Affordable Net Zero Energy Renovation

86 Craighead Street, Pittsburgh
PA 15211

48-752 ZERO ENERGY HOUSING

Krupa Patel
MSSD, Carnegie Mellon University

TABLE OF CONTENTS

ABSTRACT

In the 21st century, the terms energy efficiency and sustainability have reached a new level of awareness among the members of the design fraternity. Today, the world is facing a major challenge of climate change, high emission rate and resource crisis. As we know that buildings account for more than a third part of total energy consumption, it is our moral responsibility to pursue practices that are effective and conservative. Even building codes are thriving to optimize building performance by demanding rigorous requirements as a part of an effort to contribute

positively to address all these factors. The IECC (International Energy Conservation Code) is constantly updated and made more stringent in terms of mandatory requirements for the building to comply with. These requirements are designed in such a way that the building meeting the code is almost there to become net zero. Hence the codes are constantly thriving to make the buildings reach net zero energy efficiency, both residential and commercial.

This project is done with the assistance of REM/Rate™ software which conducts analysis for Home Energy Rating Systems (HERS®) Ratings while recognizing cost-effective and energy efficient improvements for the existing or the proposed structure. The project deals with renovation of a 20th century set of residences (duplex unit) on Craighead Street in Pittsburgh, Pennsylvania which is one of the old neighborhoods. The dilapidated condition of the house is dealt with making relevant recommendations for retrofit. First, the recommendations were made in order to make the building IECC 2009 residential code compliant. This was the baseline model that was simulated and it was further enhanced by recommending better strategies in terms of cost and energy efficiency simultaneously in order to surpass the requirements of IECC 2015 Residential and Energy Star Version 3 (Revision 8).

ACKNOWLEDGMENT

I would like to thank Professor Nina Baird (Carnegie Mellon University) for her expert advice and constant support throughout the project and for endowing us with deep insights into the challenges of handling an old building retrofit project, as well as Mr. David Howe (Urban Redevelopment Authority, Pittsburgh) for offering his valuable thoughts on our work. The project analysis was carried out in collaboration with my colleague Andrew Petralia and I thank him for successfully completing the energy modeling and analysis part of the project with me.

METHODOLOGY

According to the typical definition, “A zero energy building (ZEB) produces enough renewable energy to meet its own annual energy consumption requirements, thereby reducing the use of non-renewable energy in the building sector.” [1]

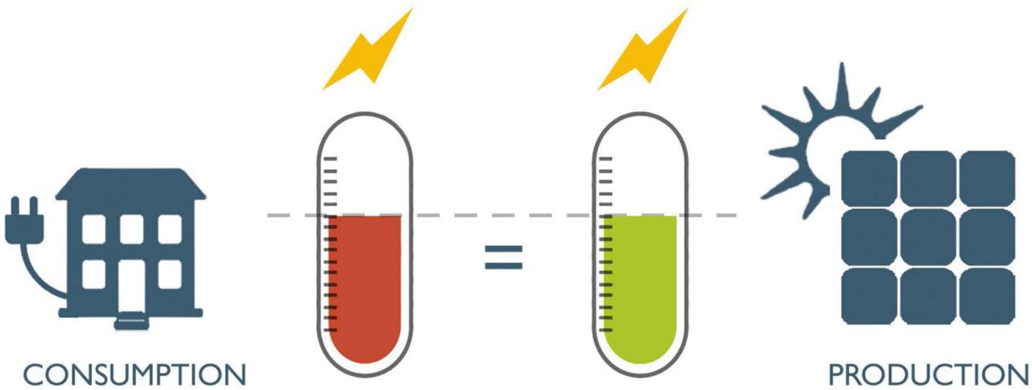

Figure 1: Net Zero Building Diagram

Illustration by Daniel Overbay. Property of Browning Day Mullins Dierdorf Architects

While trying to understand and implement the concept of net zero energy house, we followed the perception of minimizing the internal loads of the building such as various component loads instead of directly trying to balance the current energy consumption with on-site energy generation by using photovoltaics. In the process of doing this, we also dealt with the issues of cost effectiveness and seasonal variation of heat gain and ways to tackle it. We started with the enclosure as it is the primary feature of a structure associated with heat loss and heat gain. Ensuring a tighter and effective enclosure would definitely reduce the energy consumption was a presumption made by us and it proved to be correct when simulated accordingly. Similarly, other building components like mechanical system and appliances were also examined to study their effect on the overall energy consumption.

Out of the two units, we chose the smaller one with the North orientation as it was the worst case from both of them, having zero southern exposure to heat as well as having an adiabatic wall. Assumptions were made that if a net zero energy balance is achieved for this unit then the other unit would also be able to achieve it which had an added advantage of southern exposure too. On site visit proved to be helpful to us while modeling the baseline case in REM/Rate™ as we were able to know the exact measurements as well as existing materials of the site. This assisted in building up a realistic baseline rather than based on assumptions. After that, calculated strategies were experimented with by running different simulations for adding and subtracting various kinds of appliances and materials. After a series of various permutations and combinations, we received our best case products that were effective and efficient along with being economic as well. These were the final recommendations we made as part of retrofit ting guidelines. The results of the simulations were then analyzed and drafted in graphs in order to visually understand the impact of change in each system on the overall energy performance criteria of the retrofitted building. The HERS score, energy consumption and costs were compared and studied in order to decide recommendations relevant to reaching out to net zero.

EXISTING CONDITIONS

The property 86, Craighead Street is currently owned by URA (Urban Redevelopment Authority), Pittsburgh. It consists of two units out of which one is meant for the owner and the smaller one is supposed to be given as rental unit. It is in a dilapidated condition hence they have currently decided to renovate the whole building and then sell it when it is complete. The targeted potential buyer income group is supposed to be low-moderate income buyer.

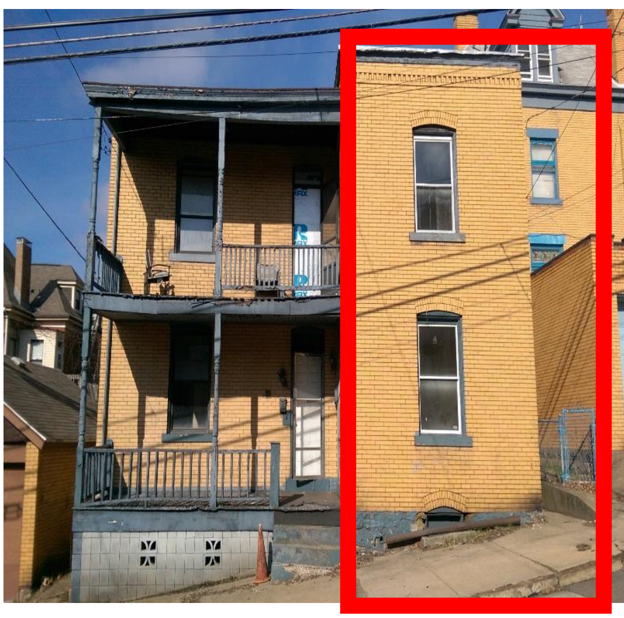

Figure 2: Selected duplex unit for modeling

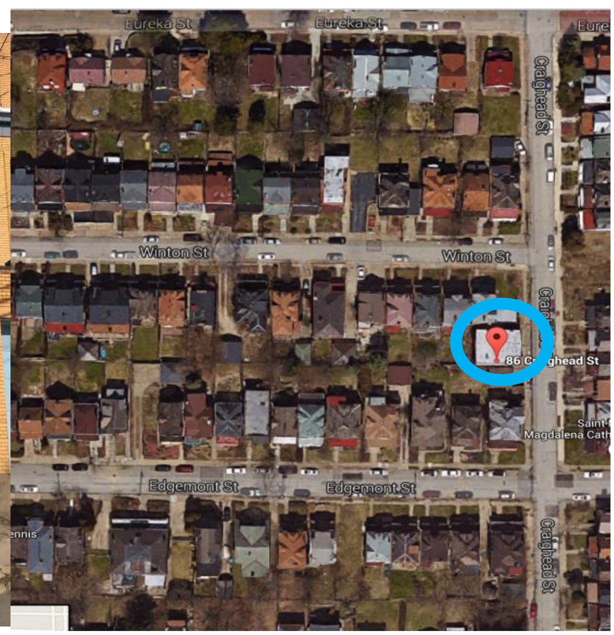

Figure 3: Satellite view of location

We chose to renovate the rental unit as it is the worst case scenario with respect to North orientation of the building. Also, the renovation recommendations need to be affordable as well as long lasting and low-maintenance as URA has very limited budget allotted for redevelopment of such old properties as well as has a dearth of resources. The recommendations have to be such that they try to reduce the utility costs.

Figure 3: Existing Interior

Figure 4: Existing exterior

One major challenge while dealing with this project was that the existing structure had to remain intact. No change in wall structure has been planes so the assembly for renovation had to be decided accordingly.

1. NET ZERO CONSIDERATIONS

Based on different perspectives of net zero definition, a home owner is free to decide which definition is to be pursued, as it involves various kinds of criteria like energy supply, transmission methods, fuel used, renewable energy generated on site or off site, and similar other factors. It can be site based if the owner wants the house to be all-electric and it can be source based if the owner opts for natural gas as a fuel.

Other intangible factors that are equally important to be considered are occupant health, environmental impact and economic feasibility. So the design decisions have to be based upon all the above mentioned criteria and not mere pursuit of the definition based approach.

We looked at net zero considerations in a three tier approach related to: Environment, Occupant Health and Building Longevity. These strategies should address environment in terms of reduction in total consumption of energy, by using renewable resources of energy and by wisely choosing the type of fuel for achieving the net zero energy status.

Occupant health should not be compromised at any cost by using low grade materials or products that could deteriorate in short time due to presence of moisture. Low VOC paints and products with non-toxic chemicals are desired. Also, we considered radon infiltration as a threat to occupant health as well as building health.

Building longevity had to ensured by preventing moisture damage, UV damage etc.

In terms of fuel, the most widely used fuels are electricity and natural gas. The site-to-source multipliers come into picture once the type of fuel is selected. The national average conversion factor for natural gas is 1.05 while for electricity is 3.15. But, on the other hand, the energy wasted in transmission of the natural gas adds on to the total calculations, hence negating the chances of using natural gas as a fuel to attain net zero using source based definition. For the all - electric assumption, even though the conversion factor is more, the possibility of onsite power generation maximizes the potential of reaching to net zero without adding on the transmission waste of energy.

For the project, an all electric approach was considered for achieving net zero energy status. We aimed to achieve net zero energy by using site-based definition. All the appliances used were selected accordingly. We also made sure hat that the embodied energy of the appliances and material is as low as possible. This includes the energy used in manufacturing the product, transporting it and the emissions occurred due to all these activities. Hence, an effort was made to minimize the overall energy wastage in all possible ways by selecting specific products and materials.

Also, sustainable enclosure was an aspect we were considering equally important. To ensure tightness of the envelope was one of the major criteria as the envelope plays a crucial role in terms of heat loss/gain and infiltration which in turn directly increases the heating or cooling loads. We intended to avoid use of materials that could intoxicate the air quality of the space which includes high off-gassing materials, high ozone depleting potential and materials which have been made by toxic chemicals that induce long term harm to the environment.
A balanced ventilation system with energy recovery was used instead of using exhaust only or supply only ventilation. Infiltration was handled by using water vapor retarders.
Carefully calculated high performing roof and wall assemblies were made by defining the path layers for each of them.
Hence, to achieve site based definition of the net zero energy status, relevant assumptions were made after examining their pros and cons while trying to preserve the three major concerns for environment, occupant health and building longevity.

2. BASELINE CASE ASSUMPTIONS

List of Assumptions and Model Inputs – IECC 2009 and Energy Star 3.0

Site Information

i. Electricity: Duquesne Light, $10.00/month service charge, $0.0472/kWh
ii. Gas: People's Natural Gas, $14.58/month service charge, $6.4599/MCF

General Building Information

i. Conditioned space of 606.5 SF per floor x 2 floors = 1,213 SF Total Conditioned Floor Area (CFA)
ii. 1st floor ceiling height of 8'-9", 2nd floor ceiling height of 8'-7"

iii. Volume of conditioned space = (8'-9" + 8'-7") x 606.5' = 10,513 CF
iv. Duplex unit, single unit, worst exposure = north
v. 2 floors above-grade
vi. 3 bedrooms
vii. Unconditioned basement

Foundation Wall Properties

viii. South foundation wall is adiabatic to adjacent apartment unconditioned basement. Location selection of "Between unconditioned basement and garage/ground" selected.
ix. Foundation wall thickness of 12"

Slab Floor Properties

x. No slab floors.

Floor Properties

xi. Floor insulation grade of I (0% gaps) selected to meet IECC 2009 UA Compliance.
xii. All path layer R-values sourced from Stein & Reynolds (2000), Mechanical and Electrical Equipment for Buildings, 9th Edition and www.coloradoenergy.org.

Rim and Band Joist Properties

xiii. 1st floor rim and band joists are "Between unconditioned bsmnt and ambient" for non-adiabatic walls (north, east, and west) and "Between unconditioned basement and garage" for adiabatic wall (south).
xiv. 2nd floor rim and band joists are "Between conditioned space and ambient" for non-adiabatic walls (north, east, and west) and "Between cond and another cond unit (adiabatic)" for adiabatic wall (south).
xv. Rim and band joist area is calculated by 12" depth x wall length.

Above-Grade Wall Properties

xvi. Brick veneer wall is not considered a "Mass Wall" and must meet the requirements for "Wood-frame Wall" in IECC 2009.
xvii. Above-grade wall insulation grade of I (0% gaps) selected to meet IECC 2009 UA Compliance.
xviii. 12" floor thickness each floor, for a total of 19.3' of exterior above-grade wall.

