SATURN

BUILDING SHELL

FIELD GUIDE

SATURN RESOURCE MANAGEMENT

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Saturn
Building Shell Field Guide

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This edition compiled by Darrel Tenter

The *Saturn Building Shell Field Guide outlines* procedures for insulating, air-sealing, and improving the shading of existing homes.

The companion volume *Saturn Energy Auditor Field Guide* describes the procedures used to analyze the performance of existing homes.

The companion volume *Saturn HVAC Field Guide* describes the procedures used to evaluate and service forced air heating and cooling systems.

The companion volume *Hydronic Systems Field Guide* includes procedures for evaluating and servicing steam and hot-water space-heating systems.

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: Martha Benewicz, Michael Blasnik, Anthony Cox, Rob de Kieffer, Rick Karg, Dave Like, Bruce Manclark, David Miller, Rich Moore, Gary Nelson, Charlie Richardson, Russ Rudy, 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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Foreword

The Saturn *Building Shell Field Guide* outlines a set of best practices for technicians who perform air-sealing work, install insulation, and replace doors and windows. It also includes guidance on the building shell repairs that are commonly needed as part of these tasks.

Chapter 1 outlines the fundamentals covered in this guide which help the shell technician to make a building more energy efficient.

Chapter 2 describes the diagnostic procedures used to evaluate air leakage through the building shell and ducts.These procedures help technicians focus their work where it will be the most beneficial. We've included simple duct tests here because they are often performed at the same time as shell analysis.

Chapter 3 provides guidance on air-sealing methods and materials. Since uncontrolled airflow can ruin the performance and durability of any insulation, these procedures should always be performed before insulation is installed.

Chapter 4 covers the installation of insulation. Insulation upgrades are still the best way to improve the performance of existing homes.

Chapter 5 describes the best methods for installing new windows and doors. Though this is a popular retrofit, many installations fall short by allowing air leakage and water intrusion into the home. The details described here should help avoid these common pitfalls.

Chapter 6 includes procedures that are specific to retrofitting mobile homes. These can pay off handsomely especially for the owners of older mobiles.

Chapter 7 focuses on the well-being of both technicians and customers. Health and safety remains paramount to our work in the building trades, and we hope you take to heart the advice contained here.

The Saturn *Field Guides* have benefitted greatly over the years from the generous feedback of our readers. Please help continue this process by sending us your comments and suggestions.

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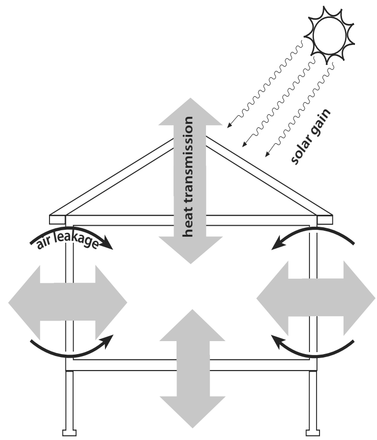
CHAPTER 1: BUILDING SHELL FUNDAMENTALS

1.1 THERMAL FLAWS

Existing buildings have a variety of thermal flaws, caused by inadequate design, faulty construction and neglected maintenance. These flaws lead to excessive energy consumption for heating and cooling because they allow excessive heat to travel through the building shell. The thermal weaknesses fall into three (3) broad categories.



Three major factors in providing comfort: The ideal home has optimal thermal resistance, an airtight air barrier, and orientation and solar control to use solar heat when needed and stop it when not needed.

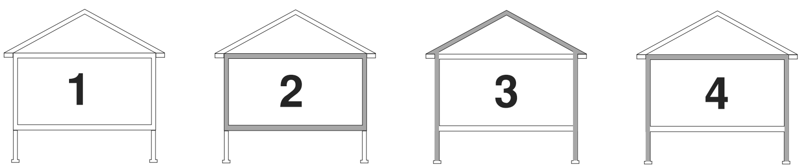
- Inadequate thermal resistance of the building shell.
- Excessive air leakage through the building shell
- Lack of shade and reflectivity resulting in excessive summer solar gain through the building shell.

