

Annual Energy 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. The report includes energy consumed for space cooling, water heating, appliance use, as well as lighting and plug loads during one full year of occupancy by the home's current owner. Offsetting site solar energy production totals for the period are also included.

Key Words: Energy Conservation, Retrofit, Housing, Community/University Partnership

Overview

American homes are significant users of energy, accounting for almost 21.4% of all the energy consumed in United States (U.S. Department of Energy, 2014). Single family homes consume about 80% of that energy, followed by multi-family homes which account for 15% of the total residential energy consumption. Although, annual energy consumption in the residential sector has steadily increased in the past 25 years, the rate of its increase is slower than the rate of increase of population of United States. Increase in the energy efficiency of homes has resulted in reduced energy consumption, but these efficiency gain have been offset by the energy consumed by increasing number of electronics and appliances within an average American home. Nevertheless, there are still opportunities for improvement in the areas of building envelope and whole-home performance.

The Deep-Energy Retrofit Demonstration Home

Purdue University participated in the Lafayette Energy Assistance Program (LEAP) and guided the technical development of a retrofit home. This demonstration home was completed to provide outreach, opportunities and potential for homeowner education within the Vinton community, where it was located. The Energy Conservation Measures (ECM's) (see Table 1) for the retrofit house were carefully chosen after thorough technical research by the faculty, students of the university, the builder and the Neighborhood Stabilization Program (NSP) program manager. In parallel with making the house energy efficient, these ECM's were selected so that each would generally be:

- appropriate for homes found in the project 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 had been minimized
- obvious to visitors and individuals that passed by the demonstration home to promote program visibility and ease of endorsement

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
Air-Tightness	Infiltration post-retrofit 2.28 air changes/hour @ 50 pcal pressure (blower door)

In order to predict its energy consumption, prior to it being occupied the retrofit house was audited by a certified Residential Energy Service Network (RESNET) Home Energy Rater and given a Home Energy Rating System (HERS) Index rating. The HERS Index Score gives an energy performance assessment of the home based on the audit results. While, a typical resale home scores 130 on the HERS Index, a home built to the 2004 International Energy Conservation Code is awarded a rating of 100 (U.S. Department of Energy). The RESNET HERS auditor, who does the energy ratings of homes, compares the energy audit data of the audited house to a 'reference home' – a designed model home of the same size and shape as the actual home. Hence the scores are always relative to the type, size and shape of the audited house. The deep energy retrofit house was given a HERS energy Rating Certificate with a rating of 17. Figure 1 shows the demonstration home's HERS Rating Certificate.

During the retrofit the house was equipped with Energy star rated appliances, CFL/LED lighting, setback capable thermostat, an Energy Recovery Ventilator (ERV) etc. (See Table 1). In addition to these, the building envelope being highly insulated and high air tightness are some factors that may have led to a HERS rating of 17.

