thermal boundary.
2. Install blower door frame, panel, and fan in an exterior doorway with a clear path to outdoors. On windy days, install the blower door on the home's leeward side if possible. Pay attention to the blower door's location and any other conditions that may affect test results.
3. Follow manufacturer's instructions for fan orientation and digital-manometer setup for either pressurization or depressurization. Depressurization is the most common orientation.
4. Connect Channel A of the digital manometer to measure *house WRT outdoors*. Place the outside hose at least 5 feet away from the fan.
5. Connect Channel B to measure *fan WRT zone near fan inlet*. The zone near the fan inlet is indoors for depressurization and outdoors for pressurization. (Hose must run from the reference port on channel B to outdoors for pressurization.)
6. Ensure that children, pets, and other potential interferences are at a safe distance from the fan.

Conducting the Blower Door Test

Follow these instructions for performing a blower door test, using a digital manometer.

1. Turn on the manometer by pushing the ON/OFF button

2. Select the MODE: PR/FL@50.
3. Select the correct DEVICE that matches the blower door you're using.
4. With the fan covered, conduct the BASELINE procedure to cancel out the background wind and stack pressures. Let the manometer average the baseline pressure for at least 30 seconds.
5. Remove the no-flow plate from the blower door fan. Complete the next two steps for tighter buildings.
6. Install the flow ring in the blower door fan which matches the expected flow rate. The fan pressure should be at least 25 Pa while measuring CFM@50.
7. Push CONFIG or Range button until you match the flow ring being used.
8. Turn on the blower door fan slowly with the controller. Increase fan speed until the building depressurization on the Channel A screen is between –45 and –55 pascals. It doesn't need to be exactly –50 pascals
9. The Channel B screen will display the single-point CFM_{50} air leakage of the building. If this number is fluctuating a lot, push the TIME AVG button to increase the averaging time period.
10. You can also use the cruise-control function to automatically control the fan speed to create and hold –50 pascals of pressure.

Blower-Door Test Follow-Up

Be sure to return the house to its original condition.

1. Inspect combustion appliance pilot lights to ensure that blower door testing didn't extinguish them.
2. Reset thermostats of heaters and water heaters that were turned down for testing.

3. Remove any temporary plugs that were installed to increase house pressure.
4. Document the location where the blower door was installed.
5. Document any unusual conditions affecting the blower door test

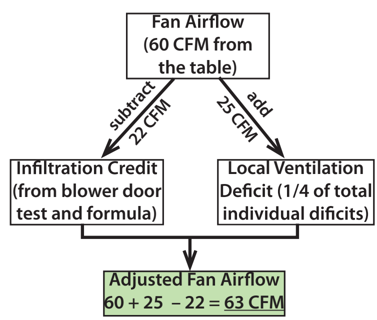
3.2.4 Approximate Leakage Area

There are several ways to convert blower-door CFM_{50} measurements into square inches of total leakage area. A simple and rough way to convert CFM_{50} into an approximate leakage area (ALA) is to divide CFM_{50} by 10. The ALA can help you visualize the size of openings you're looking for in a home or section of a home.

$$\textbf{ALA (SQUARE INCHES)} = \textbf{CFM}_{50} \div \textbf{10}$$

3.3 Evaluating Home Ventilation Levels

Most homes in North America currently rely on air leakage for ventilation. The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) publishes ventilation standards. Their current standard, ASHRAE 62.2-2010, requires fan-powered ventilation in all homes with the exception of very leaky homes. If you air-seal homes during weatherization, you are usually required to install whole-house mechanical ventilation systems under ASHRAE 62.2–2010.



ASHRAE 62.2 Process: First determine the fan airflow. Then subtract the infiltration credit and add the local ventilation deficit.

3.3.1 Whole-House Ventilation Requirement

To comply with ASHRAE 62.2–2010 Ventilation Standard, you can use either the formula or the table shown here to determine the ventilation-fan airflow. You can provide this fan-powered airflow in a number of ways.

1. A dedicated exhaust or supply fan running continuously or cycling by automatic control
2. A bathroom or kitchen exhaust fan running continuously or cycling by automatic control
3. A central air handler drawing air into its return
4. A balanced ventilation system such as a heat-recovery ventilator (HRV) or energy-recovery-ventilator (ERV).

Option 1: The Formula

Follow these steps to determine the fan airflow under 62.2–2010.

1. Determine the floor area of the conditioned space of the home in square feet (A_{floor}).
2. Determine the number of bedrooms (N_{br}).
3. Multiply 0.01 times the floor area in square feet.
4. Multiply 7.5 times the number of bedrooms plus 1.
5. Add the products of steps 3 and 4 together. This is the recommended fan airflow in cubic feet per minute.

$$\textbf{Fan Airflow(CFM)} = 0.01A_{floor} + 7.5(N_{br} + 1)$$

Option 2: The Table

You can also determine the fan airflow under ASHRAE 62.2–2010 using the table below.

Table 3-1: Fan Sizes for Homes with Average Air Leakage

Floor Area (ft^2)	No. of Bedrooms				
	0-1	2–3	4–5	6–7	>7
< 1500	30	45	60	75	90
1501–3000	45	60	75	90	105
3001–4500	60	75	90	105	120
4501–6000	75	90	105	120	135
6001–7500	90	105	120	135	150
> 7500	105	120	135	150	165

Fan flow in CFM. From ASHRAE Standard 62.2-2010

3.3.2 Local (Spot) Ventilation Requirement

There are two options for complying with the kitchen and bathroom ventilation requirements. Both bathroom and kitchen requirements may be met by dedicated exhaust fans and/or a central ventilation system.

- **Option 1:** Specify that each bathroom receives a minimum of 50 CFM of intermittent exhaust (with appropriate controls), or 20 CFM of continuous exhaust. Also specify that each kitchen receives a minimum of 100 CFM of intermittent exhaust or 5 air changes per hour (ACH) of continuous exhaust based on kitchen volume. When computing these airflow rates, count an opening window in a kitchen or bathroom as 20 CFM.
- **Option 2:** If operating existing ventilation equipment with open windows doesn't fulfill Option 1's requirements, and

existing local-ventilation equipment will remain the same, then airflow from the whole-house ventilation system must be increased to compensate for the insufficiency of local ventilation, according to ASHRAE 62.2–2010. Total the deficits from the kitchen and bathroom(s) and increase the whole-house ventilation system's airflow by one-quarter of that total CFM airflow.

Example of Local Ventilation Deficit Calculation

Example: The kitchen of a home has a small range hood providing 30 CFM and a window for an additional 20 CFM. The main bathroom has a fan providing around 30 CFM and no opening window. The second bath has an opening window but no fan. Follow the steps below to find the necessary additional airflow.

How to Find the Local Ventilation Deficit: 5 Steps

1. **Kitchen Deficit: 100 CFM – (30 + 20) CFM = 50 CFM**
2. **Bathroom 1 Deficit: 50 CFM – 30 CFM = 20 CFM**
3. **Bathroom 2 Deficit: 50 CFM – 20 CFM = 30 CFM**
4. **Total Deficit: 50 CFM + 20 CFM + 30 CFM = 100 CFM**
5. **Added CFM Needed (I_{def}): 100 CFM ÷ 4 = 25 CFM**

See also "Fan Specifications" on page 352. See also "Gas Range and Oven Safety" on page 336.

3.3.3 The ASHRAE 62.2–2010 Infiltration Credit

ASHRAE 62.2–2010 allows users to reduce the ventilation-fan airflow by an infiltration credit (I_{cred}) if the actual measured air infiltration (I_{CFM}) is greater than the air infiltration assumed by this ASHRAE standard (I_d). If the I_{CFM} is less than or equal to the assumed air leakage ($I_{d)}$, the home doesn't qualify for the infiltration credit. If the infiltration credit is greater than the fan airflow, this cancels out the required fan airflow and the home doesn't require a fan.

Three Parts to Determining the Infiltration Credit

Infiltration Credit: $I_{cred} = \frac{1}{2}(I_{CFM} - I_d)$

Measured infiltration: $I_{CFM} = CFM_{50} \div N$

Assumed infiltration: I_d = Floor area X 0.02

Table 3-2: Revised N-Values for New Jersey

Number of Stories				
1	**1.5**	**2**	**2.5**	**3**
28.1	24.9	22.8	21.4	20.2
These N-values are based on a W value for Lakehurst, NJ of 0.70				

Example Calculation: Infiltration Credit

Example: A 3 bedroom 2025 square-foot two-story home in Detroit has a measured blower-door air leakage of 2100 CFM_{50}. From the table, the home requires 60 CFM of fan-powered airflow. Does this home get an infiltration credit? How much fan-powered airflow do the air-sealers need to add? Follow the steps below to find the answers.

How to Find the Infiltration Credit

1. Find I_{CFM}: 2100 $CFM_{50} \div 17.4 = 121$ CFM

2. Find I_d: 2025 X 0.02 = 40 CFM

3. Find $I_{cred} = \frac{1}{2}(121 - 40)$ = <u>40 CFM</u>

Example Calculation: Adjusted Fan Airflow

The final step is to find the adjusted fan airflow by adding the local ventilation deficit and subtracting the infiltration credit from the initial fan airflow.

How to Find the Adjusted Fan Airflow

Adjusted fan CFM: 60 CFM + I_{def} – I_{cred}

Find adjusted fan CFM: 60 CFM + 25 – 40 CFM = 45 CFM

3.3.4 Verifying Fan Airflows for Ventilation

To fully implement ASHRAE 62.2–2010, measure the airflow of local exhaust fans in order to calculate the local ventilation deficit. Verify that central ventilation fans achieve the calculated adjusted fan airflow.

Measuring fan airflow: Use an exhaust-fan flow meter or a flow hood to verify the airflows through local exhaust fans and whole-house ventilation fans.

3.4 Pollutant Control

Controlling pollutants at the source is a higher priority than ventilation, especially in tighter homes. Mechanical ventilation can help remove and dilute pollutants, but don't rely on ventilation as the primary method of pollutant control. The relative importance of pollution control depends on the following.

1. Do sources of moisture like ground water, humidifiers, water leaks, or unvented space heaters cause indoor dampness, high relative humidity, or moisture damage? *See "Moisture Problems" on page 340.*
2. Do the occupants have symptoms of building-related illnesses? *See also "Health and Safety" on page 333.*
3. Are there combustion appliances in the living space?
4. Do the occupants smoke?

3.4.1 Pollution-Control Checklist

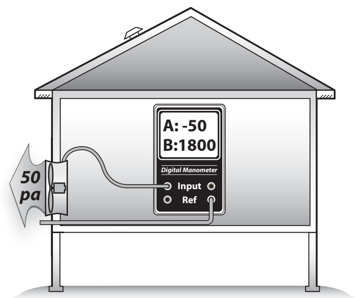
Contractors should survey the home for pollutants before performing air-sealing, and perform the following pollutant control measures if needed:

1. Repair roof and plumbing leaks.
2. Install a ground moisture barrier over any bare soil in crawl spaces or basements.
3. Verify that all dryer ducts and exhaust fans move their air to the outdoors.
4. Verify that combustion-appliance vent systems operate properly. Don't air-seal homes with unvented space heaters as their primary source of heat.
5. Move paints, cleaning solvents, and other chemicals out of the conditioned space if possible.

The home's occupants are often the source of many home pollutants. Always educate the residents about minimizing pollutants in the home.

3.5 Testing Air Barriers

Leaks in air barriers cause energy and moisture problems in many homes. Air-barrier leak-testing avoids unnecessary visual inspection and unnecessary air sealing in hard-to-reach areas.



Blower door test: Air barriers are tested during a blower-door test, with the house at a pressure of 50 pascals negative with reference to outdoors. This house has 3000 CFM_{50} of air leakage. Further diagnostic tests can help determine where that leakage is coming from.

Advanced pressure tests measure pressure differences between zones in order to estimate air leakage between zones. Use these tests to make decisions about where to direct your air-sealing efforts, for example.

1. Evaluate the airtightness of portions of a building's air barrier, especially floors and ceilings.
2. Decide which of two possible air barriers to air seal — for example, the floor versus foundation walls.
3. Determine whether building cavities like porch roofs, floor cavities, and overhangs are conduits for air leakage.
4. Determine whether building cavities, intermediate zones, and ducts are connected together through air leaks.

5. Estimate the air leakage in CFM_{50} through a particular air barrier, for the purpose of estimating the effort and cost necessary to seal the leaks.

Air-Barrier Test Results

Air-barrier tests provide a range of information from simple clues about which parts of a building leak the most, to specific estimates of the airflow and hole size through a particular air barrier.

The next table shows examples of how common building materials perform as air barriers. This information is helpful in interpreting blower door tests and selecting air-sealing materials.

Table 3-3: Building Components and Their Air Permeance

Good air barriers: <2 CFM_{50} per 100 sq. ft.	Poor air barriers: 10–1000 CFM_{50} per 100 sq. ft.
5/8” oriented strand board	5/8” tongue-and-groove wood sheeting
1/2” drywall	6" fiberglass batt
4-mil air barrier paper	1.5" wet-spray cellulose
Asphalt shingles and perforated felt over 1/2” plywood	wood siding over plank sheathing
1/8” tempered hardboard	wood shingles over plank sheathing
painted un-cracked lath and plaster	blown fibrous insulation

Measurements taken at 50 pascals pressure.
Based on information from: “Air Permeance of Building Materials” by Canada Mortgage Housing Corporation, and estimates of comparable assemblies by the author.
Although cellulose reduces air leakage when blown into walls, it isn’t considered an air-barrier material.

3.5.1 Primary Versus Secondary Air Barriers

A home's air barrier should be a material that is continuous, sealed at the seams, and impermeable to airflow. Where there are two possible air barriers, in an attic for example, the most airtight barrier is the primary air barrier and the least airtight is the secondary air barrier.

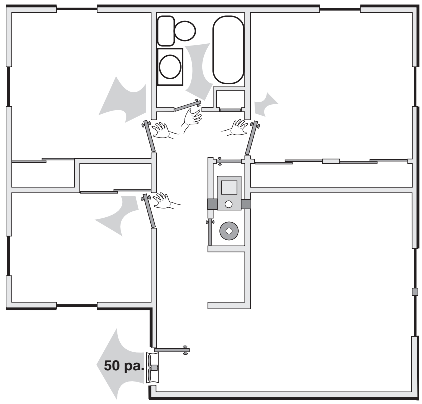
The primary air barrier should be adjacent to the insulation to ensure the insulation's effectiveness. We use pressure-diagnostic testing to verify that the insulation and the primary air barrier are together. Sometimes we're surprised during testing to find that our assumed primary air barrier is actually secondary, and the secondary air barrier is primary.

Intermediate zones are unconditioned spaces that are sheltered within the exterior shell of the house. Intermediate zones can be located inside or outside the home's primary air barrier. Intermediate zones include: unheated basements, crawl spaces, attics, enclosed porches, and attached garages.

Intermediate zones have two potential air barriers: one between the zone and house and one between the zone and outdoors. For example, an attic or roof space has two air barriers: the ceiling and roof. You should know which air barrier is the tightest.

3.5.2 Simple Pressure Tests

Blower door tests give us valuable information about the relative leakiness of rooms or sections of the home. Listed below are five simple methods



Interior door test: Feeling airflow with your hand at the crack of an interior door gives a rough indication of the air leakage coming from the outdoors through that room.

1. *Feeling zone air leakage:* Close an interior door partially so that there is a one-inch gap between the door and door jamb. Feel the airflow along the length of that crack, and compare that airflow intensity with airflow from other rooms, using this same technique.

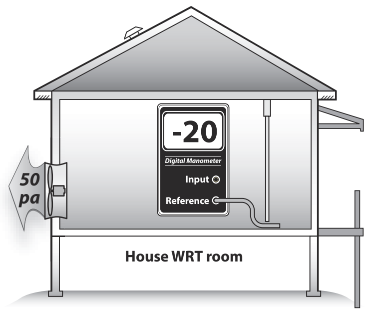
2. *Observing the ceiling/attic floor:* Pressurize the home and observe the top-floor ceiling from the attic with a good flashlight. Air leaks will show in movement of loose-fill insulation, blowing dust, moving cobwebs, etc. You can also use a small piece of tissue paper to disclose air movement.

3. *Observing smoke movement:* Pressurize the home and observe the movement of smoke through the house and out of its air leaks.

4. *Room pressure difference:* Check the pressure difference between a closed room or zone and the main body of a home. Larger pressure differences indicate larger potential air leakage within the closed room or else a tight air barrier between the room and main body. A small pressure difference means little leakage to the

outdoors through the room or a leaky air barrier between the house and room.

5. *Room airflow difference:* Measure the house CFM_{50} with all interior doors open. Close the door to a single room, and note the difference in the CFM_{50} reading. The difference is the approximate leakage through that room's air barrier.



Bedroom test: This bedroom pressure difference may be caused by its leaky exterior walls or tight interior walls, separating it from the main body of the home. This test can determine whether or not a confined combustion zone is connected to other rooms.

Tests 1, 2, and 3 present good customer education opportunities. Feeling airflow or observing smoke are simple observations, but have helped identify many air leaks that could otherwise have remained hidden.

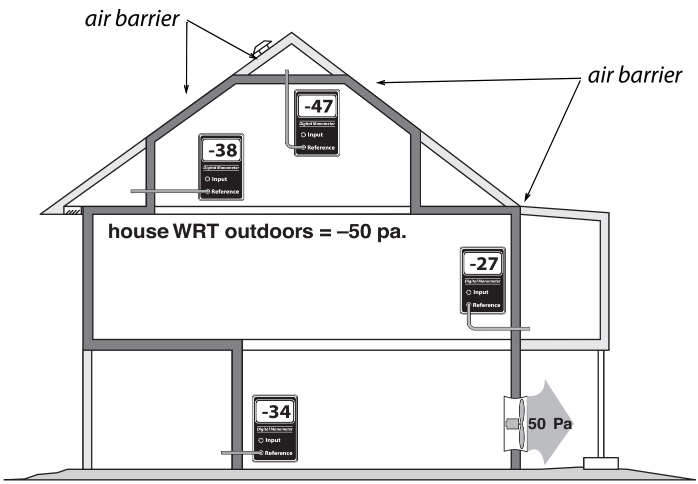
When airflow within the home is restricted by closing a door, as in tests 4 and 5, it may take alternative indoor paths that render these tests somewhat misleading. Only practice and experience can guide your decisions about the applicability and usefulness of these general indicators.

3.5.3 Simple Zone Pressure Testing

Manometers aren't limited to finding indoor WRT outdoor differences. They can also measure pressure differences between the house and its intermediate zones during blower-door tests. The purpose of these tests is to evaluate the air-tightness of the home's interior air barriers.

The blower door, when used to create a house-to-outdoors pressure of –50 pascals, also creates house-to-zone pressures of between 0 and –50 pascals in the home's intermediate zones.

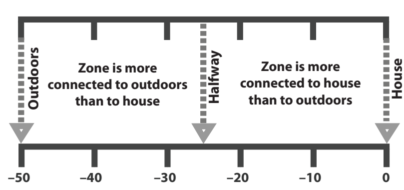
The amount of depressurization depends on the relative leakiness of the zone's two air barriers.



Pressure-testing building zones: Measuring the pressure difference across the assumed thermal boundary tells you whether the air barrier and insulation are aligned. If the manometer reads close to –50 pascals, the air barrier and insulation are aligned, if the tested zones are well-connected to outdoors.

For example, in an attic with a fairly airtight ceiling and a well-ventilated roof, the attic will indicate that it is mostly outdoors by having a house-to-zone pressure of –45 to –50 pascals. The leakier the ceiling and the tighter the roof, the smaller that the negative house-to-zone pressure will be. This holds true for other intermediate zones like crawl spaces, attached garages, and unheated basements.

Zone Leak-Testing Methodology

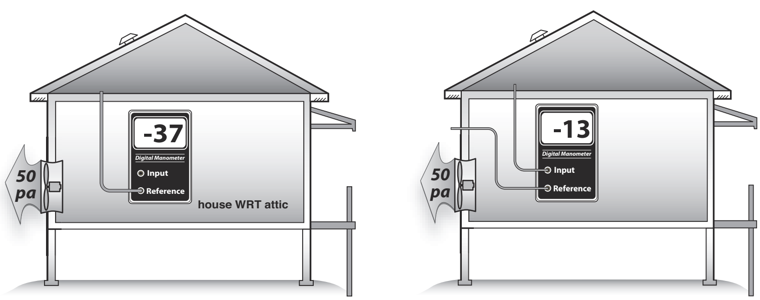


Depressurize house to –50 pascals with a blower door.

1. Find an existing hole, or drill a hole through the

floor, wall, or ceiling between the conditioned space and the intermediate zone.

2. Connect the reference port of a digital manometer to a hose reaching into the zone.
3. Leave the input port of the digital manometer open to the indoors.
4. Read the negative pressure given by the manometer. This is the house-to-zone pressure, which will be –50 pascals if the air barrier between house and zone is airtight and the zone itself is well-connected to outdoors.
5. If the reading is significantly less negative than –45 pascals, find the air barrier's largest leaks and seal them.
6. Repeat steps 1 through 5, performing more air-sealing as necessary, until the pressure is as close to –50 pascals as possible.



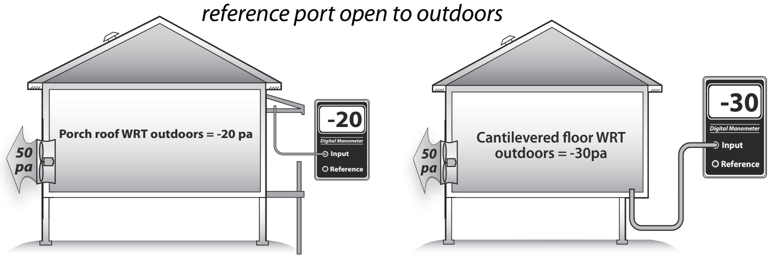
House-to-attic pressure: This commonly used measurement is convenient because it requires only one hose.

Attic-to-outdoors pressure: This measurement confirms the first because the two add up to –50 pascals.

Leak-Testing Building Cavities

Building cavities such as wall cavities, floor cavities between stories, and dropped soffits in kitchens and bathrooms can also be tested as described above to determine their connection to the outdoors as shown here.

These examples assume that the manometer is outdoors with the reference port open to outdoors

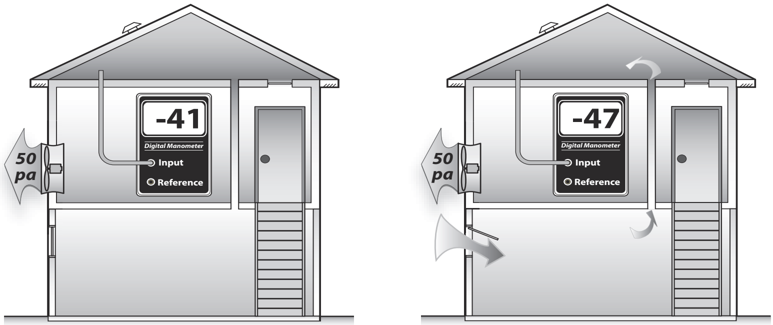


Porch roof test: If the porch roof were outdoors, the manometer would read near 0 pascals. We hope that the porch roof is outdoors because it is outside the insulation. We find, however, that it is partially indoors, indicating that it may harbor significant air leaks through the thermal boundary.

Cantilevered floor test: We hope to find the cantilevered floor to be indoors. A reading of –50 pascals would indicate that it is completely indoors. A reading less negative than –50 pascals is measured here, indicating that the floor cavity is partially connected to outdoors.

Testing Zone Connectedness

Sometimes it's useful to determine whether two zones are connected by a large air leak. Measuring the house-to-zone pressure during a blower door test, before and then after opening the other zone to the outdoors, can establish whether the two zones are connected by a large air leak. You can also open an interior door to one of the zones and check for pressure changes in the other zone.

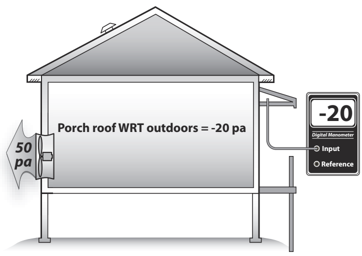


Zone connectedness: The attic measures closer to outdoors after the basement window is opened, indicating that the attic and basement are connected by a large bypass.

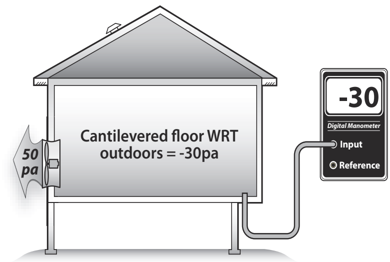
Leak-Testing Building Cavities

You can also test building cavities such as wall cavities, floor cavities between stories, and dropped soffits in kitchens and bathrooms with a digital manometer to evaluate their possible connection to the outdoors by way of air leaks.

These examples assume that the digital manometer is outdoors with the reference port open to outdoors



Porch roof Test: If the porch roof were outdoors, the digital manometer would read near 0 pascals. We hope that the porch roof is outdoors because it is outside the insulation. We find here, however, that the porch is partially indoors, indicating that it may harbor significant air leaks through the thermal boundary.



Cantilevered floor test: We hope to find the cantilevered floor to be indoors. A reading of –50 pascals would indicate that it is completely indoors. A reading less negative than –50 pascals is measured here, indicating that the floor cavity is partially connected to outdoors.

Locating the Thermal Boundary

When retrofitting, you need to decide where to air-seal and where to insulate. Zone pressures are one of several factors used to determine where the thermal boundary should be.

For zone leak-testing, the house-to-zone pressure is often used to determine which of two air barriers is tighter.

1. Readings of negative 25-to-50 pascals house-to-attic pressure mean that the ceiling is tighter than the roof. If the roof is almost completely airtight, achieving a 50-pascal house-to-attic pressure difference may be difficult. However if the roof is well-ventilated, achieving a near-50-pascal difference should be possible.

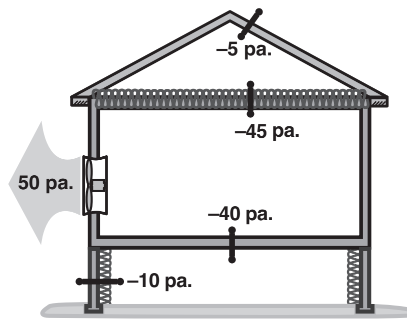
2. Readings of negative 0-to-25 pascals house-to-attic pressure mean that the roof is tighter than the ceiling. If the roof is well-ventilated, the ceiling has even more leakage area than the roof’s vent area.

3. Readings around –25 pascals house-to-attic pressure indicate that the roof and ceiling are equally airtight or leaky.

Pressure readings more negative than –45 pascals indicate that the ceiling (typical primary air barrier) is adequately airtight. Less negative pressure readings indicate that air leaks should be located and sealed.

Floor Versus Crawl Space

The floor shown here is tighter than the crawl-space foundation walls. If the crawl-space foundation walls are insulated, holes and vents in the foundation wall should be sealed until the pressure difference between the crawl space and outside is as negative you can make it — ideally more negative than –45 pascals. A leaky foundation wall renders its insulation nearly worthless.



Pressure measurements and air-barrier location: The air barrier and insulation are aligned at the ceiling. The crawl-space pressure measurements show that the floor is the air barrier and the insulation is misaligned — installed at the foundation wall. We could decide to close the crawl space vents and air-seal the crawl space. Then the insulation would be aligned with the air barrier.

If the floor above the crawl space were insulated instead of the foundation walls in the above example, the air barrier and the insulation would be aligned.

If a floor is already insulated, it makes sense to establish the air barrier there. If the foundation wall is more airtight than the floor, that would be one reason to insulate the foundation wall.

Attic Boundary

Generally, the thermal boundary (air barrier and insulation) should be between the conditioned space and attic. An exception would be insulating the roof to enclose an attic air handler and its ducts within the thermal boundary.

Garage Boundary

The air barrier should always be between the conditioned space and a tuck-under or attached garage, to separate the living spaces from this unconditioned and often polluted zone.

Duct Location

The location of ducts either within or outside the thermal boundary is an important factor in determining the cost-effectiveness of duct-sealing and insulation. Including the heating ducts within the thermal boundary is preferred because it reduces energy waste from both duct leakage and duct heat transmission.

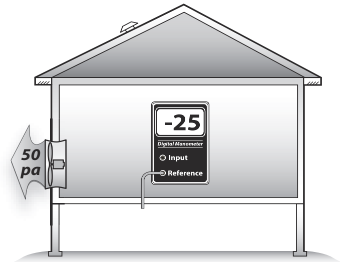
3.5.4 Decisions about Basement and Crawl Spaces

The importance of creating an effective air barrier at the foundation walls or floor depends on how much of the home's air leakage is coming through the foundation or floor, which is often a major air-leakage source especially in older homes.

You may choose either the first floor or the foundation wall as the air barrier. Install the insulation in whichever component — floor or foundation wall — was chosen as the air barrier if insulation is a weatherization priority.

The results of air-barrier tests are only one deciding factor in selecting the thermal boundary's location. Moisture problems, duct and furnace location, and the necessity of crawl-space venting are other important considerations.

Basement insulation may not be a very practical weatherization option because of moisture concerns, cost, or the requirement to drywall and fire-tape any newly insulated interior surfaces. Crawl-space insulation poses fewer problems and is often undertaken using foam sheeting, wet-spray cellulose or fiberglass, spray two-part foam, and foil-faced (FSK) fiberglass. *See "Insulating Floors and Foundations" on page 173.*



House-to-crawl-space pressure: Many homes with crawl spaces have an ambiguous thermal boundary at the foundation. Is the air barrier at the floor or foundation wall? Answer: in this case, each forms an equal part of the home's air barrier.

The tables presented here summarize the decision factors for choosing between the floor and the foundation wall as the air barrier. You may also encounter situations that aren't addressed here.

When a home has a basement and crawl space connected, both *Table 3-4 on page 98* and *Table 3-5 on page 99* are relevant to the decision-making process of selecting the air barrier and site for insulation, if insulation is cost-effective. A basement may even be divided from its adjoining crawl space to enclose the basement within the air barrier and put the crawl space outside the air barrier.

Table 3-4: Crawl Space: Where Is the Air Barrier?

Factors favoring foundation wall	Factors favoring floor
Ground moisture barrier and good perimeter drainage present or planned	Damp crawl space with no improvement offered by weatherization
Foundation walls test tighter than floor	Floor air-sealing and insulation are reasonable options, considering access and obstacles
Vents can be closed off	Floor tests tighter than foundation walls
Furnace, ducts, and water pipes located in crawl space	No furnace or ducts present
Concrete or concrete block walls are easily insulated	Building code or code official forbids closing vents
Floor air-sealing and insulation would be more difficult than sealing and insulating the foundation	Rubble masonry foundation wall
Foundation wall is insulated	Floor is already insulated

Table 3-5: Unoccupied Basement: Where Is the Air Barrier?

Favors foundation wall	Favors floor
Ground drainage and no existing moisture problems	Damp basement with no solution during weatherization
Interior stairway between house and basement	Floor air-sealing and insulation is a reasonable option, considering access and obstacles
Ducts and furnace in basement	No furnace or ducts present
Foundation walls test tighter than the floor	Floor tests tighter than foundation walls
Basement may be occupied some day	Exterior entrance and stairway only
Laundry in basement	Rubble masonry foundation walls
Floor air-sealing and insulation would be very difficult	Dirt floor or deteriorating concrete floor
Concrete floor	Badly cracked foundation walls

3.6 CONTROLLING HOUSE PRESSURE

House pressures drive air through leaks in the building shell and can cause open-combustion appliances to backdraft. For energy conservation and safety, you should measure house pressures and try to limit them.

The causes of house pressures include the following.

1. Duct air leakage
2. Unbalanced ducted airflow
3. Central ventilation systems
4. Exhaust fans in kitchens and bathrooms
5. Wind
6. Cold weather

3.6.1 Duct-Induced Room Pressures

An improperly balanced air-handling system can reduce comfort, building durability, and indoor air quality. Duct-induced room pressures can increase air leakage through the building shell from 1.5 to 3 times, compared to when the air handler is off.

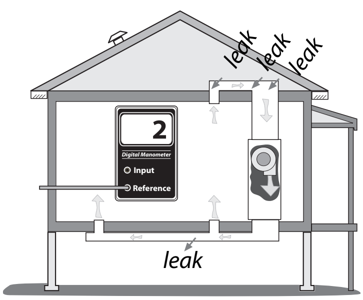
The following test measures pressure differences between the main body of the house and outdoors, between each room and outdoors, and between the combustion zone and outdoors. A pressure difference greater than +4.0 pascals or more negative than –4.0 pascals should be corrected. If the pressure imbalance is the result of occupant behavior such as covering supply or return grilles, discuss these issues with the customer.

Dominant Duct Leakage

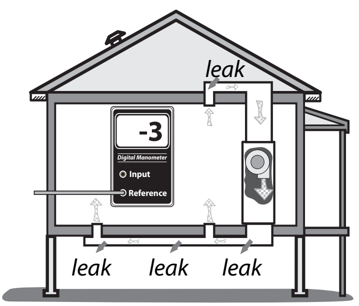
This test helps determine whether duct-sealing efforts should be directed to the supply or return duct system. This test doesn't measure the amount of duct leakage. *See "Evaluating Duct Air Leakage" on page 270.*

1. Set up house for winter conditions. Close all windows and exterior doors. Turn-off all exhaust fans.
2. Open all interior doors, including door to basement.
3. Turn on the air handler.
4. Measure the house-to-outdoors pressure difference.

A positive pressure indicates that the return ducts (which pull air from leaky intermediate zones) are leakier than the supply ducts. A negative pressure indicates that the supply ducts (which push air into intermediate zones through their leaks) are leakier than return ducts. A pressure at or near zero indicates equal supply and return leakage or else little duct leakage.



Dominant return leaks: When return leaks are larger than supply leaks, the house shows a positive pressure with reference to outdoors.



Dominant supply leaks: When supply leaks are larger than return leaks, the house shows a negative pressure with reference to outdoors.

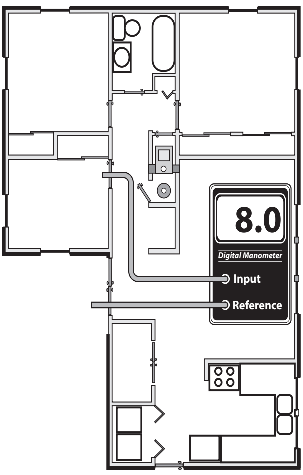
Room Pressure Imbalance

This test identifies room-pressure imbalances caused by closed doors in bedrooms, equipped with supply registers but no return registers.

1. Leave the house in winter conditions, and leave the air handler running.
2. Close interior doors.
3. Place hose from input tap on the manometer under one of the closed interior doors. Connect the reference tap to outdoors with a hose.
4. Read and record this *room-to-outdoors* pressure measurement for each room. This pressure's magnitude indicates the degree to which the air-handler's airflow is unbalanced between supply and return ducts in that room or zone.

If the pressure difference is more than ± 3.0 pascals with the air handler operating, pressure relief is necessary. To estimate the amount of pressure relief, slowly open door until pressure difference drops to between +3.0 pascals and –3.0 pascals. Estimate area of open door. This is the area required to provide the necessary pressure relief. Pressure relief may include undercutting the door or installing transfer grilles.

Blocked return path: With interior doors closed, the large positive pressure in the bedroom is caused by the lack of a air return register in the bedroom. The airflow in this forced-air system is unbalanced, creating this pressure, and forcing room air through the room's air leaks to outdoors.



Chapter 4: Air Sealing Homes

This chapter discusses the locations of air leaks and the methods and materials used to seal them. The energy auditor usually performs a blower door test before specifying air sealing or duct sealing work. The inspector may also perform various diagnostic tests during the final inspection.

Weatherization agencies evaluate ventilation and perform combustion-safety testing as a part of an energy audit and final inspection. *See "Evaluating Home Ventilation Levels" on page 78.*

4.1 Air Sealing Fundamentals

Air leakage in homes accounts for 5% to 40% of annual heating and cooling costs. Air sealing is one of the most important energy-saving retrofits, and often the most difficult.

Air travels into and out of the building by three main pathways.

1. Major air leaks, which are significant flaws in the home's air barrier
2. Minor air leaks, which are often seams between building materials
3. Through the building materials themselves (*See table 3-3 on page 86.)*

Reducing air leakage accomplishes several goals.

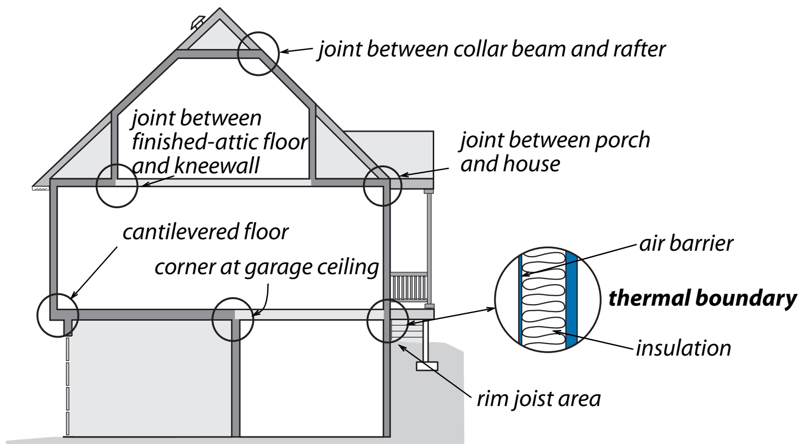
1. Saves energy by reducing unintentional air exchange with outdoors
2. Saves energy by protecting the thermal resistance of the shell insulation
3. Increases comfort by reducing drafts and moderating the radiant temperature of interior surfaces
4. Reduces moisture migration into building cavities

5. Reduces the pathways by which fire spreads through a building

4.1.1 Air Sealing Strategy

The first step to improving a building's airtightness is to formulate a strategy. Building a strategy starts by asking questions like these.

1. What building components already serve as air barriers?
2. How do we best seal the border areas between these components?
3. Where there is no obvious air barrier, where do we install an air barrier?
4. How do we seal various penetrations through the air barrier?
5. How does whole-house ventilation relate to shell air leakage? *See "Evaluating Home Ventilation Levels" on page 78.*



Thermal boundary flaws: The thermal boundary contains the air barrier and insulation, which should be adjacent to one other. The insulation and the air barrier are often discontinuous at corners and transitions.

4.2 Air Sealing Safety

Air sealing reduces the exchange of fresh air in the home, and can alter the pressures within the home. Survey the home to identify both air pollutants that may be concentrated by air sealing efforts and open combustion appliances that may be affected by changes in house pressure during the energy audit.

Don't specify air sealing when there are obvious threats to the occupants' health, the installers' health, or the building's durability that are related to air sealing. If any of the following circumstances are present, either postpone air sealing until they're corrected or specify a solution to these problems as part of the project's work scope.

1. Measured carbon monoxide levels exceed the suggested action level. *See "Carbon Monoxide (CO) Testing" on page 204.*

2. Combustion zone depressurization exceeds –4 pascals during a worst-case test. *See "Worst-Case CAZ Depressurization Test" on page 207.*
3. Combustion appliance chimneys don't meet minimum standards.
4. Unvented space heaters will be used as a primary source of heat after air sealing work.
5. Moisture has caused structural damage or respiratory hazards from rot, mold, or dust mites. *See "Moisture Problems" on page 340.*
6. Infestations, vermin, or other sanitary issues are present.

4.3 Air Sealing Materials

Air barriers must be able to resist severe wind pressures. Specify strong air barrier materials like plywood, drywall, galvanized steel, or foamboard to seal large air leaks, especially if your region has powerful winds. These strong materials should be attached with mechanical fasteners and construction adhesive. Inspect the major air seals as part of a final inspection or in-progress inspection as necessary.

Learn about the air-sealing materials that your agency uses, so you can specify the right material for a work order. Inspectors should recognize these materials and their proper installation.

4.3.1 Air Barrier Materials

Air barrier materials should themselves be air barriers. Perforated asphalt felt, concrete block, and earth are among the substantial materials that aren't considered air barriers. The materials discussed below are air barriers. *See also "Building Components and Their Air Permeance" on page 86.*

Plywood, OSB, etc.

Three-eighths-inch plywood and oriented strand board (OSB) are strong enough to resist any windstorm that spares the house. Although combustible and flammable, plywood, OSB, and masonite can be used as ignition barriers and fire stops. Attach these structural sheets with screws or nails and construction adhesive which strengthens the bond and accomplishes air sealing at the joint.

Drywall

Half-inch drywall constitutes a 15 minute thermal barrier, and is also an ignition barrier. When air sealing a fire-rated assembly in a commercial or multi-family building, choose drywall and a fire-rated caulking whenever possible. Fasten drywall with screws and construction adhesive. Don't use drywall where it will get wet or in damp locations.

Galvanized Steel

Being non-combustible, galvanized steel is used to seal around chimneys and other heat producing components. It can be used to build air seals around recessed light fixtures. A round galvanized duct with a galvanized cap makes a good air seal for round recessed light fixtures. To seal around chimneys, cut the galvanized steel accurately so that you can seal the gap with high temperature silicone or stove cement.

Foam Board

One- or two-inch foil-faced polyurethane foam board is easy to cut and fit and is an excellent insulating material. However, foam board is difficult to fasten sufficiently to resist a strong wind event. Plywood, OSB, drywall or other structural materials are far more suitable for sealing large air leaks because of the strong assembly that results by attaching structural air sealing materials to existing structural materials.

Cross-Linked Polyethylene House Wrap

House wrap is vapor permeable, waterproof, and a good air barrier. However it isn't rigid and can be pulled off its fasteners by powerful wind. When used as an air barrier underneath siding, it must be taped at the seams and protected from damage until siding is installed. House wrap isn't a very good retrofit air sealing material.

Adhesive Window Flashing

Construction tape and adhesive window flashing can be very effective air sealing materials when used correctly with house wrap or vapor barrier material. Surface preparation is extremely important when using adhesive-backed materials because dust, oil, and moisture can cause the adhesive to fail. The flashing should lay very flat without any tenting in order to allow one-part foam to seal the gap between a new window and the rough opening.

4.3.2 Stuffing Materials

Stuffing materials are used to insulate a cavity, to give the cavity a bottom, and to serve as supporting part of an air seal.

Backer Rod

Backer rod is closed-cell polyethylene foam that creates a bottom barrier in a gap that will be caulked. Backer rod doesn't bond to the caulking, and so prevents three-sided adhesion that could tear the caulking bead apart with the expansion and contraction of temperature extremes.

Fiberglass Batts

Fiberglass batts are far from being an air barrier, even if stuffed tightly. However, they can be used to fill cavities for insulation, convection reduction, and support for two-part foam sprayed over the cavity.

Blown Cellulose

Blown cellulose is considered an air barrier because of its tendency to slow air migration by becoming wedged into gaps and cracks. However cellulose isn't much better than fiberglass at stopping air movement. When used to completely fill cavities, it can reduce blower door readings significantly. However, blown cellulose isn't strong enough to resist a windstorm which would blow a hole through the plug of cellulose or simply move it out of the way. Cellulose should never be used in areas where it may get wet.

4.3.3 Caulking and Adhesives

The performance of caulking and adhesives depends on their formulation and on the substrate to which they are applied. Some caulks and adhesives are quite sensitive to dirt and only work well on particular substrates, while others are versatile and dirt-tolerant. Removing debris and cleaning the joint are required for a long lasting seal.

Water Based Caulks

A wide variety of paintable caulks are sold under the description of acrylic latex and vinyl. These are the most commonly used caulks and the easiest to apply and clean up. Siliconized latex caulks are among the most adhesive and durable sealants in this group. Don't apply water based caulks to building exteriors when rain is expected since they aren't waterproof until cured, and they stain nearby materials if they are rained upon while curing. Don't apply water based caulks when freezing weather is expected.

Silicone Caulk

Silicone has great flexibility, but its adhesion varies among different substrates. It is very easy to gun even in very cold weather. Silicone isn't as easy to clean up as water based caulks, though it's easier than polyurethane or butyl. Silicone isn't paintable, so choose an appropriate color. High temperature silicone can tolerate temperatures above 400° F and is used with galvanized steel to air seal around chimneys.

Polyurethane Caulk

Polyurethane has the best adhesion and elasticity of any common caulk. It works very well for cracks between different materials like brick and wood. It resists abrasion and is used to seal critical joints in concrete slabs and walls. It is also good for sealing the fastening fins of windows to walls. It is almost as sticky and adhesive as a construction adhesive. Cleaning it up is difficult so neat workmanship is essential. Polyurethane caulk doesn't gun easily, and should be room temperature or higher. Polyurethane caulk doesn't hold paint.

Acoustical Sealant

This solvent based or water based adhesive is used to seal laps in polyethylene film and house wrap. Acoustical sealant is very sticky, adheres well to most construction materials, and remains flexible for years after application. Acoustical sealant is used to seal building assembles for sound deadening.

Water Soluble Duct Mastic

Duct mastic is the best material for sealing ducts, including cavities used for return ducts. A messy but highly effective sealant, duct mastic can be applied with a medium thickness brush or rubber glove. Have a bucket of warm water handy to clean your gloved hands and a rag to dry the gloves. Spread the mastic and use fiberglass fabric web tape to reinforce cracks more than $^{1}/_{8}$-inch in diameter. Thorough cleaning of dust and loose material isn't necessary. Mastic bonds tenaciously to everything, including skin and clothing.

Stove Cement

Stove cement is a material that can withstand temperatures up to 2000° F. It is used to seal wood stove chimneys and to cement wood stove door gaskets in place.

Fire-Rated Caulk

Some elastomeric caulks are designed specifically for use in fire-rated assemblies. They can withstand flame and temperatures to 2000° F. Use this type of sealant when sealing air leaks in fire-rated assemblies in multifamily and commercial buildings.

Fire-Rated Mortar

Used in conjunction with foam to seal various sized holes and gaps in commercial buildings with fire-rated building assemblies. This mortar covers the foam to preserve a non-combustible surface.

Construction Adhesives

Construction adhesives are designed primarily to bond materials together. But they also create an air seal if applied continuously around the perimeter of a patch. They are often used with fasteners like screws or nails but can also be used by themselves. Higher quality construction adhesives can be used as contact adhesives to bond lightweight materials. Apply the adhesive to one surface, touch the patch down to spread the glue to both surfaces, then remove the patch to expose the adhesive to air. After a few minutes, put the patch back in place. Make sure you put the patch in the correct location because it will be extremely difficult to remove.

Use specially designed construction adhesives for polystyrene foam insulation because a general purpose adhesives decompose the foam's surface.

4.3.4 Liquid Foam Air Sealant

One-part foam: A contractor uses an applicator gun to seal spaces between framing members and around windows.

Liquid closed-cell polyurethane foam is a versatile air sealing material. Closed-cell foam is packaged in a one-part injectable variety and a two-part sprayable variety. It has a very high R-value per inch and is ideal for insulating and air sealing small, poorly insulated, and leaky areas in a single application.

Installing liquid foam is easy compared to other materials to accomplish the same air sealing tasks. However, cleanup is difficult enough that installers don't want to clean up multiple times on the same job. Instead experienced installers identify all the spots needing foam application, make a list, and foam the spots one after another.

Two-part foam: A contractor air seals and insulates around an attic hatch dam with two-part spray foam.

Liquid foam is expensive per board foot so specify foam board to cover large areas, such as rim joists, using liquid foam as an airtight sealant around the foamboard's edges.

Never specify liquid foam for air-sealing or insulating around recessed lights, chimneys, or other heat-producing appliances. For more information about the fire safety and code compliance of liquid foam. *See "Fire Protection for Closed-Cell Foam" on* *page 134.* and NJ Weatherization Policy Bulletin regarding use of expandable foam.

One-Part Foam

This gap filler has tenacious adhesion. One-part foam is best applied with a foam gun rather than the disposable cans. Cleanup is difficult if you get careless. When squirted skillfully into gaps, this material reduces air leakage, thermal bridging, and air convection through the assemblies to which it is applied. One-part foam isn't effective or easy to apply to gaps over about one inch or to bottomless gaps. This product can leave small air leaks unless applied with skill.

Two-Part Foam

Good for bridging gaps up to one inch. Two-part foam has become very popular for use with polyurethane foam board to seal and insulate large areas. Cut foam board or rigid wood-product board to $^{3}/_{4}$-inch tolerances around obstacles and fill the edges with the two-part foam. Two-part foam should be sprayed to at least an inch of thickness when it serves as an adhesive for foamboard patches over large holes for strength.

Foam Construction Adhesive

Polyurethane foam dispensed from foam guns is an excellent adhesive for joining many kinds of building materials. It works well in joining foam sheets together into thick slabs for access doors through insulated building assemblies.

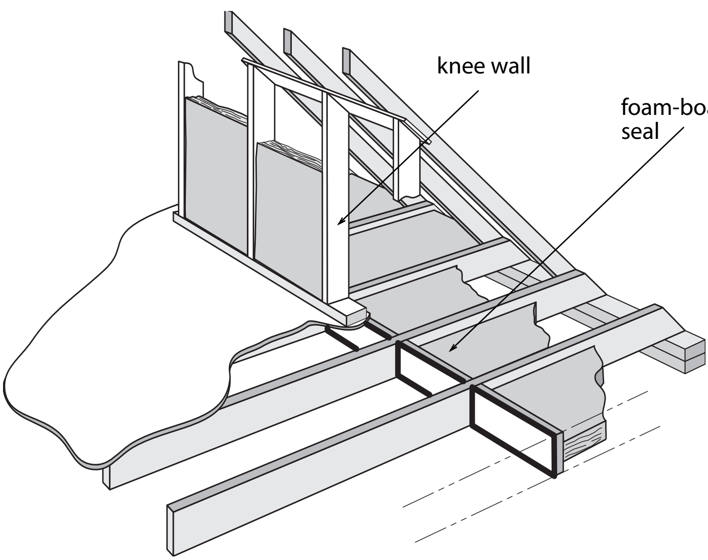
4.4 Sealing Major Air Leaks and Bypasses

Major air sealing involves finding and sealing large openings that admit outdoor air into the conditioned space. Sealing major air leaks is one of the most cost-effective energy-saving measures.

encourage installers to finish sealing major air leaks prior to insulating wherever insulation would be an obstacle to air sealing. Effective air sealing results in a significant drop in reduced blower door readings and/or changes in pressure diagnostics readings. *See "House Airtightness Testing" on page 72.*

Bypasses are pathways that allow air to migrate around the insulation. Bypasses are sometimes direct air leaks between indoors and outdoors and sometimes not. In many cases, bypasses merely allow air from indoors or outdoors to circulate around within the building cavities. Bypasses can still be a significant energy loss, however, when they are adjacent to interior surfaces of the home where circulating air can convect heat into or out of the home.

Energy auditors often find major air leaks between the conditioned space and intermediate zones such as floor cavities, attics, crawl spaces, attached garages, and porch roofs. The time and effort installers spend to seal major air leaks depends on the size and difficulty of the air leak.



Sealing under knee walls: Here an undersized piece of foam board is sealed into the joist spaces with one-part foam, forming a strong and airtight seal.

Major air leaks aren't always easily accessible without demolishing the sheeting materials. When large air leaks are behind walls, ceilings, or other building parts, installers sometimes blow dense-packed cellulose insulation into surrounding cavities, hoping that the cellulose resists airflow and plugs cracks between building materials.

4.4.1 Removing Insulation for Air Sealing

Attics are a particularly critical area for air sealing. The cost of removing insulation from an attic for the purpose of air sealing the attic may be worth the cost and effort. Batts and blankets can be rolled up, moved out of the way, and re-used. Loose fill insulation can be vacuumed with commercial vacuum machines available from the same suppliers that sell insulation-blowing machines. Many insulation companies own these large vacuums and sell the insulation-removal services.

4.4.2 Major Air Leak Locations & Treatments

This section provides a list of the most important large air leakage areas commonly found in North American residential buildings. It provides some methods and materials for air sealing these areas.

Joist Cavities Under Knee Walls

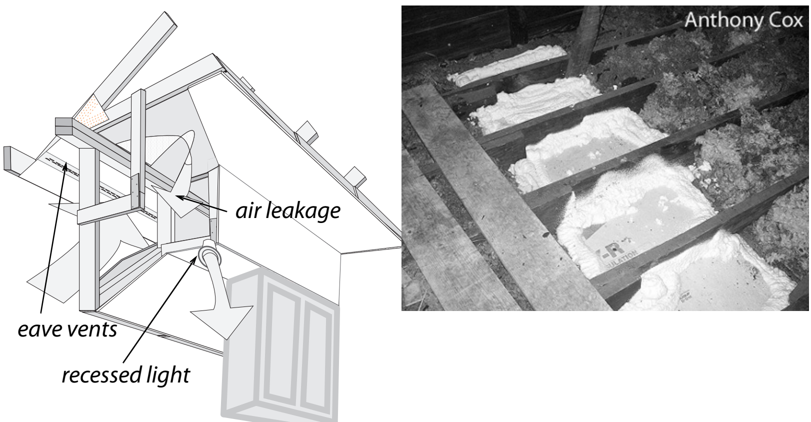
Floor joist cavities beneath knee walls allow air from a ventilated attic space to enter the floor cavity between stories. This is a problem of homes with a finished attic, also known as half-story homes.

Connect the knee wall with the ceiling of the space below by creating a rigid seal under the knee wall. Use a combination of rigid foam with one-part or two-part foam sealing the perimeter. Or, use fiberglass batt or blown cellulose with spray two-part foam as a strong airtight seal covering over the cellulose or fiberglass batt.

Kitchen or Bathroom Interior Soffits

Many modern homes have soffited areas above kitchen cabinets and in bathrooms. Large rectangular passages link the attic with the soffit cavity. At best, the air convects heat into, or out of, the conditioned space. At worst, attic air infiltrates the conditioned space through openings in the soffit or associated framing.

Seal the top of the soffit with foam board, plywood, or drywall fastened and sealed to ceiling joists and soffit framing. Seal the patch's perimeter with two-part foam or caulking.



Kitchen soffits: The ventilated attic is connected to the soffit and the wall cavity through framing flaws. Any hole in the soffit creates a direct connection between the kitchen and attic. The photo shows a soffit sealed from the attic with foam board reinforced with two-part spray foam.

Plumbing Penetrations

Seal gaps with expanding foam or caulk. If the gap is too large, stuff it with fiberglass insulation, and spray foam over the top to seal the surface of the plug.

Seal holes and cracks from underneath with expanding foam. Seal large openings with rigid materials caulked or foamed at edges.

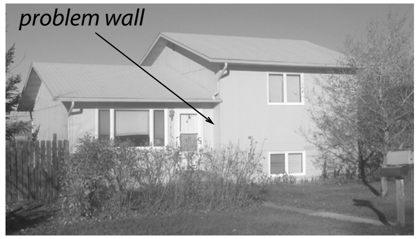
Sealing large plumbing penetrations: Foam board is attached with screws and washers. Gaps around the penetrations are filled with one-part foam to form a complete airtight seal.

Two-Level Attics in Split-Level or Tri-Level Houses

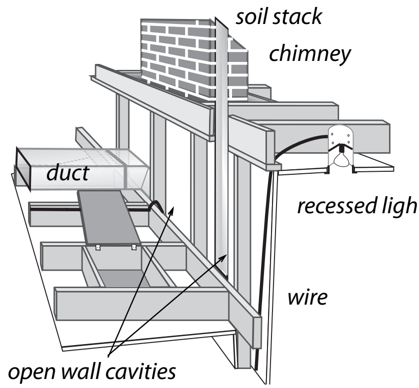
Split-level and tri-level homes have a particular air leakage problem related to the walls and stairways dividing the homes' levels.

Seal wall cavities from the attic with a rigid material fastened to studs and wall material. Or insert folded fiberglass batt and spray with at least one inch of two-part foam to create a rigid air seal. Stapling house wrap to the exposed wall over the insulation retards both air leakage and convection.

Also seal all penetrations between both attics and conditioned areas.



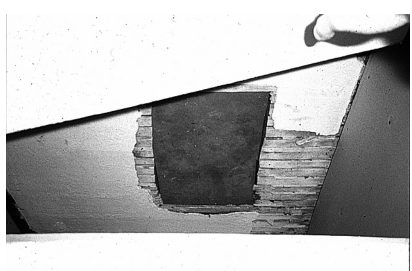
Tri-level home



Two-level attic: Split-level homes create wall cavities connected to the ventilated attic. Other air leaks shown are duct, recessed light, and chimney.

Suspended Ceilings

Suspended ceilings are installed for a variety of reasons, including hiding damage to ceilings and walls. Suspended ceilings are seldom very airtight, especially the T-bar variety. You may have to take down parts of a suspended ceiling to seal the large hidden air leaks in order to get an acceptably tight ceiling.



Fallen plaster: A suspended ceiling hides fallen plaster above.

