SOLAR NZEB PROJECT

Photo 1: Snow covered solar array at Equinox House in December 2010 at sunrise. Note the "solstice" stone in the foreground with its shadow marking the sunrise solar azimuth angle. **Photo 2:** Our laboratory's 3.2 kW, two-axis tracking array was installed in July 2008. Note Ben on ladder harvesting hops planted along the south wall of the lab for shade. The light colored wall behind the hops is 10°C (18°F) cooler than unshaded wall regions during sunny summer days.

Solar Collection & Use

By **Ty Newell,** Member ASHRAE; and **Ben Newell,** Associate Member ASHRAE

This is an exciting time for those wishing to live in a solar energy-powered dwelling. Healthy, comfortable, and energy-efficient homes can be fully powered by renewable energy technologies at economical and affordable costs. And renewable energy technologies continue to improve, while their associated costs continue to decrease.

Photo 1 shows the Equinox solar energy collector array covered with snow. December 2010 was a record-breaking month for snowfall in central Illinois with snow falling on 17 out of 31 days. Even with a colder, cloudier than average winter, the annual energy collection of the 8.2 kW solar photovoltaic (PV) system produced all the energy required by Equinox House. In fact, until we are able to acquire an electric car, we will have "donated" more than 3,000 kWh of energy to the local utility due to current Illinois law allowing utilities to zero one's energy credit each year.

Photo 2, taken during August 2009, shows our two-axis, 3.2 kW solar PV array at our laboratory in Urbana, Ill. In the background of *Photo 2* is Ben harvesting hops from the south side of our laboratory. Hops are a great vine for providing excellent summer shade lowering the south side temperature of our lab by more than 10°C (18°F) during the summer while dying back to their roots for the winter.

The challenges of implementing solar energy involve residential lending, appraisals, and market demand. The technologies work and are cost effective. For an energy-efficient dwelling, the cost of a solar energy system is no more significant than that of the kitchen cabinetry, bathroom furnishings, or flooring surface selections. It's a lifestyle preference decision. And, unlike fashion-based design features, a solar energy system pays for itself over its lifetime, rather than depreciating at a rate dictated by home style magazines and television shows.

The Equinox House solar energy collection system provides 100% of its annual energy needs with additional solar energy collection for driving an electric vehicle 8,000 miles (12 975 km) per year, and it does so with an equivalent electric energy cost of $0.12.5 per kWh and an

This is the tenth in a series of columns. Find previous columns at www.ashrae.org/ashraejournal.

equivalent vehicle energy cost that is less than $2 per gallon ($0.52 per liter) based on our installed system cost and the current 30% U.S. federal tax credit. Remember that the tax credit is not someone else's tax money given to you. It is your tax money. If you didn't pay any taxes, you don't receive the credit.

We are often asked why we did not incorporate a solar thermal energy system for water heating into Equinox House. Our economic analyses indicated that when solar PV is incorporated into a house, a solar thermal energy system is not cost effective. Once the electric lines are pulled for the solar panels, water heating is accomplished by connecting a few more PV panels to the system. A heat pump water heater coupled with a solar PV system has the same overall solar energy to thermal energy conversion as a solar thermal energy water heating system (with a free cooling/dehumidification benefit described in our April column). The solar PV system does not have the maintenance of solar thermal systems (freeze protection for many locations, air entrapment, plumbing leaks and corrosion). And finally, when you travel, the solar PV system can build energy credits, while the solar thermal system generally has no place to use the energy and must try to not overheat.

