University of Nevada Zero Energy House Project

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ABSTRACT

New housing development in the desert southwest is causing an increasing demand for energy. To mitigate this demand the University of Nevada at Las Vegas (UNLV) with other participants have developed and built a nearly "zero net energy" (ZEH) house as a model home in a tract house setting. Recently, construction on the ZEH and a conventionally built adjacent home was completed. Both homes were subjected to thermal analyses to evaluate options during the design phase. The homes have the same but inverted 1610 square foot floor plan with a 410 square foot attached garage. The ZEH was constructed using T-Mass™ walls, spectrally selective windows, foundation insulation, radiant barrier roof sheeting, and added attic insulation. The air-conditioning for the ZEH uses a highly efficient evaporative cooled condensing unit with the ductwork located in the conditioned space. The heating is provided by a hydronic fan coil unit. Water heating is accomplished by a solar hot water heater with integrated storage and a tank-less on-demand gas-fired unit. The house has ENERGY STAR® appliances and uses compact fluorescent lamps. For power generation the home uses a roof-integrated photovoltaic panel system rated at 4.8 kWe peak power. Both homes, which are open to the public, will be heavily monitored with a great deal of detailed instrumentation for 18 months, and during this period comparative studies will be made to determine the relative performance of the ZEH. These studies will be used to calibrate the numerical models for the thermal analysis applied during the design phase.

Introduction

New housing development in the desert southwest including Las Vegas, which is one of the country's most rapidly growing cities, is causing a large demand for energy. The Department of Energy (DOE) estimates that residential buildings use more than 20 percent of the primary energy consumed in the United States and contribute 313.4 metric tons of carbon dioxide emissions to the environment annually (DOE 2004). To help reduce the energy demand and reduce emissions, the University of Nevada at Las Vegas is working with Pinnacle Homes, Nevada Power Company, the National Renewable Energy Laboratory (NREL), and Consol to develop and build a nearly "Zero Net Energy" (ZEH) house which incorporates energy saving construction, solar water heating, and a photovoltaic (PV) power generation.

The home was built in a typical tract house setting in southwest Las Vegas next to a conventionally built "Baseline" home and both are used as model homes which are open to the public. Both homes have the same but inverted 1610 square foot floor plan with a 410 square foot attached garage. Both homes will be heavily monitored, with instrumentation incorporated during the construction, for 18 months to allow comparative studies to determine the performance of the ZEH.

During the design phase, both homes were subjected to thermal analysis to investigate the various construction and energy design elements to be used in the building of both homes. These elements were optimized to get near "zero net energy" performance from the ZEH (Wilkinson & Boehm 2005). Data from the monitoring will be used in the calibration of the numerical models used in the thermal analysis.

Construction

As can be seen in Figure 1, both homes are similar in appearance but with an inverted floor plan. The Baseline house was constructed to the International Residential Code (IRC) with ENERGY STAR® upgrades. The ZEH is a modified version of the Baseline house with added energy saving features and innovative construction techniques. Although the two homes have the same floor plan, one of the most noticeable differences between the houses is the orientation of the roof of the ZEH which was rotated from a predominately east-west exposure to a north-south exposure to give the roof mounted solar components better sun access. The new orientation gives nearly 1,100 square feet of south facing roof exposure (Wilkinson & Boehm 2005).

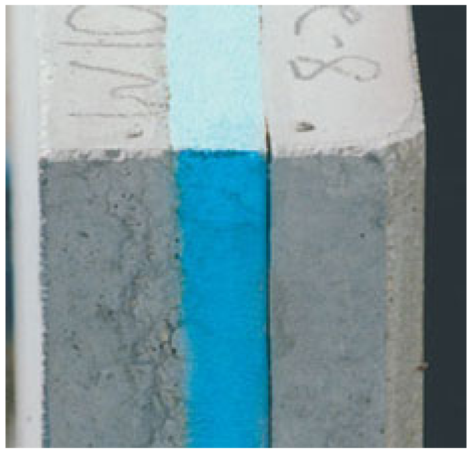
Figure 1. Photograph of the Zero Energy Home on the Right and the Baseline house on the Left Located at the Pinnacle Homes Vinings Project

Both homes were constructed on post-tension reinforced monolithic concrete slabs. The footings of the ZEH were insulated on the exterior below grade to a depth of two feet after the forms were removed. The Baseline house does not incorporate the slab insulation which is typical construction for the region.

