 

# Cooling Season Performance of the Glen Acres Deep-Energy Retrofit Home

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Existing residential buildings offer a large scale opportunity for energy-related retrofit. Nevertheless, while the technologies for energy conservation common to domestic structures are often similar within communities, many complicating factors limit production scale energy-related retrofit. Unlike new housing construction which has become uniform and systematized, energy-related housing retrofit is done on a per house basis, restricting energy-related upgrades. The limitations stem from a fragmentation of ownership, a dearth of construction organizations offering whole-house energy-related retrofit as a primary service, limited funds to advance the process, and housing valuation practices that fail to recognize value created by energy-related improvements. This paper is a preliminary performance report on a Deep-Energy Retrofit Home completed as a marketing and demonstration home for a joint neighborhood stabilization project and U.S. Department of Energy funded community-wide retrofit grant program. The demonstration home completed in 2012, which included an internet based home energy monitoring system, has been sold and occupied. A report is included outlining energy consumed for space cooling, water heating, appliance use, and lighting/plug loads during one full occupied cooling season and one partial occupied cooling season. Solar energy production totals for the period are also included.

**Keywords:** Energy Conservation, Retrofit, Housing, Community/University Partnership

## Introduction

Buildings are significant users of electricity, accounting for more than 72% of electricity use in the United States. This contributes 39% of the carbon dioxide (CO2) emissions in the United States per year, more than either the industrial or transportation sector of the economy (The U.S. Green Building Council, 2009). Adopting energy conserving measures and alternative sources of energy production for use in buildings offers vast opportunity toward reaching the national goal of energy independence and reducing climate change.

An October 2008 report of the National Science and Technology Council titled *Federal Research and Development Agenda for Net-Zero Energy, High Performance Buildings* notes the general lack of informational guides and incentives, and the misinformation that exists about energy consumption in buildings. The report recommends effective technology transfer through improved tools and guides, education and training, and market-based building valuation metrics. The basis for this technology transfer would be research and demonstration coupled with private industry activity. This paper describes a program that provides a vehicle for the suggested education and technology transfer specifically targeting residential properties and the conditions encountered in the State of Indiana.

The City of Lafayette, located in a small metropolitan area of less than 200,000 residents, was awarded grant funding from the U.S. Department of Energy for approximately 80 energy conserving retrofits in the Glen Acres and Vinton communities through a retrofit ramp-up program. Lafayette administered these funds through the use of staff currently employed under a Comprehensive Neighborhood Revitalization Fund for Glen Acres. The fund for this Neighborhood Stabilization Program (NSP) financed the acquisition of foreclosed properties that were rehabilitated for sale to low income individuals. As the primary outreach vehicle for the retrofit ramp-up program, this NSP funding facilitated the acquisition of a home for a deep-energy retrofit demonstration.

 

The neighborhoods of Glen Acres and Vinton are comprised of starter homes built from 1950 – 1970. A significant challenge for residential energy conservation market transformation in these communities was the limited ability to communicate directly with homeowners. Because Glen Acres and Vinton are conventional post World War II first ring suburban communities, no community center or other social meeting place was available for marketing outreach. As a result, no venue existed for the purpose of educating homeowners about the benefits of energy conserving retrofits or available opportunities for grant assistance to implement appropriate retrofits for low income homeowners.

As part of the Lafayette program, ultimately named the Lafayette Energy Assistance Program (LEAP), outreach opportunities and potential for homeowner education was provided by a high-profile, deep-energy retrofit demonstration home located within the Vinton community. The use of a deep-energy retrofit demonstration home within the community provided marketing outreach needed to encourage participation by community homeowners. Locating the home within the community helped to make grant implementation convenient for the community within a location appropriate for social interaction, and provided a path for bringing the retrofit program message to individuals who may not be exposed to it in the mass media. The demonstration home used established energy conservation retrofit strategies as well as PV solar energy production, some of which were beyond the current capability of participating homeowners to adopt, to draw as large an audience as possible. The program exposed homeowners in the target neighborhoods and the larger Lafayette community to currently available retrofit technologies as well as the available grant incentives.

