# Some Research Begins at Home

by Jennifer Kent

At Integrated Building and Construction Solutions (IBACOS), our mission is to enable the industry to build high-quality homes. To further that mission, IBACOS is constantly looking for opportunities to research, evaluate, and test new systems and methods used to design and build homes to higher levels of performance. Cost and time constraints often prevent production home builders from fully exploring innovative design and construction strategies. In 2002 and 2003, IBACOS had the opportunity to take a home "off line" and dig into the practices necessary to design and build to extremely high levels of performance—in terms of occupant safety, health, and comfort, as well as building durability and efficiency.

Why was IBACOS able to take such liberties in this home? It happens to be the new home of IBACOS cofounder and Chief Technology Officer Brad Oberg and his family. Currently, the home is occupied, and IBACOS is collecting performance data. IBACOS is funded in part by Building America, an industry-driven, cost-shared program sponsored by DOE through the National Renewable Energy Laboratory. (For more on the Building America program, see "Building America: Innovation in Home Building," p. 40, "Putting Technology into Practice," *HE* Mar/Apr '01, p. 42, and "Roofs Reflect Better Savings," *HE* July/Aug '01, p. 24.)

In addition to testing new design and construction strategies to achieve Building America levels of energy performance, IBACOS used the demonstration home, located in the cold climate of Pittsburgh's northern suburbs, to illustrate to consumers the key areas of construction and how quality and performance decisions are made using best practices based on IBACOS's research. The construction process was filmed and documented for a cable television series by The DIY Network, a division of the Scripps Networks. The series will air in early 2004 in a 26-part series called "Home IQ" that focuses on illustrating both the design and the construction of a high-performance home.

THE DIY NETWORK

## *Advanced Building Systems*

The 3,074 ft² home (the basement is an additional 2,911 ft²) was designed to be at least 50% more energy efficient than homes built to the 1993 Model Energy Code (MEC) benchmark. At the time this demonstration home was designed, this was the benchmark used for the HERS Reference Home, which the Building America program uses to compare the energy performance of homes. The final performance results were a HERS score of 91.4 and a reduction of more than 55% in energy use beyond the 1993 MEC benchmark.

This level of energy performance is notable, considering that the demonstration home was built using many standard construction practices. This is important, because using nonstandard practices could add to the time and costs of construction. Some standard practices were supplemented with innovative approaches that we wanted to research further. While these approaches didn't add significantly to construction time and costs, they did add to the contractors' planning and layout time.

To meet the performance goals listed above, IBACOS focused on six key factors. These were (1) improving the thermal performance of the building envelope; (2) providing mechanical ventilation; (3) installing high efficiency mechanical equipment; (4) ensuring fire safety; (5) improving the floor framing and duct design; and (6) installing high-efficiency appliances and lighting.

In the proper climate, passive-solar construction can improve both summer and winter energy efficiency. But the Pittsburgh climate (5,930 heating degree-days and 647 cooling degree-days) is predominantly cloudy in winter, so winter solar gains are very inconsistent. To achieve passive-solar benefits in this climate, windows must be extensively redesigned and the solar gain of the house must be considered from the beginning of the design. Even so, the potential benefits of passive-solar construction are very limited in the Pittsburgh climate.

IBACOS's current approach is to design homes with very good energy performance that is independent of orientation, because this enables builders to position homes with flexibility on a given site. This is not to say that passive design isn't important—indeed, it should be incorporated wherever possible. In the case of the demonstration home, the orientation on the main streetscape allows the main living space to face south to take advantage of heat gain in winter, while the rear north orientation provides shading for the outdoor deck area. The bottom line is to give builders and architects design and site flexibility and still provide high performance.

## *Improved Building Envelope*

A key factor in meeting the performance goal was improving the building envelope. Not only is the concrete block foundation insulated on the exterior with R-10 rigid fiberglass as part of the foundation waterproofing system, but it is also insulated on the interior with R-5 extruded foam boards. The 3 1/2 inches of spray foam insulation in above-grade walls (R-14) are supplemented with 1 inch of R-5 rigid extruded polystyrene sheathing, for a total insulating R-value of 19. Nine and one-half inches of spray foam insulation (R-34) was applied to the underside of the roof sheathing in the unvented attic. (In unvented attics, insulation is placed between the roof rafters rather than on top of the ceiling.) The DOE's recommended R-value for attics in Pittsburgh is R-49 (R-38 for cathedral ceilings). The reduced roof insulation in the demonstration home was a trade-off in favor of improved duct distribution efficiency, reduced infiltration, and full access to all mechanicals.

