UNIVERSITY OF DENVER

Solar Decathlon

ENGINEERING

BUILD CHALLENGE

ENGINEERING

CONCEPT OF HOUSE

The overall concept of our house is to turn a renovation into a modern eco friendly home. Our goal is to renovate a house and to turn it into a Net Zero home. We have come to a new footing in the existence of the Solar Decathlon, for there is now a remodel building team. As the first and only team doing a remodel we thought we would make it as hard as we could for ourselves. We plan to take a 1950s home and bring it as close to Net Zero as we can. Not one team has attempted a remodel in past Solar Decathlons, solely because. This is what we would like to call the New Frontier. Not to mention, our intent with this project is to have a house remodel that is largely completed by the residents themselves, with this in mind it is hard to believe Net Zero can be achieved. There is now an interest in the competition to be more sustainable than before possible, teams can either showcase a home in their home state or bring a showcase to the competition site. With this in mind, . Students now can take an existing home and turn it into a modern showcase. We plan to do that with many innovations and simple tricks to get this working.

PRELIMINARY CHALLENGES

As the only Solar Decathlon Build Design Remodel, we have come to face many challenges with this project. We have hot zones of asbestos throughout the house. This issue has come to lead to many changes and stances we have taken on this project. This project has flood zone restrictions. The existing house has asbestos to remediate. Existing utilities differ us from other projects so we have come up with solutions to guide us to Net Zero. With all this said, we have come up with amazing solutions to tackle these constraint issues.

Even though this project can seem simple with a large budget, because of the house lying in a FEMA flood zone there are restrictions we must follow. We have a budget restriction that limits how much we can accumulate in costs for structural and foundation changes. Why is this? The reason we have a limit is because the more construction there is, the more risk it will have. But with the budget restraint, if the house goes over the limit, the house's foundation must be raised and the basement filled in. This would be extremely costly and something many residents don't seem to want. With that in mind we have come up with a $125,000 budget for the entire renovation. With this maximum we are now able to start planning out our project and special features.

OUTLINE OF MODIFICATIONS

The house renovation encompassed several main efforts. First was the increased insulation, an effort to minimize energy loss and increase occupant comfort.

Second came a comprehensive replacement of appliances and water fixtures. These appliances were selected with efficiency in mind, shifting towards fully electric appliances. The water fixtures were selected on a more ad hoc basis to maximize improvements in comfort and ease of living, while minimizing budgetary impact.

Next came the smart home monitoring system. This system added integrated sensors into all major electric lines, and included a smart thermostat. While the smart thermostat provides the obvious advantages in system runtime efficiency, it is also wirelessly connected to a home analysis system, which combines and relates the electric and climate control data into a comprehensive energy use model available to the resident. This allows the resident to make informed choices and independently direct themselves towards more sustainable habits which will remain should they ever move to a different house.

There was an attempt to refit the climate control furnace component, but it proved to be an inefficient allocation of resources. Due to the house's location in a FEMA flood zone, most renovations were reserved for the top floor, and the basement and foundations remained undisturbed.

INSULATION REPLACEMENT

Due to the age and construction of the house, the insulation was rather poor at retaining heat during the colder months. The introduction of new insulation to the mostly empty wall frames became an important goal. Many options were floated, but the asbestos in the house made any opening of the walls prohibitively expensive. The team did extensive research before settling on the use of Retrofoam. Retrofoam can be inserted into the empty wall frames through a small drilled hole in the drywall. Once the hole is drilled, the foam is sprayed into the space and expands to fill it. This allows the home insulation to be improved, while not requiring any asbestos remediation or extensive reconstruction of drywall.

RetroFoam has a higher R-value, eliminates drafts and air leaks, and does not break down over time. This is one of the best solutions we came up with for dealing with a low R rating for our walls. This was done throughout the house. The point of retrofoam was to make our house competitive with other competing teams. This leads to our team making the decision to help seal up our house from possible air leaks. This increased our R rating to a level of 15.7 with the existing 2x4 walls. This is projected by the company RetroFoam with their product.

APPLIANCE/FIXTURE REFIT

The biggest component of the appliance refit was the inclusion of Solar Panels. This solar panel system allows the house to produce its own power, decreasing reliance on the grid and improving holistic energy efficiency. Our energy production capacity is likely to be sufficient for basic household operations. However, energy storage was a goal unachievable to the team. The process of introducing extensive energy storage methods would both stress the budget and was undesirable to the building's owner.