Window and Glass Door Properties

xix. Harvey brand, Majesty line, double-hung, non-metal frame, Low-E, Argon, U=0.34, SHGC=0.26 window selected for all above-grade wall windows.

xx. 1.8 SF stained glass windows above two doors. U=1.00, SHGC=0.20 modeled. IECC 2009 402.3.3 Glazed fenestration exemption, allows up to 15 SF per unit to exceed required U-value and SHGC maximums.

xxi. Foundation wall glass block window in unconditioned basement, 5.7 SF, U=0.34, SHGC=0.27, specifications from Pittsburgh Corning brand.

xxii. All door glazing modeled with same U-value and SHGC specifications as above-grade wall windows.

xxiii. Different window properties selected to meet Energy Star v3.0 (separate file).

No.	Code*	Floor	Orientation	Wall #	Width (in)	Height (in)	Area (sf)	Type
W1	1W1A	1	East	AGW 2E	40	64	17.8	Dbl hung
W2	1W2G	1	West	AGW 4W	32	64	14.2	Dbl hung
W1	1W1H	1	North	AGW 1N	40	64	17.8	Dbl hung
W3	2W3I	2	East	AGW 2E	40	60	16.7	Dbl hung
W5	2W5O	2	West	AGW 4W	32	60	13.3	Dbl hung
W4	2W4P	2	North	AGW 1N	28	60	11.7	Dbl hung
W4	2W4Q	2	North	AGW 1N	28	60	11.7	Dbl hung
DG2	1DG1A	1	South	AGW 3S	20	20	2.8	Half lite
DG2	1DG2D	1	West	AGW 4W	20	20	2.8	Half lite
DG2	2DG2E	2	South	AGW 3S	20	20	2.8	Half lite
SG2	1SG2A	1	South	AGW 3S	32	8	1.8	Stained
SG2	2SG2E	2	South	AGW 3S	32	8	1.8	Stained
GB1	BGB3	B	West	FW 4W	34	24	5.7	Glass Block

No.	Code*	Floor	Winter Shading	Summer Shading	2009 IECC (Baseline)	Energy Star v3.0	Net Zero Ready (Proposed)
W1	1W1A	1	None	None	U=0.34, SHGC=0.26	U=0.30, SHGC=0.32	
W2	1W2G	1	None	None	U=0.34, SHGC=0.26	U=0.30, SHGC=0.32	
W1	1W1H	1	Complete	Most	U=0.34, SHGC=0.26	U=0.30, SHGC=0.32	
W3	2W3I	2	None	None	U=0.34, SHGC=0.26	U=0.30, SHGC=0.32	
W5	2W5O	2	None	None	U=0.34, SHGC=0.26	U=0.30, SHGC=0.32	
W4	2W4P	2	Most	Some	U=0.34, SHGC=0.26	U=0.30, SHGC=0.32	
W4	2W4Q	2	Most	Some	U=0.34, SHGC=0.26	U=0.30, SHGC=0.32	
DG2	1DG1A	1	Some	Most	U=0.34, SHGC=0.26	U=0.27, SHGC=0.30	
DG2	1DG2D	1	None	None	U=0.34, SHGC=0.26	U=0.27, SHGC=0.30	
DG2	2DG2E	2	Some	Most	U=0.34, SHGC=0.26	U=0.27, SHGC=0.30	
SG2	1SG2A	1	Most	Most	U=1.00, SHGC=0.20	U=1.00, SHGC=0.20	
SG2	2SG2E	2	Most	Most	U=1.00, SHGC=0.20	U=1.00, SHGC=0.20	
GB1	BGB3	B	Some	None	U=0.34, SHGC=0.27	U=0.30, SHGC=0.27	

*Four character unique identifier: (x)xxx = floor, x(xx)x = size, xxx(x) = location
W = window glazing, DG = door glazing, SG = stained glass, GB = glass block

Door Properties

xxiv. Opaque areas for doors modeled as standard 1-3/4" solid wood door with storm door.

xxv. For Energy Star: selected R-5.0 (U=0.20) opaque door.

Ceiling Properties

xxvi. Built-up roof with 2" XPS above structure and fiberglass batt cavity insulation.
xxvii. Ceiling insulation grade of 1 (0% gaps) selected to meet IECC 2009 UA Compliance.
xxviii. No radiant barrier
xxix. No attic
xxx. Flat roof

Skylight Properties

xxxi. None

Mechanical Properties

xxxii. All mechanical equipment located in unconditioned basement.
xxxiii. Heating set-point of 70ºF, per IECC 2009.
xxxiv. Cooling set-point of 78ºF, per IECC 2009.
xxxv. 80AFUE 32k gas furnace (92AFUE for Energy Star 3.0)
xxxvi. 13 SEER 1.5 ton AC
xxxvii. 40gal 0.56 EF gas storage water heater (0.61 EF for Energy Star 3.0)

DHW Efficiencies

xxxviii. None

Duct System

xxxix. Number of return grilles: 3
xl. Leakage to outside is maximum allowable by code, 8 CF per 100 SF of conditioned space (8 x 1200/100 = 96 CFM @ 25 Pa). For Energy Star: 4 CFM x 1200/100 = 48 CFM @ 25 Pa.
xli. Total Duct leakage is maximum allowable by IECC 2009, 12 CF per 100 SF of conditioned space (12 x 1200/100 = 144 CFM @ 25 Pa). For Energy Star: 4 CFM x 1200/100 =
xlii. Approximately 1/3 (35%) of supply and return ducting located in unconditioned basement.
xliii. Supply and return ducting in unconditioned basement insulated to R-6.0.

Infiltration and Ventilation Properties

xliv. Measurement Type is blower door test.
xlv. Metric is air changes per hour (ACH) at 50 Pascals.
xlvi. Maximum allowable leakage by code of 7.00 ACH for both heating and cooling seasons. For Energy Star: 4.00 ACH selected for both heating and cooling seasons.
xlvii. Shelter class of 4 selected for moderate shielding in urban/suburban environment.

xlviii. No mechanical ventilation required at leakage greater than 5 ACH. For Energy Star: balanced ventilation modeled with ERV, 66 CFM, 76% recovery, 71-watt fan.

xlix. Natural ventilation (operable windows) selected for Cooling Season Strategy.

Lights and Appliances

l. Clothes washer and dryer located in unconditioned basement.

li. Minimum high efficacy lights allowable by code selected (50%). For Energy Star: 80%.

lii. For Energy Star: Energy Star certified appliances selected from website to meet minimum requirements.

Mandatory Requirements

liii. 2009 IECC

liv. Energy Star v 3.0

DOE Zero Energy Ready Home

lv. None

Interior Mass

lvi. Drywall thickness = 5/8", 0.625"

Active Solar

lvii. None

Photovoltaics

lviii. None

Sunspace

lix. None

From the following chapters, proposed strategies will be defined in order to retrofit the building in a more effective way than the baseline model. The baseline model, hence meets the IECC 2009 code which is actually practiced in Pittsburgh. Now, the next step was to try to make it IECC 2015 code compliant and thus thrive to reach net zero status.

3. BUILDING ENCLOSURE

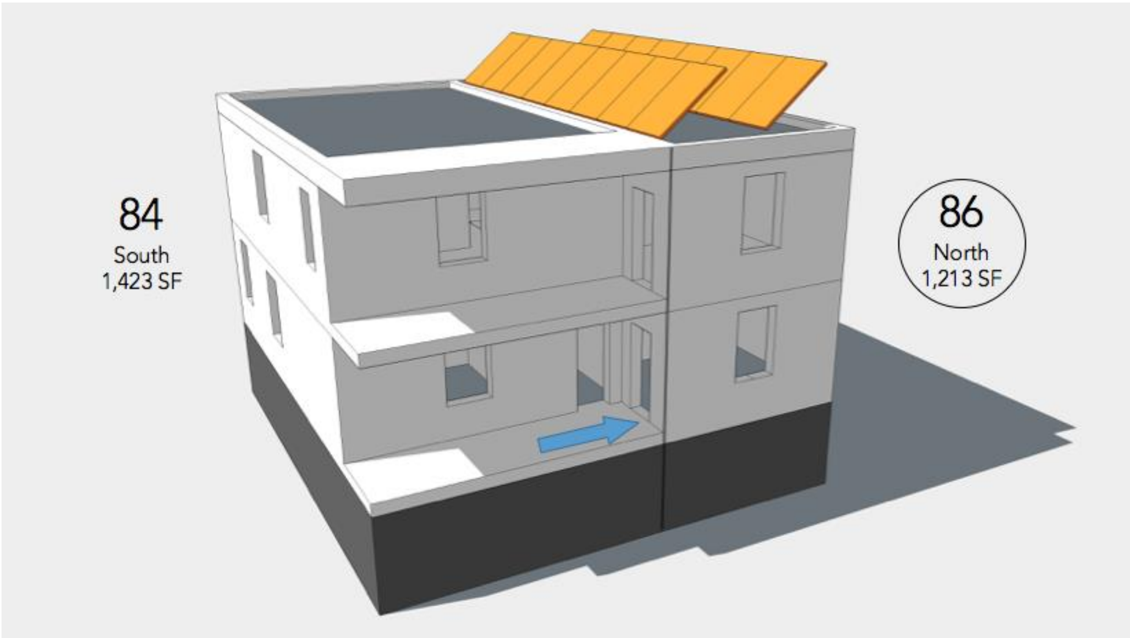

Figure 5: 3D model of the duplex units 84 and 86, Craighead Street,Pittsburgh

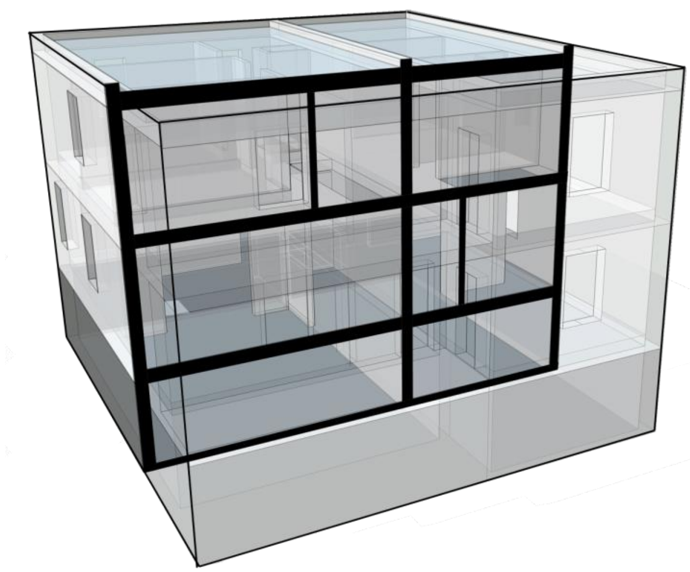

Figure 6: X-ray image of the enclosure

Building enclosure plays a crucial role in achieving net zero energy status. It consists of so many elements that contribute to infiltration and heat gain or heat loss. The selected residential unit is 86, Craighead Street which lies on the North. It has three exposed above grade walls and one adiabatic wall, which is apparently the common wall between the two units. Also, the roof and the floor are crucial assemblies which if cautiously handled, can bring tremendous results in terms of lowering the EUI to reduction in emissions.

Modulating the components of the building enclosure ensure a sure decrease in utility costs as the loads are being balanced by using better materials or products. Further sub chapters are focused on the key assumptions that the software allows us to make namely, Boundaries' selection, Above grade walls, roof, floor, Fenestrations and subsequent infiltration related data.

3.1 BOUNDARIES

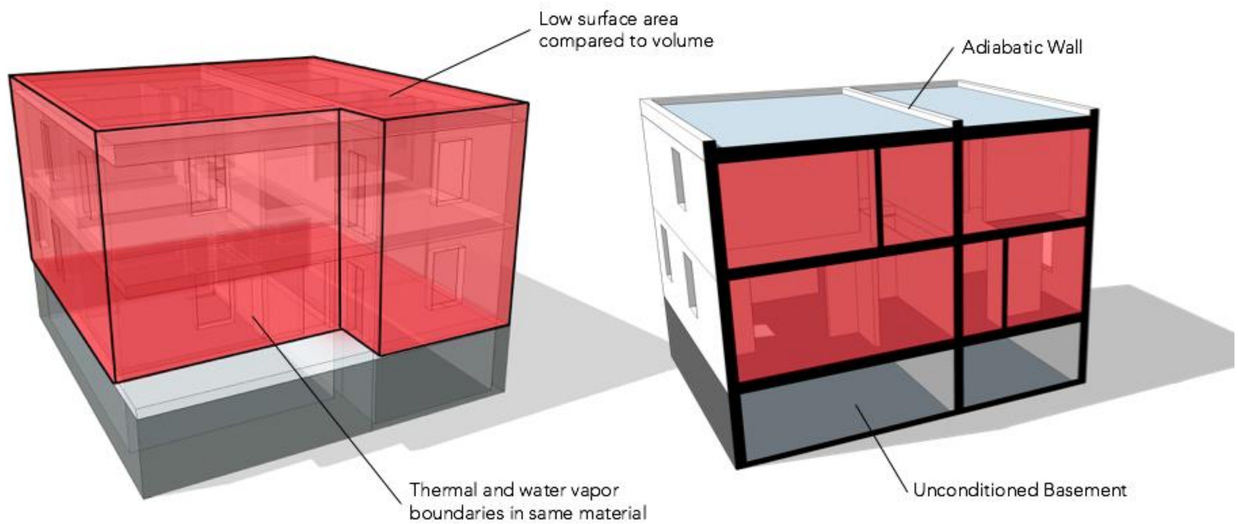

Figure 7: Relationship between exposed surface and volume of conditioned space (left) and section showing red conditioned space and grey unconditioned space

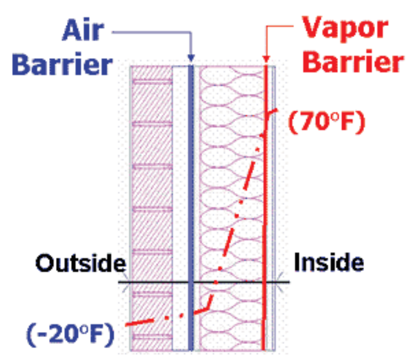

Figure 8: Location of air Barrier and Vapor barrier

The above figures show the connection between the surface exposure and volume while the second diagram shows the section with red region depicting conditioned space while grey region depicting unconditioned space. Four control layers namely thermal control, Bulk water control, Air control and vapor control are the major concerns. While dealing with air control, it is expected to select an air barrier which also efficiently acts as a water vapor boundary. Bulk water boundary can be ensured by keeping proper drainage cavities as well as appropriate use of rainscreens. The thermal boundary is critical as it has to deal with air movement as well as moisture movement. This layer is essential in differentiating the unconditioned space from conditioned space. The water vapor boundary is a little bit awkward to understand. It is defined as that layer of the assembly that allows partial permeance of air and vapor, if not chosen wisely, which in turn enters the assembly and reaches dew point temperature, and condenses inside the assembly. So, essential drying potential of the interior and exterior surface should be taken care of. Occupant health is the most important thing to be considered while selection of these layers.