In addition to providing excellent insulation, the spray foam also substantially air seals the building, further improving the overall energy performance of the home. The air sealing reduced the air leakage of the house to 1.9 $ACH_{50}$ as measured with a blower door. Fiberglass insulation products were supplied by Owens Corning, and spray foam insulation by Icynene. Both manufacturers were sponsors of research performed in the house.

Low-emissivity argon-filled windows (U-0.32), with a solar heat gain coefficient (SHGC) of 0.33 and visual transmittance (VT) of 0.53, reduce solar gains by suppressing radiative heat flow. The windows are spectrally selective.

THE DIY NETWORK

A contractor applies a polymer-enhanced asphalt membrane on top of the footer to act as a capillary break.

Tradespeople had to learn how to install a capillary break on top of the footing (see photo, above). The material used for the capillary break was a polymer-enhanced asphalt membrane (Tuff N Dri's Watchdog Waterproofing). Other techniques used to prevent moisture intrusion included installing window flashing, installing stucco wrap behind the siding, and back priming the cement board siding. Back priming involves painting the back of the siding and the cut ends with a sealer. This technique was used because cement siding absorbs water. Back priming reduces capillary wicking action behind the siding, which increases the life of the finish. Efficient framing practices, including the use of fewer studs in the corner, the use of ladder framing, and the elimination of jack studs, supplemented standard framing techniques. A specialized contractor installed spray foam insulation. This required some coordination between the builder and contractor, but did not require that any time be spent training the construction crew.

## *Ventilation*

Because the home is very tight (1.9 $ACH_{50}$), energy recovery ventilators (ERV) provide fresh outdoor air to the occupants and exhaust stale indoor air. ERVs also help to reduce indoor moisture accumulation. The controls for the ERVs are separate from the heating and cooling system, allowing the fan in the ERV to run continuously. Switches in the bathrooms put the ERV fan into high speed, allowing the ventilation rate to be doubled on demand. The exhaust air flow is designed to be the same from each bathroom, so when the ventilation rate is doubled in one bathroom, it is doubled in all of them. Although the ventilation strategy was uncommon, the materials used were typical, so there were no additional costs associated with installing the ventilation system.

## *High-Efficiency Mechanical Systems*

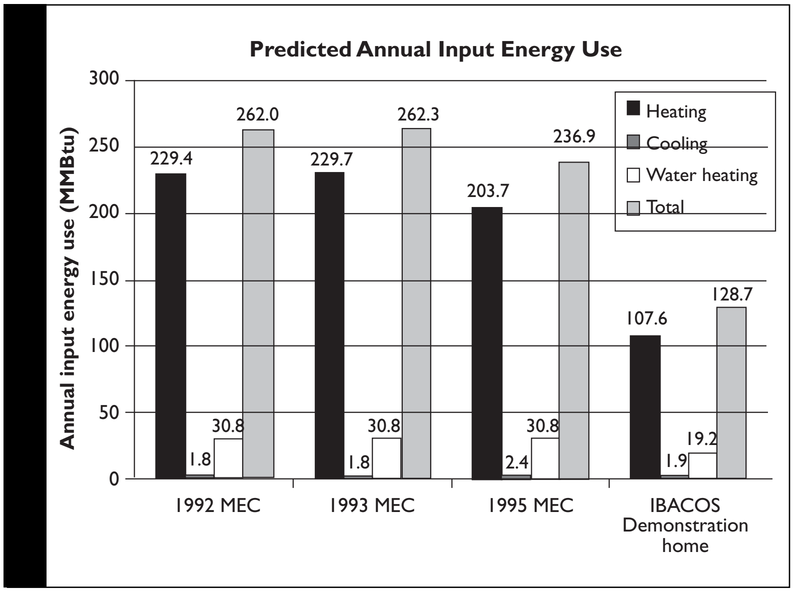
Improvements in the building envelope reduced the heating and cooling loads and with them the required capacity of the mechanical equipment. The installation of high-efficiency mechanical systems was another key performance improvement. A single heating-and-cooling system serves two zones. The first floor and basement constitute one zone, and the second floor constitutes the other. This zoning allows temperature control, so that the first and second floors can be heated or cooled in response to different rates of heat gain or loss. Space heating is provided by a gas furnace (annualized fuel utilization efficiency, or AFUE, is 96.6), and cooling is provided by a high-efficiency 14-SEER air conditioning unit. The equipment was sized to match the design loads

