Chapter 9:

Performance

I felt like I had died and gone to heaven. From sunrise to sunset we were bathed in natural light that even on cloudy days was enough to allow reading in almost every room. In November, sunshine filled the entire great room. By winter's solstice, as the sun hung low in the southern sky, rays reached across the great room and into the kitchen. On sunny days, the inside temperature rose into the 70s without lighting a fire in the woodstove or activating the heat pump, even though temperatures were well below freezing outside.

Large-as-life views through the picture windows brought nature close. Two substantial oaks and a gnarled but magnificent osage orange on the north side of the pond dominated the scene of field and woods that gently slopped over the 500 hundred feet to the wooded Plum Creek flood plain. At dawn and dusk, deer grazed in the meadow and around the pond. Common gray squirrels gathered acorns and maple seeds when not chasing each other around tree trunks or leaping from tree to tree. A dozen or more bird species flitted among the branches and pecked seeds on the ground. A pair of eagles routinely feasted on a deer carcass hidden in the trees southwest of the pond. Ducks and Canadian geese visited the pond. Occasionally, a great blue heron walked the shoreline in search of frogs and fish. We were cocooned, but still part of the world surrounding us.

Delighted, we eased into a more sane existence. However, despite our efforts and Strehles's best intentions, many small tasks remained—install door stops, ceiling fans, braces for the chimney pipe, and a board with hooks for coats, and replace incorrect LED lights (light emitting diode), a defective toilet seat, and the horrible sounding doorbell. Of course, nobody moves into a new house without a list of minor to-dos; but the decision to use our wood for flooring, the pantry counter and shelves, closet shelves, stairway bookcases, and kitchen and front porch beams meant that we had only transited to upscale house-camping from a sparsely furnished garage apartment. With no bookcases or shelves to fill, all our books and innumerable unpacked boxes remained in the barn. We slowly moved things into the house, but our approach was to think and plan first. We used the furniture we had. Virgin walls were a new experience; we wanted to hang each picture once.

Even though walls were bare, the pantry devoid of shelves, and the roof over the front porch held up by makeshift supports, we welcomed friends and strangers to see what we touted as an energy-efficient, environmentally appropriate house designed for the post-fossil-fuel world of the 21st century. But was it? My new obsession became collecting data and doing experiments to establish if performance matched prediction. Would the winter sun really heat the house when it was zero outside with a 40-mile-per-hour wind? Would the small woodstove keep the house warm? How much wood would we need to heat the house? Would the evacuated tube solar hot water system provide most of the energy to heat water as we were told, and I had assumed? And, being all electric, the biggest question was: Would we generate annually all the electricity used?

When the Oberlin city inspector activated the PV system on September 22, its production meter still displayed the kWh made in Troy: 5,167 kWh.

On the same day, the Oberlin Municipal Light and Power System (OMLPS) meter read 169 kWh, the electricity Strehle had used to date. On November 12, a few days after we moved into the house, the PV meter read 5,622, while the OMLPS meter was 99,910. The PV system had provided all the electricity that Strehle had used (365 kWh) and ran the meter backwards an additional 90 kWh. As satisfying as this was, the real question remained: What would the two meters read a year from now—November 12, 2009?

Over the summer I had made a quick calculation indicating that the Oberlin PV system would make 3,350 kWh, based on our production in Troy and about 6 percent less sunshine in Oberlin. In Troy, we had generated all the energy we used except that for hot water and heating. Believing the plug load of 2,050 kWh in Troy would be larger than ours in Oberlin, I projected 1,800 kWh for Trail Magic's plug load. I estimated heating and cooling at 500 kWh, air circulation at 200 kWh, and hot water at 750 kWh, for a total similar to that of production. This prediction, however, was fraught with unknowns, making success uncertain.

Our approach would be to use only what we needed and to know how much electricity each device used so that we could avoid waste. I had purchased a Kill-a-Watt meter in Troy to do the same. The item in question is plugged into the Kill-a-Watt meter, and the meter plugged into an outlet. I measured the Watt flow at Trail Magic for everything that had a plug: internet connection, 14 Watts; laptop computer, 20 Watts running and 1 Watt on standby; wireless router, 2 Watts; laser printer on standby, 1 Watt; TV, 75 Watts on and 1 Watt on standby; phone charger, 1 Watt when charging and no measurable reading otherwise; kitchen radio-CD player, 1 to 4 Watts depending on volume; stereo system and CD player, 30 to 100 Watts depending on volume. This knowledge affected our behavior. We can clearly hear the kitchen radio-CD player in the great room, so we routinely use the kitchen radio instead of the stereo that uses 10 to 50 times more electricity. When the computer, printer, internet connection, and router are on but not in use, 18 Watts are flowing. This doesn't seem like much electricity, but 18 Watts 24/7 for a year is 160 kWh or 5 percent of our projected PV production. We have them on only when we are using them.

