Getting to zero – Experiences of designing and monitoring a zero-energy-building: The Science House in Minnesota

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Abstract

The challenge of the Science House at the Science Museum of Minnesota was to create habitable, cold climate architecture that would result in a zero net energy building. The team used science to exert an authoritative influence to resolve design conflicts—at the intersections of functionality, aesthetics and performance. The team needed to significantly reduce annual energy consumption beginning with expectations of use and architectural form. Ultimately, renewable generation would be needed. The defining question became "how much building and power generation can we build with the given budget?" The resulting building utilizes passive solar design, daylighting, ground source heat pumps and photovoltaic (PV) panels as the major design strategies.

This poster documents the predicted energy use and actual monitored performance. It shows the extent of load reduction achieved with passive solar design. A challenge for getting to 'real zero' is the difference between expected performance and actual building performance. This poster illustrates how measured data is used to trace the causes to unexpected equipment performance, heat pump behaviour and off-line PV panels. Assumptions regarding occupancy and building use during the design phase often differ from their actual use; this makes operating a building for zero energy an additional challenge above and beyond designing one. Overall, the actual building is exceeding the design team's goals, using on average 59 kWh/m^2 annually and generating 80 kWh/m^2 to exceed even the zero net energy goals.

Goals and Process

The process outlined below was used to help determine how to design the building to achieve the desired 0 net energy results for the Science House in the Big Back Yard.

- Serve as a dynamic working model for energy efficiency and renewable energy for 50 000 annual visitors to the Big Back Yard
- Serve as a beacon for the Science Museum's environmental initiatives
- Serve as an interpretive centre for environmental programming
- Serve as headquarters in a landscape that inspires imagination, teaches Earth-systems science, and connects people to their natural and built environments
- Demonstrate integration of building design concepts with state-of-the-art energy efficiency and renewable energy features.

The first task became assessing the potential for energy conservation by addressing programmed areas, interpretive programming activities and technologies, and comfort and control expectations. Next was an assessment of generation technologies including photovoltaic, wind, micro turbines and fuel cells. The Defining Question became "How much building can we build and generate power for with the given budget?"

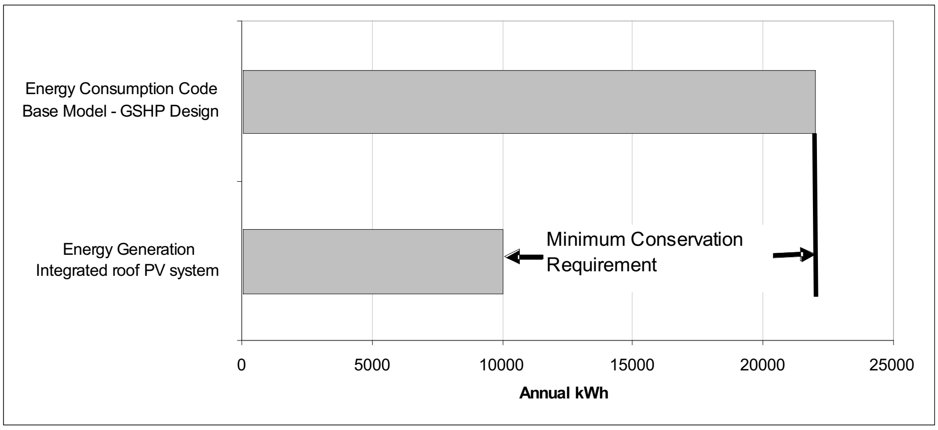

Figure 1. *Minimum Conservation Requirement.*

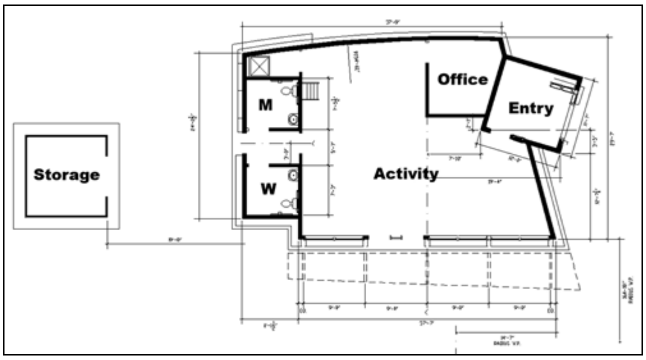

Figure 2. *Science House Plan and South elevation.*

The building spaces include a classroom space, office, restrooms, and an unconditioned vestibule tower. The south elevation shown below was designed to allow for passive solar heating.