1.2 SHELL, ENCLOSURE, AND ENVELOPE

Three common terms describe the outermost assemblies of a building. The terms are: shell, enclosure, and envelope. We use shell in this book because it is the simplest and least ambiguous term. Enclosure is also a good term that means the same as shell and is used by many building scientists. Envelope is a common term meaning shell, but envelope is also used to mean a hollow building assembly. These two different meanings for envelope make envelope unsuitable for our purpose of describing the shell of the building.

1.3 Definition: Thermal Boundary

The thermal boundary is a imaginary line, drawn at or inside the building shell, that is useful for discussing heat flow through the building shell. Ideally, an air barrier together with the thermal resistance or insulation is located at the building's thermal boundary. The thermal boundary's location was determined by either the building's designer or by an energy specialist who insulates and air-seals the building after it is built.



1. Building Shell
2. Thermal boundary surrounds conditioned space
3. Thermal boundary encloses entire building shell
4. Thermal boundary encloses conditioned space and crawl space

Typical building shell and thermal boundary configurations: The building shell is the outermost building assemblies that enclose the building. The thermal boundary is the line where the insulation and air barrier are installed. Examples 3 & 4 typically have incomplete thermal boundaries because of no insulation or air barrier on the ground underneath the building.

The thermal resistance and air barrier work together as a system, to limit heat flow across the thermal boundary. The airtightness of the adjacent air barrier has a substantial effect on the insulation's effectiveness. Insulation can retard airflow across the thermal boundary even though insulation's main purpose is to limit heat transmission.

Duct leakage and duct location (either inside the thermal boundary or outside it) are also major energy considerations. If ducts are located outside the thermal boundary, their energy loss is greater than if they are installed inside the thermal boundary.

The thermal boundary is often ambiguous because there is a choice of building assemblies between the conditioned space and outdoors. For example, attics and crawl spaces may be enclosed by the thermal boundary or outside the thermal boundary.

1.4 Insulation Fundamentals

Insulation provides buildings with thermal resistance. The thermal resistance is measured by the R-value. Insulation materials have R-values that vary from 1.5 to 3.5 per inch of thickness. Insulation resists heat transmission by conduction and convection. Insulation resists conduction by covering conductive materials like concrete. Insulation resists convection by filling cavities in building assemblies. Most insulation traps air or another gas inside bubbles or spaces created by fibers. The bubbles and fibers have poor thermal connections between them and the gas has a higher R-value than solid materials. See "Installing Insulation" on page 89.

1.5 Air Sealing Fundamentals

Traditional buildings typically have a lot of air leaks. Even most modern buildings don't have any building component specifically designed as an effective air barrier.

Controlling shell air leakage is a key ingredient in a successful energy conservation for buildings. The decisions you make about sealing air leaks affects a building throughout its lifespan.

Air leakage creates the following unpredictable effects and problems in buildings.

- Air leakage through insulated assemblies reduces insulation R-value.

CHAPTER 2: DIAGNOSING SHELL & DUCT AIR LEAKAGE

The testing described here helps you analyze the existing air barriers and decide whether and where air sealing or duct sealing is needed.

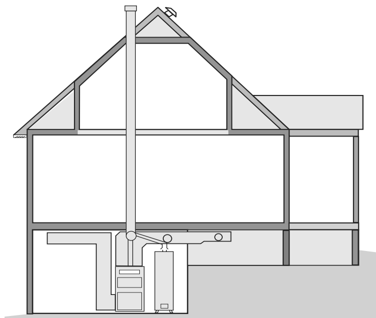
An air barrier together with the insulation is located at the building's thermal boundary. The airtightness of the adjacent air barrier has a substantial effect on the insulation's effectiveness.

Duct leakage and duct location (either inside the thermal boundary or outside it) are also major energy considerations.

