Unintentional "chimneys" let warm air into the attic. The chase containing this plumbing vent pipe extends all the way through the house and should be blocked off to prevent the loss of heated air from the attic.

Don't seal ducts with duct tape. A fiber-reinforced mastic is a belter choice than duct tape for sealing the joints in ductwork because it won't pull away and fall off.

Fixing a Cold, Drafty House

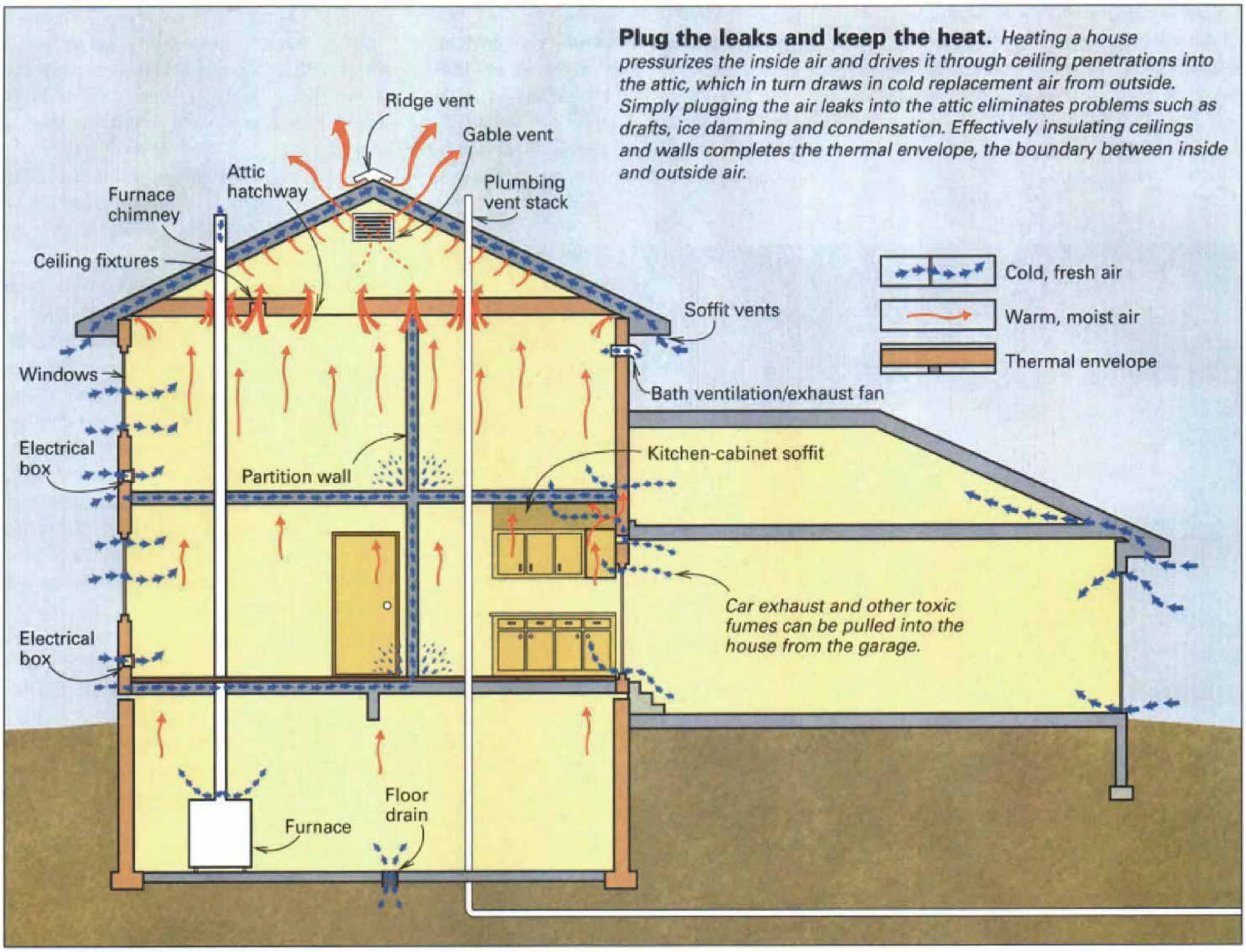
Forget about weatherstripping doors and windows. Sealing and insulating the attic are the keys to lower heating bills and a more comfortable house.

