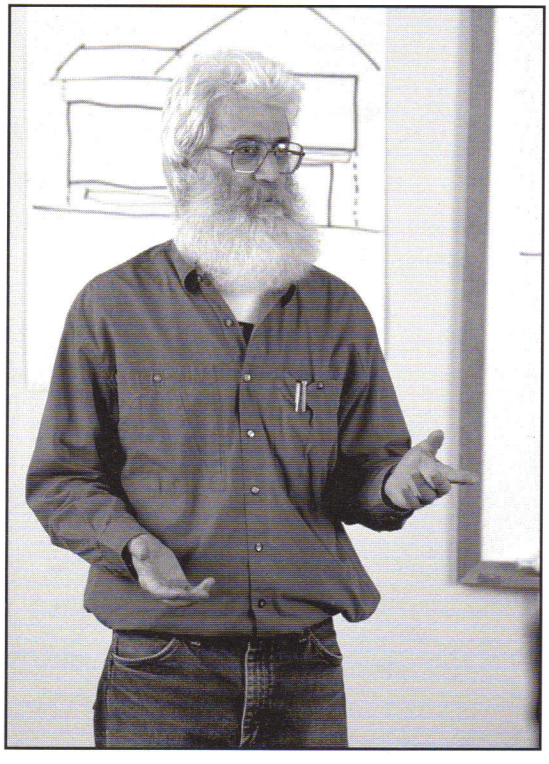
Advanced ENERGY

Transforming energy into productivity

The house that Bruce built

Would you like to build a house the way a building scientist did his own?

Bruce Davis is a building science specialist with Advanced Energy's Building Science Center. Before joining Advanced Energy in 1992, Bruce was one of the first people to investigate the impact and extent of duct leakage in typical homes. Since then, Bruce has helped to create Advanced Energy's Duct School. He currently spends most of his time diagnosing houses and commercial buildings that have failed, and teaching builders how to construct buildings and install HVAC systems right the first time.



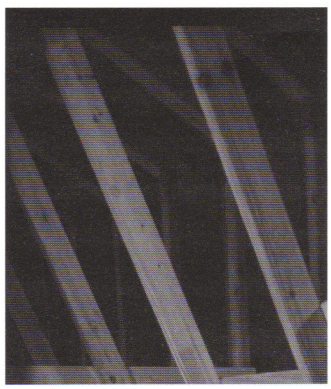
In 1996, Bruce decided to have a new home built for himself and his family, giving him an opportunity to practice what he teaches.

Here is his story...

There are several common features that most people want in a house, regardless of the price or size. They want a home that is warm in winter, and cool and dry in summer. They want a house that isn't stuffy, but is filled with fresh, clean breathable air. They want a house that is free of odors, harmful pollutants, mold, mildew, and allergens. And they want a house that is economical to operate.

Certainly, there are many ways of retrofitting an existing home to meet these goals. But the easiest, most economical, and most thorough method is to consider all of these factors during the actual construction of the home. In home construction, "Do it right the first time!" is more than just an inspirational slogan; it's a directive for building a safe, comfortable home that meets all your needs.

As a building science specialist for Advanced Energy, Bruce Davis advises home builders, HVAC contractors, and other shelter industry partners on topics such as occupant health and comfort, combustion safety, building and equipment durability, and energy efficiency. It was natural, then, that when Bruce had his own home built, he would thoroughly consider each of these areas and plan his new home to meet his family's needs. Not only did his family want a safe, comfortable, economical home, but they also needed to address their daughter's allergies and chemical sensitivities.



Before construction on their new home even began, Bruce and his family made simple but important decisions concerning the following areas:

- siting
- foundation
- framing
- insulation
- exterior surfaces
- heating and cooling
- filtration
- ventilation

As Bruce put it: "My wife knew that we were moving into a lab experiment, but none of us have any regrets. Even though our house is a fairly ordinary home, it has no drafts, excessive humidity, high energy bills, odors, noises, or hot and cold spots. Instead what we have is an extremely energy-efficient and comfortable home."