These efficiencies were increased by the replacement of older home appliances with newer, shinier models. These not only provided a direct increase in energy usage efficiency, but also assisted in the move away from natural gas as a regular utility. This centralization of utility draw on electricity further amplifies the efficiency gains from the solar panel installation, allowing a greater percentage of the home to rely solely on renewable sources.

The water and light fixtures in the home were also comprehensively upgraded. Those in the house at the beginning of the project were generally old and inefficient. Therefore, any replacement or upgrade to a more modern fixture represented a sure, if small, step towards a more efficient home. The selection of what fixtures we would upgrade to was a case by case analysis in product availability and affordability. We made efforts to update to the best fixtures available to the team at the time.

HVAC FURNACE REFIT

The senior design team put significant thought into refitting the house HVAC system to a more energy efficient model. However, we decided not to proceed with a new system. The current system is not new by any means. However, despite its age, it continues to work effectively and reliably. The design and setup of the current HVAC system is low maintenance, a fact much enjoyed by the homes owners. Moreover, the system is reliable, producing effective heating when it is needed.

However, the system is not without limitations. Most glaring is the reliance on natural gas to run the furnace. This is not conducive to a Net-Zero home, as natural gas is non-renewable and emission heavy. Furthermore the current system is relatively inefficient as an 80% efficiency forced gas furnace. This makes the prospect of upgrading the system to a more modern system quite enticing.

The refit would allow the house to transfer to a totally electric energy system. This is obviously within the desires of the Solar Decathlon project. Based on research conducted into the possible alternatives, there were several levels of refit the team could conduct. One consideration was a mini ductless system. Another was replacing the gas furnace with a heat pump. Finally, replacing the single stage 80% efficiency gas furnace with a two stage gas furnace with the same efficiency or higher were considered. All of the above options would have created a more efficient HVAC system.

Unfortunately, there is no free lunch in the remodeling business. The downsides of a furnace refit were numerous. Firstly is the price point, upwards of $10,000, which is the allotted HVAC budget. This cut into the rest of our budget severely. Additionally, any furnace replacement would require more invasivity of the current structure than desired to be able to measure the outtake duct for a proper fitting. This would require additional funding and asbestos remediation, further disincentivizing the alteration. Finally, a change to a more modern machine brings with it increasingly complex maintenance concerns, which are likely to occur with greater frequency than on the old tried and true furnace system. The current owner does not wish to have to maintain the system any more than it currently gets; therefore, we decided to keep the system as is, and use other methods to remediate the energy losses.

INTENT

Our project aims to create a smart home monitoring system that allows users to know precisely the utility usage of their homes on demand. According to the U.S. Energy Information Administration, home utilities account for an annual electricity consumption of approximately 877 kWh per month for a homeowner in the United States.

The annual global electrical consumption for 2019, exceeds 23,000 TWh, which has been steadily increasing over the past 30 years. Clearly even a marginal decrease in this number will help reduce the environmental impact of human living quarters. It is shown in Malta, which has reformed per the EU's direction, that "smart" objectives such as transitions to smart grids and cars is less energy intrusive; therefore less polluting, than more independent countries such as Romina (Leal-Arcas).

Along with the country wide scale, inefficiencies in home energy consumption are also responsible for great personal losses for consumers. Poor insulation, inefficient heating, and poor electrical connections cause huge and unnecessary utility draws, as well as safety concerns for those residents. By increasing efficiency these unneeded usages can be alleviated, along with the big financial burden they create.

DESIGN

The scope of this system is different from the normal engineering solar decathlon competition since this project is a renovation not construction from scratch. No major modifications were made to the house due to limitations set by University of Denver. Due to this, the house systems are oriented around the architectural design of the house. This regards the general size of the house and air flow to determine the HVAC, water, and gas that will be able to regulate the atmosphere efficiently.

The house is taking advantage of net metering as well which means there is no worry about producing more energy in summer and not producing enough during the winter. The house was fitted with enough solar to produce the amount of energy on average a house that size would produce in a year. The house is still connected to the grid and feeds energy into the grid where it is stored if more is produced than what is used in the house. This eliminates the need for a battery and removes many problems.