Sidebar 12:
Plug Load, Baseline Operating Energy, and Phantom Load

The plug load is the electrical draw of all devices that are "plugged" into the electrical system of a house except for items like the furnace, AC unit, and hot water heater. The baseline operating energy for an all electric house is that part of the plug load that is never turned off (e.g., refrigerator, freezer), as well as the furnace in winter and AC unit in summer. Within the baseline operating energy is the phantom load or the electrical draw of equipment on standby (garage door openers, TVs, computers, internet routers, ceiling fans) or devices performing functions like microwave and stove clocks. When residents are at work, or on vacation, the electricity used is the baseline operating energy. If the house is not all electric, then gas or oil used would also be part of the baseline operating energy.

Refrigeration is a substantial part of plug load. We wanted a freezer for garden produce and bulk purchases. I had read that a refrigerator without a freezer is more efficient than a similar sized refrigerator with a freezer. Thus, we decided to purchase a refrigerator with no freezer and a modest sized chest freezer. When I measured the energy used over three several day periods, the refrigerator had a projected annual use of 150 kWh and the freezer 230 kWh. This 380 kWh for 18 cubic feet of refrigerator space and 13 cubic feet of freezer space was good news because we had used annually over 400 kWh for 21 cubic feet in an Energy Star refrigerator in Troy that included a freezer compartment.

Although compact fluorescent bulbs had substantially reduced our electricity use for lighting in Troy, LED bulbs cut Watts per lumen by another 70%. That is, the amount of light from a 100 Watt incandescent bulb equals that of a 30 Watt compact fluorescent bulb or a 10 Watt LED bulb. LED bulbs were just becoming available, and to save electricity we put two, 12 Watt, dimmable LED bulbs in the entry way and one in the pantry. They are bright and provide the equivalent of a 120 Watt incandescent bulb. With a predicted lifespan of 50,000 hours and with usage of but a few hours a week, someone will replace them in the middle of the next century. At $75 each, however, they were expensive.

To continue our experiment with LED bulbs, I purchased seven lower Wattage bulbs online. Each of our stairways is well lighted with two 2.3 Watt LED bulbs, one directed up from the landing between floors, the other down. Because LED technology is advancing rapidly and prices are coming down, we are waiting a few years to finish the fixed lighting in the kitchen and great room, as well as to change out the rest of our frequently used, compact fluorescent bulbs with LEDs.

With all the lights in the house turned on, we flow 500 Watts from 30 compact florescent bulbs (306 Watts), 8 tube florescent bulbs (112 Watts), 10 LED bulbs (52 Watts), and one incandescent bulb (30 Watts)—or the equivalent of five, 100 Watt incandescent bulbs. We normally turn lights on only when necessary. When we go out at night, we turn on two, 2 Watt LED bulbs that cast light in the kitchen and great room. During the day, even on cloudy days, we rarely need to turn on a light because the house is so well daylighted.

It is impossible to know with any precision how much electricity we save because of excellent daylighting, but it is most likely hundreds of kWh. We can, however, crudely estimate the combined effects of house design, bulb choice, and our behavior on the amount of energy we use for lighting. According to the U.S. Department of Energy, the average US house annually uses 110 million BTUs of energy, of which 11 percent is for lighting. This would be 3,500 kWh for lighting. The average house has 2.5 people, so we would be expected to use annually 2,800 kWh. If we had all of our lights on for one hour each day, we'd annually use 183 kWh, but our use is less, likely under 100 kWh, for an annual savings of 2,700 kWh (9 million BTUs), or $270 at $0.10/kWh. In terms of carbon dioxide reduction, it would be 5,400 pounds at 2 pounds/kWh in Ohio.

Although our children and their families had been through Oberlin to see the property, they had not seen the house. They all came for a week at Christmas: Stuart's family of five and Virginia with her partner. Every room, except the great room and kitchen, became a bedroom—two rooms are furnished as bedrooms, two rooms have a Murphy-like fold down bed, and we can put a bed in the ground floor family room. The great room was the center of all activities, including meals together. Although we call it the great room, it is only 12 by 22 feet, or 264 square feet; however, the woodstove hearth comes out 5 feet from the wall, reducing usable space to about 200 square feet. We coveted a larger room!

In January, I turned my attention to finishing our LEED application. The previous May, our LEED team had met several times to go over the various forms and submit them to the provider. In June, we asked the provider to clarify some items in the LEED for Homes Project checklist, mostly concerning definitions and unclear specifications.

With Ferut and Strehle versed on LEED requirements, Mary and I focused on getting the three LEED points for excellent waste management. In August, the green rater's pre-drywall inspection uncovered no problems. Throughout the fall I reviewed and updated the LEED checklist.

Trail Magic was Strehle and Ferut's first LEED project, and my first time building much of anything. To save money, I had taken on the responsibility of team leader. Concerned about receiving every possible point we had earned, I wanted perfection in preparing our final LEED checklist. To avoid problems, I prepared for the provider and green rater detailed documentation for each category and subcategory, indicating what we did or didn't do, along with our explanations and the points earned. In early January, I emailed it to Borton, Ferut, Strehle, and Watson for corrections and suggestions. After his comments and suggestions, Watson wrote, "All in all, a splendid effort that LEED, among others, should dance and shout around."

Normally, the USGBC requires 90 points for LEED platinum, but because Trail Magic was small for a five-bedroom house, we needed only 85. Our tally was 94 points earned with 5 more points in question. We had reached platinum level with some to spare!