The entry vestibule and storage areas were reassigned as unconditioned space thus reducing energy demands. The tower is designed to assist with stack ventilation.

Using DOE2, an hour-by hour computer simulation tool developed by Lawrence Berkley Labs and supported by the United States Department of Energy, a number of different load reduction and energy saving strategies were analyzed. The final building design incorporated a 4 ton ground source heat pump to provide heating and cooling for the building. The unit has a cooling Energy Efficiency Ratio (EER) of 12.7 and a heating Coefficient of Performance (COP) of 3.1. The heat pump has the ability to supplement the electric domestic hot water (DHW) heater when it is in the cooling mode. High performance windows with a unit u-value of 1.82 and Solar Heat Gain Coefficient (SHGC) of 0.25 were installed. Icynene insulation at a U-value of 0.14 for the roof and 0.2 for the walls was used to help reduce infiltration. An energy recovery ventilator was installed and is operated when either the bathroom exhaust fans are running or when the CO_2 level in the building is greater than 1 000 ppm. Fluorescent lighting was installed in the building at 10.7 w/m^2. Occupancy sensors were installed throughout the building to turn off lights when the spaces are unoccupied. Dimming daylighting controls in the classroom space and the office reduce the electric light level during the day to maintain 538 lux in the space. All of these strategies allowed the model to predict that the building would use only 10 000 kWh of energy, which could be generated by the UNI-SOLAR PV modules laminated to the metal roof of the science house.

Prior to the opening of the Big Back Yard, the Museum was perceived, rightly, as being strictly an indoor experience and attendance suffered accordingly on days with nice weather. With the addition of the Big Back Yard, the Museum now is a great place to learn about science when the weather is bad and when it is wonderful. As the building was opening, The Science Museum of Minnesota and The Weidt Group received funding from the National Renewable Energy Laboratory (NREL) for instrumentation and monitoring.

When the building was first turned over to the owner, the heat pumps were not working and the building was heated by electric resistance heaters only. Flag #1 in the graph in Figure 3 indicates this event and its correction after 10 days. Other key events are listed below and shown in Figure 3.

1. Electric resistance heat operated for 10 days during the month of January
2. Science House becomes a job trailer on March 16, 2004 for the construction of the Big Back Yard
3. The thermostat is switched from heating to cooling mode for the season
4. Photovoltaic inverter 3 in ground fault June 3 to June 17

