Building Science Reality Check —Survey of 100 Homes

by Arnie Katz

The same old problems seem to continually show up in new home construction: namely leaky ducts, bad insulation jobs, oversized and undercharged heating and cooling systems, inadequate ventilation, and poor air sealing. These problems have a serious impact on the comfort, safety, durability, and energy efficiency of a home. Every home could and should be built to meet established performance guidelines. But as a recent survey has shown, this is seldom the case.

While a number of study models are available to show what is possible in new home construction, no comprehensive data existed to show how well new homes actually compare in performance testing. So in 1994, Advanced Energy (AE) teamed up with Southface Energy Institute (Atlanta, GA) and Bill Warren Energy Services (Chapel Hill, NC) to survey, measure, and test the energy performance of 100 new homes in North Carolina and South Carolina.

The results of the testing weren't exactly glowing: 88% of all heat pumps checked were grossly oversized. In most instances, insulation in the walls and ceilings was poorly installed, with many gaps, voids, and compressions in evidence. The saddest part of the tale, though, was that 100% of the homes tested failed to meet AE's duct leakage standard, and only 3% met the E-Seal leakage standard. All of these represent serious problems that substantially increase energy costs, and can significantly degrade the durability, comfort, and indoor air quality of the home.

Testing Shows the Truth

The project team randomly selected 100 homes for the survey: 50 homes from among all new utility connects, and 50 news connections participating in utility energy-efficiency programs. The homes ranged from 950 ft2 to 5,000 ft2 of conditioned space, with a median size of 1,800 ft2. The houses were located in all three of the Carolina climate regions – coastal plains, the Piedmont, and the mountains. All homes had been newly-completed within 12 months of the survey.

The survey teams measured all dimensions of the homes, including the walls, floors, ceilings, doors, windows, and overhangs. They noted the compass orientation of each home, along with information on how well each house was shielded from the wind. The model and serial number for all HVAC equipment was recorded. Where possible, notes were taken on the amount and type of insulation used in all assemblies, along with the condition of installation. The teams used duct pressurization devices and blower doors to check for airtightness of the homes and their duct systems. They also checked a subset of homes for heat pump condition, looking at refrigerant charge, size, and air flow/temperature change across the coils. After all the data was compiled, load calculations were run for most of the homes based on ACGVs Manual J.

Home Airtightness

To the builders' credit, the information available can be confusing at times. Everyone agrees that home airtightness is a major concern, but few people know or agree on exactly what that means. What many don't understand is that builders must be concerned about houses being both too leaky and too tight. That is, some houses are too leaky for adequate comfort and efficiency, and too tight to ensure indoor air quality (IAQ) without mechanical ventilation.

Problems with leakage and airtightness can affect a home in at least five (5) different ways:

Losses

Losses due to air leakage – both into (infiltration) and out of (exfiltration) the home – account for up to 40% of the heating and cooling bills of most homes.

Comfort Levels

Air leakage has a significant negative impact on comfort levels within the home, causing drafts, cold spots, and other complaints.

Moisture

Moisture vapor may be carried into or through a home along air currents. Excess moisture in the home leads to

mold and mildew growth. Moisture trapped in the framing assemblies can also cause wood rot, and other maintenance and durability problems.

Contaminants

Air leaks can carry pollution, pollen, and other contaminants into the home.

Indoor Air Quality

Homes that are too tight, without enough ventilation, can prevent pollution trapped inside the home from becoming safely exhausted or diluted.

Survey Results

The survey teams performed standard depressurization tests, using a blower door to measure the airtightness of each entire house. Only one house out of the one hundred tested showed a CFM50 of less than 5% (the E-Seal standard), while twenty other houses had a CFM50 greater than 10%.

Leakage per square foot of exposed interior surface (CFM50/ft2) was also calculated for each of the 51 all-electric homes in the survey. This figure examines leakage as a function of potential leakage area, and takes into account the volume of the homes. In short, it allows a more direct comparison in the leakage rate found in small houses versus larger houses.

Figure 1 shows the distribution of leakage rates per number of homes surveyed. The lowest leakage rates found during the survey was 0.19 CFM50/ft2, while the highest leakage rate was 1.46 CFM50/ft2, with a median value of 0.44 CFM50/ft2. Advanced Energy advocates a total leakage target of 0.30 CFM50/ft2. Only 3 out of 51 (or 6%) of the houses tested met the whole-house air sealing target. Even the median house was roughly 50% leakier than the recommended rate.