On January 14, I emailed the provider and green rater the 15 pages of documentation for their comments and suggestions before polishing our checklist in preparation for the green rater's final inspection. I was shocked by the reply from the provider the next day. They could not certify our project under the LEED for Homes program because we had failed to meet a few prerequisites. How could that be?

Apparently, we had incorrectly interpreted the LEED for Homes Rating System manual. Because of the way in which the manual presented the prerequisites and because nowhere in the manual was it explicitly written that certification would be denied without every prerequisite met, we believed that the program required prerequisites in a particular category only if you sought points in that category. Anybody who has been specifically trained in the LEED process wouldn't think such an interpretation possible. But I was so overwhelmed at the time that I believed we had some choices, and neither Ferut nor Strehle caught my mistake. In fact, it appeared that they had come to the same interpretation on their own.

This misunderstanding was solidified in our minds because some of the requirements weren't best practice or even appropriate in our case. One requirement—to install in all bathrooms a fan that exhausted to the outside—we didn't meet. We had decided that an exhaust fan in the half bath was inappropriate; it served no need that a window couldn't serve, and it put a hole in the envelope, allowing unnecessary air movement through the wall. In previous houses, we'd had kitchen fans that exhausted directly to the outside, but they were ineffective at clearing smoke and smell when something burned or when moisture occurred from canning. Instead, we'd open doors and windows. Therefore, we decided that adding another hole in the envelope for a kitchen exhaust fan was not best practice. Achieving a tight house was our top priority.

Neither did we use metal ducts for return air in the ventilation system. Strehle and Ferut believed that using wall plenums (the space between wall studs) for return air instead of metal ducts presented no health or safety concerns as long as we kept the plenum ducts clean and dry during and after construction. Plus, we had a very simple, compact ventilation system with just six return ducts.

Both of these prerequisite failures should have been obvious to the green rater when he'd made his pre-drywall inspection the previous August. That he didn't tell us otherwise affirmed how we'd interpreted the LEED for Homes manual. Because we believed we had flexibility in meeting prerequisites, we decided for energy efficiency and environmental lifecycle costs to forgo points in several categories.

Immediately upon having the provider reject our LEED application, I contacted the entire team. We decided to send a letter to the provider explaining our interpretation of prerequisites and requesting that our application go forward for LEED certification. First and foremost, we noted that the green rater hadn't told us of our prerequisite failures which were correctable then. Second, the presentation of prerequisites in the LEED for Homes manual led to our initial misinterpretation.

In response, the provider stated: 1) he could not forward our project to USGBC for certification under "special circumstances" and 2) neither providers nor the USGBC trained or certified green raters. With this absolute refusal, we appealed the provider's decision with the USGBC on February 4, 2009. A USGBC representative interviewed me on the phone for more than an hour on April 22. He told me that ours was the first appeal in the LEED for Homes program.

During the conversation I explained that the house had been inspected and tested for the Energy Star program and had earned the highest rating, Five Stars Plus. He had interviewed the provider and would interview the green rater and the Energy Star inspector before meeting with the LEED technical group and would get back to me with the decision as soon as possible.

Having heard nothing by July, I called the LEED representative and left a message. Several days later he sent me an email indicating a decision in a week. Over the next five months, I made several inquiries, but still silence. In early December 2009, we received the decision.

Dear Mr. McDaniel,

Thank you for contacting the U.S. Green Building Council, Inc. (USGBC) regarding your LEED for Homes project located at 495 E. College Street, Oberlin, Ohio. We greatly appreciate your commitment to educate others regarding sustainable building practices, and also your enthusiasm towards building a net zero home.

In response to your request for appeal, I regret to inform you that USGBC does not offer a process for appeal at this time. While USGBC does maintain a process for accepting and reviewing appeals, such processes are only available to project teams only after a completed application has been submitted (through a provider) and has been denied certification by USGBC to deny certification based on an extensive third party review of an application and all submitted documentation. At this time, your application for certification has not yet been submitted, and thus your current request for an appeal is premature.

You commented that you believe the LEED for Homes rating system is not clear regarding prerequisites. While the LEED for Homes ratings system is certainly complex, it, like all LEED rating systems, is comprised of a series of prerequisites and credits arranged by category. Within categories are contained both prerequisites and credits. Prerequisites constitute mandatory design and performance elements that must be achieved. The mandatory nature of these requirements is clearly and consistently communicated throughout the materials associated with the LEED for Homes program. USGBC will only award certification to the extent that a given project can demonstrate compliance with such requirements.

USGBC has instituted a "credit interpretation request" (CIR) process to permit project teams to ask for clarification of credits and prerequisites. The CIR process allows project teams to submit proposed alternative designs that satisfy the intent of a particular credit or prerequisite though deviate from the suggested method of achieving the same as identified in the LEED for Homes rating system or reference guide. CIRs may be submitted at any time following project registration and are reviewed by volunteer based USGBC Technical Advisory Groups. Your provider should be familiar with this process. Please note however, CIRs are seldom granted unless a project is physically or legally unable by legal mandate or other compelling unique circumstances to meet the prerequisites or credits as they are identified in the rating system.

