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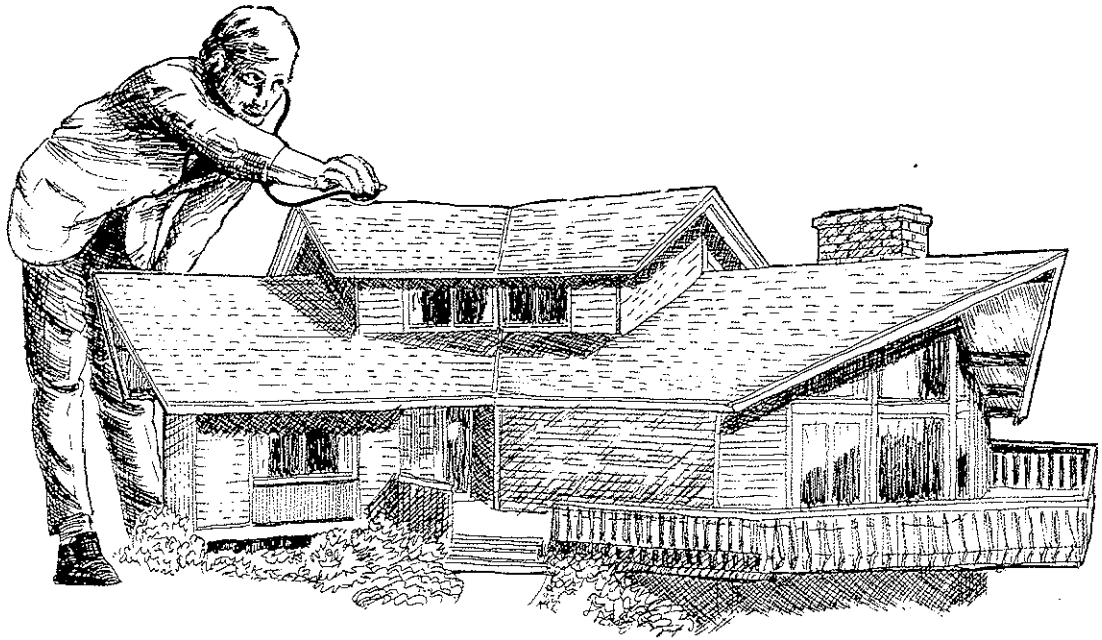

Energy Performance of Buildings Group

THE HOUSE DOCTOR'S MANUAL

Lawrence Berkeley Laboratory • University of California

Prepared for the U.S. Department of Energy under Contract DE-AC03-76SF00098

The House Doctor's Manual

R.C. Diamond, J.B. Dickinson, R.D. Lipschutz,
B. O'Regan, and B. Shohl

Energy Performance of Buildings Group

Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

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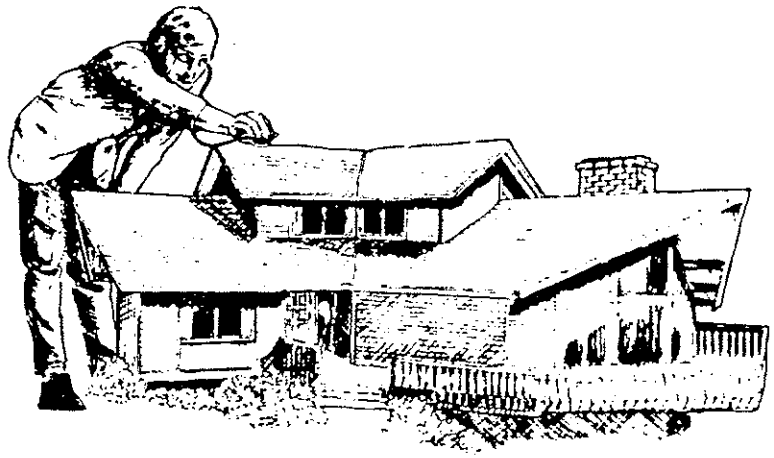
HOUSE DOCTORING

"House doctoring" is a term that describes a combination energy audit and energy-saving retrofit procedure developed at Lawrence Berkeley Laboratory and Princeton University. House doctoring analyzes areas of energy loss in which economically attractive conservation investments can be made, but goes beyond a conventional audit by locating and eliminating air infiltration sites by using special diagnostic instrumentation. While energy-saving recommendations come from the conventinal energy-audit procedure, actual retrofits are performed in house doctoring. In a house with a moderately high air exchange rate, the savings realized by house doctoring make it a very cost-effective procedure. Furthermore, house doctoring provides the builder or homeowner with valuable information about other cost-effective retrofits that can be implemented.

The House Doctor's Manual is divided into two parts: the first provides an introduction and overview of house doctoring, describing the nature of heat loss in buildings and the tools and techniques a house doctor uses to reduce them. The second part is a step-by-step walk-through of the house doctor visit, describing the actual retrofit process, materials used, the order of repairs, the labor involved, and the important step of post-retrofit evaluation. At the end of the manual are sample check lists and audit forms used in the procedure.

This manual is intended to supplement a house doctor training course which provides energy auditors and weatherization personnel with classroom and on-site training in audit and retrofit procedures.



The retrofits described here should be adapted as necessary to account for local housing stocks, climate, and level of house doctor skill.

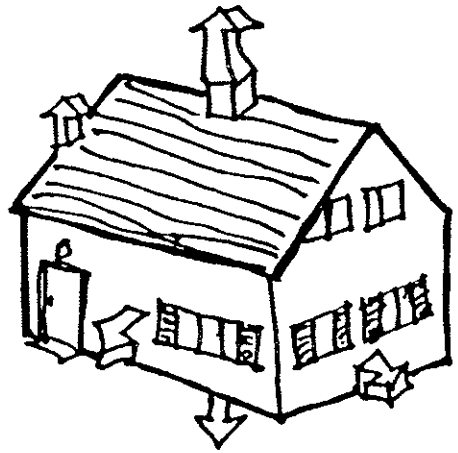
PART ONE

HEAT LOSS: CONDUCTION & INFILTRATION

Heat passes through all parts of the building envelope--the windows, doors, walls, roof, and foundation. Most heat loss takes place through two processes: CONDUCTION and INFILTRATION. Conduction is the heat loss directly through materials. Infiltration is the heat loss due to air leakage--through cracks and openings in the building shell. Conductive losses are countered by increasing the thermal resistance of the building shell through the addition of insulation and/or storm windows. This type of conservation retrofit is quite expensive and is not part of the house doctor routine. House doctors concentrate primarily on infiltration reduction. Because infiltration can account for up to 40% of the heat loss in a house, the elimination of air leakage sites is an important means of saving energy.

Infiltration commonly occurs wherever two different types of materials or two surfaces or building components meet. Some examples are the intersections of floors with walls, walls with ceilings, chimneys with floors and walls, and any penetrations in the wall, floor, or ceiling to accomodate fixtures for plumbing, electric switches and outlets, or light fixtures. Air leakage can also occur through "bypasses" from the basement and house interior into the attic. These bypasses are most often found in wall cavities and around chimneys and vent and flue pipes. Some of these leakage sites develop with age and settling of the structure; others are present from the time of construction.

Whatever their source, eliminating air leaks is a primary goal of house doctoring. Using diagnostic techniques described in the next section, the house doctor will locate these leaks and then repair the most significant ones.



TYPICAL HEAT LOSS:

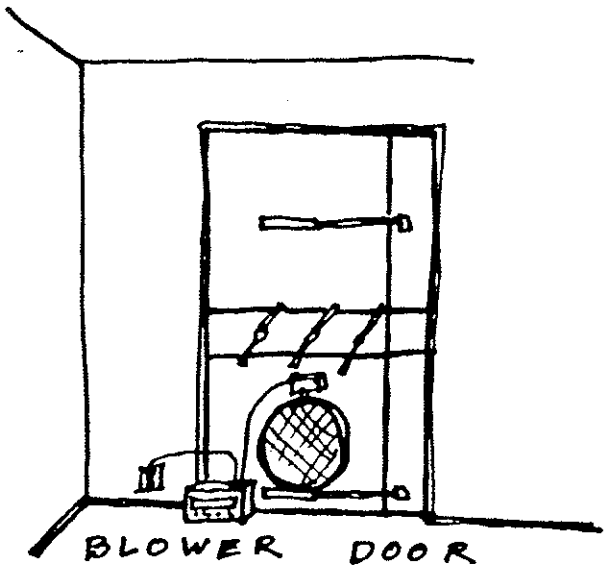
CONDUCTION:

ROOF	16%
WALLS	30%
WINDOWS	12%
BASEMENT	14%
INFILTRATION:	28%
	100%

SIX DIAGNOSTIC PROCEDURES

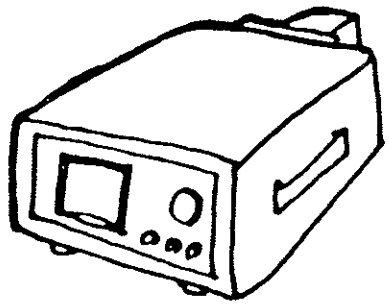
1) BLOWER DOOR

The most important tool available to the house doctor is the "blower door," a large, door-mounted variable-speed fan that can blow air into (pressurize) or suck air out of (depressurize) a house. Operation of the blower door causes air to flow through the cracks and openings in the building envelope. Knowledge of the rate at which air is flowing through the fan and the pressure difference across the building envelope allows calculation of a quantity called the "effective leakage area" of the house. This value can be used in conjunction with an infiltration model developed at Lawrence Berkeley Laboratory to calculate seasonal infiltration rates for the house. By measuring the leakage area before and after house doctoring, it is possible to quantify the effectiveness of the retrofits. If a house is found to be relatively "tight," the technicians can decide whether house doctoring will be cost-effective, or whether an alternative set of retrofits are advisable.



2) IR SCANNER

By using the infrared (IR) scanner it is possible to find the leaks through which air is escaping. The IR scanner is a heat-sensitive television camera, which, when pointed at an object, shows warm spots as bright areas. During pressurization, warm air escaping through the building envelope is detectable as a bright area on and around the building surface. The scanner is also used to look for bypass leaks in the basement and attic.



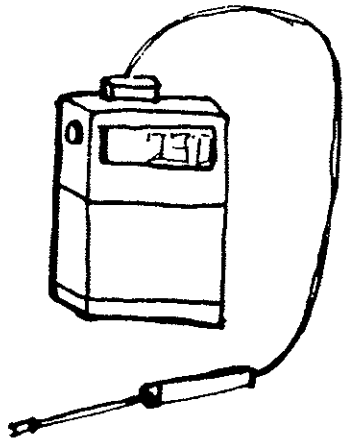
IR SCANNER

3) SMOKESTICKS

While the house is pressurized, and one technician is surveying the exterior with the IR scanner, the other technician conducts an interior leakage survey using smokesticks. The smoke is carried through cracks and holes by the air passing out of the house. Major leakage sites are marked or noted for repair. Smokesticks are also used when there is not a large enough temperature difference for the IR scanner, and in cramped basements or attic areas where operating the IR scanner would be difficult.

4) DIGITAL THERMOMETER

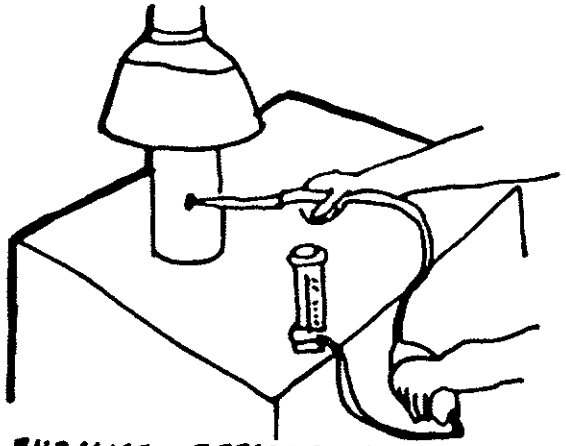
The digital thermometer is used to measure indoor air temperatures while the furnace or air conditioner is operating. Measurements are made within six inches of the thermostat and compared with the thermostat reading. In addition, temperature measurements may be taken throughout the house to determine whether the furnace distribution system is properly balanced. If there is significant disagreement, the thermostat is recalibrated. Air temperatures are measured around the furnace in order to estimate heat losses to its surroundings. Hot water temperatures are also measured with the digital thermometer.



DIGITAL THERMOMETER AND PROBE

5) FURNACE EFFICIENCY KIT

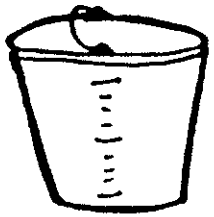
If the house has a gas furnace, one of the technicians performs a combustion efficiency test on the furnace during the interior retrofit procedure. A special testing kit allows measurement of flue gas temperature and carbon dioxide and oxygen concentrations in the flue gases. If furnace efficiency is below 75%, the technician may perform a tune-up. The technician also inspects the furnace air filter and cleans or replaces it if necessary. Finally, the technician lowers to 90-95 ^{o}F the "fan-off" temperature limit switch that controls the furnace fan. This allows more efficient heat transfer from the furnace to the house. Although a number of modifications can be made to a furnace to improve its efficiency--for example, installing electronic ignition or downsizing the nozzle orifice--such changes are generally not made during house doctoring.



FURNACE EFFICIENCY TEST

6) CALIBRATED BUCKET

Flow rates from showers (and possibly faucets) are measured with a calibrated bucket and a stopwatch. If shower flow rates are found to be high, the technician may install a low-flow showerhead or insert a flow restrictor into the existing showerhead. Faucet aerators may also be installed on bathroom and kitchen faucets.



CALIBRATED BUCKET

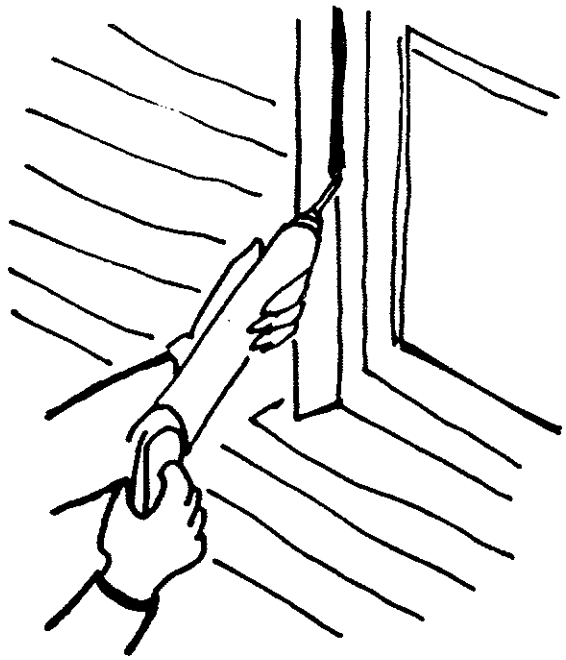
REMEDIES

The house doctor uses two primary remedies for sealing air leakage sites: CAULKING and WEATHER-STRIPPING. Caulk is generally applied where two relatively immobile surfaces meet, such as a wall to floor joint or a hole around a plumbing penetration. Caulk comes in two forms: a pliable, gum-like material that can be worked into cracks and holes, and a foam that expands and hardens upon contact with air.

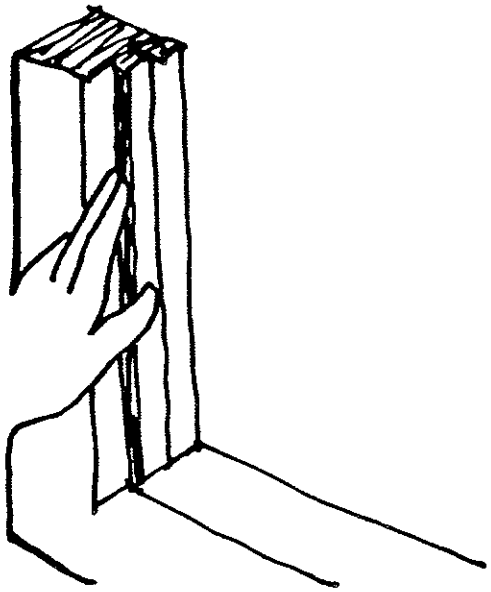
Weatherstripping is made of metal, plastic, or foam and is used where moving surfaces cause compression or friction. Weatherstripping can be applied to both doors and windows. There are four major types of weatherstripping: v-shaped metal or plastic, interlocking metal strips, vinyl tubing, and foam or felt strips. Special thresholds for weatherstripping door bottoms are also available.

House doctors also use duct tape, pieces of fiberglass insulation, and plastic sheet for sealing certain leaks. The use of these materials is described in the section on retrofits.

For a discussion on caulking and weatherstripping and indoor air quality, see: "Find and fix the leaks: A guide to air infiltration reduction and indoor air quality control" #061-000-00538-2, U.S. Govt. Printing Office.



CAULKING

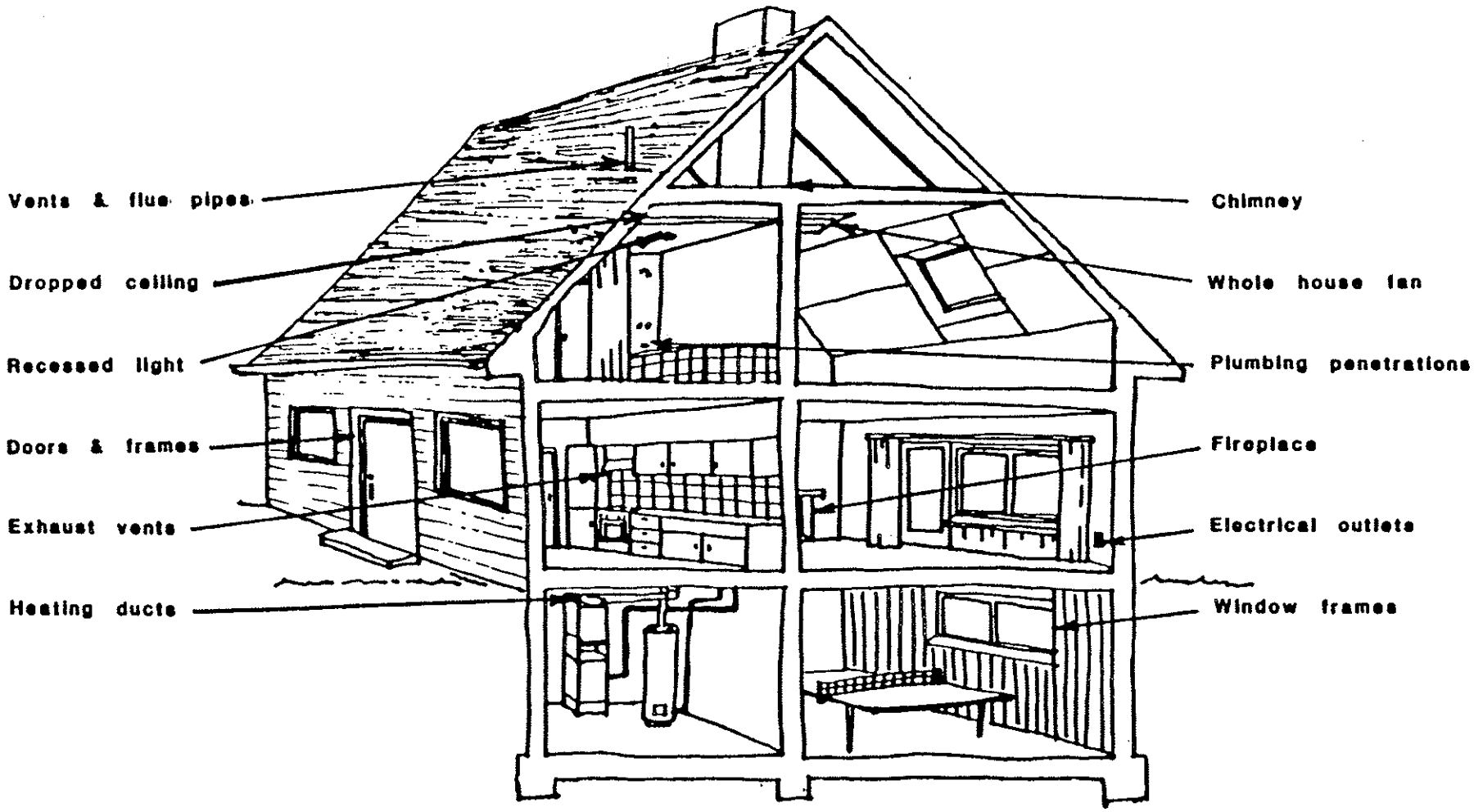


WEATHERSTRIPPING

INFILTRATION SITES & REMEDIES

Location	Leakage Site	Remedy
Interior	Light fixtures, fuse boxes	Caulk around edge
	Electrical outlets, light switches	Install foam gaskets
	Thermostat, phone jack, doorbell	Caulk electrical penetration
	Windows, doors	Install weatherstripping
	Window and door frames	Caulk cracks around edges
	Furnace and exhaust fan registers	Caulk around duct edge
	Baseboards	Caulk floor-wall seam
	Plumbing, exhaust fan cut-throughs	Stuff with fiberglass or caulk
	Window or wall-mounted air conditioner	Cover with plastic; caulk around edges
	Furnace closet door	Install weatherstripping
	Holes in furnace closet	Stuff with fiberglass
	Dryer vent	Caulk around edges
	Baseboard electric heaters	Caulk electrical penetrations
	Fireplace mantle	Caulk mantle-wall seam
	Fireplace damper	Install if not present
	Water heater and furnace flues	Stuff penetrations with fiberglass
	Joints between unlike materials	Caulk
Attic	Furnace ducts	Tape if accessible and leaky
	Furnace registers	Caulk around edge
	Light fixtures, electrical boxes	Install baffle and cover with fiberglass
	Gaps around chimney, flues	Stuff with non-combustible insulation
	Plumbing and exhaust vent cut-throughs	Stuff with fiberglass or caulk
	Dropped or staircase ceiling	Cover with plastic and fiberglass
	Ceiling-wall joints	Stuff with fiberglass or caulk
	Attic door or hatch	Install weatherstripping and insulation
	Whole house fan	Caulk around edge
Basement	Plumbing, electrical cut-throughs	Caulk or stuff with fiberglass
	Bathtub cut-through	Stuff with fiberglass
	Furnace ducts	Tape if leaky
	Raised floor	Cover with plastic
	Gaps around chimney	Stuff with fiberglass
	Cracks along rim joist and sill plate	Caulk

