FINDING the *FLAWS* in *SUPERINSULATION*

Figure 1. A chaseway for furnace and water-heater flues. The fiberglass batt used to block opening is streaked with dirt from leaking air.

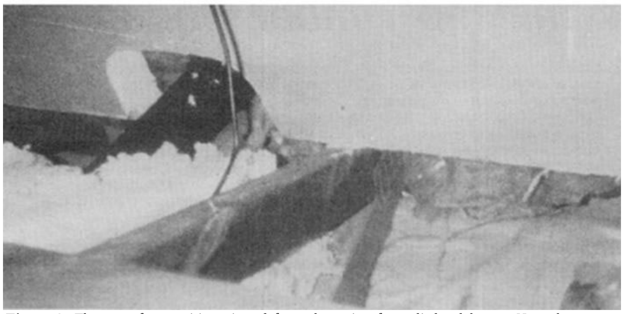


Figure 2. The top of a partition viewed from the attic of a split-level house. Note that there's no blocking atop the wall—a problem in every split-level in the study.

BATTENING DOWN THE HATCHES

In the Minnesota program Gary Nelson describes, participating builders were asked to comply with a list of house-tightening measures. If builders wanted to have a slightly higher energy-efficiency rating, they had to commit to an additional list of measures. Both lists follow: (you'll notice that not all measures were universally applicable).

- Install vestibule
- Install casement windows, swinging doors (not sliders)
- Install doors with magnetic weatherstripping
- Insulate and weatherstrip attic door
- Install vent dampers
- Install combustion air ducts
- Seal cracks at windows, doors and framing
- Install independent continuous vapor barrier
- With regard to fireplace:
  - Install damper on top of flue
  - Install glass doors
  - Install combustion-air duct
  - Install masonry thermal break
  - Insulate (airtight) partition around flues
  - Insulate firebox
  - Insulate masonry
- Caulk holes in upper and lower wall plates
- Install gaskets for electrical outlets and switches
- Install airtight heating stove with combustion air duct
- Seal joints in ducts
- Disallow ducts partially formed by joist spaces
- Disallow recessed lights
- Install sill-plate sealer and caulking
- Install vapor barriers at drop ceilings

Additional measures for higher energy-efficiency rating:

- Install air/air heat exchanger
- Caulk joint at bottom of gypsum board walls
- Exhaust fans to have motor dampers
- Caulk around all pipes and conduits
- Seal around vents and chimneys

by Gary Nelson

The thermal bugs in these 144 superinsulated houses were much the same as in any housing stock. So what have we learned?

In 1980, 144 low-energy houses were built in Minnesota as part of a demonstration project called the Energy Efficient Housing Design (EEHD) program. Twenty-three builders participated in the program, and built from two to twelve houses each. The 23 designs used were predicted to use a fraction of the energy of regular houses. (The target was 3 Btu/square foot-degree day.).

When the houses were completed, however, researchers were surprised to find that there was no correlation between the predicted energy performance and the first year's fuel bills. At that point, I was hired by the state to take a closer look at the houses. My job was to perform two-day, highly instrumented inspections of problems that would affect the energy performance of the houses. The instrumentation included a blower door, infrared scanner, wood-moisture meter, sling psychrometer (to measure relative humidity), flue-gas analyzer, and digital thermometers.

Air-Tightness Measurements

Seventeen detached houses were all tested for air tightness with a blower door. They turned out to be not much tighter than the average new home in the area. The 17 program houses averaged 4.2 air changes per hour (ac/h) when depressurized to 50 Pascals, whereas typical new houses in the area tested at 3.8 ac/h.

The program required the builders to follow a long list of air-tightening measures, and assumed that the houses had a natural infiltration rate of .5 ac/h. Builders were allowed to assume lower air-infiltration rates if they installed air-to-air heat exchangers and performed an additional long list of air-sealing measures. The houses with the heat exchangers, however, did not test out much better than the ones without them.