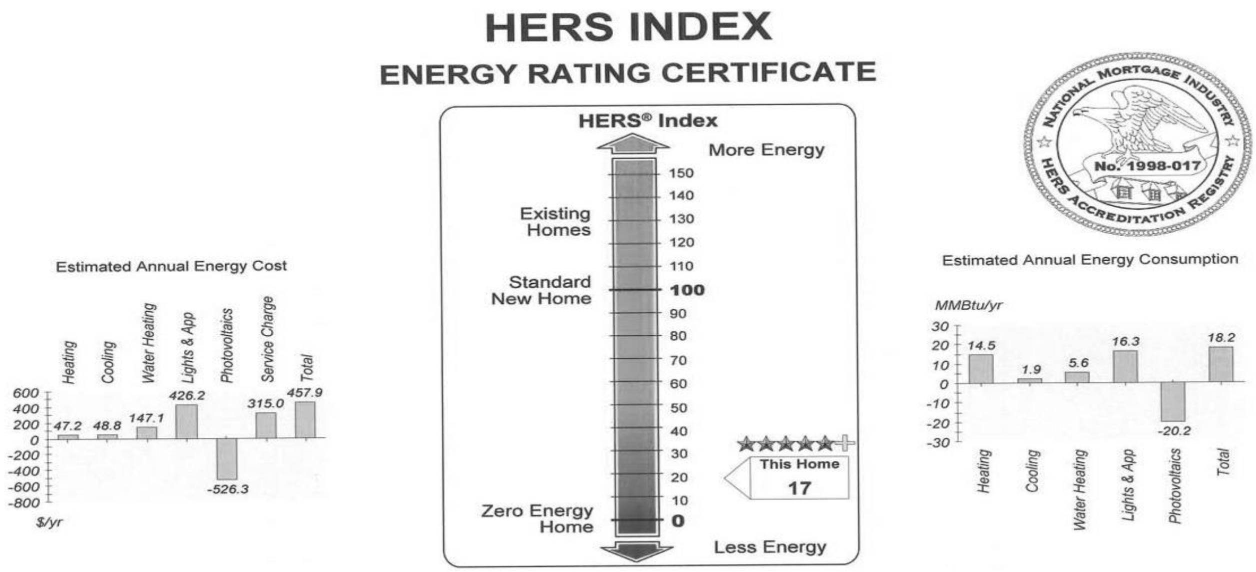

Figure 1. Demonstration Home HERS Rating Certificate

Predicted Energy Consumption and Benchmarking

According to the HERS rating scale a net zero energy home is given a rating of 0. These homes produces as much energy at the site through renewable resources as they consume, resulting in a low operating costs and an environment friendly home. Since homes with a rating of under 20 are believed to have high levels of comfort and a very low carbon foot print, a HERS Rating of 17 predicted that the retrofit house would be highly energy efficient. Reaching a HERS Index score of 17, was an indication that the retrofits performed on the house were successful.

For the purpose of benchmarking, with a total conditioned area of 1098 sf, the predicted annual energy consumption of the house was 16.57 MBtu/yr./sf (4.86 KWh/yr./sf). In comparison, an average Mid-West United States home ranging between 1000 to 1499 sf consumes 75.75 MBtu/yr./sf (22.2 KWh/yr./sf) (Residential Energy Consumption Survey, 2009). This meant the retrofit home was predicted to consume just 22 percent of the energy consumed by similar size houses in the Mid-West. In the state of Indiana, homes consume an average of 105,000 MBtu's (30,772.46 KWh) of total energy annually (Residential Energy Consumption Survey, 2009). The predicted annual energy consumption of the retrofit house was 18,200 MBtu's (5,333.9 Kwh), which is just 17.33 percent of the state average.

Retrofit Home Energy Performance

The deep energy retrofit home is monitored using the SiteSage (previously eMonitor) real-time individual circuit monitoring system. This service provides the homeowner and authors a minute-by-minute readout of electricity consumption of circuits within the house. This information is stored on a cloud server for future access. Through the same password protected web interface, the system also provides access to the electricity cost, carbon footprint, and historical information of electric energy consumption. The SiteSage portal service can also display data graphically, enabling the home-owner to understand how the home is using electricity. Data reported in Table 2 is the actual annual electricity consumption and solar production by the retrofit home starting March 13th 2014 and ending March 12th 2015. This is the first continuous full-year electricity consumption and production data available since the house was occupied.

Table 2
2014-2015 Annual Electricity Consumption & Solar Production

Energy Consumption	**Consumption Per Day**	**Solar Production**	**Net Energy**	**Net Energy Per day**
3469 kWh	9.5 kWh	8587 kWh	-5118 kWh	-14 kWh

Real time energy consumption and production data and a minute-by-minute resolution on annual electricity consumption of the retrofit house enabled the authors to study the home's energy performance. Figure 2 is a graph that presents monthly electricity consumption and solar electricity produced by the retrofit home.