It appears based on conversations you have had with USGBC homes staff, that there has been a fair amount of failed communication concerning your project between and among the project team, the provider and Green Rater. USGBC providers are well versed in LEED for Homes Rating System. Further, there are many other persons who are knowledgeable and qualified to advise you on how to satisfy credits and prerequisites, as well as comply with the program requirements and procedures. Should you choose to continue to proceed to seek LEED certification for your home, we recommend that you seek the counsel of an experienced practitioner to help guide you.

On behalf of the U.S. Green Building Council, I want to thank you for your dedication to furthering the green building movement.

Regards,
Susan E. Dorn
Legal Counsel, U.S. Green Building Council, Inc.

Despite our best intentions and persistent efforts, LEED platinum certification was placed out of our reach.

We debriefed the LEED experience in order to know how attempting LEED platinum certification had influenced what our team had done in designing and then building Trail Magic. Watson encapsulated our assessment, "LEED made no difference to me. What I did with your house was not influenced by LEED criteria. I'm an observer of LEED. A lot of what they say is helpful in raising the bar. It takes the bad to good. It does not take the good to excellent. Our goal was excellent. We knew how to achieve the good. We didn't have to be told." However, we all did agree that we were motivated, especially Strehle, Mary, and me, to push the envelope on waste reduction because of the real challenge by LEED to earn all three points.

What could have been a win-win situation became a lost opportunity. LEED could have had a positive energy, climate positive home to its credit, and Trail Magic could have received the imprimatur of LEED platinum. The media attention alone would have opened opportunities to promote efficiency in energy and resource use with off-the-shelf technologies in addition to highlighting replicable design choices, building procedures, and behavioral choices that can make both new and old homes positive energy and climate positive.

Over the first two years, I conducted many experiments and collected data that I thought would give insight into what we had and had not accomplished. My goal? To enable others to replicate our successes and avoid our failures.

I was excited about our solar hot water system, so was shocked one day when I saw that the water temperature in the storage tank dropped from 122˚F to 95˚F overnight, even though we hadn't used any hot water. Our "top-of-the-line" hot water tank was terrible.

I contacted the subcontractor, who agreed to add insulation to the tank. I measured the temperature drop in the storage tank over a dozen times, determining that the average temperature drop was 3˚F per hour. After the added insulation, which was rated at R-21 and probably tripled the tank's initial insulation, the temperature drop rate deceased by 50 percent to 1.5˚F per hour. Clearly, hot water tanks for homeowners are poorly insulated. Most of the energy used to heat the water escapes into the surrounding room.

Hot water at Trail Magic is heated in a combined evacuated tube hot water system that preheats water with sunlight and an electric on-demand heater. Copper in the evacuated tubes on the roof absorbs heat from sunlight that transfers to a glycol solution that is then pumped to a heat exchanger in the mechanical room where the heat in the glycol moves to water in an 80-gallon storage tank. When we require hot water, the solar heated water in the storage tank flows to the on-demand electric heater, where the water heats to the desired temperature, 111˚F in our case. If the preheated water is over 111˚F, the on-demand heater stays inactive.

We had selected the combined systems because we believed most of the energy to heat water would come from the sun. I could estimate the amount of energy provided by the sun if I knew 1) the amount of electricity used by the on-demand heater, 2) the electricity used to pump fluids in the solar hot water system, 3) the temperature of incoming water, and 4) the amount and temperature of hot water used. The subcontractor also wanted to know how his system performed. He agreed to install a water meter on the inflow pipe to the storage tank, if I acquired a meter to measure the electricity used by the on demand heater. I collected data for six months, from August 2009 to February 2010. The results were not what we expected. A mere 7 percent of the energy used to provide hot water comes from sunshine (28 kWh or $2.80). What had we failed to consider when designing the hot water system?

First, we designed and equipped Trail Magic to conserve hot water. Low flow shower heads provide 1.5 gallons/minute while bathroom faucets deliver 0.5 gallons/minute. The clothes washer is a front loading machine that uses 2 gallons of hot water per regular cycle when put on the cold water setting. The dishwasher uses 5 gallons of hot water per regular cycle. Mary and I take showers that consume between 4 and 8 gallons.

These design features and our demands have led to an annual hot water use of 3,000 gallons. This compares with the annual average hot water use of 8,000 gallons by U.S. couples over 60 years old.

Second, the pumping of fluids in the solar hot water system uses a substantial amount of electricity, 200 kWh annually. This compares to an annual use of 100 kWh by the on demand heater.

The decision to install this combination of hot water systems is even more embarrassing. A theoretical calculation indicated that the total amount of energy needed to heat 3,000 gallons of incoming water to 111˚F is about 1.4 million BTUs, or $41 of electricity. Even if we used the average annual amount of hot water for our age group, or about three times more than we do, it would cost about $123 if heated solely by the on-demand heater. After two years we had the evacuated tube system removed and actual measurements indicate 360 kWh or $36 for heating the 3,000 gallons of hot water we use annually.