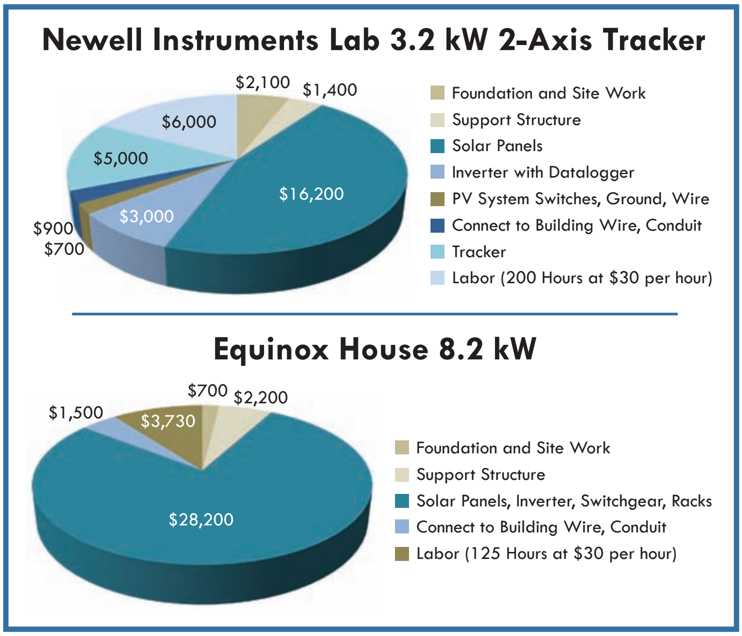

Figure 1 (top): Newell Instruments Lab solar PV system cost details.
Figure 2 (bottom): Equinox House solar PV system cost details.

The solar PV systems at our lab and at Equinox House are both "grid-tie" systems in which electric energy produced by the solar arrays is directly coupled to the utility. No batteries are required for this type of system although some homeowners with grid-tie systems do incorporate a backup battery system for use during utility power outages. A grid-tie system consists of two primary components: the solar PV panels and the power inverter. Solar PV panels come in a variety of nominal power output ranges. Nominal panel output power continues to grow due to higher conversion efficiencies and denser panel packaging, with 200 to 300 W panels now common. Our two systems are silicon-based solar cells; however, several types of solar energy conversion materials are on the market. The nominal output voltage of solar PV panels varies by manufacturer, which impacts how collectors will be interconnected for conversion to grid electricity.

Currently, most solar PV systems group a number of panels together for power conversion by centralized inverters. Our laboratory system has a single 5 kW inverter for its 3.2 kW solar panel array. Equinox House has two 6 kW inverters with each inverter connected to half of the solar panels. Solar PV panels perform their best on bitterly cold, sunny days because efficiency of solar PV materials increases with decreasing ambient temperatures. Our laboratory system will exceed 3.6 kW on sunny winter days while warm, clear days in August will peak at 2.8 kW. Longer day lengths and more sunny days in summer months result in higher overall solar energy collection.

Photo 3 shows the installation of one of the twin solar inverters to the Equinox House solar array. Inverters have different voltage windows where conversion efficiency from the solar PV panels' dc to utility grid ac is most efficient. Based on the inverter voltage window and the solar panel nominal voltage output, series connected strings of panels are grouped together in order to be inside the inverter's voltage window. The 16 solar panels for our laboratory solar PV system has four strings of four panels each, with a nominal string voltage of 300 vdc delivered to the inverter. The Equinox House solar panels have a nominal voltage output of 20 vdc and were wired as two separate systems consisting of 20 panel series connected strings for a nominal string voltage of 400 vdc.

Photo 3: Installation of one of the twin 6 kW solar PV system inverters for the Equinox House solar system.

One of the weaknesses of series connected solar panel strings is that degradation of a single panel's performance impacts the rest of the panels in the string. For example, if one collector is shaded or oriented in a less favorable manner, its current flow will control the current flow through the entire string. A technology moving into the market are "micro-inverters" that attach to each panel and perform dc–ac conversion at the panel, allowing all panels to operate at their peak performance. Another advantage of panels with micro-inverters will be increased design flexibility allowing architects to specify varying panel orientations and combinations of different panel types to achieve different aesthetic and geometric appearances. Micro-inverters that are factory-mounted onto solar panels will also lower installation costs due to elimination of dc switchgear and wiring, and less installation labor. A significant hurdle for panel mounted micro-inverters is meeting the normal panel warranty of 20 to 25 years. Central inverter warranties are typically in the five- to 10-year range.