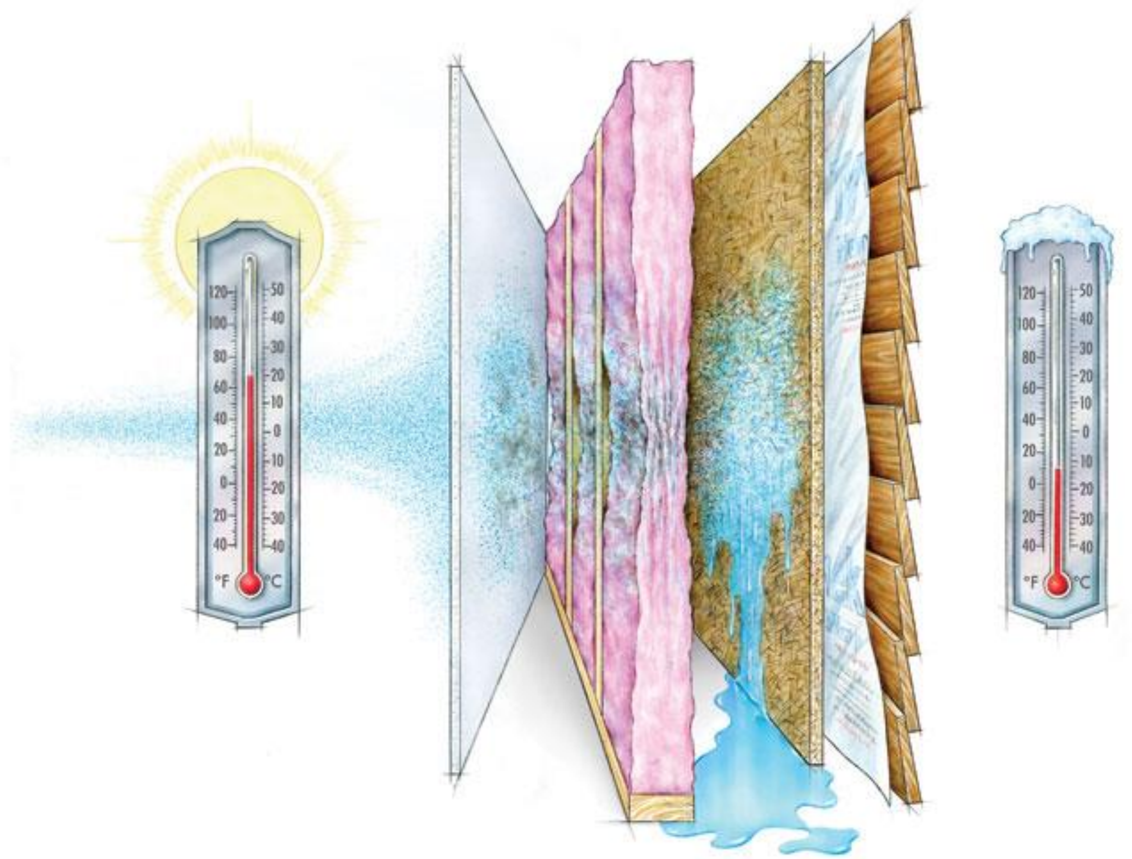

Figure 9: Wall assembly layering showing the condensation of moisture

3.2 ABOVE GRADE WALLS

The above grade walls of the site were not supposed to be assumed as if they are going to bring them down, Hence, the major challenge was to design an assembly with special kind of insulation which would increase the r value of the assembly without disturbing the existing walls. So, we assumed the old construction to be having a 4" stud construction in wood cavity.
The code compliance criteria for the climate zone 4A requires to exceed R-20 in cavity or R13 within cavity and R5 as continuous insulation.

Since the building skin cannot be brought down, continuous insulation products are meaningless to recommend. For such cases, spray applied closed cell foam type of insulation is needed that gives approximately 35 R-value by inch.

Figure 10: Pour-in-place polyurethane insulating foam

While searching for different types of insulation, we came across this amazingly unique insulation product known as Eco-Pur®. It is a soy-based insulation by Demilec offering an Rvalue of 6.5 per inch which is a valuable finding according to us.
It is known for its pour-in-place application approach. It is also eco friendly by high standards as it is soy based and is made from recycled plastics. Additionally it does not contain any ozone depleting potential. It is also fire resistant and the

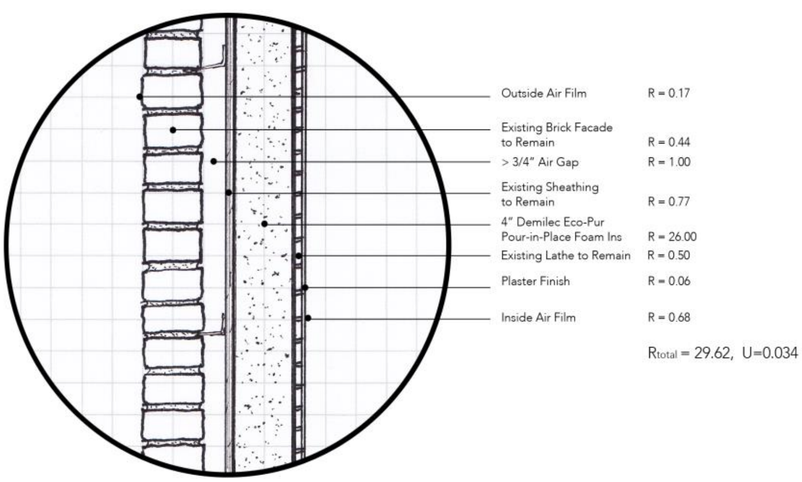

Figure 11: Construction detail of wall assembly

flame spread index is also 0. for the present recommendation, R-26 is possible to achieve for the total resistance of the assembly of R-30.
Above mentioned figure shows the layer-by-layer detail that has been devised in the path layer dialog box of the software.
After running the simulation on the software, a significant decrease the energy use intensity was visible. The HERS score was 69 from 72 (baseline), and the total annual heating consumption reduced by approximately 3.5 Mmbtu/yr.

3.3 ROOF

The building possesses a flat roof unlike many of its neighbors who have sloped roofs. This has an added advantage that we could use continuous insulation above the roof deck as well as below the roof membrane. For the selected insulation, it will also be used for rim and jist band beneath the floor. This insulation is sprayed in addition to already having fiberglass batt insulation.
So, four inches of polyisocyanurate rigid board insulation for thermal boundary surges the R value of the assembly adding up to R25.
For added insulation, two inches of Demilec's Heatlok® Soy 200 Plus product is proposed having an R-7.4 per inch of thermal resistance. This is an added insulation layer to conventional eight inch of fiberglass batt insulation, whose combined resistance is R-66, making the roof assembly code compliant by all means.
Hence, running th simulation again results in a decrease of around 1.2 Mmbtu/yr in annual heating consumption and the HERS score decresed from 69 to 68.

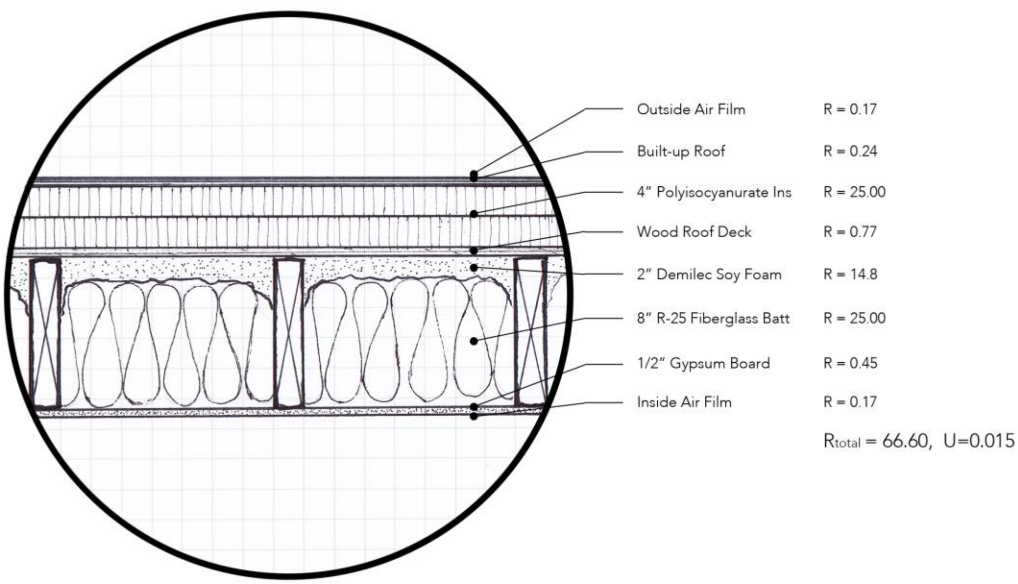

Figure 12: Construction Detail of roof assembly

Figure 13: Spray applied closed celll foam insulation and :

3.4 FLOOR

The proposal demands the basement to remain unconditioned space. This arises the challenge of coping up the heat loss from the conditioned area above the basement to it. Hence, the floor assembly has to be tightened enough to avoid energy loss. Similar to roof assembly, Demilec's Heatlok® Soy 200 Plus product is proposed to provide a air, moisture and thermal resistance. Eight inches of R-25 batt insulation achieves a total R-value of 43, which exceeds far more than the requirement by IECC 2015 (R-30).

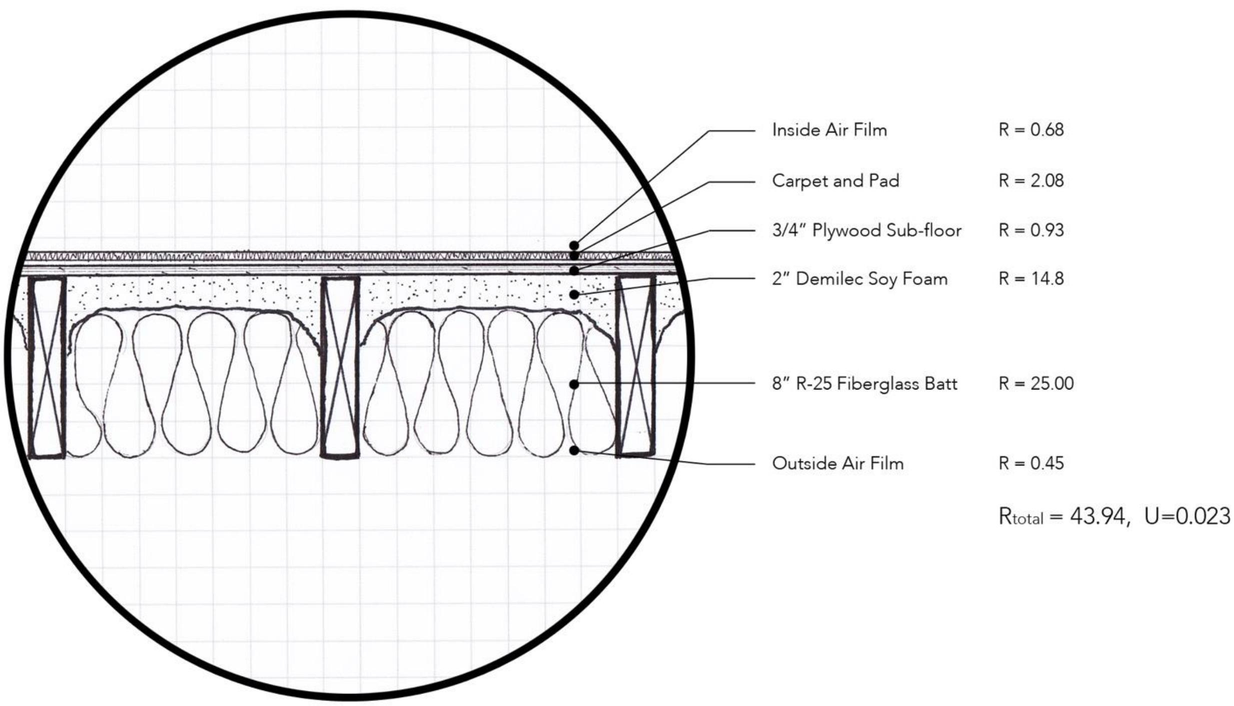

Figure 14: Construction Detail of Proposed Floor and estimated R values

3.5 FENESTRATIONS

The existing double hung windows are recommended to be replaced with some modern windows that have smart solutions to deal with infiltration and solar heat gain. These windows should harness the diffused northern light for daylighting while cut down the harsh incident sunlight on east and west orientations.