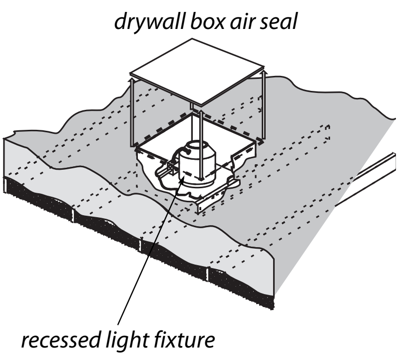
Fireplace Chimneys

Fireplace chimneys are some of the most dramatic and serious air leaks commonly found in homes. Help the customer decide whether the fireplace will be used in the future or whether it can be taken out of service.

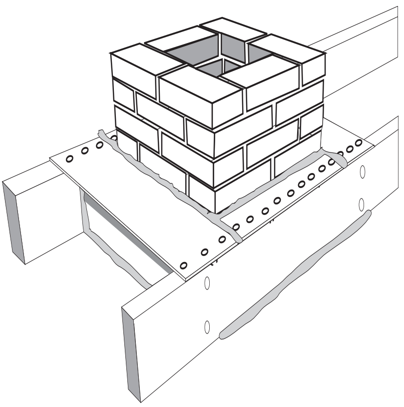
The existing fireplace damper or "airtight" doors seldom provide a good air seal. There are a number of commercial solutions for leaky or non-existent fireplace dampers. They include new tight dampers and inflatable pillows. If the fireplace is never used, it can be air sealed from the roof with a watertight, airtight seal and from the living space with foamboard, covered with airtight drywall. If you install a permanent chimney seal such as this, be sure to install a permanent notice in the fireplace.

Spaces Around Chimneys

Seal chimney and fireplace bypasses with sheet metal (minimum 26 gauge thickness). Fasten the sheet metal with nails, staples, or screws and construction adhesive. Seal the metal patch to chimney or flue with a high temperature silicone sealant or chimney cement.



Recessed light fixtures: These are major leakage sites, but these fixtures require some air circulation to cool their incandescent bulbs.



Sealing around chimneys: Chimneys require careful selection of materials for air sealing.

Exhaust Fans and Recessed Lights

Specify a drywall or sheet-metal airtight enclosure over the fixture leaving at least 3 inches clearance from insulation on all sides and to the lid of the enclosure. Seal the airtight box to surrounding materials with foam to form an airtight assembly.

Recessed light fixtures should contain 60-watt bulbs or less. Compact fluorescent lamps (CFLs) or LED lamps are preferred for recessed light fixtures because CFLs and LEDs operate cooler than incandescent lamps.

Caution: Don't cover IC-rated or airtight IC-rated fixtures with spray foam insulation. The foam's high R-value and continuous contact could overheat the fixture.

Attic Hatches and Stairways

There are a wide variety of building assemblies for providing access from the building to an insulated attic. These access doors or panels and the framing and sheeting surrounding them often constitute a major air leakage path. Consider the following improvements.

1. Weatherstrip around doors and hatches.
2. Seal gaps around frame perimeters with one-part foam or caulking.
3. Clear fibrous insulation from around the hatch framing and spray two-part foam around the perimeter to reduce heat loss through the hatch framing.

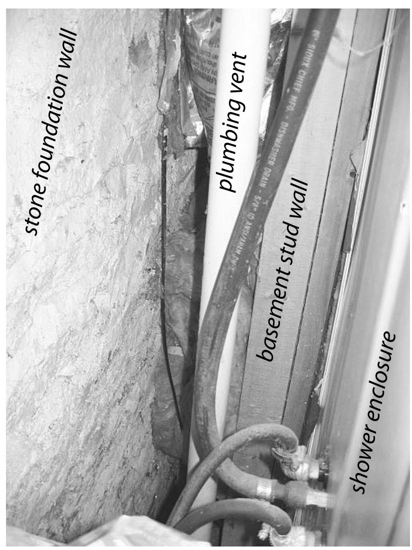
Incomplete Finished Basements

In buildings with heated basements, the insulated stud walls are often omitted in areas like laundry rooms and mechanical rooms. Missing wall segments and unsealed rim joists can allow heated basement air to circumvent an insulated basement wall, carrying heat with it.

Installers should finish incomplete basement stud walls or at least install air barriers between finished stud walls and unfinished foundation walls. Seal edges of discontinuous walls thoroughly from the basement floor to all the way to the floor sheathing of the first floor.

Seal and insulate the exposed rim joists if this retrofit was omitted during the basement insulation job.

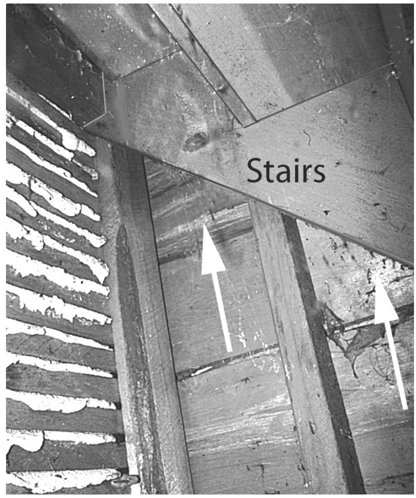
Furring strip leakage: Unsheeted furring strips behind a stairway opens a channel between basement and attic at a party wall between townhouses.



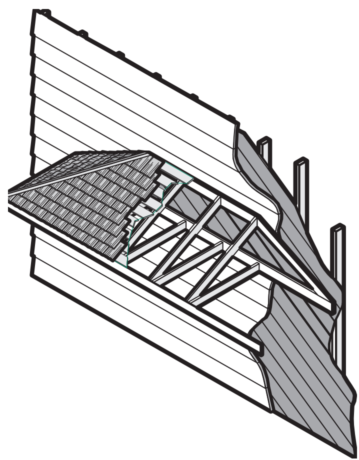
Air leakage behind a basement stud wall: Plumbing and a shower enclosure allow heated basement air to travel behind the basement's insulated stud wall.

Porch Roof Structures

Porch roofs on older homes were often built at the framing stage or before the water resistive barrier (WRB) and siding were installed. The sheeting around the porch roof sheathing, roofing, and tongue-and-groove ceiling aren't air barriers. The plank wall sheathing or unsheathed wall allows air into the wall cavities where it can migrate into the conditioned space or convect heat into or out of the building. This problem requires removing part of the porch ceiling or blowing the entire roof cavity full of cellulose insulation to reduce the airflow through the roof and wall cavities.



Leakage into attic: The space beneath attic stairs creates large air leaks into the ventilated attic.



Porch air leakage: Porch roof cavities often allow substantial air leakage because of numerous joints, and because there may be no siding or sheathing installed in hidden areas.

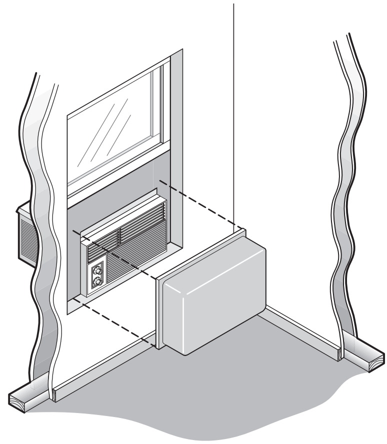
Built-In Cabinets/Shelves

Built-in cabinets and shelves are a feature of older homes and present challenges for air sealing. Sealing these areas from inside the cabinet requires care and attention to aesthetics. Use caulking that is compatible with the colors of the surrounding wood. If possible, establish both an air barrier and insulation behind the cabinet, out of sight of the occupants.

Cooling Appliances Installed through Walls or Windows

Room air conditioners, room heat pumps, and evaporative coolers are sometimes installed through walls or in windows. The units installed in windows are often very leaky because of the temporary nature of the air seals. It's best to remove units installed in windows in the fall.

If the client doesn't want to remove the unit seasonally, cover the unit with a room-air-conditioner cover as shown here.



Room-air-conditioner cover: If you can't take the unit out, cover it with a room-air-conditioner cover.

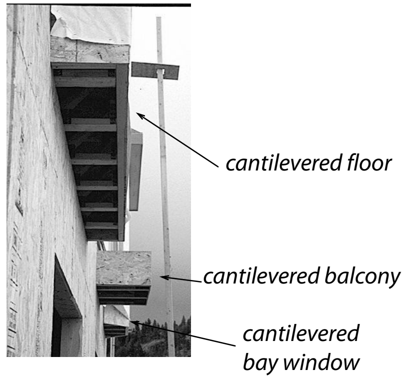
Units installed through walls should have a sheet-metal sleeve that seals well to the surrounding framing and finish. This metal sleeve provides a smooth surface to seal to the room air conditioner or heat pump. Seal the unit's perimeter with one-part foam or caulking, depending on the width of the joint.

Pocket Door Cavities

When located on the second floor, cap the top of the entire wall cavity in the attic with rigid board, caulked and mechanically fastened.

Cantilevered Floors

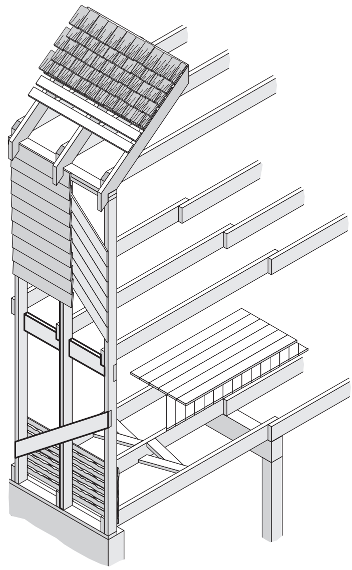
Floors that hang over their lower story are called cantilevered floors. The underside of the overhanging floor can leak considerably. Many balconies and bay windows have cantilevered floors that leak air into a building's floor cavity.



Cantilevered floors under construction: Cantilevered floors allow air leakage into floor cavities.

Remove a piece of soffit under the overhanging floor to determine the condition of insulation and air barrier. Use foam board, spray foam, and caulking as necessary to create an air barrier at the outer rim joist and the bottom of the floor cavity. Also seal any ducts you find in the cantilevered floor sections.

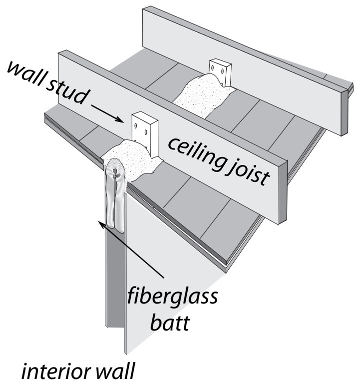
Balloon Framed Walls



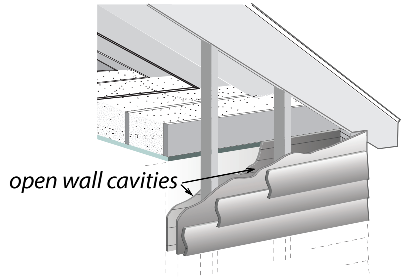
Balloon framed walls: Walls are open to the floor cavity and also to the attic and basement.

Balloon framed two-story walls are common in older homes. Some modern homes have balloon framed gable walls, where the studs rise above the level of the ceiling joists and are cut at an angle to frame the gable. Even when these balloon framed gable walls are full of insulation, air can convect through the insulation. On occasion, windstorms have actually blown the insulation out of the wall cavity into the attic.

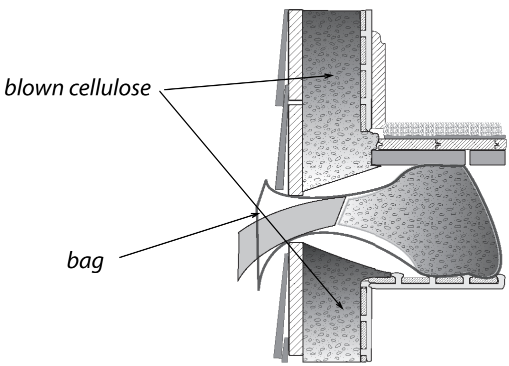
The floor joists are often nailed to long wall studs, creating a continuous cavity through uninsulated wall into the uninsulated floor. Specify dense-packed wall insulation for the wall cavities to reduce air leakage and convection. Seal stud cavities from the attic, basement, or crawl space with a fiberglass insulation plug, covered with a 2-part foam air seal. Or seal the cavities with a rigid barrier, such as $^{1}/_{4}$-inch plywood or 1-inch foam board sealed to surrounding materials with caulk or liquid foam.



Balloon framed interior walls: Fiberglass insulation covered by a 1-inch layer of two-part foam seals wall cavities.



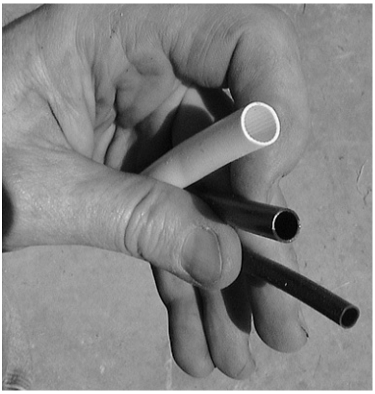
Balloon framed gable: Studs extend above the ceiling allowing convection from the attic.



Sealing wall-floor junction: Blown cellulose reduces convection through walls and floors. A bag helps contain and pack the blown insulation.

4.4.3 Minor Air Sealing

Minor air sealing includes sealing small openings with such materials as caulk, weather stripping, or sash locks. These measures tend to please the home's occupants by reducing perceived drafts, slowing the entry of dirt, or making the interior paint look better. But they rarely result in significant blower door reductions or changes in pressure diagnostic readings.



Silicone bulb weatherstrip: Silicone bulb has its own adhesive or is adhered to surfaces with silicone caulking.

Window and Door Frames

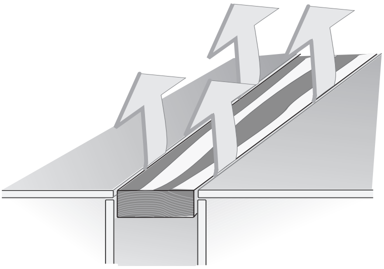
Sealing from the exterior serves to keep bulk water out and protect the building. If the crack is deeper than $^{5}/_{16}$-inch, it should be backed with a material such as backer rod and then sealed with caulk. Any existing loose or brittle material should be removed before the crack is recaulked.

Rim Joist Area

The rim joist area is composed of several joints. They can be sealed from the basement or crawl space with 2" foam board and foam, or caulk. Remove dust before applying sealant.

Masonry Surfaces

Masonry surfaces are best sealed with a cement-patching compound, mortar mix, or high quality caulking, such as polyurethane. For cement-based patches, consider priming the damaged areas with a concrete adhesive.



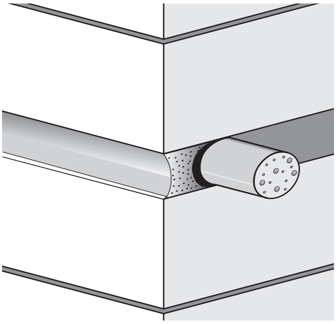
Leaky top plates: The cracks along top plates are from lumber shrinkage. They are small cracks but there are long lengths of them.

Interior Wall Top Plates

Drywall is installed after interior walls are constructed. The top plates of interior walls are open to the attic. Top plate shrinkage opens up cracks that run the entire length of the interior wall. Move insulation and seal the cracks with caulking or two-part foam.

Interior Joints

These can be caulked if blower door testing indicates substantial leakage. These joints include where baseboard, crown molding and/or casing meet the wall, ceiling, and/or floor surfaces. Gaps around surface mounted or recessed light fixtures and ventilation fans can be caulked if needed.



Backer rod: Use it to support caulk when sealing large uniform gaps. Use liquid foam for sealing irregular gaps.

CHAPTER 5: INSTALLING INSULATION

Insulation reduces heat transmission by slowing conduction, convection, and radiation through the building shell. Insulation combined with an air barrier creates a thermal boundary between the conditioned indoors and outdoors.

Installing insulation is one of the most effective energy-saving measures. Energy auditors can ensure insulation's safety and effectiveness by making these guidelines part of the work order.

1. Install insulation in a way that enhances fire safety and doesn't degrade it. *See "Safety Preparations for Attic Insulation" on page 142.*
2. Comply with lead-safe practices when disturbing paint in pre-1978 homes. *See "Lead-Safe Weatherization" on page 349.*
3. Protect insulation from air movement with an effective air barrier. Make sure that the air barrier and insulation are aligned (next to one another) using procedures outlined starting on *page 103.*
4. Protect insulation from moisture by repairing roof and siding leaks, and by controlling vapor sources within the home. *See "Insulation Durability" on page 138.*
5. Install insulation to meet or exceed the guidelines of the International Energy Conservation Code (IECC) 2009.
6. When blowing either fiberglass or cellulose insulation a generator must be used, NOT the clients electric.

5.1 INSULATION MATERIAL CHARACTERISTICS

The purpose of insulation is to provide thermal resistance, which reduces the rate of heat transmission through building assemblies. Characteristics such as R-value per inch, density, fire safety, vapor permeability, and airflow resistance help energy auditors choose the right insulation for the job. Inspectors use insulation characteristics to verify that the right material was used, during their final inspection.

5.1.1 Fibrous Insulation Materials

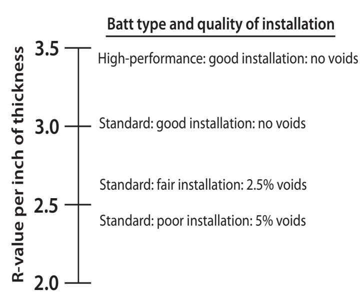
Fibrous insulation materials are the most economical source of thermal resistance for buildings. If blown at a high density, fibrous insulations aren't air barriers themselves, but they may contribute to the airflow resistance of a building assembly that functions as an air barrier. The term *mineral wool* describes both fiberglass and *rock wool*. Rock wool is both a generic term and a trade name. We use rock wool in the generic sense as an insulating wool made from rocks or slag. Fiberglass is wool spun from molten glass.

Cellulose is manufactured primarily from recycled paper and treated with boric acid or another fire retardant.

Specify a vapor permeable air barrier to cover fibrous insulation installed vertically or horizontally in human-contact areas (basements, for example) to limit exposure to fibers, which may cause respiratory distress.

Fiberglass Batts and Blankets

Most fiberglass batts are either 14.5 inches wide or 22.5 inches wide to fit 16-inch or 24-inch wood stud or joist spacing. the advertised R-values of batts vary from 3.1 per inch to 4.2 per inch depending on density. Installed fiberglass R-values are 5% to 30% lower depending on installation quality.



Evaluating batt performance: The thermal performance of batts depends on density and installation.

Installers must cut and fit batts very carefully to achieve the highest possible R-value. Batts insulate effectively only when they are touching an effective air barrier. The installed R-value per inch depends on the surface area of voids and the contact of the batt with the six sides of the cavity it inhabits.

See "Open-Cavity Wall Insulation" on page 171.

Fiberglass blankets are wider than batts. Blankets come in a variety of thicknesses from 1 to 6 inches with vinyl or foil-skrim-kraft facings. Insulation manufacturers make batts with a number of facings, including foil, kraft paper, and vinyl. However, unfaced batts are often the easiest batts to install correctly. Although fiberglass itself is non-combustible, fiberglass batts contain flammable glue and the facings.

Fiberglass blankets are used to insulate metal buildings and to insulate crawl spaces from the inside. Although fiberglass doesn't absorb much moisture, the facings on blankets and batts can trap moisture, which wets building materials and provides a water source for pests.

Blown Fiberglass

Loose fiberglass is blown in attics from 0.5 to 0.9 pounds per cubic foot (pcf). At that density the R-value is around 3.2 per inch. Expect around 5% settling within five years after installation.

Blown fiberglass is non-combustible as a virgin product, but some blown fiberglass is made from chopped batt waste, which contains a small amount of flammable binder.

Fiberglass manufacturers now provide two blowing products, one for standard densities of up to 1.6 pcf, and another for dense-packing to more than 2.0 pcf.

In closed cavities, fiberglass is blown from 1.2 to 2.2 pcf, with R-value per inch from 3.6 to 4.2, increasing with higher density. The high density fiberglass is typically reserved for walls where the superior resistance to settling, airflow, and convection has extra value compared to blowing at a lower density.

Blown Cellulose

Cellulose is the most inexpensive insulation and among the easiest insulations to install. Loose cellulose is blown in attics from 0.6 to 1.2 pcf and at that density range, the R-value is around 3.7 per inch. Expect around 15% settling within five years after installation.

In wall cavities, cellulose is blown at a higher density of between 3.5 to 4.0 pcf, to prevent settling and to maximize its airflow resistance. At the high density cellulose's R-value per inch is around 3.4. Evaluate the strength of wall cladding before blowing a wall to prevent damage during installation.

Cellulose is also mixed with sprayed water in damp-spray applications either in open cavities or directly adhered to building surfaces. Sprayed cellulose contains a non-corrosive fire retardant to prevent metal corrosion when used in metal building assemblies.

Cellulose absorbs up to 130% of its own weight in water. Before you discover a moisture problem, the cellulose could be soaked, double its dry weight, and permanently degraded in thermal resistance. Because of its moisture absorption, avoid using cellulose in humid coastal regions or anywhere where it might encounter water or long periods of high relative humidity. We believe that cellulose shouldn't be installed in the following places regardless of climate: crawl spaces, floor cavities above crawl spaces or unconditioned basements, and horizontal or sloped closed roof cavities.

Rock Wool

Rock wool is a type of mineral wool like fiberglass. Rock wool has a small market share in North America. Rock wool batts have similar R-values per inch as fiberglass batts and contain flammable binders. Rock wool itself is non-combustible so blown rock wool doesn't burn.

Testing Insulation Blowing Machines

Measure the pressure created by a blowing machine by connecting the hose to a fitting attached to a manometer. Close the feed gate and turn the air to the highest setting. The blowing machine should develope 2.9 pounds per square inch (psi) or 80 inches of water (IWC).

5.1.2 Foam Insulation Materials

Foam insulation is commonly sprayed or injected as a liquid or as fastened to building assemblies as foam board. In general, foam insulations burn readily and create toxic smoke. Foam insulation must be covered by a thermal barrier when installed adjacent to indoor spaces. An ignition barrier must sometimes cover foam in attics and crawl spaces.

Foams are insect friendly materials that can aid termites in gaining a foothold in wood floor structures. Mitigate all sources of ground water before applying foam to a foundation. When foam is installed on the outside of foundations, the surrounding soil should be treated with a termiticide. Inside a crawl space, foam should never provide a direct link from the ground to wood materials. The IRC forbids foam below grade in "very heavy" termite-infested areas.

Closed-Cell Polyurethane Spray Foam

Closed-cell polyurethane spray foam (SPF) is an air barrier and a vapor barrier and is the most expensive insulation discussed here. Closed-cell SPF is a good value when space is limited, where an air or vapor barrier is required, or where its structural strength and durability are needed. SPF is hazardous to installers and requires special personal protective equipment.

Closed-cell SPF typically installs at approximately 2 pcf density and achieves an R-value of 6 or more per inch. However, roofing applications call for a density near 3 pcf.

Fire Protection for Closed-Cell Foam

Polyurethane closed-cell foam is combustible, sometimes flammable, and creates toxic smoke when it burns. When sprayed in attics and craw spaces, closed-cell foam must sometimes be covered by an ignition barrier or 15-minute thermal barrier.

Ignition barrier materials like galvanized steel and plywood are readily available and so is drywall, the most common 15-minute thermal barrier. However these materials aren't practical as coverings for most spray-foam applications. Intumescent paint, a new fire-protection material, qualifies as an ignition barrier, in most code jurisdictions.

Fire protection requirements vary among foam formulations, according to the amount and type of fire retardant. Foam manufacturers now have at least two formulations: normal (flame spread 25) and improved (flame spread 75). In attics and crawl spaces, the more fire-resistant type of foam may not require an ignition barrier depending on the local code jurisdiction.

Code jurisdictions and individual building officials vary in their interpretation of the IRC, manufacturer's fire testing, and other and other specifications of plastic foams. Check with your local building officials before using plastic foam for building assemblies if you have doubts about where you can use foam.

5.1.3 Open-Cell Polyurethane Spray and Injectable Foam

Polyurethane open-cell foam is installed at about 0.5 pcf and achieves an R-value of around 3.7 per inch. Newer formulations are available in densities of around 1.0 pcf with an R-value of around 4.7 per inch. Open-cell foam is available in a highly expansive spray formulation and a less expansive injectable formulation.

These open-cell formulations are injected into a hole, one inch or smaller, through an injection nozzle and not a fill tube. (The plastic fill tube would clog and isn't cleanable.) The closed-cell foam can subject a wall cavity to a lot of pressure, so evaluate wall-cladding strength before injecting it.

Polyurethane open-cell foam has little structural strength. It can be trimmed to eliminate protruding excess from open wall cavities. Polyurethane open-cell foam isn't a vapor barrier and is more porous to airflow than the closed-cell foam. It is difficult to install in deep cavities without creating voids.

Open-cell foam can absorb water vapor and liquid water. It can become a medium for mold growth. Don't use open-cell foam in crawl spaces unless proper drainage and ventilation have prevented ground moisture from being a problem.

Air Krete Injectable Foam

Air Krete is a proprietary, low-expansion, non-toxic, and non-combustible insulation installed at around 1 pcf with an R-value of about 4.0 per inch. Air Krete is used when non-combustible insulation is required. It is water soluble and can be injected through a fill tube.

Tripolymer Injectable Foam

Tripolymer is a proprietary, low-expansion injectable foam installed at around 1.2 pcf at an R-value of 5.1 per inch. The material has very low flammability and smoke generation during a fire. It is widely used to insulate hollow masonry walls. It is water soluble and can be injected through a fill tube.

Expanded Polystyrene (EPS) Foam Board

EPS foam board, sometimes called beadboard, is the most economical of the foam insulations. EPS varies in density from 1 to 2 pcf with R-values per inch of 3.9 to 4.7, increasing with increasing density. EPS is packaged in a wide variety of products by local manufacturers, including structural insulated panels (SIPS), tapered flat-roof insulation, EPS bonded to drywall, and EPS embedded with fastening strips.

EPS is flammable and produces toxic smoke when burned. It has a low maximum operating temperature (160 degrees F) that is a concern for using EPS under dark-colored roofing or siding.

EPS is very moisture resistant and its vapor permeability is in the same order of magnitude as concrete, which makes EPS a good insulation for masonry walls.

Dense EPS (2 pcf) is appropriate for use on flat roofs and below grade with weatherproof coverings to prevent degradation by ultraviolet light and freezing and thawing at ground level.

Extruded Polystyrene Foam (XPS) Board

XPS is produced by only a few manufacturers and is popular for below-grade applications. XPS is more expensive than EPS and has an R-value of 5.0 per inch. XPS may be the most moisture-resistant of the foam boards.

XPS is flammable and produces toxic smoke when burned. XPS must be covered by a thermal barrier when installed in living spaces. It has a low maximum operating temperature (160 degrees F) that is a concern for using EPS under shingles or dark-colored siding. XPS must be protected from UV radiation and freezing and thawing at ground level.

Polyisocyanurate (PIC) Foam Board

PIC board has the highest R-value per inch (R-6 to R-7) of any common foam board. PIC is packaged with a vapor permeable facing or a foil (vapor impermeable) facing. PIC is expensive but worth the cost when the thickness of an insulation material is very limited.

PIC is combustible and produces toxic smoke during a fire. However some products have fire retardants that allow installation in attics and crawl spaces without ignition barriers. PIC has a low maximum operating temperature (<200 degrees F) that is a concern for using PIC under dark-colored roofing or siding.

Use the high-density (3 pcf) PIC board for low-sloping roof insulation.

Polystyrene Beads

Polystyrene (EPS) beads can be poured or blown into cavities. The cavities must be airtight or the beads will escape, making an annoying mess. EPS beads have an R-value between 2.2 and 2.5 per inch. Beads work well for filling hollow masonry walls.

Vermiculite and Perlite

These expanded minerals are pourable and used when a non-combustible insulation or high temperature insulation is needed. R-value per inch is between 2.0 and 2.7 per inch. These products are good for insulation around single-wall chimney liners to prevent condensation in the liner. Existing vermiculite may contain asbestos, and it must not be disturbed by anyone except a licensed asbestos abatement specialist.

5.2 Insulation Safety and Durability

Insulation activities require awareness about safety. Reference the following safety-related sections of this guide if necessary.

✓ *See "Moisture Problems" on page 340.*

✓ *See "Decommissioning Knob-and-Tube Wiring" on page 357.*

✓ *See "Lead-Safe Procedures" on page 348.*

The following fire-safety and durability issues are particularly important to installing foam insulation.

1. Foam insulation requires a thermal barrier covering of at least half-inch drywall when installed in a living space.
2. Foam may require an ignition barrier when installed in attics or crawl spaces or it may not.

3. A *thermal barrier* is a material, usually drywall, that protects combustible materials behind it from heat during a fire.

4. An *ignition barrier* is designed to delay the ignition of the material it protects. Ignition barriers include plywood, galvanized steel, damp-spray fiberglass, and intumescent paint. Intumescent paint is a proprietary latex coating designed to delay the ignition of foam insulation in a fire.

5.2.1 Insulation Durability

Moisture is the most common and severe durability problem in insulated building assemblies. Moisture fosters rot by insects and microbes. Entrained moisture reduces the thermal resistance of many insulation materials. Moisture affects the chemistry of some building materials: metals for example.

Moisture prevention includes denying moisture access to building cavities, allowing condensed water to drain out, and allowing moisture to dry to the indoors, outdoors, or both.

Retrofitting insulation can affect the preventive measures listed here. Consider the function and relevance of these building components whenever you specify insulation materials and methods as part of a work order. Inspectors should verify that the following components are present, if appropriate, in their final inspections.

1. **Air barrier:** Air can carry moisture into building cavities from indoors or outdoors where the moisture can condense and dampen insulation and other building materials. Air leakage is an energy problem too. The air barrier is any continuous material or building assembly that provides acceptable resistance to air leakage.

2. **Vapor barrier:** Vapor diffusion can carry large amounts of water vapor into building cavities where it can condense and dampen insulation and other building mate-

rials. Vapor barriers prevent water vapor from indoors from diffusing into cavities where condensation can wet insulation and other building materials in cold climates. Cold climates have large differences in humidity between indoors and outdoors that can push vapor through building cavities.

3. **Ground-moisture barrier:** The ground under a building is the most potent source of moisture in many buildings, especially those built on crawl spaces. Most crawl spaces require ground-moisture barriers to prevent the ground from being a major cause of moisture problems.

4. **Water resistive barrier (WRB):** Asphalt paper or house wrap, under siding and roofing, serves as the home's last defense to wind-driven rain, which can dampen sheathing and other building materials. This water resistive barrier must be protected during installation and incorporated into window openings during window replacement.

5. **Vapor permeable materials:** Most common building materials are permeable to water vapor, which allows the water vapor to follow a gradient from wet to dry. This process allows building assembles to dry out to either the indoors and outdoors.

6. **Flashings:** Seams and penetrations in building assemblies are protected by flashings, which prevent water from entering these vulnerable areas.

7. **Drainage features:** Intentional or unintentional drainage features of buildings allow water to drain out of cavities. Examples: Masonry veneers have intentional drainage planes and weep openings near their bottoms. Cathedral ceilings drain water out through their soffit vents unintentionally.

8. **Water storage:** Masonry veneers and structural masonry walls have the ability to store rainwater and dry out during dry weather.
9. **Ventilation:** Roofs, attics, crawl spaces and even some walls have ventilation features that dry out wet building assemblies.
10. **Termiticide:** When foam insulation is installed below grade in regions with termites, apply a termiticide to the soil in amounts determined by the labeling of the termiticide.

Consult with experts when necessary to preserve, protect, or install these moisture-prevention features, according to local climate and established best practices.

5.3 Attic and Roof Insulation

Attic insulation is one of the most cost-effective energy conservation measures available. *See "Fibrous Insulation Materials" on page 130.*

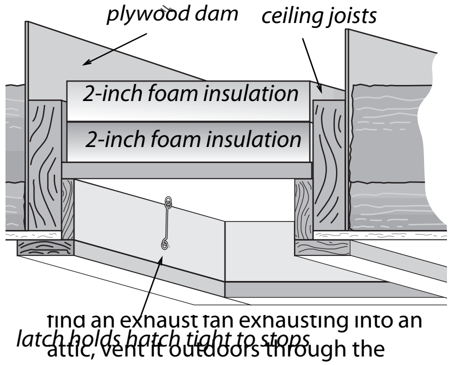
5.3.1 Preparing for Attic Insulation

Specify these preparatory steps before technicians install attic insulation.

1. Air leakage and convection can significantly degrade the thermal resistance of attic insulation. Before insulating the attic, seal air leaks and bypasses as described previously. If attic air leaks are not properly sealed, increasing attic ventilation may increase the home's air leakage rate. *See "Major Air Leak Locations & Treatments" on page 115.* Verify attic air-tightness as described in *"Zone Leak-Testing Methodology" on page 90*.
2. Repair roof leaks and remove other large moisture sources and repair other attic-related moisture prob-

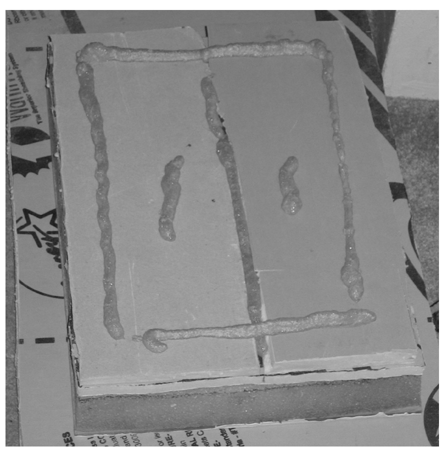
lems before insulating attic. If attic-related moisture problems can't be repaired, don't insulate the attic.

3. Vent all kitchen and bath fans outdoors through appropriate roof fittings, side wall fittings, or soffit fittings. Use galvanized steel vent pipe, and insulate the pipe to prevent condensation. Avoid using flexible plastic or aluminum duct because these materials restrict airflow. Check all fans for proper back-draft damper operation. Repair or replace the damper or the entire fan assembly if the damper doesn't operate freely.



find an exhaust fan exhausting into an attic, vent it outdoors through the roof, gable, or soffit.

Insulated attic hatch: A dam prevents loose-fill insulation from falling down the hatchway. Foam insulation prevents the access hatch from being a thermal weakness. Install foam to achieve attic-insulation R-value or at least R-30. Foam can be glued together in layers.



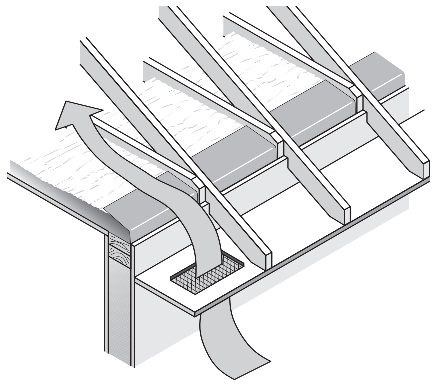
4. Install an attic access hatch if none is present, preferably at a large gable vent on the home's exterior.

5. An interior attic hatch should be at least 22 inches square if possible. Insulate the hatch to the maximum

practical R-value. The roof's height above the hatch may limit the amount of foam you can install.

6. Build an insulation dam around the attic access hatch two inches above the height of the insulation. Build the dam with rigid materials like plywood or oriented-strand board so that the dam supports the weight of a person entering or leaving the attic.

7. Install vent chutes or baffles to prevent blown insulation from plugging the space between soffit vents and the attic. The baffles help to maximize the amount of insulation that you can install over top plates without clogging ventilation paths. Baffles also help prevent the wind-washing of insulation caused by cold air entering soffit vents. They should extend at least 4 inches above the finished insulation level.



Soffit chute or dam: Install a maximum amount of insulation and prevent wind-washing and ventilation blockage with these devices.

5.3.2 Safety Preparations for Attic Insulation

Before insulating the attic, installers must protect the heat-producing fixtures from creating a fire hazard after the insulation is installed. The shielding enclosure must also serve as the air-seal for the chimney or light fixture.

Verify that chimneys, recessed light fixtures, and other heat-producing appliances are protected from combustible material and from non-combustible insulation as specified here.

Protecting Recessed Light Fixtures

There are three different types of light fixtures and light-fan fixtures.

1. Old fixtures that must not touch insulation.
2. Type IC rated fixtures that may be covered with fibrous insulation.
3. Type IC-AT, which are safe for insulation-contact and reasonably airtight (AT).

Specify one of these two options when specifying attic insulation.

1. If the existing fixture is rated IC, you can seal the fixture's enclosure to the ceiling with caulk and cover the fixture with insulation. Or you can shield the fixture with an enclosure, seal the enclosure to the ceiling with foam, and then cover the enclosure with insulation.
2. Spray foam insulation must not contact or surround recessed fixtures, chimneys, or any other heat-producing devices.

If an existing older recessed fixture must remain in place, specify these steps.

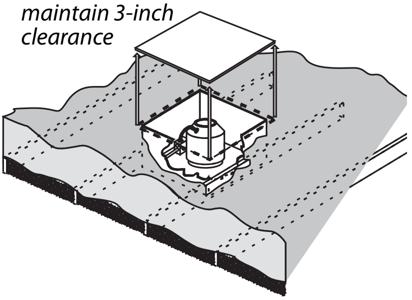
1. Install shielded enclosures around heat-producing devices like recessed lights and fan-light fixtures, which aren't labeled "IC" (IC = insulation contact).

2. Maintain 3 inches of clearance between the insulation shield and the fixture on the sides and top.

3. Fasten the shields securely to the ceiling so they don't collapse.

4. Notch the shields around wires.

5. Seal the shield's enclosure to the ceiling with spray foam.



Recessed light fixtures: Cover recessed light fixtures with fire-resistant drywall or sheet-metal enclosures to reduce air leakage to allow installers to safely insulate around the box.

6. Don't insulate the top of the shield's enclosure.

Inspectors should verify proper installation of heat shields by visual inspection or photos taken by installers.

Protecting Chimneys

The requirements for protecting chimneys from contact with insulation vary widely from one building department to another. We know of three common approaches to insulating around chimneys, which are the listed here beginning with the most restrictive.

1. Install non-combustible insulation shields around masonry chimneys, B-vent chimneys, L-vent chimneys, and all-fuel chimneys to keep insulation at least 3 inches away from these chimneys.

2. A non-combustible attic insulation or the specifications of the vent material may allow a smaller clearance than 3 inches. Type B vent has a typical minimum clearance of 1 inch and all-fuel chimneys have a typical minimum clearance of 2 inches.

3. If the insulation is non-combustible, such as blown fiberglass or rock wool, no clearance between insulation and manufactured or masonry chimneys is necessary.

Always specify air-sealing around the chimney with noncombustible material like 26 gauge galvanized steel and high-temperature sealant before insulating around it.

Electrical Junction Boxes

Specify proper covers on all electrical junction boxes and insist that installers flag them so that an electrician can find the boxes for future electrical work.

5.3.3 Attic Ventilation

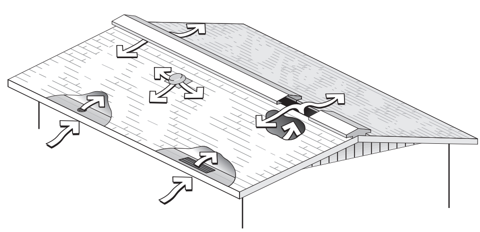
Attic ventilation is supposed to remove moisture from the attic during the heating season and to remove solar heat from the attic during the cooling season. The 2009 International Residential Code (IRC) makes these statements about attic ventilation.

1. Provide a maximum ratio of one square foot of net free vent area to 150 square feet of attic area.
2. The IRC requires only one square foot of vent per 300 square feet of attic area for ceilings, with an interior vapor barrier, or with distributed ventilation (high and low), or with thorough air-sealing of the ceiling.
3. Vents must have louvers and screens, with $^{1}/_{4}$-inch or less opening, to prevent the entry of pests and to reduce the entry of snow and rain.

Verify that exhaust fans vent directly to outdoors and never into a ventilated attic both during an energy audit and a final inspection.

High and Low Vents

A combination of high and low vents is the best way to move ventilating air through the attic. Soffit vents and ridge vents are an ideal combination for high-low attic ventilation. However, gable vents and roof vents, located high or low, also create acceptable ventilation.



Low and high attic ventilation: Distributed ventilation — high and low — is more effective than vents that aren't distributed.

Attic Ventilation as a Cure for Moisture Problems

You won't likely solve a moisture problem caused by moist air moving up from the living space by specifying additional attic vents. The best way to keep attic insulation dry is for installers to air-seal the attic floor to block moist air from entering the attic. Roof leaks are also a common cause of wet insulation.

Power Ventilators

Power ventilators have limited value in reducing air conditioning cost and consume a lot of electricity themselves. Many of these ventilating fans run longer than intended, counteracting any cooling benefit they may provide.

Unventilated Attics

According to the IRC 2009, attics may be unventilated if two conditions listed here are met.

1. The roof assembly is insulated with an air-impermeable insulation, such as high-density sprayed polyurethane, to the bottom of the roof sheathing.
2. There is no vapor barrier installed in the ceiling.

5.3.4 Blowing Attic Insulation

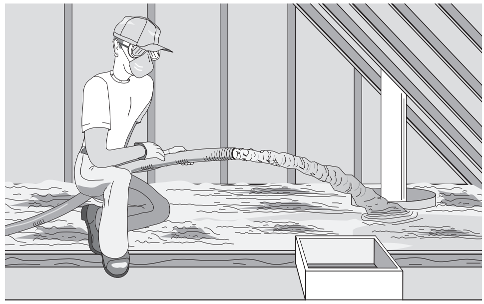
Specify attic insulation to a cost-effective R-value, depending upon existing insulation level and climatic region. Air sealing attics must happen before attic insulation and this may require removing existing insulation and debris that currently prevents effective air sealing. *See "Removing Insulation for Air Sealing" on page 115.*

Blown insulation is usually better than batt insulation because blown insulation forms a seamless blanket. Blown fibrous attic insulation always settles: cellulose usually settles 10% to 20% and fiberglass settles 3% to 10%. Blowing attic insulation at the highest achievable density helps minimize settling while minimizing air moment within the blown insulation.

Use these specifications when installing loose-fill attic insulation.

1. Calculate how many bags of insulation are needed to achieve the R-value specified on the work order from the table on the bag's label. *See "Calculating Attic Insulation" on page 364.*
2. Maintain a high density by moving as much insulation as possible through the hose with the available air pressure. The more the insulation is packed together in the blowing hose, the greater is the insulation's installed density.
3. Fill the edges of the attic first, near the eaves or gable end, then fill the center.
4. When filling a tight eaves space, snake the hose out to the edge of the ceiling. Allow the insulation to fill and pack before pulling the hose back towards you. The eave area is the home's largest thermal bridge and it's important to put as much insulation into the eaves as possible. Use baffles to provide the air space for ventilation.
5. Install insulation to a consistent depth. Level the insulation with a stick if necessary.
6. Install insulation depth rulers: one for every 300 square feet.
7. Post an insulation certificate near the attic entrance to facilitate inspection.

Blown-in attic insulation: Blown insulation is more continuous than batts and produces better coverage. Insulation should be blown at a high density to minimize settling and air convection.



5.3.5 Insulating Closed Roof Cavities

Many homes have cathedral ceilings or flat roofs that are only partially filled with insulation. The IRC 2009 building code requires a ventilated space of at least one inch above the roof insulation.

Many cathedral roof cavities have been dense-packed with fiberglass insulation without providing space for ventilation and some experts believe this is an effective solution. However, this solution usually requires engineered plans approved by the building department. Dense-packing a roof cavity with cellulose isn't a good option because of the high moisture absorption of cellulose.

Dense-Packing Closed Roof Cavities

Many homes have cathedral ceilings, vaulted ceilings, or flat roofs that are only partially filled with insulation. Whether these cavities can be safely dense-packed with fiberglass insulation is controversial and depends on climate. Dense-packing the cavities prevents most convection and infiltration, which are leading causes of moisture problems in roof cavities. Consult a knowledgeable local engineer before specifying dense-pack fiberglass insulation for a roof cavity.

To prepare for roof-cavity insulation, specify these steps.

1. In cold climates, verify that the ceiling has a vapor barrier and air barrier on the interior or install a vapor barrier and air barrier.
2. Remove recessed light fixtures and replace them with IC-AT fixtures or surface-mounted fixtures. Carefully patch and air seal the openings if you replace the recessed fixtures with surface-mounted ones.
3. Seal other ceiling air leaks with great care.
4. Reduce or eliminate sources of moisture in the home. *See "Preventing Moisture Problems" on page 343.*

Blowing from the roof deck: Technicians remove a row of shingles, drill, and blow fiberglass into this vaulted roof cavity.

Blowing from the eaves: Some vaulted ceilings can be blown from the eaves and/or the ridge.

Installers should always use a fill tube when blowing closed roof cavities. The tube should reach into the cavity to within a foot of the end of the cavity. Access the cavity through the eaves, the roof ridge, the roof deck, or the ceiling. Consider the following procedures.

1. Drilling holes in the roof deck after removing shingles or ridge roofing.

2. Removing soffit and installing insulation from the eaves.
3. Drilling through a drywall ceiling.
4. Carefully removing a tongue-and-groove plank and filling cavities through this slot.

An energy auditor or inspector might want to do an in-progress inspection of dense-packed insulation to insure that installers are achieving adequate coverage and density.

Exterior Rooftop Foam Insulation

Only install rooftop foam insulation over dense-packed roof cavities. A ventilation space would degrade the foam's R-value considerably. Roofers use this method mainly with low-sloping roofs.

1. Use high density foam: 2 pcf for polystyrene or 3 pcf for polyisocyanurate if the roof is flat or low sloping.
2. Flash all external penetrations according to the roofing manufacturer's specifications.
3. Use a cool roofing material such as white rubber or white metal to limit the foam's temperature during intense summer sunshine and to minimize cooling costs.
4. Contact a design professional to make sure the roof will drain properly after foam installation.

Many manufacturers can cut expanded polystyrene foam horizontally, providing wedge-shaped pieces to create slope for drainage. *See "Expanded Polystyrene (EPS) Foam Board" on page 135. See "Polyisocyanurate (PIC) Foam Board" on page 136.*

5.3.6 Installing Attic Batt Insulation

Follow these specifications when installing fiberglass batts in an attic. Fiberglass batts aren't the best insulation for attics because of all the resulting seams.

1. When layering batts, install alternate layers at right angles to underlying layers.
2. Install unfaced fiberglass insulation whenever possible. Faced batts don't lay as flat as un-faced batts, and the facing isn't very effective in slowing vapor movement because most of the vapor movement happens with air migration.
3. If you must install faced batts, install them with the facing toward the heated space. Never install faced insulation over existing insulation.
4. Cut batts carefully to ensure a tight fit against the ceiling joists and other framing.

5.3.7 Cathedralized Attics

A cathedralized attic has insulation attached to the bottom of the roof deck. Choose to insulate the bottom of the roof deck instead of insulating the ceiling when you want to include an attic air handler within the home's thermal boundary.

Insulating the roof deck presents some risk of moisture problems from roof leaks or condensation in the insulation. To avoid moisture condensation within the insulation or at the bottom of the roof deck in cold and temperate climates, use air-impermeable insulation such as closed-cell foam as required by the IRC. Choose one of the methods below to insulate roof decks. These methods are listed from the most moisture-resistant to least moisture-resistant.

1. Three (3) inches of sprayed closed-cell polyurethane foam with or without a layer of fibrous insulation below

the foam. The fibrous insulation qualifies as an ignition barrier and increases the R-value of the roof assembly.

2. Six (6) or more inches of open-cell polyurethane foam.
3. The rafter's depth of fiberglass batts or dense-packed fiberglass insulation between the roof deck and a rigid material such as drywall. Density is at least 2.2 pcf for the dense-packing blown fiberglass.
4. Blown fiberglass with no voids at the highest achievable density allowed by the netting or fabric. Use only in warmer climates.
5. Six (6) or more inches of damp-sprayed fiberglass insulation. Use only in warmer climates.

With any of these options, remove any existing vapor barrier from the ceiling assembly before insulating the roof.

Some building departments require an ignition barrier of 1.5 inches of fibrous insulation or a proprietary liquid-applied coating to delay the spray foam's ignition during a fire.

5.3.8 Vaulted Attics

A vaulted attic is framed with a special truss that creates a sloping roof and a sloping ceiling. Access to the cavity varies from difficult to impossible. Install insulation from either the top of the roof deck or through the ceiling. Insulation, installed at the ceiling, must have some stability to prevent gravity from pulling it downhill or wind from piling it, leaving some areas underinsulated. Consider the following options to insulating uninsulated or partially insulated vaulted attics.

1. Insulate the ceiling with fiberglass batts. Install the batts parallel to the framing if the top of existing insulation is below the framing. Install the batts perpendicular to the framing if the top of the existing insulation is above the framing.

2. Insulate the bottom of the roof deck, as described previously for a cathedralized attic if the ceiling is removed or for new construction.

3. Insulate the ceiling with sprayed foam, damp-spray fibrous insulation, or batts from the roof with the roof sheathing removed.

4. Fill the cavity to approximately 90% with loosely blown fiberglass or cellulose from indoors or through the roof. Settling allows room for ventilation and air circulation within and around the insulation. The volume of insulation prevents major movement due to wind or gravity.

5. Preserve or install openings into the ventilation space above the insulation totalling $^{1}/_{150}$ of the roof area. If the ceiling has a vapor barrier the requirement becomes $^{1}/_{300}$ of the roof area.

Foam insulated roof of vault: Vaults can be filled with stabilized insulation or their roof decks can be sprayed with foam.

5.3.9 Finished Knee Wall Attics

Finished attics require special care when installing insulation. They often include five separate sections that require different sealing and insulating methods. Seal air leaks in all these assemblies before insulating them. If necessary, remove the planking and insulation from the side-attic floor to expose the air leaks

Use these specifications when insulating finished attics.

1. Seal large air leaks between conditioned and non-conditioned spaces. *See "Air Sealing Homes" on page 103.*

2. Inspect the structure to confirm that it has the strength to support the weight of the insulation.

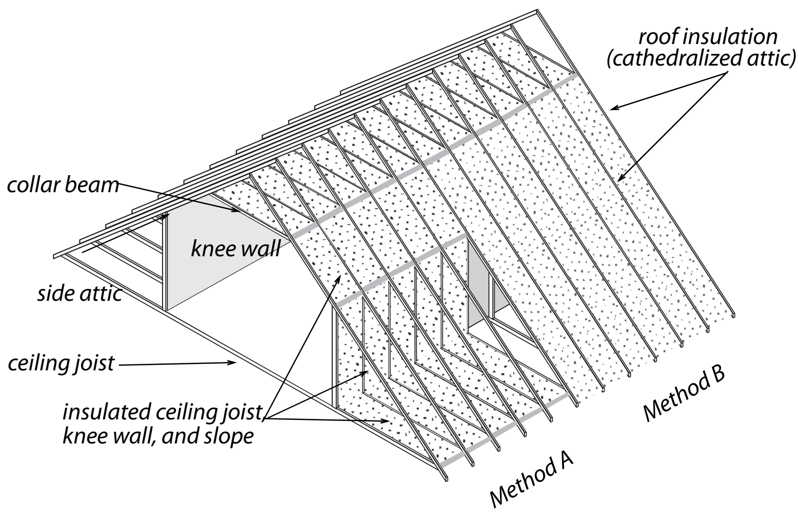
3. Insulate access hatches to the approximate R-value of the assembly through which it is located.

Exterior Walls of Finished Attic

Insulate these walls as described in *"Wall Insulation" on page 160*.

Collar-Beam Attic

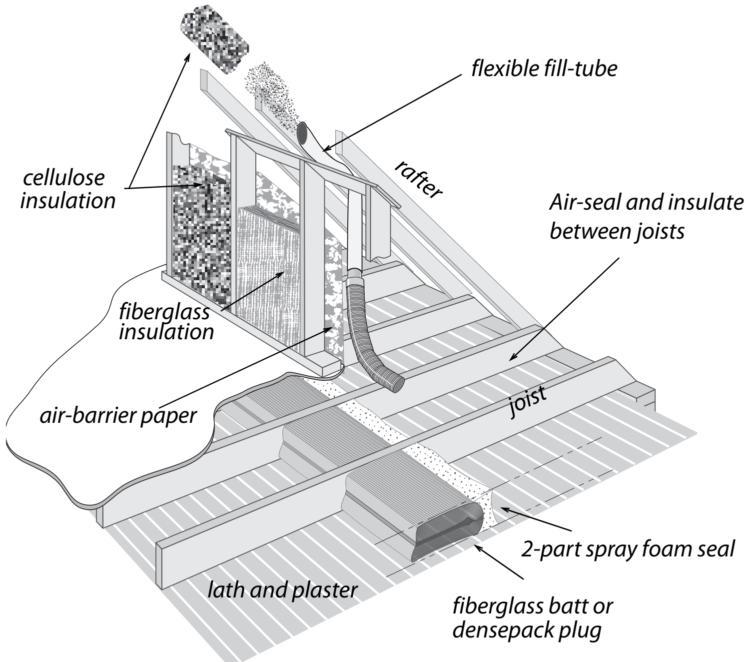
Insulate this type of half-story attic as described in *"Specify these preparatory steps before technicians install attic insulation." on page 140*.



Finished attic: This illustration depicts two approaches to insulating a finished attic. Either A) insulate the knee wall and side attic floor, or B) insulate the roof deck.

Sloped Roof

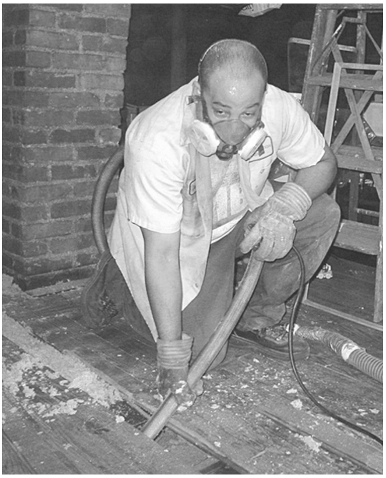
Insulate sloped roof with densepack fiberglass or cellulose insulation. Install plugs of fiberglass batt, or other vapor permeable material, at the ends of this cavity to contain the blown insulation while allowing it to breathe.



Finished attic best practices: Air sealing and insulation combine to dramatically reduce heat transmission and air leakage in homes with finished attics.

Side Attic and Finished Attic Floors

Insulate this small attic as described in *"Safety Preparations for Attic Insulation" on page 142*. If this attic has a floor, remove one or more pieces of flooring to access the cavity and blow fiberglass or cellulose insulation to a medium pack (3 pcf for cellulose or 1 pcf for fiberglass).



Finished attic floor: Find the large air leaks underneath the flooring and seal them before insulating the space between the joists.

Knee Walls

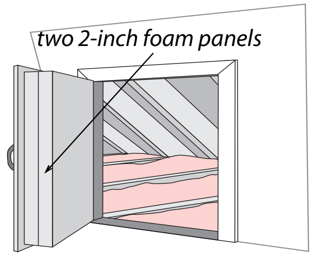
Insulate knee walls using any of these methods.

1. Install un-faced fiberglass batts and cover the insulation with house wrap on the attic side. Prefer R-15, 3.5-inch batts to the older lower-resistance batts.
2. Install the house wrap first and reinforce it with wood lath. Then blow dense-packed fibrous insulation into the cavity through the house wrap and patch the house wrap with tape. (Cellulose: 3.5 pcf; fiberglass 2.2 pcf)
3. Spray the cavities with open-cell or closed-cell polyurethane foam.

To seal and insulate under the knee wall, create an airtight and structurally strong seal in the joist space under the knee wall. This can be done by inserting 2-inch-thick foam sheets and foaming their perimeters with one-part or two-part foam, or by inserting a fiberglass batt into the cavity and foaming its face with an inch or two-part closed-cell spray foam.

For kneewall hatches, use these specifications.

1. Insulate knee-wall access hatches and collar-beam access hatch with 3 or more inches of rigid-foam insulation. Or install a fiberglass batt or batts wrapped with house wrap stapled to the hatch door.
2. Weatherstrip the hatch and install a latch to hold the hatch closed.



Insulated access door in knee wall: Try to achieve at least R-15, or the highest R-value practical.

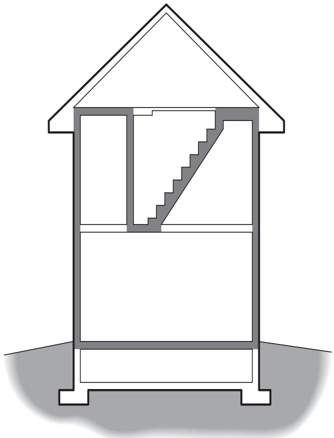
5.3.10 Walk-Up Stairways and Doors

Think carefully about how to install a continuous insulation blanket and air barrier around or over the top of an attic stairway. If you enter the attic by a stairwell and standard vertical door, use these instructions.

