JIM LARUE

Learning From the Residents

by Jim LaRue

Creating a cutting edge home is exciting, and so is getting a chance to demonstrate to other builders, Realtors, and community residents that the promises of green building can be kept without excessive costs. However, the true test of a highly efficient green home comes when real human beings experience living in it. Six months ago, three nuns from the Humility of Mary Order purchased the first sustainable home in the Cleveland area. This house was built by GreenBuilt Homes, Ltd., a company that I helped create but have since left. The nuns have been living there ever since and providing us with very thoughtful feedback on how the house works.

As part of her work with the federal Building America program, Betsy Pettit of Building Science Corporation designed the 2,500 ft^2 house, which has a conditioned crawlspace. We used the Cold Climate version of Joe Lstiburek's Builder's Guide to facilitate the building process. We worked hard to get all the details right, and we must have succeeded fairly well, because the building envelope was tested and proved to meet Building America standards (see "The Complete Test Kit").

The house is heated by the same hot water tank—a 50-gallon A.O. Smith Sealed Shot-Powered Direct Vent Water Heater—that provides the water for bathing, laundry, and cooking. This system is direct vented and gets its combustion air through vent pipes that penetrate the roof. As the only other combustion appliance in the house is the stove, we are not very concerned about backdrafting.

Controlling Air Quality

The hot water line runs through an air handler that delivers forced air through a duct system. Air is returned to the air handler through grilles located in each room that feed into a common return in the hallway. In pressure balance testing conducted by Building Science Corporation's Armin Rudd, only one of the rooms proved to be overpressurized, and we needed a slightly larger grille there to compensate. There was also some air leakage near the boots because the construction workers who put in the boots had a different take on sealing than did the A/C technicians who built the duct runs. The duct runs were all sealed with mastic. We fixed the missed crawlspace boot seams by sealing them with mastic from the exterior and applied the same treatment from the interior to the boot seams on the second floor.

A ventilation system designed by Rudd was installed. This system includes a duct from the exterior into the cold air return section of the air handler that has one of Rudd's AirCycler Smart Ventilation Controllers in it. When the air handler is not delivering conditioned air, this controller brings fresh air into the living space every 20 minutes. The other ventilation devices installed in the house are three bath fans—one is used by both the bath and the adjoining laundry

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(opposite page) Careful moisture flashing details around all windows keep water out of the walls at the most vulnerable points. *(above)* One-inch foam sheathing on the interior of cathedral ceilings combined with thorough air sealing helps stop heat transfer through the framing members.

room—and a range hood over the stove that vents directly to the outside. These fans are all manually controlled.

Other measures we took to improve the indoor air quality (IAQ) of the structure include using countertops made of straw with no formaldehyde bonding agents (ISOBORD) and sealing cabinet edges that had exposed particleboard edges. We also used low volatile organic compound (low-VOC) paints on all the interior walls and trim. And we advocated a shoes-off-at-the-door policy for the new residents.

I have long felt that lead dust, pesticides, and other stuff tracked into the house on our feet and deposited on floors and in carpeting is a major source of indoor pollutants. Several years ago, we did lead abatement in several homes and then went back six months later to see if conditions might have changed. We found almost no lead anywhere in the houses, except in the carpet near the front doors. It had been tracked in from outside from soils contaminated with lead paint and lead from auto emissions. There is a growing concern that pesticides may be tracked in from lawns as well.

For nine months the house was open for visitors who were considering taking the green building plunge. People taking the tour included staff from the community development corporations, builders, realtors, and bankers. I prepared a complete set of displays with photos of the house as it was being constructed; these displays were available in each room of the house and on the exterior. Ohio Senator George Voinovich and federal EPA Administrator Christie Todd Whitman even visited when they were in town to promote the role of private enterprise in accomplishing environmental goals. (I'm glad we had our Building America sign out in front of the house when they came!)

During the demonstration period, we learned that the house became uncomfortably warm during the late summer months. To be ready to add air conditioning if the new homeowners needed it, we had included an evaporator coil in the air handler when it was installed. We also installed a watt-hour meter to measure the electricity that would be used by an air conditioner. But while nine months of visitors can let a builder know some of what works and what doesn't in a new house, only full-time residents can truly put a house through its paces.

The Nuns Weigh In

After the nuns had a chance to settle in, I began to call them to see how they were experiencing their new living space. My first questions had to do with how effectively the heating system was working. The nuns had moved from a very old house with a typical forced-air heating system that delivered conditioned air at a very high temperature. The heat in their new house was delivered at a considerably lower temperature. Still, they reported that they were basically very comfortable. In fact, when they first moved in, they would set the thermostat back to 68°F each morning before they left for their jobs as Montessori teachers. During the first month in the house, they found that the house would be too warm when they returned, so they started putting the thermostat back to 65°F and that worked reasonably well. It turned out that the late afternoon sun through the west windows was making the

