What's Being Built Out There? Performance Tests on 100 New Homes

by Arnie Katz



There is a substantial gap between truly energy-efficient construction and what is currently being built. The problems range from lack of training to carelessness. But there are ways to cure the problems and bring best practices into widespread use.



People who know building science often cringe when they see new construction with the same old problems. Leaky ducts, poor air sealing, improperly sized mechanical systems all seem too common. But visiting construction sites only shows part of the problem.

We wanted to know how well actual construction compared to what is possible. So in 1994, Advanced Energy (AE) sent two-person teams to survey, measure, and test 100 new homes in North Carolina and South Carolina. With help from Atlanta's Southface Energy Institute and Chapel Hill's Bill Warren Energy Services, we set out to get a handle on the current state of the building art in our part of the country. Although the results we found didn't make builders look good, we are hopeful that, with the proper education and incentives for builders, buildings could be dramatically improved.

While evaluating a utility energy efficiency program, we randomly selected 50 homes from all new utility connects, and another 50 from among new connects that were participants in utility energy efficiency programs. These houses ranged from 950 to 5,000 ft^2 of conditioned space; the median size was 1,800 ft^2. They were located in all three of our climate regions—coastal plain, piedmont, and mountains. All had been completed within 12 months of the survey.

We measured every house, including walls, floors, ceilings, doors, windows, and overhangs. Our field staff noted the compass orientation and how well each house was shielded from the wind. They recorded model and serial numbers for all HVAC equipment, and, where measuring would not damage the house, the amount and type of insulation. We tested duct and house airtightness with duct pressurization devices and blower doors. Another team checked refrigerant charge, temperature change across the coil, and air flow across the coil on heat pumps in a subset of the houses. Since then, we have run load calculations based on ACCA's *Manual J* on half the houses.

Whole House Airtightness

Clichés such as "Houses are too leaky," and "Houses need to breathe" are chanted like mantras wherever builders are found. Members of the building community generally agree that home airtightness is a major concern, but there is no consensus on what we should be concerned about. It may seem confusing, but we need to be concerned about houses being too leaky *and* too tight. That is, many houses are too leaky for comfort and efficiency, and too tight to ensure indoor air quality (IAQ) without mechanical ventilation.

The five main concerns about tightness are that:

- Air leakage (infiltration/exfiltration) accounts for up to 40% of the heating and cooling bills of most houses.
- Air leakage causes substantial comfort problems.
- Air leakage is responsible for maintenance and durability problems, due to moisture being carried in on air.
- Air leakage causes some indoor air quality (IAQ) problems, due to pollutants being carried in on air.
- Airtightness may reduce indoor air pollutant dilution and cause IAQ and moisture problems.

We performed a standard depressurization test with a blower door to measure whole-house airtightness. Only 1 house out of the 100 had an ACH_{50} of under 5, while 20 houses had an ACH_{50}

Is 3% a Pie in the Sky?

With proper training and motivation, installation contractors can assemble very tight air distribution systems in new construction within the normal production routine.

At Advanced Energy, we train installers on behalf of utilities across the nation. In North Carolina, Carolina Power and Light adopted the standard of a national program called E-Seal. E-Seal won't certify a home if total duct leakage, expressed in ft^3 per minute with the house depressurized to 50 Pascals (CFM_{50}), exceeds 8% of the conditioned floor area. This is the equivalent of 5% tested at 25 Pa.

North Carolina's Duke Power and North Carolina Power have even more stringent programs. They require that total duct leakage in CFM_{25} not exceed 3% of the conditioned floor area. That is, a 1,000 ft^2 house's total duct leakage cannot exceed 30 CFM_{25}.

All of these standards are far below the 20% leakage in CFM_{25} we found in our survey. When reality is so different from a standard, it's reasonable to ask whether the standard is realistic.

Since 1993, NC Power's new construction program has sponsored several training workshops. Led by AE, workshops teach HVAC installers the hows and whys of fabricating airtight air distribution systems. NC Power regularly tests duct airtightness to determine if the ducts meet the standard.