(57,000 Btu for heating and 24,000 Btu per hour for cooling) to optimize the operation of the equipment. The result is that the air conditioning system serves 945 $ft^2$ per ton. This ratio is high relative to the conventional rule of thumb in the Pittsburgh region (500–600 $ft^2$ per ton). Carrier supplied the mechanical systems.

The home could be conditioned with the forced-air system alone. However, an additional radiant floor heating system (provided by Wirsbo) was incorporated for IBACOS's research in the finished full basement and garage. (Carrier and Wirsbo sponsored this research.) A central boiler and a 20-gallon storage tank (for added thermal capacitance to the system) are used for both the hot water supply and the radiant floor system. The radiant floor heating is a separate four-zoned system—the other two zones are both forced-air systems. The four zones of the radiant floor heating are fed from the tank, utilizing a circulating pump. Each hydronic zone has its own manifold, and a separate thermostat and valve control each manifold.

The Obergs planned to use the finished basement and garage as working and studio space. Radiant heating was chosen because these rooms have very low cooling demand and require only seasonal heating. The basement level can be heated without forcing high volumes of air to that level in winter. The flow of warm air into the basement may require seasonal rebalancing of the forced-air system. Other spaces (in the upper levels) had more balanced airflow for heating and cooling.

Installation of zoning is a standard approach, but because the contractor did not often build plenums to include zoning dampers, doing so took additional planning time.




IBACOS

**Figure 1.** The IBACOS Demonstration Home is expected to achieve a reduction of more than 55% in energy use beyond the 1993 MEC benchmark.

## Building America: Innovation in Home Building

Building America (www.buildingamerica.gov) is a private/public partnership sponsored by the DOE that conducts research to find energy-efficient solutions for production housing. The Building America program combines the knowledge and resources of industry leaders with DOE's technical capabilities to act as a catalyst for change in the home-building industry.

Building America conducts systems engineering research to

• produce homes on a community scale that use 40%–70% less energy than a benchmark house, based on the proposed new International Energy Conservation Code;

• help home builders to reduce construction time and waste;

• improve builder productivity;

• provide new product development opportunities to manufacturers and suppliers; and

• implement innovative energy- and material-saving technologies.

By using a systems engineering approach to develop cost-effective high-quality homes, Building America unites segments of the building industry that traditionally work independently of one another. It forms teams of architects, engineers, builders, equipment manufacturers, material suppliers, community planners, mortgage lenders, and contractor trades. Currently, there are five Building America teams working with more than 150 different industry partners.

Throughout the design and construction process, the research participants evaluate the interaction among the building site, the envelope, the mechanical systems, and energy use factors. In many cases, cost trade-offs allow the teams to incorporate energy-saving strategies at no extra cost. Building America research participants agree to

• provide all construction materials and labor for research projects;

• evaluate their design, business, and construction practices;

• identify cost savings;

• reinvest cost savings in improved energy performance and product quality;

• extend their efforts from discussion of possibilities to development of solutions; and

• use a design, test, redesign, and retest process to overcome technical barriers.

The research conducted by Building America teams increases the quality and performance of today's homes and provides valuable information for building better homes in the future. By supporting industry-driven systems engineering research, the Building America program provides the feedback required to develop critical next-generation building systems.

## *Fire Safety*

The installation of a whole-house sprinkler system, also provided by Wirsbo, involved new approaches. The sprinkler system, made of cross-linked polyethylene (PEX) pipe, is connected to the water supply and replaces the cold water distribution, which lowered the cost of sprinkler protection. The system is part of the domestic cold water supply; it uses shallow four-part distribution heads. When cold water is drawn for any use, the entire system flows, eliminating "dead legs" in the sprinkler line. Because this was a different approach than the plumber was used to, the plumber needed to become familiar with it before he installed the system.