In a December 2010 review of U.S. whole-home retrofit programs, the National Home Performance Council noted that utilities sponsored the majority (113) of the 126 whole-home retrofit programs identified in the study. Of this group, 38 met the home performance guidelines of the Energy Star program sponsored by the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA). To receive a Home Performance designation under the Energy Star program all of the following components were required as part of the program. Similar components were used for the LEAP as follows:

- An assessment of the home by a certified energy specialist using visual and diagnostic methods
- A set of recommendations for improving the home based on the assessment
- Assistance for homeowners in identifying contractors who can implement the recommendations
- Verification that work was installed and that health and safety issues were addressed
- Quality assurance measures

## Energy Performance Improvements in LEAP Retrofit Homes

Purdue University participated in the LEAP program development and guided the technical development of the retrofit home. In parallel with technical research for selection of energy conserving measures (ECM) for the deep-energy retrofit demonstration by faculty and students at the university, a weekly meeting was held with the builder and the NSP program manager. ECMs were selected so that each would generally be:

- appropriate for homes found in the communities
- easy for local building trades to understand and install
- available through traditional supply channels without delay
- assessed from a whole-building energy performance viewpoint
- expected to provide near-term potential for positive payback, but with no specific cut-off
- appropriate to or related to energy retrofits that could be funded by program grants

- a contributor to energy conservation first with introduction of alternative energy sources only when energy consumption has been minimized
- obvious to visitors and individuals that passed by the demonstration home to promote program visibility and ease of endorsement

The combined management teams of the NSP funding and the DOE funded grants for the Lafayette Energy Assistance Program created a positive synergy. Grant recipients were easily identified and the programs ultimately contributed to a total of 85 home energy retrofits for low income individuals. Based on before and after blower door testing, there is program wide evidence that that retrofits were successful in reducing air infiltration by approximately 17% (Ye, et al. 2014). The diversity of retrofit technologies, occupancies, and home types complicates any further program-wide energy performance analysis.

## The Deep-Energy Retrofit Demonstration Home

A detailed description of the ECMs chosen for the demonstration home is beyond the scope of this paper. Table 1 provides basic information about the ECMs.

Table 1

***Energy Conservation Measures***

| ECM | Description |
| --- | --- |
| Windows | R-5.56 triple glazed casement |
| Sun Tube | One in each bath with dimmer to provide daylight illumination and control |
| Exterior Doors | Insulated steel, thermal break frame, magnetic weather-strip, polyurethane core R-8.3 |
| Crawl Space | Damp Proof w/ sealed 20 mil poly floor cover |
| Attic Access | R-40 insulated, weather-stripped attic closure system |
| Air Seal Attic | Air seal all top plates and ceiling penetrations with closed cell foam |
| Air Seal Walls | Expanding foam seal all exterior wall penetrations |
| Insulate Attic | R-60 Loose Fill Cellulose with 3" closed cell foam - 3' wide at roof edge (R-20+) |
| Insl. Crawl Space | Conditioned crawl, 2" closed cell foam on interior of crawl wall and band joist (R-13+) |
| Insulate Ext. Walls | R-11 batts @ 2x3 wall cavity plus 4" (R-20) extruded polystyrene sheathing (2 layers of 2” foam with lapped and taped joints) |
| South Overhang | Extend to 16" for summer shading and add continuous vent |
| Hot Water | Heat Pump Water Heater with min. COP rating of 2.0 or greater |
| Solar Energy | Nominal 4 KW Solar PV System |
| Furnace & AC | Multi-speed air handler, min. 25,000 BTU gas furnace, 1 ton AC |
| Ductwork - Supply | Within conditioned space, Mastic seal all ductwork |