New Standard

Advanced Energy (AE) worked with builders, architects, engineers, and building scientists to determine an optimum airtightness standard for homes built in North Carolina. They then spent several more years talking with builders to determine additional construction and material costs, and assessing what could realistically be achieved in the field. AE's philosophy has always been to move the industry forward towards better home performance, without advocating practices or standards that are not realistic.

All of the three utilities in North Carolina now specify certain standards for acceptable duct leakage in new homes. Carolina Power and Light adopted the standards of the national E-Seal program. To be awarded E-Seal approval, a home must show less than 8% leakage in cubic feet per minute when tested at 50 Pascals (CFM50). This is the equivalent of 5% tested at 25 Pa. Duke Power and North Carolina Power both have even more stringent standards. They both require that total duct leakage (in cubic feet per minute) with the house depressurized to 25 Pascals (CFM25) must not exceed 3% of the conditioned floor area. This means that total duct leakage in a 1,000 ft2 home must be less than 30 CFM25.

Duct Leakage

Survey Results

The survey measured total leakage on 130 duct systems in 96 houses. The median measured duct leakage was 261 CFM25 per system and 360 CFM25 per house total. Expressed as a percentage of conditioned floor area, the duct system leakage ranged from 4% to an astonishing 79%, with a median leakage of 19.5%.

Of all duct systems tested, not a single one met the AE recommended standard of 3%, while only three systems met the E-Seal standard of 5% leakage. Thirteen systems showed more than 30% leakage, with the median leakage rate reading over six times the Duke Power and NC Power standard, and almost four times the E-Seal standard. From these results, it's obvious that duct leakage is still a very major problem in new home construction.

Field Findings

Duct leakage tests conducted during the survey indicated that, in general, ductwork is installed very poorly in most houses. Survey teams found several instances of catastrophic duct failure — ducts that were completely disconnected in the attic or crawlspace.

In one home, the homeowner mentioned that she had complained about a lack of heating and cooling to the master bedroom for nearly a year. Each time she called the builder, the service contractor found no problems with the system, and determined that the system was working as designed. While checking levels of crawlspace insulation, the survey team found the supply duct to the master bedroom lying loose on the ground. Since the bedroom was located in the far corner of the house, far from the crawlspace access door, the only way to find the disconnected duct was to slither like a snake beneath the rest of the ductwork. As every energy auditor knows, inaccessible spaces like these are usually where trouble the is found. The contractors sent out to diagnose the problem simply weren't willing to work that hard.

In another house, the team found an incredibly long 50-foot run of 8" flex duct. The duct started at the air handler

in one attic, wound under a window seat into another attic, then ended directly under a gable end vent. The original design seemed to be to condition the walk-in closet located beneath the duct. But whoever chose not to connect the duct simply left the end wide open, wasting a great deal of conditioned air to create an extremely comfortable attic!

In most cases, the survey teams found that duct installation fell far short of local utility standards. For some reason, installers still seem extremely resistant to the idea of sealing duct systems. Even when duct sealing is performed, it's usually done with substandard duct tape. While duct mastic (the preferred method) is readily available, its use is still the exception rather than the rule.

Ventilation

While most concern is focused on home airtightness, proper ventilation of the home is often overlooked. And in terms of indoor air quality and pollution control, ventilation may be even more important.

In many homes, the only mechanical ventilation installed is the lowly bathroom fan. While most the the bathroom fans examined in the study were actually vented to the outside, several simply terminated in the attic, breaking code requirements and risking moisture problems. And even those installed correctly often had winding duct paths, ensuring reduced air flow. These fans are seldom used for extended periods due to their high noise level, and are completely inadequate for ensuring proper ventilation to an entire house. Only one of the one hundred houses included in the survey was equipped with a whole-house ventilation system.

Many new homes today are built too tight to rely on natural ventilation, but fail to include adequate mechanical ventilation. ASHRAE recommends that homes with estimated natural infiltration rates of less than 0.35 ACH should have mechanical ventilation. Nineteen out of the one hundred houses surveyed – nearly 20% – were estimated to fall within this range. However, tracer gas testing suggested that a substantially higher number of the houses actually experienced natural ventilation well below the recommended level of 0.35 ACH.

In the Southeast, even houses with natural ventilation rates of 0.35 ACH or higher may not receive adequate fresh air during much of the year. Actual air leakage into a home depends greatly upon the driving force (wind), which can vary greatly throughout the year. This means that even a relatively leaky home may not always receive enough fresh-air ventilation.