2.1 AIR-LEAKAGE AND DUCT-LEAKAGE TESTING

Air leakage testing accomplishes a variety of purposes.

- Measures the home's air-tightness level
- Evaluates the home's ventilation requirements.
- Decides how much time and effort is required to achieve cost-effective air-leakage and duct-leakage rates. *See page 63.*
- Determines whether ducts are within or outside the home's thermal boundary.
- Compares the air-tightness of the air barriers on either side of the intermediate zone like an attic or crawl space. Comparing the ceiling with the ventilated roof gives the technician an idea of how leaky the ceiling is, for example.
- Evaluates the leakiness of individual air barriers like ceilings.
- Determines the best place to establish the air barrier in an area that has no obvious thermal boundary such as an uninsulated crawl space.



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

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 buildings. Depending on the complexity of a home, you may need to perform varying levels of testing to assess shell and duct leakage.

2.2 Air-Sealing and Duct-Sealing Strategies

We believe that there are three basic strategies for reducing air leakage, and at the same time provide adequate ventilation. *See "Whole-House Ventilation Systems" on page 195.*

1. Seal the home to its minimum ventilation requirement (MVR) and use spot ventilation to remove pollutants at their source.
2. Seal the home as tight as you can get it, according to the home-performance or weatherization budget. Provide mechanical whole-house ventilation using exhaust or supply ventilation fans.

3. Seal the home very airtight, during a major home-performance retrofit and install a heat- or energy-recovery ventilator.

2.2.1 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.

- ✔ Perform shell and duct air tightness testing.
- ✔ Analyze the test results to determine if air sealing is cost-effective.
- ✔ Locate and seal the air leaks.
- ✔ Re-test to assess the effectiveness of air sealing efforts.

2.2.2 Duct-Sealing Strategies

Duct leakage is now established as one of the major treatable energy problems in homes. However, sealing every joint without testing can be a waste of time and money. Duct-leakage tests help you investigate the severity and locations of duct leaks before duct-sealing begins. On the other hand, duct testing is time-consuming and doesn't itself save any energy. Therefore prescriptive duct sealing makes sense when the duct leaks of particular house are easy to find. Perform the duct leakage test as a final inspection tool in these cases.

The energy impact of duct leakage depends on whether the ducts are located inside or outside of the thermal boundary. If ducts are outside the thermal boundary, they are an extension of the building shell because they contain indoor air. Duct leaks aren't usually a significant energy problem if the ducts are located inside the thermal boundary. Energy contractors sometimes relocate the thermal boundary to enclose the air handler and ducts for energy savings.

CHAPTER 3: AIR SEALING HOMES

This chapter discusses the locations of air leaks and the methods and materials use to seal them. Duct leakage and sealing is included because duct-sealing often falls under the job description of a building-shell technician. Perform air-leakage testing and evaluation before beginning air-sealing or duct-sealing work. *See "Diagnosing Shell & Duct Air Leakage" on page 21.*

3.1 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 retrofits, and often the most difficult.

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

- Major air leaks, which are significant flaws in the home's air barrier.
- Minor air leaks, which are often seams between building materials.
- Through the building materials themselves (*See table 2-2 on page 39.*

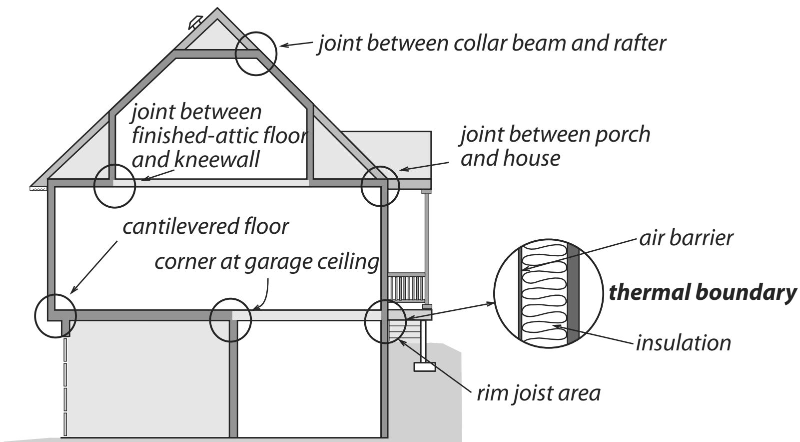
Reducing air leakage accomplishes several tasks.