From the collected data and our analyses, we now know that the most energy efficient and cost-effective hot water system for us, and for many single-family homes in climates similar to that of Oberlin, is an on-demand heater fed from a large, uninsulated storage tank—an uninsulated tank reduces heating energy because cold, incoming water equilibrates to room temperature before going to the on-demand heater.

The features that curtailed our hot water use, along with dual flush toilets that use 0.8 and 1.6 gallons/flush, reduced our indoor water use to 26 gallons/day or about 9,500 gallons/year. This compares to the average annual use for two U.S. people of 50,000 gallons. This data for hot and total water use at Trail Magic indicates that modern technology and water-conserving behaviors can reduce water consumption by 80 percent.

Sidebar 13:
Water Conservation Reduces Energy Use and CO_2 Release

Rumi Shammin in Oberlin College's Environmental Studies Department calculated the energy to take a gallon of water from the Black River, make it potable, deliver it to a home, and return it to the Black River after treating it in Oberlin's wastewater plant at 86 BTUs or 25 Watts, resulting in the release of 0.013 lbs of CO_2.

Trail Magic uses 9,500 gallons per year or 40,500 gallons less than the average two-person home, thereby resulting in an annual savings of 3.5 million BTUs or 1,010 kWh, and a reduction in carbon dioxide release of 530 lbs.

Although I had resisted installing a central heating and cooling system, believing that the Borton model of relying on several baseboard electric heaters for supplemental heat was right for us, I was convinced by others, even the Bortons, to put in a central system. Strehle is an advocate of ground source heat pumps, and we ended up with a heat pump using the pond as a heat source and sink.

To heat in the winter, the heat pump takes heat from the pond and puts it in the house. To cool in the summer, the heat from the house transfers to the pond. Ground source heat pumps are very efficient, using 1 BTU of electrical energy to move 3 to 4 BTUs of heat energy. In contrast, a high-efficiency gas furnace will use 1 BTU of energy to provide 0.97 BTU of heat: 97% efficient.

I've always loved a wood fire. For almost three decades, Mary and I have used a woodstove for some of our heat. With a high-performance, passive solar house we expected our small, soapstone woodstove to provide all our heat. Even though Oberlin had an unusually cold winter, we used about a cord of wood the first winter. Our second winter was milder, but January and February 2010 were very cloudy—over 60 days without a day of full sunshine. Again, we used about a cord of wood. With two acres of trees on the property, an annual harvest of one cord is easily sustainable.

We had installed the pond source heat pump as a back up, especially for when we aged and might not be able to manage the woodstove. A theoretical calculation using the average degree heating days for the past four years indicated that it would take about 2,600 kWh annually for heating, assuming no solar heat gain. In February 2010, we ran the heat pump for 9 days and measured the kWh that we needed to maintain the house temperature at a constant 68˚F. The data indicated that it would take about 2,100 kWh annually for heating, or $210 at $0.10/kWh. The lower value in this empirical assessment likely resulted because of modest passive solar heat gain over the nine day experimental period (six of the nine were totally cloudy while the other three were mostly cloudy).

Although it is extremely difficult to measure or calculate solar heat gain because of so many uncontrollable variables, we know it is substantial. Greenhouses become hot because of solar gain. Even on a sunny winter day, a car parked in the sun with closed windows will get toasty warm. We measured temperature gain on several winter days with the heat pump off and no fire in the woodstove. On January 16, 2009, at 10 a.m., the temperature was 62˚F inside and -10˚F outside. All day the sun sparkled in a crystal clear blue sky, and there was no noticeable wind. At 2 p.m. the temperature had risen to 68˚F inside and 0˚F outside, for a house temperature gain of 1.6˚F/hour. We also measured heat loss at night with no internal heating. On January 23, 2009, at 9 p.m., the temperature inside was 70˚F and 6˚F outside. It was a calm night, and at 8 a.m. the next day the inside temperature was 62˚F and 1˚F outside, for a temperature loss of 0.7˚F/hour. A second observation established that Trail Magic is so tight that wind has little effect on heat loss. On December 21, 2008, at 9 p.m., the temperature inside was 70˚F and 0˚F outside. A constant wind of 20 to 40 mph blew all night. At 8 a.m. the next day the inside temperature was 61°F and 5°F outside, for a house temperature loss of 0.8°F/hour. These data indicate that full sunshine provides sufficient energy not only to offset heat loss, but also to warm Trail Magic to a comfortable temperature when the temperature difference between inside and outside is about 65°F.

Our first summer at Trail Magic was cool, with few days that merited air conditioning. The second summer was hot. I ran a five day experiment to assess the annual kWh required to keep the house at a constant 75°F in summer; 910 kWh, or $91.00 at $0.10/kWh. We did not open windows for passive cooling during the experiment; however, the wind tower design feature suffices to keep the house cool except for a few afternoon hours on days over 90°F.

During our first two years at Trail Magic we've used the heat pump to determine that we could annually heat and cool with 3,010 kWh, or $301 at $0.10/kWh. Our actual annual cost was perhaps 100 kWh of PV electricity for heat pump cooling and heating and a gallon of gas for the chainsaw to cut a cord of firewood. And we do run the air circulator many days which uses 0.4 kWh per day, or annually perhaps 100 kWh.