Common Air-Leakage Sites

We found both major and minor air leaks by depressurizing each house with the blower door and then scanning with the infrared camera from the interior. For the most part, the EEDH houses leaked in the same places as in much older houses. They are the same types of leaks the researchers at Princeton University identified more than ten years ago—little has changed here.

In most cases, I had a copy of the house plans to look at during my inspections. But the plans rarely showed the details that would have been necessary to avoid the leaks that we found. The most common leakage sites are covered in the sections that follow.

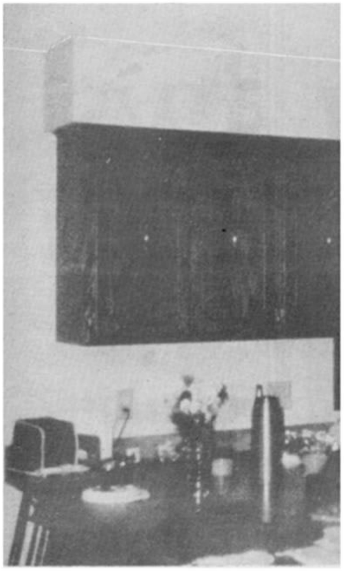
Attics

As in conventional housing, we found that the largest source of air leakage was between the house and the attic. Figure 1 shows the top of a chaseway built for a gas furnace and water-heater vent. The firestop isn't large enough to seal off the top of this chaseway. The fiberglass batt that the insulator used to keep the blown insulation from falling into the chaseway is streaked with dirt that was filtered from the air that leaked through this hole. Many builders still seem to be unaware that insulation does not make an effective air barrier.

Figure 2, taken from the attic, shows the top half of the wall that runs down the middle of a split-level house. The wall has drywall on the attic side to protect the foam insulation from fire. The photo was taken after some blown fiberglass was removed from the area where this wall intersects the ceiling of the lower level.

Notice that there is no blocking to stop air from leaking out of the wall. Since these walls generally contain major plumbing, wiring, and duct runs, it is easy for heated air to get into the stud spaces of these walls. All split-level EEHD houses had this problem. Several houses used stud cavities in these walls for return-air ducts to draw solar-heated air from the top of the house down into a rock bed. In each of these houses, cold attic air leaked into these cavities, reducing the performance of the solar systems.

Figure 3 shows a soffit above kitchen cabinets. Figure 4 is an infrared photo of the same soffit, taken with the house depressurized. The dark soffit indicates that the soffit is cold due to attic air being drawn into the soffit. In Figure 5



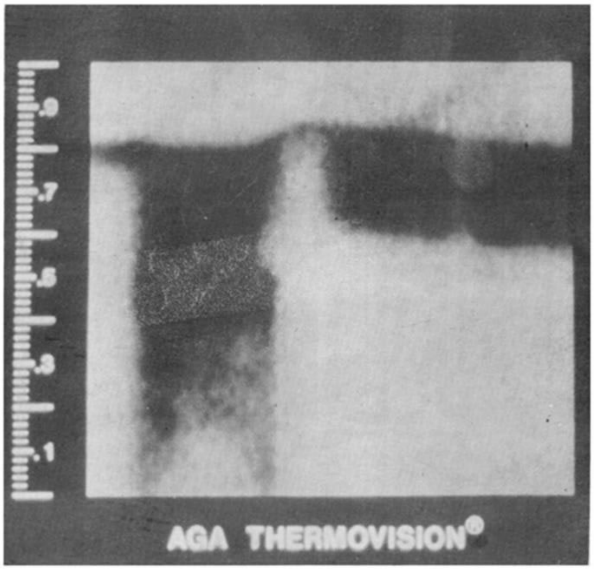


***Figure 3** shows a soffit above kitchen cabinets.*

***Figure 4** (above left) is an infrared photo of the same soffit. The dark area is caused by cold air that leaked into the soffit through cracks in the attic floor shown in **Figure 5** (above right).*

we see what the attic looked like just above the soffit. The pencil and knife are inserted to show the large cracks through which moist household air leaked into the attic from the soffit The insulation directly above the soffit was darkened and moist from the leaking air and had settled.

