Effects of various parameters on Net-Zero Energy Buildings design

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Abstract

Due to increase in climate change and urbanization, Net Zero Energy Buildings are one of the most effective solutions in energy and building sectors. Techniques to decrease the cooling and heating loads have been applied to buildings for centuries such as vernacular design. The challenge researchers are facing in the current weather scenario is to retrofit different energy efficiency measures to decrease energy load. These measures can be passive or active measures. In previous research, energy refurbishment using more than five energy efficiency measures lacks for sub tropic humid regions. The use of cork as insulation and heat pumps as energy efficiency measures has not been performed before for sub tropic humid region. In this research, a building is modeled with climatic data of Islamabad. It is later calibrated with mean bias error and calibration signature. After the verification of simulated building, six energy efficiency measures are applied such as insulation on external wall, insulation on roof, improvement of transparent objects, insulation on ground floor, change of HVAC system and solar PV panels. First passive measures are applied to the model and then active measures. Each energy efficiency measure is chosen on the basis of availability, net present value and discounted payback time. The main concept behind the research is to decrease the primary energy consumption of the building and excess energy can be exported. After the implementation of EEM, it was observed that parameter with high effect on primary energy consumption is as insulation on external with lowest effect that was of insulation on ground. Solar panels are modeled in such a way that it provides excess energy for net metering. The challenge to decrease the primary energy consumption can be solved by these measures. The policy makers, engineers and architects can benefit from this research to further research on weather like Islamabad that is sub tropic humid.

Key Words: *Net Zero Energy Buildings, Energy Efficiency Measures, Cork and Primary Energy consumptions*

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CHAPTER 1: Introduction

Background

World is facing the biggest problem of climate change and its adverse effects on all the organisms. With the rapid urbanization, increase in the population, industrialization, deforestation, and natural disasters climate change is growing rapidly including the birth of the aerosols and contaminants in the environment. Some of effects of the climate change are the excess hot in the summers and cold in winters. Global warming is one the greatest concern for the researchers and they are tackling with all the aspects. There have been severe law and agreements on which countries decided to follow the set of instructions for the global warming. One of the biggest effects that we are following now is the record-breaking heat wave in Karachi which caused severe deaths to numerous people. Changes in the climate resulting from global warming cause increases in meteorological events such as drought, desertification, imbalance and deviations of precipitation, floods, typhoon, storm, and tornado.[1] What we require in this time is to use the energy efficient, sustainable appliances and follow the rules to stop the climate change. The studies are made to create the awareness, level of knowledge and concern about the climate change.

Building designs, Renewable energies, and climate change

The concept of the vertical, sustainable buildings is being implemented all over the world to counter the global warming problems and address the issue of utilizing the population. Pakistan having the population of 220 million, still lacks the modern sustainable buildings in the vast range. The living in Pakistan is generally more inclined towards the houses than the apartments, which results in the huge construction. In recent decade, world is more intended to build such building that require less energy and is sustainable for the environment. The use of the renewable energies such as wind, solar etc. played a vital role in countering the global warming as they are completely renewable and use the natural source that is available in the adequate amount. "Building constitutes the 40% of energy of the total count. The building sector is increasing due to excessive population which results in increase of the energy consumption too. Therefore, reduction of energy consumption and the use of energy from renewable

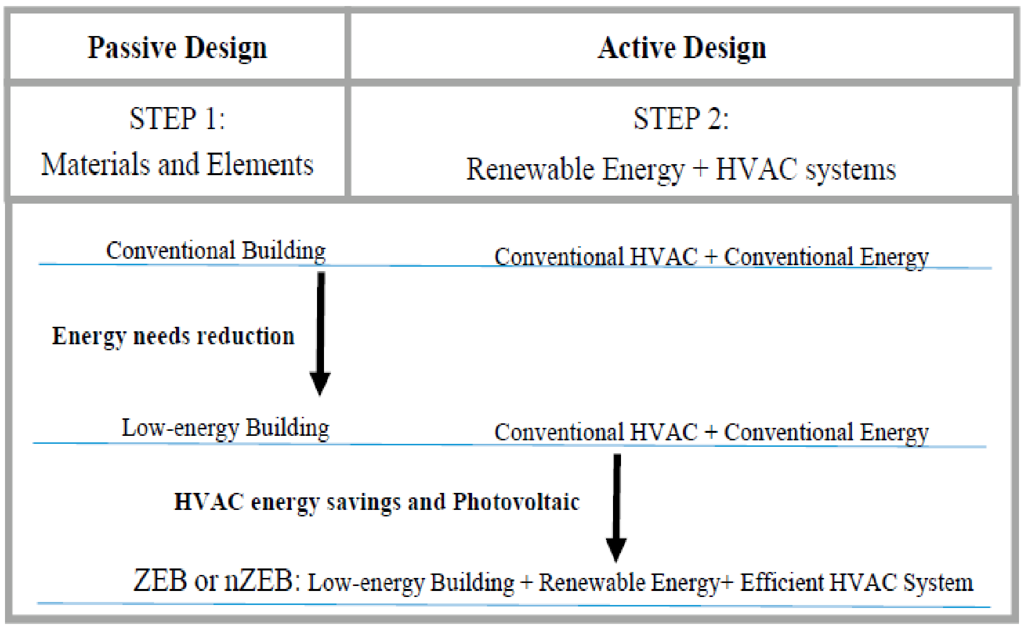

Figure 1 Passive and Active Energy efficiency measures

able sources in the buildings sector constitute important measures needed to reduce the Union's energy dependency and greenhouse gas emissions" [2].