AIR LEAKAGE SITES



REQUIRED MATERIALS

A. Retrofit Materials

___Caulking Compounds
  clear silicone
  white latex
  white butyl
  gray mortar grade
  (one caulk should be adhesive)
___Weatherstripping
  Door bottom sweeps (several lengths and thicknesses)
  Adhesive v-shaped plastic
  Adhesive foam tape (several kinds and thicknesses)
  Clear poly tape
  P and D shaped adhesive EPDM rubber
  Spring metal for doors
___Polyurethane foam caulk and cleaning fluid
___Duct tape
___Insulation
  Roll of R-19 fiberglass
  Water heater blankets
___Electrical switch, outlet gaskets and cover plates (with screws)
___Polyethylene plastic sheet
___Low-flow showerheads, sink faucet aerators, flow restrictor inserts
___Furnace filter replacements
___Warm/cold laundry detergent samples
___Circline fluorescent fixture and bulb
___Fireplace plug materials
  Plywood sheet, 1/4" x 4' x 4'
  Sheet of 3" foam board
  Metal handle and mounting screws
  4' x 1/2" x 2" wooden rod and two screw-in eyelets
  Red spray paint (for painting wooden rod)
___Furnace door latches
___Plywood sheet for attic hatch

B. Tools

___Tool Box
  16 oz. claw hammer
  tack hammer
  nail set
  screwdrivers (including phillips)
  utility knife (with spare blades)
  100-foot measuring tape
  12-foot measuring tape
  compass
  slip joint or vise grip pliers
  staple gun and staples
  2 pairs of scissors
  2 caulking guns
  hacksaw
  handsaw
  thermometer (0-100 °C)
___6-foot stepladder
___Yardstick
___Small cleaning brush
___Rake (for smoothing blown-in insulation)

C. Equipment

___Flashlight
___Head lamps (miner's or caver's type)
___50-foot extension cord
___Three-prong to two-prong adapters
___Alcohol in a squeeze bottle (for cleaning)
___Clipboard, paper, pencils
___House Doctor forms; "Furnace is Off" sign
___4 pairs of work gloves
___2 respirators
___knee pads
___jump suits
___first aid kit
___masking tape
___drop cloths
___rags and towels
___10" x 4' boards for spanning studs in attic

SAFETY

Before undertaking an audit, you should become familiar with what is involved in protecting your personal safety on the job. If you make the resident aware of the audit procedure and what it involves, he or she can often warn you in advance about such hazards as low-hanging pipes in a basement or risky steps in a stairway.

It is particularly important that you not damage anything while in or around the building (plants, collectibles, musical instruments, etc.). Before doing anything such as moving furniture or changing thermostat settings, ask for permission.

General safety guidelines are presented below. Specific safety features related to certain steps in the audit are highlighted in the text.

Attics

--Falling through attic floors is the #1 house doctor accident. Walk only on attic joists--not between--and place boards spanning across joists for additional safety. Be especially careful of attic hatch door framing-- if it is loose or non-load bearing, the edge can break off while entering or leaving the attic.

--Wear a safety helmet to protect your head from nails and low rafters. Gloves, goggles, and a good respirator (not a surgeon's mask) should be used when working around insulation.

Basements/crawlspaces

--Proper clothing is essential in crawlspaces: gloves, goggles, and respirator.

--Check with homeowner regarding recent spraying for pests, mouse traps, etc.

Interior

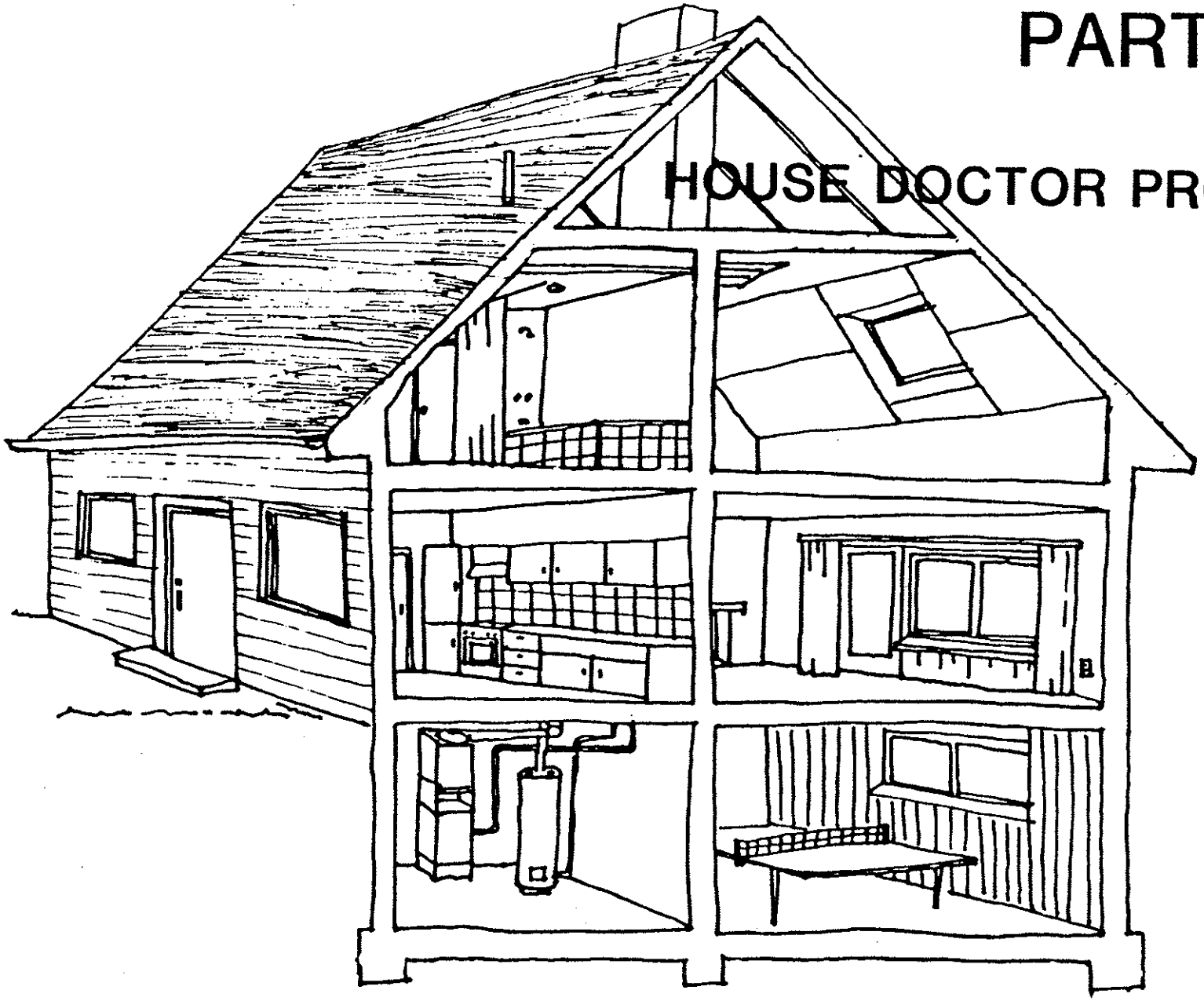
--Watch out for small children and pets. Find out where they belong and how to keep them there.

--When using the blower door, move fragile objects and house plants away from the door. Because blower door operation can stir up dust, check about allergies so that sensitive residents can leave.

--Clean out fireplace to prevent ashes blowing from fireplace during depressurization.

PART TWO

HOUSE DOCTOR PROCEDURE



STEP 1

STEP 2

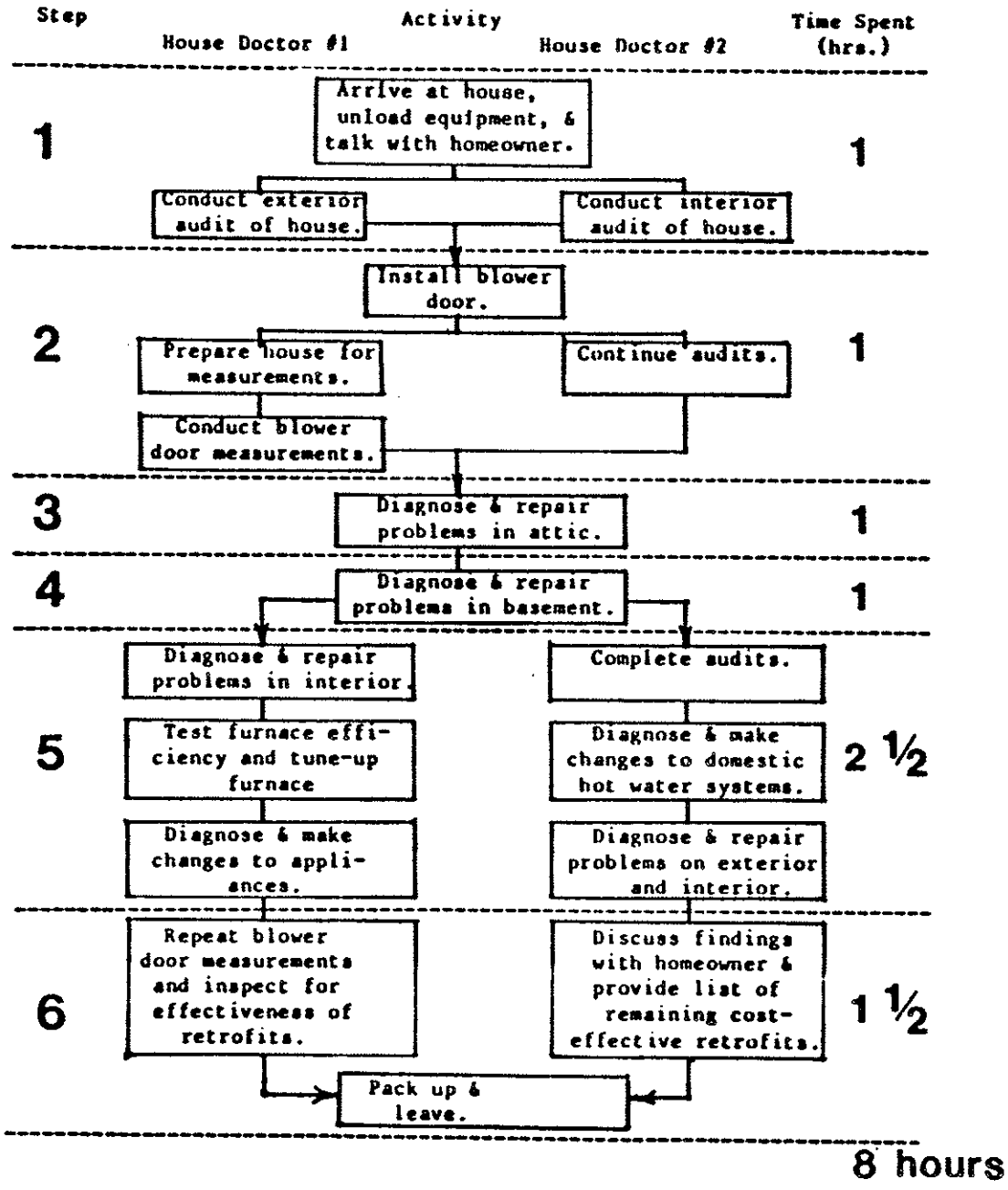
STEP 3

STEP 4

STEP 5

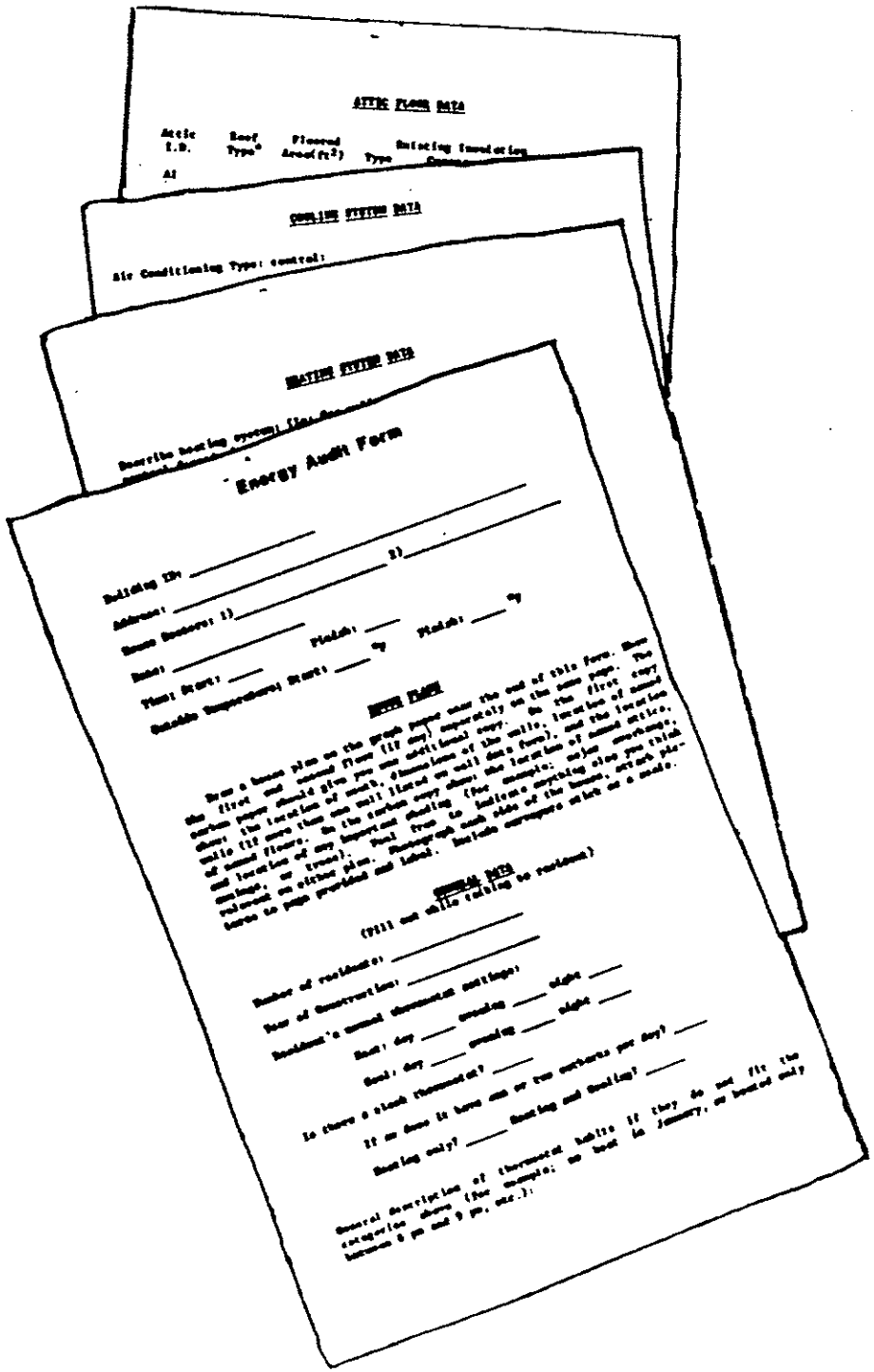
STEP 6

HOUSE DOCTOR FLOWCHART



STEP 1: Arrival at house and setting up

A. Arrive at house and unload equipment and tools
B. Inform homeowner of activities and conduct interview
C. Conduct exterior energy audit
D. Conduct interior energy audit



A. Arrive at house and unload equipment and tools

Be prompt; arrive at the scheduled time. Unload all equipment and tools necessary for the day's work and place them where they are easily accessible.

B. Inform homeowner of activities and conduct interview

Before getting started, one of the technicians should explain the day's activities to the homeowner to encourage his or her interest. The discussion should include explanations of the goals of house doctoring, the diagnostic measurements to be taken, and the repairs and retrofits that may be made in various parts of the house. The technician should obtain permission to make any modifications that may directly affect the occupants of the house or the house itself, e.g., low-flow showerheads, weatherstripping. The technician should also obtain information from the homeowner regarding their energy-use practices, such as thermostat set-backs and hot water temperature settings, as well as utility data (if not obtained beforehand), and any energy-related problems with the house.

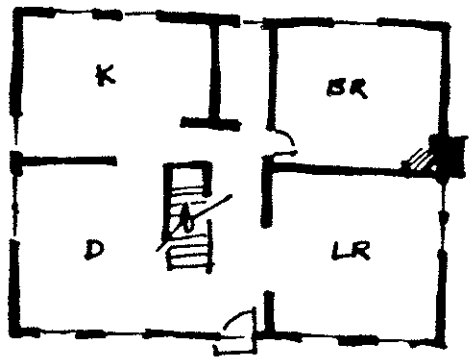
C. Conduct Exterior Energy Audit

This step and the next are performed concurrently. Information is recorded on an audit form. (A sample audit form is provided at the back of this manual). Poloroid photographs should be taken of all sides of the house. The exterior of

the house should be examined (for evidence of moisture damage, broken windows, etc.) and measured, and rough sketches of the house should be made indicating the dimensions, a plan view, and a front view showing attic, basement, and floor. House orientation, overhangs and shading from trees, bushes, and adjacent buildings should also be noted on the audit form and, if possible, on the plan view. Record the rough area of basement and attic vents, air conditioner(s), and condenser coil(s). Check windows and doors for general condition (presence of weatherstripping or caulking) and note their areas and orientations. In general, this audit should be relatively brief; almost all retrofit work is performed inside the house.

D. Conduct interior energy audit

The interior audit includes making a general check of the condition of windows, doors, and other penetrations through the building envelope, locating the furnace and water heater, checking for the presence of insulation and weatherstripping, and so on. Also note the presence of insulation in the attic, recessed electrical fixtures, dropped ceilings, chimneys, ducting, flue pipes, etc. In the basement, check to see whether hot water pipes are insulated. In addition, take temperature readings throughout the house (preferably with the furnace or air conditioner in operation) and compare them to the thermostat setting and check the balance of the heating/cooling supply system. The fireplace should be checked for a damper; if one is present, it should be closed.