The performance testing contractor, Grady Lassiter, provides additional hands-on time with any crew that doesn't meet the standard, showing them how to find and fix the problems, explaining why it's important, and working to get them excited about doing quality work. He also shows them how to cover and seal the boots, which serves two purposes—it keeps soda cans, half-eaten Big Macs, and other construction debris out of the ducts, and speeds up his testing process in future houses.

During 1993–94, Lassiter tested 171 systems. Forty-nine (29%) had more than 3% leakage, requiring a retest. Sixty-one (36%) had leakage of 1% or less on the first test. Mean leakage was 3% and the range was 0–20%. That is, some contractors actually achieved an airtight duct system and the very worst was equal to the median we found in typical new construction.

In 1995, Lassiter tested 170 systems and found only 6 (3.5%) with more than the 3% standard, and 82 (48%) with 1% leakage or less. The mean was 1.75%, and the range was 0 to 6%.

This clearly demonstrates that the 3% standard is attainable by typical crews who have the proper training, and who carry out the necessary follow-up and performance testing.

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A blower door used for pressure testing is visible in this home from the Advanced Energy study.

of over 10. We calculated CFM_{50}/ft^2 of exposed interior surface area (gross wall, floor, and ceiling area) for the 51 all-electric homes. This looks more directly at leakage in relation to potential leakage area and takes the volume of the house into account. These homes had a median 0.44 CFM_{50}/ft^2 of surface area. The tightest was 0.19 CFM_{50}/ft^2, while the loosest was 1.46 CFM_{50}/ft^2.

AE has developed targets for airtightness and duct leakage. We arrived at these targets after several years of consulting with builders, architects, engineers, and building scientists to determine an optimum airtightness standard for North Carolina. We then spent several more years working with builders, getting actual cost data, and assessing what could be achieved in the field. Our philosophy has been to move the industry forward, but never to advocate practices or standards that are not realistically achievable. Our current target calls for total leakage under 0.30 CFM_{50}/ft^2 of surface area, and duct leakage, in CFM_{25}, of less than 3% of conditioned floor area in ft^2 (see "Is 3% a Pie in the Sky?").

Only 3 houses out of 51 (6%) met our whole-house air sealing target. The median house was about 50% leakier than our recommended rate. Based on this sample, it is safe to say that typical new houses in the Carolinas have a long way to go before we would consider them tight enough with respect to energy efficiency, comfort, and IAQ.

On the other hand, they may be too tight to count on natural ventilation. ASHRAE recommends that homes with estimated natural infiltration rates of less than 0.35 ACH should have mechanical ventilation. Nineteen out of 100 houses—nearly 20%—fell into this range. Our methodology for estimating natural infiltration, however, may have overestimated infiltration. Tracer gas testing of 23 homes indicated that a much higher percentage are below 0.35 ACH. If this outcome is supported by more extensive testing, it would suggest that substantially more houses may need mechanical ventilation. Only one of the 100 houses had a whole-house ventilation system.

In our part of the country, even houses with estimated 0.35 ACH or higher may not get adequate natural fresh air during much of the year. Actual air leakage depends upon driving forces, such as wind, so there can be significant periods when even a very leaky home does not get enough fresh-air ventilation for occupant health or moisture control.

Thus ventilation often depends on the bathroom fan—a bath fan was present in all of the houses we visited. Typical bath fans make noise, and they may or may not move air out of the house.