The windows were explored with them having double or triple glazing as well as having high visible transmittance value and low emissivity as well as low SHGC value.

Windows from Marvin Ultimate Series Insert windows for renovations and existing buildings had been selected. These are double glazed and krypton filled with a wooden frame and aluminum clad exterior. They have a U-value of 0.22 and SHGC of 0.41.

It is not that there are not better windows than these. There are windows with lesser SHGC value than this which can also be modeled.

Figure 15: Double glazed insert panel window

Figure 16: Section of a double glazed window

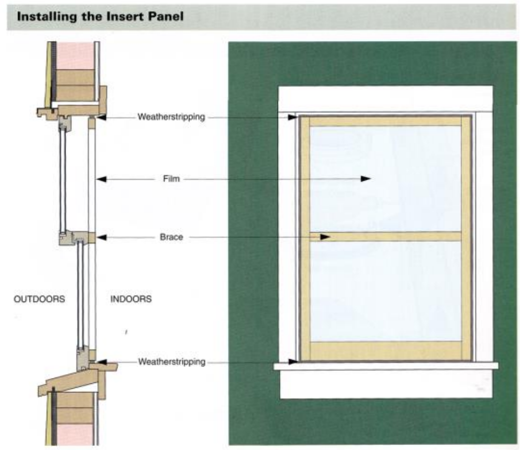

Figure 17:Installation of an insert Panel

Both the entrance doors have this interesting element of stained windows above them, which are aesthetically good but are high infiltrating areas which need to be tackled.
They are basically Stained-glass inserts above front doors with R 1. Hence, it is recommended to install insert plexi "storm-window" coverings to double the heat resistance (R = 2.0).
Regarding the doors, the existing doors are recommended to be replaced with Energy Star solid wood doors w/storm. These are opaque doors with U-value of less than 0.17 and SHGC less than 0.25. The total number of doors to be replaced are 5 with dimension of 32" x 6' 8".

3.6 INFILTRATION

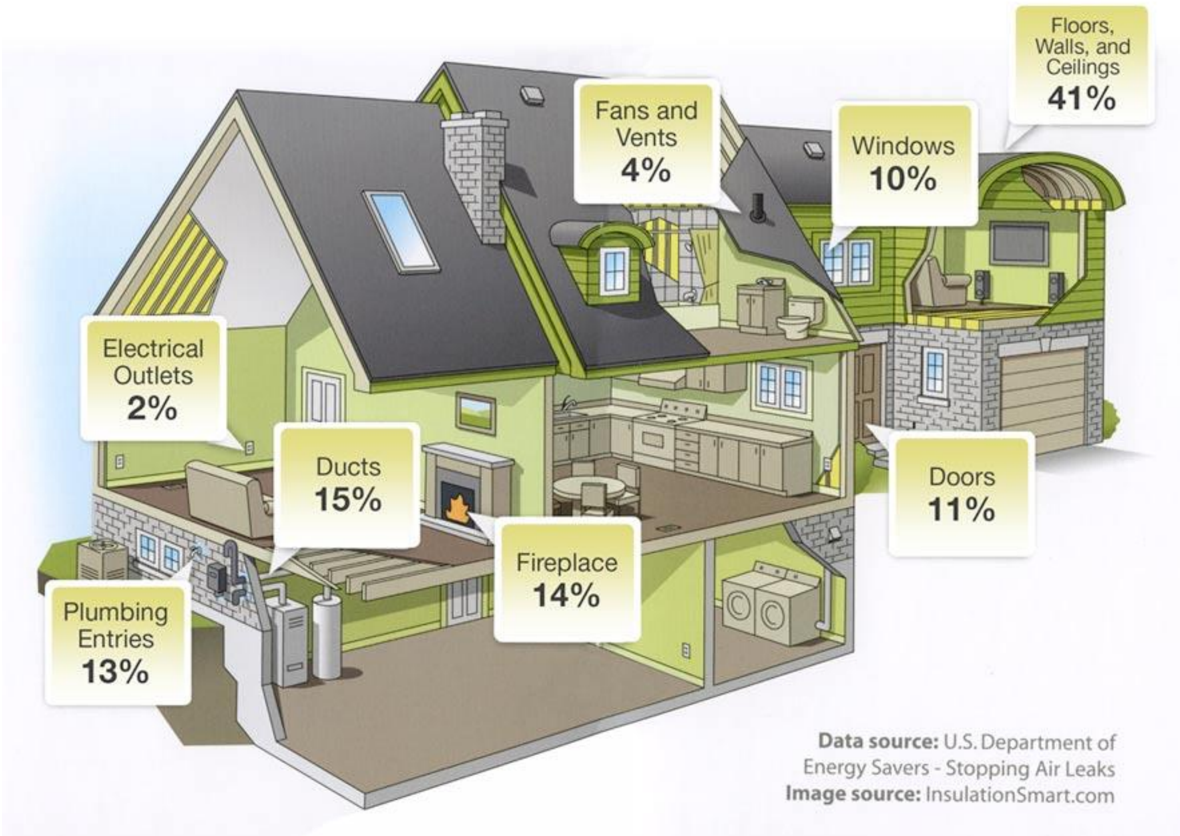

Figure 18

Infiltration is an important factor to be considered. As evident from the figure above, it occurs through a number of places an punctures in the envelope, like the outlets, through duck leakages, plumbing entries, windows, doors etc. Weatherproofing and caulking are not the only solutions but help to mitigate infiltration by a certain extent. According to IECC 2015, less than 3 air changes per hour are allowed at 50 Pascals pressure differential.

At the end of all the relevant enclosure changes, when final simulation was run, following results were achieved.

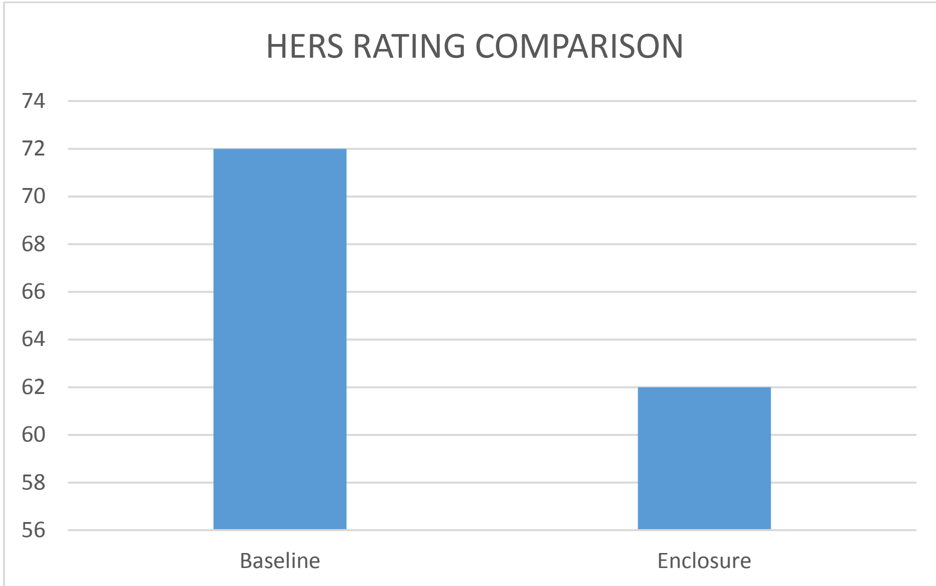

Figure 19: Hers score comparison of baseline and model after adding Enclosure recommendations

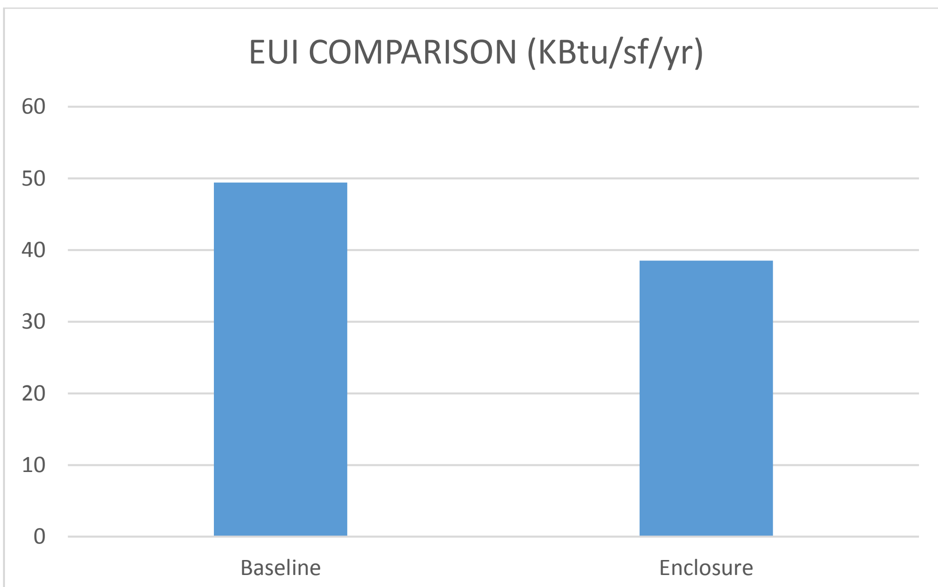

Figure 20: EUI Comparison of baseline and model after adding Enclosure recommendations

Total annual heating consumption reduced by 13.2 Mmbty/yr compared to the baseline case. The EUI has decreased by 22% while the HERS rating was reduced from 72 to 62, compared to baseline.

4. MECHANICAL SYSTEMS

For effective conditioning of space, heating and cooling should be separated from ventilation. AS the space volume increases, the demand for fresh outdoor air also increases. The mechanical systems were selected from the Home Ventilating Institute website.

4.1 VENTILATION

For ventilation, a balanced energy recovery ventilation system has been recommended. The product is from Renewaire called Renewaire, LLC.EV90P. When sized appropriately for the project by adjusting its capacities to the conditioned area of 1500 sf, total energy recovery efficiency is 63%. The fan energy is 44 watts. It is advised to install the ERV on the first or second floor in the conditioned space as it absorbs the outdoor air to operate. It should not be installed in the unconditioned basement. For retrofit purposes, existing ductwork can be reused for supply and return register.

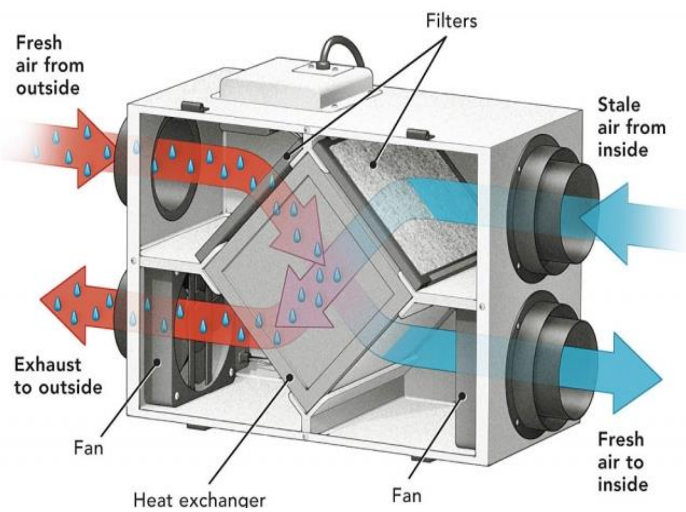

Figure 21 : Diagram of an ERV depicting ots function

According to International Mechanical Code (IMC) 2015

$$Q_{OA} = 0.03\,A_{floor} + 7.5(N_{br} + 1)$$

Required outdoor breathing air in cubic feet per minute =
(0.03 x conditioned area) + 7.5(number of bedrooms + 1)
(0.03 x 1,213) + 7.5(3 + 1) = 59 cfm

4.2 HEATING AND COOLING

For heating and cooling, various heat pumps were examined. The best one is geothermal heat pump but it could not be implemented in this project as it would have been theoretically correct but practically impossible. Hence, we chose to go with selecting the second best option that is air source heat pumps. These are over 300% efficient! They also ensure low exergy heating with no combustion.