HOUSE PLAN

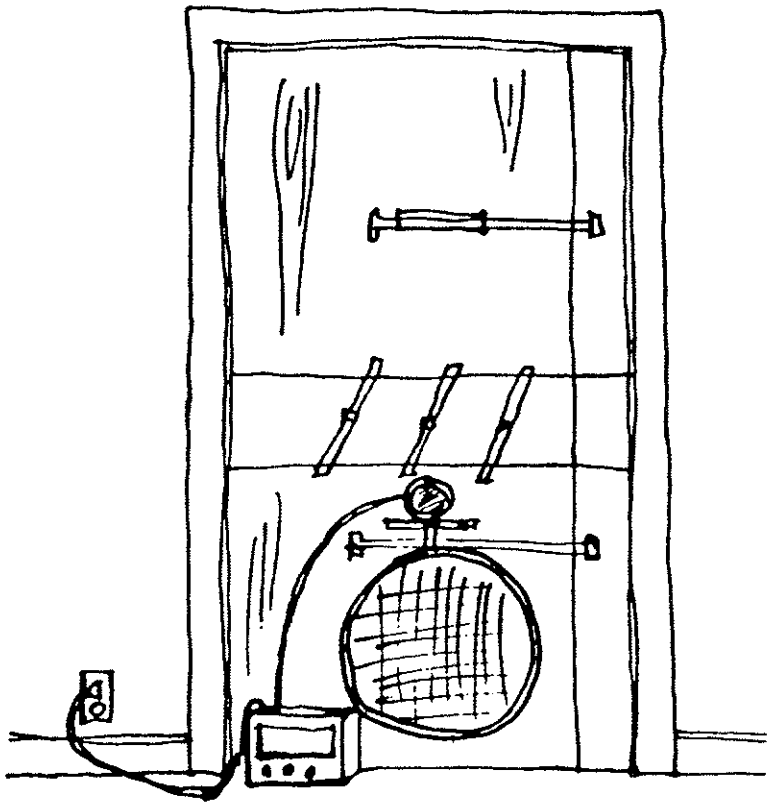
STEP 2: Blower door measurement procedure

A. Install blower door
B. Seal penetrations through building envelope
C. Make pressurization measurements
D. Make depressurization measurements
E. Calculate approximate leakage area of the house
F. Complete interior energy audit

A. Install blower door

The first procedure is to install the blower door in an exterior doorway in preparation for the infiltration survey of the house. The blower door consists of the following parts:

1. Bottom section--fan/motor assembly
2. Top section
3. Aluminum middle section
4. Controller unit with RPM gauge
5. Incline manometer (pressure gauge) or pressure transducer
6. Plastic tubing--3 pieces
7. Connecting cords for RPM gauge/ controller and power cords



The blower door is installed in the following manner:

1. Roll bottom section (with fan and motor) to the exterior door. With one person on the inside and one outside, place the section in the doorway with the bottom edge against the threshold. Adjust the jack screws on the inside of the blower door to tighten it against the door frame.

2. Place the top section of the blower door against the top of the door frame. Adjust the jack screws from the inside of the house to tighten the section in place. The top section should be in the same vertical plane as the bottom section.

3. Install the aluminum middle section of the door to finish assembly. Tighten wing nuts from the outside of the door.

4. Tape those edges of the blower door where no weatherstripping is present.

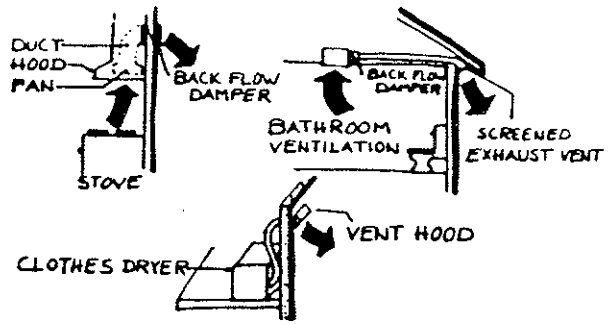
5. Connect the plastic tubing to the nipples on both sides of the blower door. Place the end of the outside tube in a location where it will be shielded from the wind.

6. Connect cords to controller unit and plug in the power cord.

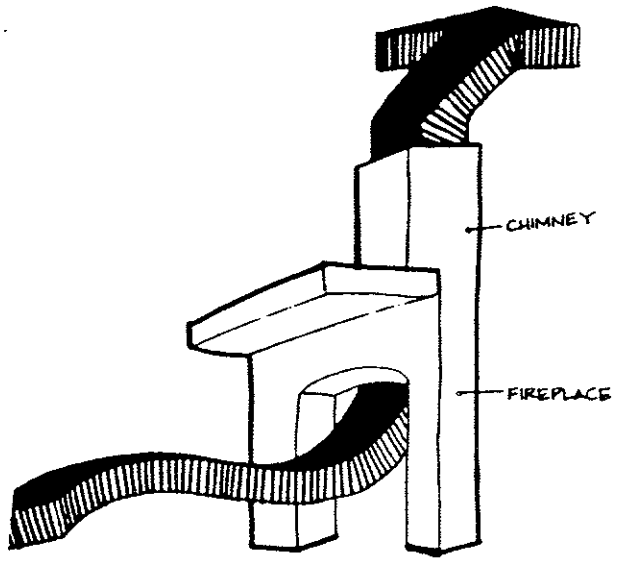
7. Set up the incline manometer or pressure transducer on a flat, level surface. Tape it to the surface to prevent it from falling over.

B. Seal Penetrations Through Building Envelope

Before any leakage area measurements are made, design ventilation penetrations through the building envelope must be sealed. While measurements are being taken, all exterior doors, windows, and closet doors should be closed. Interior doors between rooms are left open, however. Basement or attic doors are left open only if they lead into a conditioned space. Chimney dampers are closed. If a fireplace has no damper, a sheet of polyethylene should be taped over the opening. Cover bathroom, dryer, and kitchen range hood vents with plastic. The furnace or air conditioner should not be in operation while the measurements are being made.



SEAL DESIGN VENTILATION

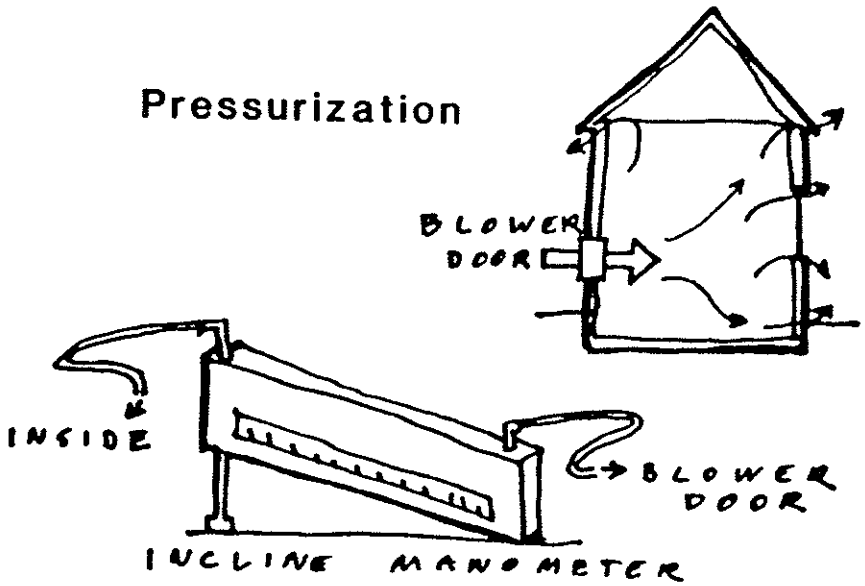


CLOSE FIREPLACE DAMPER

C. Make pressurization measurements

During pressurization, the blower door pulls outside air through the fan into the house and forces it back out the cracks and holes in the building envelope. For pressurization measurements, the plastic tube leading to the blower door is connected to the lower end of the manometer, if one is being used, and the other tube is connected to the higher end. Place the end of this second tube out of the path of the wind from the blower door. Be sure to set the switch on the control box to "Pressurization."

Level the incline manometer and set the meniscus to zero. Turn the fan on slowly until the first pressure interval is reached (usually 0.04" of water or 10 Pascals). Read the digital RPM meter to obtain the average rotation speed of the fan, and record this data. Repeat the procedure for each pressure interval. If the maximum pressure does not reach 0.12" of water or 30 Pascals with the fan at the maximum setting, it may mean that large penetrations through the building envelope have not been covered. Look for obvious leakage areas such as kitchen/bathroom vents, fireplaces or woodstoves with faulty dampers, or an attic hatch that lifts open under pressurization or is improperly sized. Seal such leaks and repeat the test.



D. Make depressurization measurements

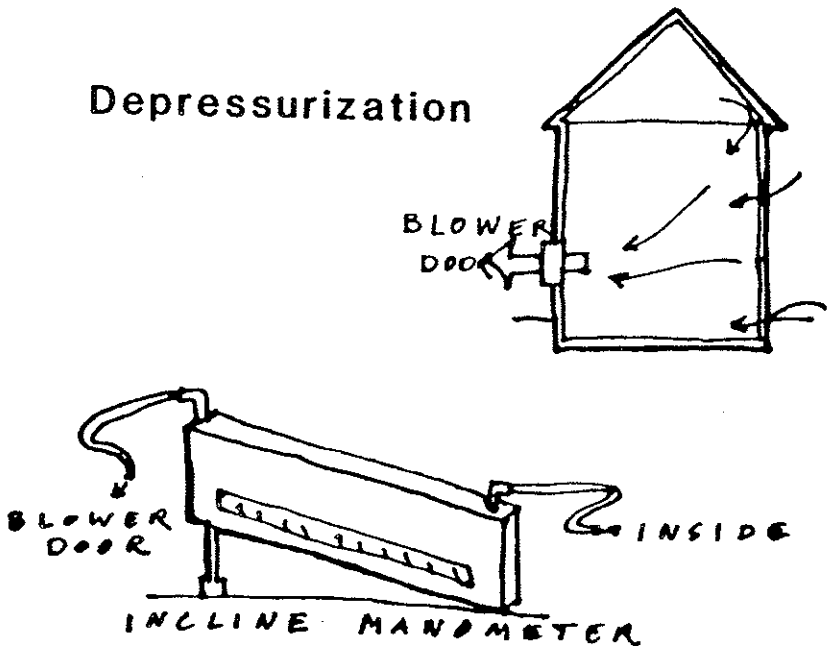
During depressurization, the blower door pushes air out of the house through the fan and pulls it in through cracks and holes in the building envelope. For the depressurization measurements, the plastic tube from the blower door should be attached to the high side of the manometer, and the second tube to the low side. The procedure for making measurements is the same as that described above.

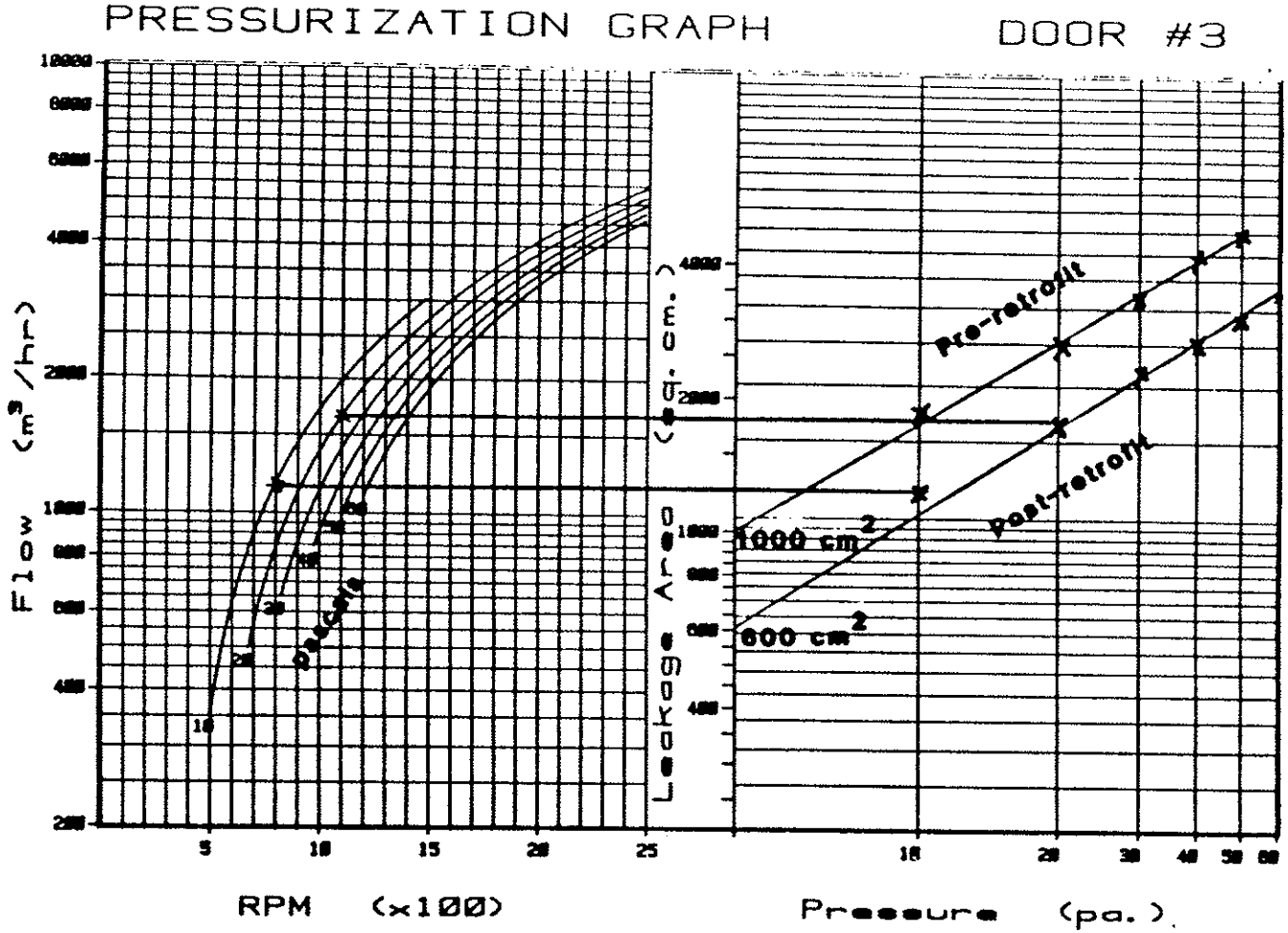
E. Calculate the approximate leakage area of the house

A calibrated blower door (one in which air flows are known for fan rotation speeds) comes with a set of pressurization and depressurization graphs (see example with instructions on next page). These graphs plot RPM on the horizontal axis and pressure on the vertical axis. They also have an axis that plots leakage area. Leakage areas are calculated under conditions of pressurization and depressurization; the average of these two values is considered the approximate leakage area of the house.

F. Complete interior energy audit

One technician can make the leakage area measurements while the second technician continues to audit the interior of the house.





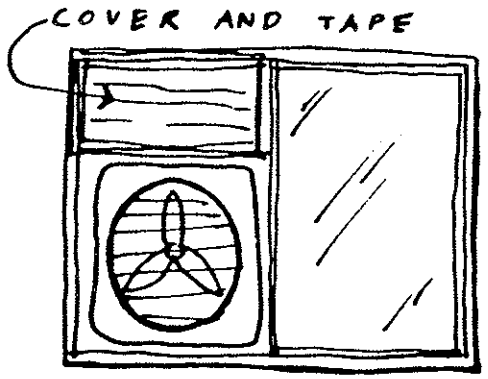
How to use this graph

Let's say you've made measurements with a blower door and have obtained the following readings: 10 pascals, 800 RPM; 20 pa., 1100; 30 pa., 1,350; 40 pa., 1,600; 50 pa., 1,800; 60 pa., 2,150. Find the RPM readings on the bottom axis of the left-hand graph and draw a straight line until you intersect the appropriate pressure curve. Mark the point with an "x." (If you want to find the air flow at that pressure, draw a line from the curve to the left hand axis marked "Flow".) Draw a straight line from each "x" to the right-hand graph until you intersect the appropriate pressure line. Mark these points with an "x." Finally, draw a straight line through all the points and find where it intersects the axis marked "Leakage Area." That point is the leakage area for pressurization; in this example, the leakage area is approximately 1000 cm^2 pre-retrofit, and 600 cm^2 post-retrofit. The same procedure is followed for depressurization, substituting the appropriate graph (not shown here).

What to do if you do not have a blower door

a) Use a window fan:

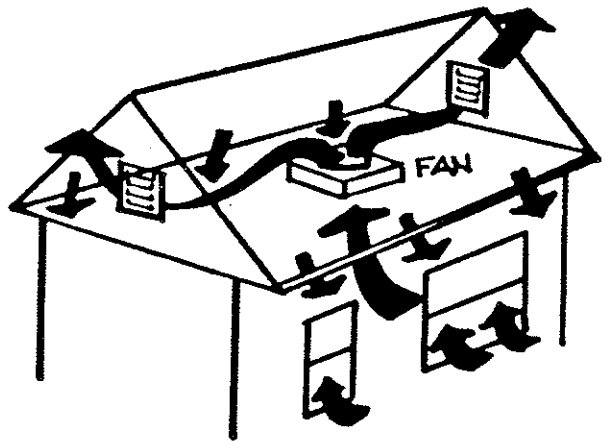
Although measuring leakage area is valuable in order to evaluate the magnitude of infiltration in a house, a blower door is not essential to performing an infiltration diagnosis. A large window fan can be used to survey interior leakage sites, and a whole house fan can help to diagnose problems in the attic and basement. If you are using a window fan, you may have to perform a room-by-room diagnosis. Install the fan in a window so that it is blowing into the room, taking care to seal all openings around the sides of the fan (with duct tape or plastic). Close all other doors and windows. Use a smokestick to look for leakage sites. (One potential problem with a room-by-room setup is that the direct flow from the fan creates turbulence around interior cracks, making it difficult to use smokesticks.)



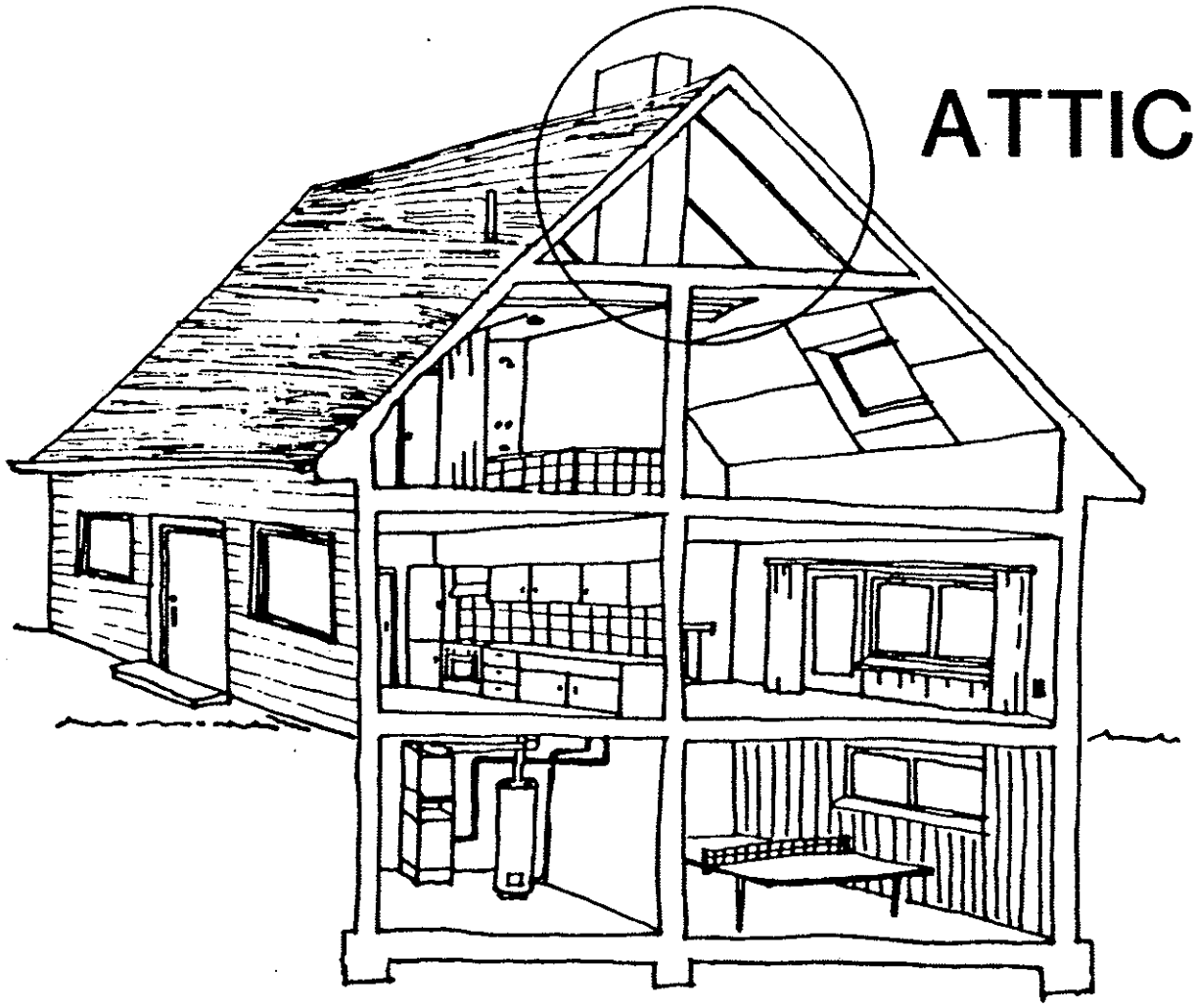
WINDOW FAN

b) Use a whole-house fan:

A whole-house fan depressurizes the house, making it easier to detect leaks from the attic, basement/crawlspace, and house exterior. If you are using a whole-house fan, exterior doors and windows should be closed, as should fireplace dampers. (It is not a good idea to seal all penetrations because depressurization might cause windows to break.) Use a smokestick to look for streams of air flowing into the house or out of the attic or basement. Further discussion of the use of smokesticks to find infiltration sites can be found below.