| | |
|---|---|
| Ductwork - Return | Within conditioned space were possible, Attic runs min. R- 20 insulation, Mastic seal all duct |
| ERV | Energy Recovery Ventilator min. 60% heat recovery, installed in conditioned space |
| Thermostat | 7-Day Setback |
| Washer | Front Load – Energy Star Rated |
| Dryer | Electric – Energy Star Rated |
| Refrigerator | Top Freezer, No water and ice through door, Energy Star Rated |
| Dishwasher | Energy Star Rated |
| Electrical | 44 circuit eMonitor® energy monitor, real-time internet energy use dashboard |
| Lighting | All lighting CFL or T-8 florescent except LED kitchen task lighting |
| Window Coverings | Living Room Insulating Cellular Shades with air sealing tracks |

Because the deep-energy retrofit home was also a NSP remodel project, the builder chosen to complete the work was a low bidder under the qualification rules of the NSP funding. They had a typical background in residential construction with no special expertise in energy-related building. The weekly meetings used in the ECM selection process were an opportunity to provide the builder and some of his key subcontractors with the technical requirements of the most unusual of the ECMs. A PhD student made weekly visits to the project site to meet with the builder, the city's program manager, and any subcontractors or material suppliers involved that week. With the builder in charge of day to day work and quality control, occasional performance issues were anticipated.

While no serious quality control issues became apparent, several things did occur that are indicative of common oversights that can be experienced in energy-related retrofit. To verify the energy performance of the demonstration house, an energy auditing firm was hired to complete a post-construction inspection using a blower door and duct blaster to confirm the success in air sealing the structure and ductwork. A preliminary use of the blower door was also utilized before installation of the interior wallboards. At this point the ceiling drywall was complete and all specified air sealing measures were to have been completed by the builder's subcontractors. Within a very short period of introducing negative air pressure to the structure, significant flows of cold exterior air were noted entering the structure. Figures 1 and 2 are examples of a few of the many poorly sealed penetrations identified by this process.

 

Figure 1. Poor Foam Air Sealing

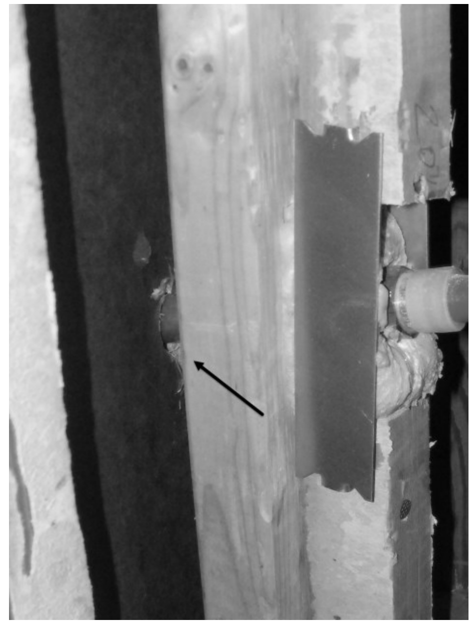

Figure 2. No Foam Seal at Exterior Penetration

Failure to commission HVAC equipment is common in residential construction. It was no different in the demonstration home. The first time the air conditioning was turned on, the air volume from the air handler was so high it caused significant noise within the home and caused papers to blow if located close to an air supply outlet. The multi-speed fan for the system was capable of servicing a range of capacities from 1.5 to 6 tons of cooling. Rather than setting the system for the design parameters, the HVAC installers left the factory preset values in place.

In addition to verifying the air infiltration and duct leakage of the completed demonstration home retrofit, the energy auditing firm completed a common U.S. home energy rating called the Home Energy Rating System (HERS). The HERS rating is an index using a score of 100 to represent the performance of homes based on a reference home built to meet the 2006 International Energy Conservation Code. A net-zero energy HERS home score is 0. The lower a home's HERS score, the more energy efficient it is in comparison to the HERS reference home. Figure 3 is the rating certificate with a score of 17 for the deep-energy demonstration home.

