Understanding Common Moisture Problems

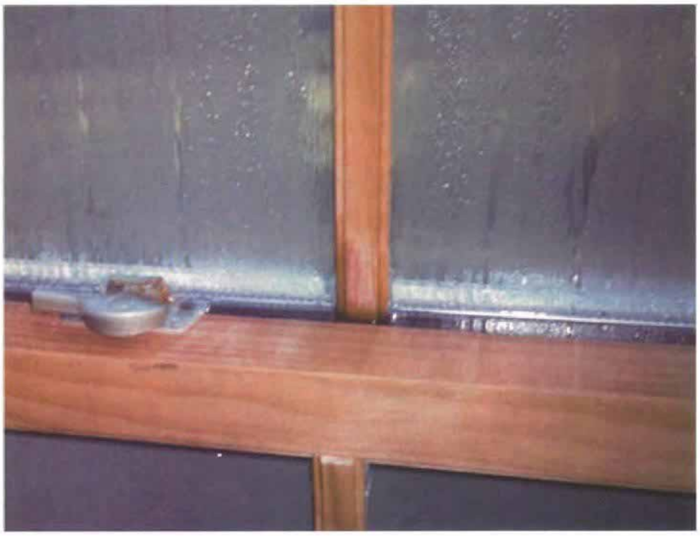
Three case studies illustrate the importance of controlling humidity and air leakage

by Marc Rosenbaum

About a dozen years ago, a couple called me to complain about serious water stains on the kitchen ceiling of their new home. The builder and the architect were at each other's throats: The builder blamed the stains on the polyethylene vapor retarder the architect had insisted he install in the ceiling, and the architect disagreed but had no alternative explanation. The confused homeowners hoped that I could offer some help.

It took less than a minute to identify the source of the water causing the stains. Six recessed lights punched holes in the ceiling, and they acted like little chimneys, transferring moist kitchen air into the attic, where the vapor condensed on the cold roof sheathing and dripped back down to the ceiling drywall.

Once everybody could see the evidence, they understood what was occurring and could agree that the solution was to seal the recessed lights.



The low outdoor temperature meets high indoor moisture. Condensation on this window could be prevented by lowering the relative humidity inside the house, increasing the window's R-value or both.

Excessive indoor humidity causes mildew growth and peeling paint. Water running off this window has saturated the sash, damaging its finish. The moisture content of wooden windows in this passive-solar house was as high as 28%, as compared with the normal level of around 10%.

What I learned that day was how much myth and dogma exist in the design and construction professions about simple, common building failures that have straightforward physical explanations.

In the three case studies that follow, I describe the nature of the problems encountered, the diagnostic methods and tools used to determine the causes, and the recommended fixes. All of these homes are in the Northeast, but the construction practices that caused the failures are common throughout the country. What varies is the type of problem that results. In the end, most residential failures are caused by uncontrolled movement of air and/or moisture, whether the building is in Mississippi or Minnesota.

First, find out exactly what's wrong- Occasionally, I may be able to diagnose a straightforward problem over the phone. But if I visit the house, first I get a thorough description of the phenomena. I want to understand what is happening, where in the house it occurs, in which seasons and how long it has been going on. This last point is important; many problems are the result of a chain reaction that follows a change in a building, like a new kitchen, furnace or windows. Any of these things might alter the humidity level or create new pathways for air.

The next step is a thorough walk-through. The homeowner may have called me because of something obvious like severe condensation on windows. But a troubleshooter might find other failures, indicating a wider problem. So my rule is to start the examination at the footing and end at the ridge.

Case #1: Frost, water stains and ice dams— In the first of the three case studies, the builder of a 3-year-old house called me because he had been unable to solve wintertime problems of severe frost buildup in the attic, stains on the second-floor ceiling below and recurrent ice dams.

The house had a gas-fired, forced-air heating system with central air conditioning and was located in a 6,500-heating-degree-day climate. (Degree days, a measure of heating demand, are calculated by subtracting the average daily outdoor temperature from a designated base temperature, typically 65°F. A day with an average temperature of 40°F, for example, would be a 25-heating-degree day. Annual figures are simply the sum of the daily figures. For comparison, San Francisco averages about 3,000 degree days and Chicago 6,500.)