by Fred Lugano

As a weatherization contractor, I meet a lot of people who are sick and tired of cold, drafty houses. Their problem—and maybe yours, too—is that they live in homes that don't work very well. These houses, new and old, cost too much to heat and to cool. Their paint peels, their roofs dam with ice, and they sometimes make their owners sick. Simply put, these homes lack a good thermal envelope, or an insulated, air-resistant boundary between conditioned inside air and outside air.

Incomplete thermal envelopes are common in old houses, but new ones can have the same or similar problems. Open-web joist systems, cantilevers, balloon-frame walls and mechanical penetrations allow outside air to penetrate buildings. Sometimes the problem is poorly installed insulation with too many voids, but more often, holes in the building are the real culprits.

Caulks and weatherstripping can help plug small holes (sidebar p. 95), but this is like using Band-Aids to treat major wounds. The total area of the holes I'm talking about is measured in



Plug the leaks and keep the heat. *Heating a house pressurizes the inside air and drives it through ceiling penetrations into the attic, which in turn draws in cold replacement air from outside. Simply plugging the air leaks into the attic eliminates problems such as drafts, ice damming and condensation. Effectively insulating ceilings and walls completes the thermal envelope, the boundary between inside and outside air.*

square feet, not in square inches. Even so, these problems can now be fixed simply and economically, and buildings a century old can be routinely upgraded to higher performance levels than typical new homes. And the principles and methods are applicable to new construction.

Air movement in floors, walls and ceilings is bad—Air infiltration is the predominant heat-loss mechanism for most buildings (drawing above), so the primary goal of any weatherization effort should be to control air infiltration. Not all infiltration is bad; humans, pets, and furnaces and other combustion devices need a continuous supply of fresh outside air, and the air in most homes should be replaced (either naturally or mechanically) about six to eight times per day.

But relying on a home's air leaks is not a good way to provide fresh air. I've worked on buildings that have suffered as many as 30 air changes per day. At that rate, the conditioned air doesn't hang around long enough for the house's insulation to have much of an effect on keeping it in.

Air infiltration forces warm, moisture-laden air into cold, dry places. The buoyant nature of hot air drives it into every ceiling penetration, and if there are large holes, the house acts like a giant chimney, pulling cold fresh air in from below, heating it and pouring it into the attic. Loose attic hatches, large cutouts for plumbing vents, exposed beams and recessed lights are perfect "chimney flues" for these air currents (top photo, facing page).

When moist air contacts a cold surface in the wall or attic, water vapor condenses. If the building has a large reservoir of moisture—a wet cellar or an unvented bath, for example—terrible things can start to happen: Recessed lights drool; drywall stains and seam tape lifts; and exterior paint peels off soaked siding and trim. And once the sheathing hits 30% moisture content, mold and mildew can start growing, a condition carpenter ants and other bugs love. This chimney effect also causes a pressure drop in the basement. Now the living areas are competing with the chimney flues for combustion gases. When the lift through the building overpowers the flues, backdrafting results.

Leaky return ducts in a forced hot-air system (bottom photo, facing page) can also vacuum up extra air from the basement and pressurize the living areas, driving conditioned air into the walls. As warm air is forced out, outside air rushes in to replace it. If the basement is tight, that air will come down the chimney, and potentially dangerous backdrafting will start again.

Combustion efficiency will drop, and dangerous pollutants from incomplete combustion, including carbon monoxide, can spill into the basement, be picked up by return ducts and be delivered efficiently to the rest of the house, a potentially life-threating situation.

Outside-air intrusion is another classic source of air movement in building cavities, blowing in through openings in walls and running the length of floors before exiting at the other end of the house. This cold outside air immediately

Drawing: Mark Hannon

comes in contact with warm interior surfaces, chilling them and causing moisture to condense. Ceiling corners are especially susceptible. Here mold can grow, and paint, ceiling texture and tape can peel off. Contrary to popular belief, most insulation doesn't block air intrusion (bottom photo).