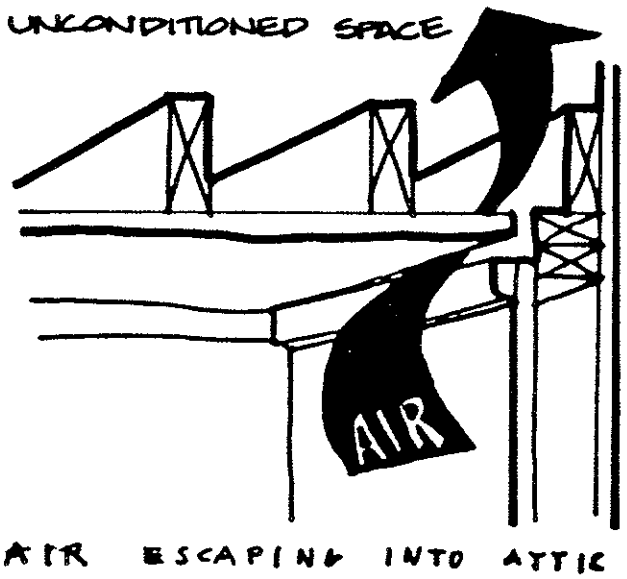


WHOLE HOUSE FAN


ATTIC

STEP 3: Attic procedure

A. Pressurize or depressurize house and take necessary equipment to the attic
B. Conduct a general survey for infiltration sites and bypasses
C. Seal holes where plumbing and wires penetrate attic floor
D. Seal cracks around heating and cooling ducts
E. Seal dropped ceilings and staircase ceilings
F. Seal openings around the furnace flue
G. Seal around exhaust vents
H. Seal leaky heating and cooling ducts
I. Seal leaky areas where interior and exterior walls meet attic floor
J. Seal cracks where the chimney penetrates the attic floor
K. Insulate and weatherstrip attic hatch door
L. Stuff insulation into split-level stud spaces
M. Seal openings in kneewalls
N. Inspect whole house and attic fan
O. Complete attic visit



AIR ESCAPING INTO ATTIC

A. Pressurize or depressurize house and take necessary equipment to the attic

If the infrared scanner is to be used for leak detection, there should be at least a 10 ^{o}F difference between the inside and the outside of the house. Pressurize the building to 0.16" of H_2O (or 40 Pascals) to push warm air from the house into the attic. If smokesticks are to be used, the house should be depressurized to 0.16" H_2O. In this case, air will be sucked from the attic, pulling the smoke with it. It should be noted that the IR scanner is most useful in insulated attics, particularly those with blown-in cellulose or fiberglass.

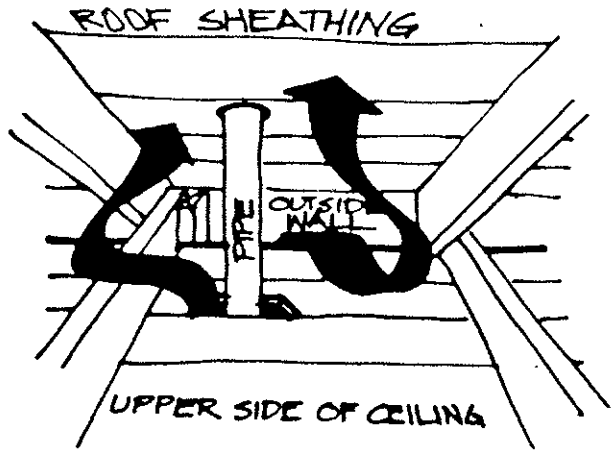
Items to take into the attic in addition to tools and protective clothing are: portable lights, caulking, polymeric foam, fiberglass, polyethylene sheeting, a staple gun, duct tape, and pieces of weatherstripping. The batch should be kept closed while work is in progress in the attic.

B. Conduct a general survey for infiltration sites and bypasses

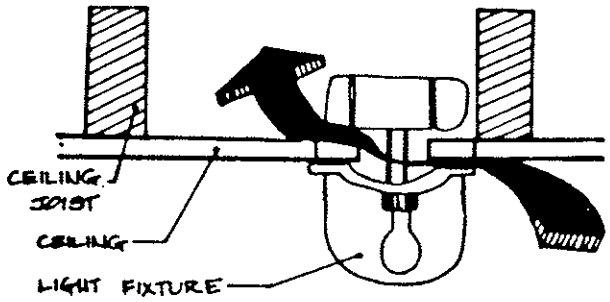
The purpose of this survey is to pinpoint infiltration sites most in need of repair. Common sites are listed in Table 1 and some are shown graphically in the accompanying figures. The infrared scanner is used to check the attic floor for "hot spots"-- places where the existing insulation blanket is inadequate or poorly installed or where warm air is flowing from the living space through the insulation. Use smokesticks to check for air currents flowing through cracks and openings in the floor, around chimneys, pipes, vents, and light fixtures. Record problem areas on a scale diagram of the attic and note the type of problem found. Mark the spot with masking tape.

C. Seal holes cut for plumbing, wires and recessed light fixtures in the attic floor

Plumbing vents normally pass through the attic and out the roof. Electrical wires often pass through the attic floor, especially those to light fixtures and switches. These openings can be sealed with caulking, fiberglass insulation, or polymeric foam. Large openings around pipes and wires can be stuffed with fiberglass insulation. Holes less than 2" in diameter can be filled with polymeric foam. Tube-type caulking can be used on smaller cracks and holes less than 1/2" in diameter.

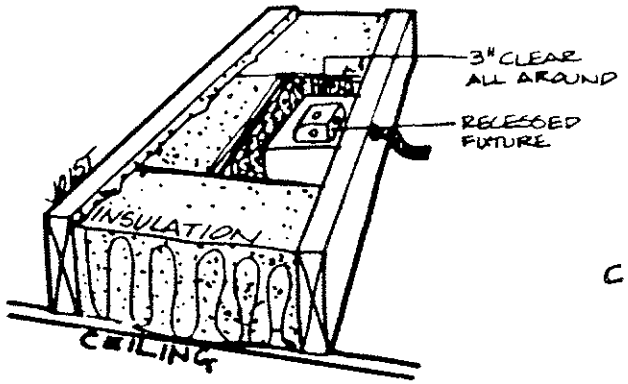


ATTIC BYPASSES



CEILING FIXTURES

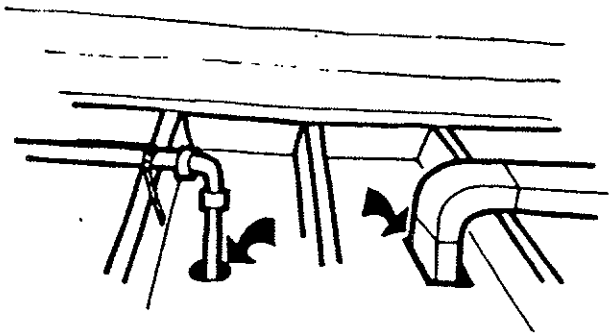
As a general rule, recessed light fixtures should be dealt with carefully. Combustible materials should not be used to insulate such fixtures. Fiberglass should be kept several inches away or, alternatively, a metal baffle can be constructed over which batting can be laid. Caulk such fixtures from the interior of the house with clear silicone caulk.



CEILING FIXTURES

D. Seal cracks around heating and cooling ducts

Holes or openings found where heating and cooling ducts penetrate the attic floor can be stuffed with fiberglass insulation or filled with polymeric foam.

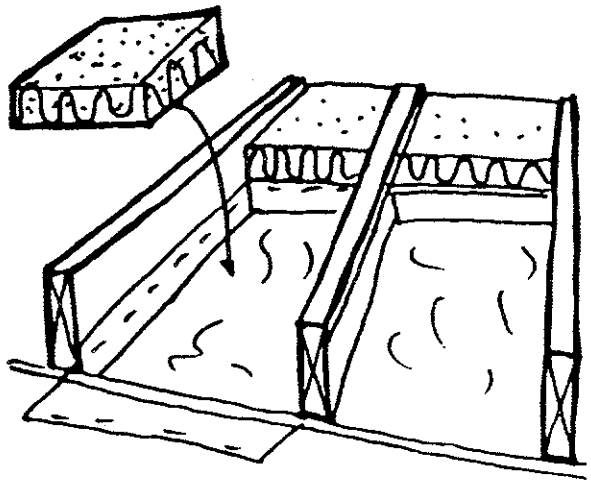


ATTIC PENETRATIONS

E. Seal over dropped ceilings and staircase ceilings

Warm air can pass from the living space into the attic through dropped ceilings over bathrooms, kitchens, closets, or staircase ceilings. Air from the attic is heated by the warm interior air that passes over the surface connecting the dropped or staircase ceiling with the interior. Even if the attic floor is already insulated, the air from the dropped ceiling can pass by the insulation and escape into the attic. Such leaks are not easily identified if the attic has been insulated, but it can be identified from the house interior with a smokestick or in the attic with the infrared scanner. A dropped ceiling may not look leaky from inside the house; it should be checked from interior and attic.

An effective method of sealing over a dropped or staircase ceiling is to lift or push aside the existing insulation and to staple a sheet of polyethylene plastic over the opening in the attic floor. Use butyl or silicone caulk to seal the edges of the plastic to the attic floor. Once the plastic is in place, replace the original insulation



COVER DROPPED CEILINGS WITH PLASTIC AND FIBERGLASS

F. Seal openings around the furnace flue

A furnace flue vents hot exhaust gases from the furnace to the outside of the building. The flue usually passes inside interior walls through the attic and out the roof. Warm air from the interior can escape through the opening around the flue where it penetrates the attic floor. By stuffing fiberglass insulation in the opening, the warm air leak can be effectively sealed. Fiberglass insulation is recommended because it can withstand higher temperatures than those found at the attic level of the flue.

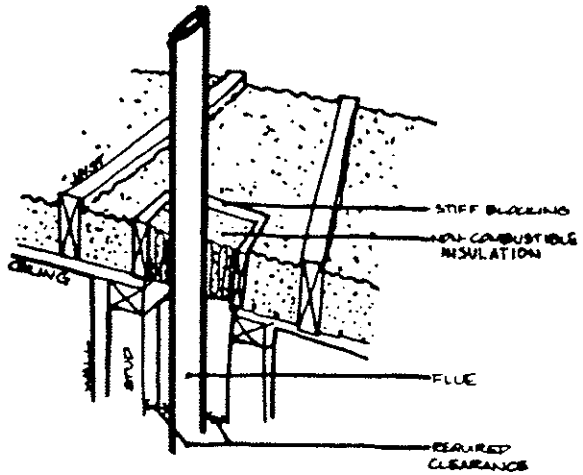
Caution: If the furnace is located in a closet in the heated portion of the building, do not seal the openings around the flue. This opening and any other venting in the closet provides combustion air to the furnace. However, the closet door should be weatherstripped in order to prevent warmed interior air from escaping through the combustion vents. Also, if the furnace closet is within 5 to 8 feet of the attic floor, the flue will be very hot. In this instance, openings should not be sealed.

G. Seal around exhaust vents

Exhaust vents from kitchen, bathroom, and laundry fans sometimes lead into the attic and through the roof. The opening around the edge of the vent can be sealed either with caulk or polymeric foam.

H. Seal leaky furnace and air conditioning ducts

Wrap duct tape around leaky joints in the ducting system. Also check for large holes or ducts that have become disconnected. If many joints need to be taped and the ducting is not easily accessible, then do simpler retrofits first. Wrapping the



FLUE PIPES

ducts with insulation is generally not considered a cost-effective retrofit for the house doctor; but if the ducts are easy to get to and pass through an unheated space, it can be cost-effective for the homeowner to wrap them.

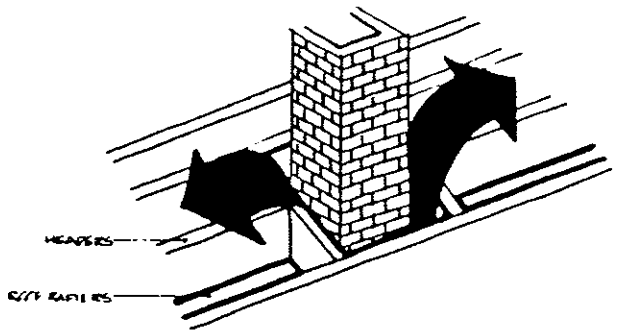
I. Seal leaky areas where interior and exterior walls meet the attic floor

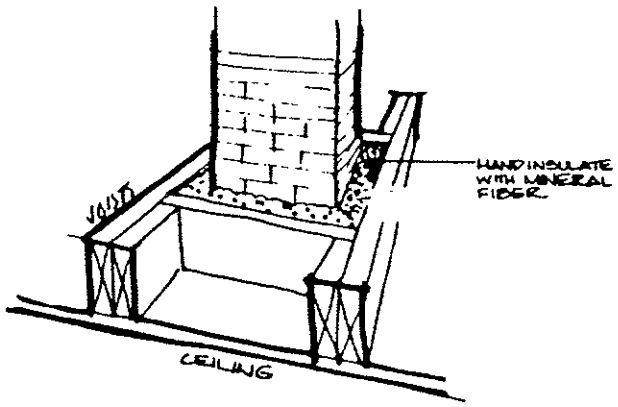
Many buildings are constructed so that warm air in the building heats the air inside the wall cavities. Such leaky areas can be found in both interior partition walls and exterior walls. Air travels upward and passes through cracks or gaps in the attic floor. Larger gaps in the attic floor can be sealed with plastic and/or stuffed with fiberglass insulation. Smaller holes and cracks can be filled with caulk or polymeric foam.

In houses with balloon-frame walls, there are likely to be cavities between the exterior sheathing and the interior lath. These cavities may extend from the basement to the attic, providing direct bypasses for passage of cold air. Such cavities should be stuffed with insulation.

J. Seal cracks where the chimney penetrates the attic floor

Cracks are frequently found where two different building materials come into contact. A typical example of such a joint is a gap of up to 2 to 3 inches where the chimney passes through the attic floor. This opening is easily plugged with fiberglass insulation or mortar grade caulk. A heat-resistant caulking compound will last longer than a conventional type of caulk and is safer.





CHIMNEYS

K. Insulate and weatherstrip attic hatch door

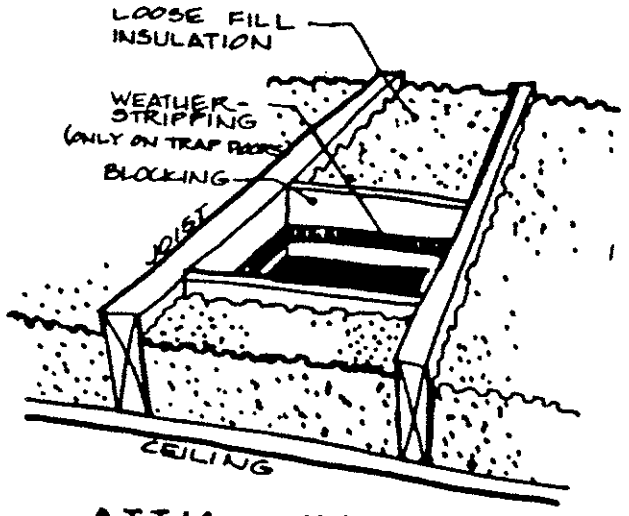
Attic hatches and doors are generally not covered by poured insulation and may not be covered even if batts are installed in the attic. Cut a piece of R-19 fiberglass insulation to fit on the attic hatch door. The insulation should be stapled or taped to the door. Next, weatherstrip the frame with hinge-type (plastic or metal) or gasket-type (adhesive-backed foam) weatherstripping. Finally, a latch (hook and eyehole type) or a weight of some kind a brick for example) should be placed against it to prevent the door from opening during pressurization and to ensure a tight seal on windy days.

L. Stuff insulation into split-level stud spaces

Some split-level houses have sloping roofs that extend from the peak of the house to the first-floor level. They may have only partial attics or small-stud spaces behind the walls of the second floor. These spaces should be checked for infiltration sites and treated in the appropriate manner.

M. Seal openings in kneewalls

Some houses have attics that have been converted to living spaces. The walls in these attics, called "kneewalls," usually cover unfinished attic spaces that may require treatment. In addition, there may be built-in closets and cabinets in the walls that often require caulking.



ATTIC HATCH

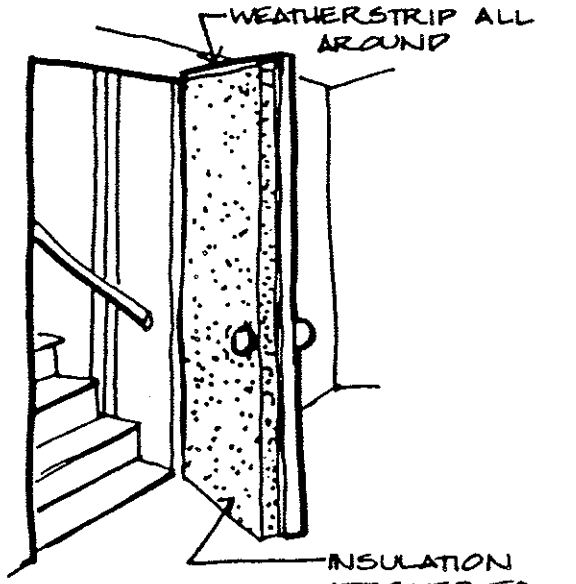
N. Inspect whole house and attic fans

The term "whole house fan" refers to a fan that cools the entire house. The whole house fan is most often located in the attic floor above a hinged trapdoor that opens into the ceiling of the top floor of the house. The fan draws warm air out of the upper level of the building and sends it into the attic. The capacity of such fans ranges from 4,000 to 16,000 CFM. Blade diameters range from 24 to 42 inches. Because the fan operates only in the summer, and then intermittently, there should be an insulating box for covering the fan during the heating season.