In this house, a piece of plywood had been installed to keep attic insulation out of the soffit. Often there are just paper-faced batts stapled to the ceiling joists. And often one of these falls into the soffit, leaving a large hole between the soffit and the attic.

Other major air leaks into the attics that I found include: the sloped ceilings above stairways, chaseways around plumbing vents, open joist spaces under knee walls, and dropped ceilings over bath tubs. Smaller leaks that are often significant because of their numbers include: holes for wiring in top plates, the cracks between the top plates and the drywall, and recessed light fixtures. It's my experience that ice dams are often the result of the heat dumped into the attic by all of the air flowing through these leaks. Every condensation problem I have seen in attics can be traced to air leakage.

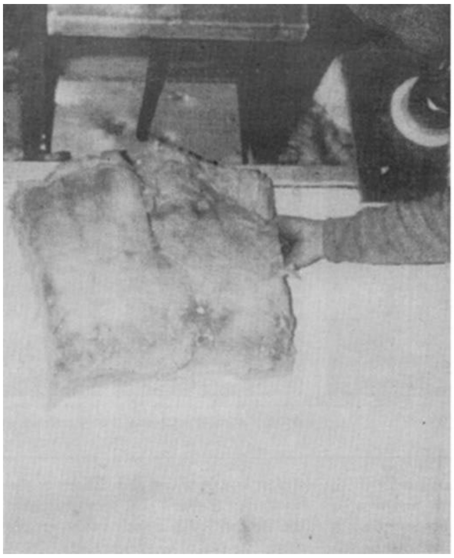


***Figure 6.** A dirt-streaked fiberglass batt being removed from the rim-joist area. Most EEHD houses have big air leaks here—where rim joist meets sill plate.*

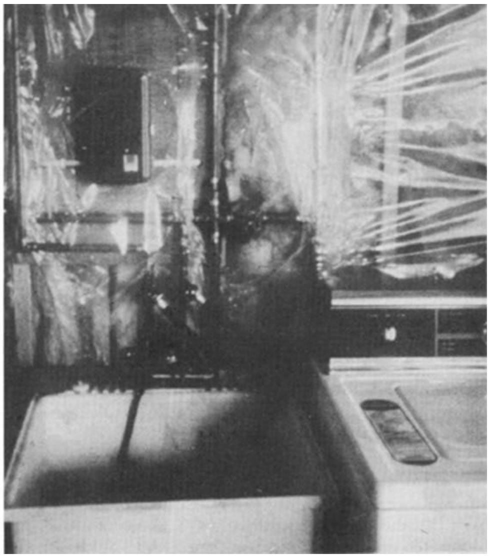


***Figure 7.** A fancy poly job turned to Swiss cheese by a careless plumber. Message: if subs aren't educated and enlisted to help, forget about airtightness.*

Other Air Leaks

Figure 6 shows a fiberglass batt being removed from the rim-joist area of one of EEHD houses. The dark streak of dirt shows that there is a large air leak between the rim joist and the sill plate. This was a significant leak in most of the EEHD houses, especially where floor joists were cantilevered out past the outside wall.

Although the builders used poly, they paid little attention to making the poly continuous where partitions or floors intersected exterior walls.

The program required continuous vapor barriers to reduce moisture problems and infiltration. Although all builders used polyethylene, they paid little attention to making the poly continuous where partitions or floors intersected exterior walls. Vapor barriers were also discontinuous behind bathtubs—creating significant air leaks there. In addition, few builders attempted to seal the poly at plumbing and electrical penetrations. Figure 7 shows a poly vapor barrier that was melted while the plumber soldered the piping for the laundry room. Subcontractors were apparently unaware or didn't care that the poly was supposed to be airtight. A better understanding of the vapor barrier was needed by the subtrades.