Table 1. Selected CO_2 Readings

Date	Time	In/Temp (°F)	CO_2 Reading (ppm)	RH (%)	Out/Temp (°F)	Notes
3/9 Sat.	10 pm	69.3	780	40	46	High winds
3/13 Wed.	12 am	70.3	791	35	——	Stove top cooking
3/17 Sun.	5:30 pm	70.6	1,353	34	40	Oven on; did not use fan
3/20 Wed.	5 pm	69.7	638	37	——	Raining
3/21 Thur.	5:30 am	69.4	727	39	36	92% RH outside
3/22 Fri.	10 pm	68.8	666	32	22	Snow, cold
3/23 Sat.	5:15 am	69.1	685	32	——	Oven on; used fan
3/26 Tues.	6:30 pm	68.6	982	39	30	Stove top cooking
3/27 Wed.	8:30 pm	70.1	894	34	——	Third nun moved into house today
3/29 Fri.	5 pm	70.7	1,151	35	57	Oven on; fan on low
3/31 Sun.	8:30 pm	70.7	1,147	37	41	Oven on; fan on low and high; several guests for dinner

The Complete Test Kit

The following series of tests is conducted on Building America (BA) houses and control houses to verify performance metrics and to determine the boundary conditions (inputs) for the computer simulation evaluation software that we use in specific performance metric evaluations. We refer to this two-hour battery of tests as SnapShot.

Building Airtightness Testing

We use a blower door to evaluate building envelope airtightness, and we compare the results to the BA specification. The building envelope met the BA specification with 1,020 CFM of leakage at -50 Pa pressure differential with respect to outdoors (see Table A). This equated to 0.18 CFM_{50}/ft^2 of building surface area, which was lower than the BA specification of 0.25 CFM_{50}/ft^2.

Air Distribution System Testing

We use a fan pressurization test to determine the amount of air leakage of a forced-air thermal distribution system under operating conditions. The BA specification limits duct leakage to outside to a maximum of 5% of the system's nominal high speed flow (at 400 CFM per ton). In this house, the entire air distribution system—air handler and ducts—is located inside the conditioned space. The air handler's high speed flow measured 1,150 CFM for the nominal 3-ton air handler. The air distribution system leakage met the BA performance goal with 0 CFM leakage to outside at 25 Pa pressure differential, but it was high on total leakage at 195 CFM. Most of this leakage to inside was expected to be at the supply boots and at the joints between the supply boots and the subfloor, which were not sealed with mastic. Pressures within the air distribution system were measured at several locations and under different conditions and were found to be normal (see Table B).

In houses with A/C systems installed, we often evaluate an A/C's refrigerant charge and system air flow using a microcomputer-based smart-system software package. The software package uses measurements of return air dry-bulb and wet-bulb temperature, supply air temperature, suction line refrigerant pressure and temperature, and outdoor temperature to calculate superheat and check for proper air flow and refrigerant charge. We did not test the A/C system at this house.

House and Room Pressurization Testing

We use a multichannel micromanometer to determine room-to-main-area and main-area-to-outside air pressure relation-

Table A. Building Envelope Leakage Test Results

Units	Measured Values	Building America Performance Goal
CFM_{50} (building leakage in ft^3/min at 50 Pa)	1,020.00	1,397.00
CFM_{50}/ft^2 building surface area (normalized building leakage)	0.18	0.25
ACH_{50} per hour (building leakage in ACH at 50 Pa)	2.60	3.60
Effective leakage area or ELA (in^2 at 4 Pa)	55.10	69.80
Equivalent leakage area or EqLA (in^2 at 10 Pa)	104.20	139.70
Natural ACH annual estimate (estimate of annual average ACH under the natural environment conditions for that building)	0.19	none

Table B. Pressures in the Air Distribution System

Pressure Measurement Location	Pressure (Pa)	Comment
Return filter grille in hall	-36	No filter
Return filter grille in hall	-42	Standard filter
Return plenum at air handler	-50	Outside air damper closed
Supply plenum at air handler	+24	Outside air damper closed
Return plenum at air handler	-43	Outside air damper open
Supply plenum at air handler	+24	Outside air damper open

Table C. Room Pressurization Measurements

Room	Room Pressure with Respect to Central Area (Pa)
Side entrance	+2.0
Study/bedroom 4	+0.3
Master Suite	+7.2 (+6.1 with one grille off; +3.5 with both grilles off)
First-floor bath	+5.3
Basement	+1.7
NE bedroom	+0.3
SE bedroom	+0.3

ships under operating conditions. The baseline house pressure with respect to outside was -1.8 Pa with the master bedroom door closed and with all other doors open. With all doors closed, the house pressure was -1.1 Pa.

The transfer grilles, which supply a path for return air flow from closed rooms back to the central return, were working well, except at the master suite (bedroom and bath). We recommended that the size of the master bedroom transfer grille be doubled to accommodate higher air flow into that space (see Table C).

Mechanical Ventilation System Testing

We use a Duct Blaster to measure outside air flow at 120 CFM. The pressure in the 6-inch-diameter metal outside air duct was -43 Pa with the motorized damper open.