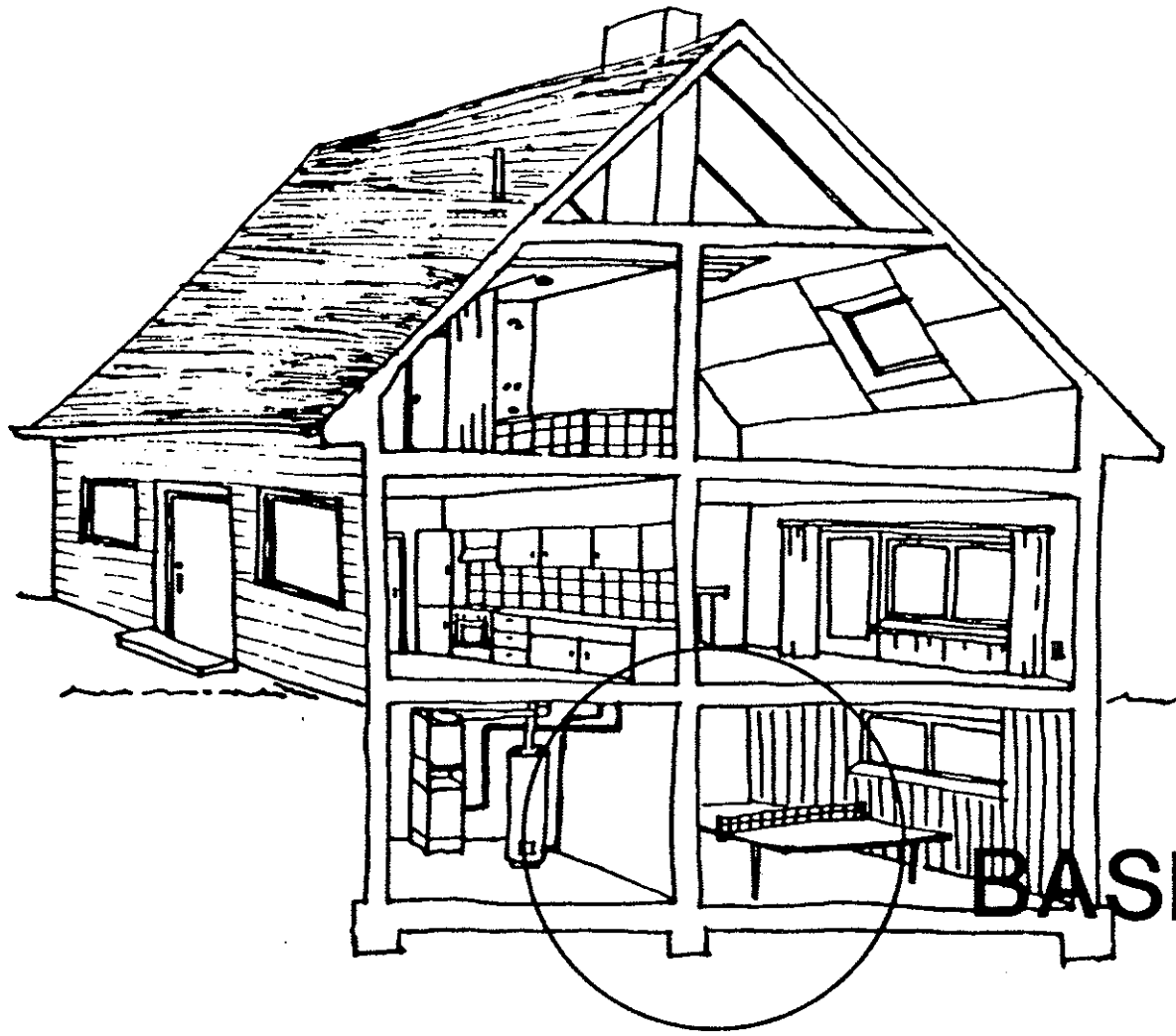
An "attic fan" is used to ventilate the attic only. It has a smaller capacity (500 to 2,000 CFM) and diameter (10 to 18 inches). It is frequently located on the attic sidewall under a gable or on the roof. The energy-saving potential of these fans is often overrated. If the attic is already insulated to 3 inches or more, for example, the attic fan does little to cool the building or reduce air-conditioning costs.

O. Complete attic visit

When the attic retrofits are complete, one technician should fill out the audit form while the other moves equipment to the basement or crawlspace. Record information on roof type, insulation, attic and whole-house fans, as well as moisture problems and retrofits performed. The attic hatch should be closed after the retrofits are completed.



ATTIC DOOR


BASEMENT

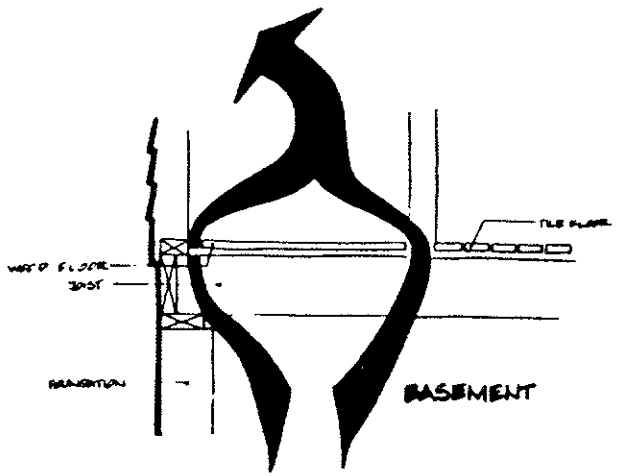
STEP 4: Basement/crawlspace procedure

A. Pressurize or depressurize house and take necessary equipment to the basement
B. Conduct a general survey for infiltration sites and bypasses
C. Seal gap between foundation wall and sill plate in heated basement
D. Seal cracks around windows in heated basement
E. Seal leaks to living space in unheated basement/crawlspace
F. Weatherstrip hatch or door to unheated basement or crawlspace
G. Seal around raised floor and non-floored area under stairwells
H. Complete basement visit

A. Pressurize or depressurize house and take necessary equipment to the basement

If the infrared scanner is used for leak detection, the house should be pressurized to 0.16" of H_2O (or 40 Pascals). If smokesticks are to be used, the house should be depressurized to 0.16" H_2O.

Items to take into the basement, in addition to tools and protective clothing, are: a ladder, portable lights, caulking, polymeric foam, fiberglass polyethylene sheeting, a staple gun, duct tape, and pieces of weatherstripping. The hatch or basement door should be kept closed while work is in progress.



BASEMENT AIR LEAKS

B. Conduct a general survey for infiltration sites and bypasses

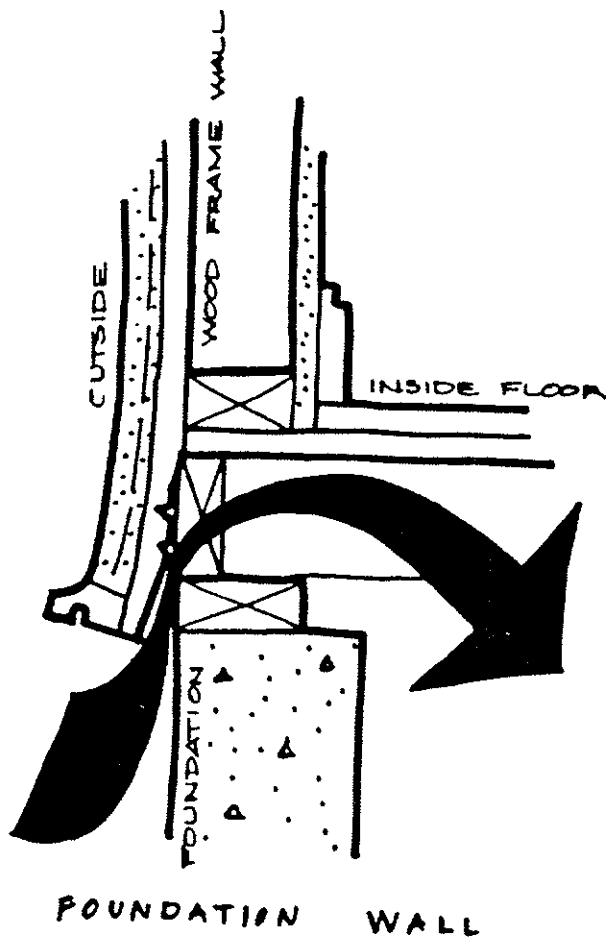
The purpose of this survey is to pinpoint those infiltration sites most in need of work. (These sites are listed in Table 1 and shown graphically in the accompanying figures.) If the infrared scanner is being used, the basement ceiling and perimeter should be checked for "hot spots"--places where warm air flows from the living space through openings in the floor and walls. If smoke-sticks are being used, check for air currents at openings in the floors and walls. Mark the spot with masking tape, and record problem areas on a scale diagram of the basement or crawlspace noting the type of problem found.

C. Seal gap between foundation wall and sill plate and around rim joist (in heated basements)

The sill plate and rim joist are often important air leakage sites in a heated basement or crawlspace. Gaps may be found where the sill plate meets the concrete foundation wall and where the rim joist abuts the exterior wall of the house. Caulk or polymeric foam can be used to fill these cracks. Foam is well suited to this task because it can be quickly applied over long cracks, expands upon application, and is easy to apply in tight corners and spaces where a caulking gun will not fit.

D. Seal cracks around windows in heated basement

Use caulk or polymeric foam to fill cracks around the window frames in a heated basement. If the windows fit poorly into the frames, they should be weatherstripped. However, if the furnace is located in the basement, the only source of combustion air may be through the windows; in this case,



do not weatherstrip. Building a furnace closet with a duct to the outside for combustion air will alleviate this problem and allow basement windows to be weatherstripped.

E. Seal leaks to living space in unheated basement/crawlspace

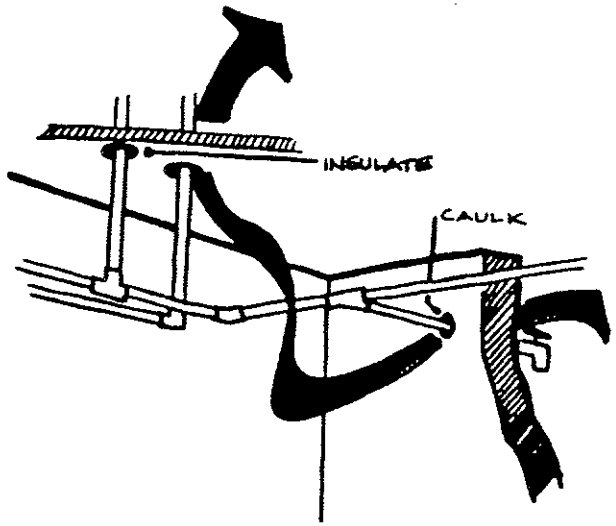
1. Plug leaks around heating/cooling ducts, plumbing, and electrical cut-throughs (see "Attic Procedure" for description). Openings around the furnace flue in the basement should not be plugged because flue temperatures are likely to be higher than the combustion points of most materials.

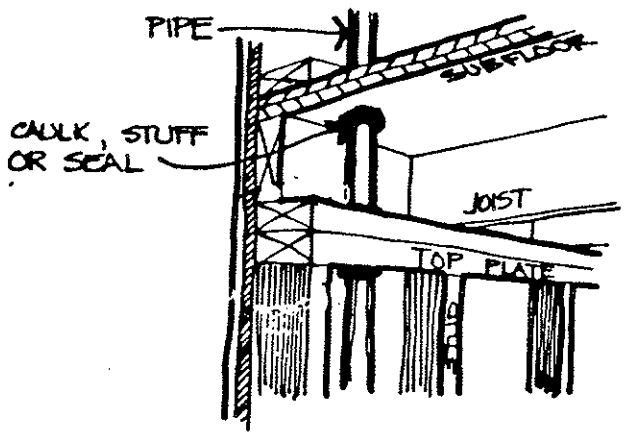
2. Tape heating/cooling ducts (see "Attic Procedure" for description). Taping is most effective in a house with a forced-air heating system. If the house has a hot water heating system and the basement is unheated, it may be cost-effective for the homeowner to insulate the hot water supply pipes. Insulate the cold water pipes as well to reduce the danger of freezing where this possibility exists.

3. A large hole may be found in the subfloor underneath the bath or shower where the drain pipe passes through the floor. This opening can be stuffed with fiberglass. Smaller remaining leaks can be sealed with polymeric foam.

F. Seal around raised floors and non-floored areas under stairwells

In unheated basements, raised floors and non-floored areas can provide bypasses for cold air to flow into the living space. Cold air is pulled through such openings because of the "stack effect" of warm air rising through the house. These leakage sites can be eliminated by the procedure used to seal raised ceilings (see "Attic Procedure" for description).





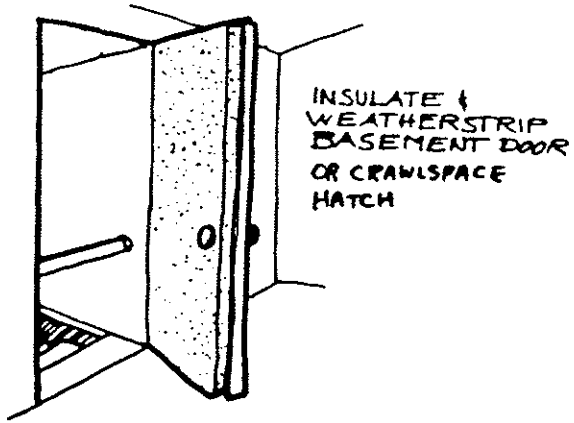
PLUMBING PENETRATIONS

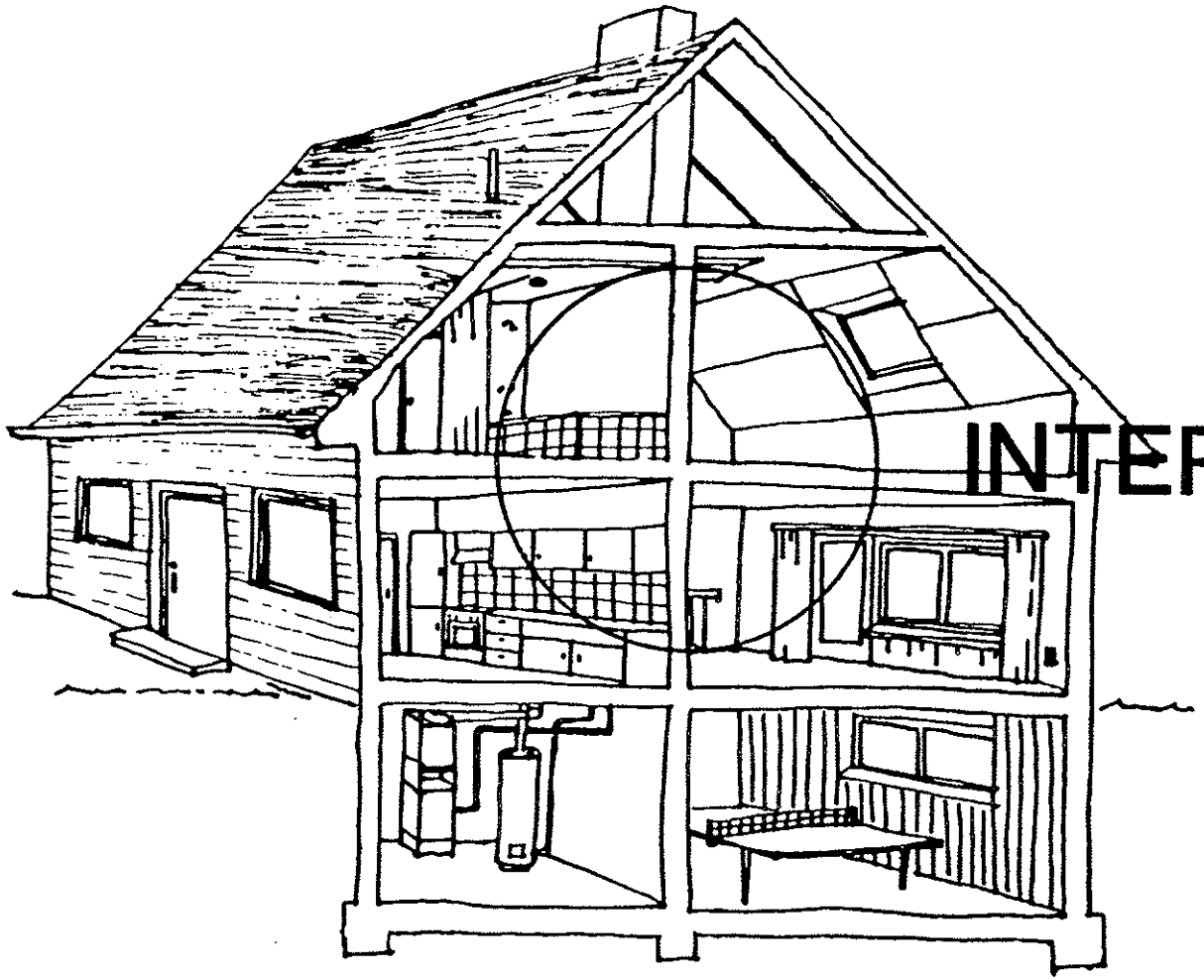
G. Weatherstrip basement door or crawlspace access hatch

Weatherstrip the basement door or crawlspace access hatch with hinge or gasket type weather-stripping. The weatherstripping should be attached to the door frame or the lower part of the access hatch. If the basement has a bulkhead door leading to the outside, this too should be weatherstripped. If the door or hatch fits loosely, a latch should be installed.

H. Complete basement visit

While one technician removes equipment from the basement, the other should complete the audit form. When the basement work is done, the door or access hatch should be closed.




INTERIOR

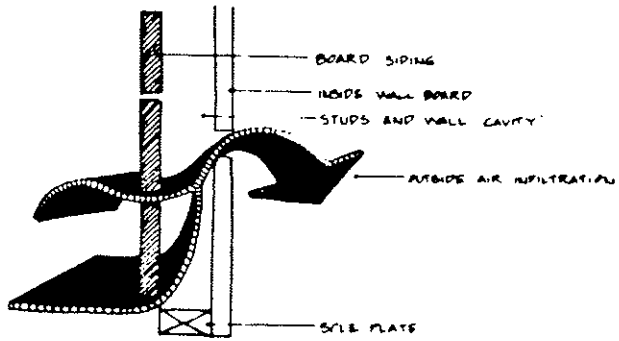
STEP 5: Interior procedure

A. Inspect the interior of the house for leakage sites
B. Determine whether walls are insulated
C. Seal holes around pipes and wires
D. Seal cracks around beams in open beam ceilings
E. Seal leaks around heating registers and exhaust fan cut-outs
F. Seal cracks around fireplaces and mantelpieces
G. Seal cracks inside and around built-in cabinets and bookcases
H. Seal holes in recessed fluorescent light fixtures
I. Seal gaps beneath leaky baseboards and behind electric baseboard heaters
J. Install fireplace plug in chimney flue
K. Weatherstrip leaky doors and windows and seal cracks around window and door frames
L. Install foam gaskets behind electrical outlets and light switches
M. Test furnace efficiency and tune up burner
N. Inspect and modify hot water system
O. Inspect and make changes to appliances

AIR LEAKAGE SITES

A. Inspect the interior of the house for leakage sites

The infrared scanner should be used for detecting interior leaks only if the inside-outside temperature difference is 10 °F or more. If it is to be used, depressurize the house to 0.16" H_2O. If smokesticks are being used, pressurize the house to 0.16" H_2O. Use the scanner or smokesticks to inspect for leaks around doors and windows, door and window frames, electrical switches and outlets, ceiling-wall joints, light fixtures, fireplaces and mantelpieces, open beam ceilings, baseboards, built-in cabinets and shelves, and staircases. Record problem areas on a scale diagram of the building and note the type of problem found. If the homeowner does not object, mark the spot with masking tape, taking care not to damage paint.



EXTERIOR WALLS

B. Determine whether walls are insulated

Determine whether insulation has been installed in the walls by one of the following methods:

1. Direct inspection;

2. Checking the homeowner's records;

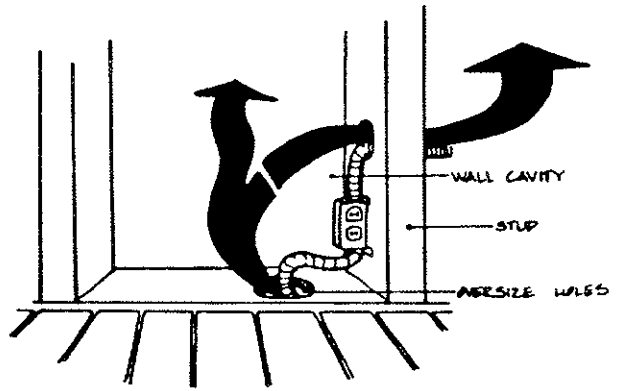
3. Using the infrared scanner. (The scanner will show gradations in intensity across a wall, indicating variations in insulation thickness, as long as the inside-outside temperature difference is sufficiently large.)