The walls for the Baseline house use standard 2 by 4 stud construction with R-13 cavity insulation and 1 inch of exterior polystyrene foam. The exterior is covered with vapor barrier, wire and stucco plaster. The interior of the walls are gypsum sheetrock and paint. The ZEH uses Dow Chemical Company's Styrofoam T-Mass™ walls. These walls are made up of 4 inches of reinforced concrete on the interior and 2 inches of concrete on the exterior with 2 inches of continuous Styrofoam extruded polystyrene foam sandwiched between the concrete layers (Figure 2). The exteriors of the walls are finished with a coat of stucco plaster with the interior walls finish coated in concrete and painted. The walls were precast off site and trucked to the site where they were erected in one day.

The energy advantage to the T-Mass™ walls is the concrete has a large thermal mass which delays the heat transfer through the walls and is combined with the foam insulation which retards the heat flow. This type of wall is effective in areas with large exterior temperature differences during a 24 hour period where the heat that is absorbed by the walls during a warm day is dissipated into a cool evening. The delay of the heat into the interior allows the air conditioning to remove this heat during cooler off-peak periods which require less power for the air conditioning. Also during cooler winter months the high thermal mass interior of the wall absorbs heat and re-radiates it into the interior space which moderates interior temperature swings (DOW 2006).

Figure 2. Cross Section of the Dow Chemical T-Mass™ Walls Used on the ZEH



Source: Dow Chemical

Conventional roof trusses were used for both houses and oriented strand board (OSB) sheeting was used for the sub roof for the Baseline house. Polar-Ply Radiant Barrier Sheeting, which has a low emissivity aluminum coating laminated on to the OSB sheeting, was used for the sub roof of the ZEH. This radiant barrier is installed reflective side toward the attic which reduces the attic temperature and reduces the heat load on the house through the attic.

The attic insulation for the Baseline house is blown-in cellulose, applied directly to the upper side of the ceiling drywall, with an R-value of R-29, while the attic for the ZEH uses the same insulation but with increased thickness to an R-value of R-38.

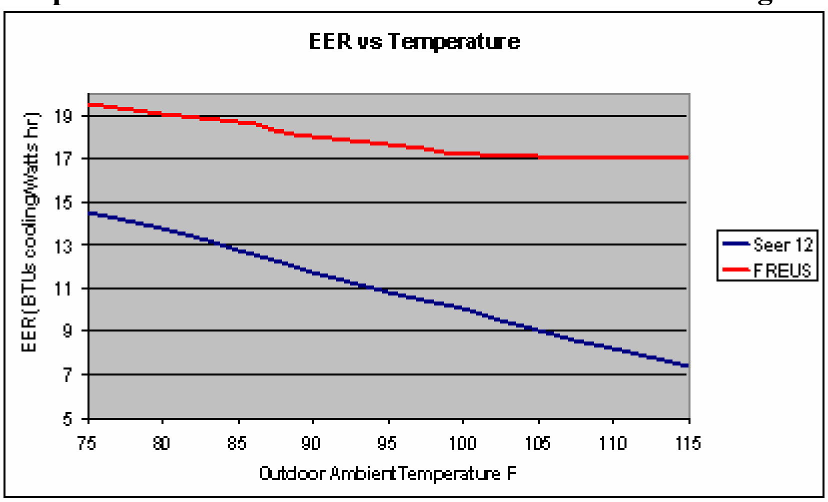
The air conditioning ductwork for the Baseline house is located in the attic above the insulation which is typical construction for the region. Since the flexible ductwork does not have the same R-value as the attic insulation, there are transmission losses to the surrounding attic. Also any air losses due to leakage are lost to the attic. In the ZEH, the duct work is located in framed soffets located below the ceiling in the conditioned space. All transmission losses are to the conditioned space and any air leakage would be in the conditioned space instead of the attic.

The air conditioning systems for both houses are single zone split system designs. The Baseline house uses a conventional horizontal gas heating furnace with an A-coil for cooling which is mounted in the attic space. The air conditioning system has a Seasonal Energy Efficiency Ratio (SEER) of 12 and uses a conventional air coil to expel heat into the air. The ZEH uses a horizontal mounted hydronic fan coil unit with A-coil for cooling. The fan coil unit is located in an insulated enclosed ceiling space above closets, bathrooms, and the laundry room but below the attic insulation. This also reduces transmission and air losses to the attic space.