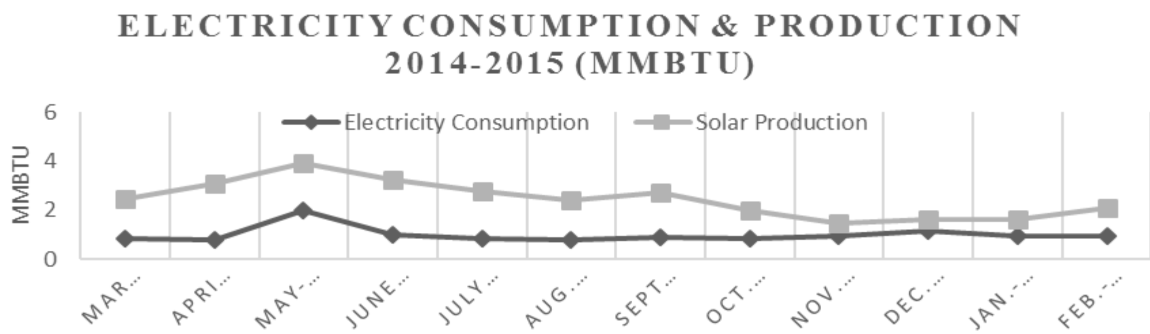

Figure 2. Monthly Electricity Consumption & Production

During the year 2014-2015 on any given month, the deep energy retrofit house produces more electricity than it consumes. The production of electricity is proportional to the amount of solar energy incident on the solar panels throughout the year and no anomalies were recorded in energy production. This data was important for authors, as it led to the conclusion that the solar panel's performance is as predicted in the HERS certificate.

Since the retrofit house uses natural gas for space heating, a complete picture of energy performance can only be generated by integration of monthly gas energy with monthly electric energy to give the total energy consumed. Figure 3 shows the total monthly energy consumption of the deep energy retrofit house, along with its individual components, gas energy and electric energy. After reviewing energy consumption of the retrofit house it can be said that its annual energy performance is comparable to a highly energy efficient house. In both the heating and cooling seasons, the energy utilized for space heating and cooling by the retrofit house is much lower than the average energy utilized for the same end uses by similar houses in the Mid-Western United States. An average Indiana home uses 55.4 MMBtu's (16,236.14 KWh) of energy for space heating and cooling combined (Residential Energy Consumption Survey, 2009). In comparison, the retrofit house consumed a total of 33.64 MMBtu's (9,858.91 KWh) of energy throughout the year for HVAC. This is just 60.7% of an average Indiana home. Although these energy consumption figures suggest that the performed retrofits were successful, the energy consumption for HVAC is still almost 205% of what was predicted by the HERS auditor.