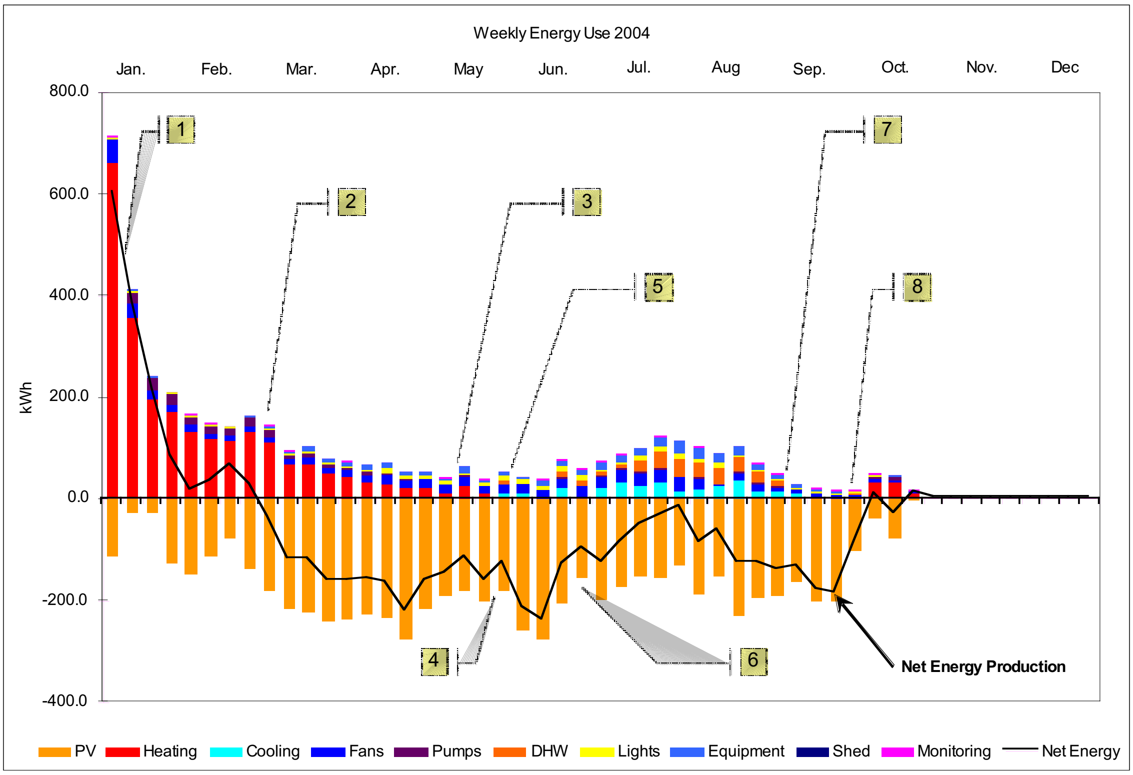

***Figure 3.** Science House 2004 Key Events with energy use represented as a positive and energy production as a negative.*

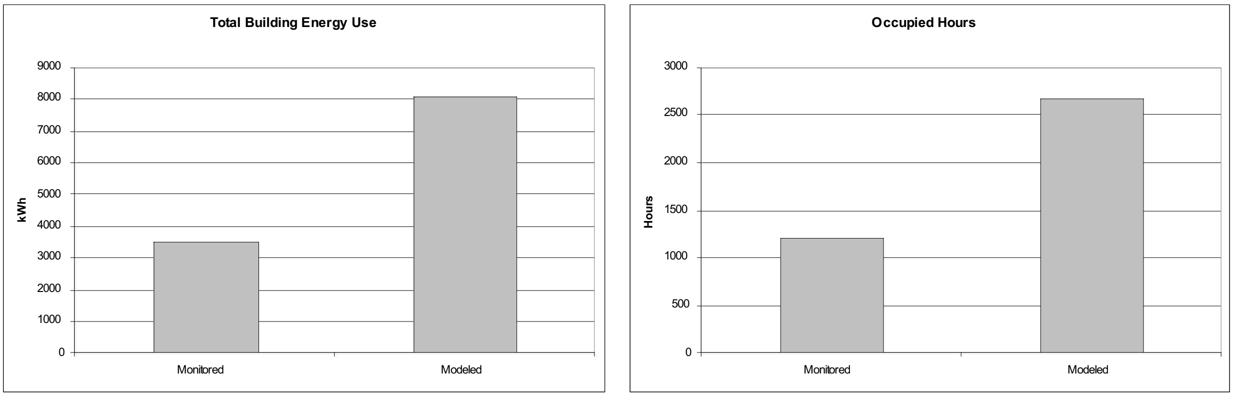

***Figure 4.** Total Building Energy Use Compared to Occupied Hours.*

5. The Big Back Yard starts to open to the public
6. Inverter 3 went into ground fault again on July 21
7. The Big Back Yard is closed for the season, and the DHW and equipment are switched off Sep. 16
8. The thermostat is switched from cooling to heating mode for the season

* Note that the Campbell Scientific monitoring equipment uses approximately 6.7 kWh per month.

The first year was an atypical year in some ways. The graphs in Figure 4 indicate how Science House has performed in its first year of partial occupancy.

In spite of its use as a job trailer and charging station for power tools, the building is using less energy than modelled primarily due to reduced occupancy. Occupancy plays a key role in energy performance. The actual building is using significantly less energy than the model predicted. The reduction in occupancy is similar to the reduction in energy use. During the design phase the building owners thought that the building would be occupied 10 -12 hours per day from March 22 to October 31 and occupied 4 to 5 hours per day during the remainder of the year. This translates to about 2 700 occupied hours per year. The first year's monitoring shows that the building is actually occupied about 10 hours a day from June 1 to September 4 and occupied 2 to 4 hours a day the rest of the year.