- Saves energy by protecting the thermal resistance of the shell insulation.
- Increases comfort by reducing drafts and moderating the radiant temperature of interior surfaces.
- Reduces moisture migration into building cavities.
- Reduces the pathways by which fire spreads through a building.

3.1.1 Air-Sealing Strategy

The first step to improving a building's airtightness is to formulate a strategy. What building components already serve as air barriers? How do we best seal the border areas between these components? What is our strategy for sealing various penetrations through the building shell? Answer these questions to develop your air-sealing strategy.

Another important part of the strategy is considering ventilation. *See "Evaluating Home Ventilation Levels" on page 32.*



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.

3.2 When Not to Air Seal

Air sealing reduces the exchange of fresh air in the home, and can alter the pressure balance within the home. Before air sealing, survey the home to identify both air-pollutants that may be concentrated by air sealing efforts, and combustion appliances that may be affected by changes in house pressure. *See "Duct-Induced House Pressures" on page 59.*

Don't perform 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, don't perform air sealing until they're corrected.

- Measured carbon monoxide levels exceed the suggested action level.
- The building is already at or below its Minimum Ventilation Requirement (MVR), and no mechanical ventilation exists or is planned. *See "Evaluating Home Ventilation Levels" on page 32.*
- Combustion-zone depressurization exceeds -4 pascals during a worst-case test.
- Combustion-appliance chimneys don't meet minimum standards.
- Unvented space heaters will be used after air-sealing work.
- Moisture has caused structural damage or respiratory hazards from rot, mold, or dust mites.
- Infestations, vermin, or other sanitary issues are present.

3.3 Air-Sealing Materials

Air barriers must be able to resist severe wind pressures. It is always preferable to use strong air-barrier materials like plywood, drywall, galvanized steel, or foamboard to seal major air leaks, particularly in regions with strong winds. These materials should be attached with mechanical and/or adhesive bonds.

Caulk should be only be used for sealing small cracks. Use liquid foam for cracks larger than $^1/_4$ inch. Don't leave any type of foam exposed to sunlight.

Chapter 4: Installing Insulation

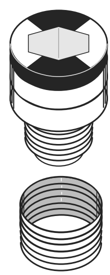
Insulation reduces heat transmission by slowing conduction, convection, and radiation through the building shell. Insulation combined with an air barrier forms the thermal boundary.

Installing insulation is one of the most effective energy-saving measures. You can ensure its effectiveness by following these guidelines.

- ✔ Protect insulation from air movement with an effective air barrier. Make sure that the air barrier and insulation will be aligned (next to one another) using procedures outlined on *page 38*.
- ✔ Protect insulation from moisture by repairing roof and siding leaks, and by controlling vapor sources within the home.

4.1 Insulation Safety Procedures

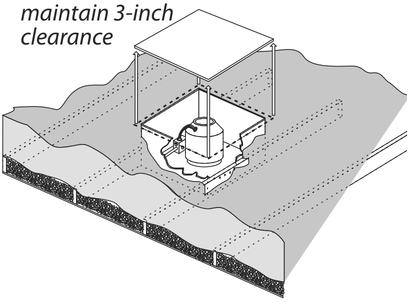
Comply with the following fire and electrical safety procedures before insulating.



S-type fuse: An S-type fuse prohibits residents from oversizing the fuse and overloading an electrical circuit.

- ✔ Inspect wiring, fuses, and circuit breakers to ensure 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. Never cover knob-and-tube wiring with insulation.

✔ Protect heat-producing fixtures such as recessed lights and exhaust fans with lights or heaters. Install an airtight box if air leakage is suspected, or a metal collar if they are airtight.