The National Climatic Data Center ranked 174 cities according to their annual percentage of possible sunshine. At 90 percent, Yuma, Arizona, is first. Juneau, Alaska, at 30 percent, is last. Cleveland, Ohio, is in the bottom fifth, at 49 percent. Most of Oberlin's possible sunshine comes from March through October, so we fully expected the electric meter to run forward in the winter. Our OMLPS meter hit its record high reading of 350 in the second week of February 2009. Although this meter reading told us that we had used 440 more kWh than we had produced since occupying Trail Magic, our average daily use of 6.9 kWh meant that we were on track to produce more electricity than we used.

On November 12, 2009, the OMPLS meter read 98,997 kWh and the PV meter read 8,814 kWh. We had used 2,279 kWh and made 3,192 kWh. On-site sunshine had provided more than 100 percent of the operating energy. We hadn't used any fossil fuels, and 913 kWh had been sent to the grid.

Trail Magic is a positive energy and climate positive home!

This achievement is testimony to Watson's exquisite schematic design, to Ferut's superb detailed design plans, to Borton's practical knowledge of physics and solar energy, and to Ferut and Strehle's professional excellence in executing the building of Trail Magic. Our success demonstrates that people can build high-performance houses using off-the-shelf technologies and building practices available to everyone.

We had accomplished the first of two primary objectives. Our second was to demonstrate that making a home positive energy was affordable and similar in cost to standard construction (see Appendix D for details). Trail Magic cost $146 per square foot of conditioned space (heated), an amount not different from that for a quality, custom-made house in northern Ohio that purchases its operating energy. Trail Magic has many upscale features including a metal roof, a sun patio, Hardiplank siding, Loewen windows, a rainwater cistern,

Sidebar 14: Annual Operating Energy in Million BTUs for Average Household and Trail Magic

Energy Category[1]	*Average Household*	*Trail Magic (all supplied by the sun)*	*% less (more) for Trail Magic*
Heating	34.1	20 with wood	41
		7 with heat pump	79
Cooling	13.2	0.3	98
Water Heating	13.2	1.3	90
Lighting	12.1	0.3	98
Refrigeration	8.8	1.4	84
Total for below items:	28.6	4.2 (electronics, clothes washer and dryer, dish washer, computers, other)	85
Electronics	7.7		
Clothes washer & dryer and dishwasher	5.5		
Computers	1.1		
Other	14.3		
Purchased Energy	110	none	100[2]
Passively Acquired Energy	small	20 (heating, 15; lighting, 5)	(~100)[3]
Total Energy	110	48 with wood heat	56
		35 with heat pump heat	68

[1]For the electrical energy in the various categories, BTUs purchased by a household from the grid and those produced by Trail Magic's PV system have different amounts of embodied energy. That is, to get energy and change it to a grid Watt-hour is about 3 times the energy available in a grid Watt-hour, while the energy to produce a PV Watt-hour is from sunshine and essentially all of it is directly available for use. Therefore, although Trail Magic uses 25% of the electricity used by the average household in Oberlin (2,400 kWh [annual amount Trail Magic uses] vs 9,500 kWh [Oberlin average annual household use]), Trail Magic actually uses 6% of the energy used by the average Oberlin home for electricity (2,400 kWh × 3412 BTUs/kWh = 8 million BTUs vs [9,500 kWh × 4] × 3412 BTUs/kWh = 130 million BTUs). The carbon emissions from the production of the electricity generated by Trail Magic's PV system are only from the indirect energy used in producing, transporting, and installing the PV system that is embodied in each kWh, which is less than 10% of the total embodied carbon emissions associated with the production of an Oberlin-grid kWh. Trail Magic heats its water with renewable solar electricity while many Oberlin homes use natural gas, a non-renewable fossil fuel.

[2]Trail Magic's operating energy is 15 million BTUs with heat pump heat and 28 million BTUs with wood heat, if the BTUs of passive heating (15 million BTUs) and daylighting (5 million BTUs) are not considered. Woodstove heating is inefficient compared to ground source, heat pump heating (geothermal); however, it requires much less material and technology. This operating energy for most homes would be purchased energy. Trail Magic's operating energy, if purchased, would be 14% ([15 million BTUs ÷ 110 million BTUs] × 100) or 25% ([28 million BTUs ÷ 110 million BTUs] × 100) of the average home and 8% or 15% of the 180 million BTUs for the 2007 operating energy of our home in Troy, NY (see Sidebar 1). These comparisons establish that design features and off-the-shelf technologies combined with behaviors that conserve resources can reduce home operating energy use to 25% or less of that used by the average U.S. home, and all of this energy can be provided by the sun in northern U.S. climates.