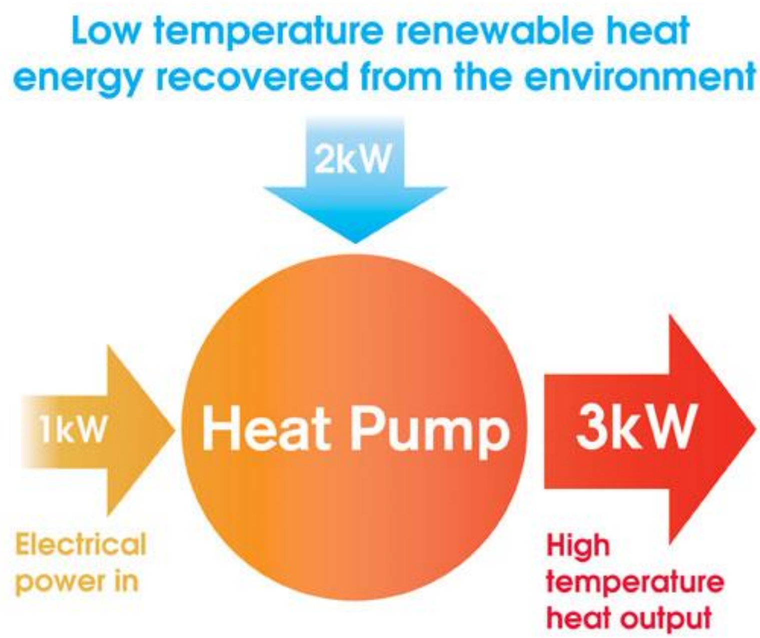

Figure 22: Energy Recovery diagram

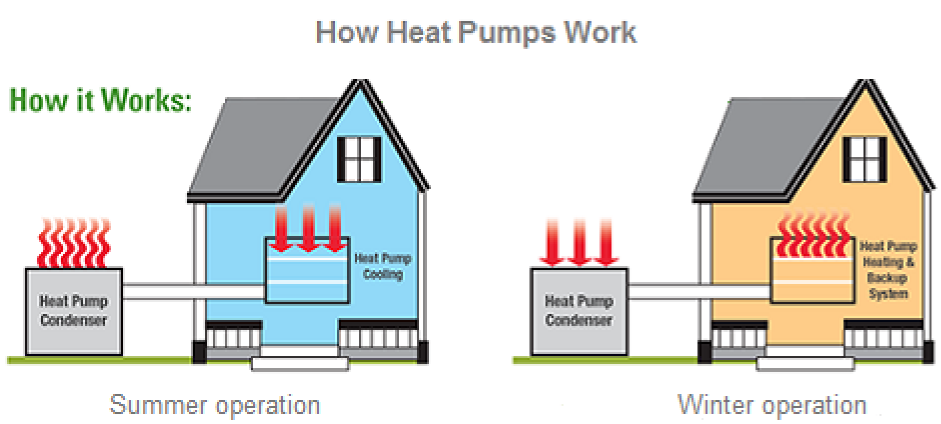

Figure 23: Summmer and Winter Operation of Air source heat pump

These heat pumps work on refrigerants. The refrigerant moves the heat by changing it phase according to temperature. In summer time, it absorbs the hot air from inside and dissipates it outside, while in winter it does the vice-versa by reversing the refrigerant flow direction and hence function.

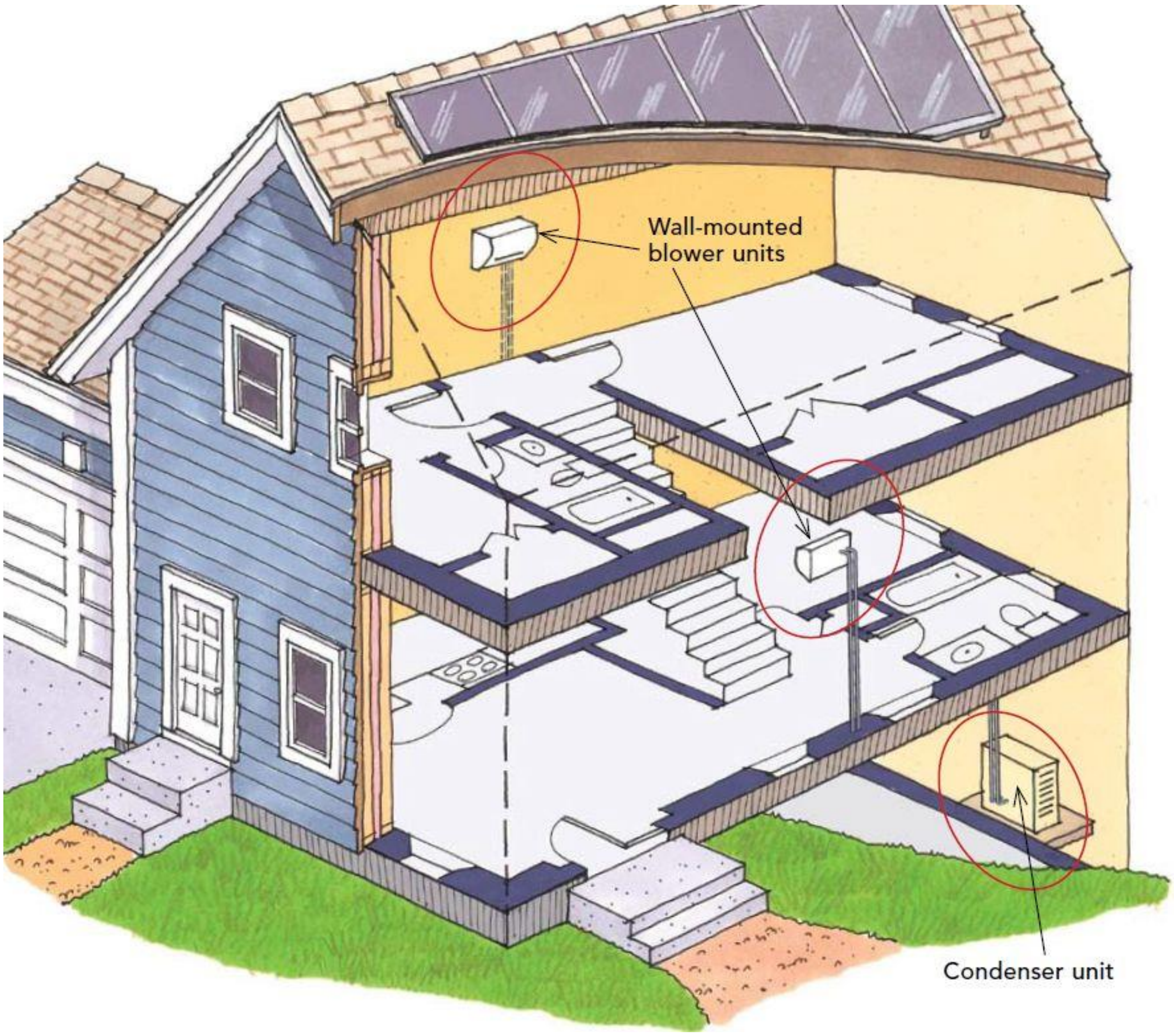

Figure 24: System diagram for placing mini splits

We propose to install two mini-split heat pumps on first and second floor each. This would negate the need of ductwork throughout the place. The heat pump selected is from Mitsubishi Electric company.

1st Floor Living Room: Mitsubishi Mr. Slim MUZ-FH12NA (8,000 Btu/h)
2nd Floor Hallway:
Mitsubishi Mr. Slim MUZ-FH09NA (6,700 Btu/h)
Industry-leading 30.5 SEER
(Energy Star > 15 SEER)
Very high 13.5 HSPF
(Energy Star > 8.5 HSPF)
Can heat even when outdoor temps are -13.0 F
Design Load: 14,000 Btu/h total

4.3 DOMESTIC HOT WATER

The domestic hot water system is an independent system proving hot water to

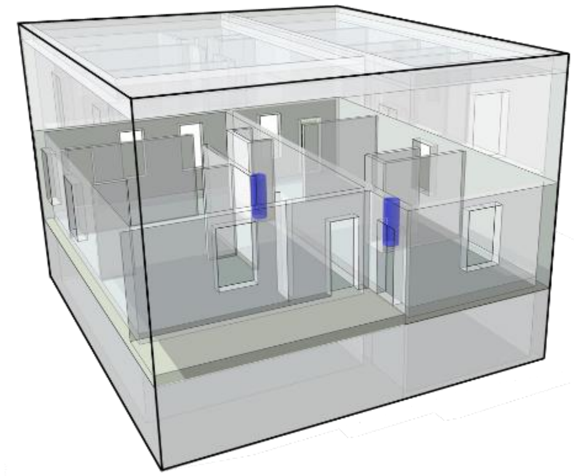

Figure 25: System diagram for DHW

kitchen and bathroom sinks, cloth washers, dishwashers tubs and other appliances.

There are various types of DHW systems:

- Gas storage water heater
- Tankless gas water heater
- Solar water heater
- Heat Pump water heater

For the given residential unit,
We considered simulating all four kinds of water heaters and their effect on the total energy consumption.

The traditional Gas Storage water heater as considered as an option because it has a low initial cost and is easy and inexpensive to replace.
Then, High efficiency condensing gas water heater was experimented with, as it cuts the energy costs by 30%, showing comparatively better results than the previous one.
In the recommendations, we did not include the tankless gas water heater.
Then, the heat pump water heater was simulated which proved to be the most efficient of all. The main advantage of a heat-pump water heater is that at least twice as much hot water is obtained from each kilowatt-hour of electricity consumed as compared to that obtained from a standard electric water heater. The Energy Factors of these units range from 2.0 to 2.5 which means that they are effectively 200% to 250% more efficient at converting the electricity into usable

heat.

Following are the recommendations we made for Domestic water heater out of which the Heat Pump Water Heater was considered to be the final choice.

<u>1. TRADITIONAL GAS STORAGE: RHEEM PLATINUM XG40T12DM40UO</u>

Performance Platinum™ Powered Damper gas water heaters
Efficiency: 0.69 EF annually for natural gas models
81% Recovery Efficiency
Capacity: 40 gallons

Figure 26: Gas Storage water heater

<u>2. HIGH EFFICIENCY CONDENSING POWER DIRECT VENT INDUCED DRAFT GAS WATER HEATER: RHEEM RHE40</u>

Efficiency: 0.82 EF annually for natural gas models
90% Recovery Efficiency
Capacity: 38 gallons

Though condensing gas storage water heaters are popular these days, people still prefer to get heat pump water heater compared o traditional gas storage water heater

Figure 27: Condensing water Heater

<u>3. : HEAT PUMP WATER HEATER BRADFORD AEROTHERM RE2H50R10B</u>

Efficiency: 0.82 EF annually for natural gas models
90% Recovery Efficiency

Figure 28: Heat Pump Water heater

Capacity: 38 gallons

Efficiency: 3.39 EF annually for electric based models
69 FHR (First hour rating)
Capacity: 50 gallons

The best feature is: Flexible Operating modes
Heat Pump (Only) Mode—Maximizes consumer savings.

Hybrid Mode—Saves while experiencing fast recovery. Hybrid mode is the factory setting combining heat pump efficiency and savings with recovery rates of standard electric when needed

Electric (Only) Mode—Operates like a standard electric water heater, and eliminates the air flow and sound from the heat pump system when preferred (fastest recovery time, but least energy efficient).

Vacation Mode—Adjusts the temperature set point down to 50°F for extended periods of time

The reason for selecting an Energy Star Heat Pump Water Heater is that eco-friendly, highly efficient, easily operable, and has flexible scheduling.

Inclusion of this recommendation to the already designed HVAC recommendation decreased the HERS score from 59 to 49. The EUI changed from 32.1 MMBtu/yr to 21.8 MMBtu/yr which is a significant change.