The house's architecture is very conducive to natural lighting and often doesn't need any lights to stay illuminated during the day. LED bulbs are used for efficiency and many can control the brightness and hue to establish the desired feel of the lighting in the house.

As specified earlier, analysis was done to the house, many solar companies use LIDAR coupled with the average energy of the house consumed over the course of a year so the solar was set up to match it.

The plot of land is not large with minimal vegetation minimizing the use for water irrigation and the backyard is dirt which requires no maintenance as well.

To what extent is energy efficiency integrated into the house design?

The space-conditioning system has not been modified outside of a new water heater and HVAC. The piping for the most part has been left unchanged as it is fit for the size of house that this project is working on.

Part of the whole system's philosophy was to keep all the modifications of the house as simple to install and use as possible. The house is fully functional as a normal house with the added benefit of being able to access a website that gives an energy breakdown of the house as well.

The energy model of the house is modelled using PowerVI getting data from the current clamps and thermostat and displayed on a mobile friendly website so easily see the data in an easy to comprehend manner. It shows not only the power consumption of every room in the house but also gives tips on how to reduce energy and where large amounts are coming from.

- ☑ Smart thermostat
  - » Replaces programmable thermostat
  - » Reduces waste HVAC usage by 15% yearly
  - » Allows system to read temperatures and HVAC up time

The first step in the smart home conversion was the selection and installation of a smart thermostat to interface with the HVAC system and increase efficiency and energy transparency. In the modern market, there are many smart thermostat options available, most designed to interconnect with a voice assistant of some description, be it Alexa, Google, or Nest. However, it was the desire of the team to remain separate from those sorts of proprietary systems. We decided to go with the Honeywell T9. It provides detailed sensing capabilities, programmability, and modular remote access from third-party sources.
It has been shown that smart thermostats provide marked improvements in HVAC system efficiency through nothing more than efficient system operations. Even the most archaic furnace and AC unit can be greatly improved through careful, calculated, and cautious operation. The team expects an efficiency improvement nearing that granted by simpler HVAC refit options.

Another excellent use of this intelligence is the integration it provides with our bespoke data analysis system. Our system can interface with the secured Honeywell system to record and process temperature, HVAC runtime, and other environmental data to provide a comprehensive and complex energy usage model to the resident user.

Furthermore, the smart thermostat allows the user to experience optimal comfort at the optimal time. It can account for environmental conditions not usually factored in, promoting comfort efficiently.

Current clamps utilizing electromagnetic fields can measure the AC current and by proxy the power through a cable it is attached around. This method was chosen for this project as it prevents the need from exposing wires in the breaker box which greatly increases risk electrical dangers when installing or performing maintenance.

In order to be able to save energy consumption in a house the first step is understanding where the energy is being consumed. This system will create a room by room breakdown of the house as well as certain appliances such as the washer and dryer which often have their own. Sending this data to a webserver and showing it in an easily digestible way will give a very clear image of the flow of energy in the house to the residents.

AC current through a wire produces an electromagnetic field that in turn produces a current in a copper coil wrapped around the wire proportional to the AC current in the first wire. Knowing the voltage which is 120V for most breaker box wires, it is easy to determine the power being consumed in that line.

For this project, an array of 12 current clamps are used to measure the different breakers of the house. An arduino mega is used for the inputs as it possesses enough analog to digital converter inputs for all 12 sensors. The data collected from the arduino is sent through a serial connection to a Raspberry Pi that is then sent to a database. The calibration of the data is performed by the arduino.

As specified earlier, the current clamps vary in current not voltage when recording values but the ADCs on the arduino are all expecting a voltage signal. To fix this problem a voltage divider circuit is added to each sensor to get a proportional voltage for the current that is readable to the arduino.

The PCB is the design to assemble the materials that were used to build the clamp sensor and that have one input and one output. The input is connected to the current clamp which measures the current breaker box. The output of the PCB, which is connected directly to the Arduino, to deliver the collected data from the current sensor.

Once the sensor has been connected to the voltage divider circuit and then the arduino, it is possible to start retrieving values from it. Using the imported EmonLib.h, energy monitor library, it is possible to easily get the voltage output of the sensor. Using a simple method of calibrating the sensor by verifying a known source the sensor is ready for installation and sending values to the Raspberry Pi.