"I felt a little like Thoreau," Bruce continued, "who said he went into the woods because he wanted to live simply, study the essential facts of life, and see if he could learn what it had to teach. I wanted to build this house according to the simplest and best building science techniques and see if, indeed, what I teach is true."

This bulletin examines the choices that the Davis family made for their new home and explains why these choices were so important. It also includes additional information on indoor pollution and prevention. Bruce hopes that his experiences will help you or your customers achieve what he and his family have built for themselves.

Construction tips from the ground up

One of Bruce's first steps was site orientation and solar-tempering considerations. The house was oriented to face south for winter solar gain through the windows. To reduce summer solar gain, the house has only one window each on the east and west ends of the house. For summer shading, the south-facing windows were selected and

installed for appropriate height and position to take advantage of the limited roof overhang.

Next Bruce created a simple design, without complex gables, transitional ceilings, or unusual room layout. "Since I couldn't be present during construction," Bruce explains, "this design allowed the framers to take a straightforward approach to the job, leaving less chance for gaps, ill-fitting members, and other mistakes." All exterior surfaces of the home were covered to protect them from the elements, with shingles on the roof, vinyl siding on the walls, and a combination of aluminum and vinyl parts for details, facia and soffits.

Using a simple design also allowed the home to be built with a continuous air barrier and insulation layer, effectively separating the interior of the house from the outside environment. The home was insulated with R30 material for the ceiling, R19 for the walls, and R22 in the floors. With the air barrier and insulation layer materials installed adjacent to each other, there is less chance of air or moisture infiltration, to maximize the effectiveness of both systems. The windows and doors, while very functional and durable, are rather ordinary compared to many of the high-technology units currently advertised. The windows have separated metal frames and plain glass, and the doors are foam core steel with plain glass sandwiches.

Since it is much easier to prevent unwanted moisture from entering a house in the first place than to remove it later, proper site preparation and drainage act as the home's front line against moisture problems. Bruce's homesite was graded to direct all groundwater flow away from the home's foundation. To promote durability and avoid moisture problems, the crawlspace was closed in, and vapor-retarding plastic sheeting covers the crawlspace floor completely. To ensure maximum coverage of the crawlspace, Bruce placed plastic sheeting under the footers for the piers and sealed this sheeting to the rest of the groundcover. This last step prevents moisture from wicking up through the concrete.

The air in a typical modern home *can contain literally hundreds of pollutants, both natural (like pollen, radon, and dust mites) and man-made, which include chemicals used in building materials (like plywood and insulation), home furnishings (carpeting, draperies, and furniture upholstery), cleaning supplies, pesticides, adhesives, paint, and other products normally found in the home. These contaminants can be made of tiny particulates, or they can be gaseous VOCs (volatile organic compounds) which gradually escape into the air. While none of these contaminants may have an immediate effect upon the home's occupants, many have been proven to cause headaches, lethargy, sinus congestion, allergies, depression, and even immune-system damage. Some people, particularly children, the elderly and sick, and pregnant women, can be particularly vulnerable to the effects of indoor pollutants. And even otherwise healthy people can develop a condition known as environmental hypersensitivity, which causes them to react severely to even the slightest amounts of VOCs and other contaminants.*

John Bower, an advocate of healthy house designs, *states that indoor air is often 5 to 10 times more polluted than the air outside. The bad news is that this situation (often called "Sick Building Syndrome") has become a more common occurrence with the advent of modern building materials and furnishings, as well as tighter building construction. The good news is that there are several steps homeowners can take to improve air quality: eliminating pollutants from the home, filtering contaminants from the inside air, and providing adequate ventilation.*

Sizing the heat pump

When a home fails to maintain its cool, homeowners often blame an undersized air conditioning system. But *undersizing* of the system is rarely the cause. An air conditioning system provides two important functions: cooling and dehumidification. Since the dehumidification is a function of air conditioner run time, the longer a system operates, the more moisture it can remove. But since the thermostat is triggered only by air temperature, an *oversized* air conditioner will cool the air down quickly without operating long enough to remove a sufficient amount of moisture from the air. This results in the home being filled with cool, humid air — not unlike the air in a cave. A/C systems must therefore be sized properly, taking into consideration the size of the home, its location, insulation levels, the amount of glass and the air leakage present.