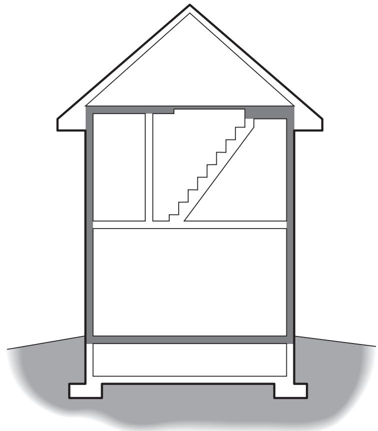
1. Blow dense-pack fibrous insulation into walls of the stairwell.
2. Install a threshold or door sweep, and weatherstrip the door.
3. Blow packed cellulose insulation into the cavity beneath the stair treads and risers.

You can also establish the thermal boundary at the ceiling level, but this requires a horizontal hatch at the top of the stairs.

When planning to insulate stairwells, investigate barriers such as fire blocking that might prevent insulation from filling cavities you want to fill, and consider what passageways may lead to other areas you don't want to fill such as closets. Balloon-framed walls and deep stair cavities complicate this measure.



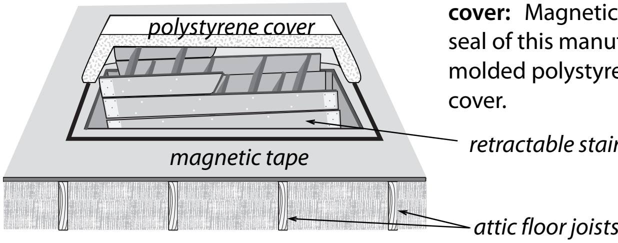
Insulating and sealing attic stair walls, doors, and stairs: Insulating and air sealing these is one way of establishing the thermal boundary.



Insulating and weatherstripping the attic hatch: Air sealing around the hatch and insulating the hatch is an alternative method.

Insulating & Sealing Retractable Attic Stairways

Retractable attic stairways are sometimes installed above the access hatch. Building an insulated box or buying a manufactured stair-and-hatchway cover are good solutions to insulating and sealing this weak point in the ceiling insulation. Be sure to educate the client on the purpose and operation of stair-and-hatchway cover, and ask them to carefully replace it if they need to enter the attic.



Manufactured retractable-stair cover: Magnetic tape forms the seal of this manufactured molded polystyrene insulated cover.

5.4 Wall Insulation

If you find the existing walls uninsulated or partially insulated, add insulation to provide complete coverage for all the home's exterior walls.

Install wall-cavity insulation with a uniform coverage and density. Wall cavities encourage airflow like chimneys. Convection currents or air leakage can significantly reduce wall insulation's thermal performance if channels remain for air to migrate or convect.

In general, insulation specialists over-estimate the R-value of walls. Thermal bridging at studs, plates, and window and door framing along with poor installation can take up to 50 percent off the nominal value of the wall-cavity insulation.

The thermal bridging problem, in particular, may require installing foam sheathing under existing or new siding to cope with future energy costs.

Blown Wall-Insulation Types

Cellulose, fiberglass, and open-cell polyurethane foam are the leading insulation products for retrofit-installation into walls.

Table 5-1: Wall Insulation Density and R-Value per Inch

Insulation Material	Density	R-Value/in.
Fiberglass (virgin fiber)	2.2 pcf	4.1
Cellulose	3.5 pcf	3.4
Open-cell urethane foam	0.5 pcf	3.8
Tripolymer	1.2 pcf	5.1
Air Krete	2.1 pcf	3.9

pcf = pounds per cubic foot; psf = pounds per square foot
* For a 2-by-4 wall cavity

5.4.1 Wall Insulation: Preparation and Followup

Inspect and repair walls thoroughly to avoid damaging the walls, blowing insulation into unwanted areas, or causing a dust hazard.

Preparing for Wall Insulation

Before starting to blow insulation into walls, take the following preparatory steps.

1. Calculate how many bags of insulation are needed to achieve the R-value specified on the bag's label. *See "Calculating Wall Insulation" on page 368.*
2. Inspect walls for evidence of moisture damage. If an inspection of the siding, sheathing, or interior wall finish shows a moisture problem, don't install sidewall insulation until the moisture problem is identified and solved.
3. Seal gaps in external window trim and other areas that may admit rain water into the wall.
4. Inspect indoor surfaces of exterior walls to assure that they are strong enough to withstand the force of insulation blowing. Reinforce siding and sheathing as necessary.
5. Inspect for interior openings or cavities through which insulation may escape. Example include balloon framing openings in the attic or crawl space, pocket doors, un-backed cabinets, interior soffits, and openings around pipes under sinks, and closets. Seal these openings to prevent insulation from escaping.
6. Verify that exterior wall cavities aren't used as return or supply ducts. Either avoid insulating these cavities, or re-move the ducts and reinstall them somewhere else.
7. Verify that electrical circuits inside the walls aren't overloaded. Maximum ampacity for 14-gauge copper wire

is 15 amps and for 12-gauge copper wire is 20 amps. Install S-type fuses to prevent circuit overloading if necessary. Don't insulate cavities containing knob-and-tube wiring. *See "Electrical Safety" on page 356.*

Patching and Finish after Insulating

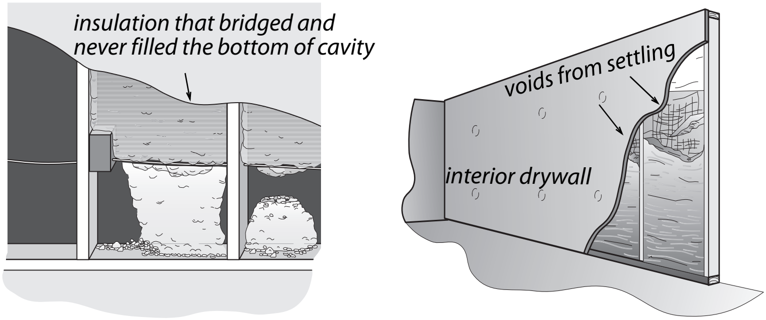
The insulators, the home owner, and others should agree about the patching method and the final appearance of the wall finish. The insulators are usually responsible for patching holes and returning the interior or exterior finish to its previous condition or some pre-agreed level of finish.

1. Patch the exterior wall sheathing with wood plugs, plastic plugs, or spray foam insulation.
2. Use caulk or putty and primer to dress exposed exterior plugs.
3. Patch interior finish with standard plastering methods or a chair rail trim board.
4. Install drywall with joint compound to open cavities to comply with IRC fire codes.

Wall Insulation Quality Control

Retrofit wall insulation has more risk of incomplete application than insulation that you can visually inspect. Consider these quality control options to verify the proper coverage and density of retrofit wall insulation.

1. Viewing the wall through an infrared camera.
2. Looking through an electrical outlet or other access hole for insulation.
3. Calculation of installed weight of installed insulation compared to wall-cavity volume and required density.



Problems with low density insulation: Blowing insulation through one or two small holes usually creates voids inside the wall cavity. This is because insulation won't reliably blow at an adequate density more than about one foot from the nozzle. Use tube-filling methods whenever possible, using a 1.5-inch hose inserted through a 2-inch or larger hole.

Drilling Exterior Sheathing: Insulation Retrofit

Avoid drilling through siding. Where possible, carefully remove siding and drill through sheathing. This procedure avoids the potential lead-paint hazard of drilling the siding. Drilling through only the sheathing also makes it easier to insert flexible fill tubes since the holes pass through only one layer of material.

If you can't remove the siding, consider drilling the walls from inside the home. Obtain the owner's permission before drilling indoors, and practice lead-safe weatherization procedures. *See page 348.*

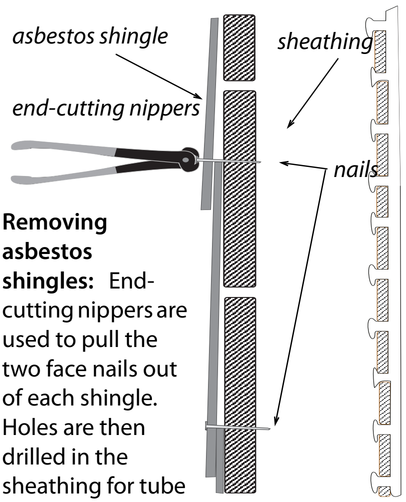
Consider these possible methods of removing siding.

1. Cut completely through the paint on wood-siding joints with a sharp utility knife before carefully prying the siding off.

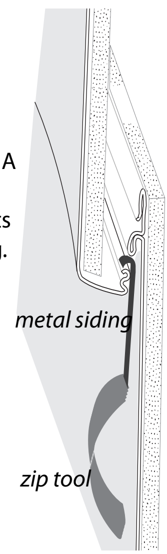
2. Remove asbestos shingles by pulling the nails holding the shingles to the sheathing, or else cut off the nailheads. Dampen the asbestos tiles to reduce dust. Wear a respirator and coveralls when working with asbestos siding.

3. Use a zip tool to remove metal or vinyl siding.
4. Insulate homes with brick veneer or blind-nailed asbestos siding from the indoors.
5. Use a decorative chair rail to cover holes drilled indoors.

Holes drilled for insulation must be returned to an appearance as close to original as possible, or so they are satisfactory to the customer.



Removing asbestos shingles: End-cutting nippers are used to pull the two face nails out of each shingle. Holes are then drilled in the sheathing for tube filling.



Removing metal siding: A zip tool separates joints in metal siding.

5.4.2 Retrofit Closed-Cavity Wall Insulation

This section describes seven ways of installing wall insulation.

1. Blowing walls with fibrous insulation using a fill tube from indoors or outdoors.
2. Blowing walls with fibrous insulation from indoors or outdoors using a directional nozzle.
3. Installing batts in an open wall cavity.
4. Injecting liquid foam into a closed wall cavity.

5. Spraying wet-spray fiberglass or cellulose into an open wall cavity.
6. Spray open-cell or closed-cell foam into an open wall cavity.
7. Blowing fibrous insulation behind netting.

Installing Retrofit Fibrous Wall Insulation

Two methods for installing sidewall insulation are commonly used: tube-fill method (one large hole) or the multi-hole method, using a directional nozzle. The tube-fill method is better because it requires only one hole, and it insulates the wall with a more predictable coverage and density compared to the nozzle.

An energy auditor or inspector might want to do an in-progress inspection of dense-packed insulation to insure that installers are achieving adequate coverage and density.

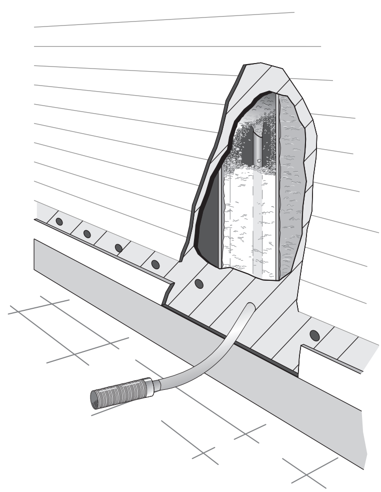
Blowing Walls with a Fill-Tube

Install dense-pack wall insulation using a blower equipped with separate controls for air and material feed. Mark the fill tube in one-foot intervals to help you verify when the tube reaches the top of the wall cavity.

Tube-filling walls: This method can be accomplished from inside or outside the home. It is the preferred wall insulation method because it is a reliable way to achieve a uniform coverage and density.

To prevent settling, cellulose insulation must be blown to at least 3.5 pounds per cubic foot (pcf) density. Fiberglass dense-pack must be 2.2 pcf and the fiberglass material must be designed for dense-pack installation.

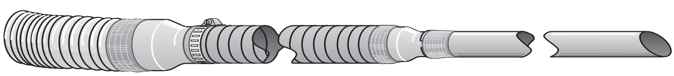
Insulate walls using this procedure.



1. Drill 2-to-3-inch diameter holes to access stud cavity.
2. Probe all wall cavities through holes, before you fill them with the fill tube, to identify fire blocking, diagonal bracing, and other obstacles.
3. Start with several full-height, unobstructed wall cavities so you can measure the insulation density and calibrate the blower. An 8-foot cavity (2-by-4 on

16-inch centers) should consume a minimum of 10 pounds of cellulose.

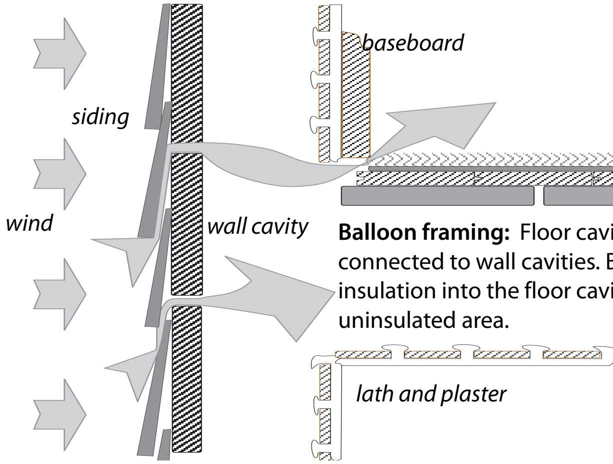
4. Insert the hose all the way to the top of the cavity. Start the machine, and back the hose out slowly as the cavity fills.
5. Then fill the bottom of the cavity in the same way.
6. After probing and filling, drill whatever additional holes are necessary for complete coverage. For example: above windows, missed areas with fire blocking.
7. Learn to use the blower's remote control to achieve a dense pack near the hole while limiting spillage.
8. Seal and plug the holes, repair the weather barrier, and replace the siding.



Insulation hoses, fittings, and the fill tube: Smooth, gradual transitions are important to the free flow of insulation.

Insulating the Perimeter of Balloon-Framed Walls

When insulating the perimeter of balloon-framed walls between the first and second floors, blow an insulation plug into the perimeter floor cavities for both thermal resistance and air-sealing. This insulation plug prevents the floor cavity from being a duct for air migration and leakage. Use a plastic or cloth bag over the end of the fill tube and blow the insulation into the plastic bag or a bag made of netting like an onion bag, which expands inside the cavity. The bag limits the amount of insulation necessary to air-seal and insulate this area.



Balloon framing: Floor cavities are usually connected to wall cavities. Blow a plug of insulation into the floor cavity to seal this leaky uninsulated area.

Multi-Hole Blowing Method for Fibrous Wall Insulation

The multi-hole method is often used when the insulator doesn't want to remove siding. The multi-hole method is the least preferable wall-insulation method because it often results in voids and sub-standard density. A nozzle can be effective to fill small cavities around doors or windows.

If you insulate walls with a nozzle, use a powerful blowing machine.

1. Drill holes into each stud cavity large enough to admit a directional nozzle. Space the holes so that the insulation is blown no more than 12 inches upward or 24 inches downward.
2. Probe wall cavities to determine location of obstacles and nature of cavities around window and door areas.

Directional nozzle: It's difficult to achieve the correct density with the multi-hole method because the density decreases as the distance from the nozzle increases.

3. Fill all wall cavities around windows and doors with insulation.
4. Seal all holes with wood or plastic plugs.

Injecting Liquid Foam

Injecting liquid foam is more expensive than blowing fibrous insulation but offers better performance when existing walls are partially filled by batts. The batts are often 1-to-2 inches thick and are usually flush with the interior drywall or plaster. Specify injecting the foam from outdoors to fill the cavity and compress the batt slightly. From indoors, the foam may just stretch the batt facing and fail to create a fully insulated wall cavity.

Open-cell polyurethane foam, formulated to expand less than the sprayed variety, is the leading wall-retrofit foam. Technicians install the foam through holes (<1 inch) spaced about two feet apart using a simple nozzle that barely enters the cavity. Technicians use drinking straws or other indicators to judge the level that the foam has filled during installation. Technicians don't normally use fill tubes to inject open-cell foam because the tube would be too difficult to clean.

Air Krete or Tripolymer are both injected through a fill tube. Both these foams are water soluble allowing technicians to clean the fill tube after application. The fill tube allows technicians to remove a piece of siding and to fill a cavity from one hole (>2.5 inches).

See "Open-Cell Polyurethane Spray and Injectable Foam" on page 134.

Open-Cavity Wall Insulation

Fiberglass batts are the most common open-cavity wall insulation. Batts achieve their rated R-value only when installed carefully. If there are gaps between the cavity and batt at the top and bottom, the R-value can be reduced by as much as 30 percent. The batt should fill the entire cavity without spaces in corners or edges.

Use the following specifications for the work order and for final inspections.

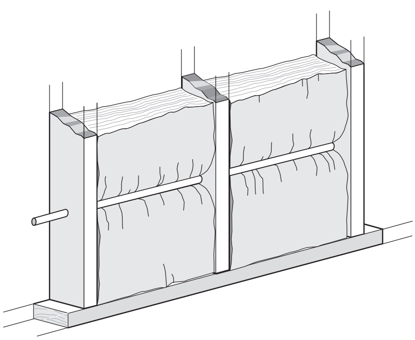
1. Use unfaced friction-fit batt insulation where possible. Fluff the batts during installation to fill wall cavity.
2. Choose medium- or high-density batts: R-13 or R-15 rather than R-11, and R-21 rather than R-19.
3. Seal all significant cracks and gaps in the wall structure before or after you install the insulation.
4. Insulate behind and around obstacles with scrap pieces of batt before installing batts.
5. Staple faced insulation to outside face of studs on the

R-15 fiberglass batts: Install R-15 batts in open walls and attach them to the face of the stud as shown above. Or install unfaced batts as shown below. Either way, cut the batts accurately and install them carefully.

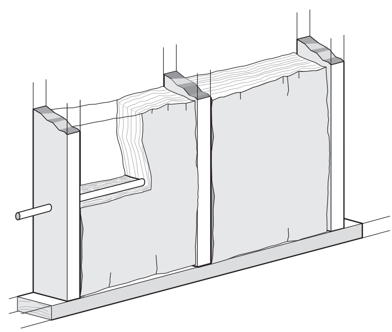
warm side of the cavity. Don't staple the facing to the side of the studs, even though drywallers may prefer that method, because this method leaves an air space that encourages convection currents.

6. Cut batt insulation to the exact length of the cavity. A too-short batt creates air spaces above and beneath the batt, allowing convection. A too-long batt bunches and folds, creating air pockets.
7. Split batt around wiring, rather than letting the wiring compress the batt to one side of the cavity.
8. Fiberglass insulation, exposed to the interior living space, must be covered with minimum half-inch drywall or other material that has an ASTM flame spread rating of 25 or less.

See "Fiberglass Batts and Blankets" on page 130.



Fiberglass batts, compressed by a cable: This reduces the wall's R-value by creating a void between the insulation and interior wallboard.



Batt, split around a cable: The batt attains its rated R-value.

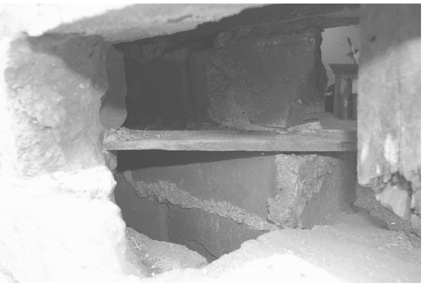
5.4.3 Insulating Unreinforced Brick Walls

Unreinforced means that the builders used no steel or other metal reinforcement. There are three common types of unreinforced brick walls.

1. Traditional brick walls with header bricks that hold two layers of stretcher bricks together. Larger buildings may have three or more brick layers instead of two.

2. Various types of hollow brick walls with usually one layer of brick on either side of an air space.

3. Wood-frame brick veneer walls with a single layer of brick veneer that is attached to a typical wood frame wall.



Hollow brick wall: Two separate single brick walls are held together by wood lath embedded in the mortar joint.

All three of these brick assemblies may have structural problems depending on the condition of the bricks and mortar joints. Mortar can turn to dust over the decades; hollow brick walls can be frighteningly fragile; and small movements can topple 100-year-old brick veneer. **Consult a structural engineer before specifying any modification to an unreinforced brick building.**

5.5 Insulating Floors and Foundations

Floor and foundation insulation and air sealing complete the thermal boundary at the bottom of the building. Floor and foundation insulation are missing in many homes. In cold climates, floor and/or foundation insulation saves energy and improves comfort.

In homes with heated and occupied basements, insulate and air-seal the basement walls to include the basement inside the thermal boundary. The choice of where to insulate and air-seal is more difficult in homes with unused basements or crawl spaces. Here you must choose between insulating the floor or the foundation walls. Decide between these two choices based on cost, energy savings, and other factors as discussed in *"Decisions about Basement and Crawl Spaces" on page 96*.

To establish an effective thermal boundary, the insulation and air barrier should be adjacent to each other. Establishing an effective air barrier — comparable to the air barriers in the above-grade walls and ceiling — may be difficult. Furthermore, foundation or floor insulation may or may not be cost-effective or practical, considering the home's weatherization budget and potential moisture problems.

Most building experts prefer to insulate and air seal the foundation walls and not the floor because this strategy encloses the furnace, ducts, pipes and other features within an insulated and air sealed space. This involves plugging crawl-space vents if appropriate.

Floor insulation is generally preferred where there are crawl-space moisture problems or where stone walls make insulating and air sealing the foundation wall difficult.

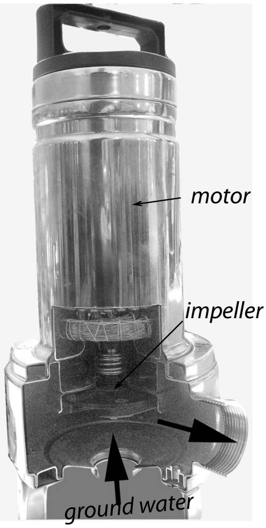
5.5.1 Preparing for Foundation or Floor Insulation

Floor and foundation insulation can increase the likelihood of moisture problems. Installers should take all necessary steps to prevent moisture problems from ground moisture before installing insulation.

Moisture Source-Reduction

Observe the following specifications for avoiding the deteriorating effects of crawl-space and basement moisture on insulation and other building materials. During a final inspection, make sure that the installers have observed the moisture precautions specified in the work order.

1. Solve all drainage problems, ground-water problems, wood-deterioration, and structural problems before installing floor or foundation insulation.
2. Slope the ground outside the home away from the foundation.
3. Install gutters in wet locations and install downspout outlets at least 3 feet away from the home.
4. Remove biodegradable matter, such as wood and cardboard, from the crawl space.
5. Install a ground-moisture barrier in all dirt-floored crawl spaces.
6. Verify that all combustion vents (chimneys), clothes-dryer vents, and exhaust fan vents are vented to outdoors and not into crawl spaces.
7. Suggest a sump pump for crawl spaces or basements with a history of flooding. The sump pump should be located in an area where it will collect water from the entire below-grade area and pump it to a drain or swale outdoors away from the foundation.



Sump pump: These pump water out of a sump or basin where water collects in a basement or crawl space.

Ground Moisture Barriers

Air, water vapor, liquid water, and pollutants move through soil and into crawl spaces and dirt-floor basements. Even soil's surface seems dry and airtight, it can allow a lot of water vapor, and soil gases to enter a home. For these reasons, all crawl spaces should have an airtight ground moisture barrier.

Instruct installers to cover the ground in the crawl space with an airtight moisture barrier to prevent the movement of moisture and soil gases from the ground into the crawl space using these procedures.

1. Cover the ground completely with a ground moisture barrier such as 6-to-10-mil polyethylene. Reinforced or cross-linked polyethylene is more durable than unreinforced polyethylene.
2. Install the moisture barrier from the ground up the foundation wall several inches. Fasten the barrier with wood strips and masonry fasteners. Installers may also adhere the barrier with polyurethane adhesive or acoustical sealant to a clean and flat masonry surface.
3. Seal the edges and seams with urethane, acoustical sealant, butyl caulking, or construction tape to create an airtight seal between the crawl space and the ground underneath.
4. To avoid trapping of moisture against wood surfaces, ground moisture barriers must not touch wood structural members, such as posts, mud sills, or floor joists.

Naturally Ventilated Crawl Spaces

When insulating the floor, the crawl space is ventilated naturally through passive vent openings in the foundation wall. A ground moisture barrier protects the floor insulation and other building materials from moisture. The vent openings can remove small amounts of moisture from the crawl space. Two specifications apply to vented crawl spaces.

1. A crawl-space with a ground-moisture barrier may have vent openings equal to 1 square foot of vent area to 300 square feet of crawl-space floor area. A minimum of two vents should be installed on opposite corners of the crawl space.
2. In a dry crawl space with a ground-moisture barrier, ventilation openings may be minimized to one square foot of net free ventilation area for every 1500 square

feet of crawl-space floor area, according to the 2009 IRC.

Power-Ventilated or Conditioned Crawl Spaces

The 2009 International Residential Code (IRC) allows you to seal the crawl-space vents when you insulate the foundation walls. These three specifications apply to unventilated, power-ventilated, or conditioned crawl spaces.

1. If you removed moisture sources like standing water and installed a ground-moisture barrier, then you can seal the foundation vents completely.
2. The IRC requires foundation insulation installed from the subfloor to the ground in the crawl space. Then install the insulation 24 inches horizontally to lengthen the horizontal heat transmission path from the crawl space to outdoors.
3. The 2009 International Residential Code (IRC) requires 1 CFM per 50 square feet of crawl space floor area in powered exhaust ventilation or the same amount of conditioned supply air from a forced-air system. In either of these options, the IRC requires openings from the crawl space into the home.

Conditioned Crawl Spaces

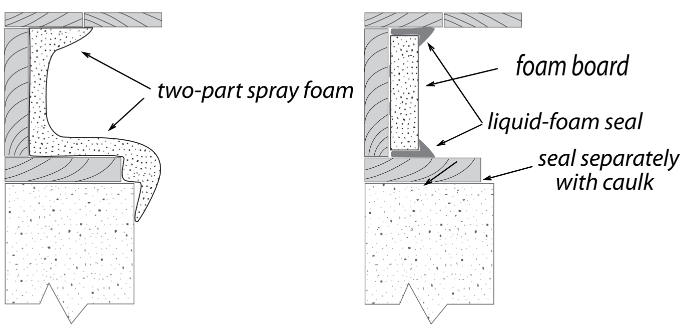
The conditioned crawl space, although allowed by the IRC, may be an ineffective moisture-and-energy solution for crawl spaces. Heating the ground in winter wastes energy. Refrigerating the ground in summer with an air-conditioning system wastes energy and may also cause moisture problems. We can't recommend this practice.

Rim-Joist Insulation and Air-Sealing

The rim-joist spaces at the perimeter of the floor are a major weak point in the air barrier and insulation. Insulating and air sealing both the rim joist and longitudinal box joist are appropriate either as individual procedures or as part of floor or foundation insulation.

Installers should air seal stud cavities in balloon-framed homes as a part of insulating the rim joist and air seal other penetrations through the rim before insulating. Two-part spray foam is the most versatile air-sealing and insulating system for the rim joist because spray foam air seals and insulates in one step. If you leave the spray foam exposed, it should have a flame spread of 25 or less and be no more than 3.25 inches thick according to the IRC.

Polystyrene or polyurethane rigid board insulation are also good for insulating and air sealing the rim joist area. When the rim joist runs parallel to the foundation wall, the cavity may be air sealed and insulated with methods similar to those as shown here.



Foam-insulated rim joists: Installing foam insulation is the best way to insulate and air seal the rim joist.

Foam-insulated rim joists: Here 4 inches of EPS foam is sealed around its perimeter with one-part foam.

Don’t use fiberglass batts to insulate between rim joists because air can move around the fiberglass, causing condensation and encouraging mold on the cold rim joist. If you use foam to insulate between the rim joists, use liquid foam sealant to seal around the edges of the rigid foam.

5.5.2 Installing Floor Insulation

The best way to insulate a floor cavity is to completely fill each joist cavity with fiberglass insulation. Blowing fiberglass insulation is the easiest way to achieve complete coverage because the blown fiberglass is able to surround obstructions and penetrations better than fiberglass batts. Avoid blown cellulose because of its weight, moisture absorption, and tendency to settle.

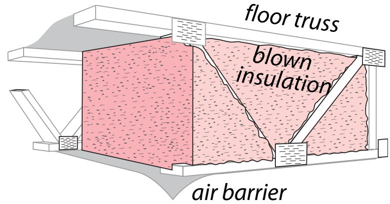
Before installing fiberglass floor insulation, make the following preparations.

1. Establish an effective air barrier at the floor, prior to insulating the floor, to prevent air from passing through or around floor insulation.
2. Seal and insulate ducts remaining in the crawl space or unoccupied basement
3. Insulate water lines if they protrude below the insulation.

Blowing Floor Insulation

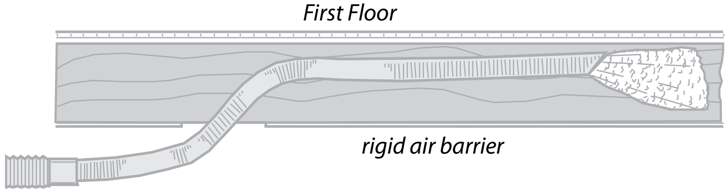
Specify these procedures and inspect for them during the final inspection.

1. Cover the entire underfloor surface with a vapor permeable supporting material such as: dust-free fabric mesh or equivalent vapor-permeable and drainable material.



Blown floor insulation: This method works particularly well with floor trusses.

2. Use wood strips to support the flexible or semi-flexible support material unless that material with its fasteners can support the floor insulation without sagging.
3. Install rock wool or fiberglass blowing wool through V-shaped holes in the air barrier.
4. Use a fill tube for installing the blown insulation. Insulation must travel no more than 12 inches from the end of the fill tube.
5. Seal all penetrations in the air barrier with a tape, approved for sealing seams in the air-barrier material.



Blowing floor cavity: Uninsulated floor cavities can be blown with fiberglass or rock wool insulation, using a fill tube.

Installing Fiberglass Batt Floor Insulation

Use these specifications for insulating under floors.

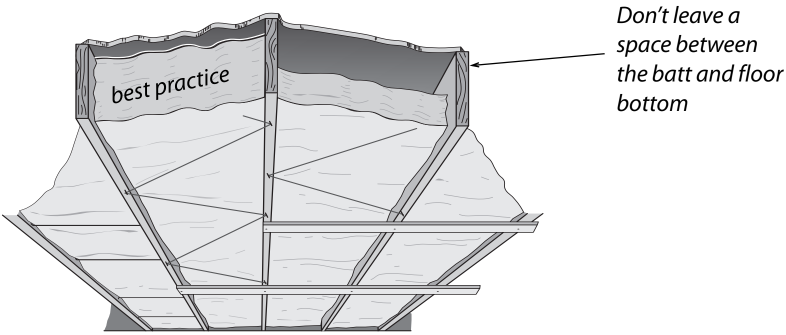
1. Choose unfaced batts for insulating floors.
2. Seal all significant air leaks through the floor before insulating the floor, using strong airtight materials.

3. Install batts in continuous contact with the subfloor.
4. Batt thickness must fill the complete depth of each cavity.
5. Batts must be neatly installed, fitting tightly together at joints, fitting closely around obstructions, and filling all the space within the floor cavity.
6. Crawl-space access doors, adjacent to a conditioned space, must be insulated to at least R-21 for horizontal openings and to at least R-15 for vertical openings.
7. Crawl-space access doors must be effectively weather-stripped.

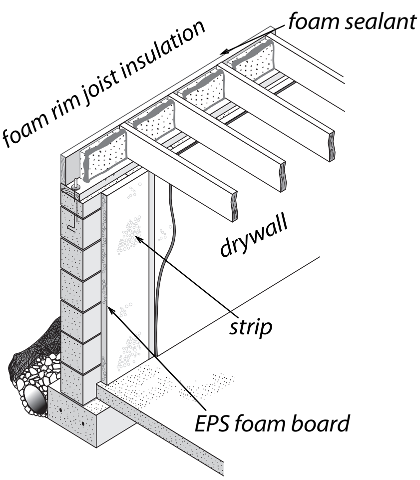
Fastening Batts in Floor Cavities

Batt insulation, installed in floors, must be supported by twine, wire, wood lath or other suitable material that keeps the insulation touching the floor. Friction-fit fiberglass batts supported by self-supporting wire insulation supports aren't good practice. Fasteners for floor insulation must resist gravity, the weight of insulation, and moisture condensation.

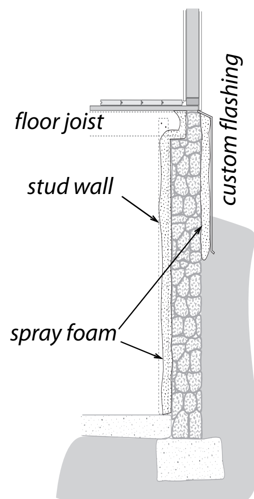
1. Choose standard wood lath $^{1}/_{4}$ inch by 1 inch. Install the lath perpendicular to joists 12 inches apart for joists on 24-inch centers and 18 inches apart for joists on 16-inch centers.
2. Choose non-stretching polypropylene or polyester twine.
3. Choose copper or stainless steel wire with a minimum diameter of 0.04 inches or size 18 AWG.
4. Install twine or wire in a zig-zag pattern.
5. Install power-driven staples 12 inches apart for joists on 24-inch centers and 18 inches apart for joists on 16-inch centers. The staples must penetrate the wood joists by at least $^{5}/_{8}$ inch. Don't hand staple the supports.



Floor insulating with batts: Use unfaced fiberglass batts, installed flush to the floor bottom, to insulate floors. The batt should fill the whole cavity if it is supported by lath or plastic twine underneath. For batts that don't fill the whole cavity, use wire insulation supports.



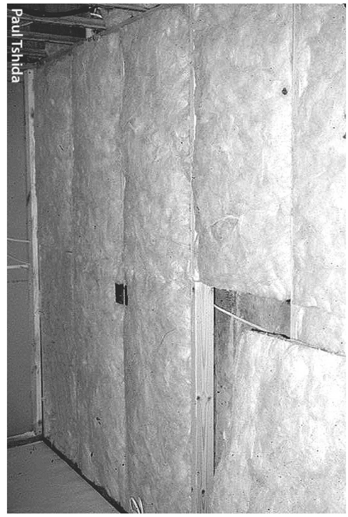
2-inch foam board with plywood strips: Installers fasten foam to the foundation wall using built-in strips. They they attach the drywall to the strips in the foam.



2-part foam sprayed on stone walls: Installers insulate stone walls on the interior or exterior with sprayed plastic foam. On the interior, they cover the foam with drywall.

5.5.3 Basement Insulation

Basement wall is seldom installed properly because of the installers' poor understanding about moisture problems.



Frame-wall method: This method can be acceptable with meticulous air sealing to prevent basement air from circulating behind the wall. Exterior water drainage must be effective to prevent moisture problems in the basement.

Frame-Wall Insulation

The most common (although not the best) way to insulate basement walls, or any masonry wall, is to build a framed wall against the masonry wall and fill the wall with fiberglass batts. The frame wall is then covered with drywall.

Unfaced batts are the best choice of fiberglass insulation since they contain no vapor barrier to trap moisture. Moisture may escape from the wall in either direction: from outdoors in or indoors out.

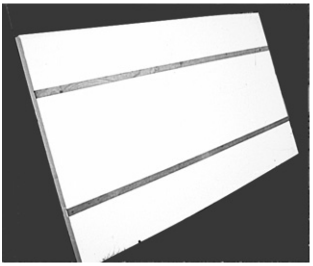
With a framed wall, the installer often neglects to seal in areas where the wall is discontinuous, such as a mechanical room. Any areas, such as unfinished wall, open rim-joist area, or unsheeted ceiling constitutes a very large air leak around the insulated wall. Avoid this problem by specifying these procedures in the work order.

1. Insulate the rim joist and air seal it.
2. Build the frame walls.
3. Wall off the entire basement. If a mechanical room or other area will not be insulated, install an airtight block at the wall's edge to prevent basement air from circulating behind the insulated wall.

4. Don’t install a vapor barrier on the interior face of the new basement wall. The wall must be able to dry toward indoors or to the outdoors.
5. Install drywall in an airtight manner on the walls and ceiling by applying sealant to the back of each sheet around its perimeter.

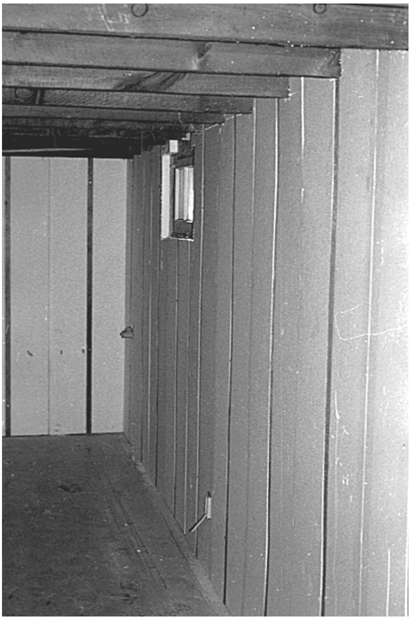
Stripped Foam Basement Insulation

Polystyrene foam is an excellent choice for insulating smooth basement walls or above-grade masonry walls.



Installing stripped foam: Installers glue and screw to the foam sheets to the masonry wall. Then they glue drywall to the foam and screw the drywall to the strips.

You can order either expanded polystyrene or extruded polystyrene equipped with grooves for fastening strips, spaced apart on 16-inch or 24-inch centers. Stripped foam sheets may be the easiest and most satisfactory way to insulate below-grade basement walls. Do these procedures to install 2-inch stripped foam on a foundation wall.



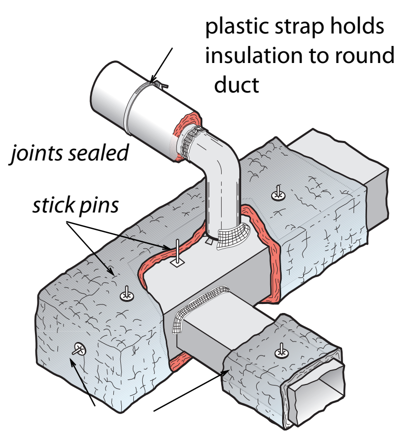
1. Apply walnut-sized globs of adhesive to the back of the sheet on one-foot centers. Use a foam-compatible adhesive and follow the instructions on the container.
2. Install at least two concrete screws or two powder-driven nails in each strip, 24 inches from the bottom and top.
3. Wherever an outlet is needed, install it between two sheets. Cut the rectangle out of one of the sheets. Install a two-inch plastic box backed by a piece of half-inch plywood, using construction adhesive and a concrete screw.

4. Leave a half-inch gap at the bottom of the polystyrene sheets to run wire. Run the wire along the floor and up into the boxes.
5. Seal the bottom gap and other gaps in the foam sheeting with one-part foam.
6. Glue the drywall using the same adhesive and pattern. Screw the drywall to each wooden strip with one-inch drywall screws.

5.6 Duct Insulation

Insulate supply ducts that are installed in unconditioned areas outside the thermal boundary such as crawl spaces, attics, and attached garages with vinyl- or foil-faced duct insulation. Don't insulate ducts that run through conditioned areas unless they cause overheating in winter or condensation in summer. Use these best practices for installing insulation.

1. Always perform necessary duct sealing before insulating ducts.
2. Duct-insulation R-value must meet or exceed IECC 2009 standards: R-8 for vented attics, R-6 for other areas.Insulation should cover all exposed supply ducts, without significant areas of bare duct left uninsulated.
3. Insulation's compressed thickness must be more than 75% of its uncompressed thickness.



Duct insulation: Insulate supply ducts, located in unheated areas, to a minimum of R-6.

Don't compress duct insulation excessively at corner bends.

4. Fasten insulation using mechanical means such as stick pins, twine, staples, or plastic straps. Cover the insulation's joints with tape to stop air convection. However, tape often falls off if the installer expects tape to support the insulation's weight.
5. Install the duct insulation 3 inches away from heat-producing devices such as recessed light fixtures.

Caution: Burying ducts in attic insulation is common in some regions and it reduces energy losses from ducts. However, burying ducts in attic insulation can cause condensation on ducts in humid climates during the air-conditioning season.

Chapter 6: Windows and Doors

This chapter presents specifications and procedures for improving the energy performance of windows and doors. Detailed specifications for window replacement provide guidance on this often-performed and potentially troublesome retrofit.

Windows and doors are a major concern to homeowners and energy specialists alike. Windows and doors were once thought to be a major air-leakage problem. However, the widespread use of blower doors has shown that windows and doors don't tend to harbor large air leaks. But the combined heat losses and gains, by conduction, convection, radiation, and air leakage through windows are usually very significant.

Unfortunately, the square-foot cost to improve windows is high, so the payback from window improvements is usually not as attractive as many other building-shell retrofits. In older buildings, though, the windows and doors may be in such poor condition that repair or replacement is essential to a building's survival even if it's not an energy-saving priority. However, windows and doors aren't health and safety measures under WAP.

All tasks relating to window and door improvement, repair, and replacement should be accomplished using lead-safe weatherization methods. *See "EPA RRP Requirements" on page 348.*

6.1 Window Replacement Specifications

The purpose of these specifications is to guide the selection and installation of replacement windows. Improper window installation can cause air leakage, sound leakage, and water leakage.

Existing window openings may have moisture damage and air leakage. These conditions require repair during the window replacement process.

Included here are specifications for two special window safety considerations.

1. Windows in high risk areas, such as around doors and walkways, must have safety glass.
2. Windows are part of fire escape planning for homes, so this egress function must be recognized and accommodated.

6.1.1 Window Replacement Options

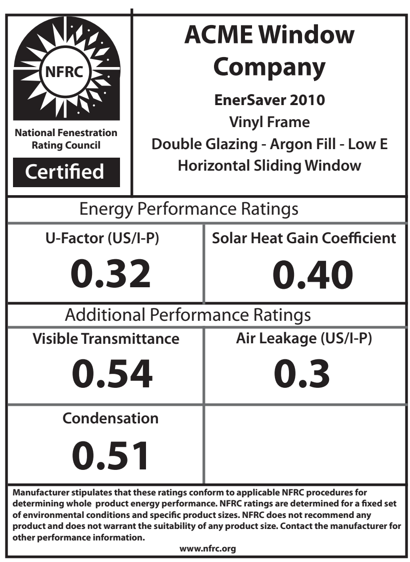
Window replacements are generally not cost-effective energy conservation measures. Specify window replacement only as emergency-repair measures when the window is missing, or damaged beyond repair, or proven to be cost-effective.

Replacement windows should have a window unit U-factor of 0.35 or less as rated by the National Fenestration Rating Council (NFRC) or approved equal.

6.1.2 Window Energy Specifications

Installing new windows incurs a large labor expense so they should be as energy-efficient as the budget allows.

1. Replacement windows must have a U-factor less than or equal to U-0.35. Lower is better, especially in cold climates.
2. Replacement windows facing east or west in air conditioned homes should have a solar heat-gain coefficient (SHGC) of less than or equal to 0.35. Lower is better, especially in hot climates.



NFRC label: The key selection criteria for window shopping is displayed on the NFRC label.

3. Consider advanced window designs with triple glazing, insulated frames and sashes, gas fillings between the glass panes, and less conductive spacers between the glass panes.

6.1.3 Removing Old Windows

Existing windows should be removed without damaging the home's interior finish, siding, exterior trim, and the water resistive barrier.

1. Protect the interior of the home from construction debris.
2. Remove window sashes, jambs, and/or siding, depending on the window-replacement method chosen.
3. Repair moisture damage to the rough opening before installing the new window.
4. Follow manufacturer's installation instructions.

6.1.4 Installing Replacement Windows

The most important considerations for installing new windows is that the window installation is weathertight and airtight.

Water leakage is a serious problem because it deteriorates building components around the window. To prevent water leakage in frame buildings, the window must be carefully integrated into the home's water resistive barrier (WRB). A frame home's WRB is a waterproof breathable membrane that stops rain water penetration through the siding from dampening the sheathing underneath. Specify the integration of the new window and existing WRB using special tapes or adhesive flexible flashing.

Installing Windows within the Rough Opening

Remove the existing window, window jambs, sill, and exterior trim. If the entire house is not re-sided at the same time, the nearby siding may need to be removed to allow proper installation of flashing. Then install the replacement window in the rough opening in a similar manner as new construction.

1. Use whatever shimming assembly is necessary including flat shims, a shimmed flat sill, or a sill pan to support the replacement window on a solid, level, and water-resistant sill surface. The window's weight should not be supported by the flanges.
2. Flash the new window around its perimeter with approved flashing. Install the flashing from bottom to top (like roof shingles) so water cannot enter the wall.
3. At the top of the window, fit the window's flange **underneath** the home's water-resistive barrier. At the sides and bottom, fit the flange **between** the siding and the water-resistive barrier.
4. Install caulking or butyl putty tape on the window flange before installing the window. Follow the manufacturer's recommendations on sealant and its application.
5. When using caulking as the window sealant, the window must be installed immediately after caulking application before the caulking becomes contaminated or forms a skin.
6. Use fasteners with heads wide enough in diameter to span the holes or slots in the window flange.
7. Avoid over-driving the fasteners or otherwise deforming the window flange.
8. Air seal the space between the window frame and the rough opening, or between the old window jambs and sill. Use one-part foam or foam backer rod with caulking. Merely stuffing this gap with fiberglass insulation doesn't create an effective air seal.

9. Windows that are exposed to wind-driven rain or without overhangs above them should have a rigid cap flashing to prevent rainwater from draining onto the window. The cap flashing should overlap the sides of the window enough to divert water away from vertical joints bordering the window.

Installing Replacement Windows: Existing Jambs and Sill

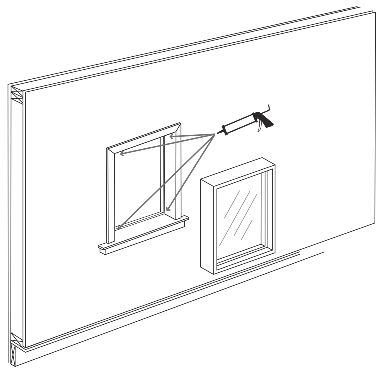
When the energy auditor is confident about the condition of the existing rough framing, jambs, and sill, replacement windows are often installed without stripping the assembly out to the rough frame. Air sealing will be more difficult and probably less effective than when the entire window assembly is removed. Specify these procedures for installing a new window in an existing window frame.

1. Install flat shims to provide a level surface to support under the vertical structural members of the new window frame. The window should not be supported by the flanges.
2. Protect the existing sill with metal and plastic flashing if necessary for drainage and to protect the protruding wood sill.
3. Seal the replacement window to a continuous stop during installation.

Flashing an existing window frame: Wrap the water-resistant barrier from the outside to the interior of the window frame so that any penetrating moisture will drain out without soaking into the wood.

4. Use correctly sized shims where the side jambs of the replacement window are fastened into the side jambs of the old window.

Block frame window installation: When installing a replacement window in the existing window frame or in a masonry wall the Block frame method is common. Windows installed Block frame have no flange. Install the window against a stop from inside the building. Caulk the stop and foam between the new window frame and the old one.



5. Seal the space between the new window frame and old window frame with one-part foam.

6.2 Window Safety Specifications

Windows have special requirements for breakage-resistance in areas that are prone to glass breakage, and for fire escape in bedrooms. This safety information is included here because of the difficulty of obtaining it elsewhere.

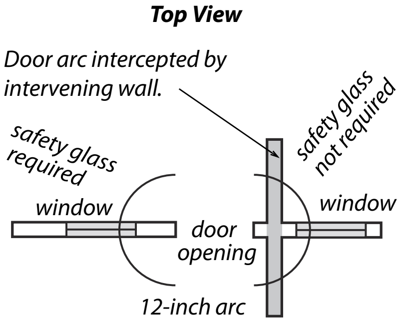
6.2.1 Windows Requiring Safety Glass

Safety glass must be either laminated glass or tempered glass bearing a permanent label identifying it as safety glass.

Instead of safety glazing, glazed panels may have a protective bar installed on the accessible sides of the glazing 34 to 38 inches above the floor. The bar shall be capable of withstanding a horizontal load of 50 pounds per linear foot without contacting the glass and be a minimum of $1^1/_2$ inches in width.

Safety glass or a protective bar is required in the following conditions.

1. Glazing wider than 3 inches in entrance doors.
2. Glazing in fixed and sliding panels of sliding doors and panels in swinging doors other than wardrobe doors.
3. Glazing in fixed or operable panels adjacent to a door where the nearest exposed edge of the glazing is within a 12-inch arc of the vertical edge of the door in a closed position and where the bottom edge of the glazing is less than 60-inches above the floor or walking surface unless there is an intervening wall or permanent barrier between the door and the glazing.

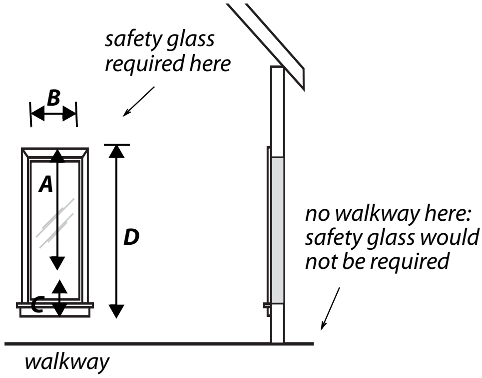


Safety glass around doors: A window near a door must be glazed with safety glass when the window is less then 24 inches from the door and less than 60 inches from the floor.

4. Glazing in any portion of a building wall enclosing showers, hot tubs, whirlpools, saunas, steam rooms, and bathtubs where the bottom exposed edge is less than 5 feet above a standing surface or drain inlet.

Glazing in an individual fixed or operable panel that meets all of the following conditions must also have safety glass:

1. An exposed area of an individual pane greater than 9 square feet, and
2. An exposed bottom edge less than 18 inches above the floor.
3. An exposed top edge greater than 36 inches above the floor.
4. One or more walkways within 36 inches horizontally of the glazing.



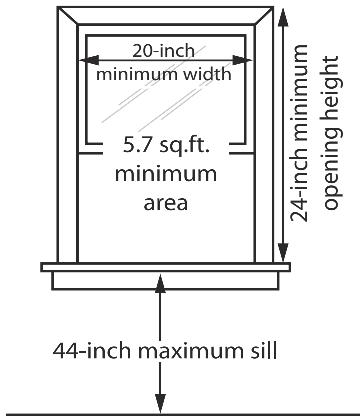
A x B = greater than 9 ft^2, and
C = less than 18 inches from floor, and
D = more than 36 inches from floor.

Large windows near walking surfaces: Safety glass is required in picture windows with a nearby walkway.

6.2.2 Fire Egress Windows

Windows are the designated fire escape for bedrooms and should offer a minimum opening for a person's escape. Observe the following specifications when replacing windows, unless the new window has an equal or greater clear opening than the existing window and the window installation doesn't require a building permit. If the window installation requires a code-approved egress window, observe these specifications.

1. Each bedroom must have one egress window.
2. Egress windows must provide an opening that is at least 20 inches wide and at least 24 inches high.
3. Egress windows must provide an opening with a clear area of at least 5.7 square feet except for below-grade windows, which must have at least 5.0 square feet of opening.



Egress windows: Windows for fire escape must be large enough and a convenient distance from the floor.

4. The finished sill of the egress window must be no higher off the floor than 44 inches.
5. According to the 2009 IRC, you may install security bars, screens, or covers over egress windows as long as these security devices are easily removable from indoors.

6.3 Door Replacement and Repair

Doors suffer a lot of wear because of their jobs as entrances for buildings. Doors need repair when they are damaged and replacement when repair costs exceed the cost of a new insulated door.

Specify flashing around doorways according to the specifications in *"Installing Replacement Windows" on page 191*.

6.3.1 Door Replacement

Door replacements are rarely cost-effective energy conservation measures. Replace a door as an emergency-repair, when the door is damaged beyond repair. Tight uninsulated doors in good condition should not be replaced. Auditors and Contractors must use RRP & LSW methods to ensure occupants and workers are not placed at risk during door repair measures. Observe the following standards when replacing exterior doors.

1. All replacement doors must be an exterior-grade foam core doors.
2. Replace the door using an insulated door-blank or a pre-hung steel insulated door.
3. Replacing an exterior panel door with another panel door is not allowed.
4. All replacement doors must have three hinges.

6.3.2 Door Repair and Improvement

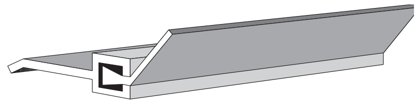
Doors have a small surface area and their air leakage is more of a localized comfort problem than a significant energy problem most of the time. However, door operation affects building security and durability, so doors are often an important repair priority.

Door repair improves home security and building durability. Door repair can also save energy if the door currently has a poor fit.

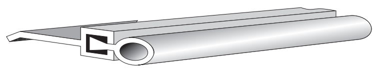
Door weatherstrip, thresholds and sweeps are marginally cost effective. Specify these measures only if they are cost effective.

1. Tighten door hardware and adjust stops so door closes snugly against its stops.
2. Use a durable stop-mounted or jamb-mounted weather-strip material to weatherstrip the door. New weather-strip must form a tight seal with no buckling or gaps when installed.
3. Plane or adjust the door so it closes without rubbing or binding on the stops and jambs, especially in homes that may have lead paint.
4. Install thresholds and door sweeps if needed to prevent air leakage. These air seals should not bind the door. Thresholds should be caulked on both sides at the sill and jamb junction.
5. Replace missing or inoperable lock sets.
6. Move the lock set and strike plate.
7. Move stops if necessary.
8. Seal gaps between the stop and jamb with caulk.
9. Install a door shoe if needed to repair damage.

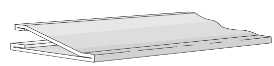
If the door binds at the top, check the tightness of screws in the top hinge and tighten them if necessary. If the hinges are tight, check the space between the door and the frame's hinge-side. If there's a $^1/_4$-inch gap between door and frame on the hinge side, you can give $^1/_8$ inch of that gap to the latch side by deepening the mortise — the chiseled-out section of door frame directly under the hinge. If the door is too tight to the hinge side, install one or more pieces of cardboard underneath a hinge.



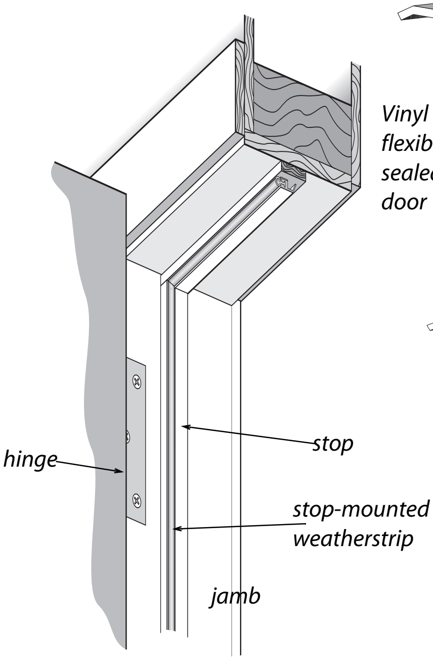
Vinyl flap weatherstrip is particularly flexible, allowing the door to remained sealed with seasonal movements of the door



Silicone bulb weatherstrip is much more flexible than vinyl bulb and therefore seals better.



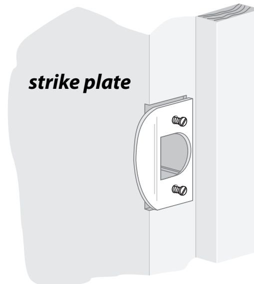
Bronze v-strip mounts on the door jamb and is very durable.



Weatherstripping doors: Weatherstripping doors is mainly a comfort retrofit. The door should be repaired before weatherstripping by tightening hinges and latches. The door stop should fit tightly against the door when it is closed.

Doors can be adjusted by moving the hinges in or out. Moving the top hinge in moves the door upward and toward the hinge. Moving the top hinge out drops the door down and moves the door away from the hinge.

If a door won't latch, inspect the door stops and weatherstripping to see if they are binding. If there is no obvious problem with the weather-strip or stops, move the strike plate out slightly or use a file to remove a little metal from the strike plate. The strike plate is mortised into the door frame that receives the latch. Use toothpicks or dowels to patch widened screw holes if you have to move the strike plate.



Minor door repair: Tightening and adjusting locksets, strike plates, and hinges helps doors work better and seal tighter.

Chapter 7: Evaluating Heating and Cooling Systems

This chapter specifies energy efficiency improvements to heating and cooling systems. It is divided into these main sections.

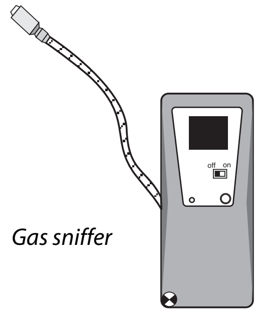
1. Essential combustion safety testing: What tests do you need to specify for every combustion heating system?
2. Heating system replacement: What are the most important specifications for replacing heating systems?
3. Servicing gas and oil heating systems: What are the most important specifications for servicing combustion heating systems?
4. Inspecting venting: What are the requirements for safe venting?
5. Heating distribution systems: what are the most important specifications for forced-air, hydronic, and steam heating distribution systems?
6. Air conditioning systems: What are the most basic requirements for efficient air-conditioning systems?

