The Best-Insulated House in the World?

ROB DUMONT

by Rob Dumont

When we built our house in 1992, we knew our plans were ambitious. But we never expected that our house would turn out to be the best insulated house on earth. A British energy efficiency researcher and author, David Olivier, recently e-mailed me that our house had the "lowest heat loss coefficient per square meter of floor area of any house in the world." Olivier has written extensively on low-energy housing, and his word is as pure as platinum. That extra insulation, as well as many other steps we took to make our house energy-efficient, turned out to be well worth the investment. Eight years later, we've found that our home more than meets the expectations we began with.

In designing the house, we wanted it to: be a leading example of energy efficiency; use renewable, sustainable energy sources; minimize environmental damage; and contribute to a better world through the use of recycled materials and carbon-based materials, primarily wood, which remove carbon from the atmosphere. Finally, we wanted a house that, while serving as a model for energy efficiency and environmental features, would be totally acceptable to average citizens. We did not want to live in a laboratory experiment—a house that sacrificed aesthetics to functionality and performance.

Our house's exterior design, Colonial Revival, dates back more than 100 years and blends well with the neighborhood.

ROB DUMONT

The stud walls in our home were double-thick 2 x 4 construction.The 16-inch space was filled with blown-in cellulose insulation. In the background is an old house on the site that was moved to the back lane and used as a garage.

ROB DUMONT

In December at 52° north latitude, the sun is low in the sky, casting long shadows. Ample windows on the south side of the home take full advantage of this light. In contrast, the smaller windows on the north side of the home decrease thermal losses, while decorative shutters make them look larger (see photo of home's north side on page 41).

We also chose fairly conventional house components. For one, we rejected 1-quart toilets, which have aesthetic drawbacks such as dark "skid marks" on the bottom of the bowl due to lack of flushing power. We also rejected gray-water reuse systems, on the grounds that bacterial growth in the water might pose a health risk. We wanted our home to reflect choices that most people would want to make and would be comfortable making.

Extra Layers

Our house does have a lot of insulation. The attic has R-80, the walls (incluiding basement walls) R-60, and the basement floor R-35. The windows are about R-5. Because of its green characteristics, we used cellulose insulation throughout the house, including in the basement walls and beneath the basement floor.

Why did we build such a well-insulated house?

For one thing, it is cold—damned cold at times—in Saskatchewan. Fewer than 1% of the world's 6 billion people live in a climate this cold. Our average temperature in January is –18°C (0°F). As I write this, the temperature outside is –24°C (–11°F), the wind is blowing, and it feels like –40°C (–40°F) in open areas. The annual heating degree days (HDD) here are 10,900 (base 65°F). By comparison, Minneapolis, which most Americans would consider a cold winter city, has "only" 8,400 HDD. The design temperature for sizing heating systems around here is –34°C (–30°F). Usually there is snow on the ground from late October until about April.

Having watched housing innovation evolve over the last quarter ce-ntury from my day job as a building science researcher (first at the National Research Council and later at the Saskatchewan Research Council), I was convinced that the only way to achieve truly superior performance in our climate was to start with a very well insulated house. Renewable energy sources are not cheap, and the old saw "insulate, then insolate" ("insolate" means expose to the sun's rays) is as true today as it was in the 1970s.

ROB DUMONT

The ceiling light fixtures use compact fluorescent lamps. Ceramic tile flooring avoids offgassing from vinyl floors.

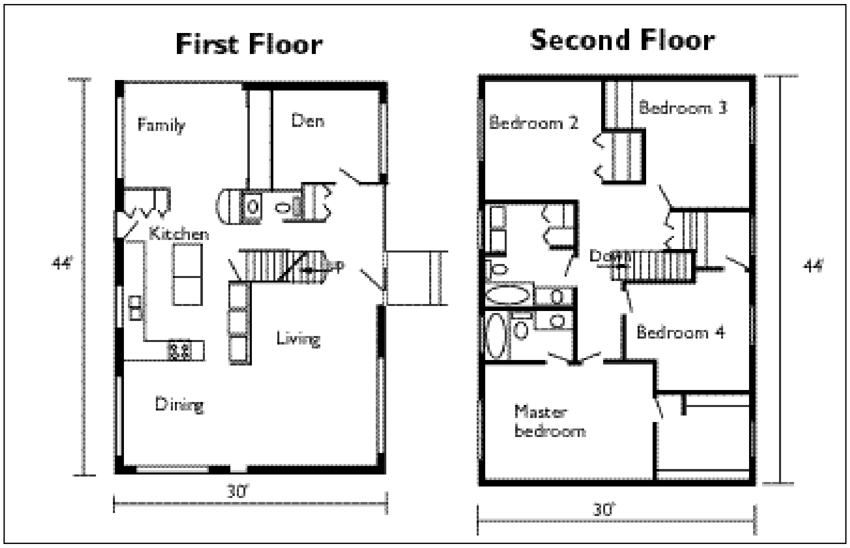
A second reason for building the house with a thick skin was a frustration with the R-20 wall mentality in these parts—the conventional wisdom being that R-20 is all that's needed. The climate change people are telling us that we must reduce our use of fossil fuels by about two-thirds for the world to be sustainable. Using more insulation is a simple, effective way to reduce energy and cut down on fossil fuel consumption.