The annual PV production exceeds the annual energy use of the building resulting in a zero net energy building for 2004. Figure 6 indicates that PV production is a little below prediction. This is partially due to inverters and portions of the PV system going off line at times throughout the year.

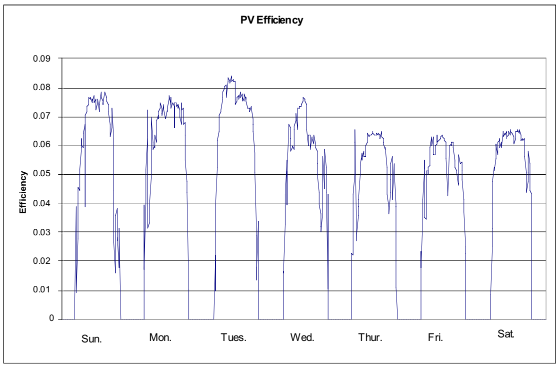

Figure 5. *PV Efficiency in July 2004.*

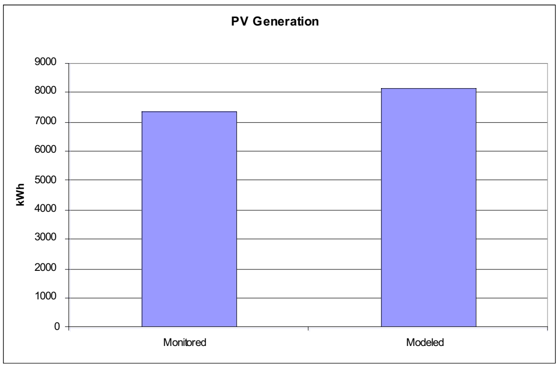

Figure 6. *PV Generation Compared to Modeled.*

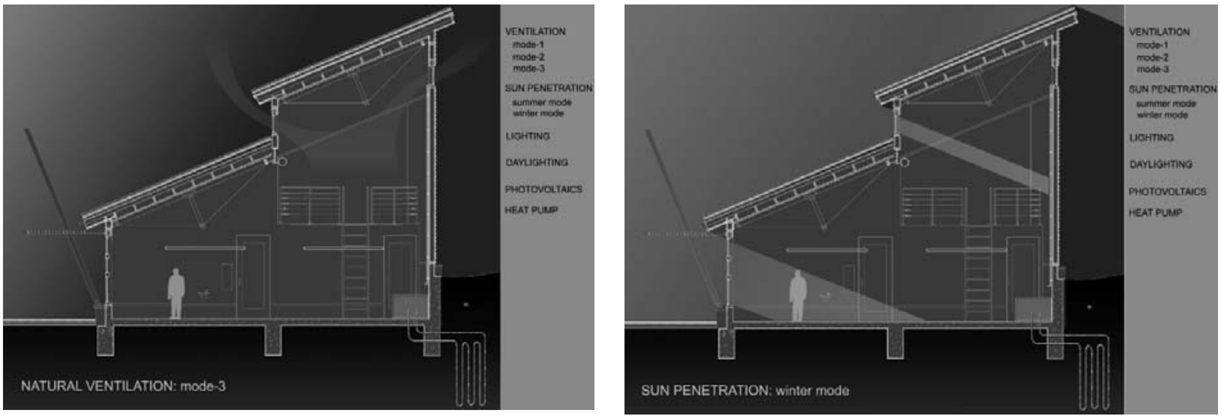

Figure 7. *Science House Section showing natural ventilation and Passive Solar Modes.*

Figure 8. *Science House north and west elevations showing balance of daylighting and envelope considerations.*

The plot above, Figure 5, shows the PV efficiency for one week – note the drop on Wednesday. This was July 21st as noted in Figure 3, item #6. Here the laminate PV slid, causing the ground wire to short on the buildings metal roof.

Currently the building is meeting its energy goals; however, an abnormally cloudy year, increased equipment (plug load) use, or increased hot water use could cause the building to perform below expectations. The largest contributor to the building energy performance is passive solar gain. As shown below, the building is heated during the winter months through its passive solar design. Figures 9 and 10 show that, on this sunny winter day, the building used 29 kWh and the PV roof produced 35 kWh generating a net gain of 6 kWh. Outside air temperature ranges from – 17 degrees C to -6 degrees C. Inside air ranges from 18 degrees C at night to 20 degrees C during the day.