Recessed light fixtures: Covering recessed light fixtures with fire-resistant drywall or sheet-metal enclosures reduces air leakage and allows installers to safely insulate around the box.

✔ Confirm that all wire splices are enclosed in electrical junction boxes. If you plan to cover a junction box with insulation, mark its location with a sign or flag.

✔ Install insulation shields around unlined masonry chimneys, B-vent chimneys, and manufactured chimneys. Seal any bypasses around chimneys with metal and high-temperature caulk.

✔ Install insulation shields around all-fuel wood-stove chimneys with 6 inches of space between the chimney and insulation.

✔ If shields are used as a barrier around heating producing devices or masonry chimneys, fasten them securely to the ceiling joist so they maintain 3 inches of clearance and don't collapse. Don't allow metal shields to contact wiring. Cover the tops of shields while installing insulation, and uncover and clean them out afterwards.

✔ Wear an approved respirators or dust mask while blowing insulation or installing batts. *See page 208.*

✔ Observe lead-safe weatherization practices with all tasks that may disturb interior paint. *See page 200.*

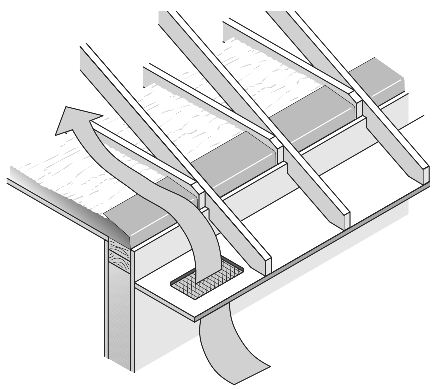
4.2 Attic Insulation

Attic insulation is one of the most cost-effective energy conservation measures available.

4.2.1 Preparing for Attic Insulation

Perform these preparatory steps before installing attic insulation.

- ✔ Before insulating the attic, seal air leaks and bypasses as described previously. Air leakage and convection can significantly degrade the thermal resistance of attic insulation. 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 75.*
- ✔ Repair roof leaks and other attic-related moisture problems before insulating attic. If attic-related moisture problems can't be repaired, don't insulate the attic.
- ✔ Vent all kitchen and bath fans outdoors through roof or soffit fittings. Use galvanized steel vent pipe, and insulate the pipe to prevent condensation. Avoid using flexible plastic or aluminum duct. 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.



Soffit chute or dam: Allows installation of maximum amount of insulation in this cold area. Also prevents wind washing and airway blockage by blown insulation.

Chapter 5: 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 heat losses and gains, by conduction, convection, and radiation through windows, are often quite high. Unfortunately, the cost to improve windows is also high, so the payback from window improvements is usually not as attractive as many other retrofits. In older buildings, though, the windows and doors may be in such poor condition that their repair or replacement essential to a building's survival even if it's not an energy-saving measure.

All tasks relating to window and door improvement, repair, and replacement should be accomplished using lead-safe weatherization methods. *See "Lead-Safe Repair Work" on page 200.*

5.1 Window Shading

About 35% to 85% of the solar energy that strikes a home's windows passes through the glass and enters the living space. Solar heat may be welcome in cold weather, but solar heating through windows accounts for up to 40% of summer overheating in many homes. To reduce cooling costs, block solar heat before it enters the home.

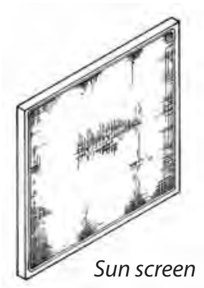
Window shading increases comfort and reduces the cost of cooling, and is one of the most cost-effective weatherization measures in hot climates. Not all windows cause overheating, so you should prioritize your efforts towards windows where the most heat enters including the following.