Climate change in Pakistan

The climate change has imposed the no of threats to Pakistan. There were numerous events of flooding, land sliding, droughts, sea storms and heatwaves In Pakistan. Heatwaves are likely to become more frequent and intense all over Pakistan, and the number of 'hot' days and nights are expected to increase significantly (high confidence). There are mere chances of the rainfall and sudden shift in the weather. Pakistan being the country whose major exports is the agriculture has been badly affected by the climate change. Agriculture accounts for the 42% of the income source of people in Pakistan, due to GLOF (Glacier Lake Outburst Flooding) people are suffering the poverty. There are many vectors borne diseases such as dengue and malaria and others due to the flooding and other natural hazards. The increase in the contaminants and aerosols in the air has impacted the respiratory systems in the people

NET ZERO ENERGY BUILDINGS

The concept of the NZEB has been increasing in the previous decade to reduce the building energy consumption. There are two ways to build the NZEBs, one is to retrofit the existing building and second one is to build the new one. The NZEBs are feasible solution which includes the use of active and passive measures to reduce the energy consumption to such extent that no energy is required from the outsource. There are multiple strategies to make the NZEBs such as use of the natural ventilation, renewable energies, insulation, window to wall ratios and others. This methodology reduces investment, reduces the energy demand, and selects the best construction materials, renewable energy, and air conditioning system[3]

NZEBs are very important for the future as it tackles most of the problems of the climate change and energy. It is a sustainable way to build the buildings and most of the developed countries have passed the law for the building to be constructed according. These buildings can store energy and sell the excess energy to the national grid or nearby building by smart grids and smart metering[4] The policy makers are working on the NZEBs as they are environmentally friendly and energy efficient.

Scope of NZEBs in Pakistan

Pakistan being located at a very important geographical has bright future. The major type of the building includes the house, flats, office buildings and malls, classified into three main categories i.e., concrete structures, timber, and masonry construction. Structures with the bricks are widely practiced while wood is being used in the northern areas due to the cold climate. Renewable energies can play vital role in the energy production of Pakistan. Out of a total of 35,372 MW, only 1,691 MW of energy is being produced through renewables despite Pakistan being offering a favorable environment for energy generation by renewable sources.

Aims and Objectives

The aim of the research work is to design the existing building on the design builder software and verify the bills. The existing building will be retrofitted with multiple parameters and will be made NZEB. There will be use of other soft tools too such as climate consultant and Ediclima. The building will be assessed in the region of Islamabad that is the capital

CHAPTER 2: LITERATURE REVIEW

Global warming

Global warming is one of the most important issues for the last few decades due to excessive urbanization and carbon di oxide emission. In Pakistan, in last year's there are glacier outburst flooding that has caused economic and social problems. The glaciers are melting in Pakistan due to variation in climate and causing global warming[5] Pakistan is experiencing a significant increase in temperature, but almost no change in precipitation, which has made temperature as the dominating factor for defining droughts in recent years.[6] The energy consumption and CO2 emissions will reach its peak in next 10 years.[7]The increase in the temperature is predicted as 1 to 3.7 degrees Celsius depending upon future greenhouse gas emission.[8] Out of these CO2 emissions, 5-7% emissions of CO2 are caused by the cement industry.[9] The results imply that carbon emissions can be reduced at the cost of economic growth or energy efficient technologies should be encouraged to enhance domestic production with the help of financial sector and import environment friendly technology from advanced countries.[10] The possible actions toward the global warming are summed by three strategies: the no action, the mitigation, and the adaptation strategy.[11] These strategies are implemented by the countries according to the agreements. Increased temperatures, and the associated heat stresses, are already expected to negatively impact crop yields in the regions.[12] If the issue of global warming will not be taken seriously then there can be many negative circumstances which includes the life risks, natural disasters, extinction, low productivity, and high carbon footprint.

Net Zero Energy Buildings

According to the analysis, in the future the extreme summer temperatures will be more in common and the heating demand will be decreased. The heating demand will be decreased by the 47% and the cooling demand will be increased by 161%. There will be 105 decreases in the water heating demand. The NZEB design is different in a climate change scenario than estimated from current weather, having slightly lower levels of insulation, improved envelope, airtightness and equipment, lighter colored surfaces with higher reflectance roof and walls, and better solar control from windows (lower G-factor) to reduce cooling needs. In summers the solar panels will produce 3 times more the energy and will supply 8% of the energy demand in the winters.[13] Multiple buildings with different U values were analyzed and MP5 has a lower median E-level than MP3 in the current climate, but in the future climates the E-level of MP3 may be lower than MP5 with median differences between 4 and 10 for the maximum climate for single family houses. The E levels became much higher in the higher climate with a change of 12-14 as compared to the MP4 and the MP5.[14] MPC is affected by the insulation, windows placement with airtightness, occupancy behavior, air tightness and HVAC systems designing. The BEP tools are very beneficial for the energy efficiency by using the "White box" (physical-based techniques are related to thermodynamic properties for in-depth modeling and analysis), "Black box" (Model on the machine learning that demands less building data) and "Grey Box" (Hybrid of white box and black box).[2] As the climate is changing the demand for cooling is increasing.[15] Due to increase in the energy consumption, the CO_2 emission is expected to be 1.64 GT in 2025, 1.72 GT in 2030 and 1.94 GT in 2040. The target of carbon neutrality, improving the building energy efficiency accounts for 50.1% while building electrification and zero carbon emissions from the grid account for 49.9%. With the retrofits the 6.41 and 9.41 GTce can be saved by 2060.[16]