The ZEH uses a highly efficient 3 ton Freus evaporative-cooled condenser. The Freus unit utilizes evaporative cooling by spraying water across specially shaped condensing coils and drawing air across the coils with the fan. This cools the refrigerant more efficiently than a conventional air coil. The shape of the coil allows expansion and contraction of the coil during normal operation which causes mineral deposits from the water to fall off of the coil. Because the unit uses evaporative cooling, the Freus unit is rated by the Energy Efficiency Ratio (EER). At an outdoor ambient air temperature of 95 F Dry Bulb (DB), the Freus unit has an EER of about 18 (CER 2005). Figure 3 shows the Freus unit and Figure 4 shows a comparison of the Freus unit with a conventional condensing unit.

Figure 3. The Freus Evaporative Cooled Condensing Unit at the ZEH and the Conventional Condensing Unit for the Baseline House in the Background

Figure 4. The Performance Rating of the Freus Evaporative Cooled Condensing Unit Compared to a 12 SEER Rated Conventional Condensing Unit



Source: CER 2005

For water heating, the Baseline house uses a 40 gallon gas water heater located on a pedestal in the garage. The ZEH combines a Sun System's Coppersun Model 340 B Integrated Collector Storage (ICS) solar water heating system with a Noritz Model N-069M-DV tankless on-demand gas hot water heater. The ICS is a passive roof mounted tempered glass and copper tube collector with a collector area of 25 square feet which holds 40 gallons of water. The on-demand water heater has no storage or pilot light and heats the water when it is needed. Energy losses from the water heater storage tank are eliminated. Both systems in the ZEH provide domestic hot water and also provide hot water to the hydronic heating system.

Power generation for the ZEH is accomplished using a roof integrated photovoltaic system as seen in Figure 5. This system is made up of 96 General Electric Model GEPV-055-G roof integrated photovoltaic panels. These are connected to two SMA Sunny Boy 2500U inverters located in the garage. The system can provide 4.8 kilowatts AC of peak power.

Figure 5. Photograph Taken From the Neighboring Yard of the South Facing ZEH Roof With the Roof Integrated Photovoltaic Panels and Solar Water Heater

The windows for both homes are of low emissivity (low e) as required by code. The Baseline house has windows which have a U-value of 0.58 Btu/hr-ft^2-F, a Solar Heat Gain Coefficient (SHGC) of 0.35 and a Visible Transmittance (VT) of 0.57. The ZEH windows exceed the codes with spectrally selective windows and for the patio doors have a U-value of 0.34 Btu/hr-ft^2-F, a SHGC of 0.21 and a Visible Transmittance (VT) of 0.35. The remaining windows for the ZEH on average have a U-value of 0.33 Btu/hr-ft^2-F, a SHGC of 0.21 and a VT of 0.35 (CER 2005). The ZEH also has large overhangs extending out 8 feet over the patio doors.

For lighting the Baseline house uses conventional incandescent bulbs while the ZEH uses Compact Fluorescent Lamps (CFL) which meet the criteria for long life, energy savings, start time, color, and brightness set by the federal government's ENERGY STAR® program (ENERGY STAR® 2006). The CFLs use 70 to 75 percent less energy compared to their incandescent equivalents. Another advantage is they generate less heat than incandescent bulbs which reduces air conditioning loads.

Both homes use ENERGY STAR® rated appliances but since the homes are being used as models and are open to the public, the appliances are not being used. The ENERGY STAR® appliances include the refrigerator and dishwasher.

Data Monitoring

Both homes were heavily instrumented during the construction phase. Sensors were installed throughout the house and interconnecting wiring was run to monitoring stations located in each garage. For data collection two Campbell Scientific Incorporated (CSI) Model CR10X programmable data loggers were installed in each monitoring station. These are each powered by CSI PS100 12 volt power supplies with charging regulators connected to a 110 volt AC to 12 volt DC power supplies with 7 amp hour backup batteries. For communications the data loggers are each connected to CSI COM 210 telephone modems which are connected to telephone lines in each house. To add monitoring channels to each data logger, CSI AM16/32 relay multiplexers were added to each data logger for an additional 32 sensor analog inputs, and CSI SDM-SW8A 8 channel switch closure input modules were added to add 8 channels of switch closure or voltage pulse inputs.