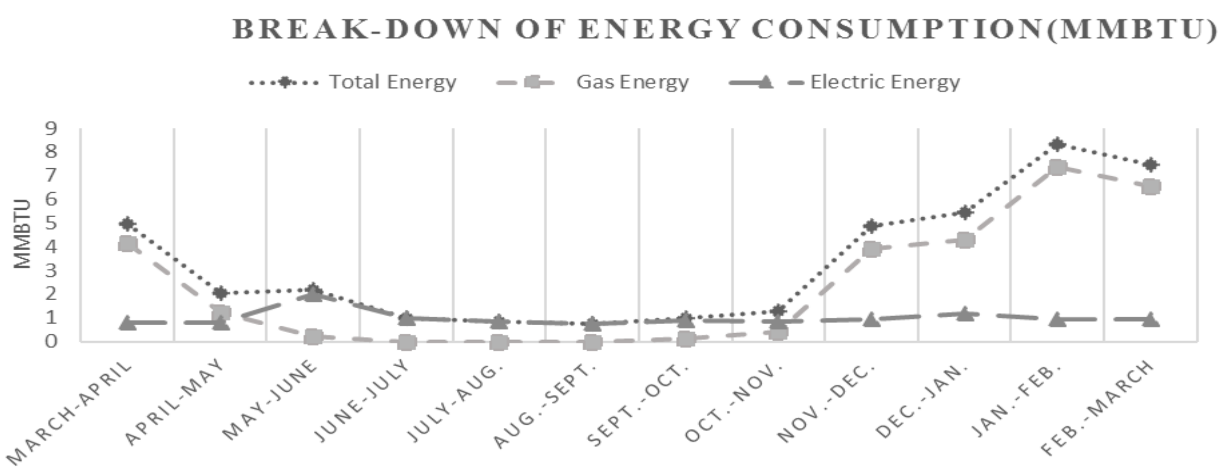

Figure 3. Monthly Gas, Electricity and Total Energy Consumption

For identifying the factors causing deviation from predicted consumption, an analysis of both electric and gas usage was performed. The electricity consumption of the house was almost constant throughout the year, peaking in the months of May-June. This increase was a result of substantially high lighting & plug loads for the month (see Table

3). The authors do not have an explanation for this increase in lighting/plug load during May-June, and no other aberrations like this have occurred. The air handler (which includes Energy Recovery Ventilator electric consumption) consumed an average of 89.6 KWh of energy every month throughout the year, but during the months of July, August, September and October the energy used by the air handler reduced substantially. The energy consumed by the water heater was almost constant throughout the year peaking in the months of December, January and February, which is typical for houses in colder regions. It was also noted that the house consumed electricity for air conditioning only during the months of May, June, July, August, September and October.

Table 3
2014-2015 Monthly Electricity Consumption by End Uses

Month	**Air Handling Unit (KWh)**	**Air Conditioning (KWh)**	**Lighting & Plug Loads (KWh)**	**Water Heating (KWh)**	**Kitchen Appliances (KWh)**	**Laundry Appliances (KWh)**
March-April	109.15	0.00	30.51	63.80	25.58	9.73
April-May	107.39	7.36	38.22	54.53	26.94	5.85
May-June	105.30	70.98	285.13	49.53	39.88	98.30
June-July	104.49	157.75	57.43	57.04	33.53	31.24
July-Aug.	50.90	101.56	65.16	59.03	52.40	16.24
Aug.-Sept.	42.10	126.19	37.95	53.52	66.52	25.36
Sept.-Oct.	60.83	19.01	60.17	64.41	47.96	22.46
Oct.-Nov.	55.00	0.00	40.89	65.41	51.87	31.52
Nov.-Dec.	81.26	0.00	43.54	75.34	50.47	23.64
Dec.-Jan.	134.92	0.00	49.39	100.83	36.04	20.73
Jan.-Feb.	112.39	0.00	20.82	95.65	23.86	27.46
Feb.-March	112.22	0.00	22.28	77.65	23.31	33.56

Overall, the electricity consumption figures did not give any compelling evidence of excessive energy being consumed for any specific end use. After studying this data, it can be said that except for a few minor anomalies in lighting & plug loads, the retrofit house's electricity consumption was as expected. On the other hand, it was noticed that even though the gas consumption of the retrofit house follows a trend similar to gas consumption trends of a typical Mid-Western home, the magnitude of consumption is higher than predicted by the HERS energy auditor. The deviation between the actual and predicted energy consumption caused the authors to investigate possible explanations for the variation from the values found on the HERS certificate.