7.1 Essential Combustion Safety Tests

The Department of Energy (DOE) requires that essential combustion safety tests be performed as part of all energy conservation jobs. Perform gas leak-testing and CO testing on all combustion appliances. For naturally drafting appliances, a worst-case CAZ depressurization test is also necessary.

7.1.1 Leak-Testing Gas Piping

Natural gas and propane piping systems may leak at their joints and valves. Find gas leaks with an electronic combustible-gas detector, often called a gas sniffer. A gas sniffer will find significant gas leaks if used carefully. Remember that natural gas rises from a leak and propane falls, so position the sensor accordingly.



Gas sniffer

1. Sniff all valves and joints with the gas sniffer.
2. Accurately locate leaks using a noncorrosive bubbling liquid, designed for finding gas leaks.
3. Identify kinked or corroded flexible gas connectors.
4. Identify flexible gas lines manufactured before 1973. The date is stamped on a date ring attached to the flexible gas line.
5. Report gas leaks to the utility company or hire a local contractor to repair gas leaks.

7.1.2 Carbon Monoxide (CO) Testing

CO testing is essential for evaluating combustion and venting. Measure CO in the vent of every combustion appliance you inspect and service. Measure CO in ambient air in both the home and CAZ during your inspection and testing of combustion appliances.

Vent Testing for CO

Testing for CO in the appliance vent is a part of combustion testing that happens under worst-case conditions. If CO is present in undiluted combustion byproducts more than 100 parts per million (ppm) as measured or 200 ppm air-free, the appliance fails the CO test under current widely accepted standards.

Ambient Air Monitoring for CO

BPI standards require contractors to monitor CO during testing to ensure that air in the combustion appliance zone (CAZ) doesn't exceed 35 parts per million (ppm). If ambient CO levels in the combustion zone exceed 35 ppm, stop testing for your own safety. Ventilate the CAZ thoroughly before resuming combustion testing. Investigate indoor CO levels of 9 ppm or greater to find their cause. This is the ASHRAE 24 hour exposure limit.

Table 7-1: Testing Requirements for Combustion Appliances and Venting Systems

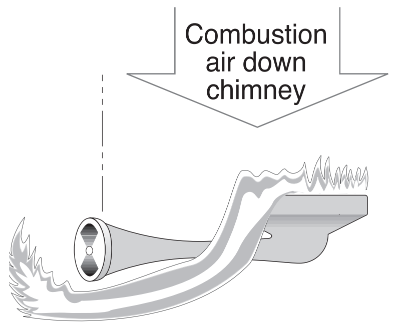
Appliance/Venting System	Required Testing
All direct vent or power vent combustion appliances	Gas leak test CO test at flue-gas exhaust outdoors Confirm venting system connected
Combustion appliances (with naturally drafting chimneys) in a mechanical room or attached garage supplied with outdoor combustion air and sealed from the home	Gas leak test CO test Confirm that CAZ is effectively air sealed from house and has combustion air from outdoors
Naturally drafting chimney and appliance located within home	Gas leak test CO test Venting inspection Worst-case CAZ depressurization and spillage testing

7.1.3 Worst-Case CAZ Depressurization Testing

CAZ depressurization is the leading cause of backdrafting and flame roll-out in furnaces and water heaters that vent into naturally drafting chimneys. Perform the worst-case testing procedures documented here.

Worst-case vent testing uses the home's exhaust fans, air handler, and chimneys to create worst-case depressurization in the combustion-appliance zone (CAZ). The CAZ is an area containing one or more combustion appliances. During this worst-case testing, you can test for spillage, measure the CAZ pressure difference with reference (WRT) to outdoors, and measure chimney draft WRT the CAZ.

Worst-case conditions do occur, and venting systems must exhaust combustion byproducts even under these extreme conditions. Worst-case vent testing exposes whether or not the venting system exhausts the combustion gases when the combustion-zone pressure is as negative as you can make it. A digital manometer is the best tool for accurate and reliable readings of both combustion-zone depressurization and chimney draft.



Flame roll-out: A serious fire hazard that can occur when the chimney is blocked, when the combustion zone is depressurized, or during extremely cold weather.

Take all necessary steps to reduce CAZ depressurization and minimize combustion spillage, based on your tests.

Preliminary Combustion Safety Tests

Verify that there are no obvious combustion-safety problems in the CAZ.

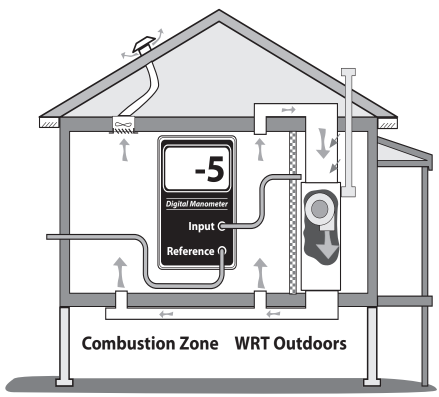
1. Begin ambient-air monitoring of CO and discontinue testing if it reaches 35 parts per million (ppm).
2. Sniff all gas fittings with a gas sniffer from the appliances to the meter. Confirm leaks with leak-detecting solution.
3. Look for soot, rust, burned wires, and fire hazards.

Worst-Case CAZ Depressurization Test

Follow the steps below to find the worst-case depressurization level in the CAZ.

1. Then make sure all exterior doors, windows, and fireplace damper(s) are closed, and measure the base pressure.
2. Set all combustion appliances to the pilot setting or turn them off at the service disconnect. Don't fire the burner of the combustion appliance yet.
3. Measure and record the base pressure of the combustion appliance zone (CAZ) with reference to outdoors. If the digital manometer has a baseline function, use this function to cancel out the baseline pressure now.

A reading in the combustion appliance zone more negative than -5 pascals indicates a significant possibility of backdrafting.



Worst-case depressurization: Worst-case depressurization tests identify problems that weaken draft and restrict combustion air. The testing described here is intended to reveal the cause of the CAZ depressurization and spillage.

4. Turn on the dryer and all exhaust fans.
5. Close the interior doors, which make the CAZ pressure more negative.
6. Turn on the air handler, if present, using the "fan on" switch at thermostat. Leave the air handler on if the pressure in the CAZ becomes more negative after you

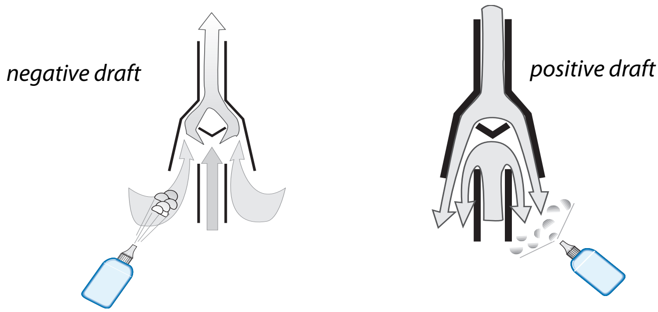
turn it on. Experiment by opening and closing interior doors while the air handler is operating to maximize the negative pressure.

7. Measure the worst-case pressure and record it. Compare this number to the table entitled, *"Maximum CAZ Depressurization for Appliances" on page 209* for the tested appliance.

Spillage and CO Testing

Next, verify that the appliance venting systems operate safely at worst-case depressurization. Test each appliance in turn for spillage and CO as described below.

1. Operate and test the appliance with the smallest BTUH capacity first and then the next largest leaving the smaller one on. Retest the smaller appliance again after testing the larger one.
2. Look for spillage at the draft diverter with a smoke generator, a lit match, or a mirror. Find out whether combustion byproducts spill and how long after ignition that the spillage stops for each appliance.
3. If spillage in one or more appliances continues under worst-case for 2 minutes or more, recommend service to correct the problem.
4. Measure CO in the undiluted flue gases after 5 minutes of operation at worst-case conditions. If CO in undiluted flue gases is more than 100 ppm as measured or 200 ppm air-free measurement, order a service call to reduce CO level (unless your CO measurement is within manufacturers specifications).



Negative versus positive draft: Air flows down the chimney and out the draft diverter with positive draft. A smoke generator helps distinguish between positive and negative draft in atmospheric chimneys.

Table 7-2: Maximum CAZ Depressurization for Appliances

Appliance	Maximum Depressurization
Power-vented or sealed-combustion furnace or boiler; pellet stove with draft fan and sealed vent *	–10 pa (–0.04 IWC)
Atmospherically vented gas systems	–5 pa (–0.02 IWC)
Oil power burner and fan-assisted (induced-draft) gas *	
Closed controlled combustion	
Decorative wood-burning appliances	
Atmospherically vented water heater	–2 pa (–0.008 IWC)

*Individual combustion appliances may be capable of operating safely at CAZ depressurization more negative than –10 pascals. However CAZ depressurization is a potential problem for numerous reasons and can usually be reduced. The causes are most often return-air leakage or large exhaust fans.

7.1.4 Improving CAZ Depressurization and Draft

If you find problems with CAZ depressurization or spillage, consider the improvements discussed next to solve the problems.

You may open a window, exterior door, or interior door to observe whether the flow of combustion air through that door improves draft. If this additional air improves draft, the problem is usually depressurization. If this additional air doesn't improve draft, inspect the chimney. The chimney may be obstructed, undersized, oversized, or leaky.

Improvements to Solve CAZ Depressurization

This list of duct improvements may solve draft problems discovered during the previous tests on a forced air heating system.

1. Seal all return duct leaks near the furnace.
2. Isolate the CAZ from return registers by air-sealing the CAZ from the zone containing the return register.
3. Reduce depressurization from exhaust appliances.

These two suggestions may reduce depressurization caused by the home's exhaust appliances.

1. Isolate combustion appliances from exhaust fans and clothes dryers by air sealing between the CAZ and zones containing these exhaust devices.
2. Provide make-up air for dryers and exhaust fans and/or provide combustion air inlet(s) to combustion zone. *See page 259.*

Table 7-3: Draft Problems and Solutions

Problem	Possible Solutions
Adequate draft never established	Remove chimney blockage, seal chimney air leaks, or provide additional combustion air as necessary.
Blower activation weakens draft	Seal leaks in the furnace and in nearby return ducts. Isolate the furnace from nearby return registers.
Exhaust fans weaken draft	Provide make-up or combustion air if opening a door or window to outdoors improves draft during testing.

Chimney Improvements to Solve Draft Problems

Suggest the following chimney improvements to solve draft problems uncovered during the previous testing.

1. Remove chimney obstructions.
2. Repair disconnections or leaks at joints and where the vent connector joins a masonry chimney.
3. Measure the size of the vent connector and chimney and compare to vent-sizing information listed in Chapter 13 of the *National Fuel Gas Code (NFPA 54)*. A vent connector or chimney liner that is either too large or too small can reduce draft.
4. If wind interferes with draft, install a wind-dampening chimney cap.
5. If the masonry chimney is corroded, install a new chimney liner.
6. Increase the pitch of horizontal sections of vent.

7.1.5 Zone Isolation Testing for Atmospherically Vented Appliances

An isolated CAZ improves the safety of atmospherically vented appliances. The CAZ is isolated if it receives combustion air only from outdoors. An isolated CAZ doesn't require worst-case depressurization and spillage tests. However you should inspect the CAZ for connections with the home's main zone and make sure it is isolated.

1. Look for connections between the isolated CAZ and the home. Examples include joist spaces, transfer grills, leaky doors, and holes for ducts or pipes.
2. Measure a base pressure from the CAZ to outdoors.
3. Perform 50-pascal blower door depressurization test. The CAZ-to-outdoors pressure should not change more than 5 pascals during the blower door test. *See "Bedroom test" on page 89.*
4. If the CAZ-to-outdoors pressure changed more than 5 pascals, air-seal the zone, and retest as described in steps 2 and 3.
5. If you can't air-seal the CAZ adequately to isolate the zone, solve worst-case depressurization and spillage problems as described in *"Improving CAZ Depressurization and Draft" on page 210*.

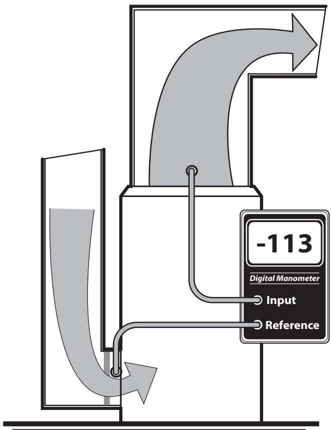
7.2 Heating System Replacement

This section discusses replacing combustion furnaces or boilers. After that we'll discuss the fuel issues of gas versus oil.

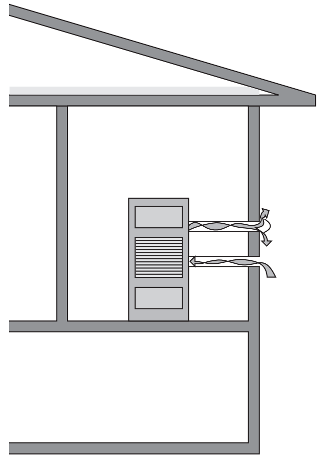
7.2.1 Combustion Furnace Replacement

This section discusses air handlers of combustion furnaces. Successful furnace replacement requires selecting the right furnace, making repairs to ducts and other remaining components, and testing to verify that the new furnace operates correctly.

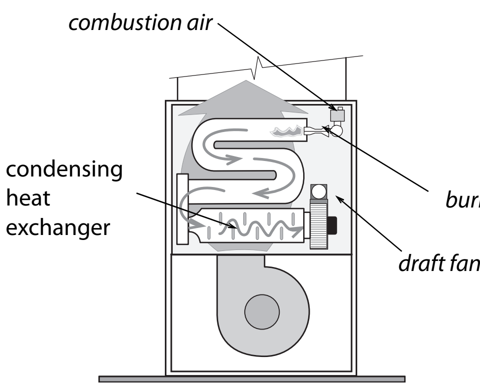
1. Follow all manufacturer's installation instructions.
2. Measure the building to determine the correct size of the furnace, using a method such as Manual J.
3. Verify that all accessible ducts were sealed as part of the furnace's installation, including the air handler, the plenums, and the branch connections.
4. If flue-gas temperature or supply air temperature are unusually high, check static pressure and fuel input. *See "Ducted Air Distribution" on page 263.*
5. Filters should be held firmly in place and provide complete coverage of blower intake or return register. Filters should not permit air to bypass the filter and the filters must be easy to replace.
6. Attach the manufacturer's literature including, operating manual and service manual, to the furnace.

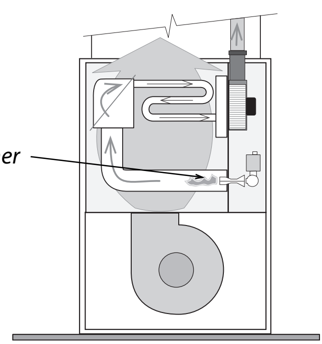


Static pressure and temperature rise: Measure static pressure and temperature rise across the new furnace to verify that the duct system isn't restricted. The correct airflow, specified by the manufacturer, is necessary for high efficiency.



Sealed combustion heaters: Sealed-combustion furnaces prevent the air pollution and house depressurization caused by some open-combustion furnaces.





90+ Gas furnace: A 90+ furnace has a condensing heat exchanger and a stronger draft fan for pulling combustion gases through its more restrictive heat exchanger and establishing a strong positive draft.

80+ Gas furnace: An 80+ furnace has a restrictive heat exchanger and draft fan, but has no draft diverter and no standing pilot light.

Supporting Air Handlers

Support the new air handlers using these specifications.

1. Support horizontal air handlers from below with a non-combustible, water-proof, and non-wicking material. Or support the horizontal air handler with angle iron and threaded rod from above.
2. Support upflow air handlers with a non-flammable material from below when necessary to hold it above a damp basement floor.
3. Support downflow air handlers with a strong, airtight supply plenum. Insulate this supply plenum with rigid duct insulation on the exterior of the plenum.

7.2.2 Gas-Fired Heating Installation

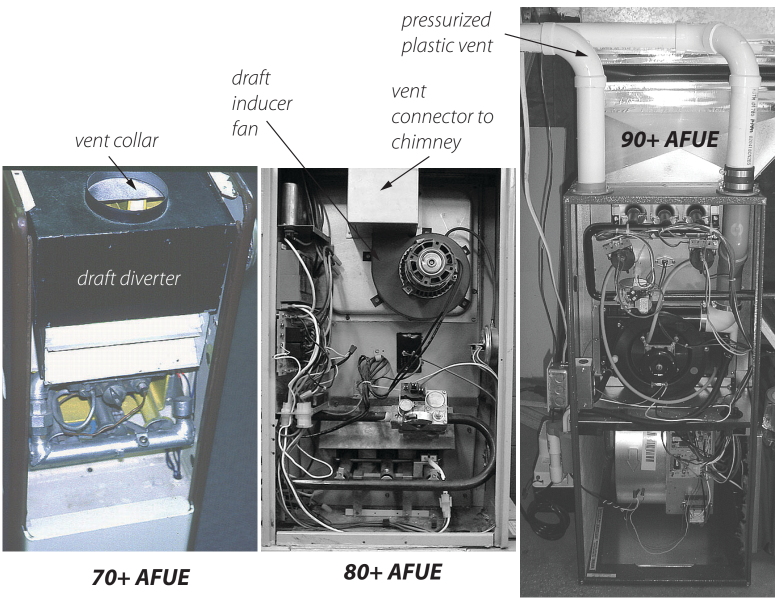
The goal of appliance replacement is to save energy and provide safe heating. The heating replacement project should produce a gas-fired heating system in virtually new condition, even though existing components like the gas lines, chimney, or ducts may remain. Include maintenance or repair on these remaining components as part of the installation. Analyze design defects in the original system and correct the defects during the heating system's replacement. Follow manufacturer's installation instructions.

1. If budget allows, select a 90+ AFUE furnace, and install it as a sealed-combustion (direct vent) unit.
2. Non-condensing furnaces with a minimum AFUE of 80% may be installed if the 90% replacement furnace isn't cost-effective or there isn't any place to drain the condensing furnace's condensate.
3. Install new gas-fired furnaces with adequate clearances to allow maintenance.

4. Follow manufacturer's venting instructions along with the NFPA 54 to install a proper venting system. *See "Inspecting Venting Systems" on page 248.*

5. Check clearances of the heating unit and its vent connector to nearby combustibles, according to the National Fuel Gas Code (NFPA 54). *See page 248.*

6. Clock gas meter to measure gas input and adjust gas input if necessary. *See page 375.*



Gas furnace evolution: Energy auditors should be able to identify the 3 types of gas and propane furnaces. Only the 90+ AFUE furnace has a pressurized vent. The two earlier models vent into traditional atmospheric chimneys.

Testing New Gas-Fired Heating Systems

7. Do a combustion test, and adjust fuel-air mixture to minimize O_2. However don't increase CO with this adjustment.

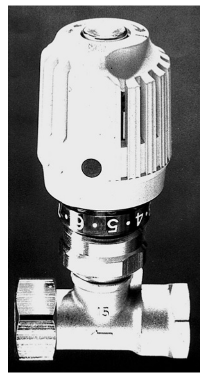
8. Measure CO in the new venting system. *See pages 204 and 225.*

9. Verify that the gas water heater vents properly after installation of a sealed-combustion, 90+ AFUE furnace. Install a chimney liner if necessary to improve the water heater's venting.

7.2.3 Combustion Boiler Replacement

Technicians replace boilers as an energy-conservation measure or for health and safety reasons. A boiler's seasonal efficiency is more sensitive to correct sizing than is a furnace's efficiency.

Boiler piping and controls present many options for zoning, boiler staging, and energy-saving controls. Dividing homes into zones, with separate thermostats, can significantly improve energy efficiency compared to operating a single zone. Modern hydronic controls can provide different water temperatures to different zones with varying heating loads.

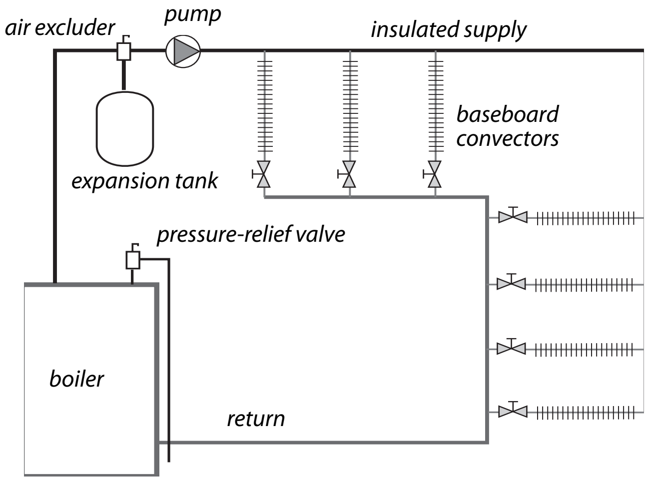


Radiator temperature control: RTCs work well for controlling room temperature, especially in overheated rooms.

Follow these specifications when recommending a replacement boiler.

1. Follow the manufacturer's installation instructions.
2. Verify an accurate sizing calculation for the new boiler, taking into account weatherization work that reduced the heating load serviced by the previous boiler. (Boilers are sized according to the installed radiation surface connected to them. The radiators are sized according to room heat loss.)
3. Specify radiator temperature controls for areas with a history of overheating.

4. A functioning pressure-relief valve rated at 30psi, expansion tank, air-excluding device, back-flow preventer, low-water cutoff, and an automatic fill valve must be part of the new hydronic system.
5. Suggest that the pump be installed near the downstream side of the expansion tank to prevent the suction side of the pump from depressurizing the piping, which can pull air into the piping system.
6. The expansion tank should be replaced, unless it is verified to be the proper size for the new system and adjusted for correct pressure during boiler installation. *See page 287.*
7. Verify that return-water temperature is above 130° F for gas and above 150° F for oil, to prevent acidic condensation within the boiler, unless the boiler is designed for condensation. Install piping bypasses, mixing valves, primary-secondary piping, or other strategies, as necessary, to prevent condensation within a noncondensing boiler.
8. Verify that flue-gas oxygen and temperature are within the ranges specified in *Table 7-5 on page 231.*

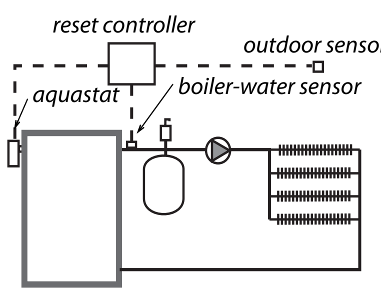


Simple reverse-return hot-water system: The reverse-return method of piping is the simplest way of balancing flow among the heat emitters.

9. Maintaining a low-limit boiler-water temperature is wasteful. Boilers should be controlled for a cold start, unless the boiler is used for domestic water heating.

10. Verify that all supply piping is insulated with foam or fiberglass pipe insulation if located in unconditioned space.

11. Extend new piping and radiators to conditioned areas, like additions and finished basements, which are currently heated by space heaters.



Reset controller: This control adjusts circulating-water temperature depending on the outdoor temperature.

12. For large boilers, install reset and cut-out controllers that adjust supply water

temperature according to outdoor temperature and prevent the boiler from firing when the outdoor temperature is above a setpoint where heat isn't needed.

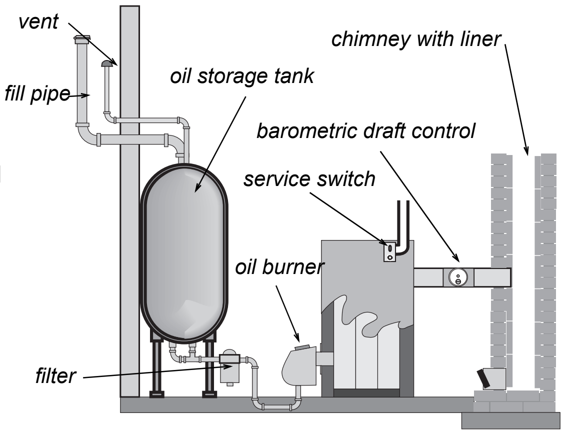
13. Verify that the chimney was inspected and upgraded if necessary. This important task is sometimes neglected.

7.2.4 Oil-Fired Heating Installation

The goal of the system replacement is to save energy and provide safer, more reliable heating. System replacement should provide an oil-fired heating system in virtually new condition, even though components like the oil tank, chimney, piping, or ducts may remain in place. Any maintenance or repair for these remaining components should be part of the job. Any design defects of the original system should be analyzed and corrected during the heating-system replacement.

1. Follow the manufacturer's installation instructions.
2. New oil-fired furnaces should have an AFUE of 83%.
3. New oil-fired furnaces should be installed with adequate clearances to facilitate maintenance.
4. Inspect the existing chimney and the vent connector for usability as a vent for the new appliance. The vent connector may need to be re-sized, and the chimney may need to be re-lined.

Oil heating system: Components of an oil heating system may need repair and cleaning during replacement of the furnace.



5. Inspect the clearances between the vent connector and nearby combustibles. See *"Clearances to Combustibles for Vent Connectors" on page 251.*

6. Install a new fuel filter and purge the fuel lines as part of the new installation.

7. Inspect the oil tank and remove dirt at bottom of the tank.

8. Verify that the oil tank and oil lines comply with NFPA 31.

9. Verify that a working emergency shut-off is installed in the living space.

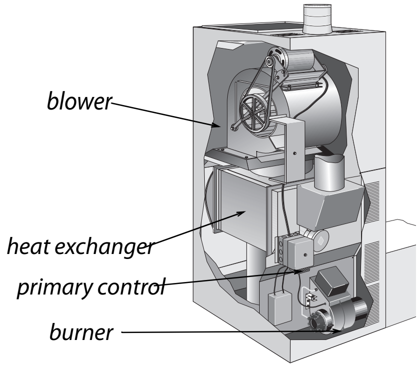
Testing New Oil-Fired Heating Systems

10. Look for a control that interrupts power to the burner in the event of a fire.

11. Measure oil pressure.

12. Look for the oil nozzle's gallon-per-minute (gpm) rating.

13. Adjust oil pressure or replace nozzle as necessary to produce the correct input. Verify the input from oil pressure and nozzle gpm, using the nozzle manufacturer's data.



Oil-fired downflow furnaces: Their design hasn't changed much in recent years except for the flame-retention burner.

14. Verify the correct spray angle and spray pattern.

15. Measure the transformer voltage to verify that it complies with the manufacturer's specifications.

16. Measure the control circuit amperage, and adjust the thermostat's heat anticipator to match the amperage. Or, read the thermostat manufacturer's instructions for adjusting cycle length.

17. Adjust oxygen, flue-gas temperature, and smoke number to match manufacturer's specifications or specifications given here. Smoke number should be zero on all modern oil-fired equipment.

Evaluating Oil Tanks

Oil tanks are now almost always installed above ground. But many old oil tanks are still buried. Inspect above-ground tanks to find leaks. Below-ground tanks and above-ground tanks can both be evaluated by tests for water in the fuel system.

1. Start by inspecting the oil filter for corrosion. Corrosion in the oil filter indicates a high probability of water and corrosion in the tank.

2. Next use water-finding paste, applied to the end of a probe, to detect water at the bottom of the oil tank. For indoor tanks, you'll need a flexible probe because of the ceiling-height limitations.

See also NFPA 31 Chapter 7 Fuel Oil Tanks.

Inspecting Above-Ground Oil Tanks

Indoor oil leaks are usually accompanied by petroleum smells. Inspect the oil tank as well as all the oil piping between the oil tank and the oil-fired furnace.

1. Look for different colors on the tank from condensation, corrosion, or fuel leaks.
2. Look at the bottom of the oil tank and see if oil is dripping from a leak.
3. Look for patches from previous leaks.
4. If the oil tank is new, don't mistake previous oil-tank leaks for leaks in the new tank.
5. Use the water test described previously.

If you smell oil but you can't see the leak, consider the following tests.

1. Use the water test described previously.
2. For hidden leaks, consider ultrasound leak detection by a oil-tank specialist.

Advice for Below-Ground Oil Tanks

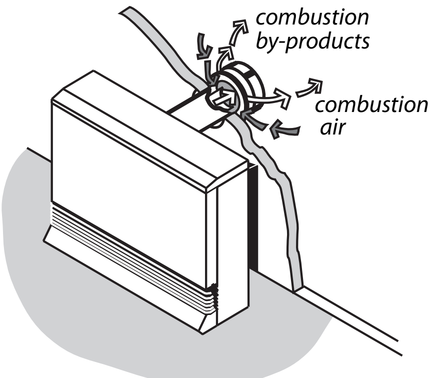
Leaky below-ground oil tanks are a financial problem and a major environmental problem. Local, state, or federal authorities may require homeowners to remove the tank, abandon it in place, or have it leak-tested by one of the following methods.

1. Use the water testing described previously.

2. A tank specialist collects multiple soil samples from around the tank and analyzes them for petroleum contamination by an approved method.

7.3 Gas Space Heater Replacement

Space heaters are inherently more efficient than central heaters, because they have no ducts or distribution pipes. For airtight and well-insulated homes, space heaters are a more practical option for heating the whole home.



Sealed-combustion space heater: Sealed-combustion space heaters draw combustion air in, using a draft fan.

Space heater controls: Many modern energy-efficient space heaters have programmable thermostats as a standard feature.

Weatherization agencies replace space heaters as an energy-conservation measure or for health and safety reasons. Use the highest efficiency space heater available. Inspect existing space heaters for health and safety problems.

1. Follow the manufacturer's installation instructions.
2. Follow manufacturer's venting instructions carefully. Don't vent sealed-combustion or induced-draft space heaters into naturally drafting chimneys.
3. Verify that flue-gas oxygen and temperature are within the ranges specified in *Table 7-5 on page 231.*

4. If the space heater sits on a carpeted floor, install a fire-rated floor protector.
5. Install the space heater away from traffic, draperies, and furniture.
6. Provide the space heater with a correctly grounded duplex receptacle for its electrical service.

7.3.1 Space Heater Operation

Inform the customer of the following operating instructions.

1. Don't store any objects near the space heater that would restrict airflow around it.
2. Don't use the space heater to dry clothes or for any purpose other than heating the home.
3. Don't allow anyone to lean or sit on the space heater.
4. Don't spray aerosols near the space heater. Many aerosols are flammable or can cause corrosion to the space heater's heat exchanger.

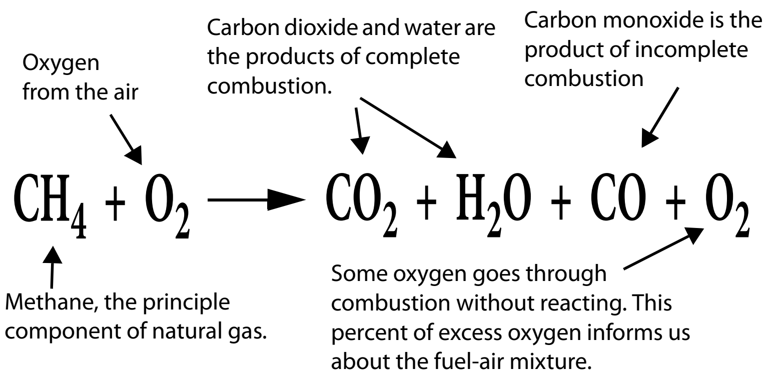
7.3.2 Unvented Space Heaters

Unvented space heaters include ventless gas fireplaces and gas logs installed in fireplaces previously designed for wood-burning or coal-burning. These unvented space heaters create indoor air pollution because they deliver all their combustion byproducts to the indoors. Unvented space heaters aren't safe. Replace them with vented space heaters or electric space heaters.

DOE forbids unvented space heaters as primary heating units in weatherized homes.

7.4 Electronic Combustion Analysis

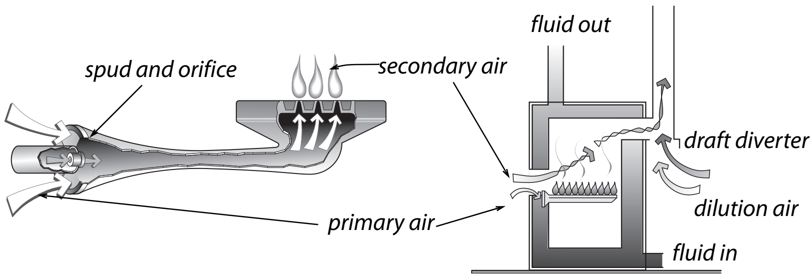
The goal of a combustion analysis is to quickly analyze combustion and heat exchange. When the furnace reaches steady-state efficiency (SSE), you can measure its most critical operating parameters. The furnace reaches SSE when the stack temperature becomes stable and doesn't rise 2°F within one minute. This information can save you time and unnecessary maintenance procedures.



Modern flue-gas analyzers measure O_2, CO, and flue-gas temperature. The better models also measure draft. Flue-gas analyzers also calculate combustion efficiency or steady-state efficiency (SSE).

A common combustion-efficiency problem is low fuel input and high O_2, which produce ineffective heat transfer. This condition can only be detected by combustion analysis. Adjust the fuel-air mixture to save 2–8% of the heater's fuel consumption.

Flue-gas temperature is another important indicator of combustion efficiency. A low flue-gas temperature is usually an indicator of efficient performance. However, if the flue-gas temperature is too low in traditional furnaces and boilers, acidic condensation forms in the vent or even inside the heat exchanger. This acidic condensation can corrode metal vents, metal heat exchangers, and masonry chimneys.



Atmospheric, open combustion gas burners: Combustion air comes from the indoors in open combustion appliances. These burners use the heat of the flame to pull combustion air into the burner. Dilution air, entering at the draft diverter, prevents overfire draft from becoming excessive.

70+ Furnace: Sample flue gases within the draft diverter inside each exhaust port.

80+ Furnace: Measure draft and sample flue gases in the vent connector above the furnace.

7.4.1 Combustion Efficiency Test for Furnaces

Perform the following procedures at steady-state efficiency (SSE) to verify a furnace's correct operation.

1. Perform a combustion test using a electronic flue-gas analyzer. Recommended flue-gas temperature depends on the type of furnace and is listed in the table titled, *"Combustion Standards for Gas Furnaces" on page 231*.
2. Measure temperature rise (supply minus return temperatures). Temperature rise should be within the manufacturer's specifications for a furnace or boiler.
3. If O_2 is high, or the estimated output from the table is low, increase gas pressure to 6% O_2 if possible as long as you don't create CO.
4. Increase gas pressure if needed to increase temperature rise and flue-gas temperature.

If you know the airflow through the furnace from measurements described in *"Ducted Air Distribution" on page 263*, you can use the table, *"Gas-Furnace Output from Temperature Rise and Airflow (1000s BTUH)" on page 230*, to check whether output is approximately what the manufacturer intended. Dividing this output by measured input from *"Inspecting Gas Combustion Systems" on page 234* gives you another check on the steady-state efficiency.

Troubleshooting Temperature Rise

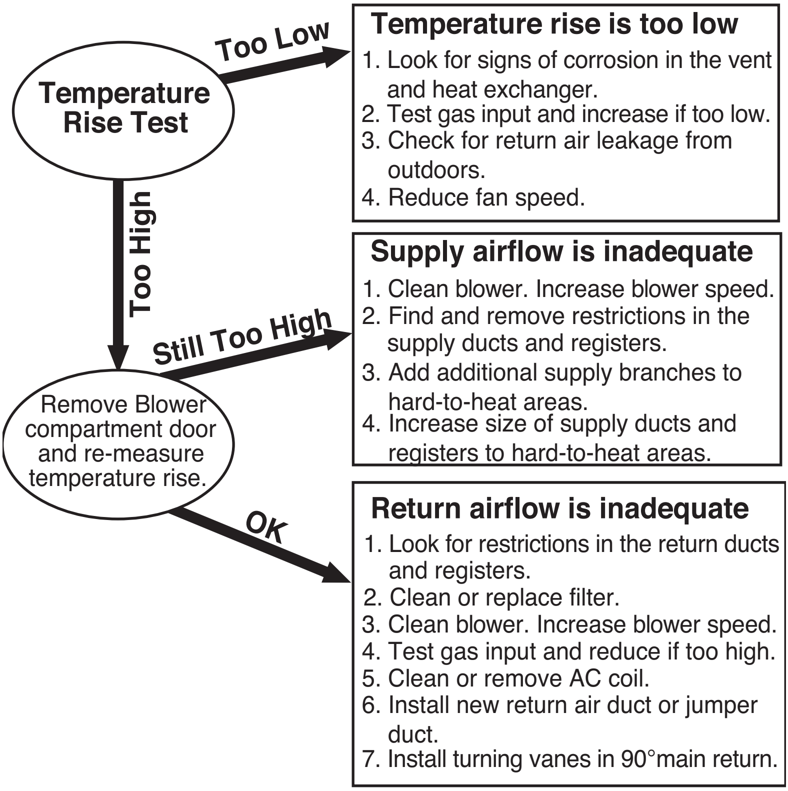


Table 7-4: Gas-Furnace Output from Temperature Rise and Airflow (1000s BTUH)

CFM	Temperature Rise (Supply F° – Return F°)					
	30	**40**	**50**	**60**	**70**	**80**
600	19.4	25.9	32.4	38.9	45.4	51.8
700	22.7	30.2	37.8	45.4	52.9	60.5
800	25.9	34.6	43.2	51.8	60.4	69.1
900	29.2	38.9	48.6	58.3	68.0	77.8
1000	32.4	43.2	54.0	64.8	75.6	86.4
1100	35.6	47.5	59.4	71.3	83.2	95.0
1200	38.9	51.8	64.8	77.8	90.7	103.7
1300	42.1	56.2	70.2	84.2	98.3	112.3
1400	45.4	60.5	75.6	90.7	105.8	121.0
1500	48.6	64.8	81.0	97.2	113.4	129.6

Table 7-5: Combustion Standards for Gas Furnaces

Performance Indicator	SSE 70+	SSE 80+	SSE 90+
Carbon monoxide (CO) (ppm)	<100 ppm	<100 ppm	<100 ppm
Stack temperature (°F)	350°–475°	325°–450°	<120°
Temperature rise (°F)	40–70°*	40–70°*	30–70°*
Oxygen (%O2)	5–10%	4–9%	4–9%
Natural gas pressure inches water column (IWC)	3.2–4.2 IWC*	3.2–4.2 IWC*	3.2–4.2 IWC*
LP gas pressure	10–12 IWC	10–12 IWC	10–12 IWC
Steady-state efficiency (SSE) (%)	72–78%	78–82%	92–97%
Draft (Pa)	–5 Pa	–5 Pa	+25–60 Pa

* pmi = per manufacturer's instructions
Use these standards also for boilers except for temperature rise.

Table 7-6: Carbon Monoxide Causes and Solutions

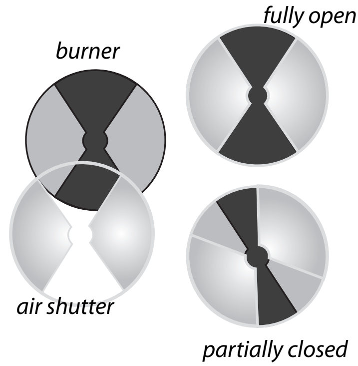
Cause	Analysis & Solution
Flame smothered by combustion gases.	Chimney backdrafting from CAZ depressurization or chimney blockage.
Burner or pilot flame impinges.	Align burner or pilot burner. Reduce gas pressure if excessive.
Inadequate combustion air with too rich fuel-air mixture.	O_2 is <6%. Gas input is excessive or combustion air is lacking. Reduce gas or add combustion air.
Blower interferes with flame.	Inspect heat exchanger. Replace furnace or heat exchanger.
Primary air shutter closed.	Open primary air shutter.
Dirt and debris on burner.	Clean burners.
Excessive combustion air cooling flame.	O_2 is >11%. Increase gas pressure.

Table 7-7: Combustion Problems and Possible Solutions

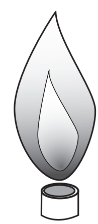
Problem	Possible causes and solutions
Weak draft with CAZ depressurization	Supply duct leaks, clothes dryer, exhaust fans, other combustion vents. Seal return leaks. Isolate CAZ. Provide make-up air.
Weak draft with no CAZ depressurization	Chimney or vent connector is blocked, leaky, incorrectly sized, or has inadequate slope. Or else CAZ is too airtight.
Carbon monoxide	Mixture too rich or too lean. Adjust gas pressure. Check chimney and combustion air for code compliance.
Stack temperature or temperature rise too high or low	Adjust fan speed or gas pressure. Improve ducts to increase airflow.
Oxygen too high or low	Adjust gas pressure, but don't increase CO level.

7.4.2 Critical Combustion-Testing Parameters

Here we discuss the most important operating parameters measured by a combustion analysis.



Primary-air adjustment: Primary-air shutters are usually fully open for natural gas combustion and partially closed for propane depending on flame characteristics. Too much primary air causes noise and flame lift-off. Too little air causes the flame, to reach out for air. A good flame is hard and blue with an inner and outer mantle.



Carbon monoxide (CO) (ppm): This poisonous gas indicates incomplete combustion. Adjusting combustion to produce less than 100 ppm is almost always possible with gas-pressure adjustments, primary-air adjustments, or burner maintenance. Combustion analyzers that measure oxygen can give an air-free CO measurement. The air-free CO measurement is higher than the CO measurement without correcting for O_2.

Oxygen (percent): Indicates the percent of excess air and whether fuel-air mixture is correct. Oxygen is directly related to steady-state efficiency. Percent O_2 may also clarify the cause of CO as either too little or too much combustion air.

Flue-gas temperature: Flue-gas temperature is an important heat-exchange measurement. Flue-gas temperature helps to determine steady-state efficiency. Excessive flue-gas temperature wastes energy and insufficient flue-gas temperature leads to condensation and inadequate draft.

Airflow (furnaces): The current furnace airflow and the likelihood of being able to increase it are very important to determine. During testing, airflow is artificially increased and the effect on flue-gas temperature and temperature rise is observed. Measuring airflow also allows you to measure furnace output fairly accurately so you can compare it to output as listed on the furnace nameplate.

7.5 Inspecting Gas Combustion Systems

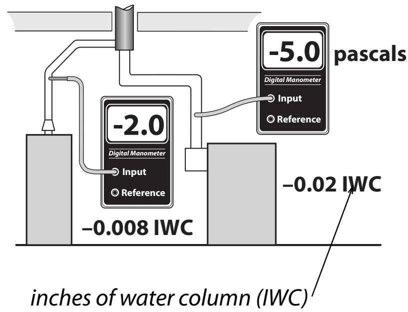
Gas burners should be inspected and maintained during a service call. These following specifications apply to gas furnaces, water heaters, and space heaters.

Perform the following inspection procedures and maintenance practices on all gas-fired furnaces, boilers, water heaters, and space heaters, as necessary. The goal of these measures is to reduce carbon monoxide (CO), stabilize flame, and verify the operation of safety controls.

1. Look for soot, melted wire insulation, and rust in the burner and manifold inside and outside the burner compartment. These signs indicate flame roll-out, combustion gas spillage, CO, and incomplete combustion.
2. Inspect the burners for dust, debris, misalignment, flame-impingement, and other flame-interference problems. Clean, vacuum, and adjust as needed.
3. Inspect the heat exchanger for leaks.
4. Verify that furnaces and boilers have dedicated circuits with fused safety shutoffs near the appliance. Verify that all 120-volt wiring connections are enclosed in covered electrical boxes.
5. Verify that pilot is burning (if equipped) and that main burner ignition is satisfactory.

6. Check venting system for proper diameter and pitch. *See page 248.*

7. Check venting system for obstructions, blockages, or leaks.



Measuring draft: Measure chimney draft *downstream* of the draft diverter.

8. Observe flame characteristics if soot, CO, or other combustion problems are present. Flames should be blue and well shaped. If flames are white or yellow, the burner may suffer from faulty combustion.

9. If you measure CO, open a window while observing CO level on the meter to see if CO is reduced by increasing the available combustion air through the open window. *See page 259.*

10. For programmable thermostats, read the manufacturer's instructions about how to control cycle length. These instructions may be printed inside the thermostat.

Burner Cleaning and Adjustment

Clean and adjust the burner if any of these conditions exists.

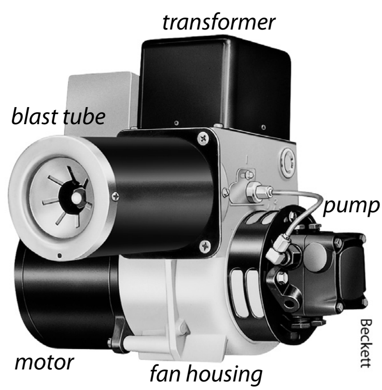
1. CO is greater than 100 ppm as measured or 200 ppm air-free measurement.
2. Visual indicators of soot or flame roll-out exist.
3. Burners are visibly dirty.
4. Measured draft is inadequate. *See page 248.*
5. The appliance has not been serviced for two years or more.

Gas-burner and gas-venting maintenance should include the following measures.

1. Remove causes of CO and soot, such as over-firing, closed primary air intake, flame impingement, and lack of combustion air.
2. Remove dirt, rust, and other debris that may be interfering with the burners. Clean the heat exchanger if there are signs of soot around the burner compartment.
3. Take action to improve the draft if it is inadequate because of improper venting, obstructed chimney, leaky chimney, or depressurization. *See page 210.*
4. Seal leaks in vent connectors and chimneys.
5. Adjust gas input if combustion testing indicates overfiring or underfiring.

7.6 Oil Burner Safety and Efficiency Service

Oil burners require annual maintenance to maintain acceptable safety and combustion efficiency. Use combustion analysis to evaluate the oil burner and to guide adjustment and maintenance. These procedures apply to oil-fired furnaces, boilers, and water heaters.

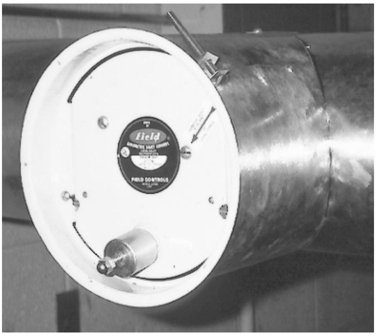


7.6.1 Oil Burner Inspection

Use visual inspection and combustion testing to evaluate oil burner operation. An oil burner that passes visual inspection and complies with the specifications on *page 239* may need no maintenance. If the test results are slightly out of preferred range, ask a qualified technician to adjust the burner. Unsatisfactory test results may indicate the need to replace the burner or the entire heating unit.

The energy auditor can inspect and specify professional service if required.

1. Verify that each oil furnace or boiler has a dedicated electrical circuit. Assure that all 120-volt wiring connections are enclosed in covered electrical boxes.
2. Verify that all oil-fired heaters are equipped with a barometric draft control, unless they have high-static burners or are mobile home furnaces.
3. Assure that barometric draft controls are mounted plumb and level and that the damper swings freely.



Barometric draft control: This control provides a stable overfire draft and controlled flow of combustion gases through the heat exchanger.

4. Inspect burner and appliance for signs of soot, overheating, fire hazards, corrosion, or wiring problems.
5. Inspect fuel lines and storage tanks for leaks.
6. Inspect heat exchanger and combustion chamber for cracks, corrosion, or soot buildup.
7. Check to see if flame ignition is instantaneous or delayed. Flame ignition should be instantaneous, except for pre-purge units with delayed oil valves where the blower runs for a while before ignition.

7.6.2 Oil Burner Testing

Combustion testing is the key to a technician's understanding the current oil burner performance level and potential for improvement. Specify that oil-heating technicians perform the following tasks as part of an oil burner tune-up.

1. Sample the undiluted flue gases with a smoke tester, after reading the smoke tester instructions. Compare the smoke smudge left by the gases on the filter paper with the manufacturer's smoke-spot scale to find the smoke number.
2. Analyze the flue gas for O_2, temperature, CO, and steady-state efficiency (SSE). Sample undiluted flue gases between the barometric draft control and the appliance.
3. Measure flue draft between the appliance and barometric draft control.
4. Measure the overfire draft over the fire inside the firebox.

Table 7-8: Minimum Oil Burner Combustion Standards

Oil Combustion Performance Indicator	Non Flame Retention	Flame Retention
Oxygen (% O_2)	4–9%	4–7%
Stack temperature (°F)	350°–600°	325°-500°
Carbon monoxide (CO) parts per million (ppm)	≤100 ppm	≤ 100 ppm
Steady-state efficiency (SSE) (%)	≥ 75%	≥ 80%
Smoke number (1–9)	≤ 2	≤ 1
Excess air (%)	≤ 100%	≤ 25%
Oil pressure pounds per square inch (psi)	≥ 100 psi	≥ 100-150 psi (pmi)*
Overfire draft (IWC negative)	–5 Pa. or –.02 IWC	–5 Pa. or –.02 IWC
Flue draft (IWC negative)	–10 to 25 Pa. or –0.040 to –0.1IWC	–10 to 25 Pa. or –0.04 to –0.1IWC

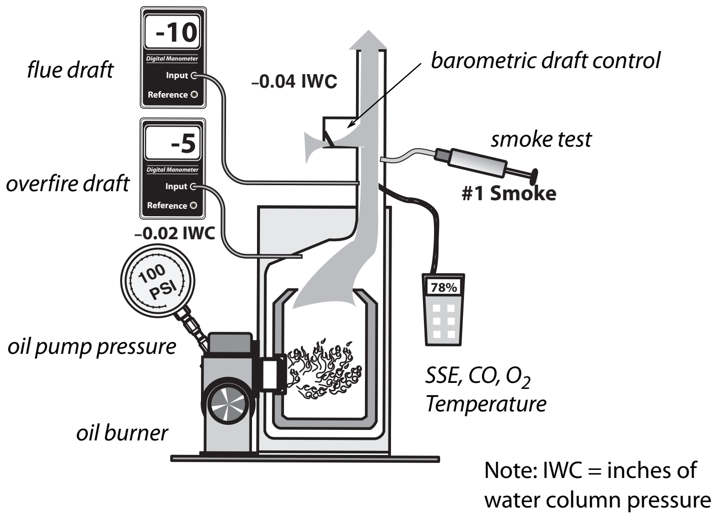
* pmi = per manufacturer's specifications

Table 7-9: Typical Safe Draft for Oil Fired Appliances

	Outdoor Temperature (Degrees F)				
Appliance	<20	21-40	41-60	61-80	>80
Oil-fired furnace, boiler, or water heater with atmospheric chimney	-15 Pa. -0.06 IWC	-13 Pa. -0.053 IWC	-11 Pa. -0.045 IWC	-9 Pa. -0.038 IWC	-7 Pa. -0.030 IWC

5. Measure the high limit shut-off temperature and adjust or replace the high limit control if the shut-off temperature is more than 200° F for furnaces, or 220° F for hot-water boilers.

6. Measure the oil pump pressure, and adjust it to manufacturer's specifications if necessary.
7. Measure the transformer voltage, and adjust it to manufacturer's specifications if necessary.
8. Time the flame sensor control or stack control to verify that the burner shuts off, within either 45 seconds or a time specified by the manufacturer, when the cad cell is blocked from seeing the flame.



Measuring oil-burner performance: To measure oil-burning performance indicators, a manometer, flue-gas analyzer, smoke tester, and pressure gauge are required.

7.6.3 Oil Burner Adjustment

Both combustion air and draft are adjustable with most oil burners. Specify the following maintenance tasks according to your inspection.

1. Replace the burner nozzle after matching the nozzle's size to the home's heat load. However don't reduce the nozzle's size by more than 20%.

2. Verify the correct spray angle and spray pattern.
3. Set the oil pump to the correct pressure.
4. Adjust the air shutter to achieve the oxygen and smoke values, specified in *Table 7-8 on page 239.*
5. Adjust the barometric damper for a negative flue draft of 5–10 pascals or 0.02-to-0.04 IWC (before barometric damper).
6. Adjust the airflow or the water flow to reduce high flue-gas temperature if possible, but don't reduce flue-gas temperature below 350°F.
7. Adjust the electrode gap and angle for proper alignment.
8. Check for the proper type fire ring of the flame-retention burner is appropriate for the size of the combustion chamber.
9. Measure the transformer voltage to verify that it complies with the manufacturer's specifications.
10. Measure the control-circuit amperage. Adjust the thermostat's heat anticipator to match the amperage, or read the thermostat manufacturer's instructions for adjusting cycle length.
11. Adjust oxygen, flue-gas temperature, and smoke number to match manufacturer's specifications or specifications given here. Smoke number should be zero on all modern oil-fired equipment.

7.6.4 Oil Burner Maintenance and Visual Checks

After evaluating the oil burner's operation, specify some or all of these maintenance tasks as necessary, to optimize safety and efficiency.

1. Clean the burner's blower wheel.

2. Clean dust, dirt, and grease from the burner assembly.
3. Replace oil filter(s) and nozzle.
4. Clean or replace air filter.
5. Remove soot from combustion chamber.
6. Remove soot from heat exchange surfaces.
7. Adjust gap between electrodes to manufacturer's specs.
8. Repair the ceramic combustion chamber, or replace it if necessary.
9. Verify correct flame sensor operation.

After these maintenance procedures, the technician carries out the diagnostic tests described previously to evaluate improvement made by the maintenance procedures and to determine if more adjustment is required.

7.7 Inspecting Furnace Heat Exchangers

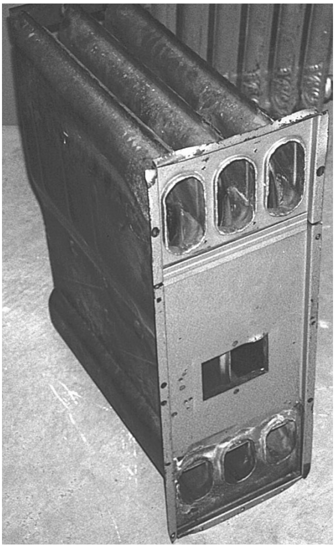
Leaks in heat exchangers are a common problem, causing the flue gases to mix with house air. Ask customers about respiratory problems, flue-like symptoms, and smells in the house when the heat is on. Also, check around supply registers for signs of soot, especially with oil heating. All furnace heat exchangers should be inspected as part of weatherization. Consider using one or more of these seven options for evaluating heat exchangers.

1. Look for rust at exhaust ports and vent connectors.
2. Look for flame-impingement on the heat exchanger during firing.
3. Observe flame movement, change in chimney draft, or change in CO measurement when blower is turned on or off.
4. Look for flame-damaged areas near the burner flame.

5. Measure the flue-gas oxygen concentration before the blower starts and then again just after the blower starts. There should be no more than a 1% change in the oxygen concentration.

6. Examine the heat exchanger by shining a bright light on one side and looking for light on the other side using a mirror to look into tight locations.

7. Employ chemical detection techniques, according to the manufacturer's instructions.



Furnace heat exchangers: Although no heat exchanger is completely airtight, it should not leak enough to display the warning signs described here.

7.8 Wood Stoves

Wood heating is a popular and effective auxiliary heating source for homes. However, wood stoves and fireplaces can cause indoor air pollution and fire hazards. It's important to inspect wood stoves to evaluate potential hazards.

7.8.1 Wood Stove Clearances

Stoves that are listed by a testing agency like Underwriters Laboratory have installation instructions stating their clearance from combustibles. Unlisted stoves must adhere to clearances specified in NFPA 211.

Look for metal tags on the wood stove that list minimum clearances. Listed wood stoves may be installed to as little as 6 inches away from combustibles, if they incorporate heat shields and combustion design that directs heat away from the back and sides.

Unlisted stoves must be at least 36 inches away from combustibles. Ventilated or insulated wall protectors may decrease unlisted clearance from one-third to two thirds, according to NFPA 211. Always follow the stove manufacturer's or heat-shield manufacturer's installation instructions.

Floor Construction and Clearances

The floor of a listed wood stove must comply with the specifications on the listing (metal tag). Modern listed stoves usually sit on a 1-inch thick non-combustible floor protector that extends 18 inches beyond the stove in front.

The type of floor underneath a unlisted wood stove depends on the clearance between the stove and the floor, which depends on the length of its legs. Unlisted wood stoves must have floor protection underneath them unless they rest on a floor of noncombustible construction. An example of a noncombustible floor is one composed of only masonry material sitting on dirt or gravel.

An approved floor protector is either one or two courses of hollow masonry material (4 inches thick) with a non-combustible quarter-inch surface of steel or other non-combustible material on top of the masonry. This floor for a non-listed wood stove must extend no less than 18 inches beyond the stove in all directions.

Vent-Connector and Chimney Clearance

Interior masonry chimneys require a 2-inch clearance from combustibles and exterior masonry chimneys require a 1-inch clearance from combustibles. All-fuel metal chimneys (insulated double-wall or triple wall usually require a 2- inch clearance from combustibles.

Single wall vent connectors must be at least 18 inches from combustibles. Wall protectors may reduce this clearance up to two-thirds. Double-wall stove-pipe vent connectors require a 9-inch clearance from combustibles or a clearance listed on the product.

See also *"Chimneys" on page 251* and *"Vent Connectors" on page 248*.