Another reason we did it this way was to show that it could be done. In other houses I have built or renovated, I have successfully used solar water heating and passive solar design, but a new house gave us the chance to go the distance: superinsulation, passive solar design, active solar features, and excellent appliances and lighting.

The last reason for using so much insulation goes back to a remark I once heard from a seasoned engineer. He told me, "Anything that has moving parts will fail—in fact, it must fail, because there is no such thing as a perfect bearing." Unlike a furnace or heat pump, insulation has no moving parts; provided it is protected from the elements with proper vapor and weather barriers, it will last indefinitely.

To accommodate the large amounts of wall insulation, we chose a double 2 x 4 stud wall (16 inches thick, total). A well-sealed 6-mil poly vapor barrier was placed on the warm side of the insulation, in order to limit vapor transport and to seal the wall against air leakage. The blown-in cellulose was installed in what is sometimes called the blown-in batt system (BIBS).

A benefit of the higher-density cellulose is the additional mass in the wall, which helps to keep the house quiet. We live on a relatively busy boulevard, and the well-sealed, double-thick walls—along with the triple glazed windows—significantly reduce noise transmission. We also added scrap gypsum to the interior walls to cut down on landfill waste and to provide additional thermal mass. This moderates the temperature



PHIL SCHAAN-DUMONT

Figure 1. The floor plan places the most frequently used rooms on the sunny south side, to take advantage of heat and light.

swing in the house caused by solar gain. In summer, the flywheel effect keeps our home cooler during the heat of the day and warmer during the night and early morning hours (see "Mass Walls Mean Thermal Comfort," *HE* May/June '99, p. 37).

Tight Is Right

After lots of insulation, the second part of a good building envelope is airtightness. The injected cellulose insulation seems to have made the house more airtight—another energy efficient home nearby that was like ours in many respects, except for use of fiberglass insulation, was quite a bit leakier. We took other measures to ensure good airtightness, as well: All joints in the air/vapor barrier were carefully sealed with acoustical sealant; the rim joists were wrapped with Tyvek, and the Tyvek was sealed to the poly. The blower door test result for our house was 0.47 ACH at 50 Pa. To my knowledge, this is the third tightest house in Saskatchewan. The Canadian R-2000 standard is 1.5 ACH at 50 Pa. It is common to achieve air tightness levels of less than 1.0 ACH at 50 Pa in new R-2000 houses in Canada; achieving less than 0.5 ACH is a different story.

Of course, with a house this tight, proper ventilation air for breathing and for removing moisture and other contaminants is a must. To provide ventilation air, we have a balanced mechanical ventilation system (see "Forum Brings Fresh Air to Ventilation Issues," p. 15). It is a double-core plate VanEE energy-efficient air-to-air heat exchanger that uses efficient fans. The unit had the highest efficiency on the market at the time it was purchased. It incorporates brushless DC motors to minimize electrical consumption. The unit is run continuously at 100 CFM (47 litres per second) to ensure a high standard of indoor air quality (IAQ). It came with foam filters, but the intake air filter was replaced with a pleated paper filter model that filters out finer particles; this filter is vacuumed every three months or so. We also took several other steps to ensure good IAQ (see "Indoor Air Quality Features").

The First Steps

Using innovative technologies like BIB insulation is not always easy if you can't find the right people to install it. We were fortunate to have an innovative contractor work with us. John Carroll of Carroll Homes had experience with building R-2000 houses (Canada's Energy Star–type program), and was not afraid of thinking creatively. Working from some initial sketches provided by us, he used a CAD program to develop the plans for the house.