The insulation was kraft-faced fiberglass batts, exceeding code-required levels, and no special air-sealing measures were implemented during construction. Soffit vents and a ridge vent, properly installed, provided adequate roof ventilation. The contemporary design yielded two separate attic spaces above second-floor bedrooms, separated by a loft, and another attic above the garage. A walk-through showed a dry basement and no evidence of water in the house except for the minor ceiling stains.

Keep heat in the living space—Ice dams are caused by warming the underside of the roof, causing snow above to melt, run down the roof and freeze again where the roof temperature drops below freezing, commonly at the eaves. (For more on ice dams, see *FHB* #98, pp. 60-63.) Water backs up behind the ice dam and leaks into the building. Although the classic solution for ice dams is to add insulation and/or roof ventilation, I look first for sources of unintentional attic heat that is warming up the roof sheathing. In this house, I didn't have far to look.

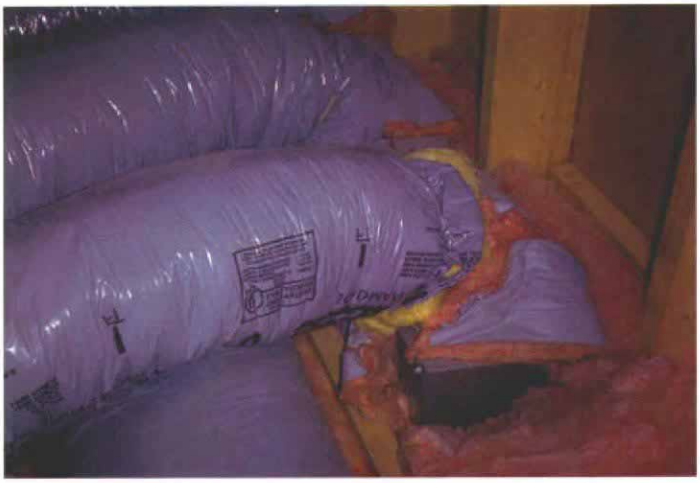
On a day that was substantially below freezing, I measured temperatures of 47°F in the attic above one second-floor bedroom and 40°F above the other. Because an insulated, ventilated attic should be only a few degrees above the outdoor temperature, we were in prime ice-dam territory. We began to look for sources of warm air leaking to the attic or locations of inadequate insulation. We found both.

A leaky building envelope—The kneewall access panels from the loft to the two attics were poorly sealed and crudely insulated with fiberglass batts duct-taped to their backsides. The door to the attic above the garage was uninsulated but had weatherstripping at the latch side and top. The fiberglass insulation in the walls between the heated spaces and these attics was open on the backside to the attic. This practice is common, but the effectiveness of fiberglass insulation is compromised when it is installed in an open cavity: Warm air adjacent to the backside of the drywall rises and moves into the attic, being replaced by cold attic air at the bottom. Fiberglass by itself does not stop air movement. Indeed, one clue a troubleshooter should always watch for is dirty fiberglass insulation. Fiberglass is a great filter, and dirty fiberglass has had a substantial amount of air moving through it.

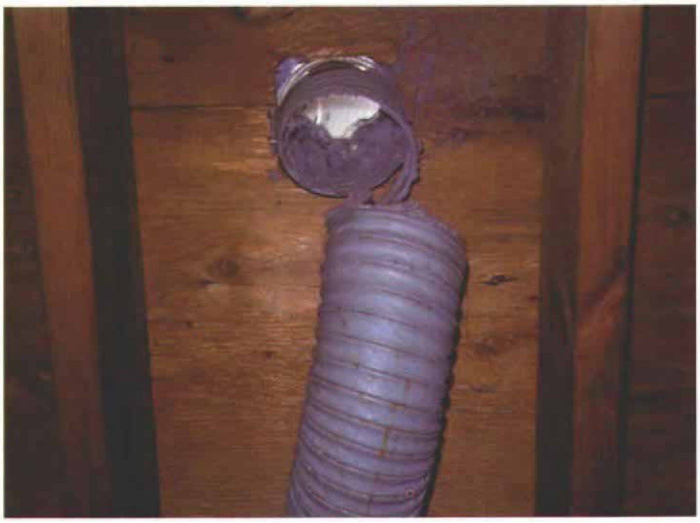
In the case at hand, the major source of heat in the attic came from a different source. The heating ducts for the second-floor rooms were in the attic, and they were unsealed. The metal ductwork was not insulated, and the flexible ductwork had 1 in. of fiberglass insulation, not much for ducts carrying 120°F to 130°F air in what is nominally an outdoor space (center photo). In addition, the attic-duct trunk came up through a basement chase that was unsealed top and bottom. This chase allowed warm basement air (the uninsulated ductwork kept the basement toasty) to rise freely into the attic. But what about the frost on the attic roof sheathing? Many homes have ice dams without this symptom also appearing. Frost occurs when water vapor in the air hits a cold surface and condenses or freezes on that surface. To solve this problem, we needed to find how moisture was entering the attic.