Energy efficiency measures

There are two ways of systems, passive which includes the natural ventilation and day light harvesting and active which includes the mechanical systems. The strategies to increase the daylight harvesting are large windows area, skylights, clerestories, external shading system, light shelves, and solar tubes. Natural ventilation decreases the cooling demand. The triple glazing and insulation reduce the energy demand by 13% than the double glazing. The GSHPs (Ground source heat pumps) saves 5% more energy than VRF (The variable refrigerant flow) systems. The use of the wind turbines and solar panels were used to make the building NZEB.[17] The hierarchical order of impact on energy efficiency potentiality of the parameters can be expressed as window glazing type > orientation along with window-to-wall ratio > thermal insulation thickness > thermal mass thickness. In terms of cost effective and efficient option such as orientation along with window-to-wall ratio > thermal mass thickness > window glazing type > thermal insulation thickness. The second order is better as it follows the energy with cost output. In Bangladesh, the WWR should be less in the South and West position and wall thickness should be about to 6.5 to

7 inches. The multiple glazing windows with Low E glazing coating prevents the heat flow.[18] To get the nZEB, it is not a good idea to increase the WWR that is optimal 10%. Increasing the WWR, the demands for heating and cooling increases. While designing the nZEB, it is important to put into the consideration the orientation and solar and thermal properties of windows and the shading devices to decrease the energy load.[19] The following techniques were applied that showed the energy saving rates.[20]

Techniques	**Energy saving rates**
North Rooms	
Add-on direct solar gain system on width direction of north rooms	5.26% and 14.72%
Add-on sunroom on width direction of north rooms	4.10% and 5.48%
Add-on direct solar gain system on elevation of north rooms	4.90%
North sealed balcony	7.01% and 7.60%
South rooms	
WWR of south façade	3.58% and 11.45%
Sunroom depth	1.22% and 7.35%
Sunroom on roof	62.31% and 31.26%

Table 1 Effects of EEM

The use of the cork as a thermal insulator provides excellent performance and also about 70% of the sound of frequency range 400-4000 Hz is absorbed. It is totally green with no carbon emission. It has the diffusion capacity and doesn't influence the release of the moisture. It can be recommended as the ecological product excellent for the thermos-hygro-sound insulation of the homes.[21] The use of bioclimatic strategy for the building construction is very beneficial for the environmental comfort.[22] The measurement of the indoor environment by the air quality sensor. There was the reduction of the cooling demand.[23] Shallow retrofits are not suitable for the buildings as it leads to the occupant dissatisfaction and problems. The futuristic studies should be made for the retrofitting so that there may not be any problem of changing.[24] The LCC(Life cycle cost) could be improved by 77% with the application of renewable energies, and the EEI(Energy efficiency index) could be reduced by 67% to achieve maximum energy efficiency in the building, compared to the initial design.[3] The investment has the payback time of 2.66 years in Pakistan and 27% reduction in the per unit cost of electricity. With the use of the hybrid PV system there is the unit cost reduction of 0.21 USD/kWh.[25] The maintenance costs are: Thermal Insulation (TI) 1.00%; Windows (WI) 0.50%; Ventilated Facades (VF) 0.00%; Green Roof (GR) 1.00%; Condensing Boiler (CB) 2.00%; Heat Pump (HP) 1.00%; Thermal Solar plant (ST) 1.00%; Photovoltaic (PV) 0.01%; Thermal Bridge (TB) 1.00 %.[26]

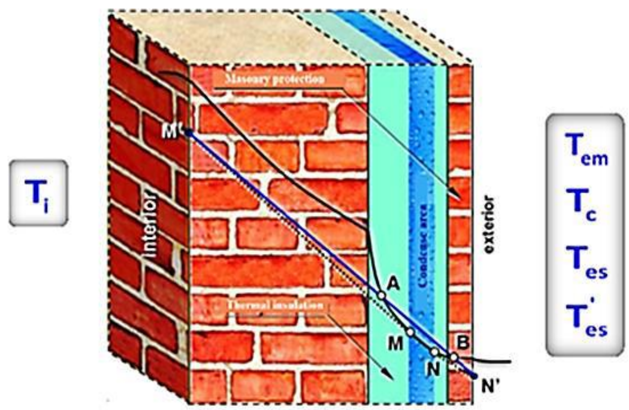

Figure 2 Insulation layers on external wall

CHAPTER 3: Methodology

Research approach

The aim behind this research is to refurbish/retrofit the current building with the energy efficiency measure to make it NZEB. The software used for this research is “DESIGN BUILDER” with “ENERGY PLUS”. The building is situated in the Islamabad with the 33.623889 North and 72.919444 East. The building is modelled in the design builder and then the multiple passive and active strategies are applied to decrease the final energy consumption of the building. The total primary energy consists of the electricity from grid and gas methane. It is nonrenewable and the primary energy factors are multiplied to it to get the desired heating and cooling load. Following are the steps for the methodology.

Steps	Analysis framework	Remark
1	Climatic data	Epw file of Islamabad with hourly mean values of certain parameters
2	Site Orientation	Lat or long of site and other inspections
3	Modeling of building	Use of building construction tools
4	Activity	Scheduling and occupancy details
5	Zoning	Use of LENI calculations
6	HVAC input	Use of systems
7	Lightning input	Thermal envelope
8	Results Simulation	Total heating and cooling loads
9	Calibration	Use of statistical and graphical indices
10	Use of EEMs	`Energy refurbishment
11	Financial Analysis	NPV and DPP calculation
12	Final Results	APE certification

Table 2 Steps for research

The whole building simulation will be on the basis of above-mentioned steps.