Insulation Defects

All of the EEHD houses that I examined had areas where the wall insulation was not performing well. Figure 8 is an infrared photo of a well-insulated wall. Note that the studs appear to be uniform in temperature and width, and are clearly distinguished from the insulated cavities. The cavities appear warmer (lighter) and are also uniform in temperature. Figure 9 is an infrared photo of a wall that's not working as well. Studs are hard to distinguish because large areas of insulated cavity are as cold as the studs. Also the studs appear to get wider and colder at the bottom of the wall. The temperature at the bottom of the wall varies greatly from one cavity to another.

I've never seen these problem patterns in walls retrofitted with blown insulation. They are also uncommon in walls with paper-faced batts. All of the EEHD houses, however, were insulated with *unfaced* fiberglass batts. Unfaced batts are rarely installed so that they completely fill the cavities. There are usually many small airspaces between the drywall and the poly, between the poly and the batts, between the batts and the exterior sheathing, between the batts and the studs, and between the batts and the plates.

I would recommend blowing insulation in after the drywall is installed, or using wet-spray cellulose blown into an open cavity.

In laboratory studies, researchers have found 50 percent reductions in the R-value of unfaced fiberglass installed vertically with air spaces on either side. The reductions were due to increased convection within the batt and within the wall cavity. This is probably what is going on in the wall in Figure 9. Most EEHD houses had some wall areas that looked good, indicating that the job can

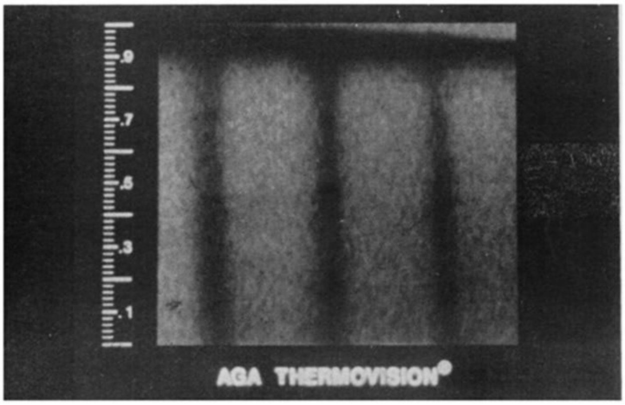


***Figure 8** is an infrared photo of a well-insulated wall with warm cavity areas and cooler (darker) stud areas.*

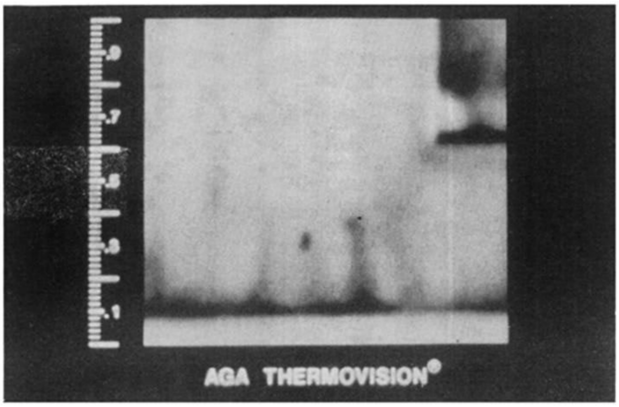


***Figure 9** shows a wall impaired by internal connection due to ill-fitting unfaced batts.*

be done correctly. But unless you can persuade the insulation contractor to do a good job, I would recommend blowing insulation in after the drywall is installed, or using wet-spray cellulose blown into an open cavity.