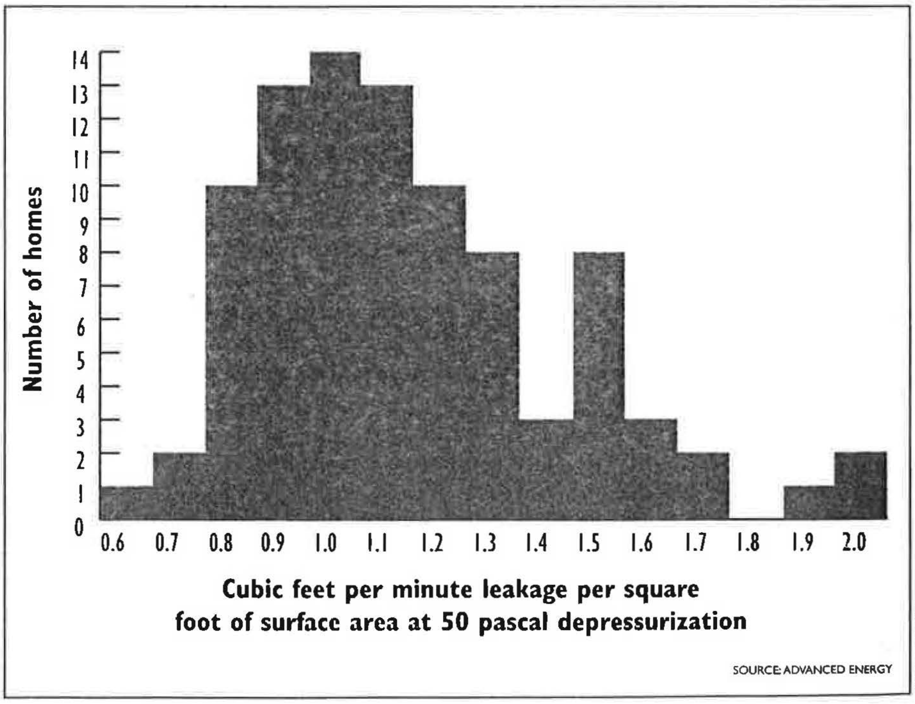


Figure 1. Distribution of homes at different leakage rates, as determined from blower door tests.

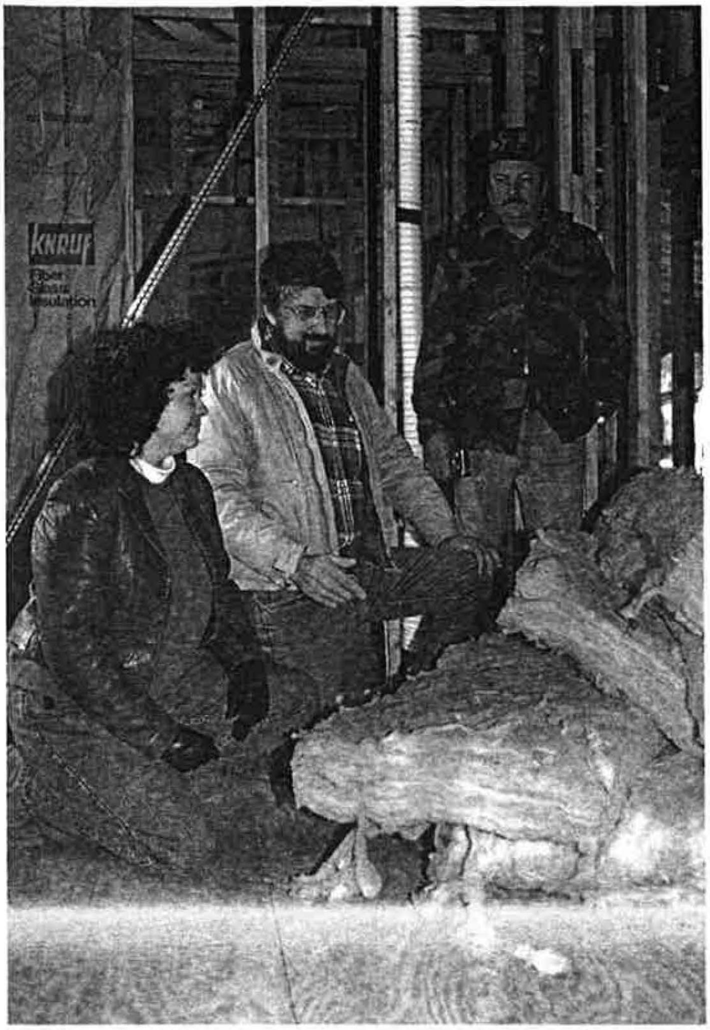
Most of the fans in the study were actually vented to the outside, but several simply terminated in the attic, breaking code and risking moisture problems, but saving construction time and cost. Among those which did vent to the outside, circuitous duct paths guaranteed reduced air flow.