Climatic Data

The design builder requires the hourly précised climatic data for the site location to simulate. The design builder with the energy plus file “epw” simulate the model on the particular location as the climatic data are major contributors towards the energy consumption of the building. The parameters that are required for the hourly climatic file are as

- Global horizontal radiation
- Direct normal radiation
- Diffuse radiation
- Dry bulb temperature
- Relative humidity
- Windspeed
- Ground temperature

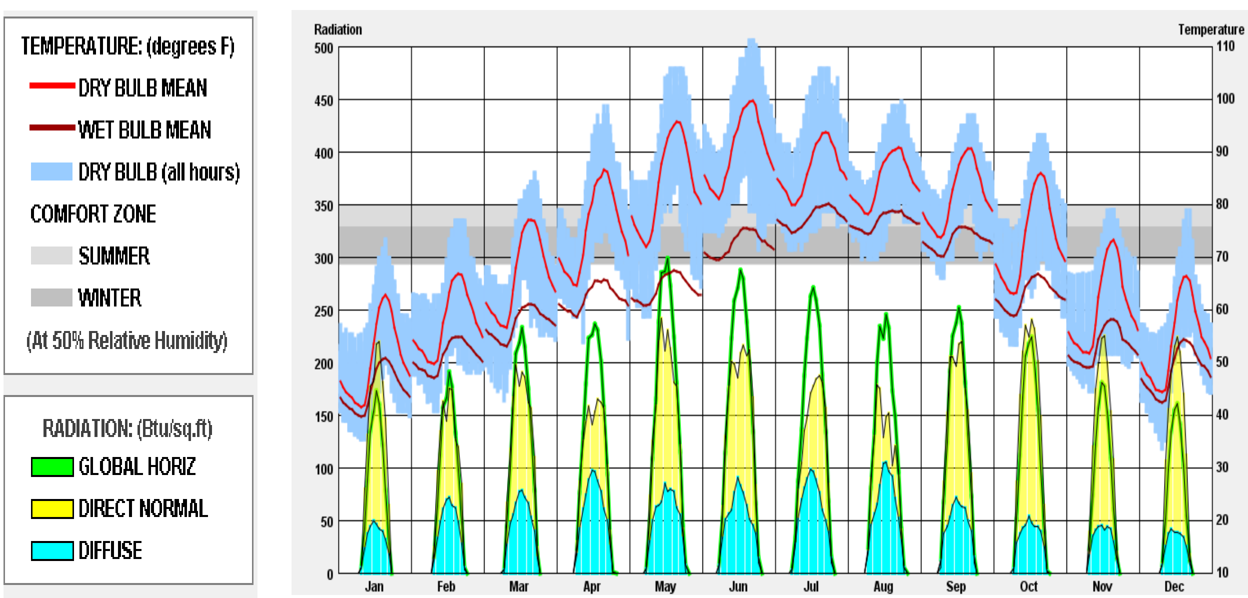

Figure 3 Climatic graph of Islamabad

The following graph shows the trends of parameters in whole annual year where it clearly shows that the maximum global solar radiation and temperature are maximum in the months of June, July, and August. These months will be considered as the cooling months and the October to February are considered as the heating months as the outside temperature is lower than the inside building temperature. The total degree days in Islamabad will be calculated with the analytical procedure.

The climatic file is uploaded in the design builder location section as follows:

Site Orientation

As mentioned before the building is marked as the residential building with the latitude and longitude of 33.623889 North and 72.919444 East. The building is double story house with total 7 rooms with attached bathrooms, 2 living lounges, 2 kitchens, 2 drawing and dining rooms, garage, garden, and staircase. The garage/garden is unconditioned space while rest of building is considered as the conditioned area. The total occupants are 5 which includes 3 adults and 2 kids. The site orientation is done in order to perform the level 2 energy performance certification

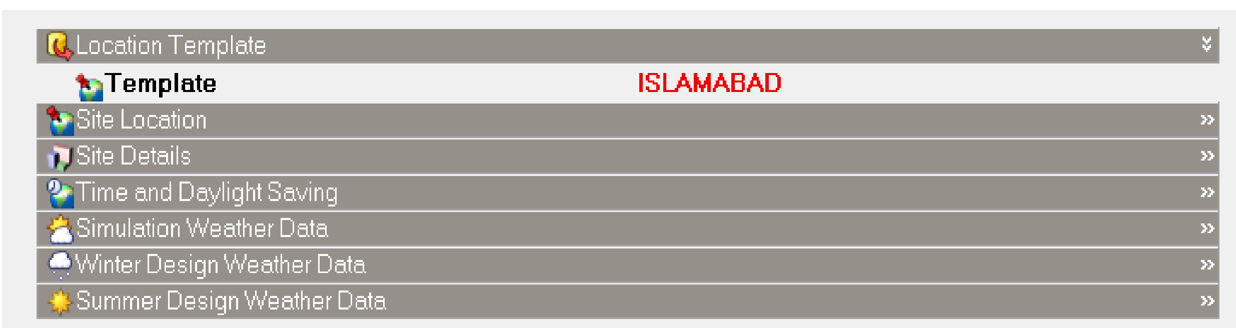

Figure 4 Ediclima Climatic location template

Construction

After site orientation, next step is to construct the building model in the design builder. The opaque and transparent elements of the thermal envelope are defined in the “construction” and “openings” section in the design builder. The elements used in the current building are as external/internal walls, roof, ground floor and windows.

