Photo 1: Aerial view of Equinox House and surrounding neighborhood, September 2010. Photo courtesy of Patricia A. Justice.

Photo 2a (top) and 2b (bottom): Computer controlled electric circuit breaker panel in Equinox House. Note the cell phone modem on top of the unit for Internet communication and the adjacent subpanel.

Equinox House Performance

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

Equinox House has been occupied since mid-November 2010, and we now have enough data to look at the actual performance of the house. *Photo 1* is an aerial view of Equinox House taken from a hot air balloon during September 2010. The house should be relatively easy to find, as it is the only house with a white roof and solar collectors in the backyard. Apart from that, from this perspective, it is quite similar to its neighbors. Any house in the neighborhood could perform as well as Equinox House through better design and better construction.

Since its occupation, we have hosted parties with up to 120 people in the house, given tours to more than 2,000 people and have had several family and friends visits. But overall, Deb and Ty Newell have lived simply as most people do, day-by-day. This column examines the energy used by Equinox House from December 2010 through April 2011 and compares the actual energy use to predicted energy requirements. We also break down the energy use into different categories for the same time period to examine the variability and trends.

We monitor energy used for lights, cooking, dishwashing, clothes washing and drying and all other house loads. Our computerized circuit breaker panel allows us to monitor and control all circuits in the house and provides circuit protection. *Photos 2a* and *2b* show the computerized circuit breaker panel. A wireless cell phone Internet connection provides us with remote control and monitoring capability.

An adjacent subpanel, also shown in *Photo 2,* contains two sets of circuits that are ganged together and connected to two circuits in the computerized circuit

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

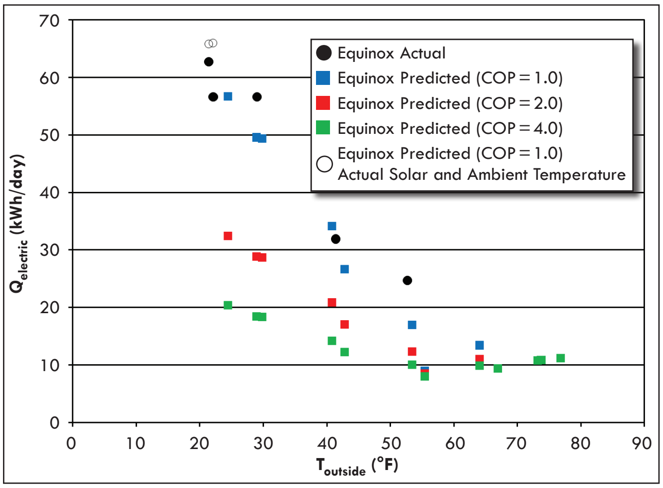

Figure 1: Actual house energy requirements from December 2010 through April 2011 and predicted Equinox House performance. Coefficient of performance (COP), equal to one, represents electric resistance winter heating and, equal to two, represents a heat pump.

Photo 3: 1,500 W space heater placed in the main living space of Equinox House. A similar space heater was placed in the master bedroom. Note "Hal," our robotic vacuum cleaner, next to the heater.

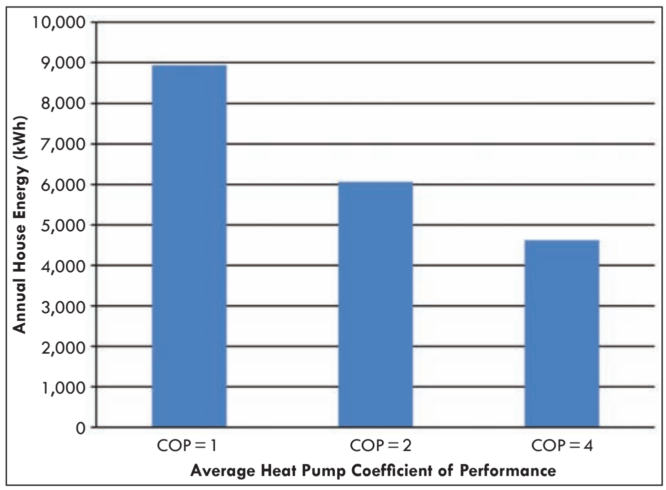

Figure 2: Effect of heating efficiency on annual house energy requirements.

panel. There are eight sub-circuits in each of the Subpanel circuits (Subpanel A and Subpanel B). The subpanel circuits are primarily miscellaneous circuits such as bedroom, bathroom, hallway, garage and exterior electrical receptacles and lights. These circuits generally do not have high load requirements. However, as will be discussed, they were the source of significant loads during the initial year due to temporary circuit configurations.