Duct System Airtightness

Our duct airtightness tests showed that duct installation was very poor; new home builders are apparently ensuring that there will always be duct repair customers in the future. Studies we have done in North Carolina, along with studies by Natural Florida Retrofit in Florida, Proctor Engineering Group in California, and Ecotope in the Pacific Northwest, have demonstrated that, on average, duct leakage accounts for 15%–25% of heating and cooling costs in homes with forced-air systems. In addition, duct leakage has been shown to be responsible for comfort problems, combustion safety problems, IAQ problems, and moisture problems.

We came upon several instances of catastrophic duct failure—ducts that were totally disconnected. We found this condition in both attics and crawlspaces. In one case, a homeowner told us she had complained about lack of heating and cooling to the master bedroom for nearly a year. Each time she called the contractor sent someone out, found no problems, and determined that the system was working fine.

While checking crawlspace insulation, we found a supply duct lying on the ground under the master bedroom. The bedroom was in the far corner of the house, far from the crawlspace access door. With major ductwork between the access door and the dead duct, the only way to find the disconnection was to slither on the ground like a snake, with barely enough clearance to get under the main trunk line. As every energy auditor knows, these are usually the places where trouble is found.



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Arnie Katz of Advanced Energy (center) and two members of the North Carolina Housing Finance Agency examine insulation they are using in a new home construction project for Habitat for Humanity.

In another house, we found a 50-ft run of 8-inch flex duct. It started at the air handler in one attic, wound under a window seat into another attic, and stopped, wide open, directly under a gable end vent. The decision not to condition the walk-in closet under the duct termination was never translated into removing the duct. While it certainly created one of the most comfortable attics I've ever been in, this wasn't helping the homeowner's energy bill. On the other hand, adding the attic and, indeed, the entire outside world, to the load of the house probably brought the equipment size closer to the actual load, given the oversizing we found.

In general, we found duct installation that fell short of local utility standards. Installers still don't seal duct systems. When they do seal, it is too often with substandard duct tape. Though mastic is appearing more and more, it is still the exception rather than the rule.

Our survey measured total leakage on 130 duct systems in 96 houses. The median measured duct leakage was 261 CFM_{25} per system and 360 CFM_{25} per house total. Expressed as a percentage of conditioned floor area, systems had a median leakage of 19.5%, ranging from 4% to 79%. This compared poorly with our standard, and with the standard set by E-Seal, a national energy efficiency program sponsored by the Edison Electric Institute. No systems met our standard of 3%, and only three met the E-Seal standard of 5%. Thirteen systems had more than 30% leakage. The median leakage is over six times the Duke Power and NC Power standard, and almost four times the E-Seal standard. Duct leakage is clearly still a major problem in new homes.

Insulation

Our survey included a visual inspection of the attic insulation. We noted the type of material installed and measured its depth in several places in the attic. The R-value of the material was recorded from the contractor's certificate, if available, or from standard insulation charts. The inspectors then estimated the average attic R-value, taking into account significant voids or other problems.

When these homes were built, the North Carolina Building Code required R-30 attics. Based on our admittedly rough methodology, we estimate that 23% of the homes have attic insulation levels clearly below R-30. Based on other recent studies, it's quite possible that had we done more extensive testing, such as cookie cutter tests (see "A Plan to Stop Fluffing and Cheating in Attic Insulation" *HE*, May/June '96, p. 10), we would have found even more homes with attic insulation below R-30. One house was insulated only by a 2-inch dusting of loose-fill insulation over about a quarter of the ceiling.