Effective insulation and air-sealing take place at the thermal boundary—A thermally efficient building must have a well-defined boundary between indoors and outdoors. The holes and voids that allow outside-air intrusion are obvious breaks in the thermal boundary, but sometimes it takes a little head-scratching to figure out just where the boundary is. It's a waste of time and money to insulate an area that is actually outside the thermal boundary, so it's important to attack the right combination of floors, walls and ceilings to yield a complete thermal envelope.

For example, although attics and basements are usually thought of as being transitional areas between inside and outside, they really aren't. There is no "in between" in a properly weatherized house. I generally consider basements and crawlspaces to be inside the thermal envelope because it is difficult to isolate these areas from the living spaces above. Besides", combustion appliances always belong inside, where they operate more efficiently and can contribute Btus to the heated space.

On the other hand, vented attic spaces should always be outside. If the attic is used often, treat the access as an exterior door, and insulate the stairwell walls and under the stairs. When an attic is rarely used, a well-sealed foam hatch over the well is sufficient. I like to use surplus sections of stress-skin panels here. They are heavy enough to compress the gasket we place around the well, they are well-insulated, and the drywall is ready for paint.

Areas behind a kneewall can fall either inside or outside, depending on the use of the space. Because air infiltration can be a real problem here, special care should be taken to seal off the floor, kneewall and sloped ceiling from the outdoors. Air-sealing and insulating the rafters down to the bottom of the band joist brings this triangular storage space inside so that it can be used for easily accessible storage. If this space is inaccessible or unusable for storage, my favorite technique is to solidify the entire volume by packing it densely with cellulose, which air-seals it and insulates it at the same time. (For more on dense-packing cellulose, read on.)

Smaller holes and cracks can be filled with caulk or foam. After attic insulation is pulled away, holes can be found and filled. Here the author fills cracks in a plaster-and-lath ceiling.

A blower door and careful investigation help to find the holes—I use pressure diagnostics to help direct my air-sealing efforts. Depressurizing the inside of a house with a blower door quickly reveals the most significant penetrations of the thermal boundary. But it doesn't take a blower door to find a lot of the major holes in the thermal envelope.

Under natural conditions, pressures are always higher at the ceiling than at the windows. Although wind and mechanically induced pressures are sometimes stronger, hot air applies constant pressure upward toward the ceiling and the attic. As a consequence, ceiling bypasses, or holes in the thermal boundary, generate more significant natural infiltration through the heating season than do window leaks.

This doesn't mean that door and window weatherstripping isn't cost-effective, but it does

Dirty fiberglass signals an air leak. As warm air pours through penetrations in the ceiling, dirt is filtered out by fiberglass batts, but the heated air goes into the attic. Holes for wiring should be filled with expanding-polyurethane foam to stop the loss of this air.

Bottom photo this page: Fred Lugano

Tightening up doors and windows

Unless the glazing is actually broken out, I've found that doors and windows are the most expensive and least productive areas for thermal renovations. A cold house may have between 10 sq. ft. to over 100 sq. ft. of air intrusions and leaks. By contrast, a rattling and ill-fitting door or window won't have more than a few square inches of leakage.

If you do choose to weatherstrip windows, avoid cheap, quick-fix products. They aren't durable or effective enough to warrant the effort to install them. I like Randall's products (Randall Manufacturing Corp. Inc., 200 Sylvan Ave., Newark, N. J. 07104; 201-484-7600), which are available in many hardware stores and feature both resilient vinyl bulbs and Q-LON bulbs.

The small, hollow vinyl bulb is easily compressed and conforms well to irregular shapes, which makes it a good choice for attic hatches. I like the Q-LON bulb, often original equipment on new doors, for its ability to conform to large bows and warps by folding and compressing. Metal carriers work well in tight spaces or with metal jambs.

I've also used products from Resource Conservation Technology (2633 N. Calvert St., Baltimore, Md. 21218; 410-366-1146) with good success.