External/Internal walls

The external and internal walls have the different stratigraphy and dimensions. The external wall all around the building is with the same dimension but internal walls in some areas have different thickness. Some of the rooms have the partition with glass or wood. These all partitions are defined as follow:

External wall

The external walls are the ones that are separating the internal conditioned space with the external environment. The common parameter that defines the thermal transmittance of the external wall is U-value. Higher the U value higher is the conductance through the wall and lower is the resistance. In general, it is suggested to have the U value of the walls under 0.28 to decrease the energy consumption of the house. In this case, the external wall is made up of internal plaster layer, bricks layer and the external plaster layer with U value higher than 0.316 Btu/h*ft^2*F. So, it is not approved under the defined value of 0.28.

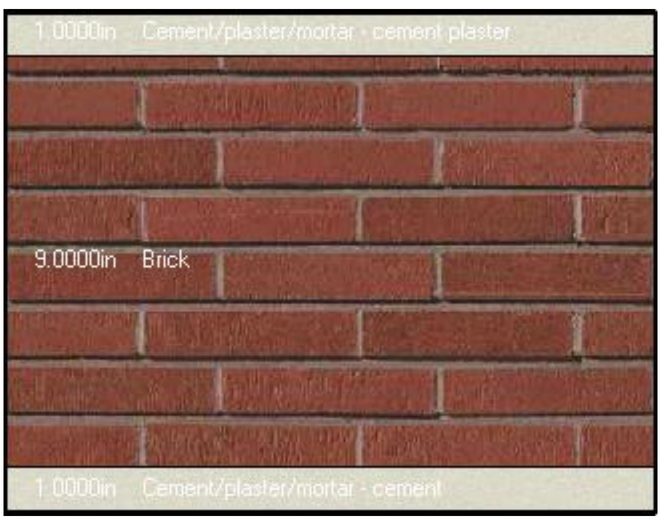

Figure 5 Stratigraphy of external wall

Internal wall

The internal walls have the same stratigraphy but different thickness of the brick layer that is 7 inches instead of 9 inches. Some of the internal walls are the partitions that are made up of glass and wood. These partitions have negligible effect on the final consumption. It has the U value of 0.361 Btu/h*ft^2*F that is also not approved under the ASHRAE guideline that is 0.28.

Roof

The roof of the ground floor has the same stratigraphy as the ground floor of the first floor, but the roof of the first floor has different stratigraphy. It has the aerated concrete slab with the plaster layers on both sides.

Figure 6 Stratigraphy of Roof

It has the U value of 0.151 Btu/h*ft^2*F.

Floor

The stratigraphy of floor is as plaster layer-aerated concrete layer-plaster layer and the clay tiles. It is applied to the floor of ground and first floor only. It has total U value of 0.130 Btu/h*ft^2*F.

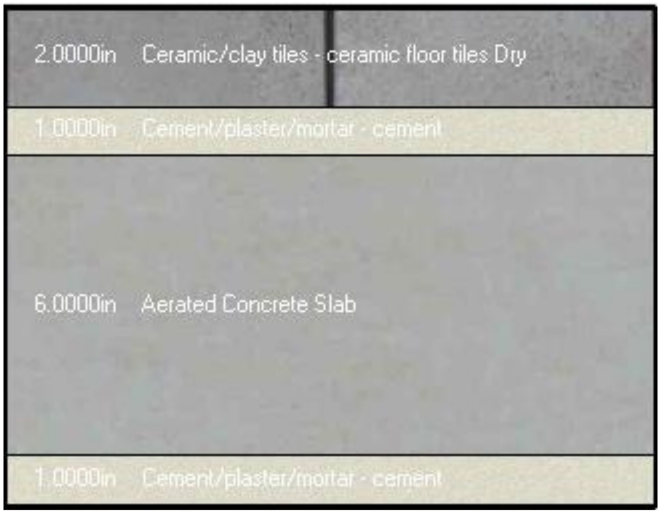

Figure 7 Stratigraphy of floor

Glazing

The windows in all the directions of the house are double glazing 3-13-3mm with air inside. There are internal venetian blinds, and some windows have the overhangs above them. Some of the windows are partially shaded with the shades above. The frame dimensions are different for different rooms and are made up of aluminum. It has the U value of 0.469 Btu/h*ft2*F.

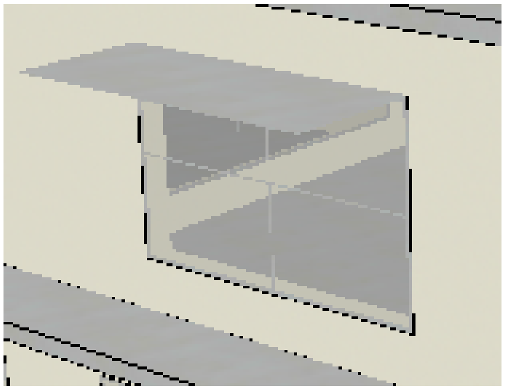

Figure 8 Stratigraphy of glazing

Doors

All the doors are wooden with different heights

Activity

For the internal gains calculation and systems working, it is necessary to define the activity in design builder. In this section, the occupancy details, DHW needs, heating and cooling setback temperatures and scheduling are defined. In the occupancy details, there are total 5 persons in the house which includes 3 adults and 2 children. The total metabolic factor is 0.84. The clothing is defined as the summer and winter clothing.