We also noted the nominal R-value of floor insulation above crawlspaces or basements, but we didn't try to quantify actual R-values. While all the houses had the code-mandated R-19 insulation installed, the field staff frequently mentioned that the effective R-value was compromised by poor to mediocre installation. Typically installed with tiger teeth supports, the insulation was usually highly compressed in the middle and had gaps along the joists. It was stuffed behind pipes, wires, cross-bridging, and other framing members, and in some cases was already falling down at the time of our survey.

The other oft-noted problem was a lack of solid sheathing material on the attic side of kneewalls. We recommend sheathing to keep 140°F attic air from circulating through the insulation. In several cases, we noted kneewall insulation that had already fallen out of the cavities.

Heat Pump/Air Conditioner Charge

Improper refrigerant charge in heat pumps and air conditioners is a major concern (see "Sizing Air Conditioners: If Bigger Is Not Better, What Is?" *HE* Sept/Oct '96, p. 13). Either over- or under-charging a system decreases its efficiency and capacity, and can lead to maintenance and durability problems.

We measured the charge in 22 systems in 13 homes. Of these 22 systems, 14 were overcharged, 5 were undercharged, and only 3 were correctly charged.

Heat Pump and Central Air Conditioner Sizing

HVAC contractors clearly still believe that bigger is better. Considering the duct leakage and the overcharging found in the survey, oversizing may in fact be necessary to maintain comfortable cooling levels. But the price for the homeowner is high.

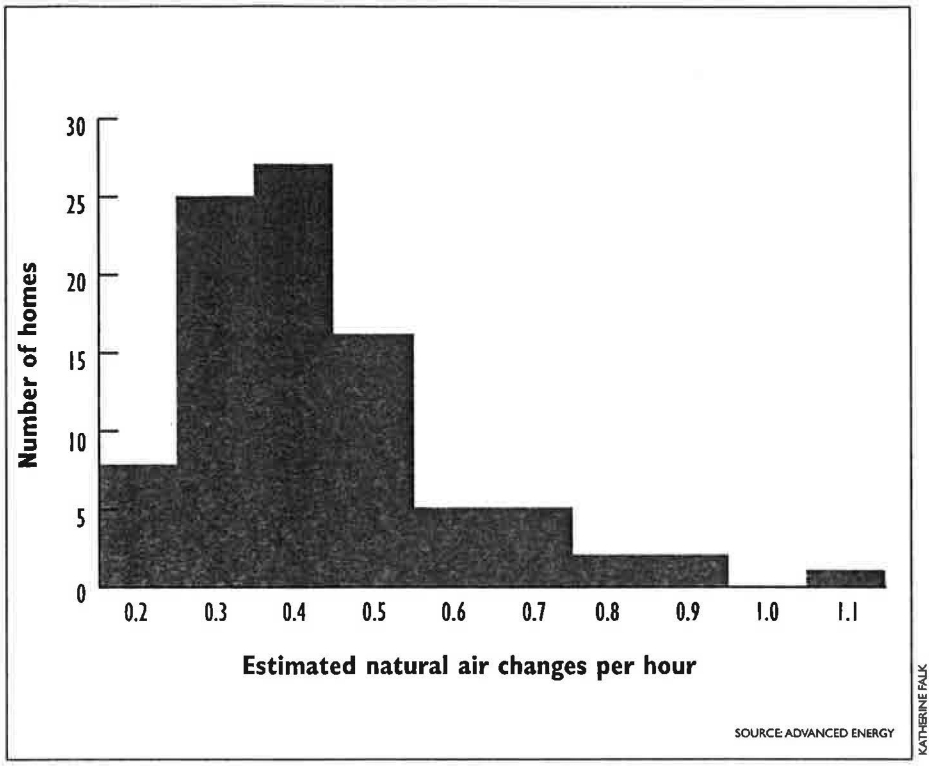

Figure 2. Distribution of homes at different natural air change rates, converted from blower door leakage data.