[3]About half of Trail Magic's total annual operating energy of 35 million BTUs, or 48 million BTUs, is acquired passively from sunlight (20 million BTUs). The investment to acquire these 20 million BTUs is close to zero, because they result from design features—long axis oriented east-west, most windows placed on south side, and shading devices like roof overhangs and trellises. These 20 million BTUs save $400 per year (20 million BTUs × $20/million BTUs). No income tax is paid on these dollars, meaning another $100 is saved. Assuming the house lasts for 100 years, the lifetime savings provided by passive solar will be $50,000, a huge return on the small investment (see Appendix D: Cost Analysis for Trail Magic). In addition, over the same time period, passive solar heating and daylighting will prevent at least 130 tons of CO_2 from being released to the atmosphere compared to using natural gas.

and custom lumber for floors, shelves, bookcases, and beams that do not enhance its energy efficiency. If these features are omitted or replaced by ones that provide similar energy efficiencies, the cost per square foot becomes $110, the price for a development house. We have established, contrary to common belief, it not only costs nothing extra to build a house that runs on sunshine, but also to do so pays handsome dividends, because operating energy is free sunshine.

We have given many talks on Trail Magic to the local community, and even presented a short course on the project at Lorain County Community College. People are uniformly surprised and enthusiastic about our huge reductions in water and energy use, and are impressed that sunshine provides total operating energy. But, the conversation always turns to what can we do with existing houses. Although many people have made improvements in their homes by replacing incandescent bulbs with compact fluorescent bulbs, weather stripping doors, or adding insulation, we seldom see documentation or publicity stating the costs, savings, and environmental consequences.

Our good friends in Troy, Margaret and Howard Stoner, who live in a typical 1950s house, listened to Borton and me talk about climate change and read environmental books that we recommended. They observed how we had reduced our energy footprint with simple conservation measures—compact fluorescent bulbs, night setback thermostats, turning off lights—and by replacing old appliances, heating with wood, and installing PV systems. In 2006, the Stoners had heard enough and decided to do something.

The Stoner house is a conventionally constructed, 1,200 square foot, one-floor dwelling with a full basement that in 2005 used 127 million BTUs of natural gas and electricity for a cost of $2,450. The next year they began simple conservation efforts: installed electric strips so computers, TV, and other devices could be turned off easily and not use electricity while on stand by; and they turned off lights in unoccupied rooms. In 2007, they installed a programmable thermostat, put plastic covers on their windows in winter, installed compact fluorescent bulbs, started using a clothes line instead of an electric dryer, and had a thorough energy audit, including a blower-door test to assess air tightness. The next year Howard caulked every crack and air leak in the house that he could find, removed the attic exhaust fan in winter and insulated the ceiling hole, insulated his basement walls and the attic floor, and hired a company to insulate first-floor walls. Blower-door tests before and after these caulking and sealing measures showed a 60 percent increase in envelope tightness. The cost for these improvements was $5,500 minus $400 in subsidies. These measures reduced the Stoner's annual energy consumption from 127 million BTUs to 57 million BTUs, or a savings of $1,400. Because they don't pay taxes on this $1,400 that they would have had to earn, the actual savings is closer to $1,900. In three years the cost of the improvements will be paid back, and the Stoners will have an annual dividend of $1,900 at current energy prices for as long as they live there. If I offered you a guaranteed 33 percent return on a $5,000 investment, you'd think it was a scam, but it isn't. It is a personal, high-return investment you can make in your home today.

The Stoners also accepted the scientific consensus that human activities are a major factor in changing the climate. To reduce their carbon footprint even more, they installed an airtight wood stove to heat their house, an efficient gas-fired boiler for hot water and backup heating, and a 3.3 kW PV system. These items cost $45,200 minus $20,000 in subsidies and tax credits, making their cost $25,200. For the past two years, the PV system produced all the electricity that they used, and the only fossil fuel that they burned each year was 180 therms of gas equivalent to 18 million BTUs and 2,160 pounds of carbon dioxide. Because their PV system produced 3,400 kWh of electricity that were not generated by the power company, they prevented the release of 6,000 pounds of carbon dioxide, *thereby making their home climate positive and essentially positive energy* (they collect firewood off site).

The simple measures taken by the Stoners to weatherize their house, along with their easy-to-replicate conservation measures, establish that we can significantly reduce home energy use at a profit. The major changes they made demonstrate that a family does not have to build a new home or spend an extravagant amount of money to create a climate positive home.

As impressive as the numbers are for the Stoners' house and for Trail Magic, the data I've presented for Trail Magic are but the easily quantifiable part of the performance story. Although we know passive solar gain is substantial, it is not easy to assess. Borton has attempted to measure his house's passive gain for years without consistent results. Likewise, he can only estimate Trail Magic's passive gain. Interestingly, it is the design features that foster passive solar heating and daylighting that also significantly enhance the quality of life for those living in a passive solar house. And, similar to solar gain, we cannot precisely know how much the quality of life is enriched.

I am a scientist, an animal and plant developmental biologist by training. For several decades I grew plants, and conducted experiments in the university's greenhouse. Merely walking into the greenhouse made me feel good, and on numerous occasions, when I was feeling down, especially in the winter doldrums, I'd find an excuse to go there. The intensity of natural light, even on a cloudy day, along with the rich green of the plants, positively affected me. On occasion, I'd bring a paper to read or change my plans and find something to do in order to remain longer.

At the other extreme, I moved into what had been a janitor's storeroom for my office during the renovation of my laboratory that had three, large, south facing windows. Several fluorescent tube lights lit the closet. Within a few weeks I felt poorly, tired, and lacked my normal motivation. I spent as little time there as possible.