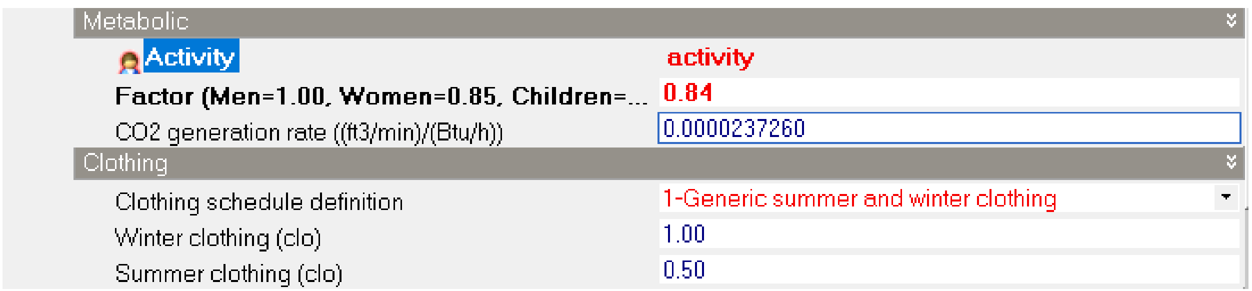

Figure 9 Activity of house

The heating and cooling setpoint temperatures are as follows with no humidification process.

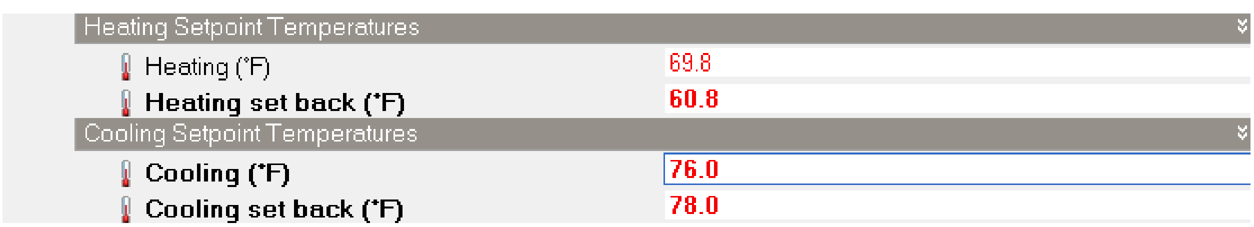

Figure 10 Heating and cooling setpoints

The above table shows the winter setpoint lower than the heating setpoint lower than the cooling setpoint because of the clothing factor because in the winters the clothing is warm.

Zoning

After the input parameters, the most important step is zoning which includes the construction of the building lines and structures. At first the construction lines are drawn which outlines the building structure. The building blocks are constructed on the lines. After building blocks are constructed the different zones are allotted to the building. Zones are the part of the thermal envelope that has the same thermal properties, building complexity and services. The building is divided into multiple zones with the help of partitioning because there are different solar gains due to the positioning of the buildings. First the Ground floor is constructed, then first floor and then mumty. While doing this step, it is important to change the building height, draw the partitions and change the fabrics of building. The buildings current elements are replaced with the construction elements that are defined before.

Figure 11 Top left: First floor Top Right: Ground Floor Bottom: Mumty

The building is double story house with total 7 rooms with attached bathrooms, 2 living lounges, 2 kitchens, 2 drawing and dining rooms, garage, garden, and staircase. The outer house boundary is not considered as they are not causing any shading towards the building.

The height of the ground and first floor is 11 ft while the building is facing towards the North. The mumty has one room with bathroom and the water tank. There are walls with open hole such as the bathrooms that makes unconditioned space.