- Windows that face east or west and so are exposed to low-angle sun
- South side windows without adequate overhangs
- Windows with no shade from landscaping or roof overhangs
- Large windows

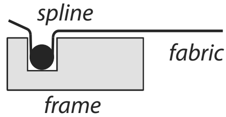
Exterior Window Treatments

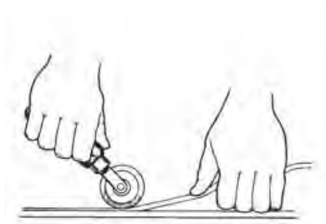
Sun screens, made of mesh fabric that is stretched over an aluminum frame, are one of the most effective window-shading options. They absorb or reflect a large portion of the solar energy that strikes them, while allowing a slightly diminished but acceptable view out of the window.

Sun screens are installed on the outside of the window, and work well on fixed, double-hung, or sliding windows. They aren't suitable for jalousie windows. For casement and awning windows, the sun screen should be mounted on the movable window sash rather than on the window frame. Sun screens are easily constructed in the shop or on the job.



Sun screen





Rolling the spline

Sun screens: Installed on the window's exterior, sun screens absorb solar heat before it enters the home. This strategy is superior to interior window treatments, which reflect heat back after it has entered.

- ✔ Cut the frames to size using a metal cutting saw.
- ✔ Fasten the frames together through reinforced corner pieces.
- ✔ Cut the fabric a few inches large in length and width, and stretch it into the frame using continuous soft plastic splines that fit into the frame.
- ✔ Cut the excess fabric from around the edges of the channel.

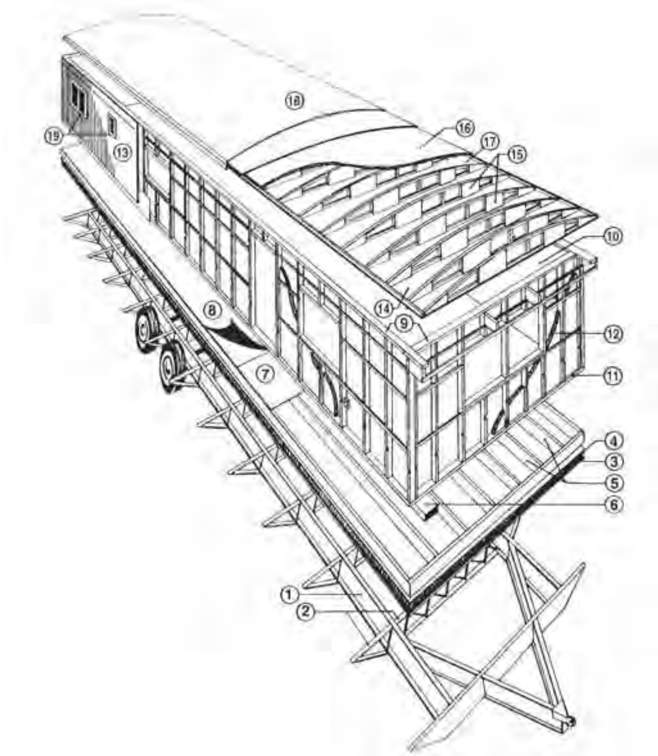
Install sun screens on the exterior of the window frame, trim, or sash. Drill pilot holes for screws that pass through the aluminum frame, or use clips that are screwed to the window frame outside the sun screen. Use aluminum fasteners on aluminum frames to avoid corrosion.

Other exterior window shades such as awnings, shutters, or rolling shades can provide good window shade, but their high initial cost makes them less cost-effective than simple sunscreens.

Chapter 6: Mobile Homes

Mobile homes typically use more energy per square foot than site-built homes. Fortunately, their consistent construction makes them easy to weatherize.

Insulation upgrades save the most energy in mobile homes, though sealing shell and duct air leaks presents good opportunities, too. Mobile home heating replacement is often cost-effective when a customer's energy usage is high.



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.

6.1 Mobile Home Air Sealing

The location and relative importance of mobile home air leaks was a mystery before blower doors. Some mobile homes are fairly airtight, and others are very leaky. Air leakage serves as ventilation in most mobile homes. Observe the minimum ventilation requirements outlined in *"Evaluating Home Ventilation Levels" on page 2-32*.