Equinox House does not have natural gas service, which makes it easy to measure house energy. An all-electric house has an estimated cost savings of $8,000 to $10,000 over 20 years. This is because even if natural gas isn't used there are still costs for installation and flues (and their associated reduction of house envelope performance) and natural gas service fees ($22 per month in our region). For a house with a solar PV array costing $20,000 for house energy needs, saving $8,000 to $10,000 by not installing natural gas service provides substantial savings.

Figure 1 shows the actual energy requirements of Equinox House from December 2010 through April 2011 compared to simulation predictions for Equinox House under different scenarios. This past winter, Equinox House was heated by two 1,500 W space heaters that each cost $20. One heater was placed in the master bedroom and the second heater was placed in the main room. Because of the isothermal nature of a highly insulated and sealed house, these localized heater placements do not result in significant temperature variations in the house.

As discussed in our May 2011 column on comfort, even the attic, which is part of the thermal envelope but isolated from the ventilation system (due to local building codes), is the same temperature as the living areas of the house. A full record of house temperatures (and other data including house energy, solar energy, carbon dioxide levels, VOC levels) can be found on our website (http://newellinstruments.com/equinox).

The space heaters were used for winter heating while the permanent air source heat pump ventilation and energy recovery system undergoes safety certification. The local building safety officials allowed us to temporarily install a portion of our fresh air ventilation system to collect *in situ* data with the understanding that it will be replaced by a "listed" system within one year. *Photo 3* shows the space heater in the main room of Equinox House, next to our robotic vacuum cleaner named "Hal." Hal consumes an average of 6.3 W for an annual energy load of 55 kWh based on two whole-house cleanings per week.

All energy loads in the house during the winter contributed to heating the house with an effective COP of 1.0 (that is, electric resistance heating). Lighting, cooking, clothes washing, stereo, computers, television, and space heaters all combined to provide the energy needed to keep the house warm during the winter.

The heat pump fresh air ventilation system currently installed in Equinox House contributed approximately 500 W to heating the house with a COP of nearly 1 when outdoor ambient temperatures dropped below –18°C (0°F). As shown in *Figure 1*, simulation predictions for Equinox House using average monthly weather conditions for Urbana, Ill., with an assumed heating system COP of 1.0 agree quite well with the actual house performance. December and January were quite cold and cloudy compared to average winter conditions. December set a record for snow, with snow falling 17 days of the month.

Two simulation data points are shown in *Figure 1* in which the actual December and January ambient temperature and solar radiation data have been used to compare more directly with the actual data and to show the variation from the long-term average data performance. During December and January, daily energy requirements of 60 kWh per day are equivalent to 2,500 W of continuous heating. During some of our most bitter cold weather, we reached 80 kWh to 90 kWh per day (3,300 W to 3,800 W) with very little modulation of the space heater operation.

Our goal is to reach a minimum average heating system COP of 2.0 (a heating seasonal performance factor [HSPF] = 6.9), with a performance as shown in *Figure 1*. A higher heating system COP of 4.0 (HSPF = 13.8), achievable with ground source or geothermal heat pump systems, is also shown in *Figure 1*.

Heat pumps result in significant energy performance gains, as shown in *Figure 2* where the annual energy totals for Equinox House with heating system COPs of 1.0, 2.0, and 4.0 from *Figure 1* are shown. Our current heating system ($40 worth of space heaters) can be assumed to be a "no cost" heating system with minimum energy efficiency (COP = 1.0). To justify the cost of an air source heat pump system with a nominal COP of 2.0, the system must cost less than the value of the annual 3,000 kWh savings. Solar energy costs $0.125/kWh, which on a simple basis results in energy cost savings of $375 per year. With a heat pump system lifetime between 10 and 20 years, the heat pump system should cost less than $3,750 to $7,500.