Find a wire that produces at least 0.5 A. A fan was used in this case. The fan was rated for 0.5 A and this value was verified by a Fluke Clamp Meter 323 also reading 0.5 A. The output voltage of the current clamp connected to the arduino was reading an integer value of roughly 0 for when the fan was off and 1.5 when the fan was on. Since the correct value should have been 0.5 we can set a calibration factor of 0.3. If the floating value for when the fan is off that can also be taken into account. An array of calibration and offset values are stored to account for if each sensor is slightly different or new sensors are swapped out in the future.

After importing the energy monitor library all the arrays of the calibration and offset values are set as well as the other global variables. The serial connection is then established for the values to be sent to a host computer. Then in the main loop the ADC inputs are read and then converted into a readable string that is sent over the serial connection after being corrected with the calibration and offset. The string is then printed over the serial connection to be parsed by the raspberry pi. The frequency of when the serial messages are easily controlled by a wait command as generally the values are only needed several times per second not continuously.

Once data has been recorded from our sensor systems, it is fed into an analysis system designed to assist and inform the user. The most important thing to a rational individual actor is, economically speaking, price. Therefore we decided to include price estimates with our utility consumption data. This is paired with utility averages across daily, weekly, and monthly timeframes. From a technical standpoint, our data analysis system is built with simplicity and ease in mind. Our main processor takes the form of a Raspberry Pi 4, an inexpensive yet powerful computer alternative. The OS is linux based, specific for the Pi, and extremely lightweight. All Pi-side code is written in Python, with the source code available to the user on the Pi. This choice was intentional, as it allows a technically inclined user or resident to interact with, debug, and even upgrade the analysis and data collection software to better suit their needs.

The first step is the intake of data. Data input streams from the smart thermostat and the current clamp Arduino are fed into a central processing rig, which coallates the data into a spreadsheet. This spreadsheet is widely used as a go between for the various aspects of the code, and finally for delivery to the PowerBI dashboard. The interval of these measurements is variable, but currently set at 5 minutes. This interval is able to be changed by the user, who is able to set up a more or less continuous record.

Each circuit has its own unique record, allowing a circuit-by-circuit breakdown of usage throughout the day. In daily and weekly averages this resolution will be lost, but a more holistic picture of the user’s energy habits will emerge. These habits can be further tracked over months, and changes or patterns will dynamically emerge from the analysis.

As the HVAC system is still partially operated with natural gas, our current clamps will have no use in determining its energy consumption. Therefore a more circumspect approach must be adopted. By recording the HVAC system status along with the temperature data, estimations as to its total active time can be made. Using this estimated uptime and a rough efficiency-consumption matrix for the HVAC system, we can come to a reasonable assumption concerning the energy usage of the HVAC.

In order to determine efficiency of the house as a complete system, we will use the total power balance of the house. The solar panels installed use an electric profile that our sensors are not able to reliably read. We will therefore use a sum of the individual circuits to determine electric consumption, and compare that to the main electric value coming in from the grid. The difference in these two values gives us the power generated by our solar system. This data will also be useful for diagnosing any issues with the solar system.
Finally, the system will use an average electric utilities rate to give a rolling estimate of utility prices for the current month. By using electricity consumed thus far, and past consumption habits, this system will inform the user of their expected bill, promoting more sustainable and energy efficient behavior.

The data access methods are designed with a 60 year old mom in mind. Data will be clear, well labeled, and helpful. Data will also be remotely accessible through a PowerBI dashboard, using a license graciously provided by the University of Denver. This will allow visualization of data, using charts, graphs, and color to relay information when bland numbers cannot.

All system data will be accessible, but the forefront will be the room-by-room (circuit-by-circuit) breakdown of consumption, the daily, weekly, and monthly averages, and the estimated price. These will all be comparable across previous data, allowing expression of historical trends and habits in a comprehensive and comprehensible way.

This effort can produce a greater increase in environmental efficiency than is first obvious. According to several studies, simply providing accurate and detailed metering data to the homeowner decreases energy consumption. Our target is to generate more efficient habits in the resident, which will contribute to more efficient home energy usage.