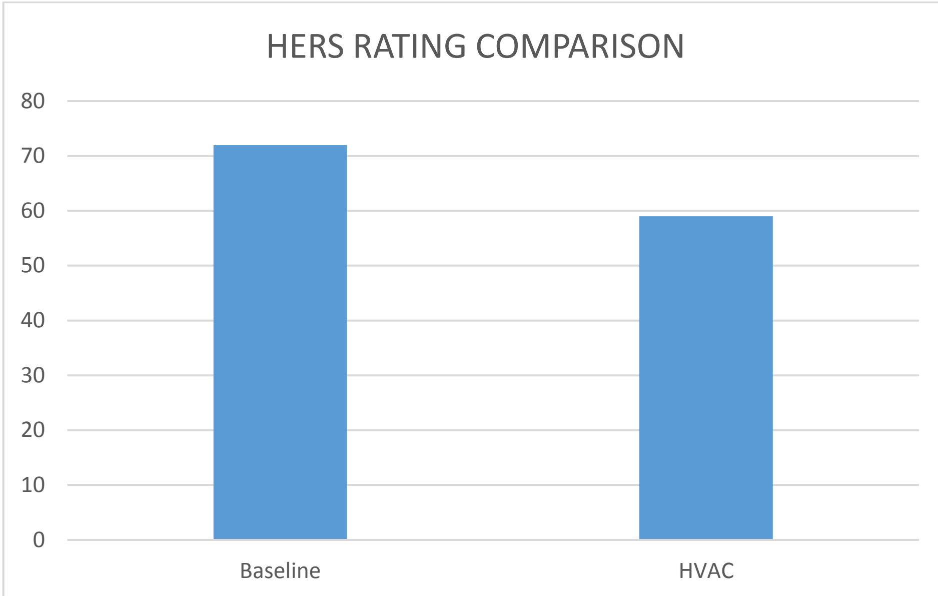

Figure 29: HERS scoreComparison of baseline and model after adding HVAC

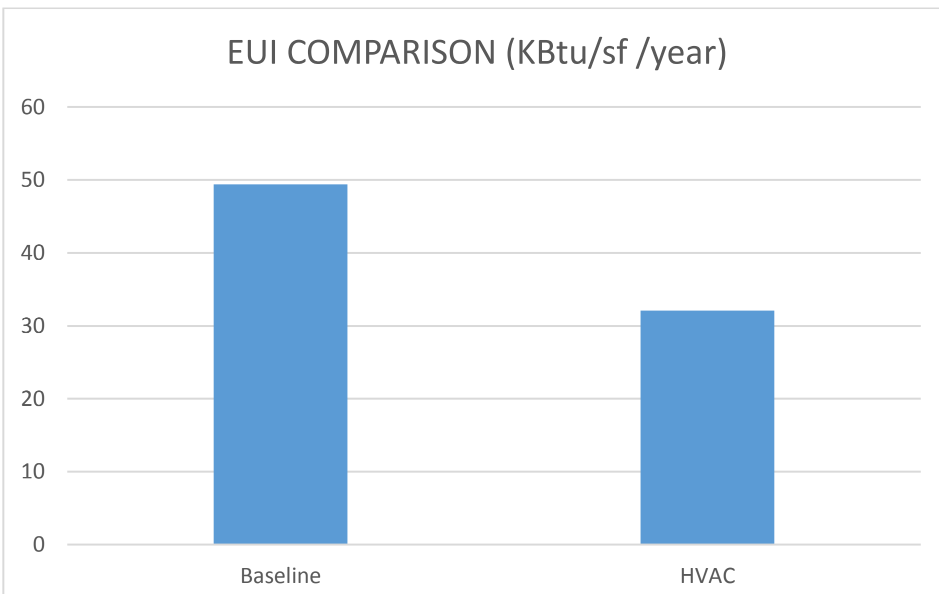

Figure 30: EUI Comparison of baseline and model after adding HVAC

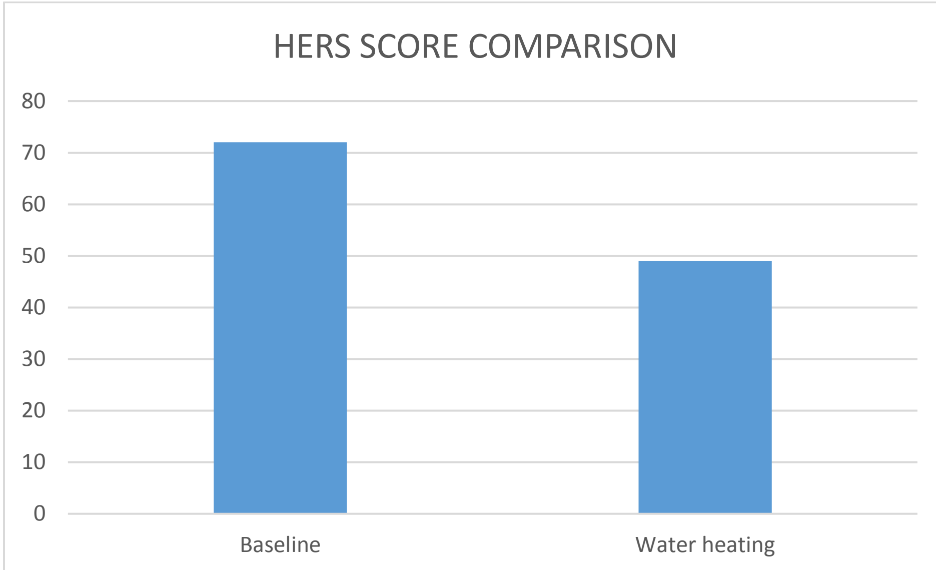

Figure 31: Hers score comparison of baseline and model afetr adding Water heating appliance

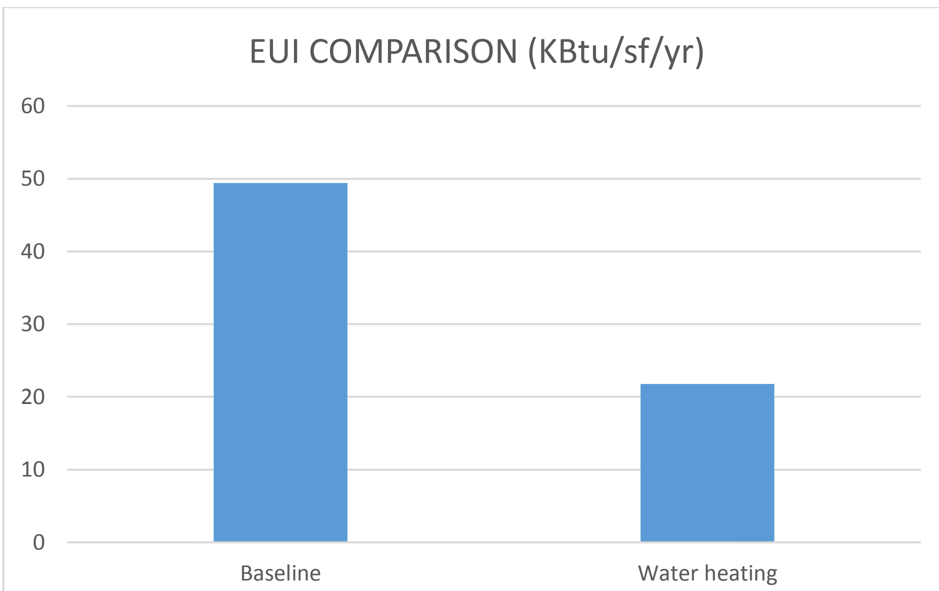

Figure 32: EUI Comparison of baseline and model afetr adding Water heating appliance

5. APPLIANCES AND ELECTRICAL LOADS

Appliances and electrical loads contribute to a major part of energy consumption as most of them run on a daily basis while some of them run during peak hours, while some run occasionally.

RemRate has a limitation which restricts the selection of only certain appliances This does not include the plug loads and other loads by several devices like DVR etc . Hence, only Refrigerator, Dishwasher, Clothes washer and Dryer, Fans are the only specified appliances.

5.1 KITCHEN

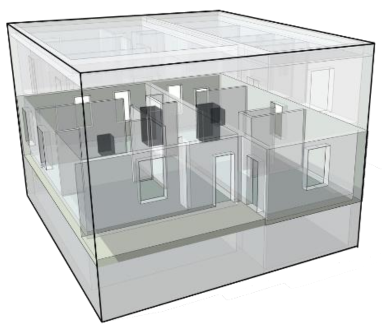

Figure 34: System Diagram for fridge and dishwasher

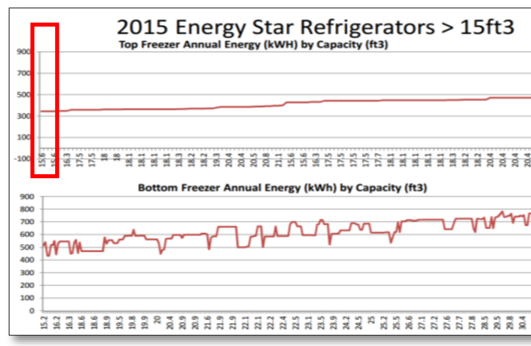

Figure 33: List of energy star rate refrigerators and their capacities, energy use (From Nina Baird)

<u>REFRIGERATOR : GE GPE16DTH</u>

Type : Top Freezer
Capacity : 15.6 Cu Ft
Annual Energy Use : 344 kWh/yr
10% less energy used than US Federal standard (384 kWh/yr)
Cost : $ 540

Units with a top-mounted freezer consume 10 percent to 25 percent less energy than models with bottom- or side-mounted freezers, according to the U.S. Department of Energy. This was the prime reason behind selected a top mounted Energy Star rated freezer.

<u>DISHWASHER : BLOMBERG DWS 55100</u>

Dishwasher Type :Built Under
Type : Top Control
Number of Place Settings : 14
Water consumption : 3.07 gallons per cycle
Annual Energy Use : 220 kWh/year
28% better than US Federal standard (307 kWh/yr)
It is one of the best energy star rated dishwasher with low water consumption.
Cost: $ 749

Figure 35: Dishwasher

5.2 LAUNDRY

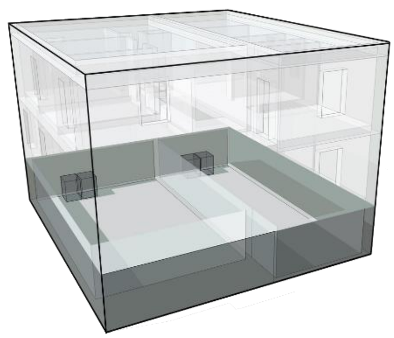

Figure 36: System diagram for Laundry

<u>WASHING MACHINE :SPEED QUEEN AFNE9RSP113+</u>

Load Configuration : Front Load
Capacity : 3.4 Cu Ft
Integrated Modified Energy Factor : 2.38
Integrated Water Factor : 3.7
Annual Energy Use : 68 kWh/yr
Annual Water Use : 3733 gallons/yr
Cost: $ 1499

Figure 37: washing machine

<u>CLOTHES DRYER : WHIRLPOOL WED7990FW</u>

Type : Electric heat pump dryer
Capacity : 7.4 Cu Ft
Combined Energy Factor : 4.5
Estimated Annual Energy Use : 531 kWh/yr
Unique moisture sensing technology
Cost: $1150

Figure 38:Cloth dryer

5.3 FANS AND LIGHTING

Fans : Haiku K3127-X2-PB-04-02-C
Product : Ceiling Fan
Size (Diameter) : 52 inches
Airflow efficiency by speed : 763 CFM/Watt (At Medium Speed)
Annual Energy Use : 5.5 kWh
Annual operation cost : $.63
Lifetime operation cost : $6.32
Consists of SenseME technology allows users to automate their comfort and
save energy year round
Number of ceiling fans required : 4
Cost (4 pieces): $ 1800
In terms of lighting , LED lamps are suggested.

Figure 39:Haiku fan

5.4 ENERGY MONITORING

Energy consumption data measurement is one of the first steps in finding an approach to minimize it. An energy monitoring system is advantageous in identifying the biggest loads in the household and adopt measures to save energy consumption.

A typical home energy monitoring system consists of a data gateway, sensors and a display to analyze the recorded information. A standard set of information includes power withdrawal (kW) and energy consumption (kWh). Also, sometimes the cost of consumed electricity is shown while some of them allow the flexibility of allowing the programming for different time-of-use rates. The sensors are required for all modes of measurement, of which Current Transducers and Pulse Sensors are most common. Meter's accuracy also plays an important role in getting updated readings. The recorded information is displayed on a countertop display or on a smartphone or on a customized personal website, if such facility is available for the specific product.

For the given residential unit, we recommend Energy Monitoring system by SiteSage which is essentially a Home Energy Monitoring system which gives minute-by-minute energy usage data and the analytics engine enables real time visibility Into the current energy consumption scenario.

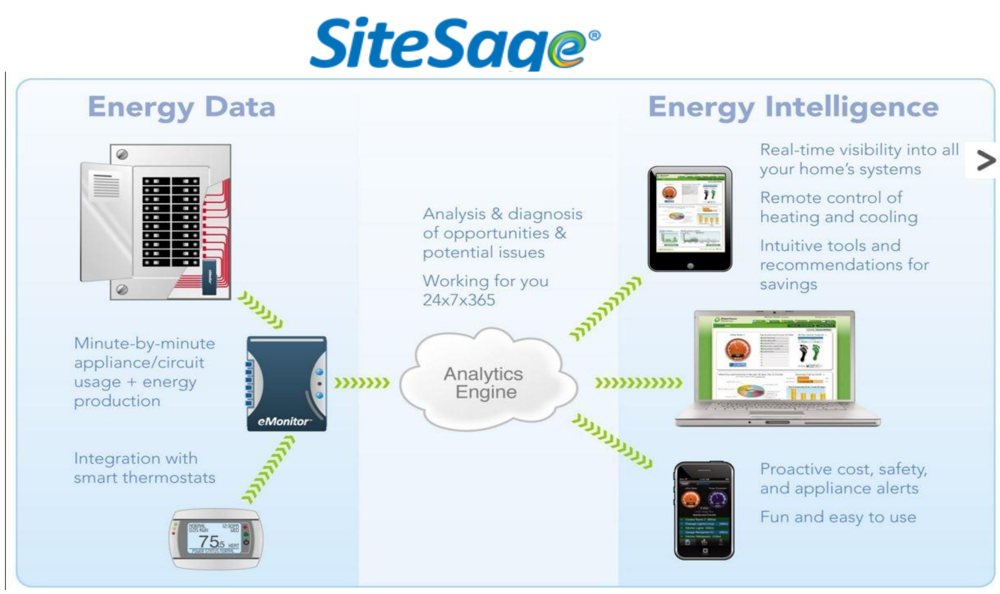

Figure 40: Energy monitoring System

Energy Monitoring: SiteSage (Residential Home Energy Monitoring System)
24 X 7 detailed data

- Electricity use
- Electricity cost
- Carbon footprint
- Historical information by day, month or year
- Circuit by circuit energy monitoring

Results displayed on a password protected website that can be accessed from an iOS app.
Useful in analyzing the current energy usage and thus helps in understanding the use of energy efficiently and effectively.

Features:
The ability to control any equipment (Single phase and 3 phase), be it HVAC or lighting.