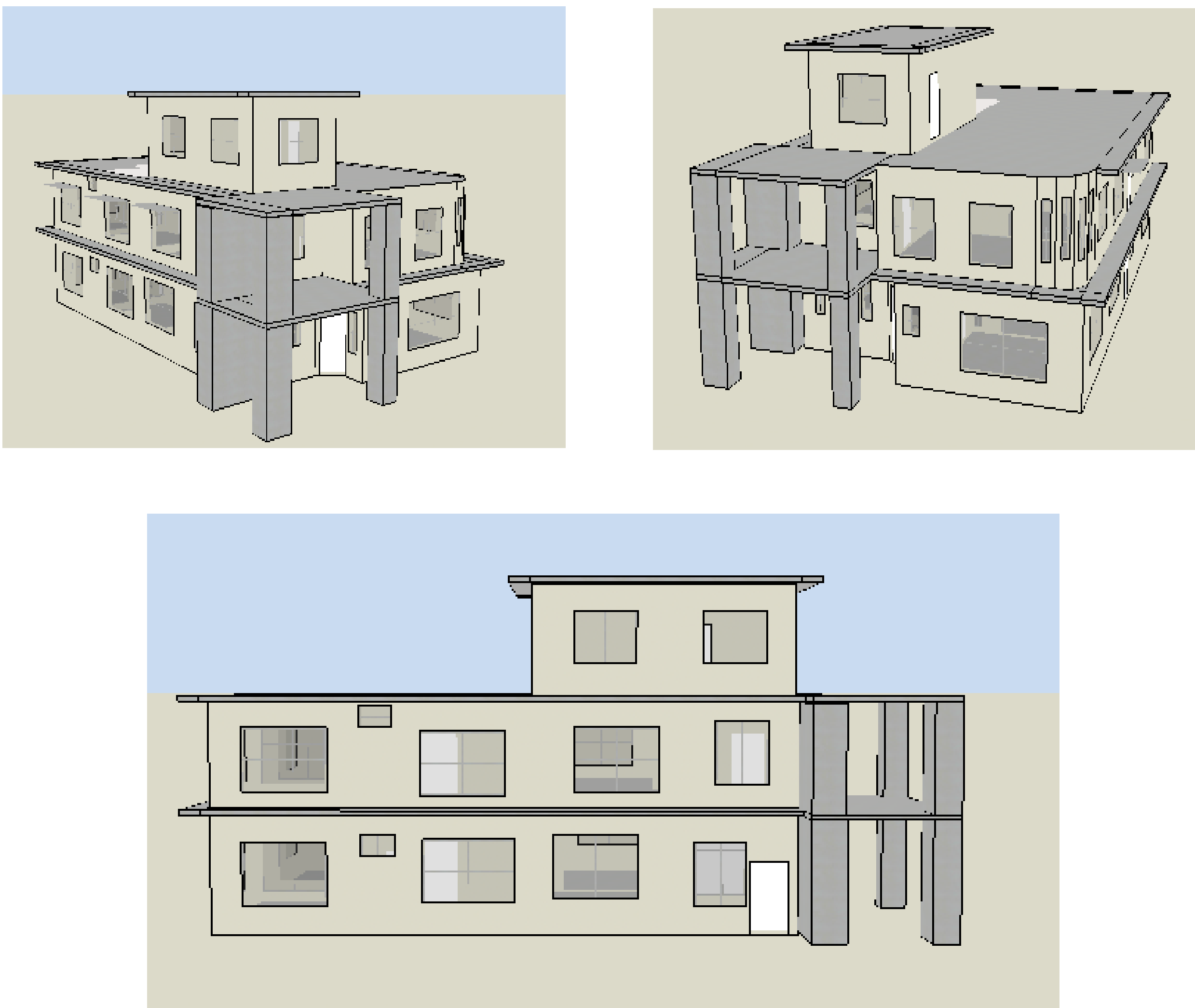

Figure 12 Views of house

HVAC

The HVAC includes the systems for the heating, cooling, and ventilation. It includes the phases from generation to control to distribution to emission systems. In the current scenario, heating systems are standalone gas heaters and split air conditioning for cooling systems. For water heating, there is a traditional boiler with 50l storage capacity. For heating systems, there are general heaters that has a COP of 0.850 and for cooling systems there are split unit of 2.5 tons with COP of 2.5. Natural ventilation is turned on with schedule.

Lightning

Lightning inputs are not considered for the residential spaces but for the calculation of the lighting input LENI (Lightning Energy Numeric Indicator) calculations are used to define the net energy demand for lightning (KWh/m^2 year]. LENI is ratio of total annual energy required for lightning to the total useful area building.

$$LENI = \frac{W}{A} = \frac{W,l + W,p}{A}$$

(1)

W = total annual energy required for lighting [kWh/a]

W,l = total energy for illumination for the time period t [kWh/ts]

Wp,t = total energy for standby for the time period t [kWh/ts]

A = total useful area of the building [m2]

$$LENI, area = \frac{Pj}{1000} Fc\ Fo\ (FD\ tD + tN) + 1.0 + 1.5$$

(2)

Pj→ lighting power density

Fc→ constant illuminance factor

Fo→ occupancy dependency factor

FD→ daylight dependency factor

tD→ daylight time

tN→ daylight absence time

1.0 → default standby energy density for battery charging (emergency) [kWh/m2a]

1.5 → default standby energy density for automated lighting controls [kWh/m2a]

After the calculation on the excel file of all of the factors that are above, with the shading of the nearby building the LENI for this building was calculated as 1.049 KWh/m^2 year.

Results Simulation

There are two major energy carriers as the primary energy towards the building that are the electricity from grid and gas in methane. The electricity from grid is used to generate the cooling from the split ACs, lighting and other auxiliaries. There are the distribution and control losses in the systems. The gas in methane is used to fire up the boiler and for the kitchen stove purposes. In this part the results are simulated on the annual period with the monthly intervals. I obtained the results in KBtu and then converted it into the KWh and also the total energy performance is calculated by multiplying the primary energy factors with the respective consumptions. In the first simulation of the project the calculated annual yearly consumption was in total 139980.9027 KWh that is higher than the original consumption. To make our model near to the original model, we follow the calibration process.

Calibration

It is one of the most important steps of the energy performance certification. Calibration is the process of fine-tuning the simulation inputs so that the observed energy consumptions closely match those predicted by simulation program. The issues related to the calibration are the standardization, calibration costs, model complexity, model input data, uncertainty in building models, discrepancies identification, automation, and users experience. I will be using the external methods of the calibration for the building. The whole building calibrated simulation approach will be followed which includes the following steps:

- Collection of data
- Data simulation
- Comparison of simulation model output to measured data
- Refining of the model until the acceptable calibration is achieved
- Produce baseline