We evolved in a world of sunlight that at dawn ever so slowly increases in intensity until it brightly illuminates our world, only to change once again by ever-so-slowly decreasing in intensity as sunset becomes dusk, and dusk merges into night. Eons have honed our genes to prescribe physiologies acclimated to these changes and to daylight itself. Sunlight and its patterns of change are elements of our habitat—what we would choose if we had a choice.

A well-designed passive solar house enables its residents to return to the world of their origins. When we entertain guests, we often eat at sunset. The two windows high on the west wall brightly illuminate our kitchen and great room until the sun descends behind the barn and the rooms darken slowly. More often than not, we continue talking and eating until, all of a sudden, we realize it is dark. Apparently, the change in light intensity is so natural that we don't notice it.

In the morning, we rarely turn on a light. Our bedroom and the great room have south-facing picture windows that allow enough light to fix breakfast or complete other morning tasks. In the winter, we often enjoy the softness of candle light at breakfast and the gradual brightening of the house feels normal. On days both cloudy and sunny, the natural light and the views through the picture windows combine with our high ceilings to create an illusion of being in the natural world—a place not bounded, but open.

Sunny days are spectacular, visually and thermally. Even when temperatures are below freezing outside, the house warms degree by degree into the high 60s or low 70s by early afternoon. As the sun eases toward the horizon, the indoor temperature slowly settles back. We may or may not light a fire in the evening, depending on mood and the likelihood of another sunny day.

The great room is lighted from different directions depending upon the time of day, but always well and evenly. Direct sunlight creates definitive shadows which move across the room and define the space, like tree shadows on a savannah.

I don't believe these lighting conditions are conducive to seasonal affect disorder, but rather promote emotional and physical health. Thermally and visually, a passive solar house is a place of gradual change that enchants our senses that were honed long ago by evolutionary forces. In more than a poetic sense, we have come home.

Our thick walls and roof exclude urban noise, and the absence of internal mechanical sounds leads to persistent quiet when the windows are closed. This silence was likely more common in our hunter-gatherer habitats than in modern human settings. Neither Mary nor I mind the deep quiet in cold weather. Perhaps it is calming and healthful. Unfortunately, the thick envelope also excludes the sounds of wind and rain; but, warm weather nights with passive cooling are delightfully filled with choruses of birds, insects, frogs and toads. Of course, I do not claim that these particular connections to the biological world are unique to passive solar houses. However, with all windows shut during the five day experiment to assess cooling cost, we missed the night sounds.

Living at Trail Magic is also enriched by design features that evoke aesthetic feelings and emotional pleasure. Ferut and Watson are the people whose profession brings visual beauty to a structure, and Trail Magic, despite my proclivity for the practical, is aesthetically pleasing. I know that Ferut and Watson employed centuries of acquired principles to the task, but for the most part, they are hidden from me. I do know that the house is attractive and looks right, inside and out. Ferut created a railing system for the deck that meets safety requirements and is elegant in its simplicity; powder polished iron railings that undulate between wooden posts permit views of the pond, trees, and field that are sensually pleasing. The colors of the roof, siding, trim, and doors flow easily with each other, and with the landscape, but cleanly define elements of the house. The placement and size of the windows not only light the rooms well, but also effortlessly bring the inside and outside worlds together. Rooms feel much larger than they are, especially the kitchen-great-room complex and master bedroom.

Although Watson and Ferut and his associates deserve most of the credit for Trail Magic's beauty, the wood from our land in the hands of George Ficke truly brought a special, unique touch to our home. The mixed colors and grains of ash, maple, and red, white, and black oak on the first floor bring new meaning to the elegance of hardwood floors. The ash flooring on the second floor holds its own with a pleasing blend of light sap wood and various shades of brown heartwood, all accented with diverse patterns of grain.

The large ash beam that visually divides the kitchen from the great room features dark and light hues of grain that complement the floor, the rustic-alder kitchen cabinets, and the Douglas fir window casements. The inch-thick-ash pantry shelves are overkill for storage space—canned goods and paper towels are rarely, if ever, so attractively stored. The white oak beams that now support the front porch roof are engaging and accent the front of the house with a finish of fine furniture.

The crowning jewel of Ficke's woodworking and Strehle's carpentry skills, however, are the stairway bookcases. Mary had found a picture of a stairway bookcase, and it became the best space-saving idea we brought to the design process. In spring 2009, when our wood was drying in the kiln, we considered many possible designs for the bookcase, but soon agreed. The casement boards and shelves would each be a combination of four species—ash, oak, maple, and black walnut. As we discussed the spacing of shelves and whether or not to make them adjustable, Ficke suggested black walnut for the facing edge of each casement board and shelf. "It will be spectacular!" he said. Instantly, we all knew he was right. The stairway bookcases are the most elegant, eye-catching feature in the house.

I write this chapter on performance from the desk in the dormer study feeling good about what we accomplished. I am also deeply humbled because I know well that it is not my or our doing. It is an ongoing culmination of the genius and hard work of many people over the centuries that made it possible for us to bring it all together, allowing Mary and me to live well in a home not estranged from the world in which humanity evolved.