SPECIAL PROJECT: Senior Design Team 2020

This team was able to come up with an easy to build and replicated design, we created an efficient and friendly approach to aquaponic growing. With all parts available at local hardware stores and the electronics available online. The project is available to create with user preference. The ability to choose how the water is fed to the plants. And with a cost effective way to monitor and maintain the levels needed to maintain the fish and plant tanks we have a sensor arduino kit that can be set up and used by any user, time permitting. All software information and help can be found online when using Raspberry Pi. This allows the user to analyze their data their own way, providing more power to the user while also lessening the energy consumption of a standard automated system. Our system only requires 2.754 kWh, with the bulk of that number, 2.16kWh, is from our chosen lights. Giving us a system with a total energy requirement of .594kWh, a very low energy system.

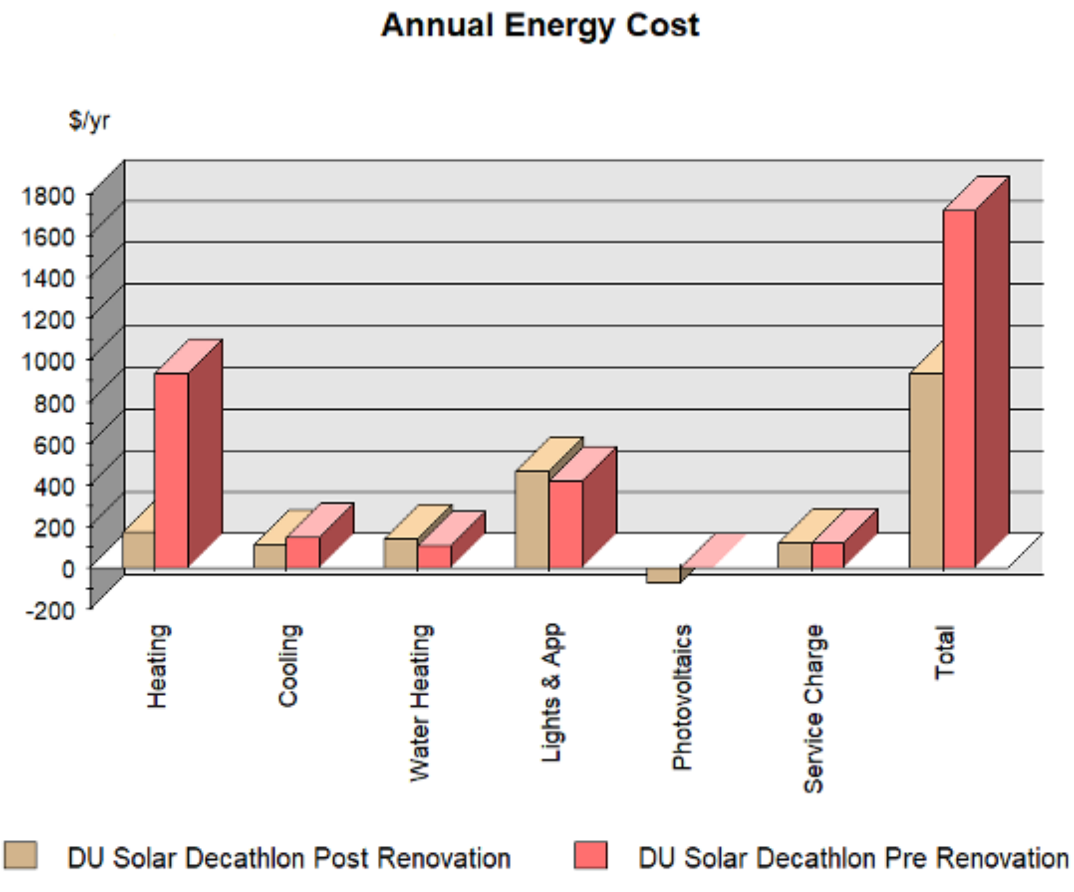
BUDGET

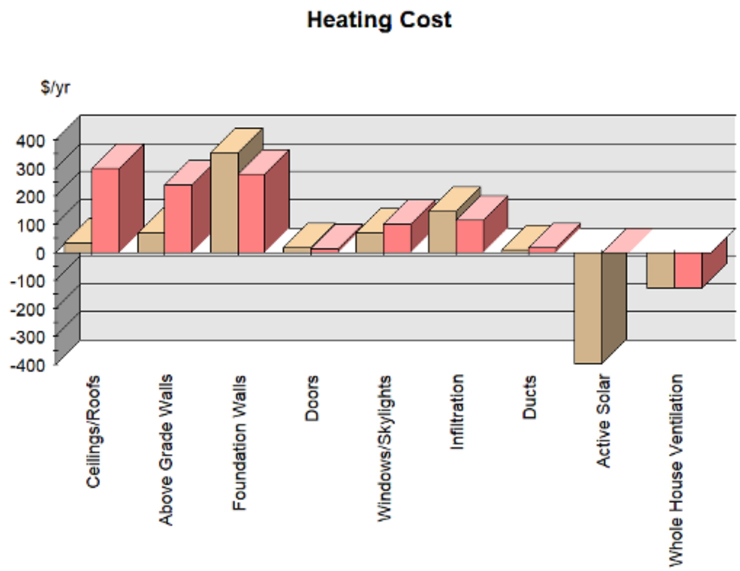
Although we have a budget of $125,000, our goal is to spend no more than $100,000 on this project. As of 2/26/21 we have spent $40,451.90 for construction and installation costs and $39,528.52 for donated materials and time commitments. We expect from $5,000-20,000 more in labor and material costs. We plan to meet our budget below the necessary limit given by the FEMA restrictions where it is 50% of the existing houses retail value.