A duct airtightness tester, which pressurizes the ducts is the best way to measure and evaluate duct air sealing. For evaluating mobile-home duct tightness, the blower door used in conjunction with a pressure pan does a good job of detecting air leaks. *See "Pressure-Pan Testing" on page 56.*

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 6-1: 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 as return-air plenum	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. Assess 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.

6.1.1 Shell Air-Leakage Locations

Blower doors have pointed out the following shell locations as the most serious air-leakage sites.

- 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.
- Torn or missing underbelly, exposing flaws in the floor to the ventilated crawl space.
- Large gaps around furnace and water heater chimneys.
- Severely deteriorated floors in water heater compartments.
- Gaps around the electrical service panel box, light fixtures, and fans.
- Joints between the halves of doublewide mobile homes and between the main dwelling and additions.
- Window and door air leakage are more of a comfort problem than a serious energy problem.

Chapter 7: Health and Safety

This chapter introduces some of the most pressing hazards that your clients face in their homes, as well as those you face at work.

When you discover serious safety problems in a customer's home, you should inform the customer about the hazards and suggest how to eliminate them. Major hazards and potentially life-threatening conditions should be corrected before you begin work in the dwelling unless the you are making the corrections as part of their work.

House fires, carbon monoxide poisoning, moisture problems, and lead-paint poisoning are the most important health and safety problems that are related to building repair work.

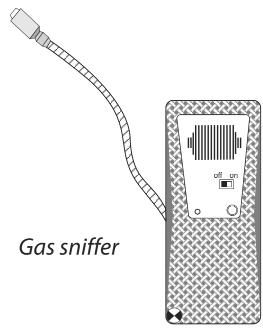
- ✔ Inspect the home for fire hazards such as improperly installed electrical equipment, flammable materials stored near combustion appliances, or malfunctioning heating appliances. Discuss the problems with the client, and perform repairs if possible.
- ✔ Test combustion appliances for carbon monoxide production and other related hazards. Test the ambient air for carbon monoxide. Solve the problems causing these hazards.
- ✔ Find moisture problems and discuss them with the client. Never make moisture problems worse. *See page 190.*
- ✔ Practice lead-safe repair techniques. *See page 200.*

7.1 Essential Combustion Safety Tests

The Building Performance Institute (BPI) requires that essential combustion safety tests be performed as part of all energy conservation jobs. BPI requires gas leak-testing and CO testing for all appliances. For naturally drafting appliances, either a worst-case venting test or zone-isolation test is also necessary. BPI considers naturally drafting appliances and venting systems to be obsolete for both efficiency and safety reasons. BPI strongly recommends that these obsolete appliances be replaced with modern direct-vent or power-vent combustion appliances.

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 find all significant gas leaks if used carefully. Remember that natural gas rises from a leak and propane falls, so position the sensor accordingly.



Gas sniffer

- ✔ Sniff all valves and joints with the gas sniffer.
- ✔ Accurately locate leaks using a non-corrosive bubbling liquid, designed for finding gas leaks.
- ✔ All gas leaks must be repaired.
- ✔ Replace kinked or corroded flexible gas connectors.
- ✔ Replace flexible gas lines manufactured before 1973. The date is stamped on a date ring attached to the flexible gas line.

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 that takes place under worst-case conditions. If CO is present in undiluted combustion byproducts more than 100 parts per million (ppm), the appliance fails the CO test.

Ambient Air Monitoring for CO

BPI standards require technicians to monitor CO during testing to ensure that air in the combustion appliance zone (CAZ) doesn't exceed 35 parts per million. If ambient CO levels in the combustion zone exceed 35 parts per million (ppm), stop testing for the your own safety. Ventilate the CAZ thoroughly before resuming combustion testing. Investigate indoor CO levels of 9 ppm or greater to find their cause.