High-tech tools aid the search—With my sling psychrometer (sidebar p. 64), I measured the relative humidity in the house: It was 50%, higher than the 35% to 40% I prefer to see during the winter. A quick blower-door test (see *FHB* #86, pp. 51-53) showed an airflow rate of 2,375 cu. ft. per minute (CFM) at a 50-pascal pressure difference (CFM50). (A pascal is a metric unit of pressure; 6,895 pascals is 1 psi.) This amount is fairly typical of new construction with no special attempt to air-seal. The house was in fact probably a bit better than the average new home with forced-air heat. These houses tend to be leakier than homes with hot-water heat because of leaky ductwork. With normal amounts of moisture be-

Paint doesn't adhere well to a moving surface. Wood siding that has not been back-primed or otherwise sealed can expand and contract as it takes on and gives off moisture. As the wood siding moves, its painted finish cracks and peels.



Losing heat on the way to the living space. Heat-supply ducts in this attic were poorly sealed and underinsulated. As a result, the temperature inside the attic was 47°F, substantially warmer than the outside air. This situation prompted the formation of ice dams.



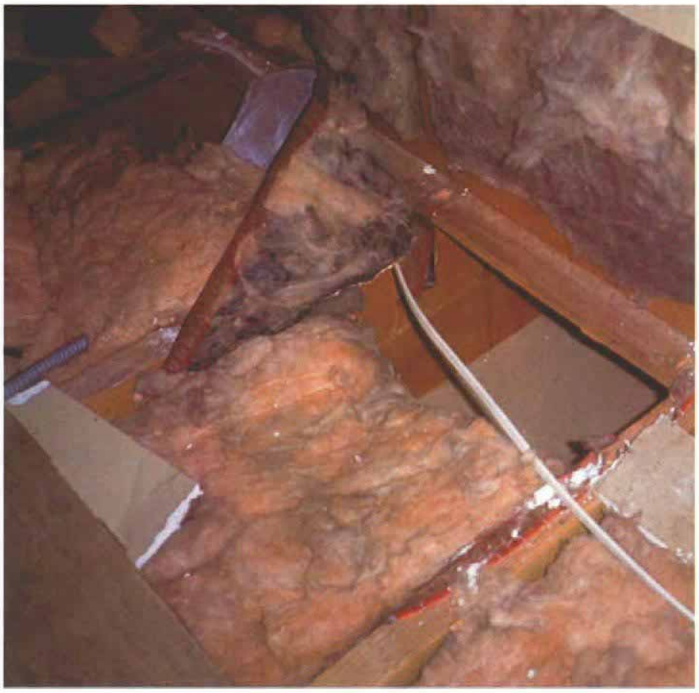
The source of moisture wasn't hard to find. This clothes-dryer duct, torn and hanging by a wire rib, is supplying warm, moist air directly to the attic.

ing generated in the house, this level of leakiness would typically result in a lower relative humidity, so I suspected an unusual moisture source somewhere. Bath fans, dryer and range hood were vented outdoors. Once again, the heating system was the major culprit.

Mounted on the furnace plenum was a central humidifier. Although it was on a low setting, the builder reported that it had only recently been turned down. I suspected that this home had been running at relative-humidity levels exceeding 60%, which is unhealthy for both the building structure and the occupants (many people are allergic to dust mites, which need high humidity to flourish). The central humidifier added moisture to the heating air, some of which leaked directly into the attic. A more effective method for moisturizing the attic could hardly be devised.

The proposed solution is twofold—I recommended that all attic ductwork first be sealed with latex mastic and then well-insulated. This task could be accomplished by covering the ductwork with loose-fill cellulose, a type of insulation made from recycled newspapers that have been shredded and treated with a fire retardant. Another alternative would have been to create a sealed duct chase out of foil-faced fiberglass duct board, laying the flexible duct in it and backfilling the space around the ducts with cellulose. I advised the homeowners that the central humidifier be disconnected.