4. Checking inside electrical outlet boxes with a plastic knitting needle; or

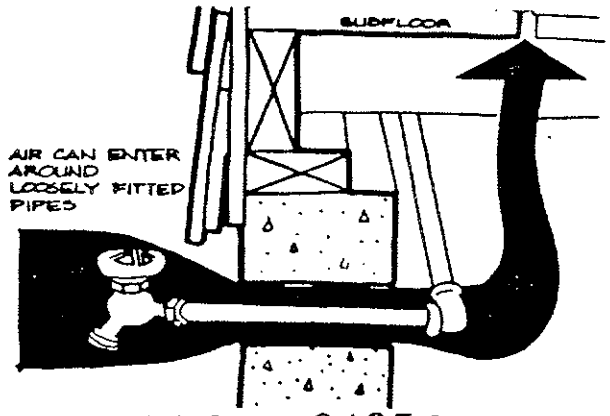
5. Checking surface temperatures with a digital thermometer. (An insulated wall should have a temperature fairly close to that of the interior air. However, as with the scanner, if the inside-outside temperature difference is very small, this method will not work.)

C. Seal holes around pipes and wires

Plumbing and electrical wires that penetrate walls usually have openings around them through which air can pass. Such holes are commonly found underneath kitchen and bathroom sinks, behind stoves, water heaters, washing machines, and dryers, and inside and around fuse boxes. These openings can be infiltration sites even if they are found in interior partition walls. Hence, it is important to inspect all walls, not just exterior ones. Caulk and polymeric foam can be used to seal most of these leaks. If the gaps are over two inches wide, insulation should be stuffed into the holes to seal them.



LEAKS AROUND WIRES



AND PIPES

D. Seal cracks around beams in open beam ceilings

Air leaks may occur along the joints where the beams intersect a ceiling or wall. Sealing these leakage sites with a clear caulking compound will close the holes without creating an eyesore.

E. Seal leaks around heating registers and exhaust fan cut-outs

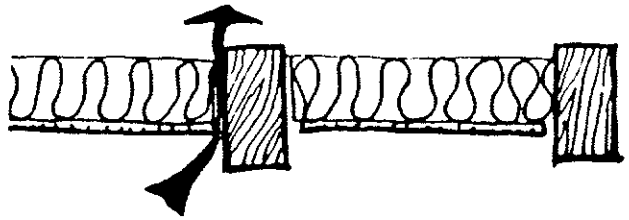
Heating registers and exhaust fan cut-outs in floors, walls, and ceilings often have gaps between the ducting and the surface they are mounted in. If smokesticks or the IR scanner show leaks, unscrew the mounting screws and remove the register or grille. Use caulking compound or duct tape to seal the gap around the edge of the duct. Replace the register and secure the mounting screws.

F. Seal cracks around the edges of fireplaces and mantelpieces

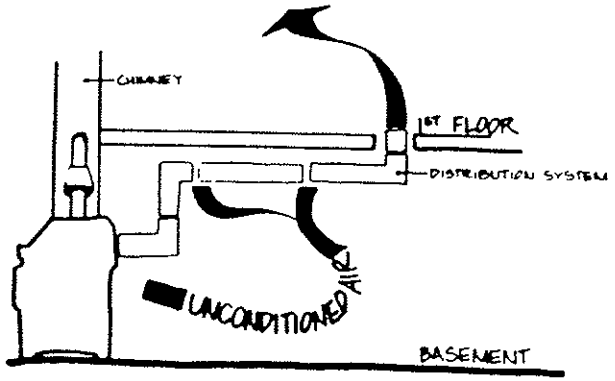
Fill any cracks where a brick and mortar fireplace or a wooden mantelpiece meets the wall or ceiling. Mortar-grade or heat-resistant caulking compounds should be used where temperatures are high; in other areas, clear silicone caulk is appropriate.

G. Seal cracks inside and around built-in cabinets and bookcases

Built-in cabinets and bookcases usually have leaky joints where they meet the wall and floor. Medicine cabinets also tend to be leaky. Cracks inside and around these built-ins should be filled with caulk or polymeric foam.



BEAM CEILINGS



FURNACE REGISTERS

H. Seal holes in recessed fluorescent light fixtures

Fluorescent light fixtures extend through the ceiling into the space between the ceiling and subfloor or attic. The cracks around the edges of these metal boxes should be filled with caulk.

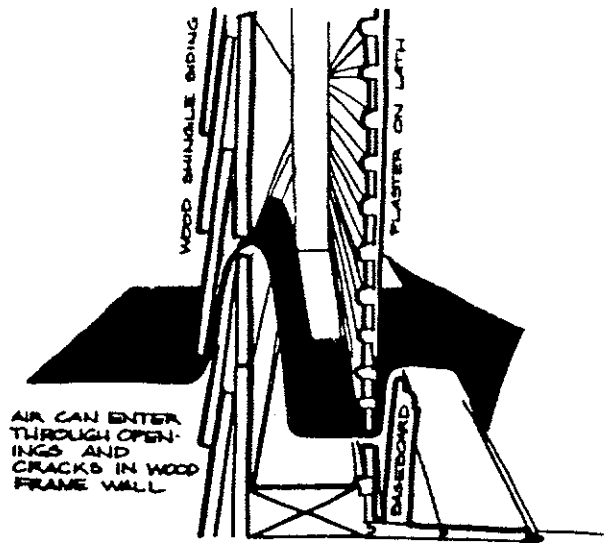
I. Seal gaps beneath baseboards and molding and behind electric baseboard heaters

Baseboards and molding cover the joints between the wall and the floor or ceiling. Because of settling or poor construction, these joints may have separated, allowing air to flow through. If there are large gaps, the baseboard or molding should be removed carefully and the gaps caulked. If, however, the wooden strips would be damaged by removing them, the gaps should be left alone.

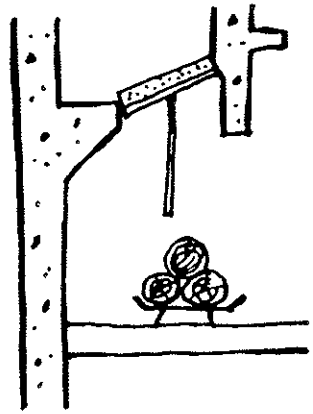
The wiring to electric baseboard heaters usually passes through a hole in the wall behind the heater. Finding these holes requires removal of the cover over the heater; be sure the power is off before removing the cover. Seal the holes with caulk or polymeric foam.

J. Install a fireplace plug in the chimney flue

If the fireplace does not have a damper, a plug can be constructed inexpensively from fire-retardent foam rubber and plywood. The foam, cut to fit tightly inside the chimney, is backed by a slightly smaller piece of plywood and then wedged into the chimney. A handle should be attached to the plywood to ensure easy removal. A supporting rod or stick may be used to hold the plug more securely inside the chimney. Paint the stick red as a reminder to remove the plug before building a fire.



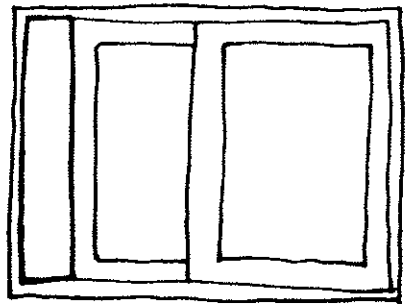
BASEBOARD LEAKS


FIREPLACE PLUG

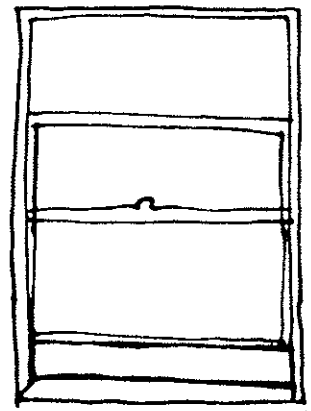
K. Weatherstrip and caulk leaky doors and windows and seal cracks around window and door frames

In many houses, older ones in particular, windows, doors, and their frames can be very leaky. Age and use cause doors and windows to become loose and move within their frame. Weatherstripping should be installed to fill these openings and restore doors and windows to a tight-fitting condition. Cracks generally develop between window and door frames and plaster walls as a result of settling. These cracks usually provide direct paths around the frames to the outdoors. They should be caulked.

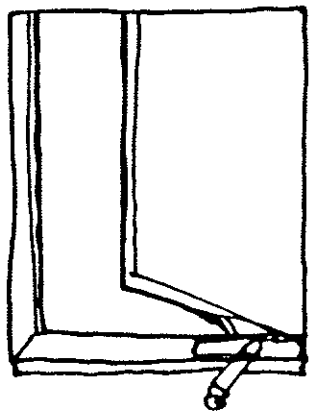
Because weatherstripping and caulking are very time-consuming tasks when done properly, they should be undertaken only if windows and doors are found to be major leakage sites. House doctors will generally only undertake a few of these retrofits, showing locations and techniques to the homeowner for completing the job. The following pages show different types of windows and doors, and describe where and how repairs should be made.



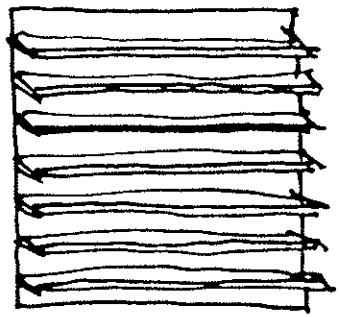
SLIDING



DOUBLE HUNG



CASEMENT



JALOUSIE

WINDOW TYPES

CAULKING

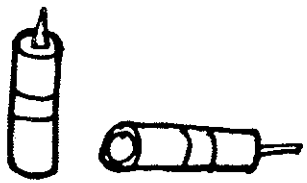
Oil-based caulk is the least expensive of the caulking compounds, although it has the lowest lifetime of the petroleum-based caulks. It comes in a tube, cures rapidly, and can be painted soon after use. It should be used only on nonmoving interior surfaces.

Latex-based caulk, is moderately expensive but is more durable than oil-based caulk. It also comes in a tube, cures rapidly, and can be painted soon after use. It should not be used on moving surfaces.

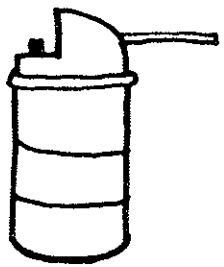
Butyl-based caulk is similar in cost and durability to latex-based caulk. It adheres well to building materials and is especially good for metal-to-masonry joints. It should be used only on joints where the amount of movement is small, however, and cannot be painted until a week after application.

Silicone caulk is expensive but adheres well to metal and glass and is very durable. It cures rapidly and comes in a variety of colors. It generally cannot be painted.

Polymeric foam sealant, also expensive and durable, comes in a spray can or cartridge. It is a foam that expands upon contact with air and is good for large cracks and hard-to-reach spots. This caulk does not adhere well to certain materials, such as plastic vapor barriers and sheet metal.



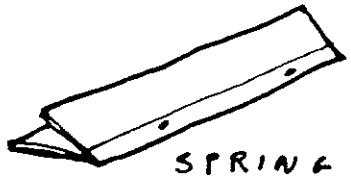
CAULK CARTRIDGES



POLYMERIC FOAM

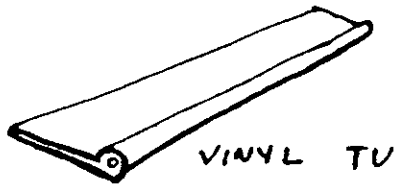
WEATHERSTRIPPING

Spring metal or plastic weatherstripping consists of strips of metal or plastic in a V-shape. It is used for compression seals and sliding seals, typically, where the bottom of the window sash contacts the window frame or in the channels of a window frame. Spring weatherstripping must be nailed or bonded to the window or door frame. Although moderately expensive, it is generally very durable.



SPRING METAL

Vinyl tubing comes in both reinforced and unreinforced form. Reinforced tubing contains a metal strip that keeps the tubing stiff. This type of weatherstripping can be used for compression and sliding seals. It is generally nailed to the window or door frame. It does not cost very much and lasts two to three years. Vinyl tubing is also available with a magnetic core for use on metal doors.



VINYL TUBING

Foam strips come in open- or closed-cell form, and are backed by adhesive. (The adhesive on foam strips is generally inadequate and it is wise to tack or nail the strips in place.) Foam is best used for compression seals. It is inexpensive and usually lasts a few years.

FOAM STRIPS

Felt, which comes in reinforced and unreinforced form, does not cost very much. It is often used for compression seals, but has an effective lifetime of only one to two years. It must be tacked in place.

FELT

WINDOWS

Double-hung windows are most effectively sealed with either metal or plastic v-strip or a vinyl tubular gasket. The vinyl gasket is more conspicuous unless installed on the exterior of the window frame, which can be an awkward procedure. The v-strip is installed in four steps:

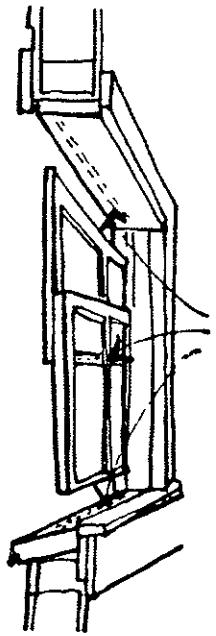
1. Measure and cut pieces to fit the side channels for both sashes, the upper rail of the top sash (unless it is fixed), the lower rail of the bottom sash, and the lower rail of the top sash where the two sashes meet. The strips for the side channels should extend two inches above the bottom sash when it is fully open, and two inches below the upper sash when it is fully open.

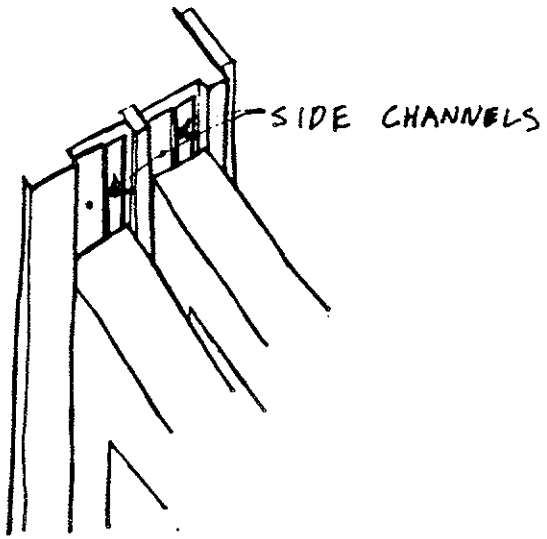
2. Insert the side channel pieces and make sure the sash slides smoothly. Do not cover the pulleys at the top of the channels. Nail or press the adhesive side in place; the 'v' should open toward the exterior.

3. The horizontal strips can either be attached in the window's top and bottom channel or to the top of the upper and bottom of the lower sash rails.

4. The last piece goes on the inside of the lower rail of the top sash.

The vinyl gasket is simply tacked all around the sash, making sure that the rolled edge fits tightly against the window on all edges.





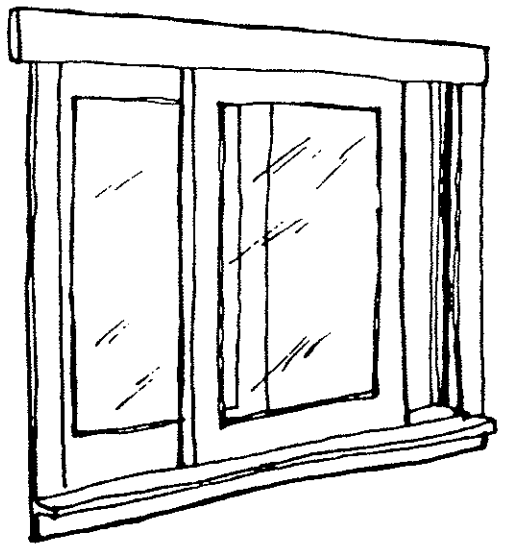
DOUBLE - HUNG

Horizontal sliding windows are weatherstripped in the same way as vertically-sliding double-hung windows. The procedure is identical to the one outlined above, except when the window has only one sliding sash. In this case, the v-strip goes into the channel that opens, and tubular gasket is used to seal against the three remaining edges of the movable sash.

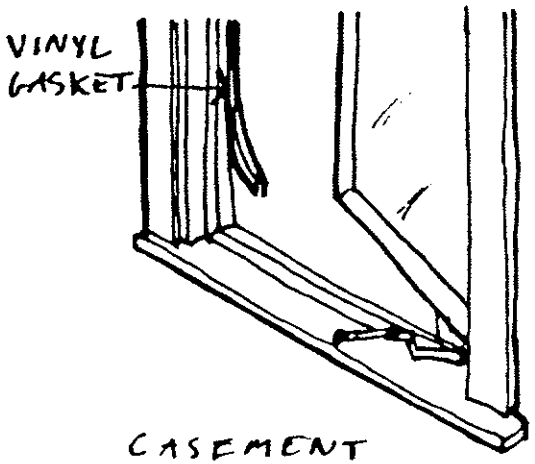
Casement or awning windows can be weather-stripped with metal or plastic v-strip, or with a grooved vinyl gasket. The strip is installed along the frame with the 'v' opening toward the inside. The gasket is fitted over the edge of the window frame and should be applied with a vinyl/metal adhesive.

Adhesive-backed foam is useful only in compression seals, but can be used on all types of windows. Clean all surfaces to which it must adhere. It is installed by peeling off the backing and pressing it in place.

Felt strips, like foam, cannot be installed where friction will cause them to rub off. It can be nailed or stapled around the window frame like the tubular gasket. Avoid using it on the outside where it will get wet, rot, and be useless within a few years.



SLIDING



CASEMENT

DOORS

The following steps for weatherstripping doors apply to most weatherstripping materials, including metal and plastic v-strip, felt, foam, and vinyl gasket.

Step 1: Truing door

Before weatherstripping a door it is important that it fit properly in its frame, without binding or sticking; so the first step is often truing the door. If the door sticks at the top or bottom, the sticking edge should be planed or sanded. If the door binds or sags, the hinges may have worked loose, or the frame may have shifted. To tighten loose door hinges, remove the door and fill the worn screw holes with match sticks dipped in glue, or with steel wool. Replace the screws, and then the hinge should fit tightly. If the door still binds, use cardboard shims under the hinges to allow the door to close.

Step 2: Cleaning

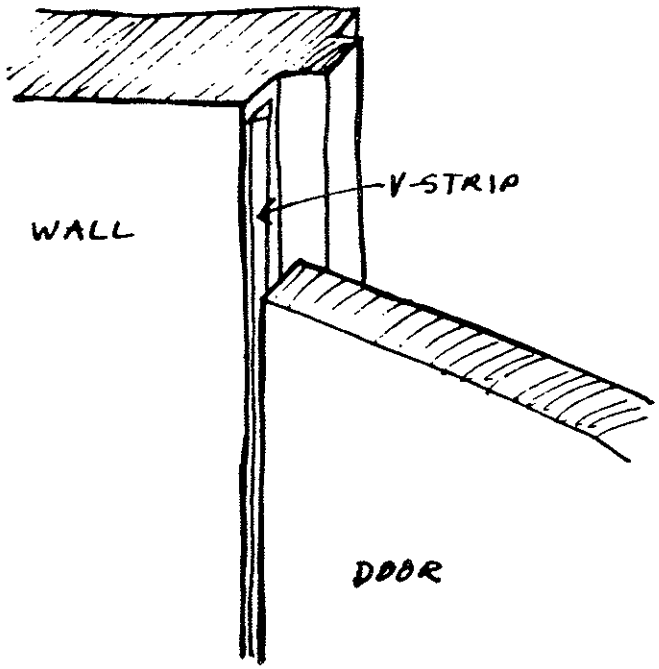
If using an adhesive type weatherstrip, clean surfaces first. Use a damp cloth for wood surfaces and alcohol or a degreaser for metal frames.

Step 3: Measuring and Cutting

Measure and cut the weatherstripping material into correct lengths. The spring metal type will need to be installed in separate pieces above and below the strike plate for the lock. Other types are usually thin enough not to interfere with the lock.