While it is not possible to separate all costs related to the energy-related retrofits from the major modifications to fully rehabilitate the demonstration home, the final costs paid for by the DOE energy retrofit grant were 18% less than the original budget for the deep-energy retrofit. Some saving came from careful selection and purchasing of ECMs, but the bulk of the savings resulted from the significant reduction of installed cost for solar PV systems that took place between 2009 when the initial budgeting was completed and the actual installation in 2012. The solar PV system was the single most expensive ECM at $21,700. The extra cost for all other energy-related items totaled $26,430. It is anticipated that this cost could have been reduced further if all items could have been selected based on cost and competitive bidding. The only ECM competitively bid was the solar PV system. Because the home remodeling contract had already been let by the city, energy-related extra costs and addition charges were determined by the builder or subcontractor for each ECM specification upgrade. This process often limited the options for materials and or suppliers involved in the energy-related retrofits.

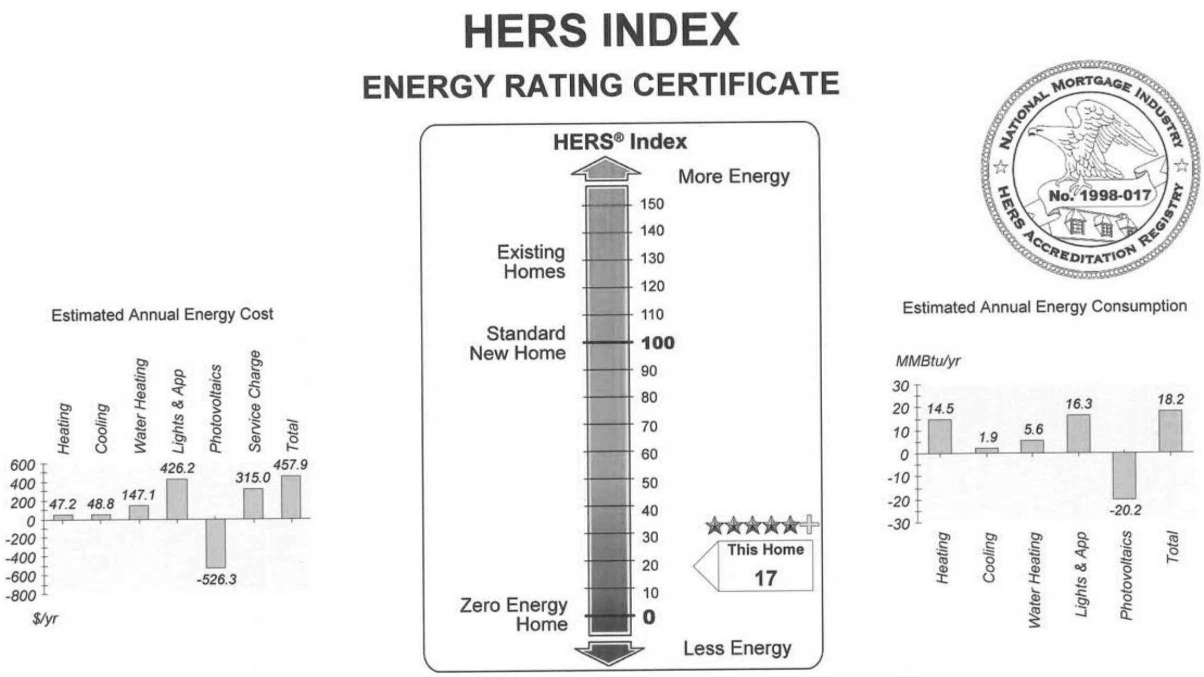


Figure 3. Demonstration Home HERS Rating Certificate

## Retrofit Home Cooling Season Energy Consumption

The retrofit home was completed in early 2012 at which time it was used for public showings and a number of educational sessions for homeowners and contractors as well as individuals attending a nearby academic conference on high performance buildings. At the end of 2012 the home was sold and occupied in early 2013. During the first half of 2013 the home was not occupied on a consistent basis, so only inconsistent data is available for this period. A monitoring equipment failure occurred beginning in September 2013. Discovery and repair of the equipment problem resulted in the loss of data through March 2014. Although full year energy use and production data are not available, data has been collected for one complete and one partial cooling season during the retrofit home's occupancy.