Recommended fixes to the building itself included sealing the duct chase at both basement and attic levels with a rigid material such as plywood or sheet metal, sealing the house-to-attic penetrations (plumbing stacks, radon stack, electrical), installing an air barrier on the backside of the kneewalls (drywall or housewrap), and weatherstripping and insulating the door and kneewall hatches to the attics. In addition, I suggested installing a fan in the master bath, vented outdoors, and sealing the basement ducts with latex mastic. These changes not only will solve the problems and increase general durability of the home, but also will reduce the home's energy use significantly.



Insulation is no good if it's not continuous. Cold air from this crawlspace has a clear path to the floor of the adjacent bedroom through this and other uninsulated joist bays. Dirt in the insulation could mean that air is escaping from the living space.

Ceiling fixture provides light below and heat above. This recessed ceiling light, installed during a remodeling job, provides a conduit for warm, humid air to flow from the living space into the attic. The preferred alternative in cases such as this one is to install the type of light fixture that can be covered with insulation completely, without causing a fire hazard.

Case #2: A passive-solar house with severe moisture problems—Our second case study is a 10-year-old, passive-solar house with a south-facing, finished walk-out basement in a 6,000-heating-degree-day climate. The problems were severe condensation and frost on the windows and glass doors, causing mildew and paint peeling (top photo, p. 60); mold in the lower corner of one of the basement bedrooms; water stains around recessed ceiling lights; stuffy air quality; and peeling exterior paint. The home had an electric furnace, forced-air heating system and three heat-recovery ventilators, one serving the main body of the house and two small ones, each serving only a bathroom.

A walk-through showed condensation also appearing against the band joist in the unfinished basement on the house's north side. Because it was May, measuring relative humidity wouldn't necessarily have given an accurate indication of winter conditions. However, I used my moisture meter (sidebar p. 64) to assess moisture levels both inside, checking the millwork and the trim, and outside, testing the exterior siding and trim. Some of the windows had spot moisture contents as high as 28%, clearly caused by condensation (bottom photo, p. 60). Interior trim was well below the danger zone of 20% or more, where wood becomes susceptible to decay organisms. Some exterior readings also were in the 20s, mostly in the areas where the trim was too close to the ground and splash-back was occurring.

The peeling of the exterior paint appeared to be caused by water penetrating from the outside (top photo, p. 61). The house had minimal overhangs on the gable ends, and the grading around the foundation put the wood too close to the ground in many places. Neither the trim nor the siding had been back-primed before installation, so water drawn up between the clapboards by capillary action could soak readily into the wood. The expansion and contraction of clapboards as they get wet and then dry eventually causes the paint film to fail. One clue suggesting an exterior problem—unrelated to high indoor-humidity levels—was that the unheated garage showed the same peeling-paint symptoms.

Ventilation wasn't as it seemed—I did a quick blower-door test and found that the house was quite tight (1,000 CFM50). Then I checked the operation of the house's three ventilators to verify that air was in fact being exhausted. The central unit was moving hardly any air at the exterior vent hood, and one of the small units was incapable of opening the flap on its vent hood at all. The third small unit worked as it was supposed to. It was clear that the house, despite appearing well-ventilated, was suffering from too little air exchange. Humid air leaking from the house into the attic condensed on the roof sheathing and dripped back to the ceiling, causing stains.

In the unfinished basement, I taped 2-ft. squares of clear polyethylene to the concrete wall and to the basement slab. If there is a significant source of ground moisture, condensation often will bead on the backside of the poly. In this case, none was observed. Moisture-meter readings on the concrete appeared reasonable. However, I had noticed that the gutter downspouts ran into standpipes leading down to the footing drains, not a good practice for keeping basements dry. I inspected the footing drains where they ran out to daylight, and no water was running, unusual for late spring in the northeast.

The mold in the lower corner of one of the bedrooms appeared where the concrete sidewall met the wood-framed south wall. The basement's concrete walls continued beyond the building to form retaining walls on the east and west, and I strongly suspected a direct thermal bridge through the concrete. This bridge would keep the wall near the corner cold in the winter, causing a rise in the relative humidity at the wall surface. This increased relative humidity causes the moisture content of the wall surface to rise to the level where it will support growth of mold.