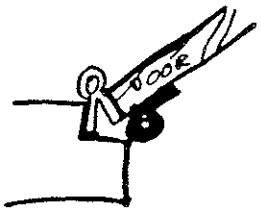
Step 4: Installation

The weatherstripping can go in either of two places, as shown in the figures. Fit the weather-stripping into the frame and test to see whether the door closes tightly. If the fit is too tight



CUT-AWAY SHOWING LOCATION OF STRIP WEATHERSTRIPPING

a) VINYL GASKET ON JAMB

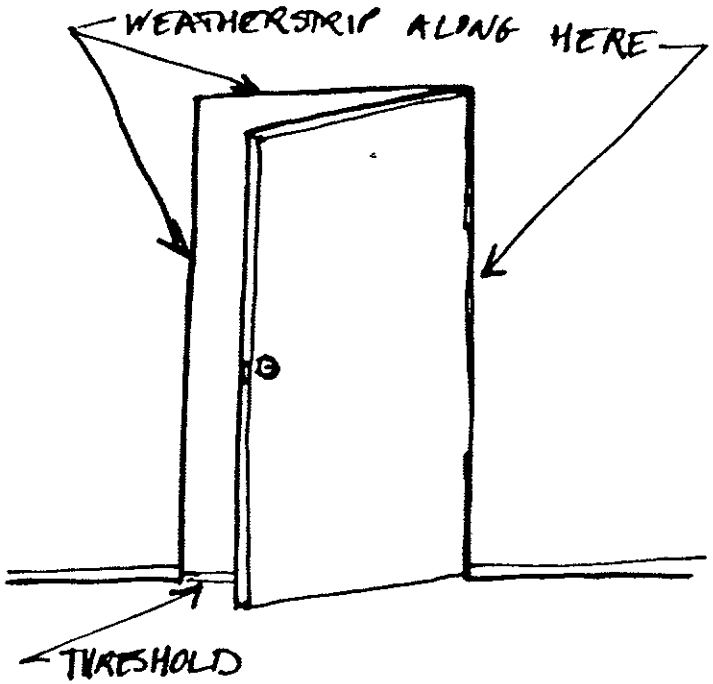


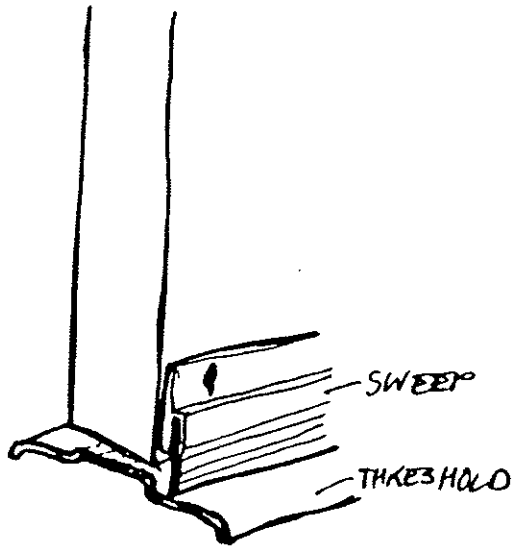
b) VINYL GASKET ON DOOR

it may become difficult or impossible to open in humid weather. Complete the installation along the top frame and hinge jamb.

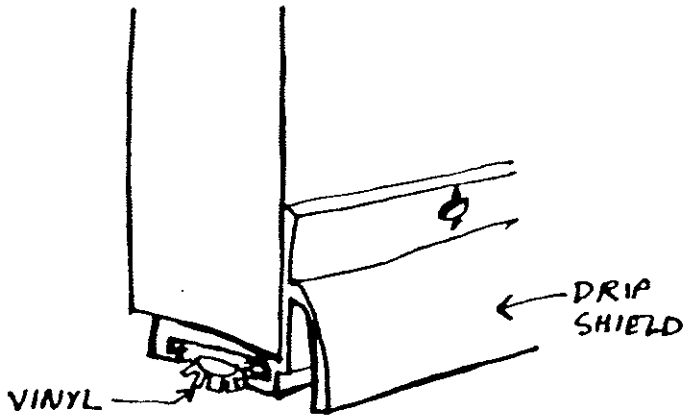
Step 5: Thresholds

The most common method for weatherstripping the bottom of a door is to install door sweeps or door shoes. A door sweep is less expensive and easier to install: cut the sweep to size and screw it to the base of the door such that the door opens and closes without difficulty. The door shoe is similar to the door sweep, but has a vinyl strip that seals against the threshold. (If the threshold is not in fairly good condition, it should be replaced.)





DOOR SWEEP



DOOR SHOE

SLIDING GLASS DOORS

Weatherstripping sliding glass doors is a straightforward, five-step process. The most effective weatherstripping for this purpose is plastic v-strip, which should be installed along the bottom and top tracks, side jamb, and middle bar.

Step 1

Take out the sliding door by lifting the frame up into the half inch or so of clear space; the bottom can then swings free of the lower track. Clean the metal surfaces with alcohol or degreaser.

Step 2

Place the plastic strip on the inside of the top track if the sliding door is on the inside, or along the fixed frame if the slider is on the outside (see figure). The 'v' should open upwards.

Step 3

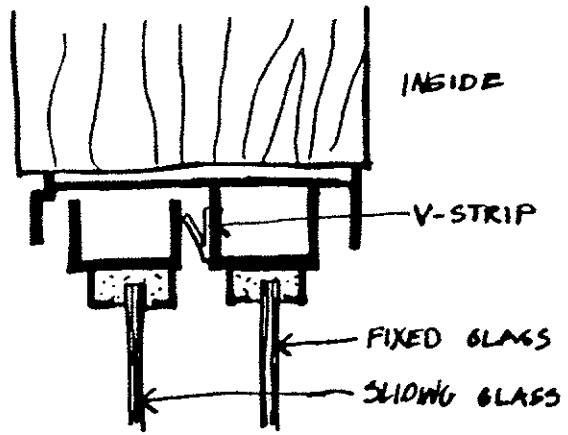
Place plastic strip along bottom track, with the 'v' opening downwards.

Step 4

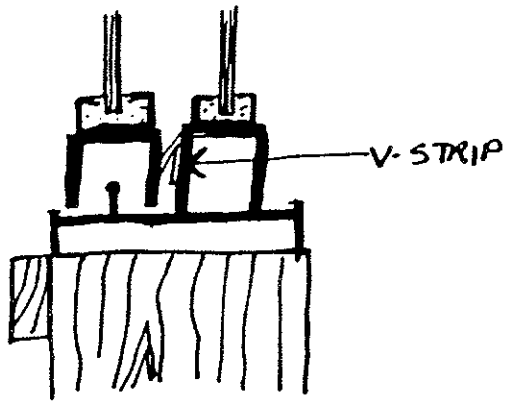
Place the plastic strip vertically along the jamb edge with the 'v' opening towards the wall.

Step 5

Place the plastic strip vertically along the middle bar with the 'v' opening in the direction that the door slides open.



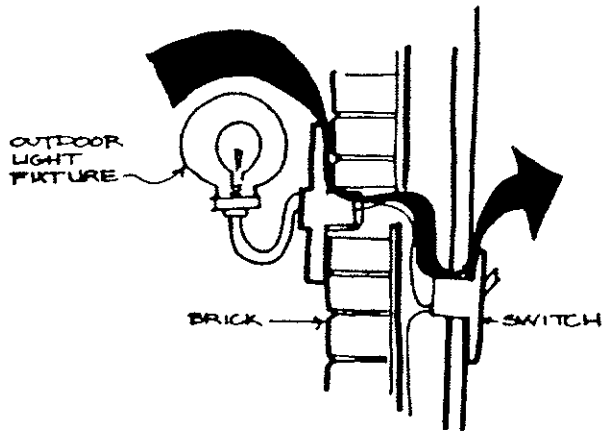
TOP TRACK



BOTTOM TRACK

L. Install foam gaskets behind electrical outlets and light switches

The openings around outlet and switch boxes allow air to infiltrate from wall cavities into the house interior and vice versa. Foam gaskets are used to seal these boxes. Demonstrate the installation of foam gaskets for the homeowner and then leave enough gaskets so the homeowner can complete the job.

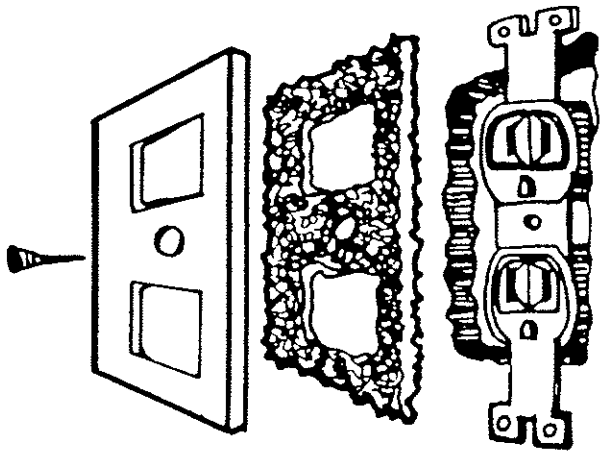


ELECTRICAL OUTLETS

M. Test furnace efficiency and tune up burner

1. General Procedure

The furnace should be turned on and allowed to warm up for 20 to 30 minutes before performing an efficiency test. Measure the air temperature four feet from the furnace at mid-furnace height using the digital thermometer. If the furnace is in the basement or attic, remeasure the air temperature elsewhere in the room. If the first measurement is much higher than the second, the furnace is losing heat to its surroundings, perhaps due to leaks from the plenum. If a smokestick test shows the furnace box to be very leaky, cracks around the edges of the box can be sealed with duct tape. Do not cover any large openings; these supply air to the unit. Check to see whether the furnace has a pilot light or electronic ignition. Check to see whether the furnace has a vent damper (located on the exhaust vent ducting). Check to see whether the furnace has a flue restrictor. Perform the furnace efficiency test as described under "2". If the furnace efficiency is 75% or higher, a tune-up is not necessary. If a tune-up is required, follow the instructions under "3". Set the "fan-off" temperature to 90-95 ^{o}F. Check the furnace filter; if it is dirty, replace it.

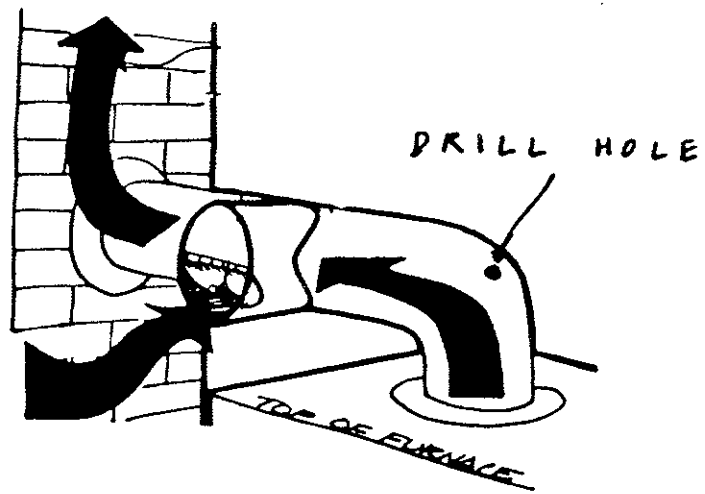

INSTALL FOAM GASKETS

2. Furnace Efficiency Test

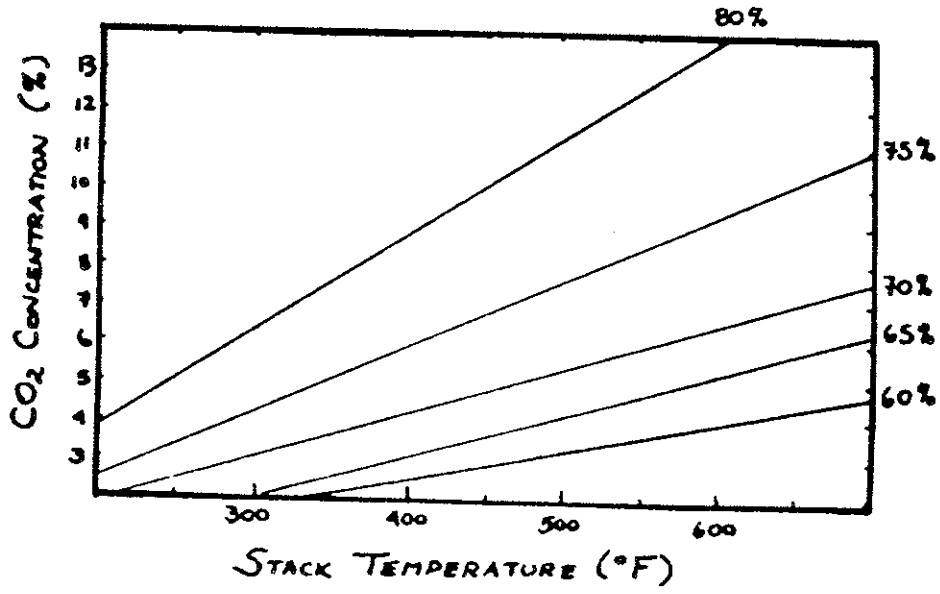
Furnace efficiency is assessed by measuring three quantities: stack temperature, carbon dioxide or oxygen concentrations in the flue gases, and carbon monoxide concentration in the flue gases. To make these measurements, there must be a 3/8" or larger hole in the flue pipe about six inches from where it emerges from the furnace. (If no hole exists, the furnace has never been tested, and a hole will have to be drilled.) The technician will need to use either a furnace efficiency test kit or a combustion efficiency meter. The former consists of individual instruments used to measure each quantity; the latter is an automatic device with a digital readout that gives instantaneous measurements. In either case, the same quantities must be measured.

a. Stack Temperature is a measure of flue gas temperatures and indicates heat transfer and combustion efficiencies; the hotter the flue gases, the lower these efficiencies. The furnace should be allowed to warm up before the temperature measurement is made, and the temperature should be allowed to stabilize before being recorded. For a typical gas furnace, the stack temperature should be in the 300-500 ^{o}F range. However, a very low stack temperature is also undesirable, unless the furnace is a high efficiency one. True stack temperature is the measured quantity minus the temperature of the room.

b. CO_2 Concentration indicates how complete the burn is. A high CO_2 concentration is desirable; the recommended range is 7-9 percent. This quantity, in conjunction with flue temperature, allows the steady-state combustion efficiency to be determined. The accompanying graph can be used to calculate this efficiency.



FURNACE EFFICIENCY TEST



COMBUSTION EFFICIENCY GRAPH

c. O_2 Concentration gives an indication of the percentage of excess air in the flue gases. Excess air is necessary for complete combustion. Theoretically, one cubic foot of natural gas requires about nine cubic feet of air for combustion. In reality, excess air must be present. Oxygen concentration should be in the range of 4-7 percent.

d. CO Concentration also helps to indicate completeness of combustion. However, because of its toxicity, high levels of this gas are dangerous. CO concentrations in flue gases should be no greater than 0.04% (400 ppm). High CO concentration indicates an inefficient burn.

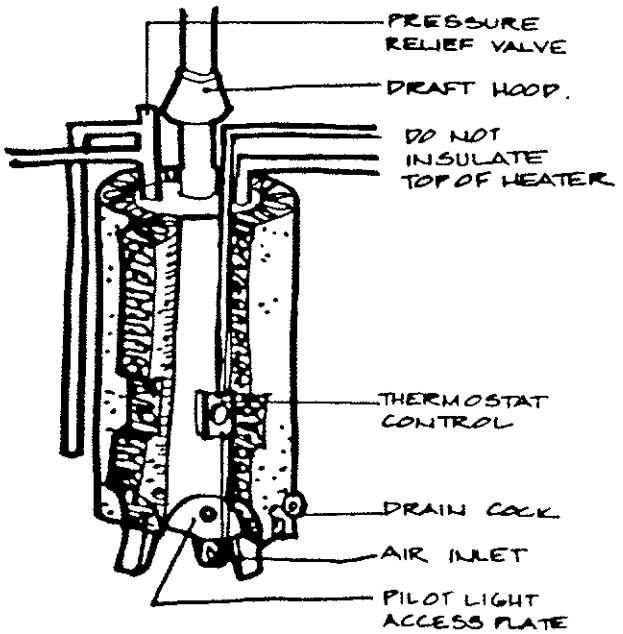
3. Furnace Tune-up

Optimum furnace efficiency depends on the gas and combustion air being in proper balance, which is obtained by adjusting the air and gas flows into the burner. The air intake, a movable collar with vents, is located on the burner. Gas flow is regulated by the gas valve, usually located near the furnace thermostat. These two flows should be adjusted until the combination of stack temperature and CO_2 concentration indicate maximum efficiency. If the stack temperature drops too low, CO_2 concentration will also drop, indicating declining efficiency.

N. Inspect and modify domestic hot water system

1. Water Heater

Locate the shut-off valves for individual units and the main supply shut-off valve, to reduce the danger of flooding in the event of accidental breaking of any fixture. Look on the side of the water heater for a metal or plastic tag giving information on the fuel, storage tank capacity



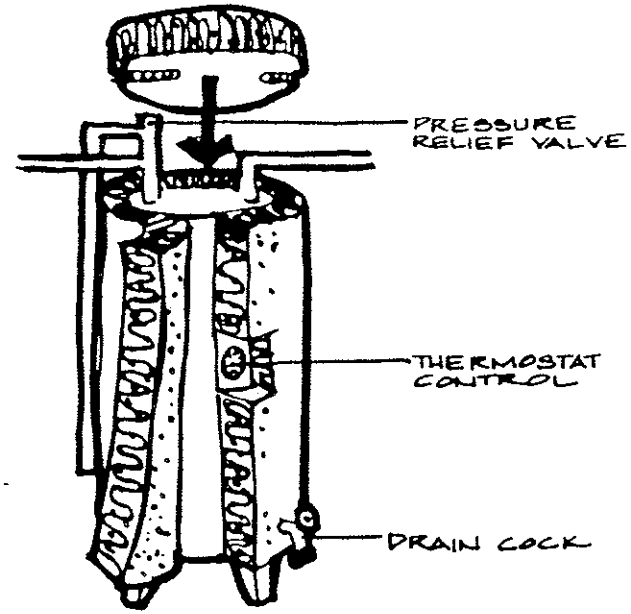
WATER HEATER
(GAS)

(gallons), and input rating (kw or Btu/hr). Note the water temperature setting and measure the temperature at the nearest hot water faucet using the digital thermometer. Check to see whether the hot water supply pipe is insulated and whether faucets have aerators and shower heads have low-flow devices. Drain sediment out of the bottom of the tank through the faucet. If the fixture is old and rusty, do not force it; it can break and flood the room.

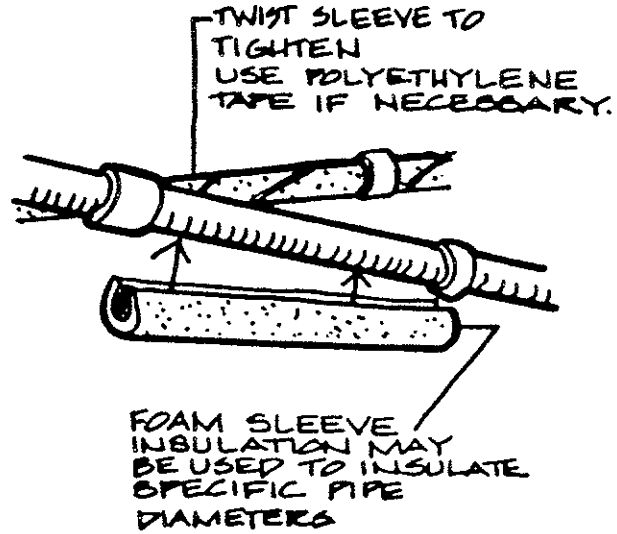
To insulate the water heater, use a water heater insulation kit or R-11 fiberglass batts with the foil side facing out. Begin by measuring the circumference and the height of the tank from the top edge to the firebox. Add about 18" to the circumference of the tank to accomodate for the thickness of a 3" thick batt. Make sure there is at least a 2" clearance between the tank and the nearest wall. (If there is insufficient clearance, do not insulate.) Use duct tape along the top edge and seams to hold the insulation against the tank. Be sure to leave the thermostat controls and pressure relief valve uncovered. When insulating a gas-fired water heater, do not cover the top of the heater.

Insulate the first 5 feet of hot water supply pipe with pieces of foil-backed fiberglass, insulating tape, or preformed pipe insulation. The hot water supply pipe should already be marked "hot." If it is not, touch the two pipes near where they emerge from the tank to determine which is warmer, and mark it. Use duct tape to hold insulation to the pipe.