To monitor the wind speed and direction, a CSI 03001 Wind Sentry Set was installed on the roof of the ZEH. Ambient temperature and relative humidity are measured using a Vaisala HMP50 temperature and relative humidity probe with radiation shield. Total hemispherical solar flux is measured using a LI-COR LI200 Silicon Pyranometer which is mounted on the roof and oriented in the same plane as the photovoltaic panels.

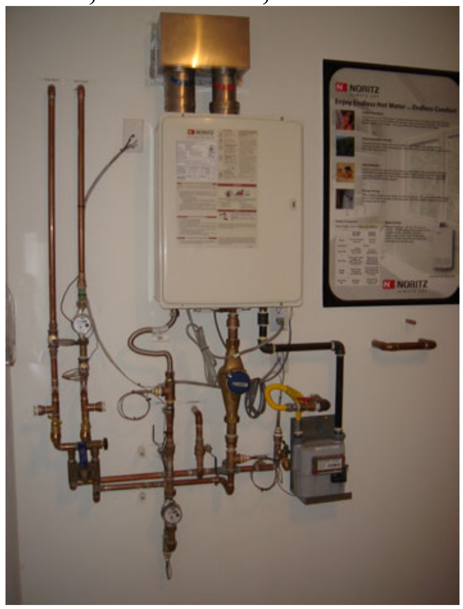
Electrical power consumption for both houses is measured for the whole house, air conditioning condensing unit, fan coil unit, and on the ZEH photovoltaic system power generation, are measured using Continental Control Systems WattNode Model WNA-1P-240P watt/watt hour transducers. These are connected to split core current transformers attached on house wires located in the main circuit breaker panel. The pulse outputs from the WattNodes are measured in the switch closure input modules.

Whole house gas consumption for both houses is measured with RIOTronics PulsePoint retrofit gas meter pulse devices which were added to the main house gas meters by the gas utility. The gas consumption for the water heaters for both houses and the gas furnace in the Baseline house are measured using E-Mon Model 200CFGM gas meters with pulse outputs. The pulse outputs from the gas meters are also measured in the switch closure input modules.

Water flows to the gas water heaters for both houses and the hydronic heater in the ZEH are measured using Omega Model FTB-4110A-P turbine water meters and an Omega Model FTB-4107A-P turbine water meter for the solar water heater in the ZEH. Water usage by the Freus air conditioning condenser on the ZEH is measured with a Seametrics Model SPX-038 low flow impeller water meter. Figure 6 shows the plumbing manifold for the ZEH with gas meter and flow meters to monitor performance of the water heater, solar water heater and hydronic heating system.

Heat flux is measured in four wall locations corresponding to each major compass direction at a height of 5 feet above finished floor and in two ceiling locations; one below the highest point in the attic and another below the lowest point in the attic. The latter two are to measure the heat flux through the ceiling in the two varying temperature extremes in the attic. The heat flux sensors used are Omega Model HFS-4 thin film heat flux sensors and are wired into the multiplexers.

Figure 6. Tankless On-Demand Water Heater With Instrumentation Including Flow Meters, Gas Meters, and Thermocouples



Temperatures are measured in several locations throughout both houses. For the temperature measurements J-type thermocouples are used which are also wired into the multiplexers. Before the floor slab was poured on the ZEH, thermocouples were placed at three locations and at four depths at these locations; three feet below grade, one foot below grade, at the base of the concrete, and 1/2 inch from the finished floor in the concrete. These thermocouples can be used to evaluate the effect of ground temperatures on the house and also be used to monitor the performance of the slab insulation. In the Baseline house the thermocouples were located at three locations at a depth of 1/2 inch below the finished floor. One additional thermocouple was installed one foot below grade at the exterior of the ZEH.

During the precasting of the T-Mass^{TM} walls for the ZEH thermocouples were imbedded into the walls just below the interior surface and just below the exterior surface. These were again placed in same four locations as the heat flux sensors. Care was taken when installing the thermocouples and heat flux sensors so as not to let them be influenced by the conduits that the sensor wires were run in. During the construction of the Baseline house, thermocouples were imbedded into the exterior plaster and into the interior sheetrock at the same locations corresponding to the wall locations in the ZEH.

Thermocouples were also placed in several locations within the mechanical equipment for both houses: in the return air grills and behind the thermostats, behind the diffusers for both the longest duct runs and the shortest duct runs, on the water inlets and outlets for the water heaters and the solar water heater, and also in the water sump for the Freus condensing unit. Temperatures are also taken at two locations in the attics of each house corresponding to the locations of the ceiling heat flux sensors.