Data reported in Table 2 covers the active cooling period of 2014, the first available full cooling season since the retrofit home was regularly occupied. The cooling season was delineated by the time period beginning with the first day of air conditioning compressor electric consumption and ending with the last day of compressor energy consumption. The home is monitored using an eMonitor® system which provides a real-time energy use dashboard. Energy use and production is measured on a minute by minute basis directly from the home's electrical panel using induction coils at each of the home's circuit breakers. The collected data is transmitted to SiteSage®, a cloud based monitoring dashboard. The SiteSage® dashboard (Figure 4) is accessed through a password protected website. The homeowner was initially excited about the dashboard's ability to provide real-time feedback on energy consumption. Because the dashboard shows both consumption on a circuit by circuit basis as well as solar power production, the system is able to provide a direct connection between specific energy consumption by circuit and energy cost. The homeowner's excitement with the monitoring system dashboard was evidently short-lived based on the long period that passed before noting that no data was available on the dashboard after the equipment failure. The researchers now have installed an alert system that sends an email to the author at any time the eMonitor® fails to send data.

Table 2

***2014 Cooling Season Energy Consumption & Solar Production***

| Energy Consumption | Consumption Per Day | Solar Production | Net Energy | Net Energy Per day |
|---|---|---|---|---|
| 1639 kWh | 12.1 kWh | 2560 kWh | -921 kWh | -6.8 kWh |

Figure 5 shows the proportion of energy consumed for the full cooling season during the summer of 2014 adjusted for a brief series of convenience outlet data reading which did not appear to be plausible. The unusual energy readings were recorded for an outdoor outlet and the circuit which serves one of the baths for a 7 day period. These readings represented 53% of all lighting and plug loads for the summer. With the exception of an occasional small use recorded for these circuits, no other consistent energy consumption on these circuits was apparent throughout the period. The homeowner was not able to identify any unusual activity that would have accounted for the data recorded. After the adjustment to remove the unusual data, the per day average lighting and plug consumption for the summer of 2014 still exceeded the 2013 lighting and plug consumption by 10% while the per day average for all uses remained relatively constant.

The total adjusted energy consumption for the full cooling season of 2014 was 12.1 kWh per day. The Indiana average annual household energy use is 105 MMBtu or 30,772 kWh (Energy Information Administration, 2009). Although this 84 kWh/day value (30,772 kWh / 365 days per year) far exceeds the retrofit home cooling season value, summer energy consumption per day is normally expected to be far below daily winter consumption. The Indiana space heating average for the 2009 EIA survey reflected nearly 50% of total annual energy consumption while air conditioning totaled only 3%. Lighting energy consumption is also expected to be higher during winter months. It is too early to tell how well the energy performance of the smaller than average retrofit home compares to average Indiana home energy consumption, but Indiana average residential energy consumption is 2.7 times the HERS audit projection for full year net energy consumption of the retrofit home.