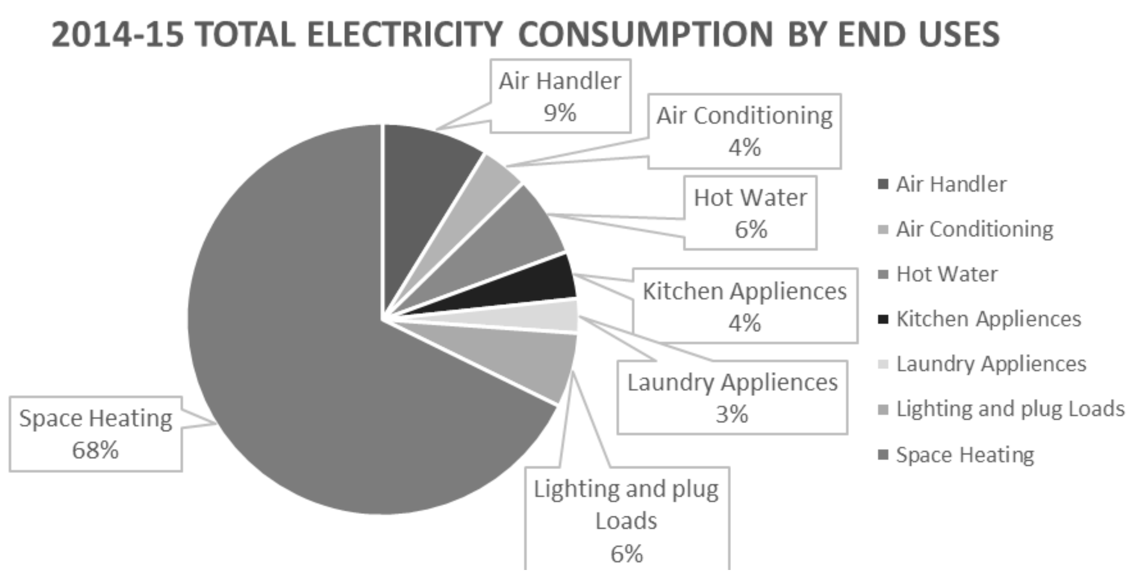

Figure 4. 2014-2015 Total Energy Consumption by End-Use

The deep energy retrofit house uses natural gas for space heating only. As a result, there is no consumption of natural gas in the cooling season (see Figure 3). Hence the energy consumed by the house for space heating can be quantified as the natural gas consumption. Conversion of electrical energy consumed within the retrofit house from KWh to MMBtu's and integrating it with gas energy consumption provides the total energy consumption. This is further broken down into consumption by end uses and presented in Figure 4. The three most significant contributors to the total energy consumption (totaling 83% of the total) are space heating 68%, air handling 9%, and water heating 6%.

Annually an average Mid-Western home uses 58.2 MMBtu's (17,056.74 KWh), 3 MMBtu's (879.21 KWh) and 18.7 MMBtu's (5,480.43 KWh) for space heating, air conditioning and water heating respectively. In comparison, the retrofit house uses 30.4 MMBtu's (8,909.36 KWh), for space heating and ventilation 3.24 MMBtu's (949.55 KWh) for air conditioning and ventilation and 2.79 MMBtu's (817.67 KWh) for water heating respectively. Comparing the energy use statistics of the retrofit house with similar homes in the Mid-West region, reveals that the energy consumed for space heating and hot water is substantially lower than the average Mid-West home, but energy consumed for A/C and ventilation is slightly higher (Residential Energy Consumption Survey, 2009). This deviation can be explained because 3.24 MMBtu's (949.55 KWh) is the total energy consumed within the retrofit house by the air conditioning, Energy Recovery Ventilator (ERV), and the blower (used even in the heating season), whereas the 3 MMBtu's (879.21 KWh) used by an average Mid-Western home is just for air-conditioning and at times ventilation. The retrofit house is occupied by just one occupant who appears to be a very light user of electricity. All the major appliances installed in the house are highly energy efficient too. As a result, the energy consumed for appliances, lighting and plug loads appears to be a small percentage of the total energy consumed and the percentage of total energy consumed for HVAC seems to be larger than the percentage of total energy used by Mid-Western homes for space heating and air conditioning (See Figure 5).