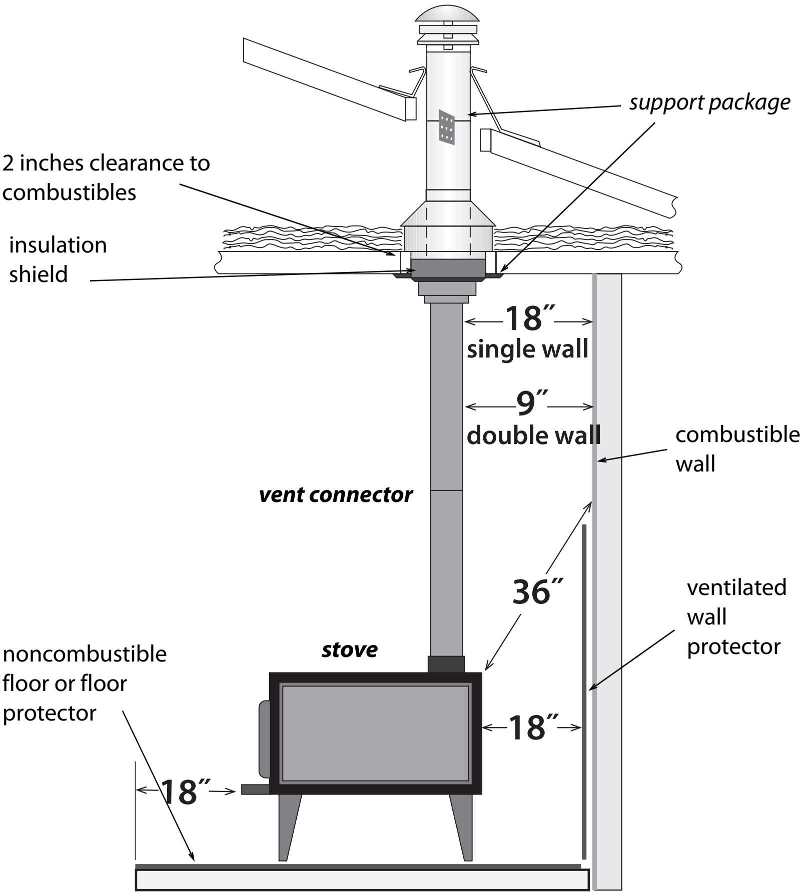
7.8.2 Wood Stove Inspection

All components of wood stove venting systems should be approved for use with wood stoves. Chimney sections penetrating floor, ceiling, or roof should have approved thimbles, support packages, and ventilated shields to protect combustible materials from high temperatures. The energy auditor should perform or specify the following inspection tasks.

1. Inspect stove, vent connector, and chimney for correct clearances from combustible materials as listed on stoves and vent assemblies or as specified in NFPA 211.
2. Each wood stove must have its own dedicated flue pipe. Two wood stoves may not share a single flue.
3. If the home is tight (<0.35 ACH), the wood stove should be equipped with a dedicated outdoor combustion-air duct.
4. Galvanized-steel pipe must not be used to vent wood stoves.
5. Inspect vent connector and chimney for leaks. Leaks should be sealed with a high temperature sealant designed for sealing wood stove vents.
6. Inspect chimney and vent connector for creosote build-up, and suggest chimney cleaning if creosote build-up exists.
7. Inspect the house for soot on seldom-cleaned horizontal surfaces. If soot is present, inspect the wood stove door gasket. Seal stove air leaks or chimney air leaks

with stove cement. Improve draft by extending the chimney to reduce indoor smoke emissions.

8. Inspect stack damper and/or combustion air intake.
9. Check catalytic combustor for repair or replacement if the wood stove has one.
10. Assure that heat exchange surfaces and flue passages within the wood stove are free of accumulations of soot or debris.
11. Wood stoves installed in mobile or manufactured homes must be approved for use in those homes.



Wood-stove installation: Wood-stove venting and clearances are vitally important for wood-burning safety. Read manufacturer's instructions for the stove and its venting components.

7.9 Inspecting Venting Systems

Combustion gases are vented through vertical chimneys or other types of approved horizontal or vertical vent piping. Identifying the type of existing venting material, verifying the correct size of vent piping, and making sure the venting conforms to the applicable codes are important tasks in inspecting and repairing venting systems. Too large a vent often leads to condensation and corrosion. Too small a vent can result in spillage. The wrong vent materials can corrode or deteriorate from heat.

NFPA Codes

The National Fire Protection Association (NFPA) publishes authoritative information on material-choice, sizing, and clearances for chimneys and vent connectors, as well as for combustion air. The information in this venting section is based on the following NFPA documents.

1. NFPA 54: The *National Fuel Gas Code 2006*
2. NFPA 211: *Standard for Chimneys, Fireplaces, Vents, and Solid Fuel Burning Appliances*
3. NFPA 211: *Standard for Chimneys, Fireplaces, Vents, and Solid-Fuel-Burning Appliance*s 2006

7.9.1 Vent Connectors

A vent connector connects the appliance's venting outlet with the chimney. Approved vent connectors for gas-fired units are made from the following materials.

1. Type-B vent, consisting of a galvanized steel outer pipe and aluminum inner pipe
2. Type-L vent connector with a stainless-steel inner pipe and a galvanized-steel outer pipe.
3. Double-wall stove-pipe vent connector with a stainless-steel inner pipe and a black-steel outer pipe.

4. Galvanized steel pipe: *See table.*

Table 7-10: Single-Wall Galvanized Vent Connector Thickness

Diameter of Vent Connector (inches)	Inches (gauge)
5 and smaller	0.022 (26 gauge)
6 to 10	0.028 (24 gauge)
11 to 16	0.034 (22 gauge)
Larger than 16	0.064 (16 gauge)

From *International Mechanical Code 2009*

Double-wall vent connectors are the best option, especially for appliances with some nonvertical vent piping. A double-wall vent connector helps maintain flue gas temperature and prevent condensation. Gas appliances with draft hoods, installed in attics or crawl spaces must use a Type-B vent connector. Type-L double-wall vent pipe is used for oil vent connectors.

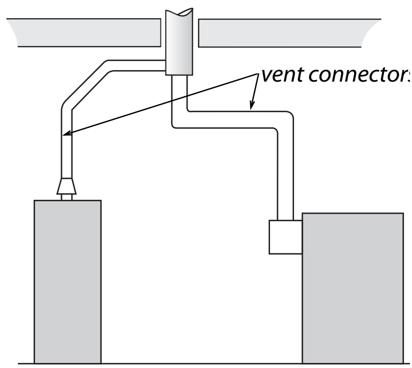
Verify that the installation complies with these specifications, concerning vent connectors.

1. Vent connectors must be as large as the vent collar on the appliances they vent.
2. Single wall vent-pipe sections must be fastened together with 3 screws or rivets.
3. Vent connectors must be sealed tightly where they enter masonry chimneys.
4. Vent connectors must be free of rust, corrosion, and holes.
5. The chimney combining two vent connectors should have a cross-sectional area equal to the area of the larger vent connector plus half the area of the smaller vent connector. This common vent should be no larger than 7 times the area of the smallest vent. For specific vent sizes, see the NFPA codes listed on *page 248*.

Table 7-11: Areas of Round Vents

Vent diameter	4"	5"	6"	7"	8"
Vent area (square inches)	12.6	19.6	28.3	38.5	50.2

6. The horizontal length of vent connectors shouldn't be more than 75% of the chimney's vertical height or have more than 18 inches horizontal run per inch of vent diameter.



Two vent connectors joining chimney: The water heater's vent connector enters the chimney above the furnace because the water heater has a smaller input.

7. Vent connectors must have upward slope to their connection with the chimney. NFPA 54 requires a slope of at least $^1/_4$ inch of rise per foot of horizontal run so that combustion gases rise through the vent. The slope prevents condensation from collecting in the vent and corroding it. *See "Clearances to Combustibles for Common Chimneys" on page 253.*

Table 7-12: Connector Diameter vs. Maximum Horizontal Length

Diameter (in)	3"	4"	5"	6"	7"	8"	9"	10"	12"	14"
Length (ft)	4.5'	6'	7.5'	9'	10.5'	12'	13.5'	15'	18'	21'

From *International Fuel Gas Code 2000*

8. When two vent connectors connect to a single chimney, the vent connector servicing the smaller appliance

should enter the chimney above the vent for the larger appliance.

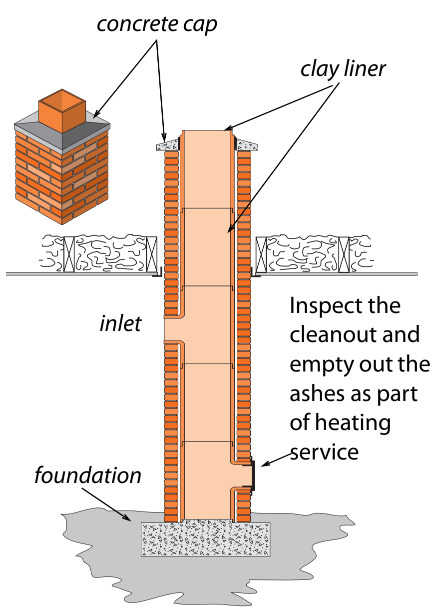
9. Clearances for common vent connectors are listed in the table shown here.

Table 7-13: Clearances to Combustibles for Vent Connectors

Vent Connector Type	Clearance
Single wall galvanized steel vent pipe	6" (gas) 18" (oil)
Type-B double wall vent pipe (gas)	1" (gas)
Type L double wall vent pipe	3" or as listed (oil)
Single-wall stove pipe	18" (wood)
Double-wall stove pipe	9" or as listed (wood)

7.10 CHIMNEYS

There are two common types of vertical chimneys for venting combustion fuels that satisfy NFPA and ICC codes. First there are masonry chimneys lined with fire-clay tile, and second there are manufactured metal chimneys, including all-fuel metal chimneys, Type-B vent chimneys for gas appliances, and Type L chimneys for oil appliances.



Masonry chimneys: Remain a very common vent for all fuels.

7.10.1 Masonry Chimneys

Verify that the following general specifications for building, inspecting, and repairing masonry chimneys.

1. A masonry foundation should support every masonry chimney.
2. Existing masonry chimneys should be lined with a fire-clay flue liner. There should be a $^1/_2$-inch to 1-inch air gap between the clay liner and the chimney's masonry to insulate the liner. The liner shouldn't be bonded structurally to the outer masonry because the liner needs to expand and contract independently of the chimney's masonry structure. The clay liner can be sealed to the chimney cap with a flexible high-temperature sealant.
3. Masonry chimneys should have a cleanout 12 inches or more below the lowest inlet. Clean mortar and brick dust out of the bottom of the chimney through the clean-out door, so that this debris won't eventually interfere with venting.
4. The chimney's penetrations through floors and ceilings should be sealed with sheet metal and high-temperature sealant as a firestop and air barrier.
5. Deteriorated or unlined masonry chimneys should be rebuilt as specified above or relined as part of a heating-system replacement or a venting-safety upgrade. Or, install a new metal chimney instead of repairing the existing masonry chimney.
6. The vertical chimney may also be replaced by a sidewall vent, equipped with a power venter mounted on the exterior wall. In this case, seal up the old chimney and take it out of service.

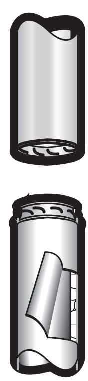
Table 7-14: Clearances to Combustibles for Common Chimneys

Chimney Type	Clearance
Interior chimney masonry w/ fireclay liner	2"
Exterior masonry chimney w/ fireclay liner	1"
All-fuel metal vent: insulated double-wall or triple-wall pipe	2"
Type B double-wall vent (gas only)	1"
Type L double-wall vent (oil)	3"
Manufactured chimneys and vents list their clearance	

7.10.2 Manufactured Chimneys

Manufactured metal chimneys have engineered parts that fit together in a prescribed way. Metal chimneys contain manufactured components from the vent connector to the termination fitting on the roof. Parts include: metal pipe, weight-supporting hardware, insulation shields, roof jacks, and chimney caps. One manufacturer's chimney may not be compatible with another's connecting fittings.

All-fuel chimneys (also called Class A chimneys) are used primarily for the solid fuels: wood and coal. All-fuel metal chimneys come in two types: insulated double-wall metal pipe and triple-wall metal pipe. Comply with the manufacturer's specifications when you install these chimneys.

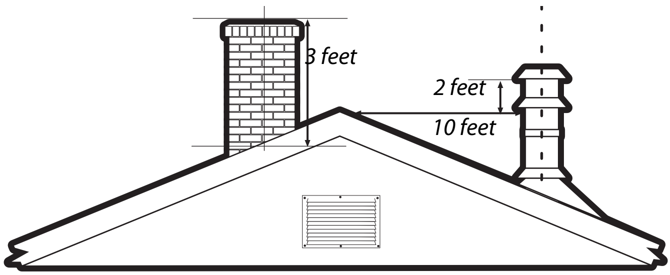


All-fuel metal chimney: These chimney systems include transition fittings, support brackets, roof jacks, and chimney caps. The pipe is double-wall insulated or triple-wall construction.

Type-B vent double-wall pipe is permitted as a chimney for gas appliances. Type BW pipe is manufactured for gas space heaters in an oval shape to fit inside wall cavities. Type L double-wall pipe is used for oil chimneys.

7.10.3 Chimney Terminations

Masonry chimneys and all-fuel metal chimneys should terminate at least three feet above the roof penetration and two feet above any obstacle within ten feet of the chimney outlet.



Chimney terminations: Should have vent caps and be given adequate clearance height from nearby building parts. These requirements are for both masonry chimneys and manufactured all-fuel chimneys.

B-vent chimneys can terminate as close as one foot above flat roofs and above pitched roofs up to a $^{6}/_{12}$ roof pitch. As the pitch rises, the minimum required termination height, as measured from the high part of the roof slope, rises as shown in this table.

Table 7-15: Roof Slope and B-Vent Chimney Height (ft)

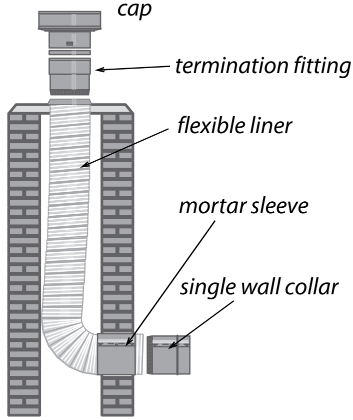
flat-6/12	6/12-7/12	7/12-8/12	8/12-9/12	9/12-10/12	10/12-11/12	11/12-12/12	12/12-14/12	14/12-16/12	16/12-18/12
1'	1' 3"	1' 6"	2'	2' 6"	3' 3"	4'	5′	6'	7'

From *National Fuel Gas Code 2009*

7.10.4 Metal Liners for Masonry Chimneys

Install or replace liners in unlined masonry chimneys or chimneys with deteriorated liners as part of heating system replacement. Use either Type-B vent, a flexible or rigid stainless-steel liner, or a flexible aluminum liner.

Flexible liners require careful installation to avoid a low spot at the bottom, where the liner turns a right angle to pass through the wall of the chimney. Comply with the manufacturer's instructions, which usually require stretching the liner and fastening it securely at both ends, to prevent the liner from sagging and thereby creating a low spot.



Flexible metal chimney liners: The most important installation issues are sizing the liner correctly along with fastening and supporting the ends to prevent sagging.

Flexible liners are easily damaged by falling masonry debris inside a deteriorating chimney. Use B-vent, L-vent, or single-wall stainless steel pipe instead of a flexible liner when the chimney is significantly deteriorated.

To minimize condensation, flexible liners should be insulated — especially when installed in exterior chimneys. Consider insulating flexible metal chimney liners with fiberglass-insulation jackets or perlite, if the manufacturer's instructions allow. Wood-stove chimney liners must be stainless steel and insulated.

Sizing flexible chimney liners correctly is very important. Oversizing is common and can lead to condensation and corrosion. The manufacturers of the liners include vent-sizing tables in their instructions. Liners should have a label from a testing lab like Underwriters Laboratories (UL).

7.11 Special Venting Considerations for Gas

The American Gas Association (AGA) publishes a classification system for venting systems attached to natural-gas and propane appliances. This classification system assigns Roman numerals to four categories of venting based on whether there is positive or negative pressure in the vent and whether condensation is likely to occur in the vent.

	Negative-pressure Venting	Positive-pressure
Non-condensing	I Combustion Efficiency **83% or less** Use standard venting: masonry or Type B vent	III Combustion Efficiency **83% or less** Use only pressurizable vent as specified by manufacturer
Condensing	II Combustion Efficiency **over 83%** Use only special condensing-service vent as specified by manufacturer	IV Combustion Efficiency **over 83%** Use only pressurizable condensing-service vent as specified by manufacturer

American Gas Association Vent Categories

AGA venting categories: The AGA classifies venting by whether there is positive or negative pressure in the vent and whether condensation is likely.

A majority of gas appliances found in homes and multifamily buildings are Category I, which have negative pressure in their vertical chimneys. We expect no condensation in the vent connector or chimney.

Condensing furnaces are usually Category IV with positive pressure in their vent and condensation occurring in both the appliance and vent. Category III vents are rare, however a few fan-assisted appliances vent their flue gases through airtight noncondensing vents.

7.11.1 Venting Fan-Assisted Furnaces

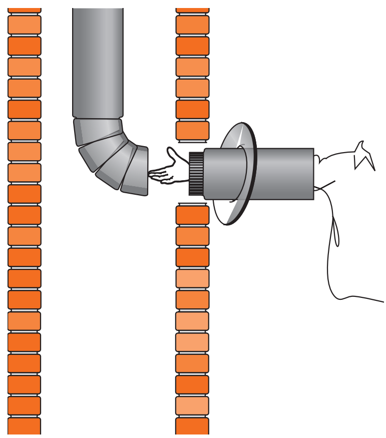
Newer gas-fired fan-assisted central furnaces control flue-gas flow and excess air better than atmospheric furnaces, resulting in a higher efficiency. These are non-condensing Category I furnaces with an 80%-plus Annual Fuel Utilization Efficiency (AFUE). Because these furnaces eliminate dilution air and may have slightly cooler flue gases, you should inspect existing chimneys to verify that the chimneys are prepared for more condensation than they experienced in the past. Reline the chimney when you see any of these conditions.

1. When the existing masonry chimney is unlined.
2. When the old clay or metal chimney liner is deteriorated.
3. When the new furnace has a smaller input (BTUH) than the old one, the liner should be sized to the new furnace and the existing water heater.

Materials for 80+ Furnaces

For gas-fired 80+ AFUE furnaces, a chimney liner should consist of one of these four materials.

1. A type-B vent
2. A rigid or flexible stainless steel liner (preferably insulated)
3. A poured masonry liner
4. An insulated flexible aluminum liner



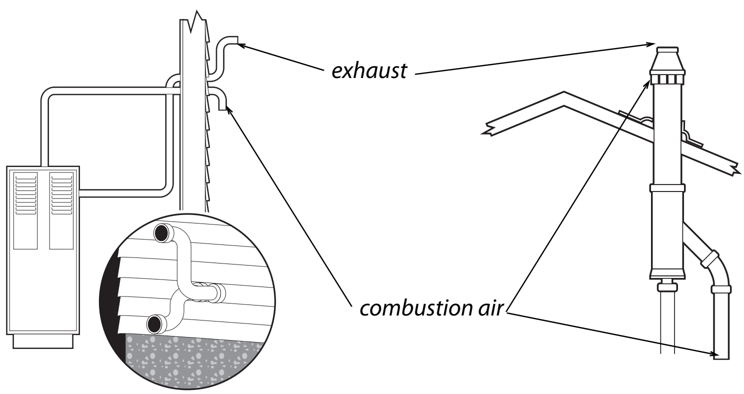
B-vent chimney liner: Double wall Type-B vent is the most commonly available chimney liner and is recommended over flexible liners. Rigid stainless-steel single wall liners are also a permanent solution to deteriorated chimneys.

Chimney relining is expensive. Therefore consider venting the appliance through a sidewall with a power venter, or replace the heating-system with a 90+ condensing heater when an existing chimney is inadequate for a new Category I appliance.

Condensing-Furnace Venting

Condensing furnaces with 90+ AFUE are vented horizontally or vertically through PVC Schedule 40 pipe. The vent is pressurized and plenty of condensation occurs, making it Category IV. Vent piping should be sloped back toward the appliance, so the condensate can be drained and treated if necessary.

Combustion air is supplied from outdoors through a sealed plastic pipe or from indoors. Outdoor combustion air is highly recommended, and most condensing furnaces are equipped for outdoor combustion air through a dedicated pipe. This combined combustion-air and venting system is referred to as direct-vent or sealed-combustion.



Condensing furnace venting: The two common types of termination for plastic condensing vents are separate pipes and a combined fitting. Vents going through the roof are preferred for their being more resistant to tampering and damage.

Table 7-16: Characteristics of Gas Furnaces

Annual Fuel Utilization Efficiency (AFUE)	Operating characteristics
70+	Category I, draft diverter, no draft fan, standing pilot, noncondensing, indoor combustion and dilution air.
80+	Category I, no draft diverter, draft fan, electronic ignition, indoor combustion air, no dilution air.
90+	Category IV, no draft diverter, draft fan, low-temperature plastic venting, positive draft, electronic ignition, condensing heat exchanger, outdoor combustion air is strongly recommended.

7.12 Combustion Air

A combustion appliance zone (CAZ) is classified as either an un-confined space or confined space. An un-confined space is a CAZ connected to enough building air leakage to provide combustion air. A confined space is a CAZ with sheeted walls and ceiling and a closed door that creates an air barrier between the appliance and other indoor spaces. For confined spaces, the NFPA 54 requires additional combustion air from outside the CAZ. Combustion air is supplied to the combustion appliance in four ways.

1. To an un-confined space through leaks in the building.
2. To a confined space through an intentional opening or openings between the CAZ and other indoor areas where air leaks replenish combustion air.
3. To a confined space through an intentional opening or openings between the CAZ and outdoors or ventilated intermediate zones like attics and crawl spaces.

4. Directly from the outdoors to the appliance. Appliances with direct combustion air supply are called sealed-combustion or direct vent appliances.

Important Note: The National Fuel Gas Code (NFPA 54 – 2009) presents two methods for calculating combustion air. The simplest of the two methods is discussed in this section. The best way to evaluate the combustion air in an existing building with an existing combustion heating system is with an electronic combustion analysis. **If the oxygen reading from the combustion analyzer is more than 5%, this oxygen measurement verifies that an adequate amount of combustion air is available.** At 5% or more of flue-gas oxygen, additional combustion air is usually unnecessary.

7.12.1 Un-Confined-Space Combustion Air

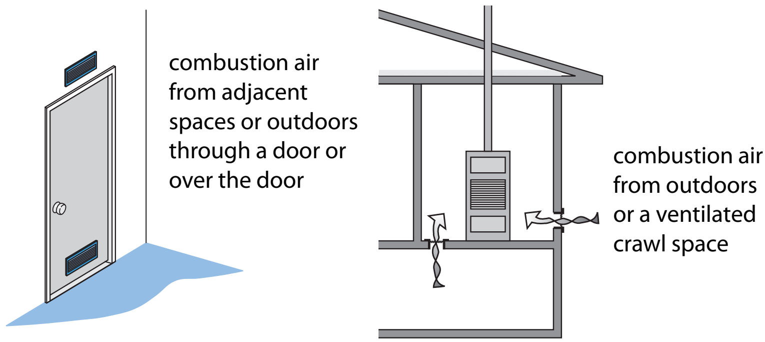
Combustion appliances located in most basements, attics, and crawl spaces get adequate combustion air from leaks in the building shell. Even when a combustion appliance is located within the home's living space, it gets adequate combustion air from air leaks, unless the house is airtight or the combustion zone is depressurized.

7.12.2 Confined-Space Combustion Air

A confined space is defined by NFPA 54 as a room containing one or more combustion appliances that has less than 50 cubic feet of volume for every 1000 BTUH of appliance input.

However, if a small mechanical room is connected to adjacent spaces through large air passages like floor-joist spaces, the CAZ may not need additional combustion air despite sheeted walls and a door separating the CAZ from other indoor spaces. You can measure the connection between the CAZ and other spaces by worst-case draft testing or blower door pressure testing.

When the home is unusually airtight (<0.20 ACHn), the CAZ may not have adequate combustion air, even when the combustion zone is larger than the minimum confined-space room volume, defined previously.



Passive combustion air options: Combustion air can be supplied from adjacent indoor spaces or from outdoors. Beware of passive combustion air vents into the attic that could depressurize the combustion zone or allow moist indoor air to travel into the attic. Also beware of taking combustion air from wet crawl spaces.

Combustion Air from Outdoors

In confined spaces or airtight homes where outdoor combustion air is needed, a single vent opening installed as low in the CAZ as practical is preferable. A combustion air vent into an attic may depressurize the combustion zone or dump warm moist air from the CAZ into the attic. Instead, connect the combustion zone to a ventilated crawl space (provided it is dry) or directly outdoors through a single low vent if possible.

Choose an outdoor location that is sheltered, where the wall containing the vent isn't parallel to prevailing winds. Wind blowing parallel to an exterior wall or at a right angle to the vent opening tends to de-pressurize both the opening and the CAZ connected to it.

Table 7-17: Combustion Air Openings: Location and Size

Location	Dimensions
Two direct openings to adjacent indoor space	Minimum area each: 100 in^2 1 in^2 per 1000 BTUH each Combined room volumes must be ≥ 50 ft^3/1000 BTUH
Two direct openings or vertical ducts to outdoors	Each vent should have 1 in^2 for each 4000 BTUH
Two horizontal ducts to outdoors	Each vent should have 1 in^2 for each 2000 BTUH
Single direct or ducted vent to outdoors	Single vent should have 1 in^2 for each 3000 BTUH

From the *National Fuel Gas Code 2009 (NFPA 54)*

Net free area is smaller than actual vent area and takes the blocking effect of louvers into account. Metal grilles and louvers provide 60% to 80% of their area as net-free area while wood louvers provide only 20% to 25%. Combustion-air vents should be no less than 3 inches in their smallest dimension.

Example Combustion Air Calculation

Here is an example of one indoor space providing combustion air to another indoor space. The furnace and water heater are located in a confined space. The furnace has an input rating of 100,000 BTUH. The water heater has an input rating of 40,000 BTUH. Therefore, there should be 280 in^2 of net free area of vent between the mechanical room and other rooms in the home.

$([100{,}000 + 40{,}000] \div 1{,}000 = 140 \times 2\ \text{in}^2 = 280\ \text{in}^2)$

Each vent should therefore have a minimum of 140 in^2.

7.13 Ducted Air Distribution

The forced-air system consists of an air handler (furnace, heat pump, air conditioner) with its heat exchanger along with attached ducts. The annual system efficiency of forced-air heating and air-conditioning systems is affected by the following issues.

1. Duct leakage
2. System airflow
3. Blower operation
4. Balance between supply and return air
5. Duct insulation levels

The forced-air system usually offers more opportunity for energy savings and comfort improvement than improving combustion or refrigeration equipment.

Sequence of Operations

The evaluation and improvement of ducts has a logical sequence of steps. First, solve the airflow problems because a contractor might have to replace ducts or install additional ducts. After duct modifications, evaluate the ducts for leakage and evaluate whether the ducts are located inside the thermal boundary or outside it. Decide whether duct-sealing is important and if so, find and seal the duct leaks. Finally, if supply ducts are outside the thermal boundary, insulate the ducts. This list shows the logical sequence of operations.

1. Evaluate and/or measure duct air leakage.
2. Find duct leaks and seal them.
3. Consider insulating supply ducts.

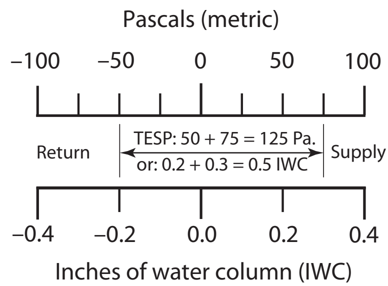
7.13.1 Solving Airflow Problems

You don't need test instruments to discover dirty blowers or disconnected branch ducts. Find these problems before measuring duct airflow, troubleshooting the ducts, or duct sealing. These steps go before airflow measurements.

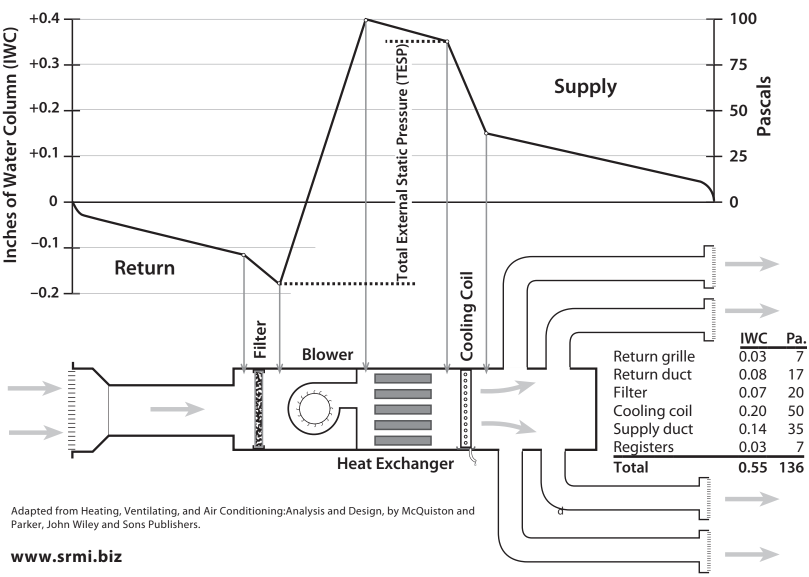
1. Ask the customer about comfort problems and temperature differences in different rooms of the home.
2. Based on the customers comments, look for disconnected ducts, restricted ducts, and other obvious problems.
3. Inspect the filter(s), blower, and indoor coil for dirt. Clean them if necessary. If the indoor coil isn't easily visible, a dirty blower means that the coil is probably also dirty.
4. Look for dirty or damaged supply and return grilles that restrict airflow. Clean and repair them.
5. Look for closed registers or closed balancing dampers that could be restricting airflow to rooms.
6. Notice moisture problems like mold and mildew. Moisture sources, like a wet crawl space, can overpower air conditioners by introducing more moisture into the air than the air conditioner can remove.

Measuring Total External Static Pressure

The blower creates the duct pressure, which is measured in inches of water column (IWC) or pascals. The return static pressure is negative and the supply static pressure is positive. Total external static pressure (TESP) is the sum of the absolute values of the supply and return static pressures. Absolute value means that you ignore the positive or negative signs when adding supply static pressure and return static pressure to get TESP. This addition represents the distance on a number line as shown in the illustration here.



TESP number line: the TESP represents the distance on a number line between the return and supply ducts.



Visualizing TESP: The blower creates a suction at its inlet and a positive pressure at its outlet. As the distance between the measurement and blower increase, pressure decreases because of the system's resistance.

TESP gives a rough indicator of whether airflow is adequate. The greater the TESP, the less the airflow. The supply and return static pressures by themselves can indicate whether the supply or the return or both sides are restricted. For example, if the supply static pressure is 0.1 and the return static pressure is 0.5, you can assume that most of the airflow problems are due to a restricted or undersized return. The TESP gives a rough estimate of airflow if the manufacturer's graph or table for static pressure versus airflow is available.

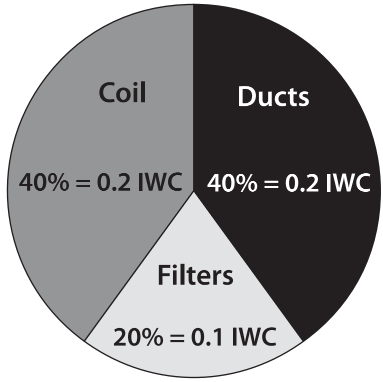
1. Attach two static pressure probes to tubes leading to the two ports of the manometer. Attach the high-side port to the probe inserted downstream of the air handler in the supply duct. The other tube goes upstream of the air handler in the return duct. The manometer adds the supply and return static pressures to measure TESP.

2. Consult manufacturer's literature for a table of TESP versus airflow for the blower or the air handler. Find airflow for the TESP measured in Step 1.

3. Measure pressure on each side of the air handler to obtain both supply and return static pressures separately. This test helps to locate the main problems as related to either the supply or the return.

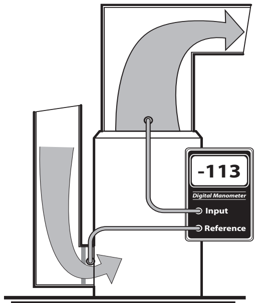
Static Pressure Guidelines

Air handlers deliver their airflow at TESPs ranging from 0.20 IWC (75 Pascals) to 1.0 IWC (250 Pascals) as found in the field. Manufacturers maximum recommended static pressure is usually a maximum 0.50 IWC for standard air handlers. TESPs greater than 0.50 IWC indicate the possibility of poor airflow in standard residential forced-air systems.



Static pressure budget: Typical static pressures in IWC and% for a marginally effective duct system.

The popularity of pleated filters, electrostatic filters, and high-static high-efficiency evaporator coils, prompted manufacturers to introduce premium air handlers that can deliver adequate airflow at a TESPs of greater than 0.50 IWC. Premium residential air handlers can provide adequate airflow with TESPs of up to 0.90 IWC through more powerful blowers and variable-speed blowers. TESPs greater than 0.90 IWC (225 pascals) indicate the possibility of poor airflow in these premium residential forced-air systems.



Total external static pressure (TESP): The positive and negative pressures created by the resistance of the supply and return ducts produces TESP. The measurement shown here simply adds the two static pressures without regard for their signs. As TESP increases, airflow decreases. Numbers shown below are for example only.

Table 7-18: Total External Static Pressure Versus System Airflow for a Particular System

TESP (IWC)	0.3	0.4	0.5	0.6	0.7	0.8
CFM	995	945	895	840	760	670

Example only

7.13.2 Evaluating Furnace Performance

The effectiveness of a furnace depends on its temperature rise, fan-control temperatures, and flue-gas temperature. For efficiency, you want a low temperature rise. However, you must maintain a minimum flue-gas temperature to prevent corrosion in the venting of 70+ and 80+ AFUE furnaces. Apply the following furnace-operation standards to maximize the heating system's seasonal efficiency and safety.

1. Perform a combustion analysis as described in *"Electronic Combustion Analysis" on page 225*.

2. Check temperature rise after 5 minutes of operation. Refer to manufacturer's nameplate for acceptable temperature rise (supply temperature minus return temperature). The temperature rise should be between 40°F and 70°F with the lower end of this scale being preferable for energy efficiency.

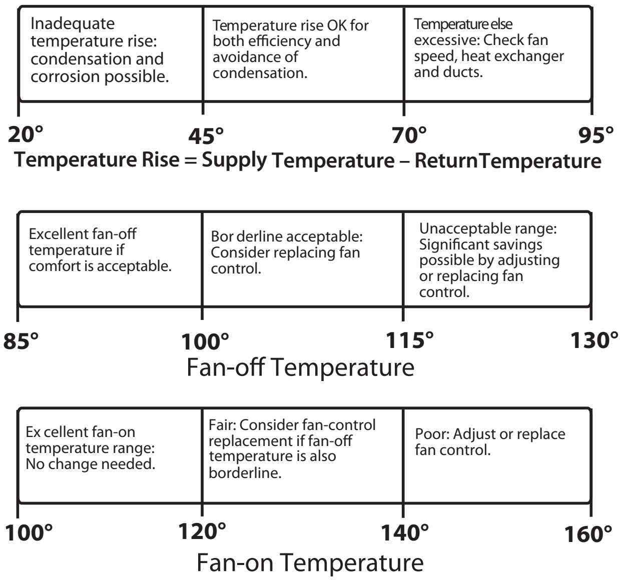
3. Verify that the fan-off temperature is between 95° and 105° F. The lower end of this scale is preferable for maximum efficiency.
4. Verify that the fan-on temperature is 120–140° F. The lower the better.
5. On time-activated fan controls, verify that the fan is switched on within two minutes of burner ignition and is switched off within 2.5 minutes of the end of the combustion cycle.
6. Verify that the high limit controller shuts the burner off before the furnace temperature reaches 200°F.
7. All forced-air heating systems must deliver supply air and collect return air only from inside the intentionally heated portion of the house. Taking return air from an un-heated area of the house such as an unoccupied basement is not acceptable.
8. Verify that there is a strong noticeable airflow from all supply registers.

Furnace Cleaning and Adjustment

If the forced-air heating system doesn't meet these standards, consider the following improvements.

1. Clean or change dirty filters. Clean air-conditioning coils.
2. Clean the blower, increase fan speed, and improve ducted air circulation. *See page 272.*
3. Adjust fan control to conform to these standards, or replace the fan control if adjustment fails. Some fan controls aren't adjustable.
4. Adjust the high limit control to conform to the above standards, or replace the high limit control.

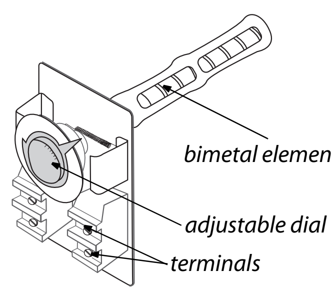
Table 7-18: Furnace Operating Parameters



After adjustments, the measured temperature rise should be no lower than manufacturer's specifications or the listed minimum values in *Table 7-5 on page 231*.

Unbalanced Supply-Return Airflow Test

Closing interior doors often isolates supply registers from return registers in homes with central returns. This imbalance often pressurizes bedrooms and depressurizes central areas with return registers. These pressures can drive air leakage through the building shell, create moisture problems, and bring pollutants in from the crawl space, garage, or CAZ.

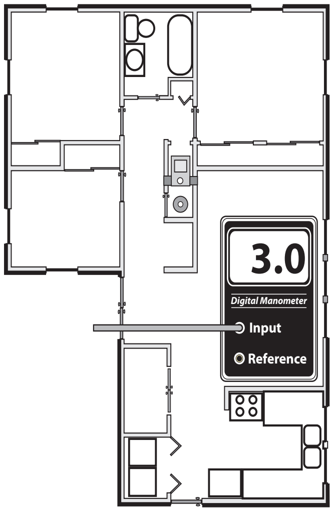


Fan/limit control: Turns the furnace blower on and off, according to temperature. Also turns the burner off if the heat exchanger gets too hot.

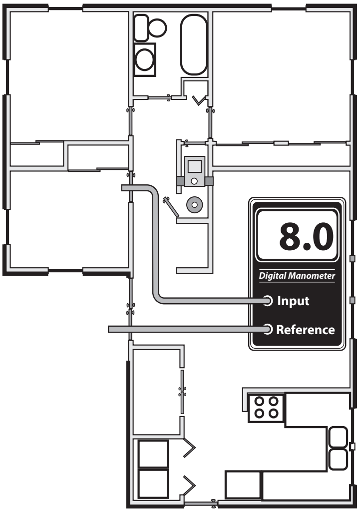
The following test uses only the air handler and a digital manometer to evaluate whether the supply air is able to cycle back through the return registers. Activate the air handler and close interior doors.

First, measure the pressure difference between the home's central living area and the outdoors with a digital manometer. Then, measure the bedrooms' pressure difference with reference to outdoors. As a simpler alternative, you can measure the pressure difference between the central zone and the bedroom.

If the difference between those two measurements is more than ±3.0 pascals with the air handler operating, pressure relief is desirable. To estimate the amount of pressure relief needed, slowly open the bedroom door until the pressure difference drops below 1 pascal. Estimate the surface area of the door opening. This is the area of the permanent opening required to provide pressure relief. Pressure relief may include undercutting the door or installing transfer grilles or jumper ducts.



Depressurized central zone: The air handler depressurizes the central zone, where the return register is located, when the bedroom doors are closed. This significantly increases air infiltration through the building shell.



Pressurized bedrooms: Bedrooms with supply registers but no return register are pressurized when the air handler is on and the doors are closed. Pressures this high can double or triple air leakage through the building shell.

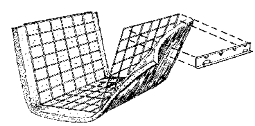
7.13.3 Improving Forced-Air System Airflow

Inadequate airflow is a common cause of comfort complaints. When the air handler is on there should be a strong flow of air out of each supply register. Low airflow may mean that a branch is blocked or separated, or that return air is not sufficient. When low airflow is a problem, consider specifying the following obvious improvements as appropriate from your inspection.

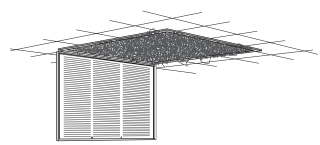
1. Clean or change filter. Select a less restrictive filter if you need to reduce static pressure substantially.
2. Clean furnace blower.

3. Clean air-conditioning or heat pump coil. (If the blower is dirty, the coil is probably also dirty.)
4. Increase blower speed.
5. Make sure that balancing dampers to rooms that need more airflow are wide open.
6. Lubricate blower motor, and check tension on drive belt.

Panel filter installed in filter slot in return plenum



Washable filter installed on a rack inside the blower compartment.



Panel filter installed in return register

Furnace filter location: Filters are installed on the return-air side of forced air systems. Look for them in one or more of the above locations.

Duct Improvements to Increase Airflow

Consider specifying the following duct changes to increase system airflow and reduce the imbalance between supply and return.

1. Modify the filter installation to allow easier filter changing, if filter changing is currently difficult.
2. Install a slanted filter bracket assembly or a enlarged filter fitting to accommodate a larger filter with more surface area and less static-pressure drop than the existing filter.

3. Remove obstructions to registers and ducts such as rugs, furniture, and objects placed inside ducts, such as children's toys and water pans for humidification.
4. Remove kinks from flex duct, and replace collapsed flex duct and fiberglass duct board.
5. Remove excessive lengths of snaking flex duct, and stretch the duct to enhance airflow.
6. Perform a Manual D sizing evaluation to evaluate whether to replace branch ducts as an ECM.
7. Install additional supply ducts and return ducts as needed to provide heated air throughout the building, especially in additions to the building.
8. Undercut bedroom doors, especially in homes with single return registers.
9. Repair or replace bent, damaged, or restricted registers. Install premium low-resistance registers and grilles.

7.14 Evaluating Duct Air Leakage

Duct air leakage is a major energy-waster in homes where the ducts are located outside the home's thermal boundary in a crawl space, attic, attached garage, or leaky unoccupied basement. When these intermediate zones remain outside the thermal boundary, duct air sealing is usually cost-effective.

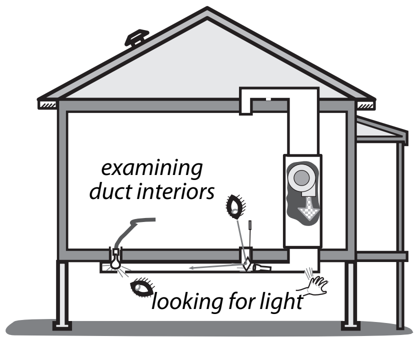
Duct leakage within the thermal boundary isn't usually a significant energy problem.

7.14.1 Troubleshooting Duct Leakage

There are several simple procedures for finding the locations of the duct leaks and evaluating their severity.

Finding Duct Leaks Using Touch and Sight

One of the simplest ways of finding duct leaks is feeling with your hand for air leaking out of supply ducts, while the ducts are pressurized by the air handler's blower. Duct leaks can also be located using light. Use one of these 4 tests to locate air leaks.



Finding duct air leaks: Finding the exact location of duct leaks precedes duct air sealing.

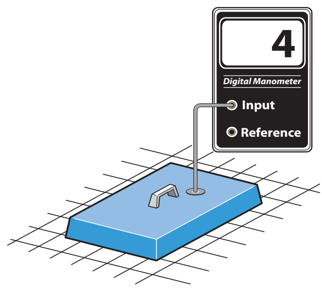
1. Use the air handler blower to pressurize supply ducts. Closing the dampers on supply registers temporarily or partially blocking the register with pieces of carpet, magazines, or any object that won't be blown off by the register's airflow increases the duct pressure and make duct leaks easier to find. Dampening your hand makes your hand more sensitive to airflow, helping you to find duct air leaks.
2. Place a trouble light, with a 100-watt bulb, inside the duct through a register. Look for light emanating from the exterior of duct joints and seams.
3. Determine which duct joints were difficult to fasten and seal during installation. These joints are likely duct-leakage locations.
4. Use a trouble light, flashlight, and mirror or a digital camera help you to visually examine duct interiors.

Feeling air leaks establishes their exact location. Ducts must be pressurized in order to feel leaks. You can feel air leaking out of pressurized ducts, but you can't feel air leaking into depressurized return ducts. Pressurizing the home with a blower door forces air through duct leaks, located in intermediate zones, where you can feel the leakage coming out of both supply and return ducts.

Pressure Pan Testing

Pressure pan tests can help both auditors and contractors identify leaky or disconnected ducts located in intermediate zones. With the house depressurized by the blower door to either –25 pascals or –50 pascals with reference to outdoors, pressure pan readings are taken at each supply and return register.

A pressure of –50 pascals is preferred if conditions allow. Pressure pan testing is reliable for homes where the ducts are outside the air barrier.



A pressure pan: Blocks a single register and measures the air pressure behind it, during a blower door test. The magnitude of that pressure is an indicator of duct leakage.

Basements are often part of a home's conditioned living space. In this case, pressure pan testing isn't necessary, although air sealing the return ducts for safety is still very important. If instead, the basement is accessed from the outside and rarely used, the basement may be considered outside the conditioned living space. In this case, open a window or door between the basement and outdoors, and close any door or hatch between conditioned spaces and basement during pressure pan testing.

1. Install blower door and set-up house for winter conditions. Open all interior doors.
2. If the basement is conditioned living space, open the door between the basement and upstairs living spaces. If the basement isn't conditioned living space, close the

door between basement and upstairs, and open a basement window.

3. Turn furnace off at the thermostat or main switch. Remove furnace filter, and tape filter slot if one exists. Be sure that all grilles, registers, and dampers are fully open.
4. Temporarily seal any outside fresh-air intakes to the duct system. Seal supply registers in zones that are not intended to be heated — an uninhabited basement or crawl space, for example.
5. Open attics, crawl spaces, and garages as much as possible to the outside so they don't create a secondary air barrier.
6. Connect hose between pressure pan and the input tap on the digital manometer. Leave the reference tap open.
7. With the blower door's manometer reading –25 or –50 pascals, place the pressure pan completely over each grille or register one by one to form a tight seal. Leave all other grilles and registers open when making a test. Record each reading, which should give a positive pressure.
8. If a grille is too large or a supply register is difficult to cover with the pressure pan (under a kitchen cabinet, for example), seal the grille or register with masking tape. Insert a pressure probe through the masking tape and record the reading. Remove the tape after the test, and test the other over-sized registers in the same way.
9. Use either the pressure pan or tape to test each register and grille in a systematic way.

Pressure Pan Duct Standards

If the ducts are perfectly sealed with no leakage to the outside, you won't measure any pressure difference (0.0 pascals) during a pressure-pan test. The higher the measured pressure reading, the more connected the duct is to the outdoors.

1. If the median pressure pan reading is 4 pascals or more and/or if one reading is more than 8 pascals, duct-sealing is usually very cost effective.

2. Following duct-sealing work, no more than three registers should have pressure-pan readings greater than 2 pascals. No single reading should be greater than 4 pascals.

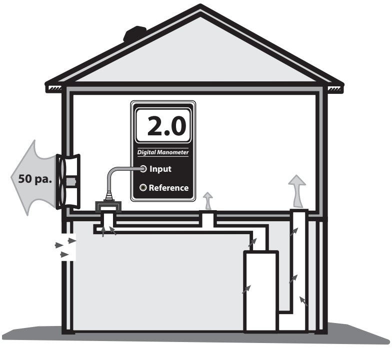
3. The reduction you achieve depends on your ability to find the leaks and whether you can access the leaky ducts. The best weatherization providers use 1 pascal or less as a general goal for all registers.

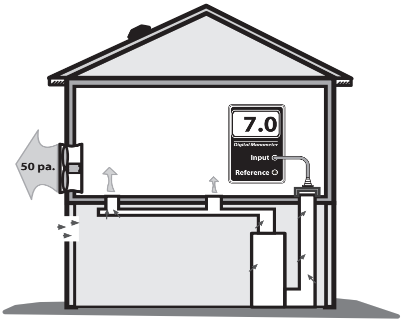
Examine the registers connected to ducts that are located in areas outside the conditioned living space. Unconditioned spaces containing ducts include attics, crawl spaces, garages, and unoccupied basements. Also evaluate registers attached to stud cavities or panned joists used as return ducts. Leaky ducts, located outside the conditioned living space, may lead to pressure-pan measurements more than 30 pascals if the ducts have large holes.

7.14.2 Measuring House Pressure Caused by Duct Leakage

The following test measures pressure differences between the main body of the house and outdoors, caused by duct leakage. Pressure difference greater than +2.0 pascals or more negative than –2.0 pascals should be corrected because of the shell air leakage that the pressure differences create.

The following house-pressure testing procedure is useful for both testing in and testing out as part of an energy audit or weatherization job.

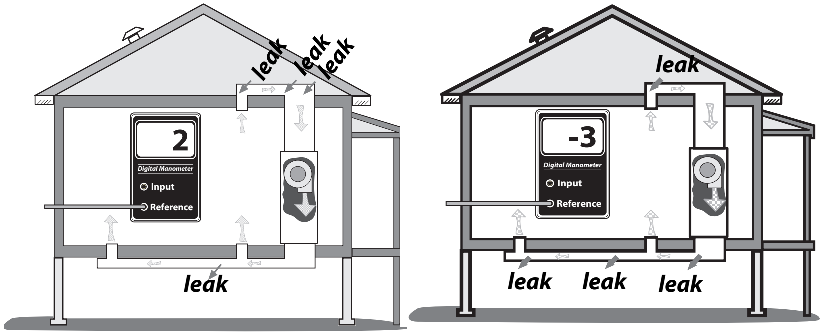




Pressure pan test: A pressure pan reading of 2 indicates moderate duct air leakage in the supply ducts.

Problem return register: A pressure reading of 7 pascals indicates major air leakage near the tested register.

1. Set-up house for winter conditions. Close all windows and exterior doors. Turn-off all exhaust fans.
2. Open all interior doors, including door to basement.
3. Measure the baseline house-to-outdoors pressure difference and zero it out using the baseline procedures described in *"Conducting the Blower Door Test" on page 76*.
4. Turn on air handler.
5. Measure the house-to-outdoors pressure difference. This test indicates dominant duct leakage as shown here.



Dominant return leaks: When return leaks are larger than supply leaks, the house shows a positive pressure with reference to the outdoors.

Dominant supply leaks: When supply leaks are larger than return leaks, the house shows a negative pressure with reference to the outdoors.

A positive pressure indicates that the return ducts (which pull air from leaky intermediate zones) are leakier than the supply ducts. A negative pressure indicates that the supply ducts (which push air into intermediate zones through their leaks) are leakier than return ducts. A pressure at or near zero indicates equal supply and return leakage or else little duct leakage.

7.15 Sealing Duct Leaks

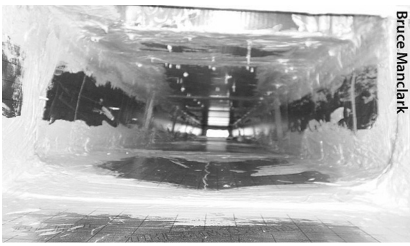
Ducts are often considered part of the thermal boundary because they are full of house air. Return ducts that are connected to attics, crawl spaces, or attached garages can create a lot of air leakage.

Ducts located outside the thermal boundary or in an intermediate zone like a ventilated attic or crawl space should be sealed. The following is a list of duct leak locations in order of their relative importance. Leaks nearer to the air handler are exposed to higher pressure and are more important than leaks further away.

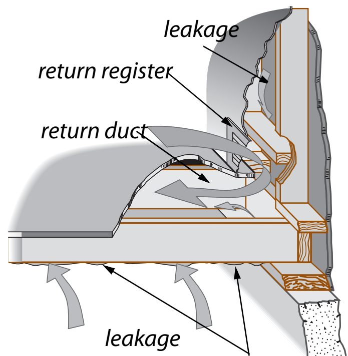
7.15.1 Sealing Return Ducts

Return leaks are important for combustion safety and for efficiency. Use the following techniques to seal return ducts.

1. First, seal all return leaks within the combustion zone to prevent this leakage from depressurizing the combustion zone and causing backdrafting.
2. Seal panned return ducts using mastic to seal all cracks and gaps within the return duct and register.



Lining a panned cavity: Foil-faced foam board, designed for lining cavities is sealed with duct mastic to provide an airtight return.



Panned floor joists: These return ducts are often very leaky and may require removing the panning to seal the cavity.

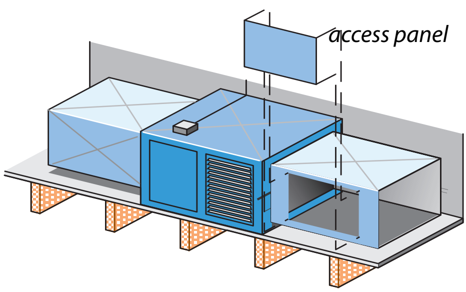
3. Seal leaky joints between building materials composing cavity return ducts, like panned floor cavities and furnace return platforms. Remove the panning to seal cavities containing joints in building materials.
4. Carefully examine and seal leaks at transitions between panned floor joists and metal trunks that change the direction of the return ducts. You may need a mirror to find some of the biggest return duct leaks in these areas.
5. Seal filter slots with an assembly that allows easy changing of filters.

6. Seal the joint between the furnace and return plenum with silicone caulking or foil tape.

7.15.2 Sealing Supply Ducts

Inspect these places in the duct system and seal them as needed.

1. *Plenum joint at air handler:* Technicians might have had problems sealing these joints because of a lack of space. Seal these plenum connections thoroughly even if you must cut an access hole in the plenum. Use silicone caulking or foil tape instead of mastic and fabric mesh here for future access — furnace replacement, for example.

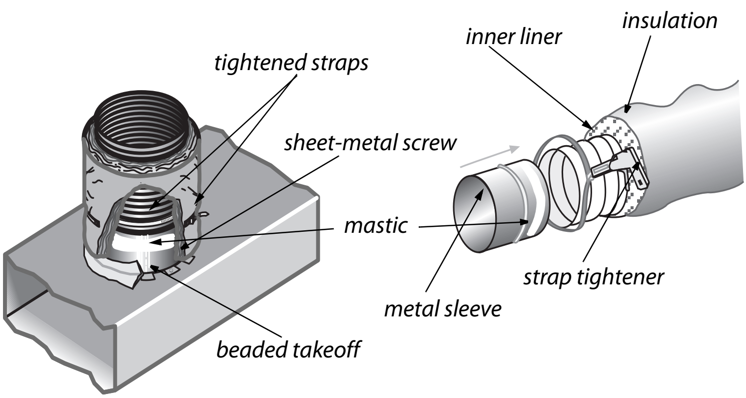


Plenums, poorly sealed to air handler: When air handlers are installed in tight spaces, plenums may be poorly fastened and sealed. Cutting a hole in the duct may be the only way to seal this important joint.

Sectioned elbows: Joints in sectioned elbows known as gores are usually quite leaky and require sealing with duct mastic.

2. *Joints at branch takeoffs:* Seal these important joints with a thick layer of mastic. Fabric mesh tape should cover gaps and reinforce the seal at gaps.
3. *Joints in sectioned elbows:* Known as gores, these are usually leaky and require sealing with duct mastic.
4. *Tabbed sleeves:* Attach the sleeve to the main duct with 3-to-5 screws and apply mastic plentifully. Or better, remove the tabbed sleeve and replace it with a manufactured takeoff.

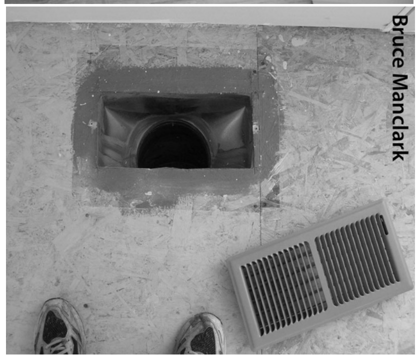
5. *Flexduct-to-metal joints:* Apply a 2-inch band of mastic to the end of the metal connector. Attach the flexduct's inner liner with a plastic strap, tightening it with a strap tensioner. Attach the insulation and outer liner with another strap.
6. *Damaged flex duct:* Replace flex duct when it is punctured, deteriorated, or otherwise damaged.
7. *Deteriorating ductboard facing*: Replace ductboard, preferably with metal ducting, when the facing deteriorates because this deterioration leads to a lot of air leakage.



Flexduct joints: Flexduct itself is usually fairly airtight, but joints, sealed improperly with tape, can be very leaky. Use methods shown here to make flexduct joints airtight.

8. Consider closing supply and return registers in unoccupied basements or crawl spaces.
9. Seal penetrations made by wires or pipes traveling through ducts.
10. Support the ducts and duct joints with duct hangers at least every 5 feet or as necessary to prevent sagging of more than one-half inch.

