Comfort in a Very Cold Climate

by Rachel Wagner

Widespread attention is now finally being paid to global warming, and many homeowners want to know how they can reduce their personal contribution to greenhouse gas emissions. They know that they must do much more than the often touted small steps such as replace incandescent lightbulbs with compact fluorescents, or buy and use a programmable thermostat. Homeowners look to architects, builders, and other design professionals for information and recommendations. Therefore, building and design professionals have the opportunity, and the responsibility, to offer approaches to building construction that reduce both energy consumption and carbon dioxide (CO_2) emissions. In professional practice, the pertinent questions may be, How far can we go? and How soon can we get there? As an architect who works primarily in residential construction, I try to answer these questions with every house I design and build.

Taking an Aggressive First Step

Buildings last. Many choices made in new construction today will have an impact on the environment for the next 100 years—much longer than the impact of decisions made in many other industries. This is why it is so critical, first, to quantify the amount of energy used (and emissions generated) in building operation, and second, to set targets for reducing both. And this is also why an incremental, or staged, approach to reductions may not work well in the building sector, unless that approach begins with an aggressive first step An example of such a first step is the 50% immediate reduction advocated in the program Architecture2030, which was developed by architect Ed Mazria. In this context, programs such as Energy Star and LEED, as they are defined today, are inadequate solutions to the problem of creating low-energy buildings. Rather, all new construction can and should be designed to immediately reduce consumption and emissions by 50% or more compared to construction that just meets code, with the further goal of creating buildings that reduce both consumption and emissions by 75% to 90% in the near future.

How will the home built today rate in 40 years? Will it be easy to add features that push it into even higher energy reductions? If the answer is to be yes, we need to build homes now with envelope and systems designs that greatly reduce the amount of energy needed for operation, and that take advantage of passive lighting, heating, and cooling options. Building homes in this way will make it easier in the future to add technologies (such as active solar-energy systems) that further reduce consumption of fossil fuels.

Targeting Energy Use

If the first step is to set a target for energy use, the second step is to quantify that target and to find the means to see that it is met. Calculated energy modeling is an essential tool for comparing assembly elements and systems design, and for quantifying their respective associated energy loads. Although miscellaneous electrical loads represent a growing percentage of total household energy use, most energy consumed in single-family residences is used for heating, cooling, and domestic hot water. In cold climates, such as we have in Minnesota, where I practice, heating consumes the most energy, so my efforts to reduce energy loads often focus on heating-associated numbers.


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The Skyline House in Duluth, Minnesota, was designed and built to provide low-energy accomodations for generations to come.

I find these three numbers most useful when quantifying and comparing design options:

1. peak heating load in British thermal units per hour per square foot;
2. annual calculated consumption in British thermal units per square foot per year; and 3. total household calculated annual consumption in millions of British thermal units per year.

As the house design is developed, I compare and modify the readily available envelope design assemblies, using an energy-modeling program. There won't necessarily be a single best assembly or component. But by comparing and quantifying different assemblies or components, I arrive at a desirable design solution. In doing so, I consider many factors, including climate, solar opportunity, budget, and regional materials and practices. I have found REM:Design (REM stands for Residential Energy Modeling) an affordable and easy-to-use program for modeling houses. More recently, I was introduced to the Passive House PHPP

Roof overhang and a trellis structure manage the solar gain.

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Table 1. Environmental Goals for Skyline House Project

Goals	Approaches Needed
Longevity	Flexible design; single-floor living for adult occupants; durable construction
Low energy use	Aggressive thermal envelope; passive-solar design; renewable energy-integrated HVAC systems
Sustainability	Environmental approach to materials; adaptability to changing circumstances

software program (developed by the Passive House Institute in Germany). The PHPP software is more difficult to use than REM, largely because one must enter an enormous amount of data in order to obtain accurate results, and because of the conversions from imperial to metric units. However, the very detailed reports that result make PHPP an extremely useful tool for modeling very low-energy buildings.

It is worth noting that different modeling programs produce different results, and the most "real" data are obtained from monitoring the actual energy consumption of a house. However, even if the modeled numbers are not exact, the process of setting up a code-designed house for each model gives me a valuable baseline that I can use to compare with each design variation. The solar-heating component of a house is hard to model, but with effective passive-solar design, it can further reduce energy consumption for heating. Post-occupancy interviews of clients living in houses constructed using this process suggest that actual energy consumption is often even less than the predicted energy consumption.

One Solution: The Skyline House

As I mentioned earlier, two questions guide my practice: How far can we go? and How soon can we get there? I was recently presented with a near-ideal opportunity to explore these questions when I was asked to design a house with a low-energy envelope that would significantly reduce energy use and associated CO2 emissions. Near-ideal because the project included a client with a strong environmental focus and a comfortable budget; a site with good solar opportunities; and a building program that fit readily into the naturally efficient form of a one-story house, with lower-level living set into the ground. Partway into the project, the clients and I decided that we should try to design and build this house so that it would meet the Passive House Standard, which sets the goal of annual energy consumption for heating at about 10% of industry standard for new construction, and overall household energy consumption at about 15% to 20% of standard. This goal correlates well to the 75% to 80% reduction in CO_2 emissions called for by leading climate scientists. Thus was born the Skyline House.