## *Floor Framing*

All of the floor framing uses open-web floor trusses. An open-web system allows for the easier routing and integration of ductwork, plumbing, and electrical wiring, with no restrictions in crossing joists. A full ACCA *Manual D* duct design was conducted, and ducts and pressure drops were sized to ensure proper flows. While the use of an open-web system was new to the tradespeople, the technique was not radically different from typical practice in that the trades only needed to learn a new way to cut the framing pieces.

## *Duct Design*

Duct design included a fully engineered duct system that located all ducts within conditioned space; ducts were sealed with UL-181-approved mastic. Duct Blaster test results showed no leakage to the outside.

There are two zone dampers located downstream of the supply air plenum. There is no bypass, which makes the system easier to install than a system that involves a bypass. The dampers are two-position, not modulating; and the minimum damper position is 30% open.

The design also incorporated both galvanized sheet-metal ducts and ducts fabricated from Owens Corning fiberglass duct board. The mechanical contractor was familiar with sealing ducts, and with the use of both sheet metal ducts and fiberglass duct board. But because this particular contractor does not often use duct board, planning for the duct board system took some additional time.

There have been concerns in the market that fiberglass duct products contribute to indoor air quality (IAQ) problems; that the surface material is conducive to mold growth; and that, in fiberglass duct systems, fibers can erode and enter the air distribution system. IBACOS is aware of these conditions. However, based on independent research by the Harry Reid Center for Environmental Studies, at the University of Nevada, Las Vegas; the North American Insulation Manufacturers Association (NAIMA); and ASHRAE—as well as on our own experience with the product—IBACOS believes that these concerns are simply not valid. Fiberglass duct board is a good option, provided that it is fabricated and installed according to the Sheet Metal and Air Conditioning Contractors National Association (SMACNA) (1992) recommendations for installation. When these recommendations are followed, ducts will be airtight, durable, resistant to microbial growth, and quite effective at reducing noise. Accordingly, we chose to use fiberglass duct board in this home. We chose it mainly for thermal performance, reduced air leakage, and reduced noise—but we should note that this material is also durable and cost-effective.

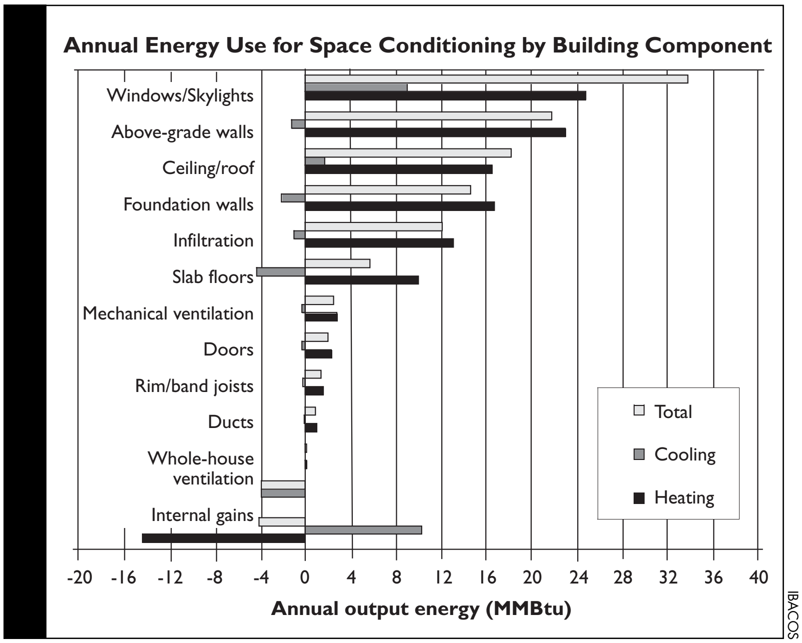



**Figure 2.** Windows account for 32% of the total space conditioning energy use, which is high because the other building components use relatively low amounts of energy.

## *Efficient Appliances and Lighting*

Energy Star-compliant laundry appliances (Whirlpool Duet Washer, GHW9200L, and Whirlpool Duet Dryer, GGW9200L); dishwasher (KitchenAid, KUDR01TJ); and refrigerator (24.5 $ft^3$ KitchenAid, KSBS25FKBT) provide savings in both water and energy. Control systems and fluorescent lighting contribute to reduced energy use and dramatically enhance the architectural character of the home. Fluorescent lights (T8, 3,000°K) were used in all of the service areas: garage, closets, and the entire basement—both storage and work spaces. (In this home, storage areas comprised 800 $ft^2$ for musical theater costumes and special effects.) Of course, garages, closets, and basements are not the high-use areas of the house, but they are the locations where builders have traditionally accepted fluorescents, and the quality of lighting did not cause complaints.