Using CSI Loggernet software, data is automatically collected remotely to a server located at the UNLV Center for Energy Research where the data is then archived for later analysis. CSI's RTDM software is currently being used to develop close to real-time displays of the data on web pages developed for this project. This will allow researchers at the university as well as the developer, utilities, and interested persons to view the measured parameters from any web browser.

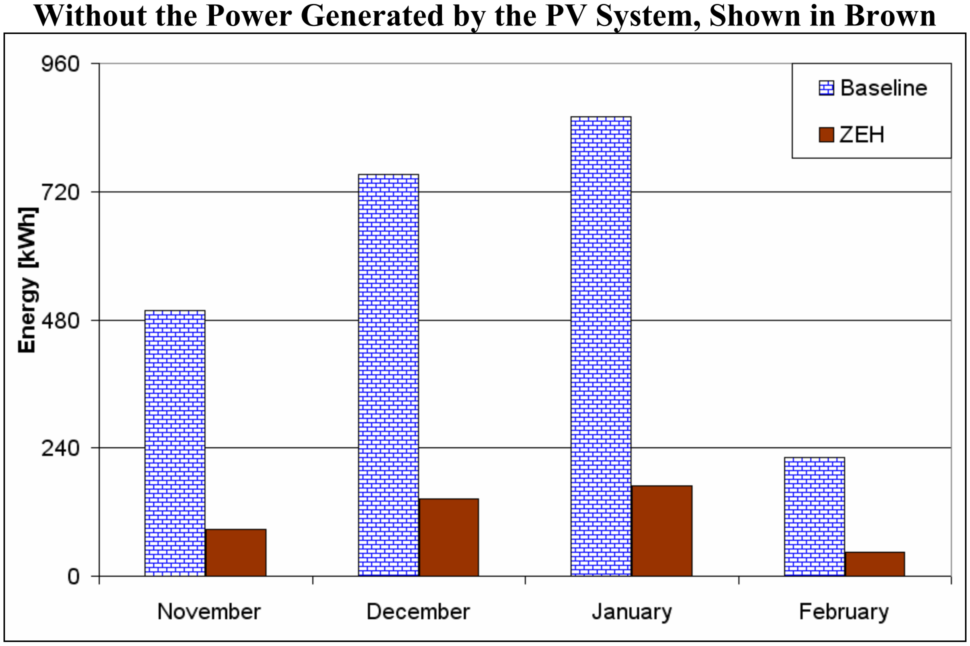
Programmable valves and timers are used to simulate hot water usage and electrical loads in both homes during the monitoring period.

Data Analysis

Data monitoring for both houses started in October 2005 with that month being used for sensor testing and calibration. Monitoring will take place for 18 months while the houses are used as model homes and open to the public.

Some of the preliminary data shows the ZEH is performing very well for energy efficiency and power generation. Figure 7 shows the net energy usage for both homes not including power generated by the photovoltaic system. The Baseline house is shown to use 5 times more energy than the ZEH during this period (CER 2006). This is mostly contributed to the energy used for the different types of lights in the two homes. The ZEH photovoltaic system performance can also be seen in Figure 8 for the monitoring period. Figure 9 shows the net energy used by both homes for the same period. As can be seen the ZEH is making more power than it is using.

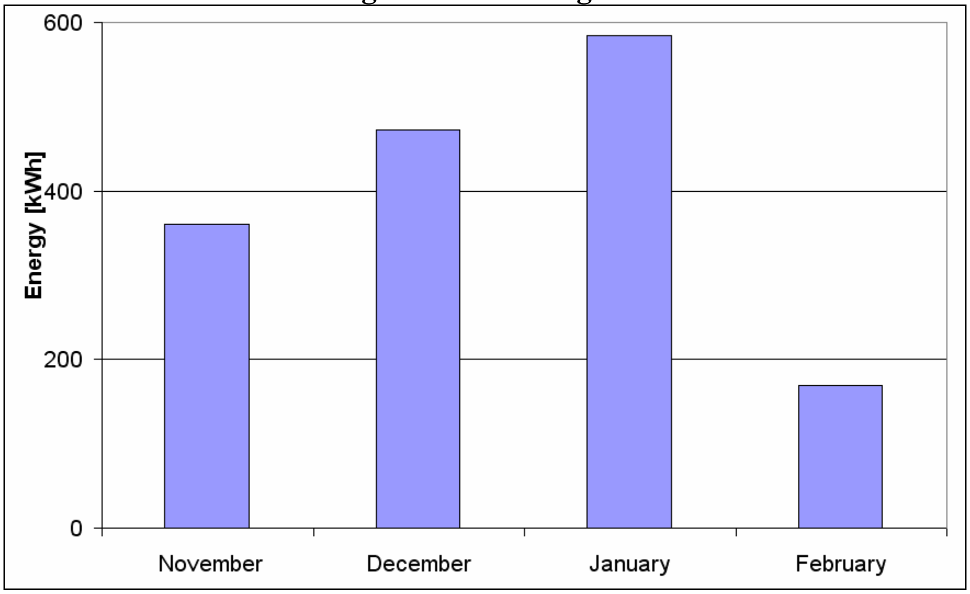
Figure 7. Net Energy in Kilowatt Hours Used by Both Houses With the Baseline House Shown in Blue and the ZEH, Without the Power Generated by the PV System, Shown in Brown