Comparison of Actual with Predicted Consumption

The house consumed more energy than predicted (HERS Certificate) for space heating and cooling Water heating as well as lighting and plug loads are the two end uses where the annual consumption is less than the predicted usage. Energy used for water heating was 50% less than predicted and energy used for lighting and plug loads was 66.8% less than predicted. All of the above mentioned factors and the fact that solar electricity production was 145% of what was predicted (See Figure 5) resulted in the net annual energy consumption of the retrofit house to be 31% less than the predicted (HERS Certificate) consumption. The predicted net annual energy consumption of the deep energy retrofit house was 18.2 MMBtu's (5,333.89 KWh). In comparison to this, the actual net annual energy consumption of the retrofit home was 12.5 MMBtu's (3,663.39 KWh).

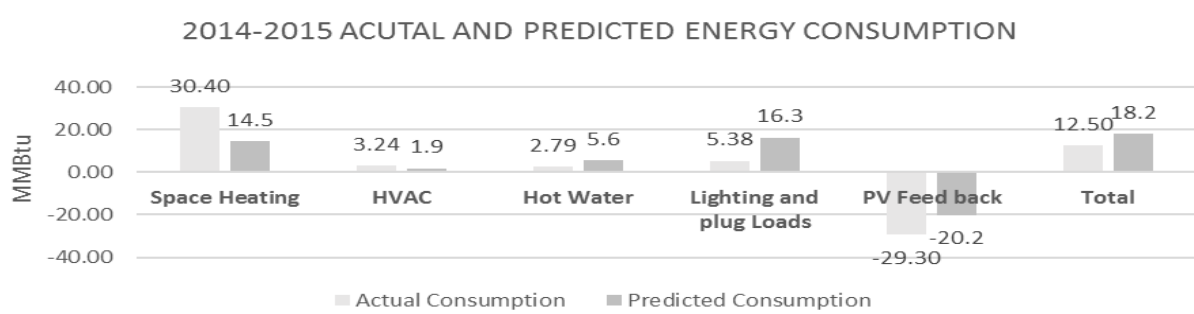

Figure 5. 2014-2015 Annual Energy Consumption & Production

Observations from Energy Consumption Analysis

After studying the energy consumption of the retrofit house and comparing its energy performance with HERS prediction (see Figure 5) and the energy consumption of similar Mid-Western homes the authors have come to the conclusion that the retrofits performed on the house were successful. The question still remains, "why did the house consume more than the predicted energy for space heating and air conditioning?" It can be said that there might be several weather related factors, physical aspects of the building envelope and behavioral characteristics of the occupant which resulted in substantial heating and cooling loads during the first full year that the energy consumption of the building was recorded.

Observations Explaining Deviation from Predicted Consumption

High Air-Conditioning Consumption: During the cooling season the recommended interior temperature for optimum balance between energy efficiency and comfort in a residential building is 78°F (Department of Energy, Thermostats). Weekly interior temperature and humidity readings recorded during the cooling season revealed that the house was maintained at an average temperature of 70°F throughout. In the summer, it is a recommended strategy to reduce central air conditioning by keeping your house warmer than normal when you are away, and setting the thermostat to 78°F only when the house is occupied and needs cooling (Department of energy, Thermostats). Contrary to this, the lower than recommended interior temperature setting of the retrofit house and failure to utilize the setback thermostat could be the cause of higher than predicted cooling consumption.

High Gas Consumption for Space Heating: With a base line temperature of 65°F the number of heating degree days (HDD) and cooling degree days (CDD) from March 13th 2014 to March 12th 2015 are 6668 HDD and 742 CDD (Weather history from KLAF). Table 4 compares the HDD and CDD for the recorded year with Lafayette's average HDD and CDD from 1901 to 2012 (Western Regional Climate Center). It is evident from the data that the winters of 2014-2015 was almost 12.3% colder than an average winter of 20th century. The winters being colder than expected may have caused increased consumption for space heating.