In selecting an adequately-sized heat pump, Bruce began with an accurate room-by-room load calculation. The heat pump system was then chosen to meet both the temperature and humidity demands calculated for the house. Using these calculations, the 1800 square foot home required only a $1\frac{1}{2}$ ton heat pump. As Bruce explained: "Many houses built today with the same heating and cooling load would have had a 3-ton system installed. In our case, following the industry standard would not only have brought higher equipment and operational costs, but would have given us a system that couldn't dehumidify the indoor air as well as our smaller unit does."

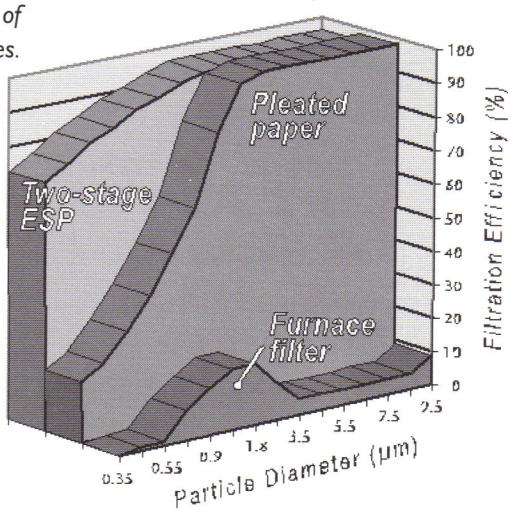
The heat pump at the Davis home is controlled with an ordinary mercury bulb thermostat, rather than an expensive programmable unit. Since the heating and cooling system is so well-matched to the house, Bruce says, "We just set it and forget it." Their house stays at a comfortable temperature, and the system rarely has to rely on the back-up heat strips inside the heat pump for supplemental heat. In fact, their heat pump is equipped with an outdoor thermostat that actually prevents operation of the heat strips unless the outdoor air temperature drops below 27°F. Except during extremely cold periods (which are fairly rare in the southeast where Bruce lives), the heat pump compressor is more than adequate to keep the Davis house warm and comfortable. As an added bonus, the scroll-type compressor that Bruce selected is extremely quiet and cannot be heard from inside the house.

Sharing the air

Research has shown that up to 15% of the conditioned air produced at the air handler *may never reach the living space*, due to duct leakage, kinked ductwork, blocked supply registers, or other airflow restrictions or leakage. A damaged, leaky, or poorly-installed duct system can defeat even the best set-up and properly-sized cooling system.

Being aware of these possibilities, Bruce ensured that the duct system was properly designed for his house and installed to be airtight. After installation, the system was pressure tested to confirm that it did not leak. The total system airflow was measured and properly set. The heat pump's refrigerant charge was properly calculated, measured, and installed. The airflow to each room was measured and balanced. Return airflow paths from each room

Figure 1: Comparing efficiencies of three filter types.



back to the central return were provided by cuts under doors, and an extra return register was installed in the master bedroom. These return paths allow free airflow throughout the house, reducing pressure behind closed doors and eliminating temperature differences from room to room. Bruce brags: "This duct system design is so efficient and effective that we can't tell from the sound whether the heat pump is on or off."

During construction, to ensure that the ducts would not become filled with construction debris (which his family would later be breathing), Bruce took the precaution of sealing each duct boot with a large piece of cardboard and duct mastic. These plugs remained in place until after the duct leakage tests were performed and were then removed.

Choosing air filters

All forced-air, central heating or cooling systems use some type of filter. However, most homeowners are unaware that the standard, 69-cent, fiber-mesh furnace filter is designed only to protect the furnace or heat pump, not to protect people's lungs. Testing has shown that these filters remove less than 20% of all particulates (see Figure 1) and are almost completely useless for removing the smaller airborne contaminants like smoke, dust, bacteria and viruses. It may seem strange, but these inexpensive filters actually perform slightly better once loaded with dust, though the accompanying pressure load places additional strain and wear on the HVAC system. Fortunately, there are several more effective alternatives to the traditional fiberglass filter.