Another common insulation defect is shown in Figure 10. The photo shows a cathedral ceiling with cold streaks beginning at the bottom and extending up the ceiling. The coldest part of each streak appears at the bottom. I suspect ventilation air coming through the soffit vent is leaking between the drywall ceiling and the fiberglass batts that were installed between the trusses. No baffles were evidently installed to force air to flow over the insulation and into the ventilation space above the insulation.

***Figure 10.** An infrared photo of cold air chilling the lower portions of a cathedral ceiling. Combine this with high humidity and you can start a mold garden on your ceiling.*

Foundations also had problems. Although the foundation walls were insulated on the exterior, many had thermal bridging that showed up as large cold areas on the interior. The thermal short circuits were caused by retaining walls and garage floors that were in direct contact with the block foundation walls. Several had exterior rigid foam with trowel-on cementitious coatings. The stucco-like coatings were often cracked and coming off at corners and around windows.

Heating Equipment

Many of the gas furnaces tested below the manufacturers' specs for steady-state efficiency—several tested at 69 to 75 percent efficient. The condensing furnaces in one group of eight houses had all been replaced due to corroded heat exchangers.

Eleven of the houses had forced-air heating systems with supply ducts beneath a concrete slab. Although the house plans called for the ducts to be insulated near the slab's outside edge (either around or below the ducts), 25 to 50 percent of the heat entering the ducts was lost before the air left the registers. A large percentage of this heat is probably lost to the ground. An analysis of one year's heating bills showed that, on average, these heating systems lose about 11 million Btus annually in the below-slab distribution system.

Thirteen houses had air-to-air heat exchangers, ten of which were centrally ducted. The ducted units were poorly installed and none had provisions for air-flow balancing. In most cases, the duct layout and sizing almost guaranteed poor balance. Only two of the units had filters, and each of these had only one filter located in the outgoing air duct just before the heat-exchange core. Control systems were complicated, operated improperly, or misunderstood by homeowners. None of the ducted systems came with owners' manuals, and none of the owners knew how to clean the heat exchanger. Many owners reported using their heat exchangers rarely.

A better approach would be a *performance* standard, such as one that requires houses to meet a tightness goal as tested by a blower door.

Four houses had solar heating with rockbed storage systems below the floor (two of these filled with water every spring). In all these houses the rockbeds and ductwork system allowed cold air to be drawn into the house whenever circulation fans were used. Some leaks were directly into the rockbed from outdoors, some were into the ducts from the attic.

Conclusions

In spite of the long list of air-tightening measures required by builders in the program, and despite the installation of poly barriers, the houses examined here are not significantly tighter than other new Minnesota houses. And although the houses had higher levels of insulation, the insulation performance was reduced by thermal defects probably due to poor workmanship.

This leads me to the conclusion that *prescriptive* standards (lists of steps to follow) are probably not effective in assuring tight construction. A better approach would be a *performance* standard, such as one that requires houses to meet a tightness goal—as tested by a blower door. A level of 3 ac/h at 50 Pascals should be easy for most builders to achieve, and would eliminate most of the common energy-related complaints in new housing: cold drafts, high bills, freezing pipes, ice dams, and condensation in attics and walls. A tougher standard of 1.5 to 2 ac/h at 50 Pascals would be more appropriate for houses with mechanical ventilation.

Throughout this study, we repeatedly asked ourselves two questions "What would it have cost to build these houses right? And how much better would they have performed, if done right?" There is more work to be done before we can answer these questions.

For More Information

A full report on the performance of the EEHD houses, *Energy Efficient House Research Project, Final Report* (order #DE86015941) is available from the National Technical Information Service, U.S. Dept. of Commerce, 5285 Port Royal Road, Springfield VA 22161. A set of 110 slides taken from the project, including the figures in this article, is available for $55 from the Minnesota Curriculum Services Center, 3554 White Bear Ave., White Bear Lake, MN 55110 (612) 770-3943. ■

Gary Nelson is a partner in The Energy Conservatory, a Minneapolis consulting firm that also manufactures The Minneapolis Blower Door.