Table 4
2014-2015 Total HDD and CDD

	Heating Degree Days	Cooling Degree Days
March 2014- Feb.2015	6668	742
1901-2012 Average	5936	972
Departure from Average	732	-230

Occupant behavior: There is a common misconception associated with setback thermostats that a furnace/air conditioner has to work harder than usual to warm/cool the conditioned space back to a desired temperature after the thermostat has been set back, resulting in little or no savings. The occupant of the retrofit house, who knew that the HVAC system could be scheduled and controlled by a thermostat that had a seven-day setback, never used the set points prior to 25th Oct. 2015 fearing increased energy consumption. This might be one of the factors that increased the energy consumption of the retrofit house.

Photovoltaic Panel Electricity Production: Historic cloud cover data in the Lafayette region Data Recorded from West Lafayette Executive Airport from 2008 to 2012 (www.weatherspark.com), states that the median cloud cover ranges from 22% (mostly clear) to 73% (partly cloudy). The sky is cloudiest on December 30th and clearest on June 22nd. The clearer part of the year begins around March 12th. The cloudier part of the year begins around November 8th. June 22nd is typically the clearest day of the year. On the other hand, December 30th is typically the cloudiest day of the year. Solar energy production by the retrofit house as shown in Figure 6 follows the predicted trend but the energy production was more than predicted in the HERS Certificate.

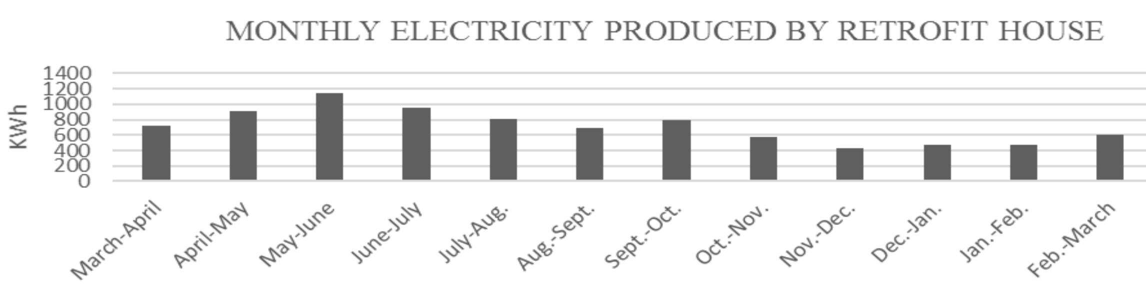

Figure 6. 2014-2015 Monthly Electricity Produced by Retrofit House

Water Heating Energy: Since the house has just one occupant, it can be inferred that lower energy consumption for water heating might be a result of less hot water being consumed. Also, the heat pump water heater installed in the house has a much higher efficiency than a traditional water heater. Inaccurate rating information for the heat pump water heater at the time of audit could have resulted in higher predicted consumption.

Lighting & Plug Loads: All of the major appliances in the retrofit house are energy star rated and all the installed lights are compact florescent lamps and T-8 tube lights. Also**,** the retrofit house is occupied by a single resident who does not occupy the house throughout daytime seven days a week. Such an occupant can be said to be a very light user of energy which explains why the house used less than predicted energy for lighting and plug loads.

Blower Door Test: After the completion of retrofit and prior to the house being occupied, a blower door test was conducted on the retrofit house. The test results mentioned that the house was highly air tight, with 2.28 air changes per hour under 50 pcal of pressure. The HERS rating of 17 was based on the fact that the retrofit had improved the building envelope energy efficiency by making it highly air-tight and insulated. It has been three years since retrofits were performed on the house. Sealant shrinkage or changes due to building movement may be causing additional air leakage.

Conclusion

After considering all of the information shared in the paper, it can be said that an energy efficient home like the retrofit house face many obstacles in order to maintain optimum energy performance. Occupant behavior, wear and tear, proper operation and maintenance are all important factors that highly affect the energy consumption of such houses. For the retrofit house, a blower door test conducted later in time and several years of energy consumption data will reveal whether the retrofits performed on the building under the LEAP program have survived the test of time.

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