Moisture is the culprit—Virtually all of the interior problems could be corrected by substantially lowering winter moisture levels. This house needed reliable ventilation, so I suggested a new heat-recovery ventilator having adequate capacity (at least 100 CFM), and operating it enough to maintain 35% to 40% relative humidity in the heating season. The original ventilator was neither well-designed nor well-installed. Mold needed to be removed and the millwork repainted.

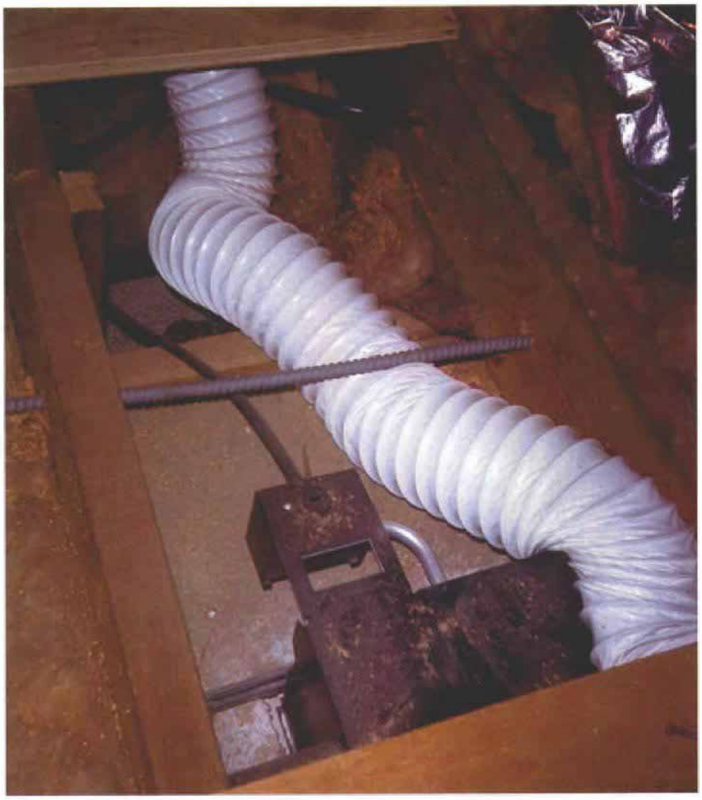
Even if the moisture is controlled, the southeast basement corner may still foster mold. This wall may need to be opened and insulated from the inside to maintain a higher interior surface temperature, and thereby a lower moisture content, not conducive to mold growth.

On the exterior, regrading would move water away from the building, and rotten trim could be replaced with wood primed on all sides. The gutter downspouts should be disconnected from the footing-drain system, and the drains should be checked for blockage. The clapboard laps could be wedged open with plastic wedges (Shur-Line Inc., 2000 Commerce Parkway, Lancaster, N. Y. 14086; 800-828-7848) and allowed to dry. (Some cracking of the clapboards is likely to occur as the wood dries out.) Once dry, they could be repainted with a good latex paint.

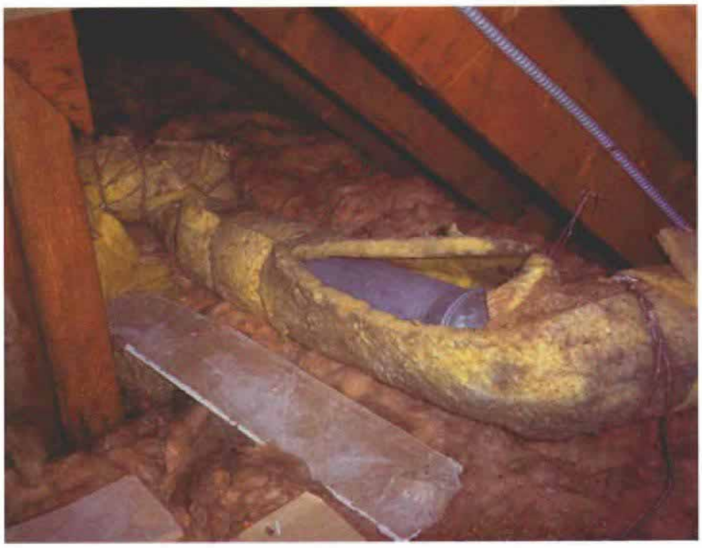
Case #3: Problems common to conventional construction—In the third case study, the owner of a 32-year-old home complained of room-to-room temperature variation in the winter, high utility bills and condensation in the attic. Located in a 5,000-degree-day heating climate, the house had forced-air gas heat. The second floor of this French Eclectic-style house was contained in flat-roofed dormers poking up through the steep hip roof. Kneewall spaces adjacent to the second-floor bedrooms were designed to be cold, and they were vented outdoors.