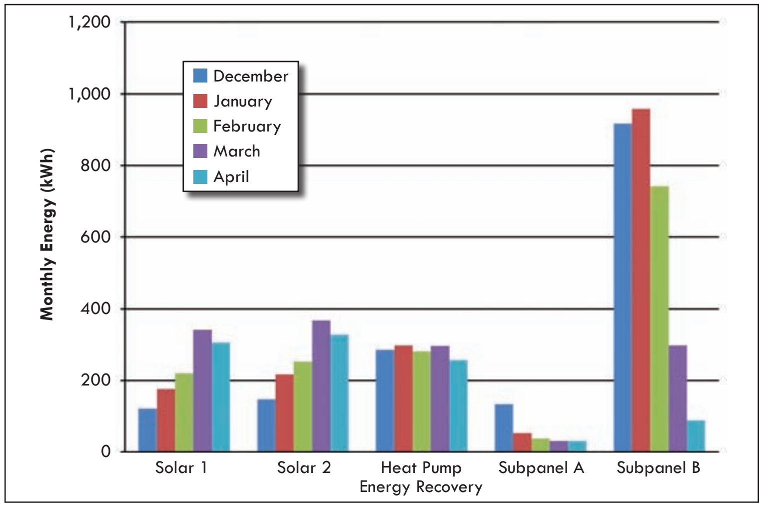

Figure 3: Monthly electric energy requirements for the major house circuits from December 2010 through April 2011.

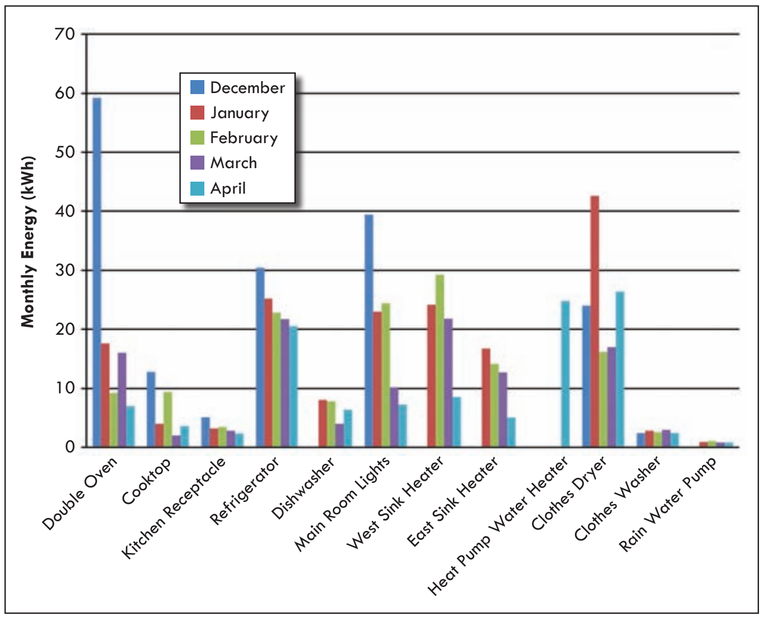

Figure 4: Monthly electric energy requirements for the minor house circuits from December 2010 through April 2011.

Likewise, a higher performing system with a heat pump system COP of 4.0 saves approximately 4,500 kWh per year relative to the electric resistance heated house, for a cost savings of $560 per year. The system cost on a simple basis should be less than $5,600 to $11,200 assuming the same lifetime. (Note, the ground source heat pump installed at our laboratory in 1988 operated 17 years before requiring replacement.)

Figures 3 and *4* provide detailed electrical circuit data for December 2010 through April 2011. *Figure 3* shows energy activities for five "major" circuits, while *Figure 4* shows the energy for the remaining "minor" circuits. Two of the major circuits in *Figure 3* are the two halves of the 8.2 kW PV solar system. December and January solar energy collection was very low compared to the average expected collection, and as observed, the amount collected is quite small compared to the three energy loads shown in *Figure 3*. February also shows significantly higher major loads compared to solar energy collection. However beginning in March, solar energy collected increases as major loads decrease. April is the month when solar energy collection is significantly greater than the major energy loads, and the house becomes heavily net positive in energy balance, and will remain so through October.

The three major load circuits shown in *Figure 3* are for the heat pump energy recovery system previously discussed and Subpanel A and Subpanel B. The heat pump energy recovery system provides a level of heating varying from 400 W to 2,000 W depending on the outside ambient temperature, with an average power requirement of 400 W to 500 W.

From early January to early April, a heat pump water heater was also connected to the heat pump circuit, which contributed approximately 30 kWh per month, or 10% of this circuit's energy load. During our final building inspection, the inspector required disconnection of the heat pump water heater while he checked the certification of our system components, so Subpanel A was used to temporarily connect an electric resistance water heater, resulting in the high December energy use of 140 kWh shown in *Figure 3*. Succeeding months after the electric resistance water heater was disconnected have energy levels in the 30 kWh to 40 kWh per month range, representing various lighting and receptacle uses in the house.