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 draft and depressurization testing

A–1 Tools for Air Sealing and Insulating

Insulation blower	Broom and dust pan
Blower hoses 4, 3, 2.5, & 2 inch	Cat's paw
Fill tubes and hose fittings	Caulking guns
Coveralls and gloves	Chisels: cold and wood
First-aid kit	Cleaning fluid and rags
Hard hat	End nippers
Respirators and filters	Flashlight
Safety glasses	Hack saw and blades
Ext. ladders, leveler, & hooks	Hammers and wrecking bars
Portable lights	Hand saws
Scaffold, planks, and handrail	Hand staplers
Step ladders: 4, 6, & 8 foot	Metal & Vinyl-siding zip tools
Circular saw with blades	Mirror
Compressor and power stapler	Pliers: electrical & slip-joint
Drill index with bits	Putty knives and scrapers
Drills, drivers, and bits	Putty warmer
Extension cords	Scratch awl and pin punches
HEPA vacuum with attachments	Steel tape measures
Lead paint drill shroud	Screw drivers and nut drivers
Reciprocating saw with blades	Squares: frame, combo, drywall
Shop vacuum, hoses, attachments	Tin snips: hand and electric

A–2 MATERIALS FOR AIR SEALING AND INSULATING

Cellulose insulation	Drywall
Closed-cell foam tape	Compact fluorescent lamps
Fiberglass batts	Energy-saving shower heads
Fiberglass blowing wool	Programmable thermostats
Fiberglass duct wrap	Window weatherstrips
Foam backer rod	High-quality door weatherstrip
Foam pipe sleeves	Replacement refrigerators
One-part squirt foam	Replacement water heaters
Sheet foam insulation	1/4-inch plywood or hardboard
Two-part spray foam	Assorted lumber
Water heater insulation	Assorted screws and nails
Assorted chimney pipe	Assorted staples
Assorted furnace filters	Construction adhesive
Duct mastic and web tape	Disposable coveralls, boot cov-
Duct tape and electrical tape	Disposable paint brushes
Furnace filter material	Plastic garbage bags
Proper vents	Plastic sheeting
Galvanized sheet metal	Pop riveter
Acoustical sealant	Putty tape
Bronze v-seal weatherstrip	Silicone or urethane caulk
Jamb-up weatherstrip	Siliconized acrylic-latex caulk
Customer-education booklets	Portable tape recorder

A–3 R-VALUES FOR COMMON MATERIALS

Material	R-value
Fiberglass or rock wool batts and blown 1″	2.8–4.0[a]
Blown cellulose 1″	3.0–4.0[b]
Vermiculite loose fill 1″	2.7
White expanded polystyrene foam (beadboard) 1″	3.9–4.3[a]
Polyurethane/polyisocyanurate foam 1″	6.2–7.0[c]
Extruded polystyrene (blue, yellow or pink) 1″	5.0
Oriented strand board (OSB) or plywood 1/2″	1.6
Concrete 1″	0.1
Wood 1″	1.0[d]
Fired clay bricks 1″	0.1–0.4
Gypsum or plasterboard 1/2″	0.4
Single pane glass	0.9
Low-e insulated glass	3.3–4.2[e]
Triple glazed glass with 2 low-e coatings	8.3

a. Varies according to density (increases with increasing density).
b. Varies according to density (decreases with increasing density).
c. Varies according to age and formulation.
d. Varies by species.
e. Varies according to Solar Heat Gain Coefficient (SHGC) rating.

A–4 Calculating Loose-Fill Attic 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. Attic insulation always settles: cellulose settles between 10% to 20% and fiberglass settles between 3% to 10%. Density should be between 1.3 and 2.0 pounds per cubic foot or conform to manufacture's specifications, to achieve the desired R-value.

Table 1-1: Example Insulation Bag Chart

R-Value at 75° F mean Temp.	**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 example table is provided by Weather Blanket Corporation. Coverage and other insulation characteristics will vary from manufacturer to manufacturer.

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