7.15.3 Duct Boots, Registers, and Chases



Apply caulk or foam to the joint between the boot and the ceiling, wall, or floor between conditioned and unconditioned areas.

If chase opening is large, seal it with a rigid barrier such as plywood or drywall, and seal the new barrier to ducts with caulk or foam.

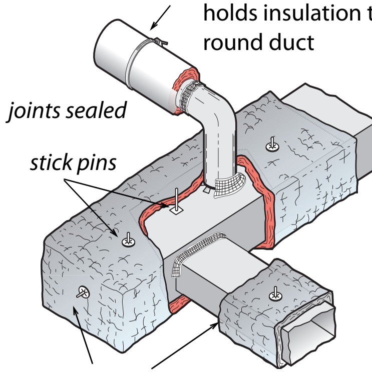
7.15.4 Materials for Duct Sealing

Duct mastic is the best duct-sealing material because of its superior durability and adhesion. Apply mastic at least $^1/_{16}$-inch thick, and use reinforcing mesh for all joints wider than $^1/_8$-inch or joints that may move.

Install screws to prevent joint movement or separation. Don't expect tape to hold a duct joint together nor expected to resist the force of compacted insulation or joint movement. Aluminum foil or cloth duct tape aren't good materials for duct sealing because their adhesive often fails. Tape should be covered with mastic to prevent its adhesive from drying out and failing if used for duct-sealing.

7.16 Duct Insulation

Specify insulation for supply ducts that run through unconditioned areas outside the thermal boundary such as crawl spaces, attics, and attached garages with a minimum of R-6 vinyl-faced or foil-faced duct insulation. Don't insulate ducts that run through conditioned areas unless they cause overheating in winter or condensation in summer. Follow the best practices listed below for installing insulation.

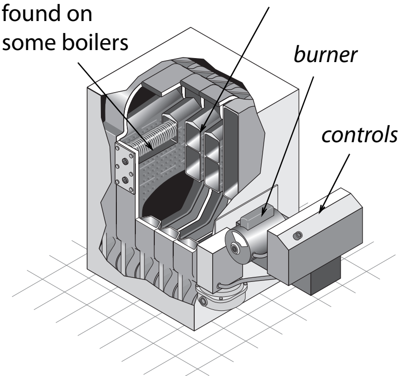


Duct insulation: Supply ducts, located in unheated areas, should be insulated to a minimum of R-6.

1. Complete duct sealing before duct insulation.
2. Cover all exposed supply ducts with insulation. don't leave sections of the duct uninsulated.
3. Fasten insulation with stick pins or plastic straps.
4. Note: Tape can be effective for covering joints in the insulation to prevent air convection, but the tape fails when expected to resist the force of the insulation's compression or weight. Outward-clinch staples can help hold the insulation facing and tape together.

7.17 Hot-Water Space-Heating Distribution

Hot-water heating is generally a little more efficient than forced-air heating and much more efficient than steam heating. The most significant energy wasters in hot-water systems are poor steady-state efficiency, off-cycle flue losses stealing heat from the stored water, and boilers operating at a too-high water temperature. For information about boiler installation, *see page 217*.



Cast-iron sectional boilers: The most common boiler type for residential applications.

7.17.1 Boiler Efficiency and Maintenance

Boiler performance and efficiency improve after effective maintenance and tune-up procedures. There are more ways for performance and efficiency to deteriorate in boilers compared to furnaces.

1. Corrosion, scaling, and dirt on the water side of the heat exchanger.
2. Corrosion, dust, and dirt on the fire side of the heat exchanger.
3. Excess air during combustion from air leaks and incorrect fuel-air mixture.
4. Off-cycle air circulation through the firebox and heat exchanger, removing heat from stored water.

Boiler Efficiency Improvements

Consider specifying the following maintenance and efficiency improvements for both hot-water and steam boilers based on boiler inspection.

1. Check for leaks on the boiler, around its fittings, or on any of the distribution piping connected to the boiler.
2. Clean fire side of heat exchanger of noticeable dirt.
3. Drain water from the boiler drain until the water flows clean.

7.17.2 Distribution System Improvements

Hydronic distribution systems consist of the supply and return piping, the circulator, expansion tank, air separator, air vents, and heat emitters. A properly designed and installed hydronic distribution system can operate for decades without service. However, many systems have installation flaws or need service.

Note: You can recognize a hot-water boiler by its expansion tank, located somewhere above the boiler. The expansion tank provides an air cushion to allow the system's water to expand and contract as it is heated and cooled. Without a functioning expansion tank excessive pressure in the boiler discharges water through the pressure-relief valve.

Safety Checks and Improvements

Work with contractors and technicians to specify and verify the following safety and efficiency tests and inspections.

1. Verify the existence of a 30-psi-rated pressure-temperature (P&T) relief valve. The P&T relief valve should have a drain pipe that terminates 6 inches from the floor. Replace a malfunctioning valve or add a P&T relief valve if none exists. Look for signs of leakage or discharges. Find out why the relief valve is discharging.

2. Verify that the expansion tank isn't waterlogged or too small for the system. A non-operational expansion tank can cause the pressure-relief valve to discharge. Measure the expansion tank's air pressure. The pressure should be one (1) psi per 2.3 feet of the distribution system's height.

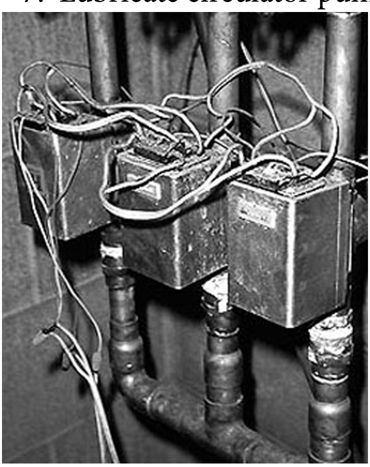
3. If you observe rust in venting, verify that the return water temperature is warmer than 140° F for gas and warmer than 130° F for oil. These minimum water temperatures prevent acidic condensation.

4. Verify that high-limit control disengages the burner at a water temperature of 200°F or less.

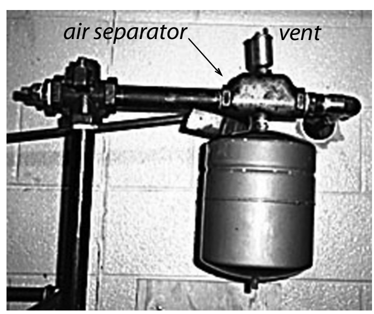
5. Verify that the boiler has an operable low-water cutoff.

6. Verify that a tankless coil used for domestic water heating has a mixing valve and an expansion tank in its piping circuit.

7. Lubricate circulator pump(s) if necessary.



Zone valves: Separate thermostats control each zone valve. Zone valves have switches that activate the burner.

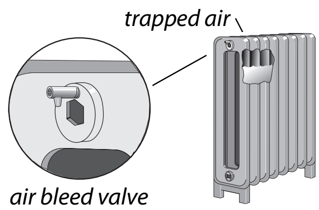


Expansion tank, air separator, and Vent: Preventing excessive pressure and eliminating air from the systems are important for hydronic distribution systems.

Simple Efficiency Improvements

Do the following energy-efficiency improvements.

1. Repair water leaks in the system.
2. Remove corrosion, dust, and dirt on the fire side of the heat exchanger.
3. Check for excess air during combustion from air leaks and incorrect fuel-air mixture.
4. Bleed air from radiators and piping through air vents on piping or radiators. Most systems have an automatic fill valve. If there is a manual fill valve for refilling system with water, it should be open to push water in and air out, during air-purging.



Purging air: Trapped air collects at the hot-water system's highest parts. Bleeding air from radiators fills the radiator and gives it more heating surface area.

5. Vacuum and clean fins of fin-tube convectors if you notice dust and dirt there.
6. Insulate all supply and return piping, passing through unheated areas, with pipe insulation, at least one-inch thick, rated for temperatures up to 200° F.

Improvements to Boiler Controls

Consider these improvements to control systems for hot-water boilers.

1. Install outdoor reset controllers on larger boilers to regulate water temperature, depending on outdoor temperature.
2. If possible, operate the boiler without a low-limit control for maintaining a minimum boiler-water temperature. If the boiler heats domestic water in addition to space heating the low-limit control may be necessary.

3. After control improvements like two-stage thermostats or reset controllers, verify that return water temperature is high enough to prevent condensation and corrosion in the chimney as noted previously.
4. Install electric vent dampers on atmospheric gas- and oil-fired high-mass boilers.

7.18 Steam Heating and Distribution

Steam heating is less efficient than hot-water heating because steam requires higher temperatures than hot water. Higher temperature heating systems are less efficient than lower temperature ones. Multifamily buildings, especially multi-story buildings, may have little choice but to continue with steam because of the high cost of switching systems.

Note: You can recognize a steam boiler by its sight glass, which indicates the boiler's water level. Notice that the water doesn't completely fill the boiler, but instead allows a space for the steam to form above the boiler's water level.

If the steam-heating system isn't replaced, operate it at the lowest steam pressure that heats the building adequately. Two psi on the boiler-pressure gauge is a practical limit for many systems although some systems can operate at pressures down to a few ounces per square inch of pressure. Traps and air vents are crucial to operating at a low steam pressure. Electric vent dampers reduce off-cycle losses for both gas- and oil-fired systems.

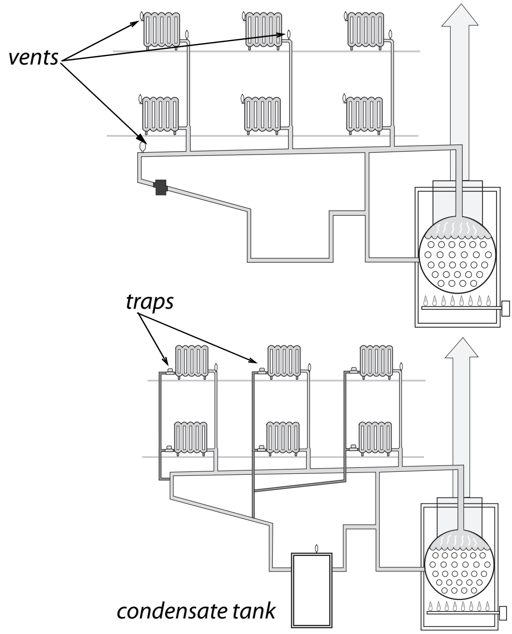
7.18.1 Steam System Maintenance

Do these safety and maintenance tasks on steam systems.

1. Verify that steam boilers have functioning high-pressure limits and low-water cut-off controls and a 15 psi pressure relief valve.

One-pipe and two-pipe steam systems: Still common in multifamily buildings, one-pipe steam works best when very low pressure steam can drive air out of the piping and radiators quickly through plentiful vents. Vents are located on each radiator and also on main steam lines.

Two-pipe steam systems: Radiator traps keep steam inside radiators until it condenses. No steam should be present at the condensate tank.

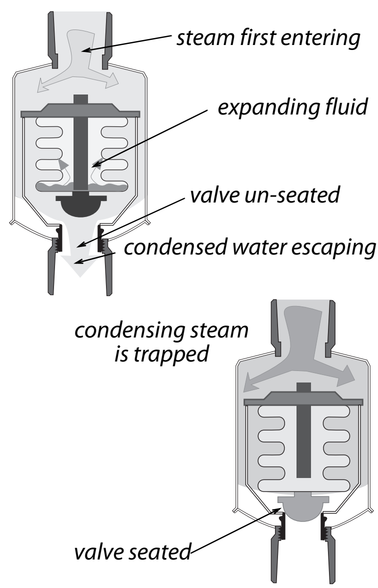


2. Verify the function of the low-water cutoff by flushing the low-water cutoff with the burner operating. Combustion should stop when the water level in the boiler drops below the level of the float. If combustion continues, repair or replace the low-water cutoff.
3. Verify that flush valves on low-water cutoffs are operable and don't leak water.
4. Ask owner about instituting a schedule of blow-down and chemical-level checks.
5. Specify that technicians drain mud legs on return piping.

7.18.2 Steam System Energy Conservation

Specify the following efficiency checks and improvements for steam systems.

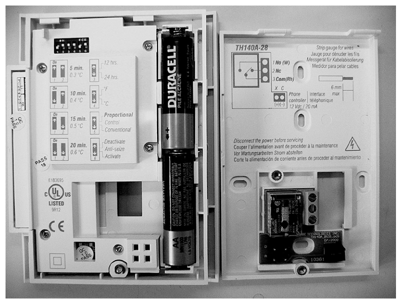
1. Verify that high-pressure limit control is set at or below 1 (one) psi or as low as acceptable in providing heat to the far ends of the building.
2. Inspect return lines and condensate receiver for steam coming back to the boiler. Check radiator and main line traps.
3. Verify steam vents are operable and that all steam radiators receive steam during every cycle. Unplug vents or replace malfunctioning vents as necessary. Add vents to steam lines and radiators as needed to achieve this goal.
4. Check steam traps with a digital thermometer or listening device to detect any steam escaping from radiators through the condensate return. Replace leaking steam traps or their thermostatic elements.Consider installing remote sensing thermostats that vary cycle length according to outdoor temperature and include night-setback capability.
5. Repair leaks on the steam supply piping or on condensate return piping.



Steam traps: Steam enters the steam trap heating its element and expanding the fluid inside. The expanded element plugs the steam's escape with a valve.

6. Consider a flame-retention burner and electric vent damper as retrofits for steam boilers.
7. Clean fire side of heat exchanger of noticeable dirt.
8. All steam piping that passes through unconditioned areas should be insulated with pipe insulation rated for steam piping.

7.19 Programmable Thermostats



Inside a programmable thermostat: In addition to the instructions on the exterior of this thermostat are instructions inside for setting the heat anticipator.

A programmable thermostat may be a big energy saver if the building's occupants understand how to program it. A programmable thermostat won't save any energy if occupants already control day and night temperatures efficiently.

If you replace the existing thermostat, as a part of weatherization work, discuss programmable thermostats with occupants. If they can use a programmable thermostat effectively, then install one. Educate occupants on the use of the thermostat and leave a copy of manufacturer's directions with them before or after installation.

Many models of programmable thermostats have settings that you select from inside the thermostat. These settings include the heat-anticipator setting, which adjusts the cycle length of the heating or cooling system.

7.20 Electric Heat

Electricity is a more convenient form of energy than gas or other fuels, but it is considerably more expensive. Electric heaters are usually 100% efficient at converting the electricity to heat in the room where they are located.

7.20.1 Electric Baseboard Heat

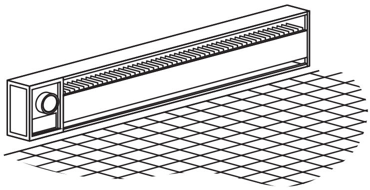
Electric baseboard heaters are zonal heaters controlled by thermostats within the zone they heat. Electric baseboard heat can reduce energy costs in many homes, if residents take advantage of the ability to heat by zones.

Baseboard heaters contain electric resistance heating elements encased in metal pipes. These are surrounded by aluminum fins to aid heat transfer. As air within the heater is heated, it rises into the room. This draws cooler air into the bottom of the heater.

1. Make sure that the baseboard heater sits at least an inch above the floor to facilitate good air convection.
2. Clean fins and remove dust and debris from around and under the baseboard heaters as often as necessary.
3. Avoid putting furniture directly against the heaters. To heat properly, there must be space for air convection.

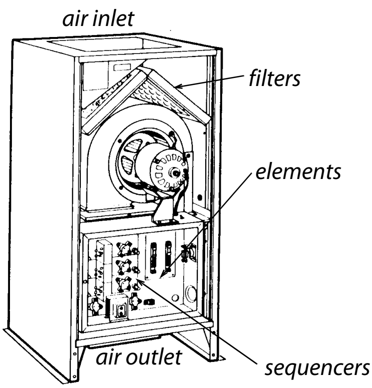
There are two kinds of built-in electric baseboard heaters: strip-heat and liquid-filled. Strip-heat units are less expensive than liquid-filled, but they don't heat as well. Strip-heat units release heat in short bursts, as the temperature of the heating elements rises to about 350°F. Liquid-filled baseboard heaters release heat more evenly and over longer time periods, as the element temperature is only 180°F.

The line-voltage thermostats used with baseboard heaters sometimes don't provide good comfort. This is because these thermostats allow the temperature in the room to vary by 2°F or more. Newer, more accurate thermostats are available. Programmable thermostats for electric baseboard heat use timers or a resident-activated button that raises the temperature for a time and then automatically returns to the setback temperature. Some baseboard heaters use low-voltage thermostats connected to relays that control baseboard heaters in rooms.



Electric baseboard: Electric baseboard is more efficient than an electric furnace and sometimes even outperforms a central heat pump because it is easily zoneable. The energy bill is determined by the habits of the occupants and the energy efficiency of the building.

7.20.2 Electric Furnaces



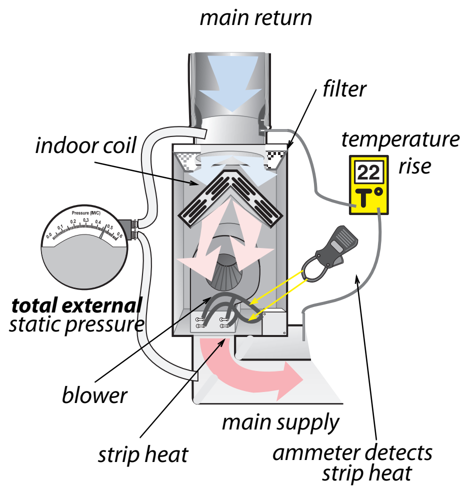
Electric furnace: A squirrel-cage blower blows air over 3 to 6 electric resistance coils and down into the plenum below the floor.

Electric furnaces are the most expensive way to heat a building. Electric furnaces have the most expensive energy source as well as inefficient ducts. Electric furnaces heat air moved by its fan over several electric-resistance heating elements. Electric furnaces have three to six elements — 3.5 to 7 kW each — that work like the elements in a toaster. The 24-volt thermostat circuit energizes devices called sequencers that bring the 240 volt heating elements on in stages when the thermostat calls for heat. The variable speed fan switches to a higher speed as more elements engage to keep the air temperature stable.

7.20.3 Central Heat-Pump Energy Efficiency

An air-source heat pump is almost identical to an air conditioner, except for a reversing valve that allows refrigerant to follow two different paths, one for heating and one for cooling. Heat pumps move heat with refrigeration rather than converting it from the chemical energy of a fuel.

Like air conditioners, air-source heat pumps are available as centralized units with ducts or as room units. Heat pumps are 1.5 to 3 times more efficient than electric furnaces. Heat pumps can provide competitive comfort and value with combustion furnaces, but they must be installed with great care and planning.



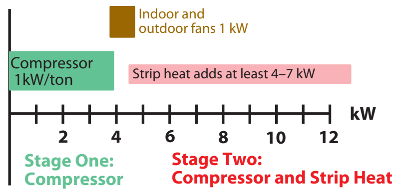
Heat pump: The air handler contains a blower, indoor coil, strip heat, and often a filter. Static pressure and temperature rise are two indicators of performance.

Heat pumps are also equipped with auxiliary electric resistance heat, called strip heat. The energy efficiency of a heat pump depends on how much of the heating load the compressor provides without using the strip heat.

Evaluating Heat Pumps During the Heating Season

Heat pumps should have two-stage thermostats designed for use with heat pumps. The first stage is compressor heating and the second stage is the inefficient strip heat. Evaluating heat pumps in the winter is more difficult than a summer evaluation. Consider these steps to evaluate heat pumps during the winter.

1. Look for a temperature rise of around half the outdoor temperature in degrees Fahrenheit.



Is strip heat activated? Using an ammeter and the nameplate data on the heat pump, a technician can know when and if the strip heat is activated.

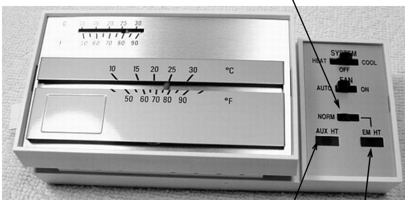
2. Check for operation of strip heat by measuring amperage. Then use the chart shown here to find out if strip heat is operating.

3. External static pressure should be 0.5 IWC (125 pascals) or less for older, fixed-speed blowers and less than 0.8 IWC (200 pascals) for variable-speed and two-speed blowers. Lower external static pressure promotes higher airflow.

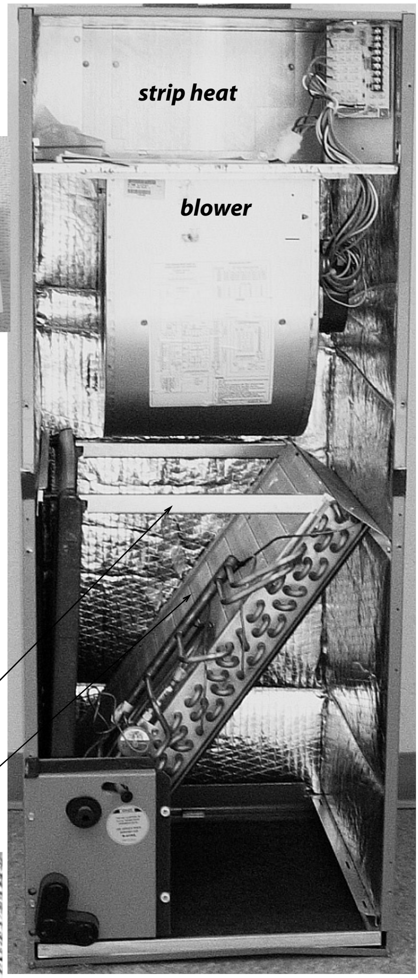
4. Seal supply and return ducts and insulate them after you've verified the airflow as adequate. Return ducts should be sealed too.

Most residential central heat pumps are split systems with the indoor coil and air handler indoors and outdoor coil and compressor outdoors. Individual room heat pumps are more efficient since they don't have ducts, and are factory-charged with refrigerant. The illustrations show features of an energy-efficient heat pump installation.

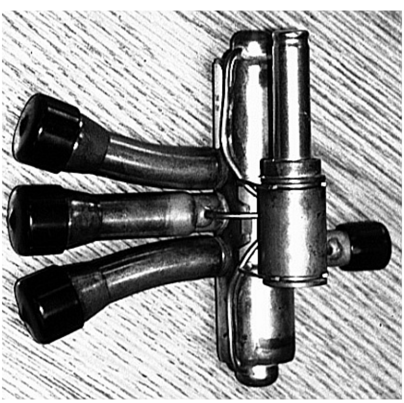
In the summer, use the same procedures to evaluate central heat pumps as to evaluate central air conditioners, described on *page 301*.



Heat pump thermostat: These should have two indicator lights, one for auxiliary heat and one for emergency heat.

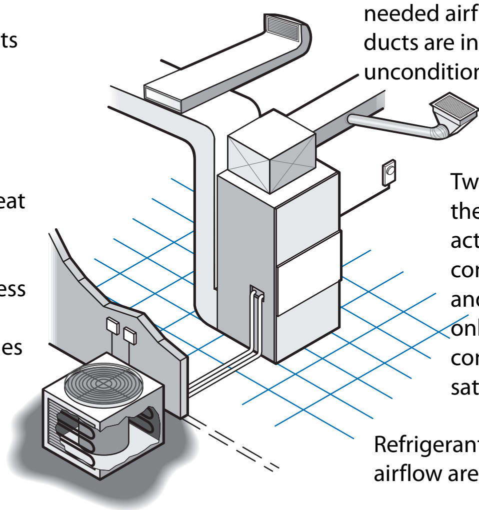


Heat pump: This upflow indoor air handler contains a blower, indoor coil, strip heat, and filter bracket.



Reversing valve: The outdoor unit contains a reversing valve installed near the compressor.

The illustration shows features of an energy-efficient heat pump installation.



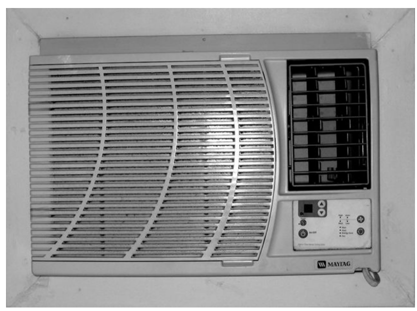
7.20.4 Room Heat Pumps

Room heat pumps can provide all or part of the heating and cooling needs for small homes. These one-piece room systems (also known as terminal systems) look like a room air conditioner, but provide heating as well as cooling. They can also provide ventilation air when neither heating nor cooling are required. They mount in a window or through a framed opening in a wall.

Room (or unitary) heat pumps can be a good choice for replacing existing unvented gas space heaters. Their fuel costs may be somewhat higher than gas furnaces, though they are safer and require less maintenance than combustion appliances. Room heat pumps also gain some overall efficiency because they heat a single zone and don't have the delivery losses associated with central furnaces or central boilers. If they replace electric resistance heat, they consume only one-half to one-third the electricity to produce the same amount of heat.

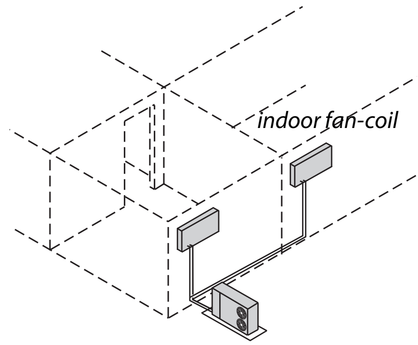
Room heat pumps draw a substantial electrical load, and may require 240-volt wiring. Provide a dedicated circuit that can supply the equipment's rated electrical input. Insufficient wiring capacity can result in dangerous overheating, tripped circuit breakers, blown fuses, or motor-damaging voltage drops. In most cases a licensed electrician should confirm that the house wiring is sufficient. Don't run portable heat pumps or any other appliance with extension cords or plug adapters.

Unitary heat pumps: These unitary ductless heat pumps sit inside an exterior wall. They are a very efficient kind of electric heating and cooling.



7.20.5 Ductless Minisplit Pumps

Minisplit heat pumps contain an outdoor condenser and one or more indoor fan-coil units that heat or cool the rooms. Mini-split heat pumps are among the most efficient heating and cooling systems available, providing 2-to-4 watt hours of heating or cooling for each watt hour of electricity they use. Specify minisplits heat pumps as replacement HVAC solutions when they are appropriate, for example.



Ductless mini-split heat pumps: These systems have very high efficiency: 200% to 400%.

1. Homes currently having no ducts.
2. Homes with poorly designed or deteriorating ducts outside the thermal boundary or located in inaccessible areas, such as floor cavities.
3. Isolated part of a building such as an addition or a bonus room.
4. Very well-insulated, airtight, and shaded homes.
5. Bedrooms needing cooling in homes with no central air conditioning.
6. Masonry buildings being retrofitted to replace to obsolete central space-conditioning systems (often steam).

7.21 Evaluating Ducted Central Air-Conditioning Systems

Problems with air conditioning often go hand in hand with problems with the building shell. An energy-efficient home shouldn't need more than a ton of air-conditioning capacity for every 1000 square feet of floor space. Window shading, attic insulation, and air leakage should be evaluated together with air-conditioner performance.

The following four installation-related problems are characteristic of central air conditioning systems.

1. Inadequate airflow.
2. Duct air leakage.
3. Incorrect charge.
4. Oversizing.

Refrigerant-charge tests and adjustment should come after airflow measurement and improvement, and after duct testing and sealing. This sequence is because the airflow should be adequate before you do duct-sealing in case you have to add or enlarge ducts. Manufacturers recommend that you verify adequate airflow before the refrigerant charge is checked and adjusted.

Table 7-19: Compiled Research Results on HVAC Performance[a]

Installation-Related Problem	%[b]	Savings Potential
Duct air leakage (Ave. 270 CFM_{25})[c]	70%	17% Ave.
Inadequate airflow	70%	7% Ave.
Incorrect charge	74%	12% Ave.
Oversized by 50% or more	47%	2–10%

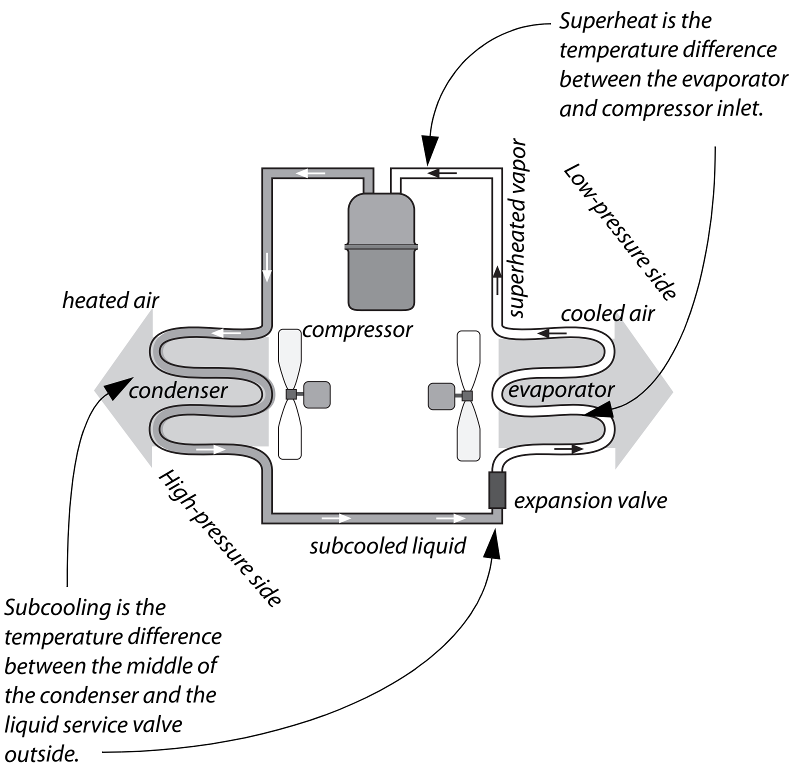
a. Report sponsored by Environmental Protection Agency (EPA) and compiled from research from Multiple Field Studies
b. Percent of tested homes found with a significant problem.
c. The number of homes of the duct-leakage studies was around 14,000; the number for the other problems was over 400 each.

7.21.1 Central Air-Conditioner Inspection

Air conditioners move a lot of air, and that air contains dust. The filter in the air handler is supposed to catch all the dust, but depending on how good the filter and its mounting assembly are, some dirt gets through or around the filter. The condenser coil outdoors isn't protected by a filter and is usually quite dirty.

1. Inspect the condenser coil and know that it is probably dirty even if it looks relatively clean on the outside. Take a flat toothpick and shove it in between the fins to the other side. Can you scrape dirt out from between the fins? Can you push the toothpick through the dirt?

2. Clean the condenser either with a biodegradable coil cleaner or by special high-pressure spray, used by professional coil cleaning contractors.



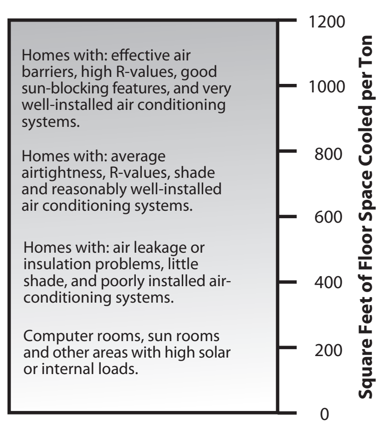
3. Inspect the filter slot in the air handler or the filter grille in the return air registers. Do the filters completely fill their opening? Is the filter dirty?

4. Inspect the blower in the air handler after disconnecting power to the unit. Can you remove significant dirt from one of the blades with your finger? If the blower is dirty, then the evaporator coil is also dirty.

5. Clean the blower and evaporator. Technicians should use an indoor coil cleanser for the cleaning.

7.21.2 Air-Conditioner Sizing

Calculate the correct size of an air conditioner before purchasing or installing it. An energy auditor or HVAC specialist can calculate the correct size using a computer.



Air-conditioner sizing: An energy-efficient home shouldn't need more than a ton of air-conditioner capacity per 1000 square feet of floor area.

The number of square feet of floor space that can be cooled by one ton of refrigeration capacity is determined by the home's energy efficiency. Air-conditioners provide cooling most cost-effectively when they are sized accurately and run for long cycles. The auditor's cooling-cost reduction strategy should focus on making the home more energy efficient and making the air conditioner work more efficiently. Making the home more efficient would involve shading, insulation and air leakage reduction. Making the air conditioner more efficient would involve either service or repair to remove installation-related flaws.

7.21.3 Duct Leakage and System Airflow

Unfortunately, duct leakage and poor airflow afflict most air-conditioning systems. The testing and mitigation of these problems was covered earlier.

1. *See "Evaluating Duct Air Leakage" on page 274.*
2. *See "Ducted Air Distribution" on page 263.*

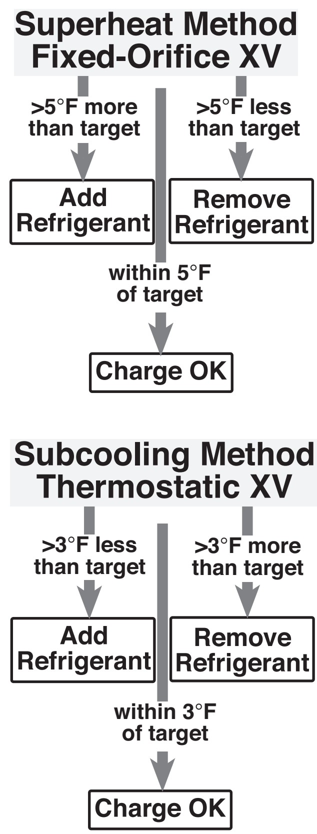
7.21.4 Evaluating Air-Conditioner Charge

Any complete weatherization job should include charge-checking. HVAC technicians evaluate refrigerant charge by two methods depending on what type of expansion valve the air conditioner has.

1. If the expansion valve has a fixed orifice, the technician performs a superheat test.
2. If the valve is a thermostatic expansion valve (TXV), the technician performs a subcooling test.

These two tests indicate whether the amount of refrigerant in the system is correct, which is directly related to the efficiency of the air-conditioning system.

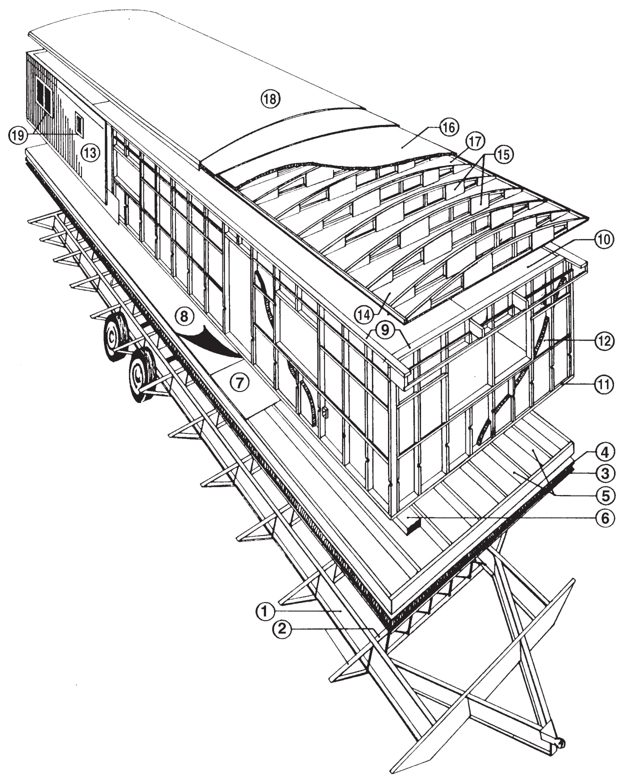
Charge-checking is performed after the airflow tests, airflow adjustments, and duct-sealing are complete. Do charge-checking during the cooling season while the air conditioner is operating.



Charge-checking: Two methods help technicians judge whether charge is correct. The remedy for incorrect charge is to either add or remove refrigerant.

Chapter 8: Mobile Homes

Mobile homes typically use more energy per square foot than site-built homes. Fortunately, their consistent construction makes them easy to weatherize. Mobile homes aren't governed by the International Residential Code 2009, allowing energy auditors more flexibility in specifying energy conservation measures (ECMs) for mobile homes' unique energy problems.



Typical components of a mobile home: 1–Steel chassis. 2–Steel outriggers and cross members. 3–Underbelly. 4–Fiberglass insulation. 5–Floor joists. 6–Heating/air conditioning duct. 7–Decking. 8–Floor covering. 9–Top plate. 10–Interior paneling. 11–Bottom plate. 12–Fiberglass insulation. 13–Metal siding. 14–Ceiling board. 15–Bowstring trusses. 16–Fiberglass insulation. 17–Vapor barrier. 18–Galvanized steel one-piece roof. 19–Metal windows.

Specify the following mobile home ECMs according to their cost-effectiveness, according to the Manufactured Home Energy Audit (MHEA). *See "SIR Calculations with Energy Software" on page 29.*

1. Duct sealing
2. Roof insulation
3. Air sealing
4. Wall insulation
5. Floor insulation
6. Heating service or replacement
7. Air-conditioning service or replacement

8.1 Mobile Home Air Sealing

The location and relative importance of mobile home air leaks were little known before blower doors. Some mobile homes are fairly airtight, and others are very leaky. Perform a blower door test during your energy audit to evaluate the

Air leakage serves as ventilation in most mobile homes. Observe the Minimum Ventilation Guidelines outlined in *"Evaluating Home Ventilation Levels" on page 78*.

A duct airtightness tester, which pressurizes the ducts and measures their air leakage, is the best way to measure and evaluate duct air sealing. *See "Evaluating Duct Air Leakage" on page 270.* For simply locating duct leaks, the blower door used in conjunction with a pressure pan does a good job. *See "Pressure Pan Testing" on page 272.*

Most mobile home duct sealing is performed through the belly. This work is more difficult once the belly has be re-insulated. Inspect the ductwork and seal any major leaks, such as disconnected trunk lines, before insulating the belly.

Table 8-1: Air Sealing Locations & Typical CFM_{50} Reduction

Air Sealing Procedure	Typical CFM_{50} Reduction
Patching large air leaks in the floor, walls and ceiling	200–900
Sealing floor cavity used as return-air plenum (*See "Floor return air" on page 312.*)	300–900
Sealing leaky water-heater closet	200–600
Sealing leaky supply ducts	100-500
Installing tight interior storm windows	100-250
Caulking and weatherstripping	50–150

Mobile home shell air leakage is often substantially reduced when insulation is installed in roofs, walls, and belly cavities. Prioritize your efforts by performing these tasks in this order.

1. Evaluate the insulation levels. If adding insulation is cost-effective, perform the usual pre-insulation air sealing measures that also prevent spillage of insulation out of the cavity.
2. Install cavity insulation. Perform duct sealing first if the belly is to be insulated.
3. Re-check the air leakage rate.
4. Perform additional air sealing as needed.
5. Install a ventilation fan if needed.

8.1.1 Shell Air Leakage Locations

Blower doors identify the following shell locations as the most serious air leakage sites.

1. Plumbing penetrations in floors, walls, and ceilings. Water-heater closets with exterior doors are particularly serious Air Leakage problems, having large openings into the bathroom and other areas

2. Torn or missing underbelly, exposing flaws in the floor to the ventilated crawl space
3. Large gaps around furnace and water heater chimneys
4. Severely deteriorated floors in water heater compartments
5. Gaps around the electrical service panel box, light fixtures, and fans
6. Joints between the halves of double-wide mobile homes and between the main dwelling and additions

Note: Window and door air leakage is more of a comfort problem than a serious energy problem.

8.1.2 Duct Leak Locations

Blower doors and duct testers identify the following duct locations as the most serious energy problems.

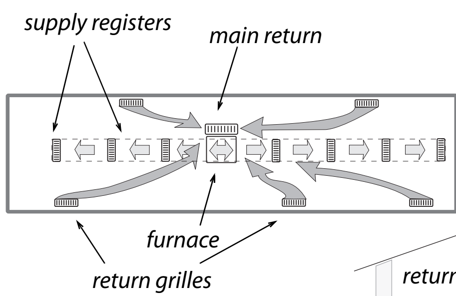
1. Floor and ceiling cavities used as return-air plenums — These floor return systems should be eliminated and replaced with return-air through the hall or a large grille in the furnace-closet door.
2. Joints between the furnace and the main duct — The main duct may need to be cut open from underneath to access and seal these leaks between the furnace, duct connector, and main duct. With electric furnaces you can access the duct connector by removing the resistance elements. For furnaces with empty A-coil compartments, you can simply remove the access panel to seal the duct connector.
3. Joints between the main duct and the short duct sections joining the main duct to a floor register
4. Joints between register boots and floor
5. The poorly sealed ends of the duct trunk, which often extend beyond the last supply register
6. Disconnected, damaged or poorly joined crossover ducts
7. Supply and return ducts for outdoor air conditioner units
8. Holes cut in floors by tradesmen.
9. New ductwork added to supply heat to room additions

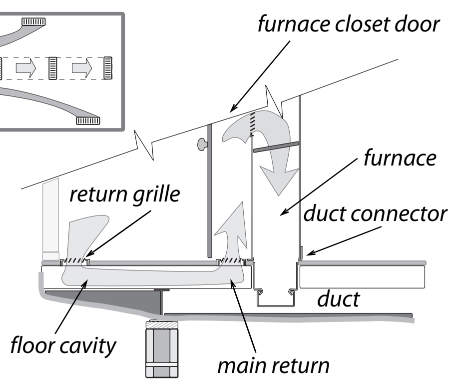
Caution installers to seal floor penetrations and ductwork before performing belly repair or insulation. Repair work can disturb pollutants in the crawl space such as mold and dust. Insulation can enter ducts. These pollutants can be drawn into the home by duct depressurization. Inspectors should inspect the ducts to ensure that insulation hasn't entered them.

8.1.3 Belly Pressure Test

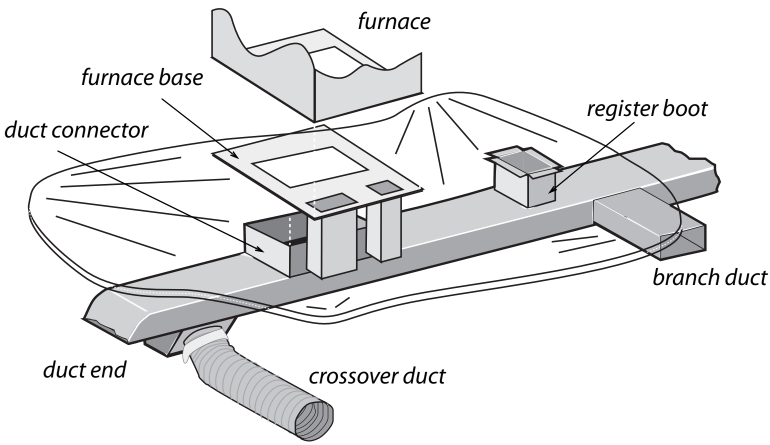
Energy auditors use this quick test to evaluate supply duct leakage.

1. Mobile home supply duct leaks pressurize the belly cavity. Follow these steps to perform this rough test to determine if duct leaks are present and their general location.
2. Repair the rodent barrier.
3. Turn on the air handler.
4. Insert a manometer hose into the belly through the rodent barrier and test the pressure with-reference-to the outdoors.
5. Start near the furnace, and work your way toward the ends alongside the trunk line. A pressure rise gives you a rough idea of the location of leaks, size of leaks, and tightness of the nearby rodent barrier.
6. Repair the ducts and re-test.

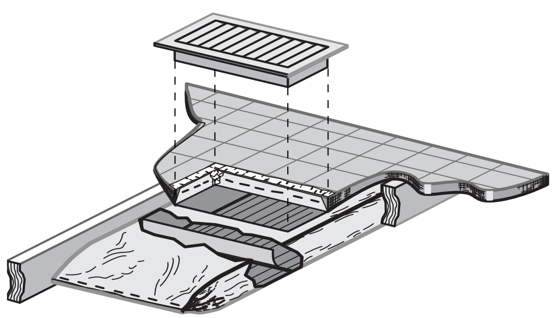




Floor return air: Return-air registers at the floor's perimeter bring air back to the furnace. The floor cavity serves as one big leaky return duct. When leakage is serious, the floor return system should be eliminated.



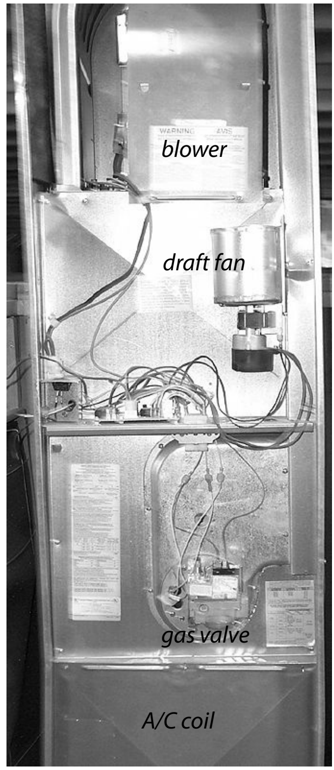
Mobile home ducts: Mobile home ducts leak at their ends and joints — especially at the joints beneath the furnace. The furnace base attaches the furnace to the duct connector. Leaks occur where the duct connector meets the main duct and where it meets the furnace. Branch ducts are rare, but easy to find, because their supply register isn't in line with the others. Crossover ducts are found only in double-wide and triple-wide homes.



Sealing the end of the main duct: The main duct is usually capped or crimped loosely at each end, creating a major air leakage point. Seal this area and improve airflow by installing a sheet metal ramp, accessed through the last register, inside the duct. Seal the ramp to the ductwork with metal tape and silicone or mastic.

8.2 Mobile Home Heating

Mobile home furnaces are similar to furnaces for site-built homes in some ways and different in other ways. Mobile home combustion furnaces have been sealed-combustion since the early 1970s. Gas furnaces are either the old atmospheric sealed-combustion type or the newer fan-assisted mid-efficiency furnaces. Some older less-efficient sealed-combustion furnaces had draft fans too.



Fan-assisted, mid-efficiency mobile home furnace: The draft fan draws outdoor air into the combustion chamber to feed combustion.

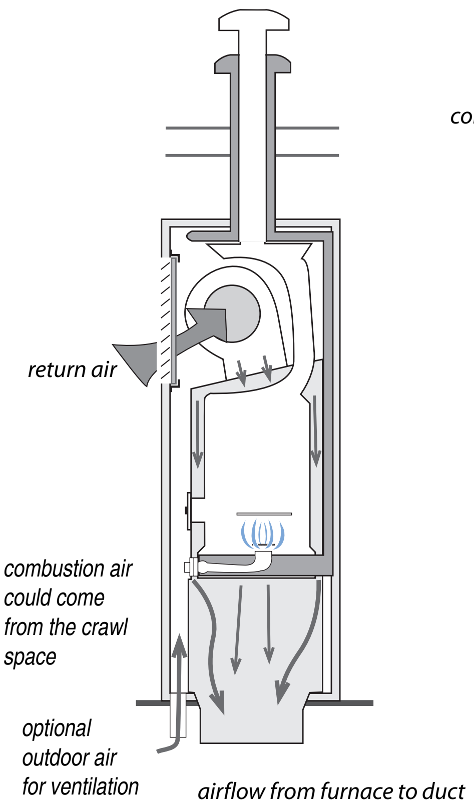
Mobile-home oil furnaces are a close relative to oil furnaces in site-built homes. However, they should have a housing that fits around the burner air shutter and provides outdoor air directly to the burner. See *"Oil Burner Safety and Efficiency Service" on page 236.*

Mobile-home furnaces are different from conventional furnaces in the following ways.

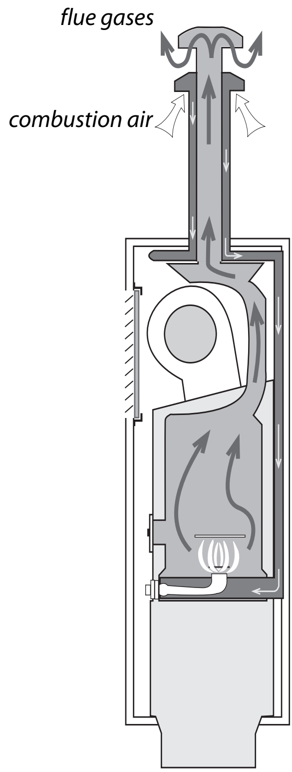
1. A great majority of mobile homes are equipped with downflow furnaces, designed specifically for mobile homes.
2. Mobile home combustion furnaces are sealed-combustion units that use outdoor combustion air, unlike most furnaces in site-built homes.
3. Gas-fired furnaces have kits attached, containing alternative orifices, to burn either propane or gas.

4. Return air is admitted to the furnace through a large opening in the furnace rather than return ducts.
5. Maintain manufactures listed clearances and ensure that insulation shield is present.
6. Seal the interior ceiling chimney perimeter with sheet metal (26 gauge) and high temperature sealant.

Important Note: Only furnaces designed for mobile homes should be installed in mobile homes. In addition, all applicable safety and local codes must be complied with for new installations and repairs.



Mobile home furnace airflow: Return air flows from the hallway through the furnace grill. The air is heated and distributed through the ducts.



Mobile home furnace combustion: Combustion air enters through the flue assembly on the roof and feeds the flame through a sealed passageway.

8.2.1 Furnace Maintenance and Energy Efficiency

Mobile home furnaces should comply with this guidebook's combustion safety and efficiency standards. See *"Combustion Efficiency Test for Furnaces" on page 228* and *"Oil Burner Testing" on page 238.*

8.2.2 Furnace Replacement

Mobile home furnaces must be replaced by furnaces designed and listed for use in mobile homes. If a heat exchanger is available to replace the existing cracked heat exchanger, consider heat-exchanger replacement as a repair priority instead of replacing the furnace.

Consider replacing the existing furnace with a sealed-combustion, downflow, condensing furnace. *See "Combustion Furnace Replacement" on page 212. See also "Condensing-Furnace Venting" on page 257.*

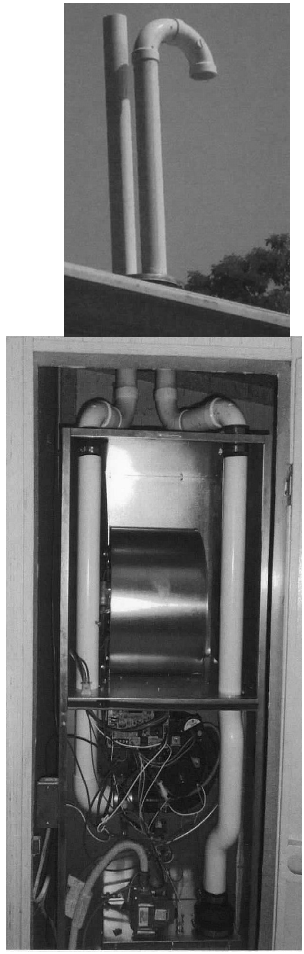
Mobile home furnaces may be replaced when any of the following is observed.

1. The furnace has a cracked heat exchanger.
2. Repair and retrofit exceed half of the replacement cost.
3. The furnace isn't operating and isn't repairable.

Mobile home furnaces require an outdoor source of combustion air. Mobile home furnaces have either a manufactured chimney that includes a passageway for combustion air or a combustion-air chute connecting the burner with the crawl space.

1. Size the new furnace to meet the heating/cooling load, according to Manual J calculations.
2. Install a new furnace base unless you're sure that the existing base exactly matches the new furnace.
3. Attach the furnace base firmly to the duct, and seal all seams between the base and duct with mastic and fabric tape before installing the furnace.

4. Support the main duct underneath the furnace with additional strapping if necessary.
5. When replacing mobile home furnaces, note the differences between old furnace and new in the way each supplies itself with combustion air.
6. Install a new chimney that is manufactured specifically for the new furnace.
7. If the old chimney opening doesn't exactly line up with the new furnace's flue, cut the opening larger so that the new chimney can be installed plumb. Also make sure the chimney cap is installed absolutely straight.
8. Repair the roof around the new chimney and seal the area around the chimney to be permanently waterproof.
9. If the new furnace isn't compatible with an existing air conditioner, contact your program monitor



Mobile home condensing furnace: One plastic pipe brings combustion air in and the other exhausts warm combustion gases to outdoors.

Disposing of Condensate

Mobile homes seldom have floor drains in which to discharge the condensation from the combustion process. Follow these guidelines for disposing of the furnace's condensate.

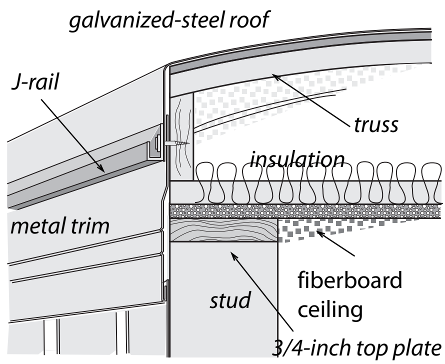
1. Dispose of condensate, using drain piping according to manufacturer's instructions into an area where the condensate won't cause any problems.
2. If local experience indicates that condensate is a problem, collect liquid condensation from condensing furnaces discharge it into an approved plumbing fixture or disposal area in accordance with the manufacturer's installation instructions.
3. If the condensate needs to be neutralized, use a condensate-neutralizer kit designed for use with condensing furnaces.

8.3 Mobile Home Insulation

Specify that installers solve all significant moisture problems before insulating. The most important single moisture-control measure is installing a ground-moisture barrier. *See "Moisture Problems" on page 340. See also "Ground Moisture Barriers" on page 175.*

8.3.1 Insulating Mobile Home Roof Cavities

Blowing a closed mobile home roof cavity is similar to blowing a closed wall cavity, only the insulation doesn't have to be as dense. Specify fiberglass blowing wool because cellulose is too heavy and absorbs water too readily for use around a mobile home's lightweight sheeting materials.



Bowstring roof details: Hundreds of thousands of older mobile homes were constructed with these general construction details.

There are three common and effective methods for blowing mobile home roof cavities.

1. Cutting a square hole in the metal roof and blowing fiberglass through a flexible fill-tube.
2. Disconnecting the metal roof at its edge and blowing fiberglass through a rigid fill-tube.
3. Blowing fiberglass through holes drilled in the ceiling.

Preparing to Blow a Mobile Home Roof

Require installers to follow these preparatory steps before insulating mobile home roofs.

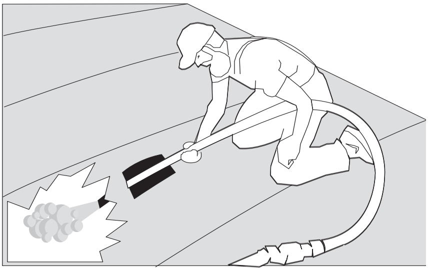
1. Reinforce weak areas in the ceiling.
2. Inspect the ceiling, and seal all penetrations.
3. Install blocking to maintain safe clearances between insulation and recessed light fixtures and ceiling fans.

Blowing Through the Top

Blowing through the roof top does a good job of filling the critical edge area with insulation, and the patches are easy to install if you have the right materials. However, since the roof will be vulnerable to rain or snow during the job, installers should complete the work during good weather.

If the roof contains a strongback running the length of the roof, the holes should be centered over the strongback, which is usually near the center of the roof's width. A strongback is a 1-by-4 or a 1-by-6, installed at a right angle to the trusses near their center point, that adds strength to the roof structure.

1. Cut 10-inch square holes at the roof's apex on top of every second truss. Each square hole permits access to two truss cavities.
2. Use a 2-inch or 2-1/2-inch diameter fill-tube. Insert the fill-tube and push it forcefully out toward the edge of the cavity.
3. Blow fiberglass insulation into each cavity.

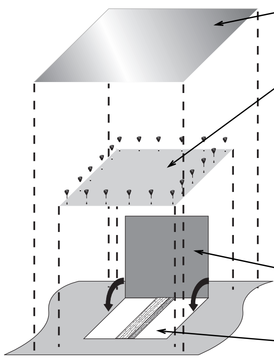


Roof-top insulation: Blowing fiberglass insulation through the roof top is effective at achieving good coverage and density on almost any metal roof.

4. Stuff the area under each square hole with a piece of unfaced fiberglass batt so that the finished roof patch will stand a little higher than the surrounding roof.

5. Patch the hole with a 14-inch-square piece of stiff galvanized steel, sealed with roof cement and screwed into the existing metal roof.

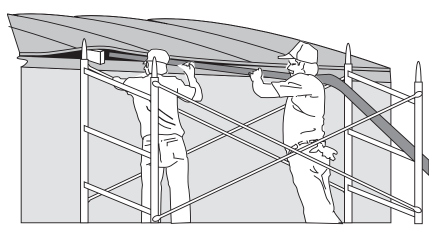
6. Cover the first patch with a second patch, consisting of an 18-inch-square piece of foil-faced butyl rubber.



Square roof patch: An 18-inch square of foil-faced butyl rubber covers a base patch of galvanized steel, which is cemented with roof cement and screwed with self-drilling screws.