Dealing with old doors and windows—Old doors or windows have character and are usually worth fixing up. Simply adjusting the stops will tighten up a rattling double-hung window. Products such as pulley covers (Anderson Pulley Seal, 5158 Bloomington Ave. S., Minneapolis, Minn. 55417; 612-827-1117), retrofit vinyl jamb liners and side-mounted sash locks (H. B. Ives, 62 Barnes Park N., Wallingford, Conn. 06492; 203-265-1571) can also help to make a tight seal.

To make a seal, the bulb must compress slightly when the door is closed, and I've found that the Door-Tite ratcheting striker plate (Trion Co., P. O. Box 110358, Carrollton, Texas 75011; 800-532-9995) can help folks who have trouble generating enough force to make the door latch completely. This plate has a series of stepped flats instead of one surface for the bolt to catch on.

Tools of the trade. Counterclockwise from top left: Brown and white Q-LON weatherstripping; vinyl bulbs mounted in wood and metal carriers; side-mounted sash lock; ratcheting strike plate; brown and white pulley covers with adhesive backing; weatherstrip tape; P-profile EPDM tape.

And what about caulk?—I think life is too short to justify the time spent filling a square foot of 1/16-in. cracks. If you use caulk, use it sparingly. I carry a dull putty knife and a damp towel to cut corners tightly and to wipe surfaces flush. Rutland makes several paintable, acrylic co-polymer caulks that adhere aggressively and tool cleanly (Rutland Products, P. O. Box 340, Rutland, Vt. 05702-0340; 800-544-1307). Rutland 500 RTV is the standard when you're air-sealing chimneys to sheet metal.—*F. L.*

mean that most doors and windows don't need replacement. There are reasons to replace windows, but unless there is glass missing or a large gap between sash and jamb, thermal performance is not a compelling one. There are better places to spend energy-conservation dollars.

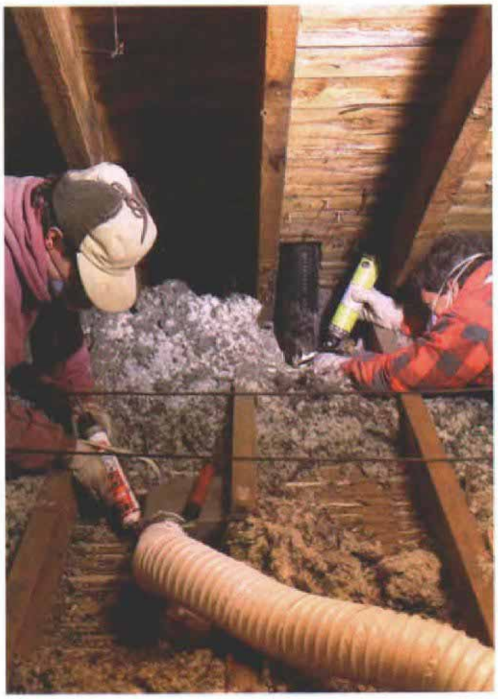
Another place to concentrate on is the common wall between the house and its attached garage, if there is one. Air leaks here always have the potential to vacuum car exhaust, solvent and weed-killer fumes, and fuel gases into the living space, so this is a spot that requires a NASA-grade air-seal. Obvious holes are usually easy to find and fix in the open framing. Caulking framing and sheathing joints down to and along the foundation makes a big difference.

Basements and crawlspaces should also get a thorough inspection. Musty odors are a sure sign that moisture and cold air are mixing and that wood is under attack. Crawlspaces are usually built to save money, and difficult access is often a reliable indicator of potentially significant building defects. We often have to saw our way into crawlspaces, where we can find bare soil, open concrete-block cores, no insulation, no sill seal, empty whiskey bottles, mold, decay, and lots of insect and animal debris.