We recommended installing a manual balancing damper to allow reduction of the outside air flow to the design amount of about 85 CFM (about 26 Pa measured in the outside air duct upstream of the balancing damper). To better filter the outside air, a 10-inch register box, fitted with a slot for a standard 12 inch x 12 inch filter, should be installed where the outside air duct joins the return plenum.

The outside air duct was not insulated. The entire outside air duct must be insulated to avoid condensation on the outside of the duct in winter and on the inside of the duct in summer.

AirCycler controls were installed for operation of the ventilation system and the combination space and domestic hot water heating system.

—Armin Rudd

Armin Rudd is principal engineer with Building Science Corporation, in Westford, Massachusetts. He has worked in the field of buildings research and consulting since 1987 and was self-employed in building construction before that.

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Two-inch foam panels under the slab and up the walls of the crawlspace not only reduce heat loss, but also greatly reduce the chance of condensate forming on the slab.

house several degrees warmer than the thermostat temperature setting.

Moisture hasn't been a problem so far; moisture levels have remained near a constant 35% relative humidity (RH) as measured by an inexpensive hygrometer that was placed on a balcony overlooking the living/dining area. When the nuns are in the bathroom, they always use the bath fan, and they never cook without turning on the range hood fan. No moisture has appeared on the Andersen windows. The humidity level on a cheap, instantaneous-reading hygrometer I had installed in the floor trusses in the crawlspace has remained well below 50% RH.

I was particularly concerned with the rate of air changes in the house, and with whether the CO_2 levels were appropriate. Measured CO_2 levels can indicate whether sufficient ventilation air is being provided to dilute pollutants generated by the people in a house. I provided the nuns with a Telaire 7001 CO_2 and Temperature Monitor and asked them to write down the readings on four occasions during the day and to note what activities were going on when the monitor was registering too high or too low levels of CO_2. They kept a careful record over a four-week period, and the results were most satisfying (see Table 1).

The Telaire Ventilation Rate Conversion Chart suggests a range of 650–800 ppm CO_2 as ideal ventilation. Less than 650 ppm means that energy is being wasted because the house is overventilated. More than 800 ppm means that the house is underventilated, and IAQ is poor. Another guideline to use that Leadership in Energy and Environmental Design (LEED) recommends is that indoor CO_2 levels should not be more than 530 ppm higher than the CO_2 levels found outdoors. (If outdoor CO_2 levels are high, it is very difficult to get low levels indoors. Base outdoor levels generally are in the 350–390 ppm range.) Over the four weeks, the average reading was 747 ppm, but there were two occasions when the readings went over 1,100 ppm.

The first incident occurred the first time the nuns used the oven for an extended period. They had been careful to use the range hood fan when using the stove top, but they had neglected to do so when using the oven. One of the nuns, who had become very interested in their home's performance and who frequently checked the meter just for fun, happened to notice that the CO_2 level was very high. They thought about what might be causing the problem and quickly concluded that the oven was the source of the excess CO_2. They turned on the range hood fan, and within an hour CO_2 levels were back to normal. Since then, they routinely turn on the fan when using the oven and the problem has not recurred.

The second incident occurred when they invited a group over for the evening. At some point they noticed that the CO_2 level had gotten quite high and assumed that it was because of the additional people in the house. Their solution was to turn on the bath fan in the second-floor bathroom. Within an hour or so, the CO_2 level began to drop, and by the next morning, it was normal again. During a more recent group meeting, they started the second-floor bath fan soon after the first guest arrived, and the CO_2 level never got inappropriately high.

This brief study taught me a compelling lesson: It was the very act of creating a comprehensive, controlled ventilation strategy that permitted these women to notice and solve the temporary ventilation problems they were having in their house. Is it necessary for us to put a CO_2 detector in every house we build? No. What is important is that we learn what conditions trigger higher or lower CO_2 levels and what the residents can do about it. The more effectively we tighten and ventilate a home, the more likely it is that the residents will be able to maintain a healthy IAQ on their own with minimal energy loss.

A side benefit of all of our efforts to produce a healthy indoor environment in this home occurred when another member of the nuns' order spent most of a day with them in their home. This person has asthma that is triggered by numerous environmental causes. After several hours visiting with her colleagues, she noted that she had not felt so comfortable in any indoor space in a long time.

Future Data Mining

We look forward to finding out exactly how the house performs in really hot weather. During this summer we will be monitoring the CO_2 levels for several weeks while the air conditioning is in operation to determine how effectively air is being changed during cooling conditions. The information we gather during this time, together with the cost of electricity for the air conditioner use, will give us a pretty good idea of what it costs per year to operate a healthy and comfortable house in this climate.

We have installed several small, battery-powered temperature and humidity data loggers (HOBOs) in the house and on the detached garage. We will download data from them early this fall to get a picture of temperature and humidity throughout the structure during both winter and summer. I expect that we will learn a few more lessons that can be passed on to others who have the opportunity to live in tight, energy-efficient, and effectively vented living spaces.

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