Blowing a Mobile Home Roof from the Edge

Erect scaffold to do this procedure safely and efficiently. Mobile home metal roofs are usually fastened only at the edge, where the roof joins the wall.



Roof-edge blowing: Use a rigid fill tube to blow insulation through the roof edge. This avoids making holes in the roof itself, though this process requires much care in refastening the roof edge.

1. Remove the screws from the metal j-rail at the roof edge. Also remove staples or other fasteners, and scrape off putty tape.

2. Pry the metal roof up far enough to insert a 2-inch-diameter, 10- to 14-foot-long rigid fill-tube. Two common choices are steel muffler pipe and aluminum irrigation pipe. Inspect the cavity with a bright light to identify any wires or piping that could be damaged by the fill tube.
3. Blow insulation through the fill-tube into the cavity. Turn off the insulation-material feed and blower on the blowing machine when the tube is a couple feet from the roof edge, in order to avoid blowing insulation out through the opening in the roof edge. Stuff the last foot or two with unfaced fiberglass batts.
4. Fasten the roof edge back to the wall using galvanized roofing nails, a new metal j-rail, new putty tape, and larger screws. The ideal way to re-fasten the metal roof edge is with air-driven galvanized staples, which is the way most roof edges were attached originally.

The re-installation of the roof edge is the most important part of this procedure. Putty tape must be replaced and installed as it was originally. This usually involves installing a layer of putty tape or a bead of high quality caulk under the metal roof and another between the metal roof edge and the j-rail.

The advantages of blowing through the edge is that if you have the right tools, including a powered stapler, this method can be very fast and doesn't require cutting into the roof. The disadvantages of this procedure are that you need scaffolding to work at the edges, and it won't work on roof systems with a central strongback that stops the fill tube from reaching all the way across the roof.

Blowing a Mobile Home Roof from Indoors

The advantage to this method is that you are indoors, out of the weather. The disadvantages include being indoors where you can make a mess — or worse, damage something.

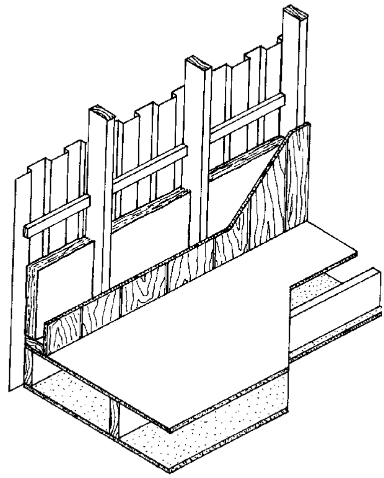
Blowing the roof cavity from indoors requires the drilling of straight rows of 3-inch or 4-inch holes and blowing insulation into the roof cavity through a fill tube.

Specify this procedure.

1. Drill a 3-inch or 4-inch hole in an unseen location to discover whether the roof structure contains a strong-back that would prevent blowing the roof cavity from a single row of holes.
2. Devise a way to drill a straight row of holes down the center of the ceiling. If a strongback exists, drill two rows of holes at the quarter points of the width of the ceiling.
3. Insert a flexible plastic fill tube into the cavity, and push it as far as possible toward the edge of the roof.
4. Fill the cavity with tightly packed fiberglass insulation.
5. Cap the holes with manufactured plastic caps. Care must be taken not to damage the holes so that the plastic hole covers fit properly. You can also install a piece of painted wood trim over the line of holes.

Blowing through the ceiling: The contractor pushes the fill-tube into the cavity and out near the edge of the roof. The holes are drilled in a straight line for appearance sake.

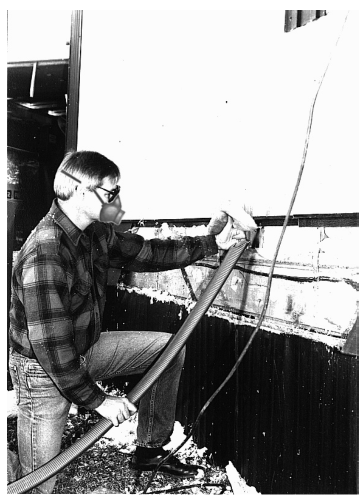
8.3.2 Mobile Home Sidewall Insulation



Standard mobile home construction: 2-by-4 walls and 2-by-6 floor joists are the most common construction details

The sidewalls of many mobile homes aren't completely filled with insulation. This reduces the nominal R-value of the existing wall insulation because of convection currents and air leakage. Specify these steps for adding insulation to partially filled mobile home walls.

1. Check the interior paneling and trim to make sure they are securely fastened to the wall. Repair holes in interior paneling and caulk cracks at seams to prevent indoor air from entering the wall. Note the location of electrical boxes and wire to avoid hitting them when you push the fill tube up the wall.



Adding insulation to mobile home walls: A contractor uses a fill tube to install more insulation in a partially filled mobile home wall.

2. Remove the bottom horizontal row of screws from the exterior siding. If the vertical joints in the siding interlock, fasten the bottom of the joints together with $^1/_2$-inch sheet metal screws to prevent the joints from coming apart. Pull the siding and existing insulation

away from the studs, and insert the fill tube into the cavity with the point of its tip against the interior paneling.

3. Push the fill tube up into the wall cavity until it hits the top plate of the wall. The tube should go in to the wall cavity 7-to-8 feet. It is important to insert the tube so that its natural curvature presses its tip against the interior paneling. When the tip of the fill tube, cut at an angle, is pressed against the smooth paneling, it is least likely to snag the existing insulation on its way up the wall. If the fill tube hits a belt rail or other obstruction, twisting the tube will help its tip get past the obstruction.

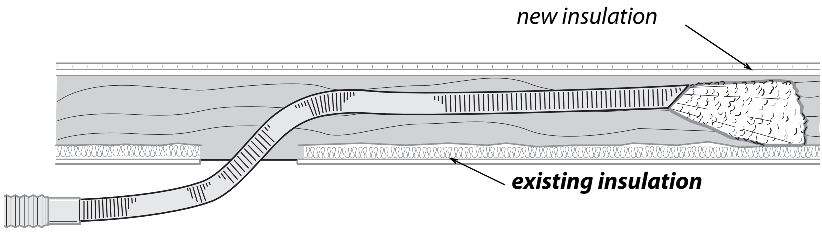
4. Stuff a piece of fiberglass batt into the bottom of the wall cavity around the tube to prevent insulation from blowing out of the wall cavity. Leave the batt in-place at the bottom of the wall, when you pull the fill tube out of the cavity. This piece of batt acts as temporary gasket for the hose and insulates the very bottom of the cavity after the hose is removed. This batt also eliminates the need to blow fiberglass insulation all the way to the bottom, preventing possible spillage and overfilling. If you happen to overfill the bottom of the cavity, reach up inside the wall to pack or remove some fiberglass insulation, particularly any that lies between the loose siding and studs.

5. Draw the tube down and out of the cavity about 6 inches at a time. Listen for the blower fan to indicate strain from back-pressure in the wall. Watch for the fiberglass insulation to slow its flow rate through the blower hose at the same time. Also watch for slight bulging of the exterior siding. These signs tell the installer when to pull the tube down.

6. Carefully refasten the siding using the same holes. Use screws that are slightly longer and thicker than the original screws.

8.3.3 Mobile Home Floor Insulation

Mobile home floor insulation is a good energy-saving measure in cool climates. The original insulation is usually fastened to the bottom of the floor joists, leaving much of the cavity uninsulated and subject to convection currents. This greatly reduces the insulation's R-value. Blown-in belly insulation also tends to control duct leakage.



Blowing bellies: A flexible fill-tube, which is significantly stiffer than the blower hose, blows fiberglass insulation through a hole in the belly from underneath the home.

Preparing for Mobile Home Floor Insulation

Prior to installing floor insulation, always perform these repairs.

1. Repair plumbing leaks.
2. Tightly seal all holes in the floor.
3. Inspect and seal ducts.
4. Repair the rodent barrier.
5. Install a ground-moisture barrier in the crawl space if the site is wet.

Patching the Belly

Mobile homes have two common types of belly covering: rigid fiber board and flexible paper or fabric. The fiberboard is normally stapled to the bottom of the floor joists. To patch a rigid belly, simply screw or staple plywood or another rigid material over the hole.

Flexible belly material may have no solid backing behind the hole or tear because the material forms a bag around the main duct, which is installed below the floor joists. In this case, use both adhesive and stitch staples to bind the flexible patch to the flexible belly material.

Insulating the Floor

Specify one of these two methods of insulating mobile home floors. Recommend blown fiberglass over cellulose.

1. Drilling through the 2-by-6 rim joist and blowing fiberglass through a rigid fill tube into the belly.
2. Blowing fiberglass insulation through a flexible fill tube or a rigid fill tube into the underbelly.

First repair all holes in the belly. Use mobile home belly-paper, silicone sealant, and stitch staples. Use these same patches over the holes cut for fill-tubes. Screw wood lath over weak areas if needed.

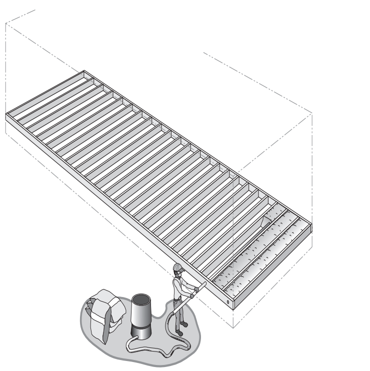
Patching a flexible belly: The technicians uses both adhesive and stitch staples to fasten a patch.

Blowing a floor through the belly: The contractor inserts a rigid fill tube through the belly to blow insulation into the floor cavity and underbelly.

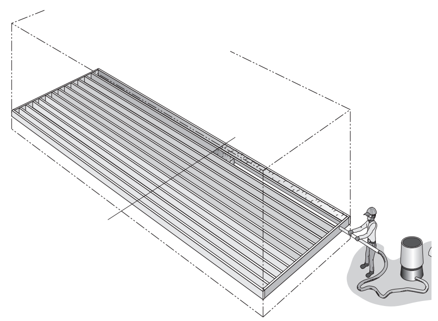
When blowing through holes from underneath the home, consider blowing through damaged areas before patching them.

Identify any plumbing lines, and avoid installing insulation between them and the living space if freezing could be an issue. Installers can fasten a piece of belly-paper under the pipes, and insulate the resulting cavity, to include the pipes in the heated home's heated space.

Installers may also use unfaced fiberglass batts to insulate floor sections where the insulation and belly are missing. The insulation should be supported by lath, twine, or insulation supports.



Blowing crosswise cavities: Blowing insulation into belly is easy if the floor joists run crosswise. However, the dropped belly requires more insulation than a home with lengthwise joists.

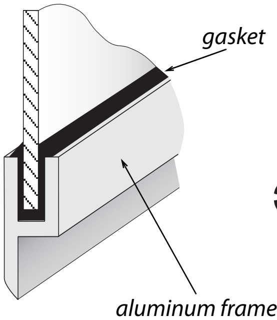


Blowing lengthwise cavities: Floors with lengthwise joists can rarely be filled completely from the ends because of the long tubing needed. The middle can be filled from underneath.

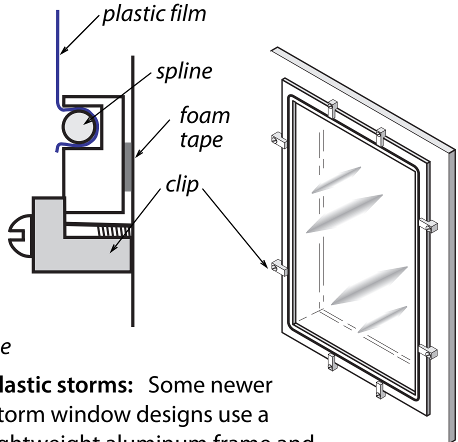
8.4 Mobile Home Windows and Doors

Installing storm windows or replacing existing windows is expensive per square foot and isn't as cost-effective as insulation. However, storm windows and replacement windows are both ECMs that are worth considering depending on the condition of existing windows and the cost-effectiveness of these ECMs.

8.4.1 Mobile Home Storm Windows



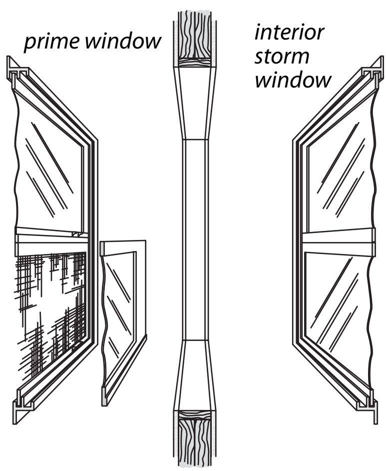
Glass interior storms: Traditional mobile home storm windows have aluminum frames glazed with glass.



Plastic storms: Some newer Storm window designs use a lightweight aluminum frame and flexible or rigid plastic glazing.

Interior storm windows are common in mobile homes. These stationary interior storms insulate awning and jalousie windows. Sliding interior storm windows pair with exterior sliding prime windows.

1. Interior storm windows double the R-value of a single-pane window. They also reduce air leakage, especially in the case of leaky jalousie prime windows.
2. Consider repairing existing storm windows rather than replacing them unless the existing storm windows can't be re-glazed or repaired.



Mobile home double window: In mobile homes, the prime window is installed over the siding outdoors, and the storm window is installed indoors.

3. When sliding primary windows are installed, use a sliding storm window that slides from the same side as the primary window. Sliding storm windows aren't removed seasonally, so they are less likely to be lost or broken than fixed storm windows.

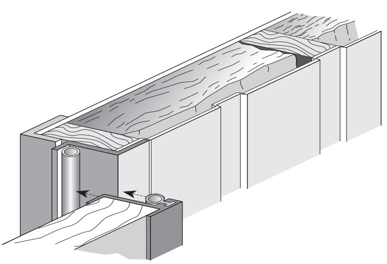
8.4.2 Replacing Mobile Home Windows

Replacement windows should have lower U-factors than the windows they replace. Inspect condition of rough opening members before specifying window replacement. Installers should replace deteriorated, weak, or waterlogged framing members.

Prepare the replacement window by lining the perimeter of the inner lip with $^{1}/_{8}$-inch thick putty tape. Caulk exterior window frame perimeter to wall after installing the window.

8.4.3 Mobile Home Doors

Mobile home doors come in two basic types: the mobile home door and the house-type door. Mobile home doors swing outwardly, and house-type doors swing inwardly. House-type doors are available with prehung storm doors included.



Mobile home door: Mobile home doors swing outwardly and have integral weatherstrip.

8.5 Cool Roofs for Mobile Homes

Cool roof coatings reduce summer cooling costs and improve comfort by reflecting solar energy away from the home's roof and slowing the flow of heat into the home. Cool roof coatings can reduce cooling costs by 10-20%, and are a good ECM for mobile homes or site-built homes with low slope or flat roofs.

Cool roof coatings are usually bright white, and must have a reflectivity of at least 60% to meet the ENERGY STAR or equivalent requirement for cool roof coatings.

Cool roof coatings are usually water-based acrylic elastomers, and are applied with a roller. They can be applied over most low-sloped roofing such as metal, built-up asphalt, bitumen, or single ply membranes. Some underlying roofing materials require a primer to get proper adhesion. Check the manufacturer's recommendations for asphalt-shingle roofs before specifying a cool roof.

Surface preparation is critical when applying any roof coating. The underlying roofing materials must be clean so that the coating sticks. Installers should repair and prime the roof if the existing roofing is cracked or blistered. Roof coatings won't stick to dirty or greasy surfaces, and won't by itself repair deep cracks in roof surfaces.

Specify the following preparatory steps for installing cool roof coatings.

1. Install the coating when dry weather is predicted. Rain heavy dew, or freezing weather, if it happens within 24 hours of installation, will weaken the coating's bond to the underlying roofing.

2. Protect any nearby windows, siding, or automobiles from splatters. For roller application, use a large brush for the edges, and a shaggy 1 to 1 1/2-inch roller on a 5- or 6- foot pole for the field. Run the coating up the roof jacks and other penetrations to help seal these areas. Install at least two coats, with second coat applied in the opposite direction to the first to get more complete coverage. Allow a day for drying between coats.

3. Clean the roof of loose roofing material and other debris.

4. Wash the roof with a water/try-sodium phosphate (tsp) solution, or comparable mildew-cide, and scrub brush. Better yet, use a pressure washer.

5. Buy the highest quality coatings, and look for those that are specifically formulated as mobile home roof coatings.

6. Reinforce any open joints around skylights, pipe flashing, roof drains, wall transitions, or HVAC equipment. For build-up asphalt or bitumen roofs, repair any cracks, blisters, or de-laminations. Use polyester fabric and roof coating for these reinforcements and repairs by dipping fabric patches in the roof coating and spreading them over the existing roofing, or by laying dry fabric into a layer of wet coating. Smooth the patches down with a broad-knife or squeegee to remove bubbles or wrinkles. Allow any repairs to cure for 1 to 2 days before applying the topcoat.

7. For metal roofs, sand any rusted areas down to sound metal. Install metal patches over any areas that are rusted through, followed by polyester patches as described above.

8.6 Mobile Home Skirting

The primary purpose of skirting is to keep animals out of the crawl space. Skirting must be vented to reduce moisture accumulation in many climates, so there isn't much value in insulating it.

Installation and repair of mobile home skirting is seldom cost-effective. Locate the thermal boundary at the floor of mobile homes.

CHAPTER 9: HEALTH AND SAFETY

This chapter discusses some of the most important hazards that you find both in residential buildings and on the job.

When you find serious safety problems in a home, you should inform the customer about the hazards and suggest how to remove them. Improve major hazards and potentially life-threatening conditions before or during your work on the building.

For detailed guidance on what work can and can't be done using DOE Health and Safety funds, please refer to the Health and Safety table on *page 378*.

Customer Health and Safety

House fires, carbon-monoxide poisoning, moisture problems, and lead-paint poisoning are the most important health and safety problems found in homes. Alert residents to any health and safety hazards that you find.

1. Ask occupants to discuss known or suspected health concerns, and take extra precautions based on occupant sensitivity to environmental hazards.
2. Inspect the home for fire hazards such as improperly installed electrical equipment, flammable materials stored near combustion appliances, or malfunctioning heating appliances. Discuss these hazards with the occupant, and remove these hazards if possible.
3. Test combustion appliances for carbon monoxide and related hazards. Also measure carbon monoxide (CO) in the ambient air. Investigate and eliminate CO.
4. Find moisture problems, and discuss them with the occupant. Never make moisture problems worse with your work. *See page 340.*

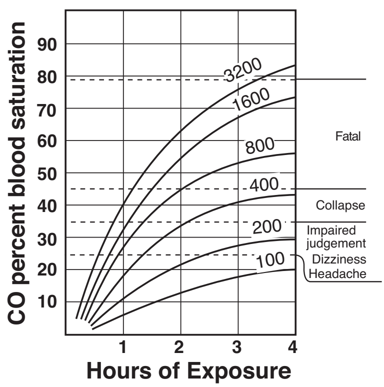
5. Obey the EPA Repair, Renovation, and Painting rules when working on homes built before 1978. Prevent dust during all weatherization projects. Explain the lead paint hazard and tell residents what you're doing to protect them. *See page 348.*

Worker Health and Safety

In the worker-safety section at the end of this chapter, we discuss the most dangerous hazards present during weatherization and how to avoid these hazards. Hazards include: driving, falls, back injuries, cuts, chemical exposure, repetitive stress, and electrical shocks.

9.1 Carbon Monoxide (CO)

The EPA's suggested maximum 8-hour CO exposure is 9 ppm in room air. CO at or above 9 ppm is often caused by malfunctioning combustion appliances in the home, although cigarette smoking or automobile exhaust are also common CO sources.



Effects of CO: This graph's 6 curves represent different CO exposure levels in parts per million.

9.1.1 Causes of Carbon Monoxide

CO is often caused by unvented gas space heaters, kerosene space heaters, backdrafting vented space heaters, gas ranges, leaky wood stoves, and motor vehicles idling near the home. Central furnaces and boilers that backdraft may also lead to high levels of CO.

Measure CO at the exhaust port of the heat exchanger. CO is usually caused by these things.

1. Gas appliances that are overfired compared to their rated input.
2. Backdrafting of combustion gases that are smothering the flame.
3. An object interferes with the flame (a pan over a gas burner on a range top, for example).
4. Too-little combustion air.
5. Rapidly moving air interferes with the flame.
6. Misalignment of the burner causes a distorted flame.
7. Blockage in the flue or heat exchanger interferes with the flow of flue gases.

Identify and correct these problems.

Testing for Carbon Monoxide

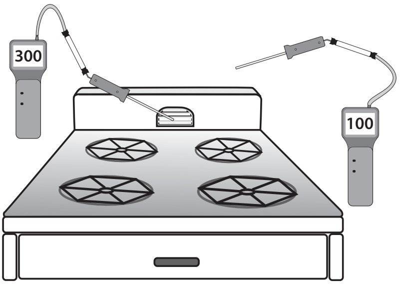
The most common CO-test instruments use electronic sensors with a digital displays showing parts per million (ppm). Read the manufacturer's instructions on zeroing the meter — usually by adjusting the meter in outdoor air. CO test equipment must usually be re-calibrated every 6 months, using factory-specified procedures.

Air-free CO measurement includes both CO and O_2 sensing with a calculation to find the CO concentration in undiluted flue gases that contain no oxygen. Air-free CO measurement avoids the perception that moving the testing probe or diluting CO are solutions to elevated levels of CO. *See "Carbon Monoxide (CO) Testing" on page 204.*

Technicians must test for CO both before and after weatherization.

9.1.2 Gas Range and Oven Safety

Gas ovens can release CO into a kitchen. Oven burners are far more likely to release CO compared to range top burners so the oven burner is the most important burner to evaluate. Test the oven for combustion safety with these steps and take the recommended actions.



CO from range and oven: Measure CO at oven in undiluted flue gases. Measure CO at burners from8″ away.

1. Turn the oven on and set it to bake on high temperature. Sample the CO level in exhaust gases at the oven vent and in the ambient air after 10 minutes.
2. If the CO reading is over 100 ppm or if the ambient-air reading rises to 25 ppm or more during the test, discontinue testing. Take action to reduce CO, including cleaning the oven, removing aluminum foil, adjusting the burner's gas control, or replacing the range and oven. Many range and oven burners are equipped with adjustable needle-and-seat valves.
3. If you suspect that the stove burners are producing CO, test each stove-top burner separately, using a digital combustion analyzer or CO meter. Hold the probe about 8 inches above the flame.
4. Clean and adjust burners producing more than 25 parts per million (ppm). Burners may have an adjustable gas control.

Client Education about Ranges

Program funds can't be spent to replace a range/oven. Educate clients about the following safety practices in using their gas range.

1. Never use a range burner or gas oven as a space heater.

2. Open a window, and turn on the kitchen exhaust fan when using the range or oven.
3. Buy and install a CO alarm, and discontinue use of the oven and range burners if the CO level rises above 9 ppm.
4. Never install aluminum foil around a range burner or oven burner.
5. Keep range burners and ovens clean to prevent dirt from interfering with combustion.
6. Burners should display hard blue flames. Yellow or white flames, wavering flames, or noisy flames should be investigated by a trained gas technician.

Caution: To protect yourself and the occupants, measure ambient air in the kitchen during these tests. The ambient air should never be more than 9 parts per million (ppm).

CO Mitigation for Ovens

When you measure CO at 100 ppm as measured, either at the oven vent while the oven is lit or one foot above the burners while they are lit, do these two steps.

1. Make adjustments to reduce the CO level, or recommend a service call by a gas combustion specialist to adjust the fuel-air mixture of the burners.
2. Install a CO alarm in the kitchen.

In the case of CO measurements greater than the above standards, arrange an immediate service call to identify and correct the cause of CO production. Install an exhaust fan with a capacity of 100 cubic feet per minute (cfm) in the kitchen.

Kitchen exhaust fans installed as part of weatherization work must vent to outdoors and be equipped with these features.

1. Solid metal ducting to the outdoors.
2. A weatherproof termination fitting.
3. A backdraft damper, installed in the fan housing or termination fitting.
4. Noise rating of less than 2 sones.

Advanced 4-speed range fan: Lower speeds for continuous ventilation and higher ones for spot ventilation.

9.2 Smoke and Carbon Monoxide Alarms

All homes should have at least one smoke alarm on each level, including one near the combustion zone and at least one near the bedrooms. Carbon monoxide (CO) alarms are appropriate wherever the CO hazard is likely.

Combination CO alarm/smoke alarms are now available. Single-function alarms or combination alarms can be interconnected for whole-house protection. If one alarm sounds the other alarms sound too.

Educate occupants about the alarms and what to do if an alarm sounds. Also discuss alarm testing and lifespan. These are the specifications for installing CO alarms and smoke alarms.

9.2.1 Smoke Alarms

Install smoke alarms in homes where they don't exist or don't work.

1. Install one smoke alarm in each home on each floor.
2. If mounted on a wall, mount the alarm from 4 to 12 inches from the ceiling.
3. If mounted on a ceiling, mount the alarm at least 6 inches from the nearest wall.

4. If battery powered, prefer long-life lithium batteries.
5. If hard wired, connect the alarm to a circuit that is energized at all times.

Don't install smoke alarms in these situations.

1. Within 12 inches of exterior doors and windows
2. With an electrical connection to a switched circuit
3. With a connection to a ground-fault interrupter circuit (GFCI)

9.2.2 CO Alarms

Install at least one CO alarm in all weatherized homes or weatherized apartments. CO alarms must comply with these specifications.

1. Have a label with a UL 2034 listing.
2. If hard wired, connect to a circuit that is energized at all times by plugging in to an electrical receptacle.
3. If battery powered, prefer long-life lithium batteries.
4. Have a digital display of the CO measurement.
5. Have a sensor-life alarm.

Don't install CO alarms in these cases.

1. In a room that may get too hot or cold for alarm to function properly
2. Within 5 feet of a combustion appliance, vent, or chimney
3. Within 5 feet of a storage area for vapor-producing chemicals
4. Within 12 inches of exterior doors and windows
5. Within a furnace closet or room
6. With an electrical connection to a switched circuit

7. With a connection to a ground-fault interrupter circuit (GFCI)

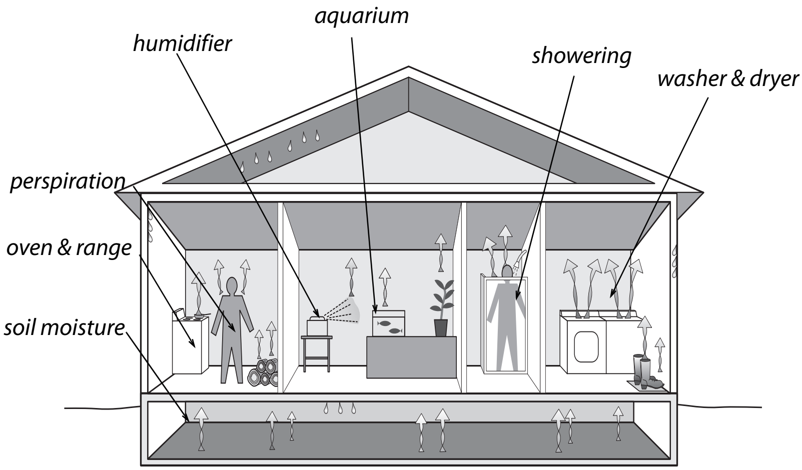
9.3 Moisture Problems

Moisture causes billions of dollars worth of property damage, sickness, and high energy bills each year in American homes. Water damages building materials by dissolving glues and mortar, corroding metal, and nurturing pests like mold, dust mites, and insects. These pests, in turn, cause many cases of respiratory illness.

Water reduces the thermal resistance of insulation and other building materials. High humidity also increases air-conditioning costs because the air conditioner removes moisture from the air to provide comfort.

The most common sources of moisture are leaky roofs and damp foundations. Other critical moisture sources include dryers venting indoors, showers, cooking appliances, and unvented gas appliances like ranges or decorative fireplaces. Clients control many of these moisture sources, so educate them about how to reduce the moisture sources discussed here.

Climate is also a major contributor to moisture problems. The more rain, extreme temperatures, and humid weather a region experiences, the more its homes are vulnerable to moisture problems.



Moisture sources: Household moisture can often be controlled at the source by informed and motivated occupants, who work to control moisture sources like these.

Reducing moisture sources is the first priority for solving moisture problems. Next most important are air and vapor barriers to prevent water vapor from migrating through building cavities. Relatively tight homes need mechanical ventilation to remove accumulating water vapor.

Table 9-1: Moisture Sources and Their Potential Contributions

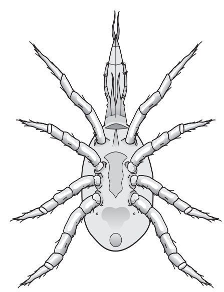
Moisture Source	Potential Amount Pints
Ground moisture	0–105 per day
Unvented combustion space heater	0.5–20 per hour
Seasonal evaporation from materials	6–19 per day
Dryers venting indoors	4–6 per load
Dish washing	1–2 per day
Cooking (meals for four persons)	2–4 per day
Showering	0.5 per shower

9.3.1 Symptoms of Moisture Problems

Condensation on windows, walls, and other cool surfaces signals high relative humidity and the need to reduce moisture sources. During very cold weather or summer air conditioning, condensation may occur on cold surfaces. This occasional condensation isn't a major problem. However, if condensation is a persistent problem, reduce moisture sources. Adding insulation helps eliminate cold walls, ceilings, or air-conditioning ducts where water vapor condenses.

Moisture problems arise when parts of the building become wet often and stay wet for periods of time. Moisture in organic or porous building materials reaches a threshold that allows pests like mold, dust mites, and insects to thrive. These pests can cause or aggravate asthma, bronchitis, and other respiratory ailments because they produce potent biological allergens.

Rot and wood decay indicate advanced moisture damage. Unlike surface mold and mildew, wood decay fungi penetrate, soften, and weaken wood.



Dust mites: Biological pests create bioaerosols that can cause allergies and asthma.

Peeling, blistering, or cracking paint may indicate that moisture is moving through a wall, damaging the paint and possibly also the building materials underneath.

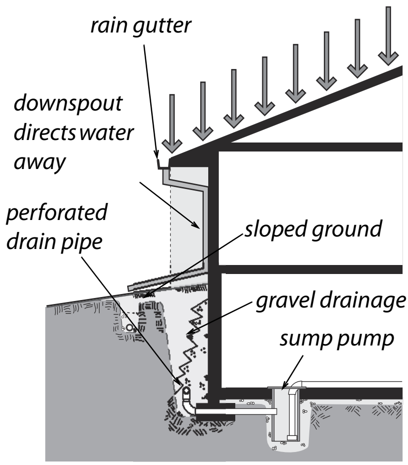
Corrosion, oxidation, and rust on metal are unmistakable signs of moisture problems. Deformed wooden surfaces may appear as the damp wood swells, and later warps and cracks as it dries.

Concrete and masonry efflorescence often indicates excess moisture at the home's foundation. Efflorescence is a white, powdery deposit left by water that moves through masonry and leaves minerals from mortar or the soil behind as it evaporates from the masonry surface.

9.3.2 Preventing Moisture Problems

Preventing moisture problems is the best way to guarantee a building's durability and its occupant's respiratory health. Follow these preventive measures before trying any of the solutions in the next section.

1. Rainwater flowing from roofs often plays a major role in dampening foundations. In rainy climates, install or repair rain gutters with downspouts that drain roof water away from the foundation.



Stopping water intrusion: Take all necessary steps protect homes from water intrusion.

2. A sump pump is the most effective remedy when ground water continually seeps into a basement or crawl space and collects there as standing water. Serious groundwater problems may require excavating and installing drain pipe and gravel to disperse accumulations of groundwater between a home and the underlying soil.
3. Install a ground moisture barrier, which is a piece of heavy plastic sheeting laid on the ground. Black heavy plastic film works well, but tough cross-linked polyethylene is even more durable. The edges should be sealed to the foundation walls with urethane adhesive and/or

mechanical fasteners. The seams should be sealed as well.

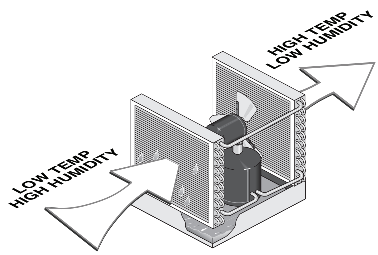
4. Verify that clothes dryers and exhaust fans vent to the outdoors and not into crawl spaces or attics.
5. Educate customers to avoid excessive watering around the home's perimeter. Watering lawns and plants close to the house can dampen its foundation. In moist climates, keep shrubbery away from the foundation, to allow wind circulation near the foundation.

Solving Moisture Problems

If moisture source reduction isn't adequate to prevent moisture problems, try these solutions after preventive measures are in place.

1. Seal water leaks in the foundation.
2. Seal water leaks in the roof, gutters, and downspouts.
3. Install or improve air barriers and vapor barriers to prevent air leakage and vapor diffusion from transporting moisture into building cavities. *See page 103.*
4. Add insulation to the walls, floor, and ceiling of a home to keep the indoor surfaces warmer and less prone to winter condensation. During cold weather, well-insulated homes can tolerate higher humidity without condensation than can poorly insulated homes.
5. Insulate air-conditioning ducts to prevent summer condensation.
6. Educate clients about ways of reducing home moisture that are under their control.

7. Ventilate the home with drier outdoor air to dilute the more humid indoor air. However, ventilation is only effective when the outdoor air is drier than the inside air, such as in winter. In summer, outdoor air may be more or less humid than indoor air depending on climate and whether the home is air conditioned.



Dehumidifiers: In damp climates, dehumidifiers protect homes from excessive moisture.

8. Remove unvented space heaters from the home.
9. As a last resort, remove moisture from indoor air by cooling the air to below its dew point with compressor-based air-conditioning systems in summer and dehumidifiers in winter.

9.4 Other Pollutants

Radon and asbestos are also important hazards to both occupants and workers.

9.4.1 Radon

Radon is a dangerous indoor air pollutant that comes from the ground through rocky soil. Studies predict about 20,000 lung cancer deaths per year that are caused by radon exposure.

Energy conservation work usually has little effect on radon concentrations. However, all housing specialists should be aware of: the radon hazard, radon testing procedures, and radon mitigation strategies.

The EPA believes that any home with a radon concentration above 4 pico-Curies per liter (pC/l) of air should be modified to reduce the radon concentration. There are several common and reliable tests for radon, which are performed by health departments and private consultants throughout the U.S.

Since radon comes through the soil, mitigation strategies include the following.

1. Installing a plastic ground barrier and carefully sealing the seams
2. Sealing the walls and floor of the basement
3. Ventilating the crawl space or basement to dilute radon
4. Depressurizing the ground underneath the basement concrete slab

The first two mitigation strategies may already be prescribed by the weatherization work order and may help to keep radon levels acceptable after air-sealing.

9.4.2 Asbestos

Asbestos is classified as a "known carcinogen." Asbestos is found in the following materials: boiler and steam-pipe insulation, duct insulation, floor tile, siding, roofing, and some adhesives. Workers who may encounter asbestos in the workplace must be trained to recognize asbestos and to avoid disturbing it. Penalties for mishandling asbestos-containing materials can amount to $25,000 per day.

DOE weatherization policy requires weatherization agencies to observe the following safety precautions regarding asbestos.

1. Remove asbestos siding only if you can remove the siding without damaging it. Don't cut or drill asbestos siding.

2. Don't remove vermiculite. Test vermiculite for asbestos, and use air monitoring if asbestos is present in the vermiculite in a home you're weatherizing.
3. Assume that asbestos is present in old grey-colored pipe insulation and duct insulation. Don't disturb asbestos-containing pipe or duct insulation; also caution occupants to avoid disturbing asbestos.
4. Consult with your program monitor before contracting with a certified asbestos tester and abatement specialist to mitigate asbestos problems before or during weatherization, if necessary.

9.5 Lead-Safe Procedures

In 2010, The Environmental Protection Agency's (EPA) Lead-Safe Renovation, Repair, and Painting (RRP) rule became a legal mandate for weatherization work.

Lead dust is dangerous because it damages the neurological systems of people who ingest it. Children are often poisoned in pre-1978 homes because of paint disturbance during home improvement and because hand-to-mouth behavior is common. Homes occupied by lead poisoned children (blood lead level of 10 micro-grams per deciliter or higher) must be deferred when lead will be disturbed by weatherization work.

Lead paint was commonly used in homes built before 1978. Contractors working on these older homes should either assume the presence of lead paint or perform tests to rule out its presence. *See "Weatherization Program Notice Page 7" on page 384.*

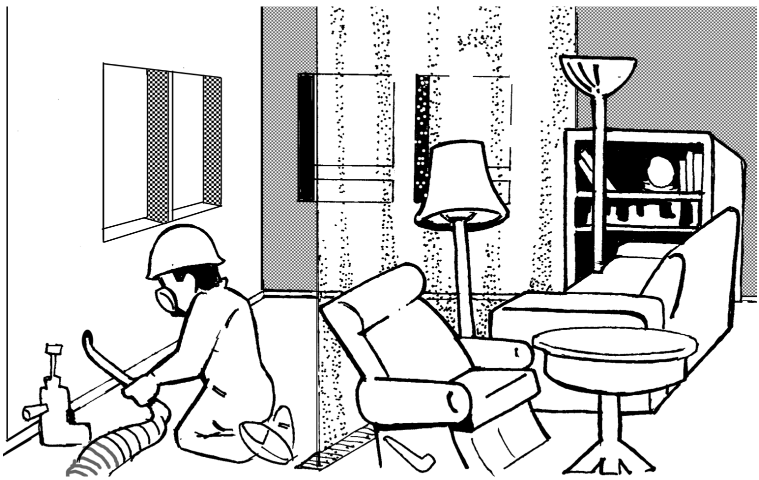
9.5.1 EPA RRP Requirements

The RRP rule requires lead-safe containment procedures whenever workers disturb painted surfaces of more than 6 square feet of interior surface per room or more than 20 square feet of exterior surface per side by cutting, scraping, drilling, or other dust-creating activities in pre-1978 homes. Disturbing paint on windows always requires containment.

The RRP requires certifications, warnings, dust-prevention, dust collection, and housecleaning as summarized here.

1. With pre-1978 homes, either test for lead-based paint or assume that lead-based paint is present.
2. Every pre-1978 weatherization or renovation job must be supervised by a certified renovator with 8 hours of EPA-approved training when workers will disturb more than the minimum paint area or when they will disturb paint on windows.

3. Renovation firms must be registered with the EPA and employ one or more certified renovators.
4. Signs and barriers must warn occupants and passersby not to enter the work area.
5. Floor-to-ceiling dust-tight barriers must prevent the spread of dust from the work area.



Protective sheeting: Dust-tight floor-to-ceiling barriers must separate work areas from living areas, according to EPA's RRP rule.

6. Plastic sheeting must protect surfaces and fixtures within the work area.
7. Workers must clean work surfaces sufficiently to pass an EPA-approved dust-wipe test, conducted by the certified renovator.
8. Workers must not track dust from the work area into the home.

9.5.2 Lead-Safe Weatherization

Lead-Safe Weatherization (LSW) is a set of procedures developed prior to the enactment of the RRP rule. LSW requires the same basic procedures as RRP in pre-1978 homes. When engaging in the paint-disturbing weatherization activities, follow these lead-safe work practices that were established by weatherization experts.

1. Wear a tight-fitting respirator to protect yourself from breathing dust or other pollutants.
2. Confine your work area within the home to the smallest possible floor area. Seal this area off carefully with floor-to-ceiling barriers made of disposable plastic sheeting, sealed at floor and ceiling with tape.
3. Don't use heat guns or power sanders in LSW work.
4. Spray water on the painted surfaces to keep dust out of the air during drilling, cutting, or scraping painted surfaces.
5. Erect an effective dust-containment system outdoors to prevent dust contamination to the soil around the home.
6. Use a dust-containment system with a HEPA vacuum when drilling holes indoors.

Drill shroud connected to HEPA vacuum: Collect dust where you're generating it.

7. Avoid taking lead dust home on clothing, shoes, or tools. Wear boot covers while in the work area, and remove them to avoid tracking dirt from the work area to other parts of the house. Wear disposable coveralls, or vacuum cloth coveralls with a HEPA vacuum before leaving the work area.

Wash thoroughly before eating, drinking, or quitting for the day.

9.6 Whole-House Ventilation Systems

This section discusses three options for design of whole-house ventilation systems.

- ✓ Exhaust ventilation
- ✓ Supply ventilation
- ✓ Balanced ventilation

See "Evaluating Home Ventilation Levels" on page 78.

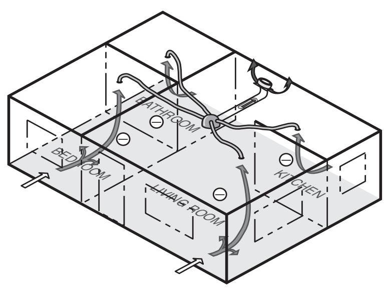
Discuss the choice of ventilation system with the client before making a final choice.

9.6.1 Exhaust Ventilation

Exhaust ventilation systems employ an exhaust fan to remove indoor air, which is replaced by infiltrating outdoor air.

Installing a two-speed bathroom fan is a common ventilation strategy. The new fan runs continuously on low speed for whole-house ventilation. An built-in occupancy sensor switches the fan automatically to a high speed to remove moisture and odors from the bathroom quickly.

A remote fan that exhausts air from several rooms through ducts (4-to-6 inch diameter) may provide better ventilation for larger more complex homes, compared to an single-point exhaust fan.

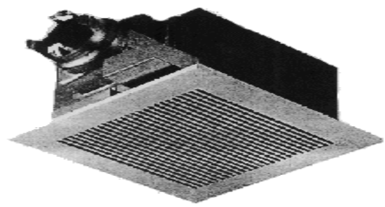


Multi-port exhaust ventilation: A multi-port ventilator creates better fresh-air distribution than a single central exhaust fan.

Exhaust ventilation systems create a negative house pressure, drawing outdoor air in through leaks in the shell. This keeps moist indoor air from traveling through building cavities, which would occur with a positive house pressure. The negative house pressure reduces the likelihood of moisture accumulation in building cavities during the winter months in cold climates. In hot and humid climates, however, this depressurization can draw moist outdoor air into the home through building cavities. Therefore we recommend supply ventilation for warm humid climates rather than exhaust ventilation.

Fan Specifications

Continuous ventilation is highly recommended because it simplifies design and control. Continuous ventilation also minimizes depressurization by allowing selection of the minimum-sized fan. Exhaust fans, installed as part of weatherization work, must vent to outdoors and include the following features.



Specifying exhaust fans: Specify quiet energy-efficient fans.

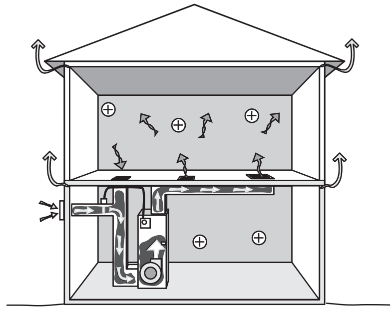
1. The ENERGY STAR® label.
2. Rated for continuous operation.
3. A weatherproof termination fitting.
4. A backdraft damper, installed in the fan housing or termination fitting.
5. Noise rating and ventilation efficacy as specified.

Table 9-2: Fan Capacity, Maximum Noise Rating, & Efficacy

Fan Capacity	Noise Rating (sones)	Efficacy cfm/Watt
<50 CFM	<1 sone	2.8
50–100 CFM	<1.5 sones	2.8
>100 CFM	<2.0 sones	2.8

9.6.2 Supply Ventilation

Supply ventilation typically uses the furnace or heat pump as a ventilator. A 5-to-10 inch diameter duct is connected from outdoors to the furnace's main return duct. This outdoor-air supply duct often has a motorized damper that opens when the air-handler blower operates. This outdoor air is then heated or cooled by the furnace/air conditioner before being delivered to the living spaces.



Supply ventilation: A furnace or heat pump is used for ventilation with a control that ensures sufficient ventilation.

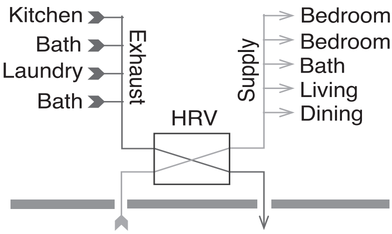
At least one manufacturer makes a control for operating both the furnace blower and the ventilation damper. The control estimates how much ventilation is supplied during heating or cooling and whether the air handler needs to activated for additional ventilation air without heating or cooling.

Supply ventilation, using the home's air handler, is never operated continuously as with exhaust ventilation because the furnace or heat-pump blower is too large and would over-ventilate the home and waste electrical energy. Supply ventilation may not be appropriate for tight homes in very cold climates because supply ventilation can push moist indoor air through exterior walls, where moisture can condense on cold surfaces.

9.6.3 Balanced Ventilation

Balanced ventilation systems exhaust stale air and provide fresh air through a ducted distribution system. Of the three ventilation systems discussed here, balanced systems do the best job of controlling pollutants in the home.

Balanced systems move equal amounts of air into and out of the home. Most balanced systems incorporate heat-recovery ventilators or energy-recovery ventilators that reclaim heat and moisture from the exhaust air stream.



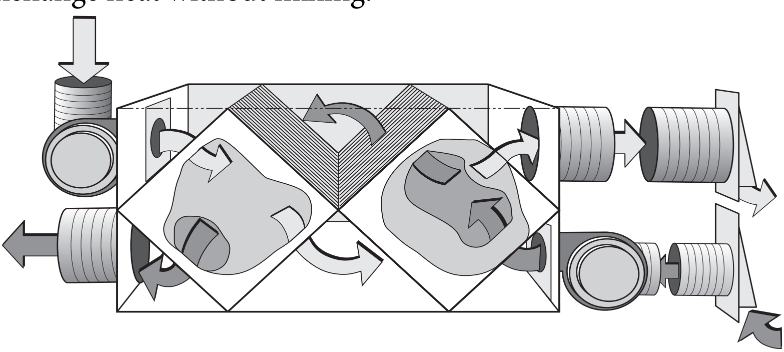
Centralized balanced ventilation: Air is exhausted from areas most likely to contain pollution and fresh air is supplied to living areas.

These complex systems can improve the safety and comfort of home, but a high standard of care is needed to assure that they operate properly. Testing and commissioning is vital during both the initial installation and periodic service calls.

Heat-Recovery and Energy-Recovery Ventilators

The difference between heat-recovery ventilators (HRVs) and energy-recovery ventilators (ERVs) is that HRVs transfer heat only, while ERVs transfer both sensible heat and latent heat (moisture) between airstreams.

HRVs are often installed as balanced whole-house ventilation systems. The HRV core is an air-to-air heat exchanger in which the supply and exhaust airstreams pass one another and exchange heat without mixing.



Heat-recovery ventilator: Heat from the exhaust air heats a plastic or aluminum heat exchanger, which in turn heats the fresh intake air. Two matched fans provide balanced ventilation.

9.6.4 Adaptive Ventilation

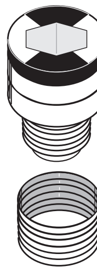
The home's residents can maintain good indoor air quality by using spot ventilation together with opening windows and doors. Depending on climate and season, residents can control natural ventilation to provide clean air, comfort, and energy efficiency.

1. Choose windows and screen doors in strategic locations to ventilate using prevailing winds.
2. Make sure that windows and screen doors, chosen for ventilation, open and close and have effective insect screens.
3. Open windows to provide make-up air when an exhaust fan or the clothes dryer is operating.
4. Understand that dust and pollen may enter through windows or screen doors and consider the consequences.

9.6.5 Electrical Safety

Electrical safety is a basic housing need affecting home weatherization and repair. Observe the following specifications for electrical safety in weatherizing existing homes.

Non contact voltage tester: Test voltage wires near your work area and take action to turn off the circuit if appropriate.



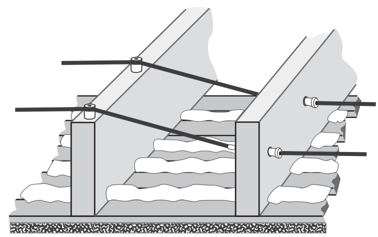
S-type fuse: An S-type fuse prohibits residents from oversizing the fuse and overloading an electrical circuit.

1. Whenever working around wiring, use a non-contact voltage tester to determine whether circuits are live. Turn circuits off at circuit breakers as appropriate.
2. Inspect wiring, fuses, and circuit breakers to verify that wiring isn't overloaded. Install S-type fuses where appropriate to prevent circuit overloading. Maximum ampacity for 14-gauge wire is 15 amps and for 12-gauge wire is 20 amps.
3. Confirm that all wire splices are enclosed in electrical junction boxes. If you plan to cover a junction box with insulation, attach a flag to mark its location.
4. Don't allow metal insulation shields to contact wiring.
5. Verify that the electrical system is grounded to either a ground rod or to a water pipe with an uninterrupted electrical connection to the ground.
6. Install S-type fuses where appropriate to prevent occupants from installing oversized fuses.
7. Perform a voltage-drop test to evaluate the size and condition of hidden wiring on older homes if appropriate.

8. Whenever you doubt the integrity of a clients electrical system, use a generator.

Decommissioning Knob-and-Tube Wiring

Decommission knob-and-tube wiring before or during weatherization if possible. Try to convince your clients or their landlords to replace knob-and-tube wiring with their own funds.



Knob and tube wiring: Obsolete and worn wiring should be replaced during energy retrofit work so that building cavities can be sufficiently insulated.

Use a non-contact voltage tester to determine whether the knob-and-tube wiring is live. If you're unsure about whether the wiring is still live, schedule an inspection by a qualified and experienced electrician.

If the knob-and-tube wiring in an attic is live, ask an electrician and/or an electrical inspector to determine whether the attic wiring can be decommissioned and replaced with non-metallic sheathed electrical cable. Depending on the situation, the electrician may choose one of these two options.

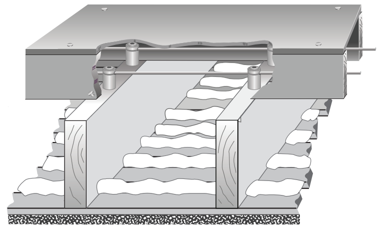
1. Terminate the existing attic knob-and-tube correctly, and connect the new circuit directly to the main service box.

2. Install a flagged junction box in the attic to connect the knob-and-tube riser to new cable in the attic.

Consider installing a hard-wired CO/smoke detector in a common area near the bedrooms on the new circuit.

Constructing Shielding for Knob-and-Tube Wiring

You may install attic insulation up to the bottom of knob-and-tube wiring, but never surround knob-and-tube wiring with insulation that covers the wires.



Shielding knob and tube: If you can't decommission knob-and-tube wiring, you may construct a box to shield it from being surrounded by insulation.

1. Construct structural shielding to maintain a 3-inch clearance between insulation and knob-and-tube insulation and the shield. Then cover the shielding with insulation to achieve the required R-value.
2. Flag the shielding structure before insulating over it to mark it for future access or removal.
3. If attic is floored, don't remove the flooring or attempt to construct shielding.

APPENDICES

A–1 RESOURCES

ASHRAE 2005 Fundamentals, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc; Atlanta GA 1993, www.ashrae.org

ASHRAE Standard 62.2 2010, American Society of Heating, Refrigerating and Air Conditioning Engineers, Inc; Atlanta GA 2010, www.ashrae.org

Homeowner's Handbook to Energy Efficiency, Saturn Resource Management, by John Krigger and Chris Dorsi, www.srmi.biz

HVAC Duct Standard, Building Performance Institute (BPI), draft, www.bpi.org

HVAC Quality Installation Specification, ACCA/ANSI 5 QI-2007, Air Conditioning Contractors of America, www.acca.org

International Energy Conservation Code 2009, International Code Council, www.iccsafe.org

International Residential Code 2009, International Code Council, www.iccsafe.org

Residential Energy: Cost Savings and Comfort for Existing Buildings, Saturn Resource Management, by John Krigger and Chris Dorsi, Fourth Edition, 2004, www.srmi.biz

Residential Weatherization Specification Manual, Northwest Regional Technical Forum, 2011, www.nwcouncil.org/energy/rtf/

Workforce Guidelines for Home Energy Efficiency Retrofits, DOE EERE Weatherization and Intergovernmental Program, http://www1.eere.energy.gov/wip/wap.html

A–2 ENERGY AUDITOR PREREQUISITES

Candidates for the energy auditor certification must complete these proposed prerequisites before taking the written and/or field exam certification exams.

- Education: High school diploma, GED, or equivalent education from another country.
- Must pass criminal background check: no crimes against persons; larceny, burglary, robbery, violent crimes, felony charges, sexual assault.

Experience: Minimum of 1,000 hours of relevant experience, during which the candidate has accomplished one or more of the following roles:

- ✓ Be a crew lead in a weatherization (WAP) trade or related field, or
- ✓ Be in a building science trade performing audits under the supervision of an auditor, or
- ✓ Be an energy auditor.

Candidate must completed (with proof) 15 comprehensive whole house energy audits, such as home performance, WAP, RESNET, or BPI

Candidates must obtain a minimum of **20 points** from any combination of activities below:

1. Building experience: framing, roofing, drywall, siding, etc) **maximum of 10 points**

- **5 Points** for each 1,000 hours

2. Training from industry specific training center (training whose content can be matched against and lines up with the content of the job task analysis for the certification)**; maximum of 10 points**

- **5 points** for every 40 hours

3. Industry Certifications (RESNET, BPI, NATE, EPA) other certifications considered through application**; maximum of 10 points**

- **5 points** per certification

A–3 Q.C. Inspector Prerequisites

Candidates for the quality-control inspector certification must complete these prerequisites before taking the written and/or field exam certification exams.

- Education: High school diploma, GED, or equivalent education from another country.
- Must pass criminal background check: no crimes against persons; larceny, burglary, robbery, violent crimes, felony charges, sexual assault.

Candidates must obtain a minimum of <u>**40 points**</u> from any combination of activities below:

1. Industry inspector experience (site visits, inspections, diagnostics) <u>**maximum of 20 points for items 1 & 2**</u>

- **10 Points** for each 1,000 hours

2. Other industry-specific experience (crew leader, energy auditor)

- **5 Points** for Crew Leader
- **10 Points** for Energy Auditor, who completed at least 15 audits (proof required)

3. Building Experience (Framing, Roofing, Drywall, Siding, etc); <u>**maximum of 10 points**</u>

- **5 Points** for each 1,500 hours

4. Training from industry specific training center (training whose content can be matched against and lines up with the content of the job task analysis for the certification); <u>**maximum of 10 points**</u>

- **5 points** for every 40 hours

5. Industry Certifications (RESNET, BPI, NATE, EPA) other certifications considered through application; <u>**maximum of 10 points**</u>

- **5 points** per certification

A–4 REQUIRED DIAGNOSTIC EQUIPMENT

Minimum Equipment For Instrumented Air Sealing

- ✓ Fully instrumented and calibrated blower door capable of measuring CFM_{50} (Cubic feet per minute at 50 Pascals).
- ✓ Handheld Digital Manometer.
- ✓ Smoke generator.

Minimum Equipment for Heating System Analysis

- ✓ Combustion analyzer.
- ✓ CO testing capacity.
- ✓ Draft gauge or manometer.
- ✓ Heat exchanger leakage testing equipment.
- ✓ Ammeter (sensitive enough to adjust thermostat anticipators).
- ✓ Combustible-gas leak detector.

A–5 R-VALUES FOR COMMON MATERIALS

Material	R-value
Fiberglass or rock wool batts and blown 1″	2.8–4.0
Blown cellulose 1″	3.0–4.0
Vermiculite loose fill 1″	2.7
Perlite 1″	2.4
White expanded polystyrene foam (beadboard) 1″	3.9–4.3
Polyurethane/polyisocyanurate foam 1″	6.2–7.0
Extruded polystyrene 1″	5.0
Sprayed 2-part polyurethane foam 1″	5.8–6.6
Icynene foam 1″	3.6
Oriented strand board (OSB) or plywood 1/2″	1.6
Concrete or stucco 1″	0.1
Wood 1″	1.0
Carpet/pad 1/2″	2.0
Wood siding 3/8–3/4″	0.6–1.0
Concrete block 8″	1.1
Asphalt shingles	0.44
Fired clay bricks 1″	0.1–0.4
Gypsum or plasterboard 1/2″	0.4
Single pane glass 1/8″	0.9
Low-e insulated dbl. pane unit glass (Varies according to Solar Heat Gain Coefficient (SHGC) rating.)	3.3–4.2
Triple glazed glass with 2 low-e coatings	8.3

A–6 Calculating Attic Insulation

Auditors and inspectors also help crews determine how much insulation is needed for ceilings and walls.

Calculating Attic Loose-Fill Insulation

Loose-fill attic insulation should be installed to a uniform depth to attain proper coverage (bags per square foot) so it attains the desired R-value at the settled thickness. Follow the manufacturer's labeling in order to achieve the correct density to meet the required R-value. Attic insulation always settles: cellulose settles between 10% to 20% and fiberglass settles between 3% to 10%. For this reason, it's best to calculate insulation density in square feet per bag rather than installed thickness.