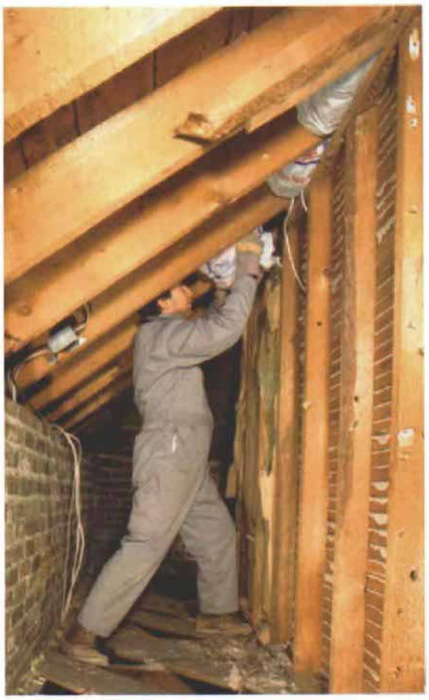
Blocking moisture in the form of water vapor from the soil with 6-mil poly is an important first step to air-sealing here. Cover the ground completely, overlap seams if there are any, and lap the poly right up onto the foundation wall. Then the foundation, sills and band joists can be air-sealed and insulated with sheets of rigid foam and plenty of caulk. It's tough to do perfect work in a tight space. Sometimes it's possible to work from the outside by applying rigid-foam panels or stuccoing the stonework.

With the house depressurized by the blower door, I feel for drafts with the back of my hand and spray expanding-urethane foam into trouble spots. Spiders can also offer clues; they always hang their webs in a draft. If the combustion devices have separate fresh-air supplies, foundation walls should be sealed as tightly as possible all the way to the ground, including foundation vents. Although often required by code, foundation vents allow crawlspaces to load up with moisture in warm months and allow cold air to circulate freely through the thermal envelope in the cold months. If moisture can be prevented from entering this space, then it doesn't need to be vented out.

It's important always to work at the boundary of the thermal envelope. Often during a blower-door test, an air leak to an electrical outlet, radiator pipe or wainscoting will show up in the middle of the house. But it won't do any good to stop the airflow there because the air will just find another exit point. Leave these interior



Ceiling fixtures and plumbing can be trouble spots. Bath fans are a good candidate for caulking, but the irregular hole around the vent stack is better sealed with foam. Insulated ductwork will keep the warm, moist exhaust air from cooling and condensing before exiting.



Larger air passages can be blocked with insulation-filled poly bags. Rafter bays are blocked with bagged fiberglass insulation prior to being insulated from above with blown cellulose. Later the plaster-and-lath walls will be insulated as well.

Blown cellulose makes a good insulation blanket. An alternative to fiberglass batts, cellulose easily flows over and around framing and into cavities. Eliminating gaps or voids helps to prevent cold air from washing through the thermal envelope.

holes alone and track down where the airflow actually enters the envelope. Air can travel long distances through floor bays and interior partitions in conventionally insulated homes. Airsealing away from the envelope only redirects the airflow to another hole.

The most effective air-sealing is done in the attic—Insulation must trap still air; it won't work with air blowing through it. Current residential-insulation practice often ignores this fact. Many homes have vented attics that are actually inside the thermal envelope because the ceiling has so many penetrations. Instead of being trapped by the insulation, warm air pours right up through and into the attic. Everything looks fine when the holes are covered with a blanket of insulation, but when melting snow shows the rafter pattern on the shingles, it becomes obvious that the thermal boundary is really the roof deck. The 12 in. of insulation in the ceiling is yielding an R-value of close to 0.

This isn't the time to add more useless insulation or ugly vents or an ice-dam membrane under the shingles. The best way to correct the problem is to dig through existing insulation and find and seal air leaks (top photo, p. 94).

Partition walls without top plates in older homes are often a major source of air leaks. Plumbing, wiring and chimney penetrations should be checked, and light beaming up into the attic from a ceiling fixture below is a sure sign of trouble.

I also look for blackened insulation (bottom photo, p. 94). As warm air finds a hole and jets through the insulation and into the attic, the dirt gets filtered out. Batt insulation wasn't designed to stop the loss of warm air from a building, but it does a good job of cleaning it.

Framing around chimneys should be sealed to the masonry with sheet metal and high-temperature silicone caulk. Mechanical penetrations are usually filled with nonexpanding-polyurethane foam from a gun (photo top left), while larger holes are best stuffed with fiberglass insulation wrapped in a poly bag (photo top right). We generally recycle our empty cellulose bags this way. For bigger holes, fasten down appropriately sized sheets of rigid foam, metal or ¼-in. oriented strand board and caulk the edges.