We ran load calculations on 50 houses (59 systems) with heat pumps using Elite Software's RHVAC program. The program calculates loads based on *Manual J*. The recommended practice down here in the mold belt of the United States is to size heat pumps based on the cooling load and make up any difference in the heating load with electric resistance strip heaters.

We compared the *Manual J* cooling load with the actual cooling capacity of

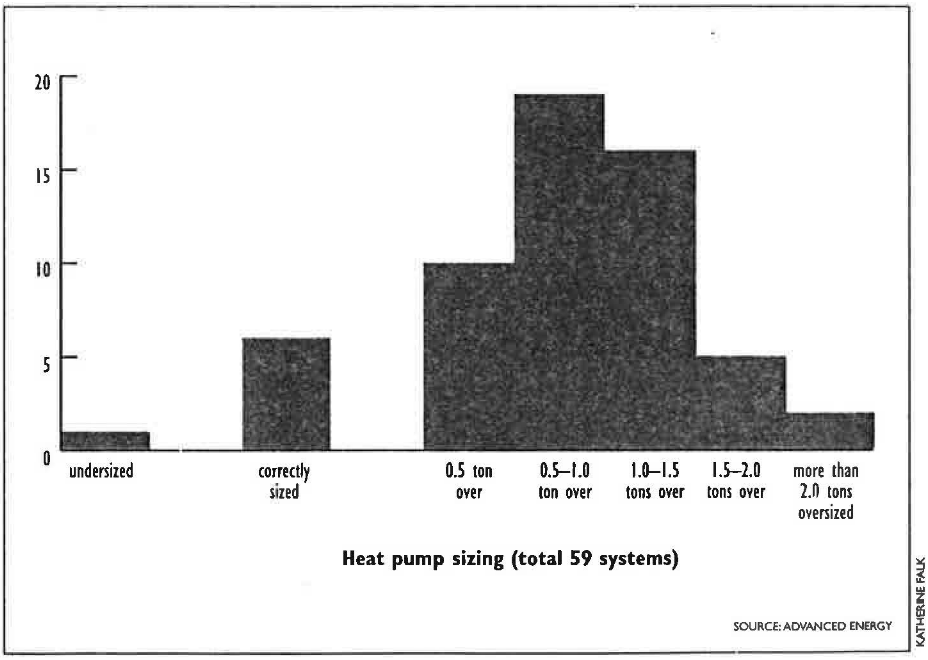

Figure 3. Distribution of homes with undersized, correctly sized, and oversized heat pumps.

the unit installed in each house and used ACCA *Manual S* to determine proper sizing guidelines. Specifically, *Manual S* says, "If heat pump equipment (air-source or water-source) is installed in a warm climate or moderate climate, the total cooling capacity should not exceed the total cooling load by more than 15 percent."

Unfortunately, out of 59 heat pumps, only 6 lived up to this standard. One was undersized. The remaining 52 units, or 88% of the heat pumps, were oversized. Median oversizing was 0.81 tons, with the most oversized unit rated to provide an extra 2.3 tons of cooling. Oversized air conditioning equipment tends to be noisy and suffers from short-cycling. Short-cycling can cause moisture buildup and a major loss of efficiency (see "Bigger Is Not Better: Sizing Air Conditioners Properly," *HE* May/June '95, p.19).

Duct hunting season.

Bathrooms

We also noted particular problem areas. One was the prevalence of huge, totally unsealed holes under bathtubs. Our field staff also repeatedly commented on home buyers' apparent desire for bathrooms big enough to entertain half the neighborhood. We made no effort, however, to correlate bathroom size with whole house air leakage. We also decided not to speculate about why builders or plumbers like to leave large holes right where people are often standing wet and naked.

What Is to Be Done?

Field measurements and observations in 100 new homes in North and South Carolina identified serious problems that typically lead to substantial increases in energy usage. These problems also affect maintenance, durability, comfort, and indoor air quality.

Each of these problems can be substantially improved or eliminated at relatively modest cost, using proven techniques and equipment. This is not, after all, rocket science. It's simply building science.

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