Subpanel B shown in *Figure 3* includes wall receptacles in the master bedroom and main living area where the two space heaters are located. During December and January, the coldest months of the winter, Subpanel B had energy loads of 900 kWh to 950 kWh, or average space heater loads of 1,200 W, indicating that the rated 3,000 W total space heater power was modulated at 40% capacity if other miscellaneous loads on this subpanel are negligible. By April, the space heaters were operating less than 5% of the time. The heat pump energy recovery system became the dominant heating source along with increased levels of solar radiation. As of the second week in April, the "equinox overhang" on the clerestory windows blocked direct solar radiation.

The "minor" circuits shown in *Figure 4* are individually quite small, but collectively they represent 110 kWh to 180 kWh per month, equivalent to 150 W to 250 W of continuous power. December and January energy totals for the minor circuits were the highest, with a decreasing trend toward spring. Regarding the overall trend, December shows a substantial load for the double oven and cooktop due to holiday activities and family visitors for nearly two weeks. We held a winter solstice party with 120 people that necessitated significant cooking preparation. Cooking activities subsided through the rest of the winter with only two occupants for the majority of the time.

Kitchen receptacles included those used regularly: coffee pot (Ty) and electric teapot (Deb). The refrigerator is energy efficient, although it is a fairly large, French door unit. The trends in its energy use reflect cabinet use with almost a 30% drop in energy from December to April as kitchen activities subsided. The dishwasher shows approximately 5 kWh to 8 kWh per month, which represents five to eight dishwashing loads per month (1 kWh per dish load).

The lights in the main room reflect the seasonal change in daylighting. December was again the highest lighting load with snowy days and visitors regularly in the house over a two-week period. The main room lights consist of 45 LEDs with a power draw of 8 W per bulb for a total of 360 W when all lights are on, but are controllable in 50 W to 75 W groupings. The 40 kWh during December is an average of 55 W of main room lighting, or an average of seven bulbs activated. As the lights contributed to the winter house heating at an efficiency equivalent to that of the electric space heaters, the lights could be considered an alternative heating source. Longer days and lower occupancy levels since December have significantly reduced lighting loads.

For future switching of shower and laundry water to rainwater, we incorporated two small (2 gallon, 1,500 W) electric water heaters for sinks in the "east" end (full bathroom sinks and laundry sink) and "west" end (half bathroom sink, kitchen sink and garage sink) of the house. This ensures potable water at all sinks. These water heaters are poorly insulated (and it's difficult to add additional insulation). The west end water heater was the dominant load with kitchen sink use. After the first week of April, the sink water heaters were disconnected, and the sink hot water lines were connected to the heat pump water heater. The electric circuit for the heat pump water heater was also shifted from the electric circuit for the heat pump energy recovery system to its own circuit for monitoring. The remaining three weeks of April show that the heat pump water heater required 25 kWh, less than the combined amount of the two small sink heaters for any of the other months. Overall, the heat pump water heater has reduced the water heating energy by a factor of 3 (that is, an average COP of 3.0) since December when all water heating was electric. We plan to add a second heat pump water heater for potable water for sinks at a future date when we are able to convert laundry and shower water to rainwater.

Clothes washing requires little energy with today's modern appliances. Coupled with cold water detergent and low water consumption, clothes washers have little impact on the house energy demand, averaging 2.5 kWh per month as shown in *Figure 4*. The clothes dryer has a significant energy impact relative to other appliances as discussed in our April 2011 column on appliances. For two occupants, the clothes dryer energy demand is averaging 20 kWh per month. Finally, *Figure 4* shows the energy required by the rainwater pump that supplies our toilets. The pump is a typical shallow well pump with diaphragm tank that operates on a pressure switch. Through April we have used nearly 20,000 L (5,300 gallons) of rainwater for toilets and garden watering with an average of 1 kWh per month.

Overall, the energy performance of Equinox House is close to our design modeling predictions with no major surprises or unexplained trends. Of course, there is always the possibility that our interpretation of why things are happening and the actual reason are two different things. As we incorporate the full heat pump conditioning system into the house, we expect to realize additional decreases in house energy requirements. Detailed breakdown of the house electric energy use indicates that the patterns in energy loads have some seasonal variations related to both the activities (holidays) and the time-of-year. We are pleased that Equinox House is comfortable with a healthy indoor air environment in addition to being an energy efficient house.

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