Figures 1 and *2* (Page 73) show a breakdown in system installation cost without any tax credits or rebates. The two-axis tracking system at our lab, installed in 2008, and the Equinox House system, installed in late 2009, show significant cost differences. The installed cost of our lab system was $35,300 and the Equinox House system's installed cost was $36,300. Two-axis tracking systems increase the solar energy collection potential by 25% in our climate relative to a stationary array. Assuming our lab system is equivalent to a stationary 4 kW solar PV relative to Equinox House solar PV system at 8.2 kW, the installed costs per watt for the systems are $8.83/W and $4.43/W. The primary reason for the substantial cost difference was a price drop in solar panels and solar system equipment in 2009. We purchased the solar system for Equinox House as a packaged system, which included some of the array-mounting racks, switch gear, inverters and collector panels for $28,200. For our lab system, we purchased individual components. Adding the cost of the solar panels, inverter and tracker together, we have a cost of $6.05/W for the lab system compared to $3.43/W for the Equinox House system package. And today, a search of similar capacity solar PV panel systems will show systems with quality components (20- to 25-year panel warrantees) costing less than $3/W.

Differences in installation cost will be site specific. For example, we decided to locate the Equinox House system on the berm in the backyard to allow visitors to see the system in detail. If we had mounted the collectors on the roof, we would have reduced the installation cost by a few thousand dollars by eliminating the amount of support steel and site work. The site work for our lab system was more expensive than the larger array at Equinox House because it was located 61 m (200 ft) away from the building while the Equinox House system was only 30 m (100 ft) from the building electrical connection. Also, the system at Equinox House was coordinated with other activities such that the solar array concrete footers were poured with the house foundation, and most of the trench for the electrical conduit was already excavated for the rainwater harvesting system and foundation walls.

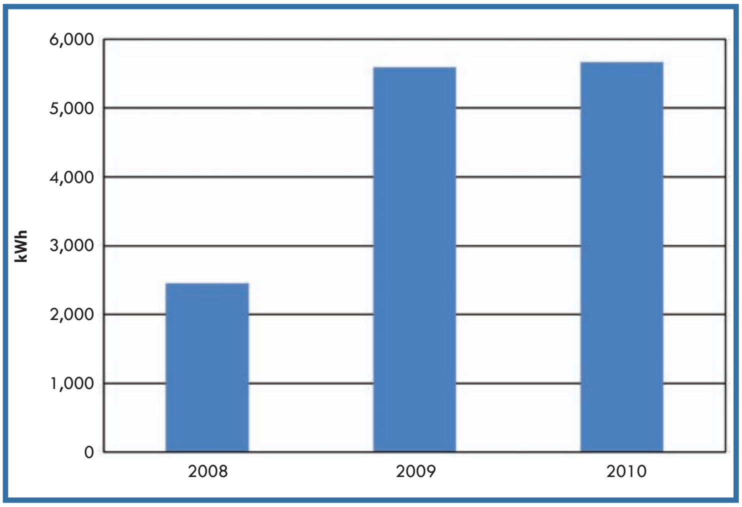

Figure 3: Newell Instruments Laboratory 3.2 kW solar PV system energy production.

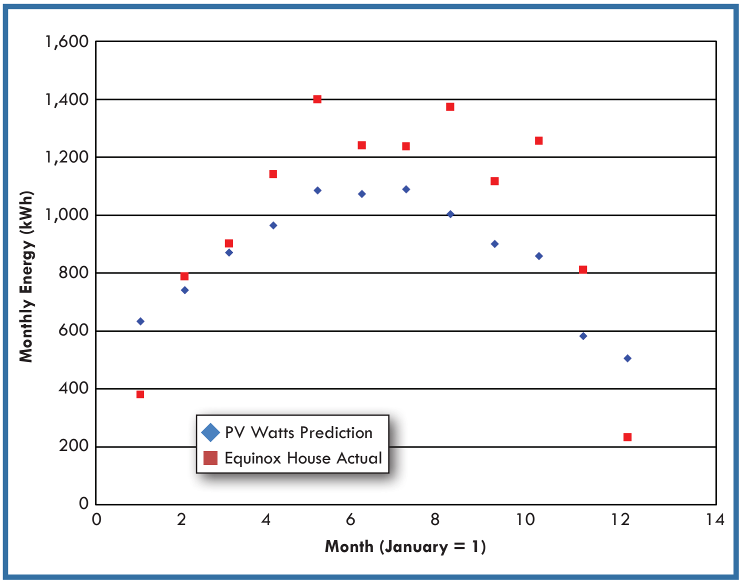

Figure 4: Comparison of PV watts model prediction with actual Equinox House solar PV system 2010–2011 energy collection.