Multiple scheduling for different types of each equipment
Benchmarking energy usage and equipment performance

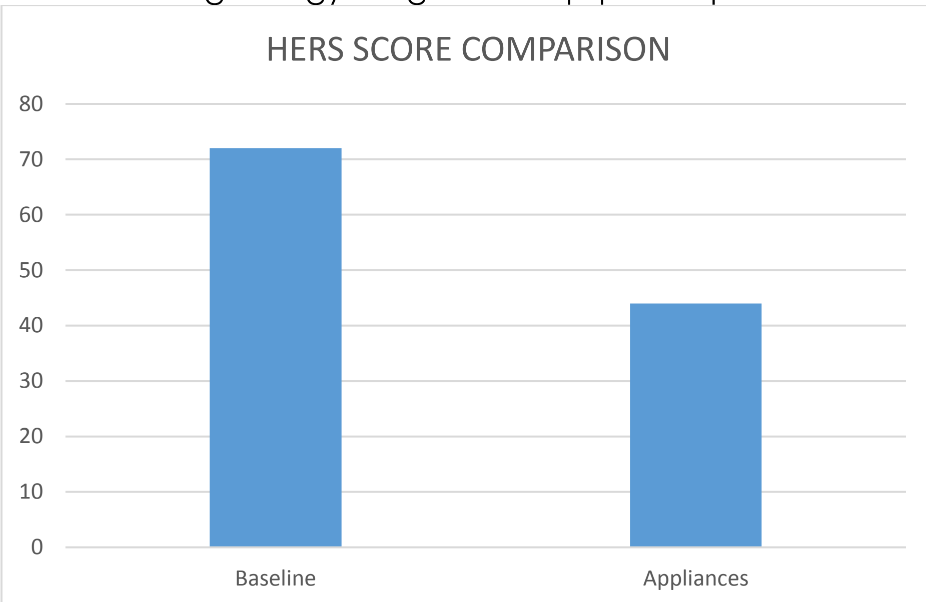

Figure 41 HERS Score comparison of baseline and model with appliances

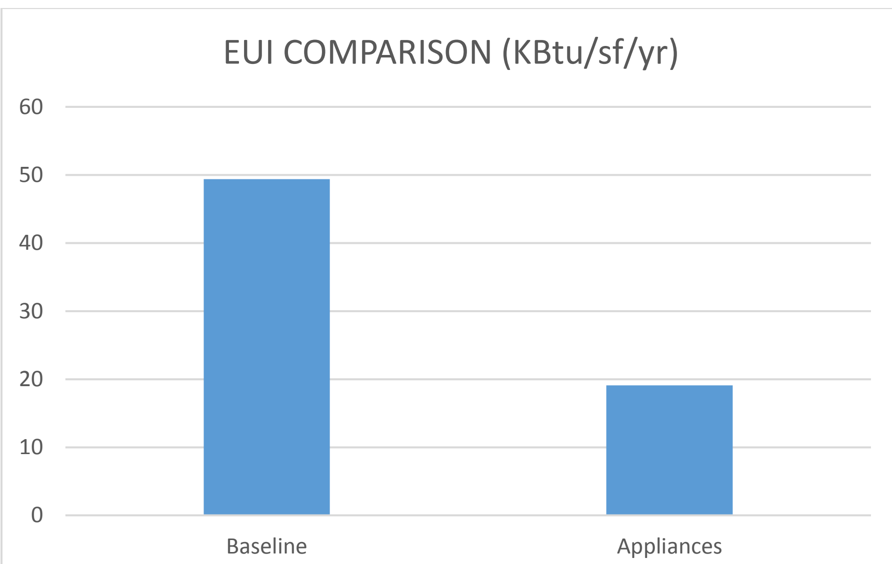

Figure 42: EUI Comaprison of baseline and model with appliances.

6. PHOTOVOLTAICS

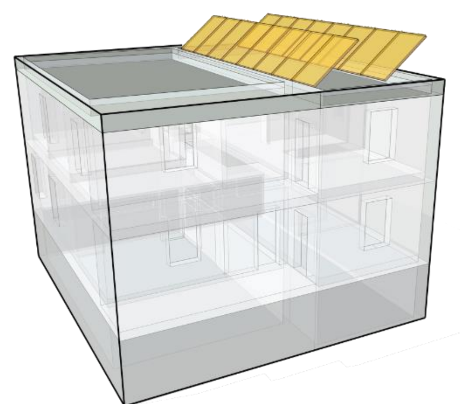

Figure 43:System diagram for PV

For a net zero building, the total energy consumption demand of the building is met by generating equal or more amount of renewable energy on site. Utilizing solar energy is important in order to meet the net zero energy balance. If the building needs extensive energy consumption then the photovoltaics compete to get ample space on façade as well as roof.

6.1 SOLAR ACCESS

For the given residence, the main benefit of the location was absence of taller structures in the surroundings. This ensured ample sunlight throughout the day during sunny period. Hence it was possible to recommend installation of photovoltaic panels on the flat roof with appropriate tilt. The tilt was decided by simulating the specified PV panels. Three simulations were carried out with horizontal, **30, 40, 50** degree tilts.
Net zero energy balance was achieved efficiently at the the tilt of 30 degrees giving HERS score of -3.

Figure 44:PV on horizontal surface

The recommended Photovoltaic system for the given residence is as follows:

Figure 45: Recommended panel : Helios 9T6

<u>Helios 9T6 420, 96 Cell, 420 Watt Monocrystalline Solar Panel</u>
Technology: Mono (96 Cell)
Dimension: 1,976 mm x 1,310 mm (77.8" x 51.57")
Area: 2.58 m2 (27.77 Sq Ft)
Thickness: 40 mm (1.58")

Weight: 31.30 kg (69 lbs)

6.2 PANEL SIZING AND CONFIGURATION

PV INSTALLATION ON SITE (CALCULATION)

The roof area covered by the photovoltaics was 78% of the total roof area.
Available roof area: 606.5 Sq Ft
Area for PV installation: 472 Sq Ft
(78% of roof area)
Number of required panels: 17
Tilt Angle: 30 Degrees
Array peak Power: 7140 W

6.3 INVERTER AND GRID CONNECTION

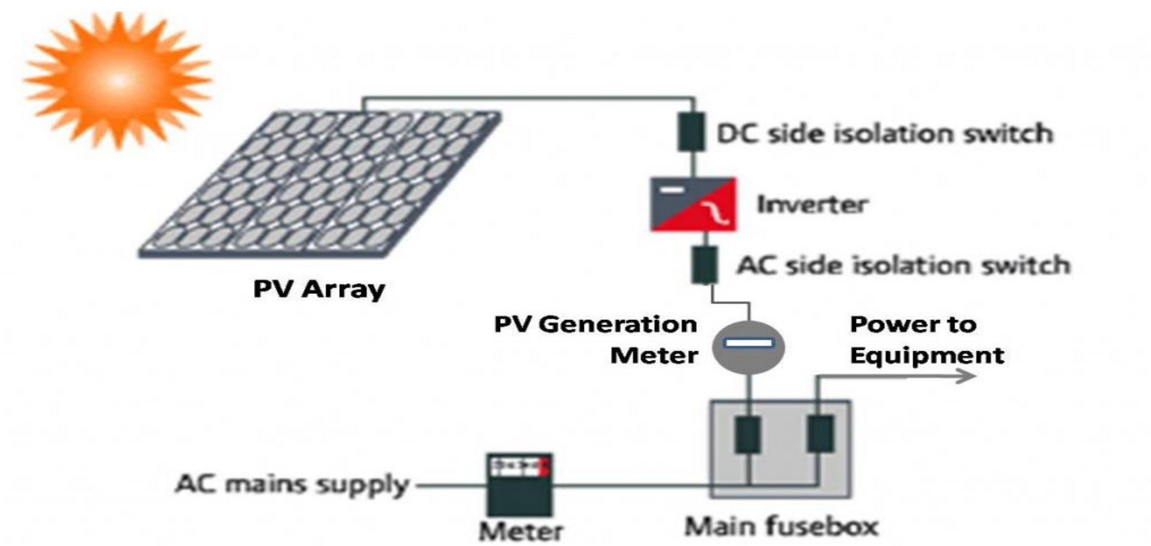

Figure 46: System diagram for working of a PV array and inverter

Solar panels generate electricity in terms of Direct current (DC)Inverters are devices that convert the variable DC output of the solar panel to utility frequency alternating current (AC).

An advanced version of inverters are transformerless inverters. Transformerless inverters use a computerized multi-step process and electronic components to convert DC to high frequency AC.
Without the transformer, the inverter becomes lighter and compact.
Use of electronic (rather than mechanical) switching, thus reducing the amount of heat and ˜hum' generated by the unit.

INVERTER: SunnyBoy11000TL-US, Transformerless inverter

Manufacturer: SMA America
Model: SB11000TL-US (240V)
Rating: 11000 W

> **Efficiency : 98%**
> Superior MPP Tracking (Maximum Power Point Tracking) with OptiTrac
> WebConnect compatible

Hence recommending a 98% efficient inverter made it possible to achieve net zero effectively.

The excess amount of energy would be sold to the utilities through net metering policy.

Figure 47:Transformerless Inverter

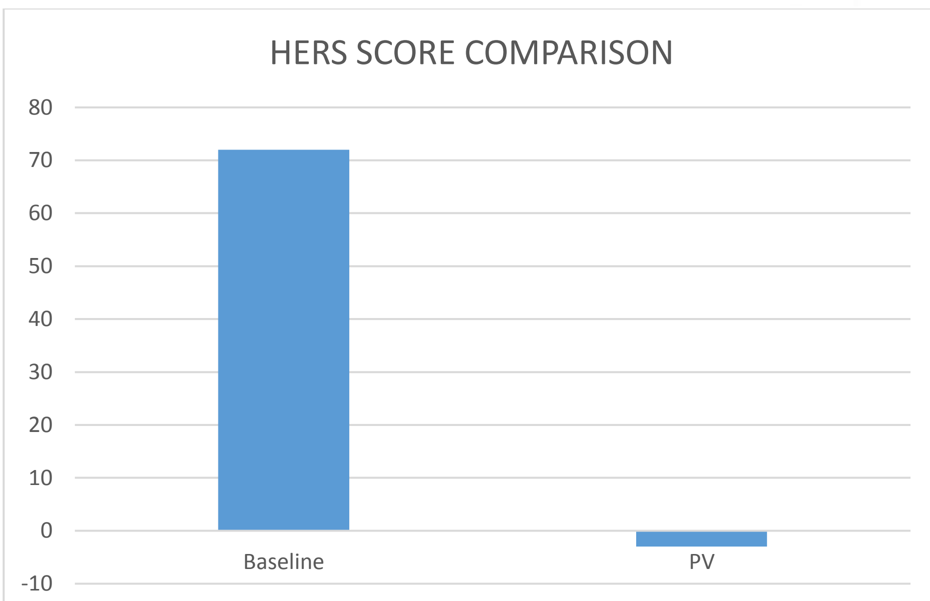

Figure 48: HERS Score Comparison of Baseline and PV integrated case

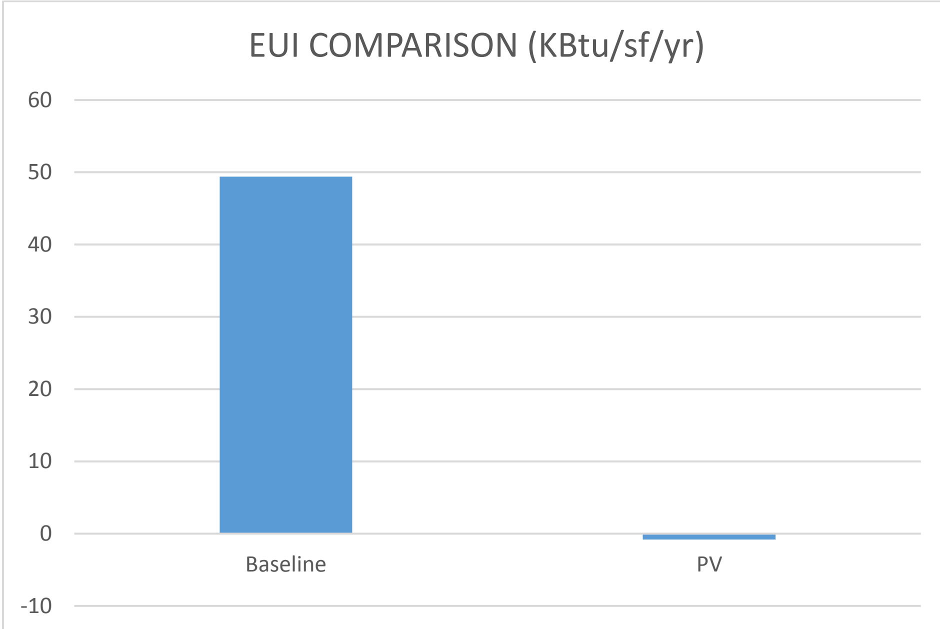

Figure 49: EUI Comparison of Baseline and PV integrated case

7.RESULTS

7.1 PARAMETRIC SIMULATIONS

This list of parametric simulations includes the results of simulation and its effect on HERS SCORE in a legible manner. This shows the significant decrease in HERS score as well as EUI as we move on to make recommendations on the enclosure, HVAC, Appliances, and finally the Photovoltaics.