Bruce's choice for filtering was to use 2-inch paper-media pleated filters in each return grille, which offer a tremendous increase in filtering ability for the price of a few dollars. He also installed a special six-inch pleated filter at the heat pump air handler in the crawlspace. These filters have pores small enough to trap 65% to 90% of most pollen, mold spores, animal dander and hair, and even do a good job of removing airborne fibers, skin flakes, and some bacteria. Their pleated design yields greater surface area than a flat filter, allowing less resistance to airflow and a longer useful life. Like fiberglass filters, these are more efficient after being loaded with dust. Recent studies seem to indicate that such pleated paper-media filters provide the best overall efficiency for removing a wide range of particulates at a reasonable price.

An even more efficient filter system is an electrostatic precipitator (ESP), which uses a high-voltage field to place a charge on airborne particulates, then attracts the particulates to electrically-charged plates or wires. Though ESPs are expensive, they work well and remove even very fine contaminants. Besides the higher cost, the main drawback of these filter is that they require frequent cleaning to maintain their efficiency. Bruce believes he gets the same effectiveness with the lower-cost and lower maintenance filters he selected.

Breathing fresh air

Proper ventilation also helps to rid a

home's indoor air of contaminants. However, it provides an even more important function that no amount of filtering can replace: it brings a supply of fresh oxygen into the home. In the race to build tight, efficient houses, many home designers fail to allow for adequate ventilation, leaving the air inside stuffy and full of pollutants.

To ensure proper ventilation of his home, Bruce installed a balanced mechanical ventilation system that provides filtered outdoor air to each room in the house, continually removing stale, contaminated air at the same rate. It operates 24 hours a day, helping remove pollutants that are released from construction materials, household chemicals, and the like. The ventilation system Bruce installed is called an energy recovery ventilator (ERV). This type of ventilator is designed to strip out much of the moisture and heat from the incoming air during the summer and transfer it to the exhaust air, thus reducing the added load on the conditioning system. During the winter, the ERV retains much of the moisture and heat that would otherwise be exhausted with the stale, outgoing air. With their balanced ventilation system in operation, Bruce says: "We breathe fresh, outdoor air all year long. We avoid the unpleasant and often health damaging 'new house smells' that come from outgassing chemicals."

Another simple step that Bruce took to improve ventilation was to be sure that the standard exhaust fans in both bathrooms and the exhaust hood over the kitchen range were all properly ducted to the outside. Since these rooms are the most common sites for cleaning products use, mold and mildew growth, and excess water vapor, adequately ventilating these areas has a very positive effect on air quality in the home.

Reducing heat and combustion sources

Certain interior sources of heat — stoves, water heaters, and lights — are unavoidable. Bruce took steps to reduce their impact on the cooling load of the home. Fluorescent lights burn much cooler than traditional incandescent bulbs. Covering the hot water heater with an insulating blanket reduces the amount of waste heat radiated to the home and the energy needed to maintain water temperature, providing a double savings.

An improperly-vented clothes dryer can dump enormous amounts of waste heat and moisture into the home. Bruce ensured that his home's dryer was properly vented to the outside. Dryer ductwork should be inspected occasionally (particularly after the appliance has been moved) to ensure that proper sealing is still maintained and that no damage has occurred to the dryer vent or connections.

To avoid the pollution and safety issues surrounding combustion appliances, Bruce chose an all-electric heating and cooking design. This eliminates any combustion by-products (soot and carbon monoxide) from the air, and greatly reduces associated fire hazards.

Preventing indoor pollution

To address the problem of his daughter's allergies, Bruce made several decisions concerning construction materials and furnishings. By installing vinyl flooring rather than carpeting throughout the house, a major source of outgassing chemicals was eliminated along with a habitat for dust mites and molds and a collection site for pollen and normal house dust. The vinyl flooring facilitates cleaning, as would have the more expensive options of pine or hard-

wood floors. None of the Davises smoke, and their dog lives outside in a solar-heated (and summer-shaded) dog house.