The Colonial Revival design turned out to be a great choice. Our ancestors lacked air-to-air heat exchangers and so on, but they understood well the benefits of building relatively compact, rectangular, two-story houses. They avoided building homes with inefficient shapes, because they knew such houses would be hard to heat.

The lot orientation was chosen so that windows on the house face south

Indoor Air Quality Features

Along with our mechanical ventilation system, we took the following steps in our home to avoid IAQ problems:

1. No combustion sources were allowed in the home—we didn't even allow the construction crew to smoke inside the house as it was built!
2. We constructed a dry basement, free of mold and mildew, by installing excellent exterior perimeter water drainage and water proofing, and by ensuring that all of the insulated surfaces are warm.
3. No particle board or oriented strand board was used inside the house, to avoid off-gassing of VOCs from the formaldehyde and glue that these materials contain. Instead, we used Douglas fir plywood for the subfloor, and solid hem-fir joists for the floors. Kitchen cabinets and vanities were birch plywood and solid oak, and we avoided using particle board furniture.
4. We used prefinished solid oak strip flooring, which off-gasses much less than flooring that is finished during home construction.
5. We did not install any wall-to-wall carpets.
6. We used ceramic tiles instead of vinyl flooring.
7. We used low-VOC paints for the gypsum board Sheetrock on the interior walls and ceilings.
8. We used a wick-type humidifier that releases no solid particles into the air.

Table 1. Breakdown of Incremental Costs

Item	Cost in Canadian $
Windows	$2,310
Solar panel system	$4,500
Attic insulation	$1,050
Wall insulation	$4,620
Floor insulation	$920
Premium ventilation system	$800
Water conservation	$100
Energy-efficient lighting	$200
Savings from not installing central air conditioning	<$1,500>
Total incremental cost	$13,000

for passive solar gain. Saskatoon enjoys 2,400 hours of bright sunshine each year, and passive gain works well with properly chosen window strategies. Triple-glazed windows with two low-e coatings, argon gas fill, low conductivity spacer bars, and wood frames were used. Overhangs are present on all the south windows to limit overheating during the summer period. Thanks to the overhangs and fenestration design, no air conditioning is needed. The efficient appliances we chose (see below) also reduce the internal heat gains and the need for air conditioning. Decorative shutters were placed on the smaller north-facing windows to give the appearance of larger windows without the heat loss and poor solar performance that accompanies large north windows during the coldest part of the winter.

The interior design of our house was developed by my wife, Philippine. She has extensive experience in interior design. Phil developed the floor plan to have the family room, dining room, kitchen, and main bedrooms on the sunny south side of the house. She placed less-used rooms—such as guest bedrooms, the living room, the den, and the closets—on the north side of the house (see Figure 1). We chose an active solar hot-water system with 168 ft^2 of selective-surface liquid solar panels. This system has a low-cost wood-framed, EPDM synthetic-rubber-lined tank, which holds about 1,400 U.S. gallons of water. This large tank of water serves to improve the year-round efficiency of the solar collection. The hot water in the tank is used to heat the domestic hot water and also heats the house. This operates via a water-to-air heat exchanger within our forced-air furnace, which uses a brushless direct-current fan motor. The fan provides about 800 CFM of air flow using only 110 watts of fan power. Additional heat is available through five electric baseboard heaters located around the house. We considered using hydronic heat, but with our hardwood floors, we didn't want to take the risk of leaks.

We made some plans for future upgrades. For example, the garage roof was oriented to the south so that a solar electric system can easily be added at a later date as the price of photovoltaic panels declines. Also, separate ABS piping was installed in the upstairs bathrooms and laundry sewer piping so that the heat in the warm water from the baths and washing machine could be captured at a later date in a graywater heat exchanger.

Home Details

When it came to home appliances and fixtures, we made choices for energy efficiency as often as possible. We picked high efficiency appliances, including a convection/microwave oven and the most efficient full-size refrigerator made in Canada (rated at 36 kWh per month). For interior lighting, we specified compact fluorescent and T-8 lamps. A high-efficiency specular (shiny) reflector in the kitchen light provides approximately 85 lumens per watt of effective lighting from a T-8/electronic ballast fixture.

We also opted for some water efficiency measures, including low-flow showerheads, a variable-water-level clothes washer, and low-flow toilets. For landscaping, we picked drought-resistant vegetation instead of a conventional lawn at the front, and we use rain and snowmelt runoff from the roof for irrigation.