There are sometimes areas where it is difficult to rebuild a solid, continuous thermal envelope. For example, suspended ceilings are usually real trouble. When batts are laid over the grid, the assembly behaves like an open skylight, and air flows up through all the openings. In cases such as this, dig into the building until something solid and patchable can be found.

Dense-packed cellulose fills the gaps and stops the leaks—Once the flow of warm, moist, indoor air is cut off from the attic, the space can be prepared for adequate insulation. Because of the difficulty of installing fiberglass batts properly in an attic, I like to use blown cellulose. Potential ignition sources such as unrated recessed lights and chimneys should be dammed with sheet metal in order to keep them from contact with insulation. Hatches and soffit vents can be dammed with scrap lumber or plywood. This typically involves cutting and fitting a 10-in. or 12-in. deep box, or well, around framing so that it surrounds whatever needs to be dammed and keeps loose insulation out. Flagging electrical-junction boxes is a nice touch that you or your electrician will appreciate when it comes time to find them again. Finally, cellulose can be blown in at low pressure and low speed on top of the existing material to yield an honest R40 (bottom photo). Treating open cavities is the easy part of weatherization.

Insulating and air-sealing closed cavities is more difficult. In old homes with plaster walls and board sheathing, you can't simply caulk or foam every seam. Fortunately, dense-packing cellulose into closed cavities provides a cheap method of insulating and air-sealing in one step; it is so effective that it has become a cornerstone of weatherization practice. Instead of being fluffed in, the insulation can be crammed in at twice the conventional density. At 3.5 lb. per cu. ft., it becomes an air-sealing medium too dense for wind to penetrate, while at the same time maintaining its R-value.

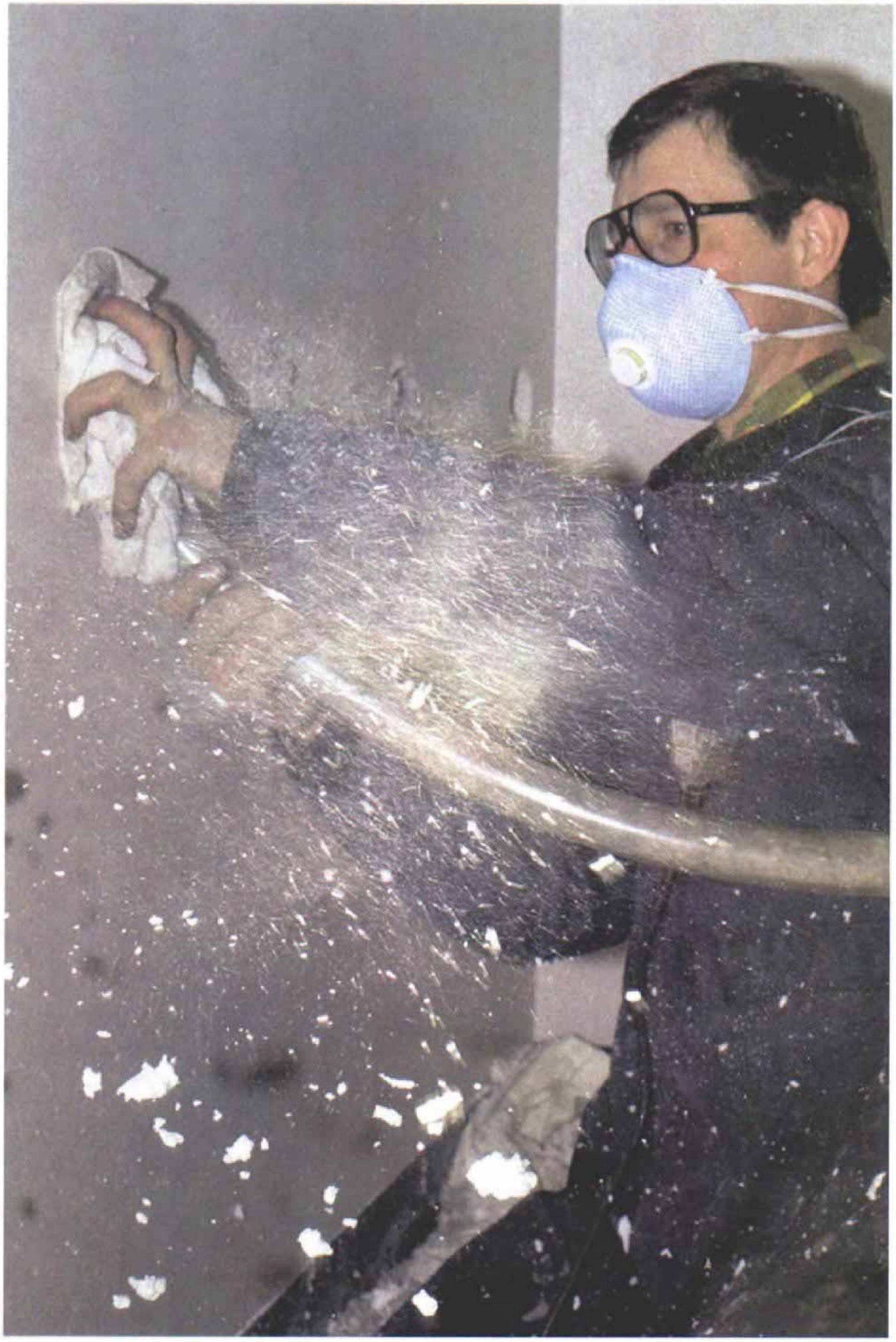
To gain access to the cavities, we drill a 2½-in. access hole from either the inside or the outside (photo right). When we can, we work outside because blowing cellulose is a dusty job. Some contractors drill right through the siding, but usually enough siding can be removed to gain direct access to the sheathing. Later, after the holes are drilled and the cellulose is blown in, the siding can be reinstalled.