Source: CER 2006

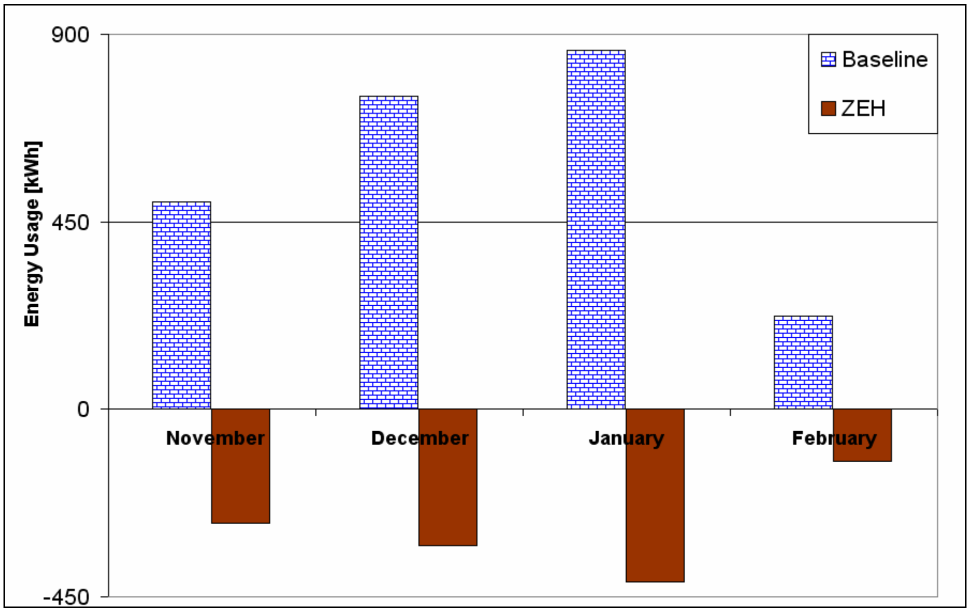
The performance of the walls can also be seen in the data. Figure 10 shows the interior and exterior wall temperatures for the Baseline house for January 25 and 26. As the exterior of the wall is heated by the sun, a lag in the interior temperature of the wall is seen. The small drops in temperature at 12:30 and 14:30 are caused by shading at the sensor location. Ambient temperatures were in the low 40’s at night to a high of 70 degrees F during the day. Figure 11 shows the wall temperatures for the ZEH on the same days. As can be seen, the exterior wall temperature had very little effect on the interior wall temperature.

Figure 8. Monthly Energy Produced in Kilowatt Hours for the ZEH During the Monitoring Period