The bedrooms usually were cold—no mystery once I got in the crawlspaces. The ductwork to the bedrooms ran through the cold spaces, was leaky and had minimal insulation (bottom photo). The 2x4 kneewalls themselves were insulated with fiberglass batts, the backs of which were open to the cold. But the biggest offender was the fact that the 2x12 second-floor joist cavity was open to the kneewalls (top photo, facing page). Cold outdoor air could flow into the kneewall cavity, through the joists and to the other kneewall cavity. The net effect was like having an uninsulated floor in contact with the outdoors.

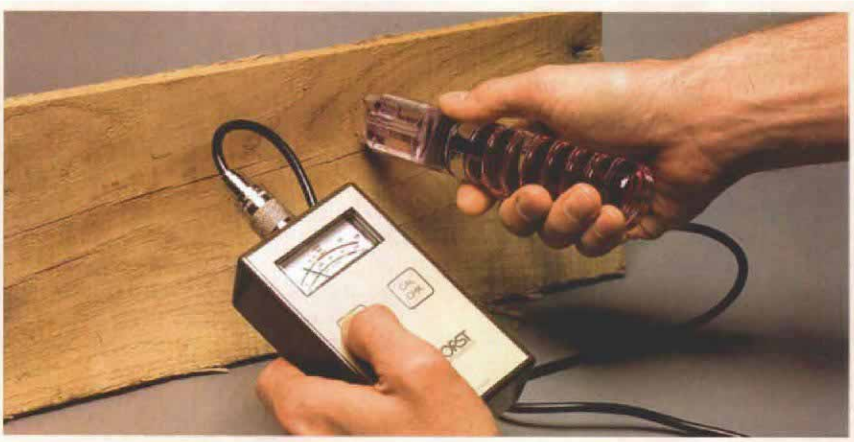
Heat loss through the ducts—The blower-door test gave a result of over 4,000 CFM50—very leaky. I started the furnace and used a smoke pencil—a small squeeze bottle containing chemical vapors that produce a smokelike gas on contact with air—to look for duct leaks. There were plenty. A good portion of the hot air generated by



Don't forget to replace the insulation. In his work, the author commonly finds conditions such as this uninsulated bathroom exhaust fan. The insulation, cleared away to make room for the retrofit fan and duct, was never replaced.

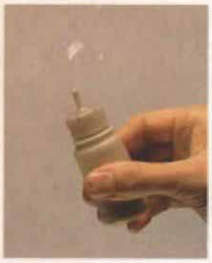


Close the gaps. Poorly insulated heat-supply ducts raise the temperature of attics, increasing the chances of condensation and ice damming.

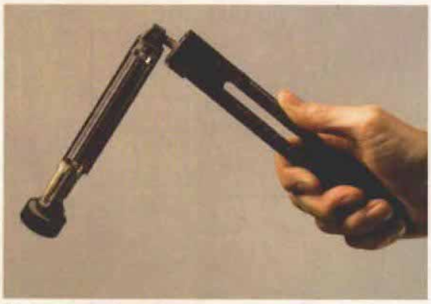


Moisture meter.

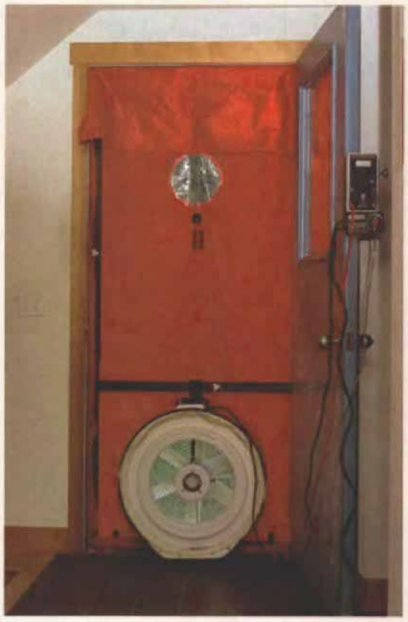
Thermometer.