A vinyl tube is snaked through until it bumps the end of the cavity. The tube acts as a vertical probe, and if it doesn't extend to either end of the bay, another hole will have to be drilled above or below the blockage. We blow in a lean mixture of air and cellulose at high speed. As the bay pressurizes, the fine cellulose particles flow into every crack.

When the pack becomes airtight, it stalls the flow in the hose, so we pull the tube back until it finds more loose fill. The completed bay is now solid, insulated to R-3.8 per in.; fire-, insect- and rodent-resistant; and air-sealed. When the cellulose is dense-packed so tightly that it stops the flow of air from the blower, it will also stop any wind pressure that nature can exert.

We use this method in walls, in cantilevered floors, under attic stairs and in odd triangular spaces behind kneewalls. Dense-pack is also an effective method for insulating cathedral ceilings, the inaccessible thin edges of attics under shed roofs and inaccessible joist and rafter bays. I think that properly installed cellulose is the finest insulation technique for new construction, too, but its versatility and ability to fill and to air-seal voids in the wall cavities of old houses makes it indispensable in effective weatherization. Together with attic air-sealing, a dense-packed envelope will generally cut natural air infiltration in half before doors, windows and basement are even touched.

Although dense-packed cellulose won't bring R-19 levels to 2x4 walls, it will still reduce infiltration in ancient buildings to minimal rates. Because most heat loss is caused by air changes anyway, these beautiful and invisibly updated period houses can now perform at higher comfort and efficiency levels than conventionally insulated new ones.



Walls can be packed with cellulose from the inside or the outside. Drilled through either the exterior sheathing or the interior finished wall, **2½**-in. holes provide access to the stud bays. A rag placed over the opening while it is being tubed helps to control the dust.

Weatherization is tough business—Insulating a building is physical, dirty work that can take you into tight, uncomfortable spaces. I don't know of anyone who likes working in a confined space at 140°F wearing a respirator.

And what is the payoff for these weatherization efforts? Even in times of relatively stable, low fuel prices, a 20% to 30% return on investment in fuel savings is the norm. Even better are the long-term maintenance issues, such as peeling paint and ice damming, that effective weatherization helps to solve. But best of all is the increased level of comfort for the home's residents: No longer does an old house—or even a new house—have to be cold, drafty and difficult to heat. □

Fred Lugano owns Lake Construction and is a weatherization contractor in Charlotte, Vermont. Photos by Andrew Wormer, except where noted.