	v.	Cummulative Design Changes (Simulation)	Heating Design	Heating Capacity	Heating Cons	Cooling Design	Cooling Capacity	Cooling Cons	Appliances Cons	Water Heating	Solar	Total Cons	EUI	Total UA	HERS Index	Annual Cost
			kBtu/hr	Tons	Mmbtu/yr	kBtu/hr	Tons	Mmbtu/yr	Mmbtu/yr	Mmbtu/yr	Mmbtu/yr	Mmbtu/yr	Kbtu/sf/yr	no unit	0-150+	$/yr
	-	Existing, Uninsulated Conditions	45.4	3.8	100.0	22.3	1.9	1.4	19.4	16.6	0.0	137.5	113.4	946.6	151	$2,025
	1	Baseline IECC 2009 Compliant	19.9	1.7	25.7	12.0	1.0	1.5	17.9	14.8	0.0	59.9	49.4	183.3	72	$1,241
Enclosure	2	1 and Above Grade Walls Insulation	18.5	1.5	22.4	11.7	1.0	1.5	17.9	14.8	0.0	56.6	46.7	160.2	69	$1,213
	3	2 and Flat Roof Insulation	18.2	1.5	21.5	11.4	1.0	1.5	17.9	14.8	0.0	55.8	46.0	154.3	68	$1,207
	4	3 and Floor Insulation	18.1	1.5	21.2	11.4	1.0	1.5	17.9	14.8	0.0	55.5	45.8	151.1	68	$1,205
	5	4 and Rim and Band Joist Insulation	16.9	1.4	18.5	11.1	0.9	1.6	17.9	14.8	0.0	52.8	43.5	133.4	66	$1,188
	6	5 and Insert Windows	16.0	1.3	16.2	10.9	0.9	1.7	17.9	14.8	0.0	50.7	41.8	118.7	65	$1,174
	7	6 and Infiltration and Weathersealing	14.4	1.2	12.2	10.1	0.8	1.8	17.9	14.8	0.0	46.7	38.5	118.7	62	$1,164
HVAC	8	7 and Balanced Ventilation w/ Energy Recovery	15.5	1.3	14.9	10.7	0.9	1.7	17.1	14.8	0.0	48.6	40.1	118.7	62	$1,134
	9	8 and Ducted Heat Pump in Basement	13.6	1.1	6.9	10.4	0.9	1.2	17.1	14.8	0.0	40.0	33.0	118.7	62	$1,261
	10	8 and 2 Ductless mini-splits (one each floor)	10.0	0.8	6.0	8.9	0.7	0.9	17.1	14.8	0.0	38.9	32.1	118.7	59	$1,216
Water Heating	11	10 and Gas Storage Condensing DHW	10.0	0.8	6.1	8.9	0.7	0.9	17.1	10.3	0.0	34.4	28.4	118.7	51	$1,186
	12	10 and Heat Pump DHW	10.1	0.8	6.1	8.8	0.7	0.9	17.1	2.4	0.0	26.5	21.8	118.7	49	$1,208
	13	10 and Gas Tankless DHW	10.1	0.8	6.1	8.9	0.7	0.9	17.1	8.0	0.0	32.1	26.5	118.7	49	$1,170
	14	10 and Traditional Gas Storage DHW	10.0	0.8	6.0	8.9	0.7	0.9	17.1	12.7	0.0	36.8	30.3	118.7	55	$1,202
Appliances	15	12 and Refrigerator	10.1	0.8	6.1	8.8	0.7	0.8	17.0	2.4	0.0	26.4	21.8	118.7	49	$1,203
	16	15 and Dishwasher	10.1	0.8	6.1	8.8	0.7	0.8	17.0	2.4	0.0	26.4	21.8	118.7	49	$1,203
	17	16 and Electric Induction Range w/ Oven	10.1	0.8	6.4	8.6	0.7	0.8	14.9	2.2	0.0	24.2	20.0	118.7	46	$1,217
	18	17 and Electric Heat Pump Dryer	10.1	0.8	6.4	8.6	0.7	0.8	14.2	2.2	0.0	23.6	19.5	118.7	46	$1,075
	19	18 and Washing Machine	10.1	0.8	6.4	8.6	0.7	0.8	14.0	2.2	0.0	23.4	19.3	118.7	45	$1,067
	20	19 and Fans and Lights	9.9	0.8	6.2	8.5	0.7	0.8	13.9	2.2	0.0	23.2	19.1	118.7	44	$1,060
Photovoltaic	21	20 and 2 degree Tilt PV Array	10.1	0.8	6.4	8.6	0.7	0.8	13.9	2.2	-21.6	1.7	1.4	118.7	2	$222
	22	20 and 50 degree Tilt PV Array (Latitude + 10)	10.1	0.8	6.4	8.6	0.7	0.8	13.9	2.2	-22.8	0.5	0.4	118.7	0	$177
	23	20 and 40 degree Tilt PV Array (Latitude)	10.1	0.8	6.4	8.6	0.7	0.8	13.9	2.2	-24.0	-0.7	-0.6	118.7	-2	$130
	24	20 and 30 degree Tilt PV Array (Latitude + 10)	10.0	0.8	6.4	8.6	0.7	0.8	13.8	2.2	-24.2	-1.0	-0.8	118.7	-3	$117

Figure 50: List of all parametric simulations and consecutive results

7.2 ENERGY BALANCE

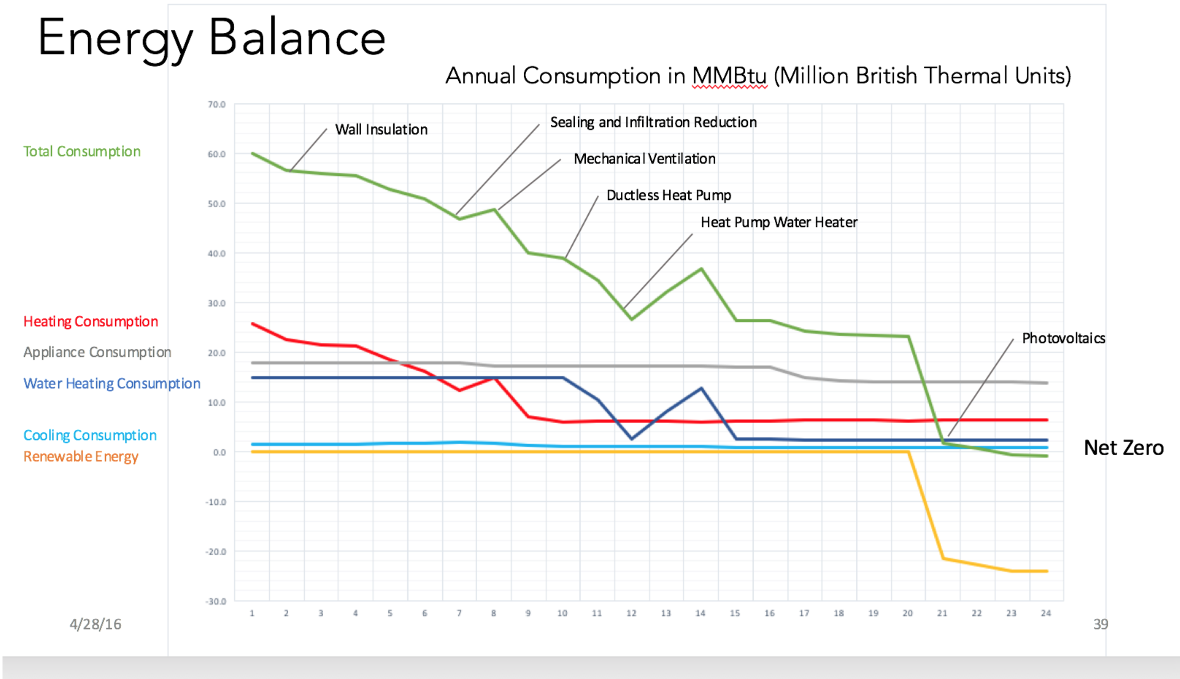

Figure 51: Consolidated graph of Total energy consumption and Segregated individual graphs for different kinds of consumptions

As apparent from the graph, highest energy consumption is due to the cooling loads and the appliance loads. RemRate has a limitation of not including the plug loads which are also responsible for a major fraction of total energy consumption.

7.3 EUI AND EMISSIONS

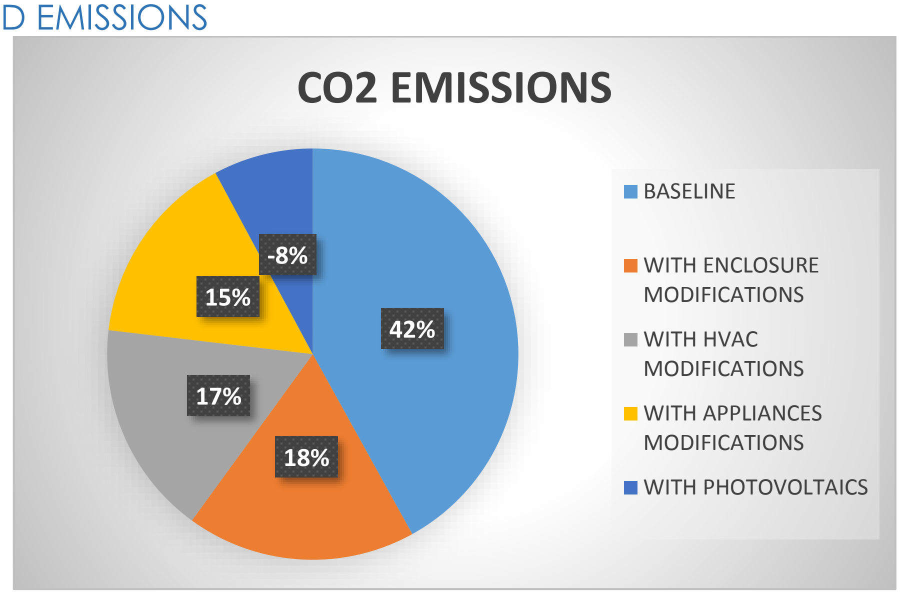

Figure 52: Pie chart showing Carbon Dioxide Emissions with consequent addition of different recommendations suggesting that the model with PV has the lowest carbon dioxide emission

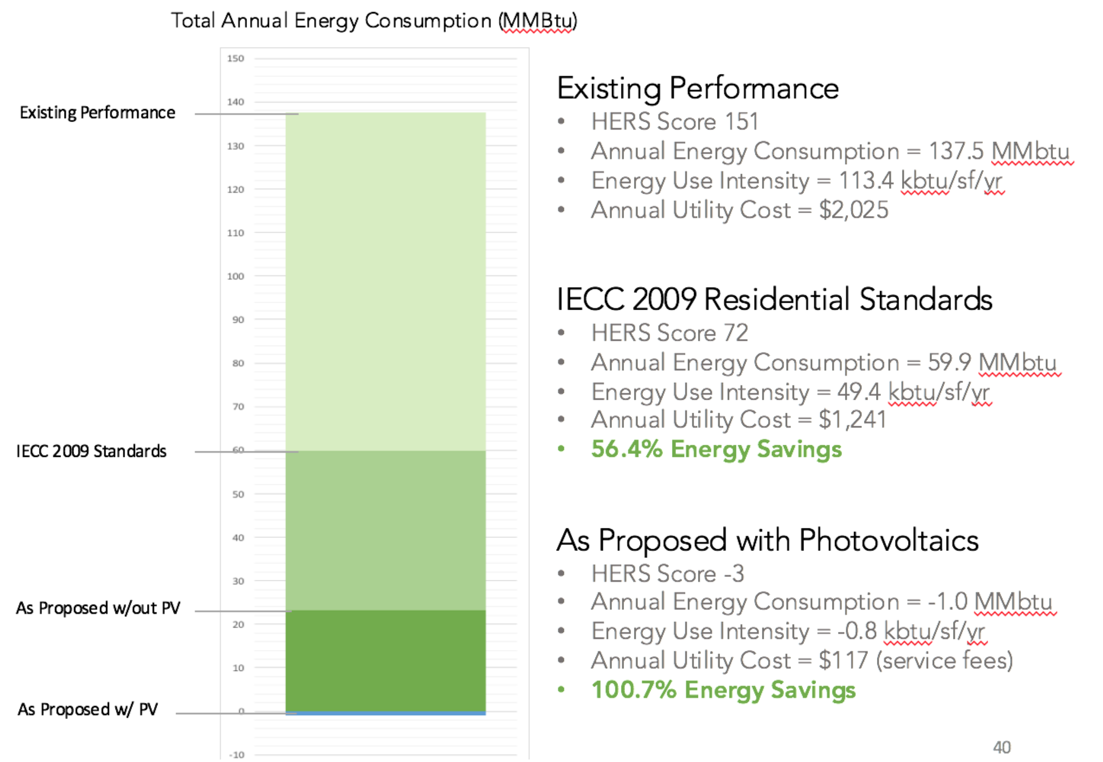

Figure 53: Consolidated graph of Comparison of HERS score, Annual Energy Consumption, EUI and Annual Utility cost on the Existing building, Baseline model, proposed model with and without PV

CONCLUSION

This project proved to be a great learning exercise by having an actual site to work on. After doing this whole exercise, it can be concluded that proper site analysis, relevant recommendations that are economic as well as energy efficient and modeling the same in RemRate software to audit its effectiveness, gives an insight into the HERS rating system and how it changes according to the changes inputs. Comparing the baseline model to the proposed model gave us a crystal clear idea of the differences and the improvements made upon them.

RemRate is a very user friendly software and allows energy auditing of housing pretty well. Net zero balance status can be achieved by simulating different aspects and balancing them by proposing and evaluating on site generated energy through means like photovoltaics.

In the last simulation, we were able to achieve the net zero energy balance by having the photovoltaics tilted at 30 degrees on the horizontal roof in combination with other recommendations.

Hence, this project was a hands on experience with real life situation and how it can be handled by smartly using the software tactics to reach to net zero status.

REFERENCES

1. A Common Definition for Zero Energy Buildings September 2015 Prepared for the U.S. Department of Energy by The National Institute of Building Sciences
2. www.GreenBuildingAdvisor.com
3.
4. Vapor Boundary info from Joe Lstiburek: http://www.jlconline.com/how-to/insulation/q-a-ceiling-vapor-barrier-yes-or-no_o
5. Insert Panel Illustration from: Wing, 2013. The Visual Handbook of Energy Conservation: A Comprehensive Guide to Reducing Energy Use at Home

1. http://www.thermo-casa.com/air-source-heat-pumps.php
2. : http://www.greenbuildingadvisor.com/blogs/dept/musings/just-two-minisplits-heat-and-cool-whole-house
3. http://www.greenbuildingadvisor.com/blogs/dept/energy-solutions/report-our-ductless-minisplit-heat-pump
4. https://www.energystar.gov/index.cfm?c=most_efficient.me_ceiling_fans_under_52_inches
5. http://www.gogreensolar.com/products/helios-9t6-420-420-watt-solar-panel
6. http://www.solarchoice.net.au/blog/conventional-and-transformerless-inverters/

APPENDIX

SYSTEMS DIAGRAMS


Enclosure
Thermal Boundary
Moisture Boundary
Above Grade Walls
Floor
Roof
Windows and Doors
Infiltration
HVAC
Ventilation
Heating and Cooling
Ductless Mini Splits
DHW
Domestic Hot Water
Kitchen
Refrigerator
Dishwasher
Laundry
Washing Machine
Clothes Dryer
Solar
Photovoltaic
Inverter
Energy Monitoring