The improved filtration system helps clean the air of particulates, keeping allergen concentrations lower. As well, the 24-hour ventilation system removes volatile organic compounds and other natural and man-made pollutants from the indoor environment. It fills the home with clean, filtered outdoor air. Since the home's heat pump is sized correctly and removes excess internal humidity, the indoor air has the right moisture content for human health, while discouraging mold and dust mite growth.

To eliminate particulates in his family's water system, Bruce installed a pair of 5-micron sediment water filters (in tandem) in an accessible location under the house, between the water source and the pressure tank. The filter housing incorporates a quick shut off and pressure relief valve. Since this system filters *all* of the water supplied to the home, it not only improves the quality of the drinking water, but reduces the potential of sediment blockage in the washing machine, dishwasher, faucets and shower heads. It also reduces the amount of sediment build-up in the water heater, potentially lengthening its life.

Figuring the cost of comfort

To assist with his "optimized home data collection," Bruce installed several submeters in his house to monitor the amount of electricity used by various systems. He participates in a local utility company program that charges different rates for on-peak and off-peak electricity use (on-peak being certain morning and evening hours, and off-peak, all other hours plus holidays and weekends). The only two modifications that Bruce's family made to their electricity usage was to install a timer on their water heater and to limit the use of their clothes dryer to off-peak hours.

For a family of four (including two active teenagers), the total electric use for the Davis household in their first year was 16,311 kWh. Of that, a subtotal of 7666 kWh was used for all the heating, cooling and ventilating loads, with 1157kWh of that being used by the two motors of the ERV. By comparison, the upright freezer used a total of 989 kWh. At 0.055 cents per kWh, the family paid an average of only $2.46 per day to maintain a clean, comfortable home, along with all their modern electrical conveniences. Broken down, it costs $1.16 per day for space conditioning (heating, cooling, ventilation and filtration) and $1.30 per day for all other energy uses (including water heating). It should be noted that the Davis family did not alter their electric usage or lifestyle in any way. They didn't lower their thermostat at night, leave rooms unheated, reduce their lighting or television use, or make any sacrifices. They just made smart decisions while building their home.

Continuing the lab experiment

"I wanted to build a plain house and see how it would perform. Performance can only be measured by testing," said Bruce. "The usual performance tests are completed: blower door for house leakage, duct tester for duct leakage, fan and door driven building pressures. However, I am now measuring overnight and week-long temperatures, pressures, carbon dioxide levels, energy ventilator recovery performance and air flow, energy consumption, sound, comfort, durability, crawlspace moisture behavior, and all the rest.

There are endless questions to ask. This house has continuing stories to tell and per-

formance physics to teach me. I have a self-financed, finished house as my lab!"

Bruce expects to use the information to confirm, as first-hand experience, what he has known as data. He will have the chance to understand things that he never before was able to explore in depth. "What I learn here I can teach to many others," he concludes.

"I bought what I taught"

Bruce says, "We love our new home; it's the most comfortable house we've ever lived in or visited. We don't suffer from excess noise, obnoxious and unhealthy odors, hot or cold spots, unwelcome drafts, excessive humidity, high energy bills, or strict energy-use restrictions. We simply relax and enjoy a healthy, comfortable home. Our house is so comfortable that we've gotten a bit spoiled. We're often surprised when we visit a friend or relative's home, and notice all the *dis*comforts that our own home no longer contains."

The choices made by Bruce's family are not the only options; several solutions exist for each issue, whether a choice of ventilation systems, construction design, or flooring. The most important action is to extensively investigate each of these and any other issues that may be meaningful to your family before buying, building, or remodeling your next home. Even ordinary, commonly-designed homes can be extremely comfortable and energy efficient. Because Bruce avoided the big mistakes and included the most important choices, his house is living up to its full potential.

"We love our new home; it's the most comfortable house we've ever lived in or visited."

An independent nonprofit organization, Advanced Energy helps residential, commercial and industrial customers improve the return on their energy investment. With expertise in applied building science, industrial process technologies, and motors and drives, Advanced Energy provides solutions through testing, training, and consulting. Through its Applied Building Science Center, Advanced Energy provides training and consultation on improving the health, safety, durability, comfort and energy efficiency of homes and commercial buildings.

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