Smoke pencil.



Sling psychrometer.



Blower door.

Tools for troubleshooting

I carry several instruments with me on all of my residential troubleshooting adventures. The first is a digital thermometer, useful for measuring attic temperatures, duct temperatures and the like. It costs about $20.

For measuring relative humidity, I use a sling psychrometer. This instrument consists of two thermometers, one of which has a dampened wick on the bulb. The tool is whirled around so that the thermometer bulbs are in moving air. The thermometer with the wick relates to how much moisture is in the air. The relative humidity is calculated from the two measurements. Mine is made by Bacharach Inc. (625 Alpha Drive, Pittsburgh, Penn. 15238; 412-963-2000) and costs about $70.

A blower door—an instrumented, portable fan installed in an exterior door—is the tool for assessing how tight a house is and where the leaks are. My kit includes a two-channel, digital micromanometer, which measures pressure differences between indoors and outdoors, or between rooms or floors in a home. The Minneapolis Blower Door, including the micromanometer, costs about $2,000. It's made by The Energy Conservatory (5158 Bloomington Ave. S., Minneapolis, Minn. 55417; 612-827-1117).

A smoke pencil is a small plastic squeeze bottle containing chemicals that produce a visible gas on contact with air.

Finally, a moisture meter, which measures the moisture content of wood and other materials as a percentage of dry weight, is invaluable. Mine is made by Delmhorst (Delmhorst Instrument Co., 51 Indian Lane East, Towaco, N. J. 07082; 800-222-0638). It cost about $300.—*M. R.*

the furnace was not getting into the living spaces. There was a lot of leakage in the basement ductwork and in the return side of the system, which used joist and wall cavities, some panned with sheet metal, as ducts. Another reason for the high utility bills was that the original furnace had been replaced in the late 1980s with a new unit that had a 67% efficiency rating—unimpressive at a time when furnaces were available with efficiency ratings as high as 95%.

In the attic, I found the source of moisture causing the condensation. A recent kitchen and bath remodel had added a number of recessed lights and two bathroom-ceiling exhaust fans. The insulation around each fixture and fan had been removed, and not the faintest attempt had been made to seal the ceiling penetrations (bottom photo, p. 62; top photo, p. 63). Most of the insulation in the attic was black with dirt, indicating rampant air leakage from the rooms below. Both fans had been vented with 3-in. flexible plastic duct, which had been flattened so that very little air actually made it outdoors. To top things off, the dryer had been vented through the roof, also with plastic duct. The duct was torn and hanging only by a wire rib to the roof vent cover (bottom photo, p. 61). And the vent cover was screened and plugged with lint. The net result: All of the moisture from the dryer was venting to the attic.

Stem the flow of air on all fronts—To reduce air leakage in the house, I recommended the bath fans and recessed light fixtures be sealed. The insulation could be improved by filling the second-floor joists with blown-in, densepack cellulose insulation, or by sealing the joists from the kneewall area with rigid-foam insulation, foamed in place. The back of the kneewalls should be sealed with housewrap or drywall. Plastic sheeting should not be used on the cold or attic side of insulation because it can trap moisture inside the wall (see *FHB* #88, pp. 48-53). Another alternative would be to insulate the sloped portions of the roof with dense-pack cellulose, bringing the kneewall areas within the heated envelope.

Ductwork should be sealed with latex mastic. Return ducts using standard joist bays should be lined with metal and sealed. Insulation should be added to ductwork in kneewall areas after it is sealed. Insulating basement ductwork would increase comfort by maintaining air temperature on the long duct runs. The dryer vent should be replaced with sealed metal ductwork. The long-term strategy would include replacing the low-efficiency furnace.

Marc Rosenbaum, P. E., owns Energysmiths in Meriden, New Hampshire, and designs energy-efficient and environmentally sound housing. Photos by the author except where noted.

Further reading

Two excellent resources of related information are *Advanced Air Sealing* (Iris Communications, 258 E. 10th Ave., Suite E, Eugene, Ore. 97401; 800-346-0104) and *Moisture Control Handbook* by Joseph Lstiburek and John Carmody (Building Science Corp., 273 Russett Road, Chestnut Hill, Mass. 02167; 617-323-6552).

Photo bottom right: Reese Hamilton. Other photos: Scott Phillips.