Figures 7 and 8 illustrate the integration of design and engineering concepts that make Science House a well received public demonstration. The cross sections in Figure 7 illustrate the use of architectural form to orient the building integrated PV system and provide passive solar shading, bilateral daylighting and passive stack ventilation. With these physical parameters established, the owner and design team believed that it was important to render the building with an aesthetic treatment reminiscent of the forms of its industrial riverfront location. However, the public is reminded that building integrated, passive solar designs can have many looks. The choice of an electrically operated ground

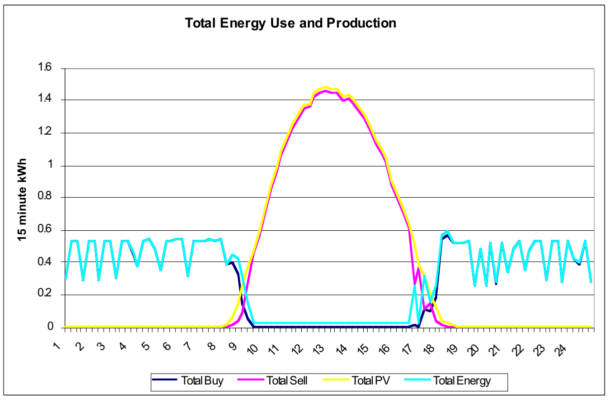

Figure 9. *Total energy use and production (single day)*

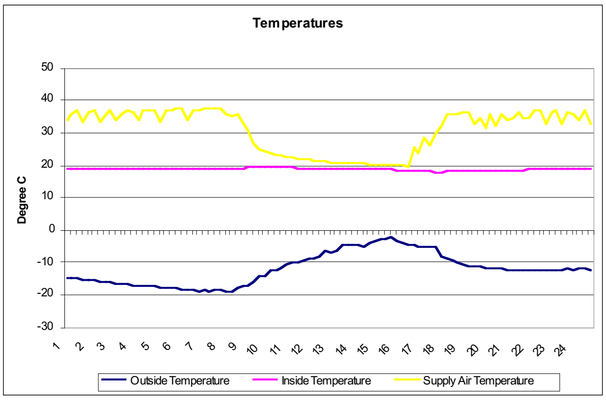

Figure 10. *Temperatures (single day)*

Figure 11. *East elevation.*

Figure 12. *Southwest (above) Southeast (below).*

source heat pump for heating and cooling made the clarity of its demonstration intentions easier to render to the general public.

The building is located in St. Paul, Minnesota. This climate has 7 981 heating degree days and 699 cooling degree days at a base of 18.3 degrees C. Thus passive solar heating has the potential to greatly reduce energy use.

On the day indicated in Figures 9 and 10, the building supply air temperature was the same as the building space temperature during the day and all of the energy generated by the PV system was sold. This further demonstrates the successful passive solar performance of this building.

Bibliography

The work presented here is original. There are no external bibliographical sources. Elements of this work have been presented within the following contexts:

Build Boston, November 16, 2004, Boston, MA: “Design Challenges and Performance Results for a Zero Emissions Building”

AIA Minnesota Convention, November 2, 2004, Minneapolis, MN: “Science House at the Science Museum of Minnesota: Design Challenges and Performance Results for a Zero Emissions Building”

AIA Iowa Convention, September 25, 2003, Des Moines, IA: “Science House- A Case Study”

2004 MEI Environmental Initiative Award: Energy Category. Presented by the Minnesota Environmental Initiative

2004 CSI Environmental Sensitivity Award. Presented by the Minneapolis-St. Paul Chapter Construction Specifications Institute

2003 EEBA Excellence In Building Award. Presented by The Energy & Environmental Building Association

"Sustainable Design Strategies: Nine Case Studies- Environmental Experiment Center, Science Museum of Minnesota," *Architecture Minnesota*, January-February 2003

"The Little House that Science Built: Energy Modeling and Design Strategies for Science House," *Specifics*, Winter 2004