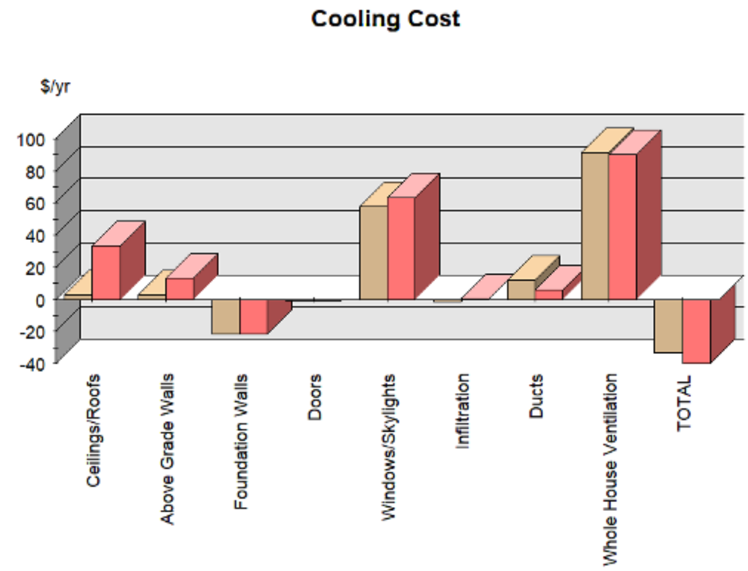
Asbestos remediation is the most costly of parts in this remodel. Alone it cost $25,000 just for small remediation. Therefore we choose to not mess with the chances of issues.

ENERGY MODEL

The Senior Design sub-team also developed a model of the home using the ResNET software. This software's took into account most architectural factors of the house and provided data on where most energy is being lost from.







Analysis

Updated: 03:57:52 PM

Design Loads (kBtu/hr)	
Heating	69.2
Cooling	34.6
Annual Loads (MMBtu/yr)	
Heating	108.2
Cooling	17.5
Water Heating	13.6
WH w/out Tank Loss	9.9
Annual Consumption (MMBtu/yr)	
Heating	173.0
Cooling	6.1
Water Heating	20.9
Lights and Appliances	22.9
Photovoltaics	-0.0
Total	222.9
Annual Energy Costs ($/yr)	
Heating	935
Cooling	144
Water Heating	105
Lights and Appliances	415
Photovoltaics	-0
Service Charge	120
Total	1718
HERS Index	195

FIGURE 1 - PRE RENOVATION ANALYSIS

Analysis

Updated: 04:03:12 PM

Design Loads (kBtu/hr)	
Heating	38.5
Cooling	21.0
Annual Loads (MMBtu/yr)	
Heating	15.7
Cooling	13.3
Water Heating	5.9
WH w/out Tank Loss	8.8
Annual Consumption (MMBtu/yr)	
Heating	26.6
Cooling	4.7
Water Heating	6.0
Lights and Appliances	19.8
Photovoltaics	-3.1
Total	54.0
Annual Energy Costs ($/yr)	
Heating	173
Cooling	109
Water Heating	142
Lights and Appliances	465
Photovoltaics	-73
Service Charge	120
Total	935
HERS Index	62

FIGURE 2 - POST RENOVATION ANALYSIS

The ResNET data derived, shown above, showed an improvement in HERS rating from 195 to 62.