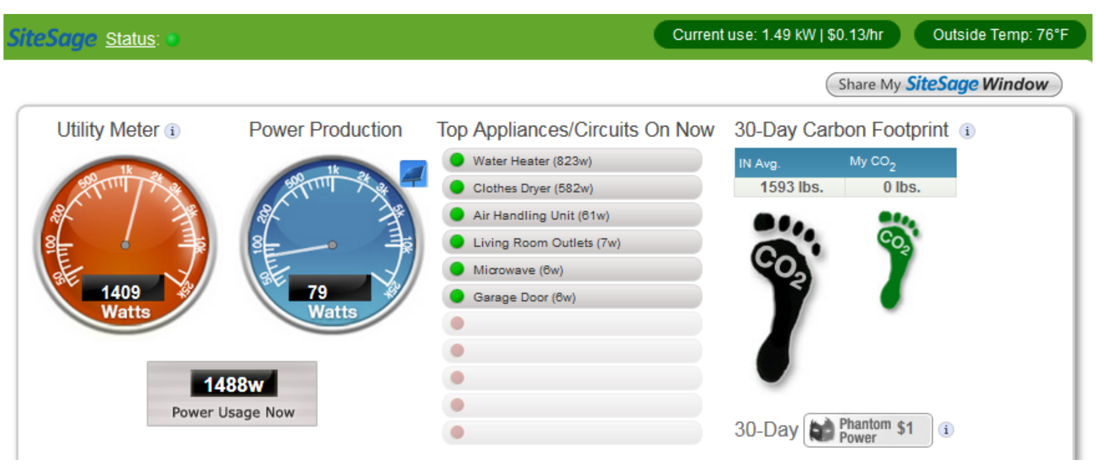


Figure 4. SiteSage® Energy Dashboard

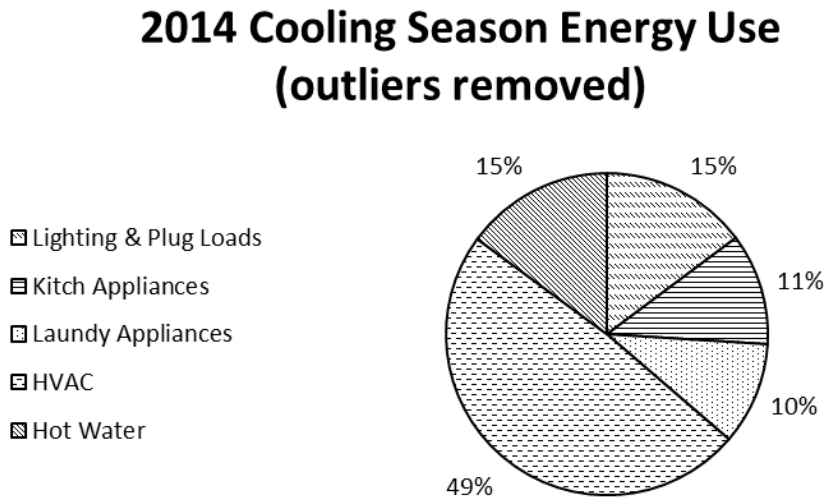


Figure 5. Retrofit Home 2014 Cooling Season Energy Consumption by Use Category

During the summer of 2013 when occupancy of the retrofit home was not consistent, energy use in all categories was substantially lower than 2014 on a per day basis with the exception of hot water energy consumption. The heat pump hot water heater initially installed did not function properly in the energy efficiency mode. This flaw my not have been detected if not for the eMonitor® system. After the water heater was replaced with a second generation model, water heater consumption dropped nearly 25% on a daily basis. It is somewhat difficult to compare the proportion of total energy use represented by individual categories of energy use for the retrofit home with those for Indiana homes in the EIA survey of 2009. Average annual values are provided in the EIA tables which require adjustment for summer only proportions, skewing data which already has a rather high error rate. Nevertheless, if the actual annual survey site energy consumption data is adjusted to include 100% of Air Conditioning consumption, no Heating consumption , 30.4% (the portion of the year AC was used in the retrofit home) of Water Heater and Other consumption, some basis of comparison is possible. With these adjustments to the EIA survey average home data, 55% of energy consumption was for lighting, plug loads or appliances (Other), 16% was for Air Conditioning, and 29% for Water Heating during a cooling season. While too early to tell definitively, increased appliance, lighting, and water heating efficiency may be shifting the consumption category proportions to a greater dominance of AC consumption in the retrofit home.