Figure 3 shows the energy collection from our laboratory solar PV system, which totals over 13,000 kWh since its startup in August, 2008. The system supplies approximately 30% of the 410 m^2 (4,400 ft^2) laboratory's energy. The lab is all electric with ground source heat pump providing comfort conditioning. We have additional plans for cost-effective building improvements that should result in approaching net-zero energy operation. Simulation modeling of our lab's two-axis solar array using the National Renewable Energy Laboratory's "PV Watts" simulation program yields results within 10% of the actual energy collection during 2008 and 2009. *Figure 4* shows a comparison between a PV watts simulation prediction and the Equinox House stationary 8.2 kW array over the past year. The 2010 summer months in central Illinois were sunnier than usual while the winter was more cloudy and snowy than average. Overall, the Equinox House system produced 12,000 kWh from Feb. 23, 2010, when it was activated to Feb. 23, 2011, of this year.

Figures 5 and 6 show additional detail of the solar energy collection and use over the past year at Equinox House. In *Figure* 5, the accumulated solar energy collection has outpaced energy use since its start on Feb. 23, 2010. The difference between the accumulated solar energy collection and the accumulated house energy use is the difference that will be zeroed by the utility in April of each year. Approximately 1,000 kWh of energy credit was lost in April 2010 and another 2,000 kWh was lost in April 2011 for a total of 3,000 kWh oversupply. As previously mentioned, our design assumes an electric vehicle, which will remove our "excess" energy and for the time being, the donation of a few hundred dollars of energy to our local utility is a worthwhile demonstration that solar energy-powered homes are real. The accumulated energy "gap" narrows from November through March, and then widens from April through October when excess solar energy collection is fed into the grid.

Figure 6 displays daily solar energy collection data and Equinox House daily energy use data. From February 2010 through July 2010, all energy use was for construction activities at the house. During the construction phase, approximately 1,000 kWh was used, which was easily outpaced by the solar energy system's collection. The energy used for construction primarily powered air compressors for nail guns, lighting, and miscellaneous power tools. The largest energy requirement during the construction phase was for fans used by the drywallers for drying compound over a two-week period. Some days with nearly 30 kWh of energy use are observed in the April – May time frame when 1,000 to 1,500 W of fans were placed throughout the house. Daily energy requirements for Equinox House for April through October are predicted to be 10 to 20 kWh per day.

Construction activities ended at the end of July 2010, but delivery of the kitchen cabinetry from Italy was delayed until the end of October. We installed our fresh air, heat pump energy recovery system described in our previous column, plugged in the refrigerator, and operated the heat pump water heater from August 2010 until the house was occupied in mid-November 2010 when the kitchen cabinets were installed and final occupancy inspections were completed. The move into Equinox House in mid-November was quickly followed by a sharp decrease in solar energy collection and increase in house energy requirements caused by a sharp change in the weather as seen in the trends in *Figure 6.*