It should be noted that ResNET is unable to perform a full accurate analysis on an active solar panel system that does not have a storage system. The program automatically creates its own assumptions to continue the analysis.

NET-ZERO PLUS ENERGY SUBCONTEST CHECKLIST

CONTEST INTENT

This Contest evaluates the building's energy use and production, as well as its capability to provide energy services—whether connected to the electricity grid or operating with on-site and/or stored power.

EVALUATION CRITERIA

Net-Zero Plus Energy Subcontest Each team's modeled energy production and estimated energy consumption will be evaluated by the organizers for the target site, as well as evaluated for whether or not the house will produce at least as much energy as it will consume over the course of 1 year, including the charging and operation of an electric vehicle estimated to be driven 20 miles per day. Reduced points are earned for an annual net consumption between 0 kWh and 2,000 kWh. Reduced points are scaled linearly. No points are earned for an estimated annual net-energy consumption more than 2,000 kWh.

INSTRUCTIONS

The checklist is designed to help Solar Decathlon competition organizers understand what information is being provided by each team for the Net Zero Energy Plus Sub-Contest. Please complete this form for the measures that apply to your team's house.

SUPPORTING DOCUMENTS (CHECK WHAT IS PROVIDED)

- ☐ Construction drawings
- ☑ **Energy model**
- ☐ Project manual
- ☐ PV system size
- ☐ Make and model of Vehicle assumed
- ☐ Video of constructed house

TEAM NAME: UNIVERSITY OF DENVER SOLAR DECATHLON

ENERGY PERFORMANCE TARGETS

ANNUAL ENERGY CONSUMPTION (KWH/YR)	**Baseline**	65,325.54
	Proposed Design [1]	15,825.83
ONSITE RENEWABLE ENERGY (RE)	**Capacity (kW)**	N/A
	Estimated Energy (kWh/yr) [2]	N/A
ELECTRIC VEHICLE CONSUMPTION (KWH/YR)	**Proposed Design [3]**	N/A
	Miles per Gallon of Gasoline-Equivalent (MPGe)	N/A
NET ENERGY (KWH/YR) ([1] – [2] + [3])	**Estimated Net-Zero Plus Energy**	N/A
EUI (KBTU/FT2/YR)	**Baseline**	4.243
	Proposed Design (w/o RE): Percent energy savings:	
	Proposed Design (w/ RE): Percent energy savings:	
HERS RATING (0-100) Post renovation HERS Rating with and without PV Panels.	**With RE**	62
	Without RE	104
SOFTWARE TOOLS (USED FOR ESTIMATE)	**Others**	ResNET Analysis (See PDF below)

SUMMARY OF ENERGY EFFICIENCY AND RENEWABLE ENERGY STRATEGIES

ENVELOPE	**Estimated savings (kWh/yr)**	4084.77
	Savings (%)	54.42
Measure description and assumptions (Describe building envelope technology and its effective U-value)		
Wall	Insulation added on the above grade walls.	
Roof	Insulation added in the attic.	
Window	Large dining room window is being switched into a double-vinyl.	

LIGHTING AND CONTROLS	**Estimated savings (kWh/yr)**	908.52
	Savings (%)	13.54
Measure description and assumptions	Switching all lighting from FL & CFL to LED.	

WATER HEATING	**Estimated savings (kWh/yr)**	4,366.75
	Savings (%)	71.29
Measure description and assumptions	Switching current gas water heater to an electric water heater.	

HEATING AND COOLING SYSTEM	**Estimated savings (kWh/yr)**	43,315.9
	Savings (%)	83.80

ONSITE PV SYSTEM	**Estimated savings (kWh/yr)**	
	Savings (%)	
Measure description and assumptions	ResNET is unable to perform a full accurate analysis on newly added solar panel system that does not have a storage system. The program automatically creates its own assumptions to continue the analysis.	