Insulation Calculation Table

R-Value at 75° F mean Temperature	Minimum Thickness	Maximum Net Coverage	
Desired R-Value of Insulation	**Minimum Insulation Depth**	**Maximum Coverage per Bag (sq. ft.)**	**Bags per 1000 sq. ft.**
R-60	16.0	11.7	85.8
R-50	13.3	14.0	71.5
R-44	11.7	15.9	62.9
R-40	10.7	17.5	57.2
R-38	10.1	18.4	54.4
R-32	8.5	21.6	45.8
R-30	8.0	23.3	42.9
R-24	6.4	29.1	34.3
R-22	5.9	31.8	31.5
R-19	5.1	36.8	27.2
R-13	3.5	53.8	18.6
R-11	2.9	63.6	15.7

Insulation Coverage Table: This table is provided by Weather Blanket Corporation. Coverage and other insulation characteristics will vary from manufacturer to manufacturer.

Example: Calculating Number of Bags

30 FT X 50 FT= 1500 SQ FT

Width Length Area of Attic

Step 1: Calculate area of attic
Multiple length times width of the attic to get the area of attic.

R-50 – R-26 = R-24

Desired R Existing R R Needed to Add

Step 2: Calculate R-value that you need to add
Subtract existing R from desired R to get the R-value you need to add.

1500 SQ FT ÷ 29.1 = 52 BAGS

Net wall Area

Sq. Ft. Coverage per Bag (from chart)

Estimated Bag Count

STEP 3: Calculate bag count
Divide area of attic by coverage per bag from the chart on the bag (number highlighted in chart on *"Insulation Calculation Table" on page 365*) to get your Estimated Bag Count.

Example: Calculating Density of Attic Insulation

1500 SQ FT X 6.4/12 FT= 800 CU FT

Area — Depth in Inches — Inches per Foot — Volume of Insulation

Step 1: Calculate volume of installed insulation
Multiple area times depth of the attic insulation to get the volume of insulation.

52 BAGS X 24 LBS/BAG = 1248 LBS

Number of Bags — Weight of a Bag — Installed Weight

Step 2: Calculate the weight of insulation you installed
Take the number of bags times the weight per bag to get the total weight.

1248 LBS ÷ 800 CU FT = 1.56 LBS/CU FT

Pounds of Insulation — Insulation Volume — Installed Density

STEP 3: Calculate density of installed insulation
Divide pounds of insulation by cubic feet of insulation volume to get density.

> *Note*
> Density should be between 1.3 and 2.0 pounds per cubic foot or conform to manufacturer's specifications for density, coverage, and bag count for the desired R-value.

A–7 CALCULATING WALL INSULATION

Wall insulation should be installed to a density of 3.5 to 4.5 pounds per cubic foot. These calculations serve to calculate the number of bags necessary to insulate walls and to judge density after completing the wall-insulation job. Calculate the bag count based on information from the agency's insulation supplier.

Example: Calculating Number of Bags for Wall Insulation

(2 X 50 FT) + (2 X 30 FT) = 160 FT

Length — Width — Perimeter of House

STEP 1: Calculate perimeter of house
Calculate the perimeter of the house. If the house is a simple rectangle or near a simple rectangle, use the formula above. If the house has numerous unequal sides, simply add the lengths together to find the perimeter.

160 FT X 8 FT= 1280 SQ FT

Perimeter of House — Height of Wall — Total Wall Area

STEP 2: Calculate total wall area
After calculating the perimeter of the house, multiply it times the wall height. This will give you the total wall area.

$$1280 \text{ SQ FT} - 150 \text{ SQ FT} = 1130 \text{ SQ FT}$$

Total Wall Area

Area of Windows and Doors

Net Wall Area

STEP 3: Calculate net wall area

Calculate the sum of the areas of windows and doors. Subtract them from the total wall area to get net wall area.

$$\frac{1130 \text{ SQ FT} \times 1.2 \text{ LBS/SQ FT}}{24 \text{ LB PER BAG}} = 57 \text{ BAGS}$$

Net Wall Area

Weight of a Bag

Pounds per Square Foot

Bags of Insulation Needed

STEP 4: Calculate bag count

To achieve 4.0 lbs. per cubic foot, multiply net wall area by 1.2 pounds per square foot for a 2-by-4 wall (4.0 lbs. per cubic foot ÷ 12 x 3.5 = 1.2). Then divide by the number of pounds per bag to get the bag count.

Example: Calculating Density of Wall Insulation

$$1280 \text{ SQ FT} \times 3.5/12 \text{ FT} = 373 \text{ CU FT}$$

Net Wall Area

Inches of Wall Depth

Inches per Foot

Wall Volume

STEP 1: Calculate wall volume

Multiply the wall's surface area times the depth on the wall cavity converted to feet.

57 BAGS X 24 LBS/BAG = 1368 LBS

Bags Installed

Pounds of Insulation

Weight of a Bag

STEP 2: Calculate weight of insulation
Multiply number of bags you installed times the weight of a single bag to get the weight of the installed insulation.

1388 LBS ÷ 373 CU FT= 3.67 LBS/CU FT

Pounds of Insulation

Insulation Volume

Installed Density

STEP 3: Calculate density of installed insulation
Divide pounds of insulation by cubic feet of insulation volume to calculate density.

A–8 CALCULATING MOBILE HOME INSULATION

Consider a 14´ x 66´ mobile home, totaling 924 square feet.

- ✓ Ceiling: 9″ cavity at the center and 2″ cavity at the edge with a 2″ batt
- ✓ Belly: $5^1/_2$″ cavity at the wings and $16^1/_2$″ cavity at the center with a 2″ batt fastened to floor bottom
- ✓ Walls: $3^1/_2$″ cavity with a $1^1/_2$″ batt at $7^1/_2$´ high

General formulas

CAVITY VOLUME X DESIRED DENSITY = WEIGHT OF INSULATION

WEIGHT OF INSULATION ÷ POUNDS PER BAG = BAGS OF INSULATION

Ceiling Bag Count Estimates

1. Calculate the average ceiling cavity (9″ + 2″ = 11″) (11″ ÷ 2 = $5^1/_2$″ average cavity)
2. ($5^1/_2$″ cavity minus the 2″ batt = $3^1/_2$″ cavity). The existing insulation batt will compress when additional insulation is added, allow 1″ for compression ($3^1/_2$″ + 1″ = $4^1/_2$″ cavity)
3. Convert $4^1/_2$″ to feet (4.5″/12″ = 0.375´)
4. Multiply 0.375´ x 924 sq. ft. = 346.5 cubic feet
5. Multiply cubic feet by desired density: Fiberglass ceiling insulation density must be 1.0 to 1.5 lbs/cubic foot.

   a. 347 x 1.0 = 347 lbs. / 35(lbs/bag) = 9.9 bags

   b. 347 x 1.25 = 434 lbs. / 35(lbs/bag) = 12.4 bags

   c. 347 x 1.5 = 521 lbs. / 35(lbs/bag) = 14.9 bags

Belly Bag Count Estimates

Calculate the average belly cavity (5-$^{1}/_{2}$″ + 16-$^{1}/_{2}$″ = 22″)

(22″ ÷ 2 = 11″ average cavity) (11″ cavity – 2″ batt = 9″ cavity) The existing insulation batt will compress when additional insulation is added, allow 1″ for compression (9″ + 1″ = 10″ cavity)

1. Convert 10″ to feet (10″ / 12″ = 0.83′)
2. Multiply 0.83′ x 924 square feet = 767 cubic feet
3. Multiply cubic feet by desired density.
4. Belly insulation density at 1.0 to 1.5 lbs/cubic foot.

   a. 767 x 1.0 = 767 lbs. / 35(lbs/bag) = 22 bags

   b. 767 x 1.25 = 959 lbs. / 35(lbs/bag) = 27 bags

   c. 767 x 1.5 = 1151 lbs. / 35(lbs/bag) = 33 bags

A–9 ASHRAE 62.2 VENTILATION

This is a worked example of how to size a ventilation fan for the New Jersey WAP Program, according to ASHRAE Standard 62.2 - 2010. The method was developed by Anthony Cox.

ASHRAE 62.2 Ventilation Calculation (EXAMPLE)

FILL IN BLUE SHADED CELLS WHEN USING EXCEL

Ventilation Needed

BR+1 or People X 7.5cfm

3	7.5	22.5	1

Square ft / 100

1500	100	15.0	2

Required cfm	Window	Measured Cfm	Deficit	
Kitchen (100)	-20	-70	10.0	
Bath 1 (50)	-20	-20	10.0	
Bath 2 (50)			None	
		Total Deficit	20.0	
		Deficit /4	5.0	3

Ventilation Needed	**42.5**

Infiltration Credit

CFM50 / N-Value

1500	28.1	53.4	A

Square ft x .02

1500	0.02	30.0	B
Difference (A-B)		23.4	C
Infiltration Credit		**11.7**	c/2

Continuous Ventilation to Add *(Needed - Credit)*	**30.8**

Calculate CONTINUOUS Ventilation needed

1) Multiply Greatest of Bedrooms + 1 or Number of People x 7.5cfm

2) Calculate 1 cfm per 100 Sq ft Floor Area.

3) Calculate Local (Spot) Ventilation Deficit by taking required ventilation (e.g. Kitchen 100cfm or Bathroom 50cfm) and subtracting 20 cfm if operable window in room and subtracting measured cfm of existing fan. Divide Total Deficit by 4.
Add Calculations (1, 2 and 3) to Determine Ventilation Needed.

Calculate Infiltration Credit

A) Calculate Infiltration Credit By taking CFM50 Blower Door Reading and Dividing by N-Value. *(See Table Below)*

B)Calculate Sq Ft Floor Area and Multiply by .02
IF A is Greater than B, Then take difference (C) and Divide by 2 for Credit
(if A is not greater that B, then there is no credit)

Determine Ventilation to Add
Subtract Infiltration Credit from Ventilation Needed

N-Values for Infiltration Credit *(Saturn Resource Management)*

New Jersey	W	1	1.5	2	2.5	3
Lakehurst	0.70	28.1	24.9	22.8	21.4	20.2

A–10 Refrigerator Dating Chart

Refrigerators are listed by brand name, followed by the coding system. If several manufacturers used the same system, they are listed together. Some rules of thumb for easy identification are: (1) Refrigerators that are any color of green, brown, yellow, pink, or blue (actually KitchenAid makes a new unit in cobalt blue); have mechanical handles; have doors held shut with magnetic strips; have rounded shoulders; have a chromed handle; or have exposed "house door" type hinges are at least 10 years old, and (2) the following brands have only been manufactured since around 1984 - Roper, Estate, KitchenAid, Caloric, Modern Maid, and Maytag.

Brand(s)	What to look for	What to avoid	How to decode	Example
Montgomery Wards, Signature (2000)	Serial # - 1st two digits	n/a	Reverse the digits	56xxxxx = 1965
Sears, Kenmore, Coldspot	Model # - 1st & 3rd digits after (.)	n/a	Combine the digits	xx.6x2xxx = 1962
Whirlpool	Model # - 1st 3 letters (pre 1982) Serial # - 2nd digit (post 1982)	Serials with letters	No need as 1st two digits Add "198_" to it	ABCxxx = pre 1982 x2xxx = 1982
Amana	Serial # - 1st digit (pre 1986)	n/a	BLACKHORSE B=1, L=2	Hxxxx = 1966 or 1976 61 is the oldest
Frigidaire	Serial # - 1st & 4th digit (pre 1989)	Serials with no letter in the 4th space	Add "196, 197, or 198" to the 1st digit. The letter in the 4th space is a month code used only on older models.	3xxBxx = 1973 or 1983
Gibson, Kelvinator	Serial # - 3rd digit (pre 1989)	n/a	Add "196, 197, or 198" to it	xx3xx = 1963 or 73 or 83
White, Westinghouse	Serial # - 2nd letter (pre 1989)	Serials without letters	A,V,W=78, B=79, C=80 etc. pre-1978, R=74, U=77 etc.	xLxxx = 1988 74 is the oldest year
Tappan, O'Keefe & Merritt	Serial # - 7th digit (pre 1989)	n/a	Add "196, 197, or 198" to it	xx xxx-x8xx = 1968 or 78 or 88
Admiral, Crosley, Norge, Magic Chef, Jenn Air	Serial # - last letter	n/a	A=1950 or 1974 (+14 yrs) B=1951 or 1975, etc.	xxxxxxD = 1953 or 1977
General Electric (GE)	Serial # - 2nd letter	n/a	See chart below	xGxxx = 1950 or 1980
Hotpoint	Same as GE with some exceptions. See GE and Hotpoint exceptions chart below			

GE Decoder Chart:	A = 44, 65, 77, 89	B = 45, 66	C = 46, 67	D = 47, 68, 78, 90	E = 48, 69	F = 49, 79, 91	G = 50, 80, 92
	H = 51, 81, 93	J = 52	K = 53	L = 54, 70, 82, 94	M = 55, 71, 83	N = 56, 72	P = 57, 73
	R = 58, 84	S = 59, 85	T = 60, 74, 86	V = 61, 75, 87	W = 62	X = 63 Y = 64	Z = 76, 88

Hotpoint Exceptions: U = 61, V = 62, W = 63, X = 64, Y = 65, Z = 66, A = 67, B = 68

Revised 5/6/94

A–11 MEASURING BTU INPUT ON NATURAL GAS APPLIANCES

Use the following procedure when it's necessary to measure the input of a natural gas appliance.

1. Turn off all gas combustion appliances such as water heaters, dryers, cook stoves, and space heaters that are connected to the meter you are timing, except for the appliance you wish to test.
2. Fire the unit being tested, and watch the dials of the gas meter.
3. Carefully count how long it takes for one revolution of $^1/_2$, 1, or 2 cubic-foot dial. Find that number of seconds in *Table Appendices-3* in the columns marked "Seconds per Revolution." Follow that row across to the right to the correct column for the $^1/_2$, 1, or 2 cubic-foot dial. Note that you must multiply the number in the table by 1000. Record the input in thousands of BTUS per hour.
4. If the measured input is higher or lower than input on the name plate by more than 10%, adjust gas pressure up or down within a range of 3.2 to 3.9 IWC until the approximately correct input is achieved.
5. If the measured input is still out of range after adjusting gas pressure to these limits, replace the existing orifices with larger or smaller orifices sized to give the correct input.

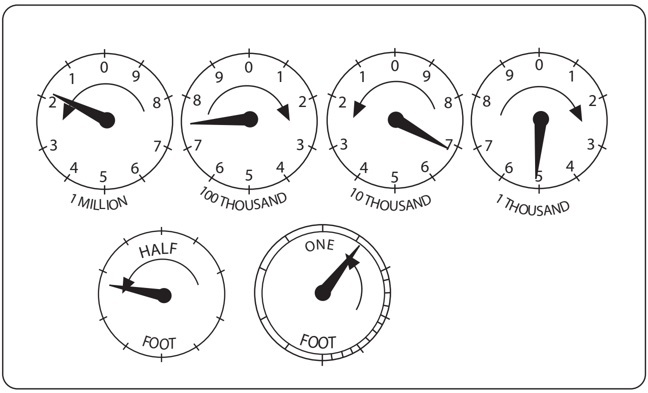
Table Appendices-3:Input in Thousands of Btu/hr for 1000 Btu/cu. ft. Gas

Seconds per Revolution	Size of Meter Dial			Seconds per Revolution	Size of Meter Dial			Seconds per Revolution	Size of Meter Dial		
	1/2 cu. ft.	1 cu. ft.	2 cu. ft.		1/2 cu. ft.	1 cu. ft.	2 cu. ft.		1/2 cu. ft.	1 cu. ft.	2 cu. ft.
15	120	240	480	40	45	90	180	70	26	51	103
16	112	225	450	41	44	88	176	72	25	50	100
17	106	212	424	42	43	86	172	74	24	48	97
18	100	200	400	43	42	84	167	76	24	47	95
19	95	189	379	44	41	82	164	78	23	46	92
20	90	180	360	45	40	80	160	80	22	45	90
21	86	171	343	46	39	78	157	82	22	44	88
22	82	164	327	47	38	77	153	84	21	43	86
23	78	157	313	48	37	75	150	86	21	42	84
24	75	150	300	49	37	73	147	88	20	41	82
25	72	144	288	50	36	72	144	90	20	40	80
26	69	138	277	51	35	71	141	94	19	38	76
27	67	133	267	52	35	69	138	98	18	37	74
28	64	129	257	53	34	68	136	100	18	36	72
29	62	124	248	54	33	67	133	104	17	35	69
30	60	120	240	55	33	65	131	108	17	33	67
31	58	116	232	56	32	64	129	112	16	32	64
32	56	113	225	57	32	63	126	116	15	31	62
33	55	109	218	58	31	62	124	120	15	30	60
34	53	106	212	59	30	61	122	130	14	28	55
35	51	103	206	60	30	60	120	140	13	26	51
36	50	100	200	62	29	58	116	150	12	24	48
37	49	97	195	64	29	56	112	160	11	22	45
38	47	95	189	66	29	54	109	170	11	21	42
39	46	92	185	68	28	53	106	180	10	20	40

Natural Gas Heat Content

Note that *Table Appendices-3 on page Appendices-376* assumes that gas is 1000 BTUs per cubic foot. Where BTU values differ from this figure — especially at high elevations — obtain the correct BTU value from the gas supplier and apply the formula shown below.

(BTU VALUE FROM SUPPLIER ÷ 1000) X BTU/HR INPUT FROM TABLE = ACTUAL BTU/HR INPUT OF APPLIANCE



Clocking the Meter: Count the number of seconds per revolution of the one-foot dial and refer to*Table Appendices-3 on page 376* to find the appliance's input.

A–12 DOE HEALTH AND SAFETY GUIDANCE

Department of Energy
Washington, DC 20585

WEATHERIZATION PROGRAM NOTICE 11-6
EFFECTIVE DATE: January 12, 2011

SUBJECT: WEATHERIZATION HEALTH AND SAFETY GUIDANCE

PURPOSE: To update and provide clarification and additional information related to the implementation and installation of health and safety measures as part of the Department of Energy (DOE) Weatherization Assistance Program (WAP). This guidance also provides recommendations to Grantees as they develop their Health and Safety Plans and procedures. This Program Notice replaces Weatherization Program Notice 02-5 and related guidance, and in conjunction with other referenced guidance materials should be used when making decisions on how to address health and safety issues while conducting weatherization work. The information in this guidance as well as many additional health and safety resources related to weatherization are available on the Internet at www.waptac.org.

SCOPE: The provisions of this guidance apply to all Grantees applying for financial assistance under the DOE WAP.

LEGAL AUTHORITY: Title IV, Energy Conservation and Production Act, as amended, authorizes the Department of Energy to administer the Weatherization Assistance Program. All grant awards made under this Program shall comply with applicable law including regulations contained in 10 CFR Part 440, the Energy Policy Act of 2005, the Energy Independence and Security Act of 2007, the American Recovery and Reinvestment Act of 2009 (Recovery Act), and the Occupational Safety and Health Act of 1970 (29 USC §651), 29 CFR Part 1900, 1926, general industry and construction respectively.

BACKGROUND: Based upon DOE reviews and reports from Grantees, DOE determined that health and safety issues were being inconsistently addressed across the weatherization network. In order to create clarity and consistency in how health and safety issues are approached by Grantees, DOE reconvened its Health and Safety Committee to review current trends and practices for the health and safety concerns of the WAP network.

This Program Notice will assist Grantees in their development of a comprehensive approach to health and safety matters.

WEATHERIZATION PROGRAM NOTICE PAGE 2

GUIDANCE: Over the years, a number of issues have been addressed to ensure that weatherization activities do not cause or exacerbate health and safety problems for workers and occupants. According to 10 CFR Part 440, allowable energy related health and safety actions are those actions necessary to maintain the physical well being of both the occupants and/or weatherization workers where:

- Costs are reasonable as determined by DOE in accordance with the Grantee's approved Grantee Plan; **AND**
- The actions must be taken to effectively perform weatherization work; **OR**
- The actions are necessary as a result of weatherization work.

Two questions to ask here are:

1. What must we do within reasonable costs to get the home to a point we can go forward with weatherizing, where the weatherization work will be lasting and effective?
2. What must we do to ensure that the weatherization work we conducted does not create a health or safety problem for the occupant?

Health and safety measures are allowed where, cumulatively, they do not exceed reasonable costs, as approved by DOE, outlined in each Grantee's approved Health and Safety Plan. DOE considers Grantees' proposed Health and Safety Plans on a case-by-case basis and determines whether submitted costs are reasonable. Health and safety measures are allowed to be conducted only where energy efficiency measures are identified for installation. Grantees are required to identify health and safety procedures and the percentage of costs involved as a part of their overall Health and Safety Plan to be approved by DOE. This approach gives Grantees and Subgrantees the ability to incorporate new technologies and their costs into their programs by removing health and safety costs from the per-house limitation; if they are budgeted separately. In providing this approach, DOE encourages Grantees to be prudent in their oversight of the percentage of funds approved for health and safety mitigation on homes weatherized by their Subgrantees.

The regulations do not mandate a separate health and safety budget cost category, but rather encourages Grantees to budget health and safety costs as a separate category and, thereby, exclude such costs from the average per-unit cost calculation. This separate category also allows these costs to be isolated from energy efficiency costs in program evaluations. Grantees are reminded that, if health and safety costs are budgeted and reported under the program operations category, the related health and safety costs should be included in the calculation of the average cost per home and cost-justified through the audit.

Grantees should carefully consider the approach to be taken when they draft their health and safety procedures. While ease of accounting is an important consideration, Grantees should keep in mind that activities assigned to the health and safety budget category do not have to be cost justified by the energy audit. The same items assigned to incidental repair, weatherization material, or installation cost categories must be cost-justified.

There are some instances where, depending on circumstances, the measure can be considered either a health and safety measure OR an energy conservation measure (e.g., furnaces). In those instances where the measure has a cost-effective savings-to-investment ratio (SIR) of one (1) or greater, the measure should be treated as a weatherization efficiency measure[1].

Deferral may be necessary if health and safety issues cannot be adequately addressed through this guidance. The decision to defer work in a dwelling is difficult but necessary in some cases. This does not mean that assistance will never be available, but that work must be postponed until the problems can be resolved and/or alternative sources of help are found. In the judgment of the auditor, any conditions that exist, which may endanger the health and/or safety of the workers or occupants, should be deferred until the conditions are corrected. Deferral may also be necessary where occupants are uncooperative, abusive, or threatening.

The following Health and Safety Guidance Table was developed within applicable legislation and DOE regulations. While not every possible health and safety issue is addressed herein, the guidance should provide enough relevant examples and direction to provide clarity to the many issues presented to DOE. The section following the Guidance Table provides direction on what must be addressed within the Grantee's Approved Health and Safety Plan as part of their Grantee Plan.

Some common themes and requirements that should be considered when utilizing the Guidance Table are as follows:

- Where removal or replacement is addressed in the document, proper disposal is required, and allowed as a health and safety cost.
- Where hazards are identified, clients must be informed in writing and the document must be signed by the client and a copy maintained in the client file.
- State and local (or jurisdiction having authority) codes must be followed while installing health and safety measures.
- Workers must be qualified and adequately trained according to state and local (or jurisdiction having authority) codes specific to the work being conducted (electrical, plumbing, etc.).
- Where Actions/Allowability, Testing, Client Education, and Training are allowed or required, DOE funds may be used unless specified otherwise. Health and safety expenditure limits apply to the specific action being taken to address the health and safety issue.

[1] Any measures being considered as an efficiency measure that is not on the DOE-approved priority list for the Grantee will require a site-specific audit to be performed on the dwelling in order to justify the measure being installed as an efficiency measure.

Health and Safety Issue	Action/Allowability	Testing	Client Education	Training
Air Conditioning and Heating Systems	"Red tagged", inoperable, or nonexistent heating system replacement, repair, or installation is allowed where climate conditions warrant, unless prevented by other guidance herein. Air conditioning system replacement, repair, or installation is allowed in homes of at-risk occupants where climate conditions warrant.	Make sure systems are present, operable, and performing. Determine presence of at-risk occupants.	Discuss and provide information on appropriate use and maintenance of units and proper disposal of bulk fuel tanks when not removed.	Awareness of guidance.
Appliances and Water Heaters	Replacement of water heaters is allowed on a case by case basis. Replacement and installation of other appliances are not allowable health and safety costs. Repair and cleaning are allowed. Also see Air Conditioning and Heating Systems and Combustion Gases.	Determine whether appliances/water heaters are performing safely. Combustion safety testing is required when combustion appliances are present.	Discuss and provide information on appropriate use, maintenance, and disposal of appliances/water heaters.	Awareness of guidance. Conducting diagnostic training.
Asbestos - in siding, walls, ceilings, etc	Removal of siding is allowed to perform energy conservation measures. All precautions must be taken not to damage siding. Asbestos siding should never be cut or drilled. Recommended, where possible, to insulate through home interior.	Inspect exterior wall surface and subsurface for asbestos siding prior to drilling or cutting.	Inform the client that suspected asbestos siding is present and how precautions will be taken.	Safe practices for siding removal and replacement. How to identify asbestos containing materials.
Asbestos - in vermiculite	When vermiculite is present, unless testing determines otherwise, take precautionary measures as if it contains asbestos, such as not using blower door tests and utilizing personal air monitoring while in attics. Where blower door tests are performed, it is a best practice to perform pressurization instead of depressurization. Encapsulation by an appropriately trained asbestos control professional is allowed. Removal is not allowed.	Assess whether vermiculite is present. Asbestos Hazard Emergency Response Act of 1986 (AHERA) certified prescriptive sampling is allowed by a certified tester.	Clients should be instructed not to disturb suspected asbestos containing material. Provide asbestos safety information to the client. Formally notify client if test results are positive for asbestos and signed by the client.	Audit training on how to recognize vermiculite. AHERA course for testing. AHERA or other appropriately trained or certified asbestos control professional training for encapsulation.
Asbestos - on pipes, furnaces, other small covered surfaces	Assume asbestos is present in covering materials. Encapsulation is allowed by an AHERA asbestos control professional and should be conducted prior to blower door testing. Removal may be allowed by an AHERA asbestos control professional on a case by case basis.	AHERA testing is allowed by a certified tester.	Clients should be instructed not to disturb suspected asbestos containing material. Provide asbestos safety information to the client.	AHERA course for testing and asbestos control professional training for abatement. How to identify asbestos containing materials.

Health and Safety Issue	Action/Allowability	Testing	Client Education	Training
Biologicals and Unsanitary Conditions - odors, mustiness, bacteria, viruses, raw sewage, rotting wood, etc.	Remediation of conditions that may lead to or promote biological concerns and unsanitary conditions is allowed. Addressing bacteria and viruses is not an allowable cost. Deferral may be necessary in cases where a known agent is present in the home that may create a serious risk to occupants or weatherization workers. Also see Mold and Moisture guidance below.	Sensory inspection.	Inform client of observed conditions. Provide information on how to maintain a sanitary home and steps to correct deferral conditions.	How to recognize conditions and when to defer. Worker safety when coming in contact these conditions.
Building Structure and Roofing	Building rehabilitation is beyond the scope of the Weatherization Assistance Program. Homes with conditions that require more than incidental repair should be deferred. See Mold and Moisture guidance below.	Visual inspection. Ensure that access to areas necessary for weatherization is safe for entry and performance of assessment, work, and inspection.	Notify client of structurally compromised areas.	How to identify structural and roofing issues.
Code Compliance	Correction of preexisting code compliance issues is not an allowable cost other than where weatherization measures are being conducted. State and local (or jurisdiction having authority) codes must be followed while installing weatherization measures. Condemned properties and properties where "red tagged" health and safety conditions exist that cannot be corrected under this guidance should be deferred.	Visual inspection. Local code enforcement inspections.	Inform client of observed code compliance issues.	How to determine what code compliance may be required.
Combustion Gases	Proper venting to the outside for combustion appliances, including gas dryers is required. Correction of venting is allowed when testing indicates a problem.	Combustion safety testing is required when combustion appliances are present. Inspect venting of combustion appliances and confirm adequate clearances. Test naturally drafting appliances for draft and spillage under worst case conditions before and after air tightening. Inspect cooking burners for operability and flame quality.	Provide client with combustion safety and hazards information, including the importance of using exhaust ventilation when cooking and the importance of keeping burners clean to limit the production of CO.	How to perform appropriate testing, determine when a building is excessively depressurized, and the difference between air free and as-measured.

Health and Safety Issue	Action/Allowability	Testing	Client Education	Training
Drainage - gutters, down spouts, extensions, flashing, sump pumps, landscape, etc.	Major drainage issues are beyond the scope of the Weatherization Assistance Program. Homes with conditions that may create a serious health concern that require more than incidental repair should be deferred. See Mold and Moisture guidance below.	Visual inspection.	Importance of cleaning and maintaining drainage systems. Information on proper landscape design.	How to recognize drainage issues.
Electrical, other than Knob-and-Tube Wiring	Minor electrical repairs are allowed where health or safety of the occupant is at risk. Upgrades and repairs are allowed when necessary to perform specific weatherization measures.	Visual inspection. Voltage drop and voltage detection testing are allowed.	Provide information on overloading circuits, electrical safety/risks.	How to identify electrical hazards. Local code compliance.
Electrical, Knob-and-Tube Wiring	Minor upgrades and repairs necessary for weatherization measures and where the health or safety of the occupant is at risk are allowed. Must provide sufficient over-current protection prior to insulating over knob-and-tube wiring.	Inspect for presence and condition of knob-and-tube wiring. Check for alterations that may create an electrical hazard. Voltage drop and voltage detection testing are allowed.	Provide information to client on over-current protection, overloading circuits, basic electrical safety/risks.	How to identify electrical hazards. Local code compliance.
Fire Hazards	Correction of fire hazards is allowed when necessary to safely perform weatherization.	Check for fire hazards in the home during the audit and while performing weatherization.	Inform client of observed hazards.	How to identify fire hazards.
Formaldehyde, Volatile Organic Compounds (VOCs), and other Air Pollutants	Removal of pollutants is allowed and is required if they pose a risk to workers. If pollutants pose a risk to workers and removal cannot be performed or is not allowed by the client, the unit must be deferred.	Sensory inspection.	Inform client of observed condition and associated risks. Provide client written materials on safety and proper disposal of household pollutants.	How to recognize potential hazards and when removal is necessary.
Injury Prevention of Occupants and Weatherization Workers - Measures such as repairing stairs and replacing handrails.	Workers must take all reasonable precautions against performing work on homes that will subject workers or occupants to health and safety risks. Minor repairs and installation may be conducted only when necessary to effectively weatherize the home; otherwise these measures are not allowed.	Observe if dangers are present that would prevent weatherization.	Inform client of observed hazards and associated risks.	Awareness of potential hazards.

Health and Safety Issue	Action/Allowability	Testing	Client Education	Training
Lead Based Paint	Follow EPA's Lead; Renovation, Repair and Painting Program (RRP). In addition to RRP, Weatherization requires all weatherization crews working in pre-1978 housing to be trained in Lead Safe Weatherization (LSW). Deferral is required when the extent and condition of lead-based paint in the house would potentially create further health and safety hazards.	Testing is allowed. Job site set up and cleaning verification is required by a Certified Renovator.	Follow RRP requirements.	All weatherization crews working on pre-1978 homes must receive LSW training and be accompanied by an EPA Certified Renovator. Grantee Monitors/Inspectors must be Certified Renovators and receive LSW training.
Mold and Moisture	Limited water damage repairs that can be addressed by weatherization workers and correction of moisture and mold creating conditions are allowed when necessary in order to weatherize the home and to ensure the long term stability and durability of the measures. Where severe Mold and Moisture issues cannot be addressed, deferral is required.	Visual assessment is required and diagnostics such as moisture meters are recommended pre and prior to final inspection. Mold testing is not an allowable cost.	Provide client notification and disclaimer on mold and moisture awareness.	National curriculum on mold and moisture or equivalent.
Occupant Preexisting or Potential Health Conditions	When a person's health may be at risk and/or the work activities could constitute a health or safety hazard, the occupant at risk will be required to take appropriate action based on severity of risk. Temporary relocation of at-risk occupants may be allowed on a case by case basis. Failure or the inability to take appropriate actions must result in deferral.	Require occupant to reveal known or suspected health concerns as part of initial application for weatherization. Screen occupants again during audit.	Provide client information of any known risks. Provide worker contact information so client can inform of any issues.	How to assess occupant preexisting conditions and determining what action to take if the home is not deferred. Awareness of potential hazards.
Occupational Safety and Health Administration (OSHA) and Crew Safety	Workers must follow OSHA standards and Material Safety Data Sheets (MSDS) and take precautions to ensure the health and safety of themselves and other workers. MSDS must be posted wherever workers may be exposed to hazardous materials.	Grantees must perform assessments to determine if crews are utilizing safe work practices.	Not applicable.	Use and importance of personal protection equipment. OSHA 10 hour training is required for all workers. OSHA 30 hour training is required for crew leaders.

Health and Safety Issue	Action/Allowability	Testing	Client Education	Training
Pests	Pest removal is allowed only where infestation would prevent weatherization. Infestation of pests may be cause for deferral where it cannot be reasonably removed or poses health and safety concern for workers. Screening of windows and points of access is allowed to prevent intrusion.	Assessment of presence and degree of infestation and risk to worker.	Inform client of observed condition and associated risks.	How to assess presence and degree of infestation, associated risks, and need for deferral.
Radon	Whenever site conditions permit, exposed dirt must be covered with a vapor barrier except for mobile homes. In homes where radon may be present, precautions should be taken to reduce the likeliness of making radon issues worse.	Testing may be allowed in locations with high radon potential.	Provide client with EPA consumer's guide to radon.	What is it, how it occurs. What factors may make radon worse. Weatherization measures that may be helpful. Vapor barrier installation.
Refrigerant	Reclaim refrigerant per Clean Air Act 1990, section 608, as amended by 40 CFR82, 5/14/93.	EPA testing protocols.	Clients should not disturb refrigerant.	EPA-approved section 608 type I or universal certification.
Smoke, Carbon Monoxide Detectors, and Fire Extinguishers	Installation of smoke/CO detectors is allowed where detectors are not present or are inoperable. Replacement of operable smoke/CO detectors is not an allowable cost. Providing fire extinguishers is allowed only when solid fuel is present.	Check for operation.	Provide client with verbal and written information on use of smoke/CO detectors and fire extinguishers where allowed.	Where to install detectors. Local code compliance.
Solid Fuel Heating (Wood Stoves, etc.)	Maintenance, repair, and replacement of primary indoor heating units is allowed where occupant health and safety is a concern. Maintenance and repair of secondary heating units is allowed.	Required inspection of chimney and flue and combustion appliance zone depressurization.	Provide safety information including recognize depressurization.	How to perform CAZ depressurization test and proper inspection.
Space Heaters, Stand Alone Electric	Repair, replacement, or installation is not allowed. Removal is recommended.	Check circuitry to ensure adequate power supply for existing space heaters.	Inform client of hazards and collect a signed waiver if removal is not allowed.	Awareness of guidance.
Space Heaters, Unvented Combustion	Removal is required, except as secondary heat where the unit conforms to ANSI Z21.11.2. Units that do not meet ANSI Z21.11.2 must be removed prior to weatherization but may remain until a replacement heating system is in place.	Testing for air-free carbon monoxide (CO) is allowed. Check units for ANSI Z21.11.2 label.	Inform client of dangers of unvented space heaters - CO, moisture, NO2, CO can be dangerous even if CO alarm does not sound.	How to perform air-free CO testing. Understanding the dangers of unvented space heaters.

WEATHERIZATION PROGRAM NOTICE PAGE 9

Health and Safety Issue	Action/Allowability	Testing	Client Education	Training
Space Heaters, Vented Combustion	Should be treated as furnaces.	Venting should be tested consistent with furnaces.	Not applicable.	Proper testing methods for safe operation (draft and CO) should be conducted and for steady state efficiency if possible.
Spray Polyurethane Foam (SPF)	Use EPA recommendations (available online at http://www.epa.gov/dfe/pubs/projects/spf/spray_polyurethane_foam.html) when working within the conditioned space or when SPF fumes become evident within the conditioned space. When working outside the building envelope, isolate the area where foam will be applied, take precautions so that fumes will not transfer to inside conditioned space, and exhaust fumes outside the home.	Check for penetrations in the building envelope. Sensory inspection inside the home for fumes during foam application.	Provide notification to the client of plans to use two-part foam and the precautions that may be necessary.	Training on use of various products with specification for each application type. MSDS sheets. Temperature sensitivity.
Ventilation	2010 (or most current) ASHRAE 62.2 is required to be met to the fullest extent possible, when performing weatherization activity (must be implemented by January 1, 2012). Implementing ASHRAE 62.2 is not required where acceptable indoor air quality already exists as defined by ASHRAE 62.2. Existing fans and blower systems should be updated if not adequate.	ASHRAE 62.2 evaluation, fan flow, and follow up testing are required to ensure compliance.	Provide client with information on function, use, and maintenance of ventilation system and components. Include disclaimer that ASHRAE 62.2 does not account for high polluting sources or guarantee indoor air quality.	ASHRAE 62.2 training required including proper sizing, evaluation of existing and new systems, depressurization tightness limits, critical air zones, etc.
Window and Door Replacement, Window Guards	Replacement, repair, or installation is not an allowable health and safety cost but may be allowed as an incidental repair or an efficiency measure if cost justified.	Not applicable	Provide information on lead risks.	Awareness of guidance.

Grantee Health and Safety Plan Updates

All Grantees must amend their Health and Safety Plans in their master files of their Grantee Plan to be effective in Program Year 2011. Before any DOE funds can be expended for health and safety, Grantees must provide in the master file the hazards to be remedied and anticipated approaches including testing, training, client education, and conditions that require referral to other agencies that, therefore, necessitate a delay of weatherization services.

As a part of the Health and Safety Plan, Grantees must set health and safety expenditure limits for their Subgrantees, providing justification by explaining the basis for setting these limits and providing related historical experience. It is possible that these limits may vary depending upon conditions found in different geographical areas. These limits must be expressed as a percentage of the average cost per dwelling unit. For example, if the average cost per dwelling is $5000, 10 percent would equal an average of $500 per dwelling unit for health and safety. These funds are to be expended by subgrantees in direct weatherization activities.

At minimum, grantees must develop and include within their Health and Safety Plan, separate detailed components and explanations for:

- A system with guidelines for determining and documenting if the potential health and safety issue should be remedied, referred to other agencies, result in partial weatherization, or lead to deferral. Subgrantees are expected to pursue reasonable options on behalf of the client, including referrals, and to use good judgment in dealing with difficult situations. Documentation forms must be developed and should include the client's name and address, dates of the audit/assessment and when the client was informed, a clear description of the problem, conditions under which weatherization could continue, the responsibility of all parties involved, and the client(s) signature(s) indicating that they understand and have been informed of their rights and options.
- Procedures that include a method used to determine when DOE monies will be used to remedy the health and safety issue, and how the Grantee will treat problems that cannot be remedied with DOE monies after discovery.
- How training will be provided in order to meet the requirements of the health and safety issues.
- Testing for the presence of health and safety issues, including, at a minimum, those tests required in the above Guidance Table.
- Implementation of ASHRAE 62.2, which will be required one year after the date this guidance becomes effective. Grantees must provide justification if making changes to AHRAE 62.2 specific to their housing stock and local considerations in their Grantee Plan.
- Implementation of Smoke/CO Detector installation parameters and procedures.
- Implementation protocols on Air Conditioning and Heating System installation and repair including justification for allowability that includes degree days for cold weather and hot weather climates, and how to define at-risk occupants.

- Detailed procedures on how the Grantee will handle problems discovered during testing of Combustion Gases.
- Implementation of OSHA and MSDS requirements related to crew and worker safety, how the 10 and 30 hour training requirements will be met, and what the process is for determining if crews are utilizing good safe work practices according to all requirements (EPA, OSHA, etc.).
- Protocols for addressing mold found in the client's homes. The protocol should include a method of identifying the presence of mold during the initial audit or assessment, notification to the client, and crew training on how to alleviate mold and moisture conditions in homes.
- Implement and verification of compliance with RRP and LSW.
- Developing procedures and protocols for informing clients of hazards that are identified during weatherization. Clients must be informed in writing and the document must be signed by the client and a copy maintained in the client file.
- Developing procedures for requiring clients to reveal known or suspected occupant health concerns as part of the initial application for weatherization, additional screening of occupants again during the audit, and how steps will be taken to ensure that weatherization work will not worsen the health concern.

CONCLUSION: The Weatherization Assistance Program continues to make progress in addressing health and safety issues and ensuring the health and safety of weatherization workers and recipients of weatherization services. In addition to this guidance, DOE will continuously update and provide best practices and referral opportunities on the Internet at www.waptac.org.

LeAnn M. Oliver
Program Manager
Office of Weatherization and Intergovernmental Program
Energy Efficiency and Renewable Energy

INDEX

A

Acoustical sealant 110
Adhesives
- caulking as 109-111
- construction 111
- for polystyrene foam 111, 185

Air barriers
- air permeance of 86
- definition 87
- primary vs. secondary 87
- testing for leaks 85-97
- testing with manometers 89-96

Air conditioners
- inspections 303-304
- sizing 304

Air conditioning
- reducing costs of 44-45
- refrigerant charge 305

Air filters
- oil burner 242

Air handlers
- See also Blowers
- see also Furnaces
- and house pressures 100-102
- sealing holes in 213

Air leakage
- of materials, rates 86
- sealing 105-128
- when to test 72

Air leaks
- ceilings 116-118
- chimneys 119
- floor cavities 115
- plumbing 117
- porches 122
- size, type 105
- soffits 116
- stairways 122
- types, locations 113-125

Air permeance
- of building materials 86

Air quality 333
- See also Indoor air quality

Air sealing 105-128
- door/window frames 127
- duct boots 284
- masonry surfaces 128
- materials for 106-109
- mobile homes 308-310
- return ducts 281-282
- supply ducts 282-283
- with foam 178-182

Air separator 288
Air shutters, oil 241
Airflow
- improving low 272
- testing for unbalanced 270-271
- troubleshooting 264-271

Air-free CO measurement 335
Air-to-air heat exchangers 354
Alarms
- carbon monoxide 338
- smoke 338

American Gas Association
- venting categories 256

Annual Fuel Utilization Efficiency (AFUE) 256
Appliances
- energy measures 47-52

Asbestos 346-347
Attics
- air leakage 122
- air sealing 118
- finished 114, 154-158
- hatches 120
- insulation 140-158
- ventilation 142-147

Automatic fill valve 289

B

Backdrafting 205-206
Backer rod 108
Balloon framing 168
Band joists
  air sealing 127
  insulation 177-178
Barometric dampers 237
Baseload
  analysis example 41
  measures 47-54
Basements
  air sealing 121
  insulation 183-186
  testing for air leakage 93
  thermal boundary 96-99
Bathtub
  air sealing 117
Batts
  floor cavities 180-181
  for basements 183-184
  open wall cavities 171-172
Blower doors
  components/description 72-74
  preparing for tests 74
  pressure diagnostics 85-97
  simple zone testing 88-89
  test procedures 76
  testing 72-77
  testing air barriers 89-96
Blowers
  controls 269
Boilers
  corrosion 286
  efficiency 289
  low-limit control 289
  maintenance/efficiency 286-287
  sizing 217
Burners
  gas, servicing 203-204
  nozzle for oil 240
  oil 236-242
B-vent chimneys 144
Bypasses 113-125

C

Cad cell 240
Cans. See Lights, recessed
Cantilevered floor
  testing 92
Cantilevered floors
  air sealing 124
Carbon monoxide 231, 334-340
  air-free measurement 335
  alarms 338
  causes of 334
  causes/solutions 231
  exposure limits 335
  standard for oil 239
  testing 205, 335
Caulking 309
  fire-rated 111
  interior cracks 128
  types of 109-111
  uses of 115-128
CAZ 261
Ceilings
  air leakage 116-118
  insulation 140-158
Cellulose insulation
  characteristics 132
  stuffing material 109
  wet-spray 97
CFL 65
  See also Compact fluorescent lamps
CFM50
  defined 72
Charge
  refrigerant 305
Chimney effect. See Stack effect
Chimney liners
  insulating 255
  sizing 255

Chimneys 251-254
air leakage 119
air sealing around 119
all-fuel 253
and insulation safety 144
clearances 253
masonry specifications 252
measures to improve draft 211
mobile homes 317
retrofit liners 254, 257
termination 254
types 251
when to reline 257
Clothes dryers 61, 66-67
efficient use 43
CO 333
See also Carbon monoxide
Coils
cleaning 303
Combustion
oil standards 239
problems/solutions 232
testing/analysis 225-234
the chemical process 226
Combustion air 259-262
cfm requirements 206, 259
confined spaces 260-261
methods of providing 259
mobile home furnaces 316
unconfined spaces 260
Combustion losses
excess air 289
Combustion zone
definition 206, 259
depressurization 106
Comfort
staying cool 44-45
Compact fluorescent lamps 65, 120
Computers, energy consumption 61
Condenser coils
cleaning 303
Construction adhesives 111
Consumption
of energy 38
Convectors
fin-tube 289
Cooling
energy saving tips 44-45
with fans 44
Corrosion 286
Costs
seasonal/baseload 40
Crawl space
thermal boundary 95
Crawl spaces
air sealing 127
thermal boundary 96-99
ventilation 189
Customer education 41-45

D

Dampers
balancing 264
Dense-packed insulation 166-168
Diagnostics
airflow 264-271
building shell 85-93
equipment for 362
house pressure 278-280
pressure-pan testing 276-278
unbalanced airflow 270-271
Doors 198
mobile home 330
replacement 198
sealing frames 127
weatherstrip 200
Draft
and duct improvements 210
measuring, illus. 235
over-fire 238
strength & types of 205-206
Draft proofing
see also Air sealing

Draft-proofing 105-128
Drainage 139, 189
Drywall 107, 120, 128, 184, 186
  thermal barrier 134
Duct mastic 110
Ductboard
  deteriorating facing 283
Duct-induced house pressure 278-280
Ducts 186-187, 263-264, 274-285
  air sealing boots 284
  and house pressures 100-102
  evaluating leakage 274-277
  finding leaks 275-277
  improvements to solve draft problems 210
  in crawl spaces 179
  Insulation 186-187
  mastic 110
  mobile home leakage 311-312
  pressure-pan testing 276-278
  return, blocked 102
  sealing leaks 280-283
  sealing return 281-282
  sealing supply 282-283
  static pressure 265-267
  thermal boundary and 96
  troubleshooting leakage 274-284
Dust
  and respirators 350

E-F

Education
  customer 41-45
Efficiency
  storage water heaters and 56-57
Efflorescence 342
Egress windows 197
Electric furnaces. See Furnaces, electric
Electric heat 293-300
  baseboard 294-295
  furnaces 295
Electrical safety 356-357
Energy
  baseload measures 47-54
  consumption 38
Energy audit
  health and safety 28
  interior/exterior inspection 22-25
  mechanical inspection 26
Energy auditor
  responsibilities 17-45
Energy audits
  ethics, bias 18
Energy consumption 61
Energy factor 56
  water heating 54
Energy recovery ventilators 354
Energy use
  analysis 38-41
  analysis, example 41
EPA lead rules 348-349
Ethics 18
Excess air
  oil burners 239
Expansion tanks 288
Fans
  for cooling 44
  ventilation, sealing 128
Fiberglass insulation
  basements 183-184
  characteristics 130-131
  floor batts 180-181
  floor blowing 179-180
  for stuffing 108
  mobile homes 319-328
  R-value 160
  wall batts 171-172
  wet-spray 97
Fill tubes
  use for wall insulation 325
Filters 304
  air, installation 213
  changing 42

Fire safety
closed-cell foam 134
insulation 142-145
light fixtures 120, 143
Fireplaces
air leakage 119
Fire-rated assemblies 111
Flame characteristics 235, 242
Flashings 139, 191
Flexduct
joints 283
Floors
cantilevered 92, 124
insulation 179-180
mobile homes 326-328
sealing cavities 115
thermal boundary 95
Flue dampers. See vent dampers
Flue-gas analysis 238
Fluorescent lamps
compact 65, 120
Foam
basements, spray 182
characteristics of materials 133-137
closed-cell polyurethane 133-134
injectable 134-135
liquid applied 178-182
liquid sealant 112-113
one-part 113
open-cell polyurethane 134-135
spray 133-134
two-part 113
Foam board 107
basement insulation 185-186
EPS 135-136
polyisocyanurate 136-137
XPS 136
Furnace fans, energy consumption 61
Furnaces 263-285
installation 212-217
mobile homes 314-318
operating parameters 269
replacement 212-217
sealing holes in 213
temperature rise 268

G

Galvanized steel 107
Garages
thermal boundary 96
Gas burners
clocking gas meter 375
operation of 227
Gores 282
Grilles
cleaning 42
Ground moisture barrier 98, 139, 176

H

Hazardous materials
protective equipment 350
Hazards
avoiding 333-358
Health and safety 333-358
communication 333
customer 334-357
inspection 28
Heat exchangers
mobile-home furnaces 316
Heat pumps
efficiency 295-299
room 299-300
testing 296-297
Heat recovery ventilators 354
Heating systems
electric 293-300
electric baseboard 294-295
electric furnaces 295
forced-air 263-285
heat pumps 295-299
hot-water 286
hydronic 217-219, 287-290
mobile homes 314-318
oil-fired 236-242

replacement 220
room heat pumps 299-300
steam 290-293
High limit
hot-water heating 288
steam 292
Hot tubs, energy consumption 61
House depressurization limit
for determining BTL 84
House pressures
duct-induced 100-102
limits 102, 271
measuring 73
reducing 210
unbalanced airflow 270-271
HRVs.
See Heat recovery ventilators
Hydronic heating systems 287-290

I

IAQ 333
See also indoor air quality
IC-rated fixtures 120, 143
Ignition barriers 133, 134, 138
Indoor air pollution
controlling 334-347
Indoor air quality 334-347
see also Ventilation
Infiltration 105
See also
Air sealing, Air leakage
Inspections
air conditioners 303-304
final 32
health and safety 28
in-progress 32
interior/exterior 22-25
mechanical systems 26
Insulation
attic 140-158
basements 183-186
cellulose 132
cellulose stuffing 109
characteristics 129-137
dense-packed cellulose 166-168
durability 138-140
facing 152
fiberglass batts 171-172, 180-181
fiberglass, blown 179-180
fire safety 142-145
foam 178-182
hydronic pipe 219
hydronic piping 289, 293
injectable foam 134-135
mobile home 319-328
non-combustible 132, 137
polystyrene beads 137
pourable 137
rock wool 132
safety 137-138
spray foam 133-135
steam piping 289, 293
to reduce condensation 344
wall 160-173
wall, mobile home 324
water heaters 49-50
Intermediate zones
defined 73
Intumescent paint 134, 138

J-M

Kneewalls 115, 157-158
Laundry
energy savings in 44
Lawrence Berkeley Laboratory (LBL)
61
Lead safety 348-351
EPA RRP rule 348-349
Lead-safe weatherization 349-351
Leakage area 78
Light fixtures
fire safety 120, 143
recessed 120

Lighting 65
Line-voltage thermostats 294
Low-flow shower head 53
Low-limit 219
L-vent chimneys 144
Manometers
  digital 74, 78, 206
Masonry
  sealing 128
Mastic
  duct 110
Mesh tape 282
Metering
  refrigerators 62-64
Mildew 105
  See also Mold
Mobile homes 307-332
  air sealing 308-310
  air-leakage locations 309-310
  construction/components 307
  doors 330
  duct leaks 311-312
  duct pressure testing 314
  floor insulation 326-328
  furnaces 314-318
  insulation 319-328
  roof insulation 319-323
  skirting 332
  wall insulation 324
  windows 329-330
Moisture
  and health 342
  barriers, ground98, 176, 189, 343
  problems 340-345
  source reduction 343-345
  sources 340-342
  water leaks 343-344
Mold 342

N-O

National Fire Protection Association
  standards 248
Natural gas
  heat content 377
  leak testing 375
NFPA. See National Fire Protection Association
Oil burners 236-242
  air filter 242
  excess air 239
  ignition 237
  maintenance/adjustment240-242
  nozzles 240
  performance indicators 231, 239
Oil filters 242
Oil pressure 231, 239
Outdoor thermostat 299
Over-fire draft 238

P-Q

Paint
  failure 342
Perlite 137
Pipe insulation 289, 293
  DHW 52
Plaster 115
Plumbing penetrations
  sealing around 117
Plywood
  air barrier 107
Pollution
  controlling sources 334-347
Polyethylene
  cross-linked 108
Polyisocyanurate foam board 136-137
Polystyrene (EPS) beads 137
Polystyrene foam
  adhesive for 111
  expanded 135-136
  extruded 136
Polyurethane
  caulking 110
  closed-cell foam 133-134
  foam sealant 112-113

open cell foam 134-135
Porch roof
testing air leakage through 92, 94
Porches
air leakage 122
Power venters 257
Pressure
See also House pressures
measuring differences in 73
pan testing 276-278
WRT notation 73
Pressure boundary. See Air barrier
Pressure diagnostics. See House pressures, See Diagnostics
Pressure pan testing 276-278
Pressure tank 218
and pump 218
Pressure-relief valve 218, 287
Primary air
adjustment 233
Programmable thermostats 294
Propane 256
finding leaks 204
Pumps
hydronic, installation 218
Quality assurance 33
Quality control 32, 33

R-S

Radiators 289
Radon 345-346
Recessed lights
air sealing 119
Refrigerant
charge 305
Refrigerators
evaluation and replacement61-64
metering 62-64
Registers
opening 42
sealing around 284
unoccupied spaces 283
Renovation, repair and painting rule 348-349
Reset controllers 290
Respirators 350
Rim joists
air sealing 127
insulation 177-178
Rock wool 132
Roofs
mobile homes 319-323
R-values
see also Thermal resistance
of blown insulation 160
Safety
communication 333
electrical 356-357
fire 142-145
insulation 137-138
of residents 346
storage water heaters 55
windows 194-197
Safety and health 333-358
Sealants
caulking 109-111
foam 112-113
one-part foam 113
two-part foam 113
Siding 191
removal 163
Silicone
caulking 109
Siliconized latex caulk 109
Sizing
air conditioners 304
Skirting
mobile home 332
Smoke alarms 338
Smoke number 239
Soffits
kitchen 116
Split-level homes 118
Stairways
air leakage 122

Static pressure 265-267
Steady-state efficiency 231, 239
testing for 238
Steam heating 290-293
Steam traps 290, 292
Steel
galvanized 107
Stick pins 187, 285
Storage water heaters 54-57
efficiency 56-57
safety 55
Storm windows
mobile home 329-330
Stove cement 111
Stuffing materials 108-109
Subcooling 305
Superheat 305
Superheat test 301-302
Supply ventilation 353

T-V

Tape
holding power 284
Televisions 61
Temperature rise
furnace 231, 268
Termites 133, 140
Termiticides 133, 140
Thermal barriers 133, 138
Thermal boundary
see also Insulation
basements and crawl spaces96-99
flaws in 105
ideal location 95
Thermal bypasses
locations of 113-125
sealing 113-125
Thermal resistance
see also R-values
improving 129-137
of insulation materials 363
Thermostats
cooling settings 44
line voltage 294
outdoor 299
programmable 294
two-stage 299
Torchiere 65
Tri-level homes 118
Utility bills
analysis, example 41
Vapor barriers 138
Vent connectors 248-251
clearances 249, 251
materials 248
specifications 249
Vent dampers 290
Ventilation
attic 142-147
balanced 353-354
crawl spaces 189
determining need for 84
exhaust 351-352
supply 353
systems 351-354
through windows and doors 355
whole house 351-354
see also Indoor air quality
Venting
AGA categories 256
atmospheric 248-255
fan-assisted 256
for condensing furnaces 257
sealed-combustion 257
Vermiculite 137

W-Z

Walls
dense-packing 166-168
inspection 162
insulation 160-173
Water
leakage 343-344
Water heaters
draining sediment 44
efficient use 44

energy efficiency 47-51
insulation 49-50
pipe insulation 52
setting temperature 51
storage 54-57
Water temperature
setting 51
Water-resistive barriers 139, 191
Weatherstrip
attic hatches 120
doors 200
Well pumps, energy consumption of 61
Windows 189-190, 194-197
egress 197
installation 191-194
mobile home 329-330
replacement 189-194
safety 194-197
sealing frames 127
Wood decay 342
Wood heating 243-246
clearances 243
inspection checklist 245
Wood stoves
UL-listed 243
Work orders 30-31
Worst-case draft test 106, 205-206
Zones
combustion-appliance 206
input vs. reference 73
intermediate 73, 274
simple pressure test 88

- •Energy Audits, Client Relations, and Inspections
- •Baseload Measures
- •Diagnosing Shell Air Leakage
- •Air Sealing Homes
- •Installing Insulation
- •Windows and Doors
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