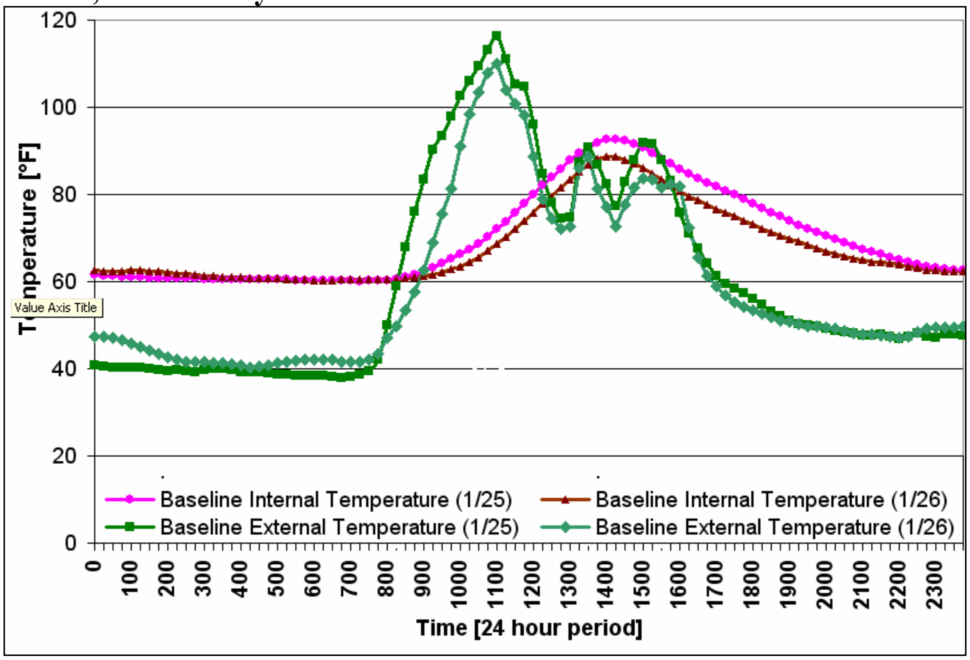
Source: CER 2006

Figure 9. Monthly Total Energy Used by Both Houses With the Baseline House Shown in Blue and the ZEH Shown in Brown



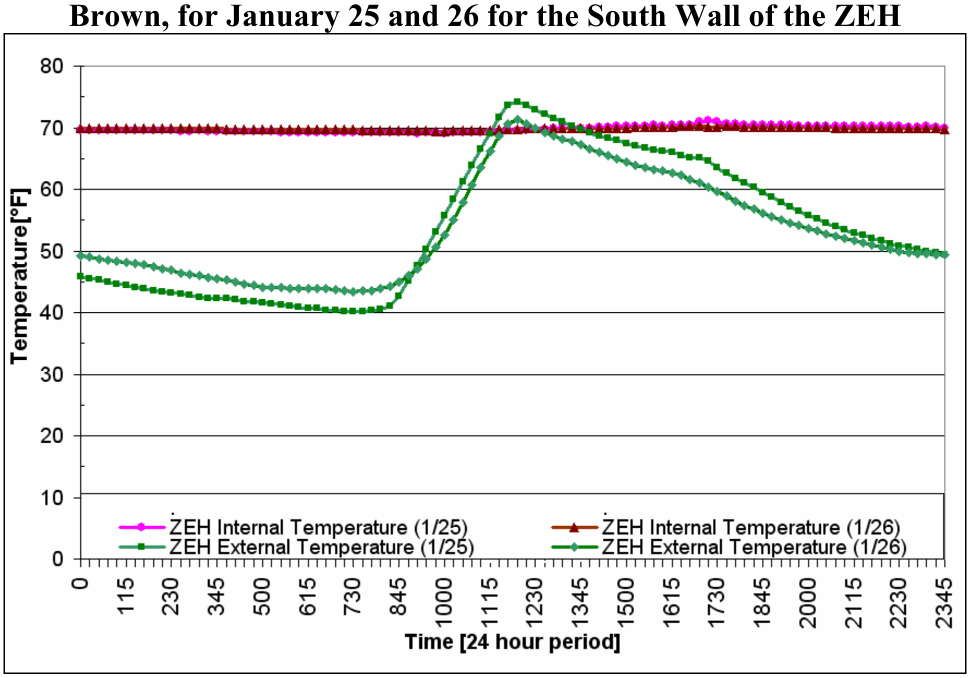
Source: CER 2006

Figure 10. Temperatures of the Exterior, Shown in Green, and Interior, Shown in Pink and Brown, for January 25 and 26 for the South Wall of the Baseline House



Source: CER 2006

Figure 11. Temperatures of the Exterior, Shown in Green, and Interior, Shown in Pink and Brown, for January 25 and 26 for the South Wall of the ZEH



Source: CER, 2006

Conclusions

Preliminary analysis on the data for both houses shows the ZEH is performing well in energy conservation and power generation. Continued work is needed in the analysis to understand the interaction of components such as the solar water heater, on-demand water heater, and hydronic heating system and evaluate the configuration best used for these components.

Projects such as this are important to show developers and the home buying public options that are available in the design, building, or retrofit of homes for energy conservation and reduced energy demand.

Acknowledgement

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