The client was a young family with two children. They had a steeply sloped site in Duluth, Minnesota, with spectacular views of Lake Superior, and they wanted to build a home geared toward generations of living to come. We defined three main environmental goals for this project: longevity, low energy use, and sustainability, and adopted a specific approach to achieve each of these goals (see Table 1).

Obstacles

Like any good design challenge, the project was not without obstacles. For the environmental goals set forth above, the chief obstacles were climate, site constraints, and the timing of the project. The climate in Duluth is often cold, with 9,800 heating degree-days per year. Solar exposure (insolation) is fairly good at the site, but it is sometimes compromised by the Lake Superior's cloud effect. Other site constraints included the steep slope, and a narrow lot. In addition, the best views were found at 30∞ to 45∞ east of south, which meant that the orientation best adapted to take advantage of these views was not ideal for passive solar. Finally, since Skyline House was not initially conceived of as a Passive House project, the timing for designing to meet this goal was not ideal. PHPP analysis and modeling were only begun after construction documents were under way.

Energy Modeling

The 2,660 square foot house, which has three bedrooms, two bathrooms, and an attached two-car garage, was first modeled with REM:Design. When the calculation showed an estimated peak heating load of 8 British thermal units per square foot (a number that roughly correlates to a 65% to 70% reduction in energy use compared to a code-built house of the same design), the clients and I began the discussions that led to us setting a goal for even higher performance—the Passive House Standard.

The client was interested in the Passive House approach, and excited about the prospect of improving the design to a level that might achieve Passive House certification. The house was modeled using the PHPP software package used for Passive House design and certification. The PHPP process starts with specific energy consumption targets, regardless of climate, and sums all envelope component and primary energy loads using specific building location climate data.

The detailed and extensive modeling approach led to some changes in envelope design, with the goals of approaching the Passive House Standard of 4,750 British thermal units per square foot per year. Already-aggressive insulation levels were increased in the ceiling, in the walls, and under the slab. The goal for airtightness was increased, and geothermal tempering loops were added to the design to preheat the incoming air for the mechanical ventilation system.

Since the attempt to meet the Passive House Standard began well into the design process, I was unable to make a few possible changes (in particular to site orientation) that might have made meeting these requirements easier. In addition, the recently translated software package contained some confusing language that may have contributed to my entering data incorrectly. Nonetheless, the PHPP software proved a valuable tool, and it helped guide the decisions needed to create an ultralow-energy house in a very cold climate. The PHPP-calculated energy for heating on the Skyline House is 23 kilowatt-hours per square meter—or 7,266 British thermal units per square foot—per year. The peak load with the PHPP-inspired changes was reduced to 6.9 Btu per square foot per hour. The final calculated heating loads in the Skyline House, with both REM:Design and PHPP, correspond to a reduction in energy use of about 75% compared to use for a house of the same size and design in the same location, built to Minnesota code. (See "Skyline House Basics.")


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A stone dining terrace abuts the west facade.

The design relies on a very high performance envelope and passive-solar heating to lower annual loads. Heat and domestic hot water are delivered with a whole-house combination system using a solar-thermal storage system with gas-fired backup. A geothermal ventilation air tempering system optimizes the use of renewable energies. Finally, an airtight wood stove with direct-combustion air supply provides another means of using a renewable fuel source to contribute to meeting the home's heating needs.

HVAC and Plumbing

Water for heating and plumbing is stored in two tanks. An 80-gallon tank holds domestic hot water, and a 275-gallon tank is used for thermal storage. A 48-tube (120 square foot) evacuated solar thermal array first heats the water in the smaller tank. When water in this tank reaches the set temperature, the solar thermal energy is diverted to the larger tank. The thermal energy stored in the larger tank can be transferred to the domestic hot water tank or used for space heating. The water from the domestic hot water tank runs through the on-demand water heater, which acts as a boost when the system needs a rise in temperature. One distribution loop from the thermal storage tank provides hydronic floor heat on the lower level and to the upper-level bathroom. A second loop distributes warm air to the upper level via the ventilation system.

Ventilation Strategies

Passive House Standards require mechanical ventilation with heat recovery. This is considered best practice in any case where the house is very tight and minimum use of

Skyline House Basics

Modeled Energy Loads for Heating

1. Peak heating load = 5.9 British thermal units per hour per square foot.
2. Annual calculated consumption = 7,266 British thermal units per square foot per year.