With the homeowner's permission, turn the water heater thermostat down to 120 ^{o}F. If the thermostat is already lower than this, do not reset it. Mark the original setting with a felt pen so the homeowner can return the temperature to the higher setting if necessary. (If the house has an automatic dishwasher, the thermostat should be set no lower than 140 ^{o}F.)



WATER HEATER (ELECTRIC)



INSULATE HOT WATER PIPES

2. Low-Flow Showerhead

Using the calibrated bucket and a stopwatch, measure shower flow rate(s) with both valves fully on. If the shower uses more than 2.75-3.0 gallons per minute, a low-flow showerhead should be installed with the homeowner's permission. Use teflon tape or pipe compound to seal the pipe threads. If the new showerhead is not compatible with the pipe stub coming out of the wall (for example, if a ball-joint connects the showerhead with the shower arm), try to insert a plastic flow controller into the old showerhead. Replace the showerhead and remeasure the flow. Be sure to demonstrate the use of the new showerhead to the homeowner, and leave behind the old parts.

Caution: Be careful when removing the old showerhead because the supply line to the showerhead might be breakable plastic pipe.

3. Faucet Aerators

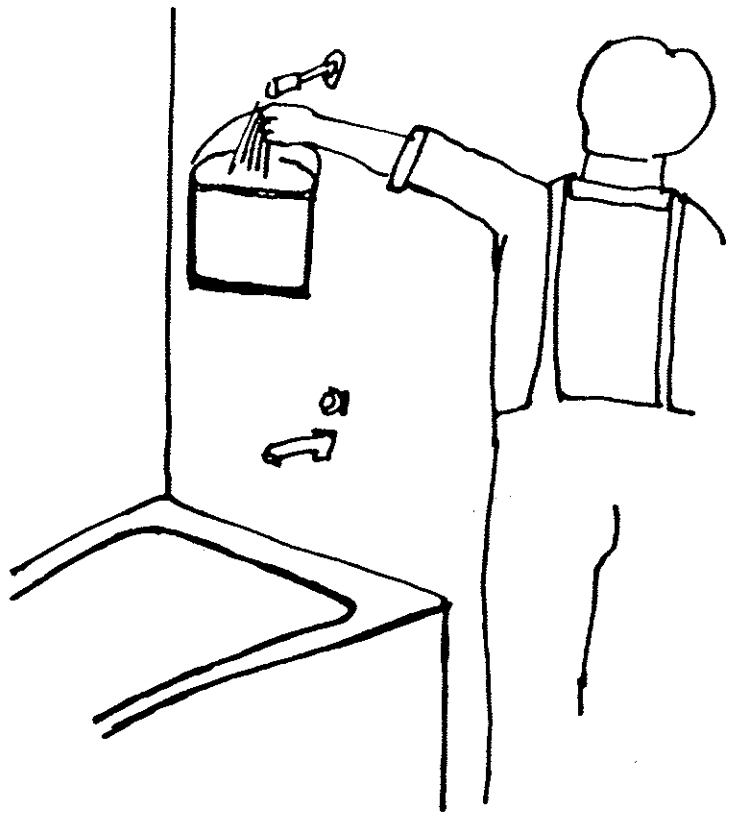
Install flow-restricting aerators on faucets that do not already have them. Check to see whether the faucet has threading (either inner or outer) at the tip. If so, then screw on the proper size aerator.

O. Check and Make Changes to Appliances

1. Explain to the homeowner the benefits of using warm/wash and cold/rinse cycles on the washing machine.

2. With the homeowner's permission, install a circline fluorescent fixture in a much-used area, such as the kitchen, living room, or hallway. Show the homeowner how to replace the bulb.

3. If the refrigerator has a "dry/humid" switch, set it to dry. This conservation measure saves



energy by turning off the refrigerator's anti-sweat heater designed to keep moisture from appearing on the side of the appliance. In dry climates, the heater is unnecessary.

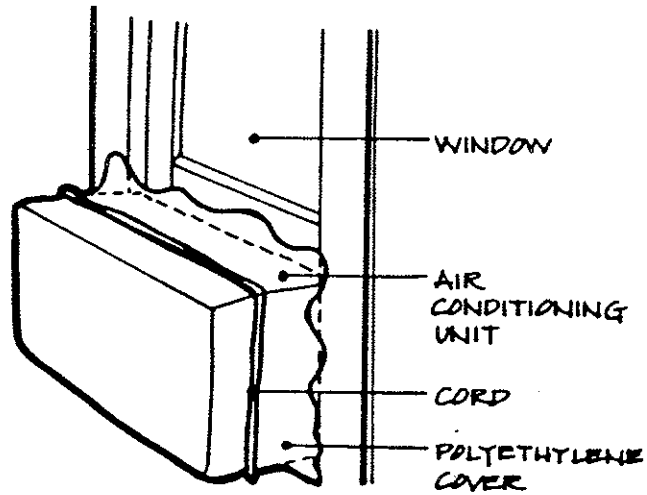
4. Tell homeowner about the cost advantages of using the "air dry" setting on an automatic dishwasher, if it has one.

5. If a heated waterbed is present in the house, tell the homeowner about using a quilt, comforter or foam pad to reduce heat loss from the bed.

6. If the homeowner does not set back the thermostat in the winter, it will be to his or her advantage to turn down the furnace at night and use an electric blanket on the bed.

P. Cover air conditioner with plastic, and caulk around seams

If the house has a window- or wall-mounted air conditioning unit, tape a piece of plastic over the exterior of the unit during the heating season. Show the homeowner how the plastic should be installed. Caulk any openings around the edges of the air conditioner. Remind the homeowner that the air conditioner filter should be cleaned or replaced periodically.



AIR CONDITIONER COVER

STEP 6: Complete house doctor procedure

A. Repeat blower door measurements
B. Inspect house interior for effectiveness of retrofits
C. Discuss findings with homeowner and provide list of remaining cost-effective retrofits
D. Pack up equipment and depart

A. Repeat blower door measurements

When the retrofit procedures have been completed, repeat the leakage area measurements with the blower door. This information provides an evaluation of the effectiveness of the retrofits in reducing infiltration. Make sure the furnace is off. Make sure all exterior doors and windows are closed and bathroom, kitchen, and dryer vents are sealed. Record RPM data for pressurization and depressurization modes. Find the leakage area using the pressurization and depressurization graphs. The measurement process should be repeated if any further retrofits that affect infiltration are made.

B. Inspect house interior for effectiveness of retrofits

After the measurements have been completed, and while the blower door is pressurizing the house, make a qualitative inspection of interior, attic and basement retrofits with the smokesticks. Repaired areas should show greatly reduced airflow. (It is a good idea to conduct this evaluation with the homeowner.)

C. Discuss findings with homeowner and provide a list of further cost-effective retrofits

At this time, the homeowner should be provided with the "House Doctor Checklist" which indicates what repairs were made to the house (see below). The homeowner should be advised of the initial and final leakage area measurements, the problem areas that were found and repaired, any problem areas that were found but not repaired, the efficiency and condition of the furnace, changes made to the domestic hot water system, changes in habits that can save energy, and any further cost-effective retrofits that can be made by the homeowner.

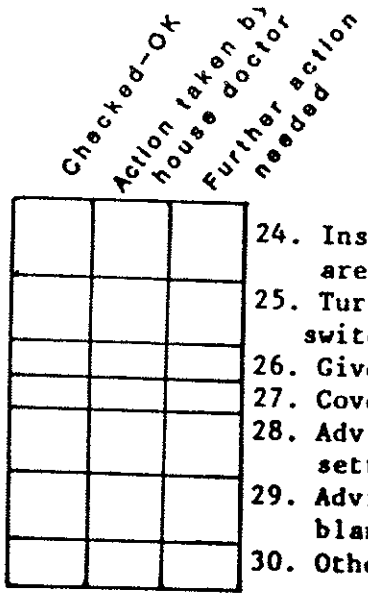
Whenever possible, the technician should indicate the potential energy savings from each retrofit. If the reduction in the heat load of the house is significant, the furnace may be oversized; in this case the homeowner should be advised that replacement with a smaller furnace may be a prudent decision at some time in the future. As a follow-up, the homeowner should receive a written evaluation of the house, the retrofit work performed, expected energy savings, and further cost-effective retrofits that may be made to the house.

D. Pack up equipment and depart

When all procedures are completed, take a final water temperature measurement at the kitchen sink, verify that all audit forms are complete, make sure the furnace pilot light is on and turn on the furnace, if necessary. Load equipment into the van, thank the homeowner, and leave.

House Doctor Checklist

Checked-OK	Action taken by house doctor	Further action needed	
			Water Heating System
			1. Install low-flow showerhead(s).
			2. Install faucet aerator(s).
			3. Insulate water heater.
			4. Turn water heater thermostat down to 120 °F if house does not have an automatic dishwasher.
			5. Insulate first 5 feet of hot water pipe from water heater.
			6. Other (continue on separate sheet if necessary).
			Furnace System
			7. Replace furnace air filter, if necessary.
			8. Test and adjust furnace to maximum steady-state efficiency.
			9. Set furnace fan "off" control to 90 °F.
			10. Other (continue on separate sheet, if necessary).
			Heat and Air Leakage
			11. Seal over dropped ceilings.
			12. Seal around pipes, electrical wires and exhaust vents in attics.
			13. Stuff openings around furnace flue and chimney with fiberglass or caulk.
			14. Weatherstrip attic and basement/crawlspace hatch or door.
			15. Insulate attic hatch or door with R-19 fiberglass.
			16. Seal leaky ducts in attics and basements.
			17. Seal around pipes, wires, and chimneys in unheated basement/crawlspace.
			18. Install a fireplace plug if no damper is present.
			19. Install foam gaskets behind leaky switchplates and outlets.
			20. Caulk around windows and doors.
			21. Caulk baseboards and around electric baseboard heaters.
			22. Seal holes behind sink and bathroom fixtures.
			23. Other (continue on separate sheet, if necessary).



Appliances

24. Install circline fluorescent lamps in much-used areas.
25. Turn on "power miser" switch or turn off "humidity" switch on refrigerator.
26. Give homeowner sample cold water wash detergent.
27. Cover heated water beds with quilts.
28. Advise homeowner of benefits of using "air dry" setting on dishwasher.
29. Advise homeowner of advantages of using electric blankets.
30. Other (use separate sheet if necessary).

GLOSSARY

Air changes per hour (ach): the number of times the volume of air in a house is exchanged in an hour.

Air infiltration: the uncontrolled flow of air through cracks and openings in the building envelope.

Attic fan: a small capacity fan used to vent the attic.

Blower door: a device consisting of a fan mounted in a framework that can be sealed into a doorway to pressurize or depressurize a house.

Building envelope: the exterior surface of a building, including walls, roof, and floor.

Bypasses: direct connections between conditioned and unconditioned spaces, in wall cavities, around flues, pipes, etc.

Caulking: pliable substance used to fill cracks and reduce air leakage between non-moving materials.

Clock thermostats: a thermostat that can be set to turn the furnace on and off automatically at predetermined hours.

Combustion air: the air needed to support combustion (burning) in a furnace or similar fuel-burning device.

Conditioned space: any space in a building that is served by a heating or cooling system.

Conduction: the movement of heat through a material or by contact from one material to another.

Crawlspace: an unfinished space under the house, usually only a few feet in height.

Dropped ceilings: a part of the ceiling lower than the rest, generally found over stairways, bathrooms, and kitchens.

Energy retrofit: a measure taken to improve the energy-efficiency of an existing structure.

Foam gaskets: foam pieces cut to fit behind outlet plates to reduce air leakage.

Flue pipe: an exhaust pipe that carries the products of combustion from furnace, boiler, or water heater to the outside.

Incline manometer: device used to measure a pressure difference.

Indoor air quality: The quality of indoor air with respect to various pollutants and pollutant sources inside the house.

Infiltration: see "Air infiltration"

Infrared (IR) scanner: a viewer that scans infrared (heat) emissions from an object to indicate temperature gradations.

Jalousie window: a type of window consisting of several slats of glass that are opened and closed simultaneously by means of a crank.

Jamb: the piece of frame into which a door or window fits; the top jamb is known as a "head", the bottom as a "sill", the side as a "side jamb".

Low-flow showerhead: a showerhead with a maximum flow of three gallons per minute.

Polymeric foam sealant: a foam sealant that is squirted into cracks where it expands to create a tight seal.

GLOSSARY

R-value: a measure of the resistance of a material to heat flow.

Recessed light fixture: a light fixture recessed into the ceiling so that the surface of the fixture is flush with the ceiling.

Rim joist: a board resting on the sill-plate running horizontally along the outside surface of the joists (also called a "band joist").

Sill plate: a board secured to the top surface of the foundation wall.

Smokesticks: small glass tubes that when opened give off a steady stream of smoke used for detecting air leaks.

Unconditioned space: any space not served by a heating or cooling system, e.g., crawlspaces, attics, basements.

Weatherstripping: narrow strips of various materials placed over or in the movable joints of doors and windows to reduce air leakage.

Whole-house fans: a fan, usually mounted in the ceiling, that ventilates the entire house and exhausts air out through the attic.

********** AUDIT DATA FORM **********

Building ID: _____

Address: _____

House Doctors: 1)_____ 2)_____

Date: _____

Time; Start: _____ Finish: _____

Outside Temperature; Start: _____ °F Finish: _____ °F

HOUSE PLANS

Draw a house plan on the graph paper near the end of this form. Show the first and second floor (if any) separately on the same page. The carbon paper should give you one additional copy. On the first copy show: the location of south, dimensions of the walls, location of named walls (if more than one wall listed on wall data form), and the location of named floors. On the carbon copy show: the location of named attics, and location of any important shading (for example; major overhangs, awnings, or trees). Feel free to indicate anything else you think relevant on either plan. Photograph each side of the house, attach pictures to page provided, and label. Include surveyor's stick as a scale.

GENERAL DATA
(Fill out while talking to resident)

Number of residents: _____

Year of construction: _____

Resident's normal thermostat settings:

Heat: day _____ evening _____ night _____

Cool: day _____ evening _____ night _____

Is there a clock thermostat? _____

If so does it have one or two setbacks per day? _____

Heating only? _____ Heating and Cooling? _____

General description of thermostat habits if they do not fit the categories above (for example; no heat in January, or heated only between 6 p.m. and 9 p.m., etc.):

GENERAL DATA
(continued)

Current thermostat setting: _____ °F

Thermostat thermometer reading: _____ °F

Temperature near thermostat as measured by digital thermometer: _____ °F

Is the house zoned (more than one thermostat)? _____ How many thermostats? _____

Primary space heating fuel: _____ (if not gas, describe on heating page)

Secondary heating used: (if significant fraction of heating)

Fireplace Used?	Damper Condition?	Plug Installed?
1		
2		

Are some rooms underheated or overheated in winter? (These are places where resident might want the duct balance adjusted or where the house doctor might look for high leakage). Specify:

Ask resident (and describe here) about any appliances (pottery kiln, second refrigerator) or habits (use of exterior safety lights, use of drier twice a day) that might significantly affect their energy use:

BASEMENT

This house has:
basement: _____ crawlspace: _____ slab: _____
(If a combination of the above, show locations on house diagram)

Is the basement heated? _____

Wall I.D.	Height Above Grd	Height Below Grd	Insulation Type	Insulation Thickness	Construction Materials
BW1					
BW2					
BW3					
BW4					

FLOORS OVER UNHEATED SPACES

Floor I.D.	Construction Materials	Insulation Type	Insulation Thickness	Exposure *
F1				
F2				
F3				
F4				

* Under exposure, indicate what the underside of the floor faces (i.e., basement, crawlspace, outside air)

General condition of crawlspace or basement with respect to leakage and actions taken:

ATTIC FLOOR DATA

Attic I.D.	Roof Type*	Floored Area(ft^2)	Existing Insulation Type	Existing Insulation Coverage	Existing Insulation Thickness	Venting **
A1						
A2						
A3						

* In this column indicate type of roof. For instance: hip, gable, flat, or cape cod.

** In this column include approximate area of vents from attic to outside and note the presence of attic fans or a whole-house fan.

KNEE WALLS OF ATTIC
(Exposed to living space)

I.D.	Area (ft^2)	Existing Insulation Type	Existing Insulation Coverage	Existing Insulation Thickness
AW1				
AW2				
AW3				
AW3				

General condition of attic with respect to leakage and actions taken:

LIVING SPACE EXTERIOR WALLS

If all walls are identical (insulation, height, etc.) write "all walls" under Wall I.D. and fill in one line of these tables. Otherwise fill in a line for each type of wall, and mark the extent of that type of wall clearly on the house plan using the Wall I.D. The same basic instructions hold for attics and floors.

Wall I.D.	Floor 1st/2nd	Interior Height	Insulation Type	Insulation Thickness	Construction Materials
W1					
W2					
W3					
W4					

DOOR DATA

Door	Type	Opens Into*	Condition	Action Taken
D1				
D2				
D3				
D4				
D5				

* Under this heading indicate what space the door opens into. (i.e., garage, basement, outside, etc.)

WINDOW DATA

(Sliding glass doors and glass area of other doors are considered windows.)

Total Area (approx.); North: _____ South: _____ East: _____ West: _____

Type (approx area %); Double Hung: _____ Fixed: _____ Casement: _____

Horizontal Sliding: _____ Tilting: _____

Jalousie (Louvered): _____

Other: _____ (Type?_____)

Double Glazed (approx area %) Sealed: _____ Storm: _____

Inside Storm: _____

General condition (before visit) with respect to caulking, weatherstripping, or other important features (include approx. number of windows that need weatherstripping and those that need caulking):

Actions taken:
Number of windows weatherstripped? _____ Caulked? _____
Other actions taken:

If there are window treatments (reflective shades, tinted windows, extensive use of curtains) that seem important enough to affect air conditioning use, describe here. Remember to note shading by trees, overhangs, and awnings on house diagram.

HEATING SYSTEM DATA

Describe heating system: (i.e., gas wall furnace in living room, or central forced-air furnace)

Furnace location (heated or unheated area?): _____

Is furnace insulated? _____ If so, describe _____

Are the ducts (if any) leaky? _____ Was this remedied? _____

Are ducts (or pipes, if a water system) insulated? _____

If so, how much insulation? (inches) _____

Does the furnace have a filter? _____

Was the filter clean? _____ New filter installed? _____

Has the furnace been serviced recently? _____

Describe below: 1) Major secondary source of heat (if any),
or 2) Main source of heat if not gas furnace.

Furnace input as clocked: _____ ft^3/hour

Efficiency at beginning of visit: _____

Efficiency at end of visit (if changed): _____

IID installed: _____

Vent damper installed? _____ (Only if furnace combustion air is from heated area of house.)

COOLING SYSTEM DATA

Air conditioning type: central: _____ window units: _____(#)

none: _____ other: _____

Location of air conditioner(s): _____

Location of condenser if separate from unit (especially if exposed to direct sun in afternoon): _____

What kind of cooling system: compressor: _____ evaporative: _____

combined with heat pump used for heating: _____

other: _____

If central air conditioning, are ducts separate from heating system? _____

If separate, are air conditioning ducts insulated? _____ (inches): _____

Air conditioner manufacturer: _____

model: _____

(The following are probably not listed, but if they are please record them.)

Input rating: _____ (kw) output rating: _____ (btu)

EER if listed: _____

Blower rating: _____ (cfm)

(Remember to detail cooling thermostat habits on general data page.)

WATER HEATER DATA

Water heater fuel: _____

Storage tank capacity: _____ (gal.)

Location (note whether in heated or unheated space): _____

	At start of visit	At end of visit
Water temperature setting: (temp. at outlet pipe):	_____ °F	_____ °F
Thickness of water heater blanket (if any):	_____ in.	_____ in.
Water temperature at kitchen faucet:	_____ °F	_____ °F
Does kitchen faucet have an aerator:	_____	_____

Shower	Flow rate (gal/min, with hot and cold full on) before	after
1		
2		

Blower Door Data

Wind velocity: _____ Wind direction: _____

Blower door number _____

CAUTION: MAKE SURE FURNACE IS OFF

All interior doors stay open.

Depressurize (RPM)			Pressurize (RPM)	
Before	After	Pressure (inch water)	Before	After