Conclusion

The first lesson we learned in building an energy-efficient home is that the investment in these technologies pays off. The incremental costs for the energy efficiency and water efficiency measures amounted to about CAN$13,000 (see Table 1), and the annual energy and water savings amount to about CAN$800, giving a simple payback period of about 16 years, or an annual return of about 6.2% after taxes. The measured energy consumption of the house over the calendar years from 1993 to 1999 is presented in Figure 2. Over the seven years, the total consumption has averaged 15,300 kWh per year, or 46.9 kWh per square meter per year (14,900 Btu/ft^2 per year). See Table 2. The average use in Saskatchewan is 300 kWh/m^2.

We learned (or rather, confirmed) five other lessons, too:

Table 2. Energy Performance of Dumont Home for 1999

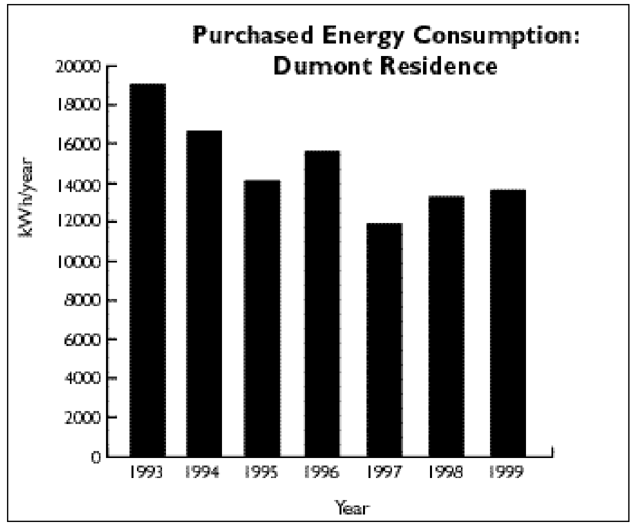
Item	Total Purchased Energy Consumption for 3,511 ft^2 Floor Area	
	Kilowatt-Hours	Percentage of Total
Space heating	7,047	49.3%
Lights and appliances	4,657	32.6%
Domestic hot water	1,980	13.9%
Air-to-air heat exchanger	595	4.2%
Total	14,279	100.0%


ROB DUMONT

The ceiling light in the kitchen is a four-lamp T-12 fluorescent fixture that was retrofitted with two T-8 lamps, an electronic ballast, and a silver reflector. Light levels are excellent, with 80 foot-candles available below the fixture. The cabinets are birch plywood and solid oak, to minimize off-gassing from wood products containing formaldehyde.

- Energy efficiency, even when taken to levels that some people consider extreme, is not all that expensive.
- A well-insulated house does not have to have a heating source under each window, or even under every large window. With high-quality windows, the space-heating source can be centralized. This can reduce the cost of warm-air heating systems, with outlets placed anywhere in a room, including interior walls.
- A rectangular two-story house is a lot easier to heat than a sprawling rancher.
- Good indoor air quality in a new home need not be expensive, but is easily achieved through not using polluting materials such as carpeting and particle board.
- A low-embodied–energy house need not cost much more than a conventional one. On our house, the use of a cedar shake rather than asphalt shingle roof, wood flooring rather than synthetic wall-to-wall carpets, and preserved wood instead of concrete basement walls and floor all reduced the embodied energy of the structure considerably. Cellulose insulation is also much less energy intensive than fiberglass.

Our house, if transported to a milder climate such as that in a coastal city like Seattle, would probably be a zero-energy space heating house. The big challenge will be to raise the efficiency



ROB DUMONT

Figure 2. Energy consumption over seven years fluctuated with the weather; because we use energy mainly for heating, consumption is lower during warmer years.

standards of all new houses so that ours is no longer the best-insulated house in the world.

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Green Features

Recycled items in the construction included the use of polyethylene “lumber” for the front and back stairs that were manufactured from recycled plastic waste, and the re-use of a small, poorly insulated old house on the site as a garage. Had the garage been demolished, a significant amount of waste material would have ended in the landfill. The gas furnace from the old house was sold and re-used in another building. Lumber from the floor beams in the old house was used in the construction of the new house.

To assist with ongoing recycling, a special chute under the kitchen sink directs metal and plastic cans and bottles to a large container in a closet in the basement. The container has been found to hold about a six month’s supply of cans and bottles. The cans and bottles are then taken to the recycling depot.

A composting container made of recycled polyethylene is conveniently located near the garage and is used year-round.