3. Total household calculated annual consumption = 19.3 million British thermal units per year.

Design Basics

- One-story house with lower-level walk-out
- 1,540 gross square feet per floor
- 1,330 conditioned square feet per floor (total 2,660 conditioned square feet)
- Attached two-car garage
- Three bedrooms, one on the upper level, two on the lower level
- Two full bathrooms, one up and one down
- Stacked levels, no cantilevers
- Bathroom and plumbing clustered and close to the mechanical room

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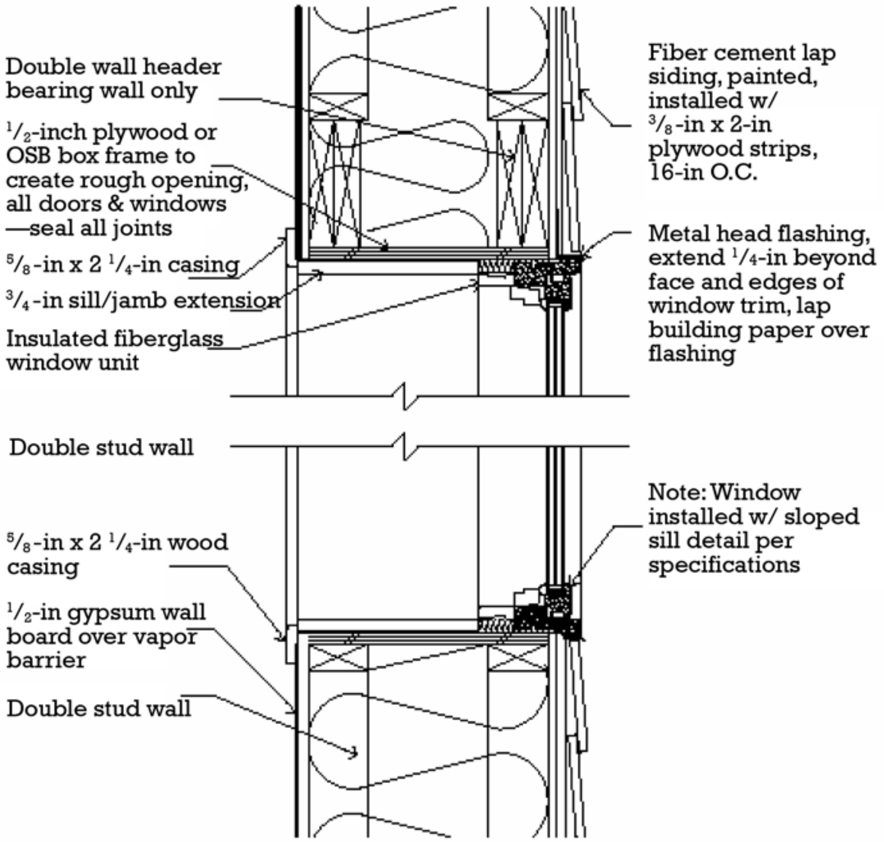
Insulated fiberglass window frames with triple-pane glazing allow solar gain and prevent heat loss.

Window Detail and Framed Wall



energy is desired. Controlled, whole-house mechanical ventilation creates a healthy indoor environment with the least energy penalty during the heating season. The Skyline House has a whole- house, balanced heat recovery ventilation (HRV) system with a high- efficiency HRV unit. Fresh air is delivered to all living spaces and exhausted from bathrooms and kitchen. An independent makeup air system was installed to balance the kitchen range exhaust.

Two geothermal loops of PEX tubing filled with a mixture of water and propylene glycol, one deep under the house slab and one underground outside the house, connect to a water-to-air heat exchanger in the outdoor air duct of the HRV to provide ventilation air tempering. This system pre-warms ventilation air in winter and pre-cools it in summer. Passive- solar design and good cross-ventilation reduce the need for air conditioning.

Getting the Details Done

Most of the construction methods and materials used in the Skyline House required only minor alterations to standard practice. Extra attention was paid during construction to airtightness, and to maintaining the integrity of the defined thermal boundary. The contractor and the energy and building performance consultant stayed in communication, and most potential problem areas were identified before detailed work was done in those areas. A smooth and successful construction process was made possible by ongoing communication between the trades and the design and performance consultants. The general contractor knew why envelope performance goals had been set so high, and he understood the client's priorities. He set the tone and the expected level of performance for all of the subcontractors, and he helped coordinate a process designed to facilitate excellence.

Airtightness was tested with a blower door test, with a measured air infiltration of .12 cubic feet per minute per square foot at 50 Pascals, or .93 air changes per hour at 50 Pascals. Construction was completed at the end of 2007, so comprehensive real-life energy data will not be available until after the 2007-2008 heating season. In the future, actual energy use will be compared to modeled energy use. I expect my clients—and their children and grandchildren—will be comfortable in this house for many decades to come.

Rachel Wagner is a partner at Wagner Zaun Architecture, which is based in Duluth, Minnesota.

For more information:

The energy and building performance consultant for the Skyline House was Conservation Technologies. The general contractor was J & R Sundberg Construction. To learn more about other Wagner Zaun projects, visit www.wagnerzaun.com.