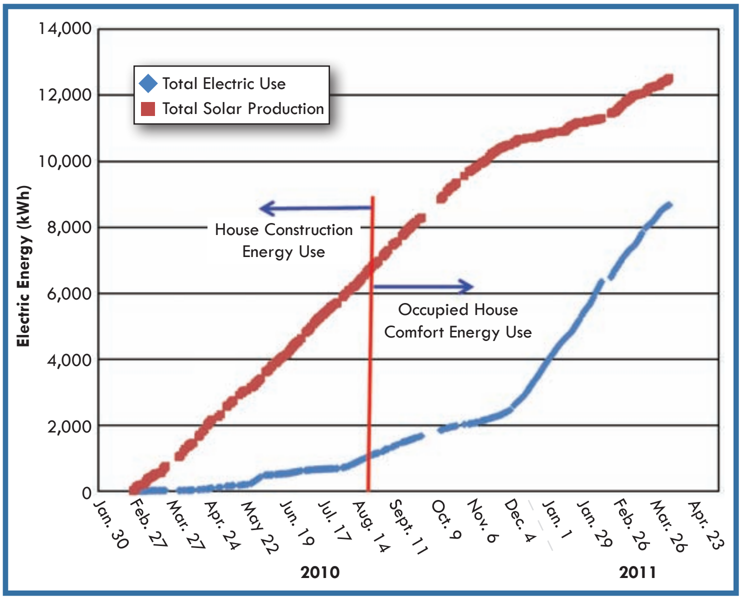

Figure 5: Comparison of the accumulated Equinox House solar PV system energy production and Equinox House energy use. Note that the difference between the accumulated production and accumulated use is an energy credit that will be donated to the local utility due to current Illinois legislation.

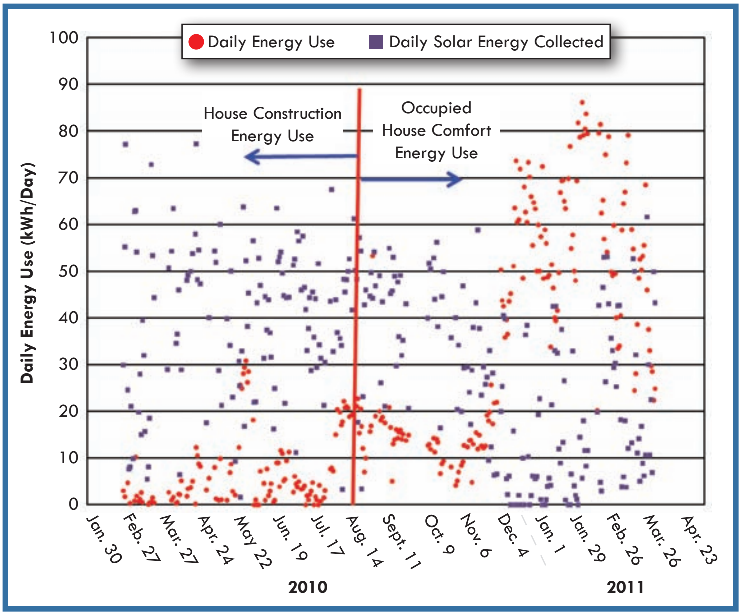

Figure 6: Daily Equinox House energy use and daily solar PV system energy collection. A sharp change in November's weather switched Equinox House from an energy producer to an energy consumer. A return to an energy producer is occurring in March, with net positive energy production expected in April through next October.

Photo 4 shows some of the construction equipment used for site work and erection of the house wall and roof panels. We asked our construction crews to monitor their fuel use so we could estimate the total energy required for house construction. During the two month period from the beginning of the site work until electric power was available in February 2010, a total of 1050 L (275 gallons) of diesel fuel was used. This includes fuel for a generator, air compressor, forklift (*Photo 4*), small front end loader (*Photo 4*), mini-excavator, backhoe, and self-operated crane (*Photo 4*). The portable air compressor required 245 L (64 gallons) of fuel and the portable generator required 365 L (96 gallons) of fuel based on 16 days of use.

The energy of all fueled equipment is estimated to be 10,500 kWh (36×10^6 Btu). If electric energy had been available at the site, and if site vehicles were based on electric energy, assuming the fueled equipment to be 20% efficient, 2,100 kWh of electric energy would have been required.

In many regions around the U.S., solar PV system installations have become as routine as installation of hot tubs. Some regions require new housing developers to offer solar PV as an option, and some housing developments featuring homes with and without solar PV systems have found that homes with solar PV sell more quickly than those without. Continued advances in the technology, manufacturing and installation labor will accelerate the advancement of solar energy systems. We are even seeing progressive HVAC manufacturers incorporating solar PV into their systems, piggybacking wiring, roof mounting and labor costs together in a manner that increases their revenue and profit margins. This is an exciting time for those wishing to live in a solar energy-powered dwelling!

Photo 4: View of the mini-front end loader, forklift and crane used during house panel erection. Other site equipment used for construction are the backhoe and mini-excavator.

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