## Observations for Future Analysis

These preliminary results do not show a full picture of the energy saving through increased envelope efficiency for the retrofit home because the Indiana climate is most taxing on the energy budget of every structure during the winter months. High envelope efficiencies and improved efficiency of the heating plant for the retrofit home will both provide the most benefit during winter months.

The excess energy generated by the solar PV system during the summer months was significant. The electric energy produced by the solar PV array exceeded actual energy consumption during the 136 days of AC use in 2014 by 921 kWh. This represents at least a 56% power generation surplus going into the heating season. The non-HVAC intensive periods of spring and fall will further boost this surplus. This energy supply surplus is necessary to offset the heavy heating energy load. Based on 2012-13 solar energy production values, solar PV back-feed is likely to be reduced from the summertime peak by about one-third during the last two month of the year and two-thirds in the first two month of the year. The actual solar back-feed for the full 2012-13 year was 5400 kWh (18.4 MMBtu), well short of the 20.2 MMBtu/yr projected by the HERS audit.

It will be interesting to see if the 14.5 MMBtu/yr (4,250 kWh) heat load estimate from the HERS audit is accurate. The heat load during the partially occupied winter of 2012-13 was 202.7 therms of natural gas or 5,941 kWh which exceeded the HERS projection by nearly 40%. Daily approximations based on available 2013 and 2014 data shows HVAC consumptions exceeded the HERS projection while water heating, appliances, lighting and plug loads all consumed less than projected. It appears that the net energy consumption after solar back-feed is considered may still be less than the HERS audit projection. Data to date is inadequate to conclusively conclude that the HERS rating of 17 has been achieved for near net-zero performance. Actual full year data with consistent occupancy will not be available until May of 2015 to confirm this performance level.

An interesting observation was made about air handler power consumption for periods when the AC compressor was not operational. An Energy Recovery Ventilator was installed to capture energy from the exhaust air and transfer it to the outside ventilation air which is consistently supplied to the retrofit home as a way to maintain indoor air quality in a controlled manner. This system is electrically connected to the HVAC air handler and is controlled by a humidity control device and a switch located in each bathroom. The bathroom switch allows the homeowner to exhaust bathroom air through the ERV when necessary. The daily air handler energy consumption exclusive of heating or cooling demand has been rising with time, suggesting greater ERV energy consumption. During the month prior to first AC use in 2014 the air handler electric demand increased by over 50% and gradually diminished to a more typical level after over a month of consistent AC operation. Because it appears that the ERV electric consumption can be as high as 25% - 30% of the full HVAC cooling energy consumption, it would be interesting to examine how humidity, occupant control, maintenance, ERV control setting, or other factors influence ERV energy use.

## Conclusions

While no conclusive evidence is available to date which can confirm or deny the accuracy of the HERS audit projections for near zero-energy performance of the retrofit demonstration home, initial data from partial year operation are encouraging. A substantial surplus of electricity was generated by the home's solar PV array during the summer months to offset the anticipated heavy energy use necessary to heat the home in the upcoming winter period. Final energy balance conclusions must await the availability of full year energy consumption data. As expected, the energy projections on which the HERS rating is based do not appear to be an accurate predictor of actual energy consumption. Performance to date would indicate that actual HVAC consumption is higher than projected and that all other energy use categories are lower than projected. Clearly occupant behavior plays a significant role in actual performance. Energy consumption by the ERV is also higher than anticipate and variable consumption rates have raised questions about potential ERV maintenance or control problems. In any event, the retrofit home appears to be performing far better than the average home located in similar mid-western regions of the United States. Nevertheless, it is yet to be seen whether the solar power production will be adequate to pay back the initial cost of the solar system during the anticipated 20 year useful life of the system.

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