Our objective was to begin to improve the light quality and thus show homeowners that fluorescent is an acceptable way to go. To this end, specification-grade lamps were chosen at 3,000°K correlated color temperatures.

These lamps are produced at the 70 or 80 color-rendering index (CRI). For these areas, the 70 CRI lamps represent a major improvement over the old cool white or warm white lamps of the past.

Lighting controls regulated three levels of lighting:

• wayfinding lighting, to illuminate principal pathways at low levels, saving energy;

• ambient lighting to provide overall illumination while dramatically featuring high spaces, cabinetry, and wood finishes; and

• task lighting, to apply to areas and activities as needed.

In addition, dimmers were used in many circuits not included in the lighting control system to reduce light levels consistent with the occupants' needs and activities, again saving energy. The electrician was familiar with the Lutron lighting control packages that we used, but he spent time with the Lutron technical representative to learn more about how to install the system.

## Energy Use Analysis

IBACOS analyzed the energy performance of the home using REM:Rate software. The home is predicted to use 129 MMBtu per year for cooling and heating (space and water). This is more than 55% less energy than a similar home built to the 1993 MEC benchmark uses (see Figure 1, p. 40). The most significant energy use component is windows. Windows account for 25% of the heating energy use (which is high because the other building components use relatively low amounts of heating energy) and 32% of the total space conditioning energy use, even though they are 50% larger in area than the windows that were originally designed in the home (see Figure 2). Window area totals 853 $ft^3$.

Above-grade walls account for 21% of the predicted space conditioning energy use, and the roof accounts for 17%. The energy use for domestic water heating is 19.2 MMBtu per year, which is 38% less than MEC due to the use of a high-efficiency gas-fired water-heating system. The predicted annual energy input (not including the energy use of lights and appliances), normalized for floor area, including basement, is 18,296 Btu/$ft^2$. The climate-normalized values are 3 Btu/degree-day/$ft^2$ for heating and 0.5 Btu/degree-day/$ft^2$ for cooling.


This efficient framing technique allows a continuous area for insulation to be placed behind the ladder framing.

## Cost Considerations

Because this was a research house, cost increases do not represent the average increase that production builders might expect. We elected to use several strategies that represent one approach out of several that a builder could choose. For example, spray foam insulation and fiberglass with air sealing have different associated construction costs but achieve the same result. The performance improvements added approximately 5% to construction costs.

However, some of the measures implemented were for future IBACOS research projects; they were not necessarily what we would recommend to a builder. For example, two ERVs were installed in order to investigate a more responsive ventilation system by studying ambient and demand ventilation. For most homes, one ERV is sufficient. The additional unit accounted for 7% of the upgrade cost. In addition, we utilized spray foam in the home in lieu of other insulations that would cost half as much. The spray foam was 33% of the upgrade cost. Radiant floor heating was a significant added cost (60% of the upgrade cost). We chose to use radiant floor heating for research purposes, but we do not feel that it is necessary for production home builders. Similar levels of performance can be achieved at a lower cost using forced air systems. The specifications that we would recommend to a builder, without the additional features that we incorporated for our research, would probably add approximately 2 1/2 % to the construction costs.

## Future Research Studies

The home was completed in spring 2003 and is currently occupied. IBACOS is monitoring air temperature and humidity as they relate to occupant comfort, and tracking the annual energy efficiency of the ERVs for future research studies. Another research study will compare the comfort levels of an insulated slab and an insulated slab with radiant heat.

The DIY Network has chosen to use the IBACOS demonstration home to show a national audience how high-quality construction practices result in a high-performance home. The 26-part cable TV series will also teach consumers how integrating systems can achieve a 50% reduction in energy use for heating and cooling, compared to the1993 MEC. In addition, this project demonstrates that a large home with many amenities, which responds to the current market desire for sizeable homes, can achieve a high level of energy performance with a combination of load reduction and the efficient supply of conditioning.

*Jennifer Kent is the communications manager for IBACOS, a research, development, and education firm based in Pittsburgh, Pennsylvania, whose mission is to enable the industry to deliver high-quality homes.*