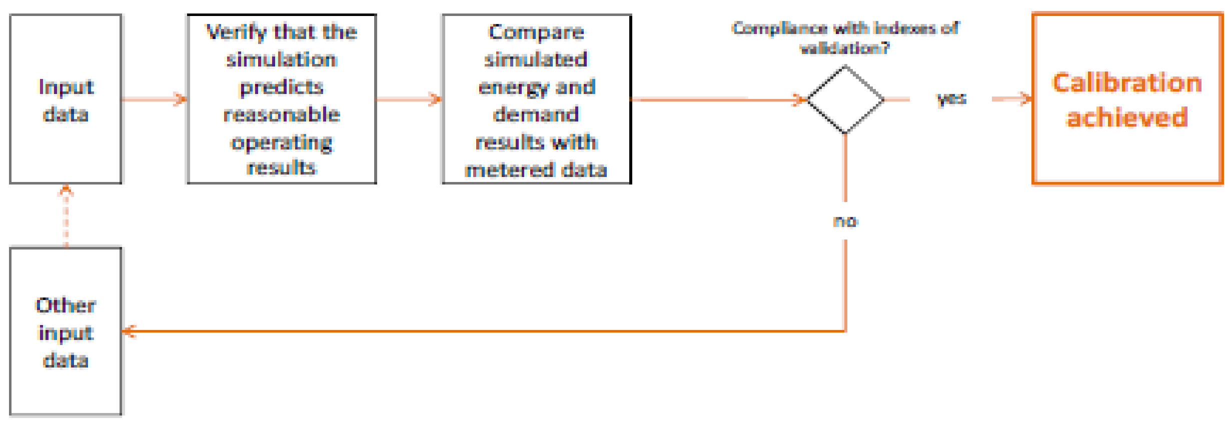

Figure 13 Calibration process

As mentioned before, level 2 calibration is achieved from the building as there are site visits and the inspections. Now, the different calibration strategies that are applied to the building will be studied.

Calibration Signature

It is used for the energy performance of the building by normalizing plot of difference between the predicted and the simulated energy consumptions as the function of the outdoor temperature. First of all the residual is calculated that is the difference between the simulated and the measured consumption. Then the calibration signature is calculated by the following formula:

$$Calibration\ signature = -\frac{Residual}{Mmaximum} \times 100\%$$

(3)

After the formula, the trend of the signature is studied by plotting the calibration signature versus the outdoor temperature. With the first simulation, following are the results achieved.

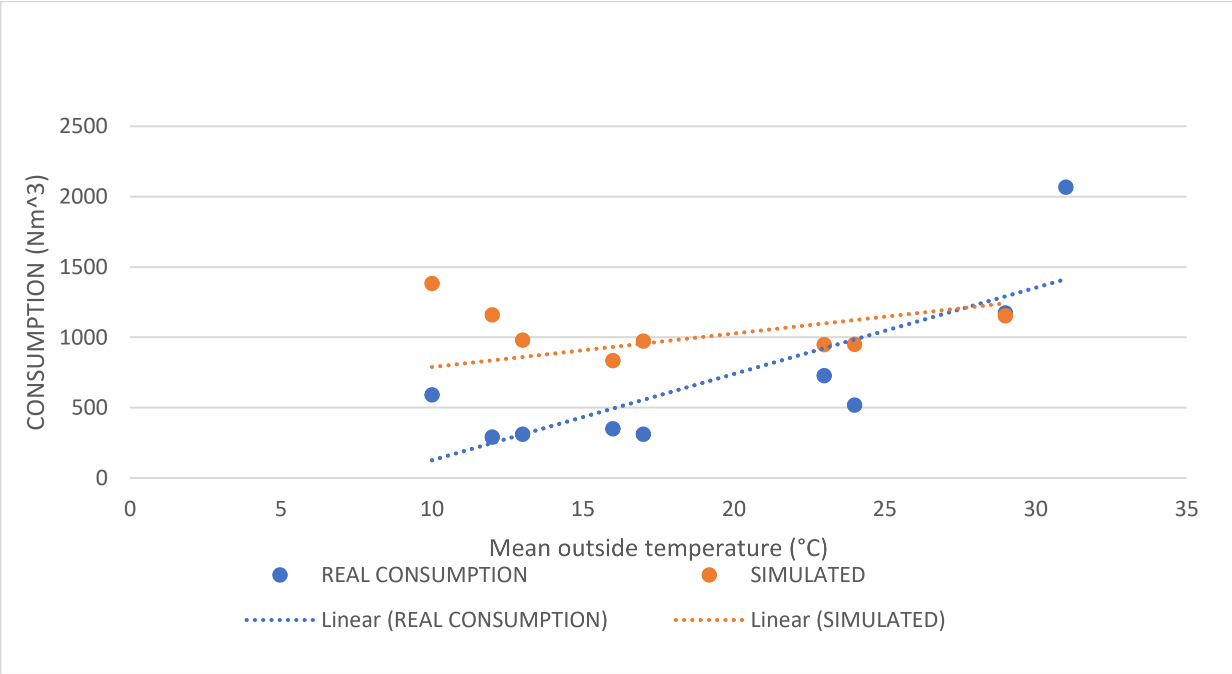

Figure 14 Calibration signature of first model simulation

Above clearly stated that the model is not calibrated, and certain changes have to be done in order to have the calibration. At first, the model's fabric inaccuracy has been catered by changing the fabric nearer to the original buildings and using their U value. Then the activity factor is changed as in weekends the users go to other cities and their habits were studied to schedule the systems in the house. The mumty is usually unused and 2 out of 6 rooms are not used. The kitchen auxiliaries' schedules have been changed. After the changing in thickness of the plaster in the wall and other design strategies, the model was found as,

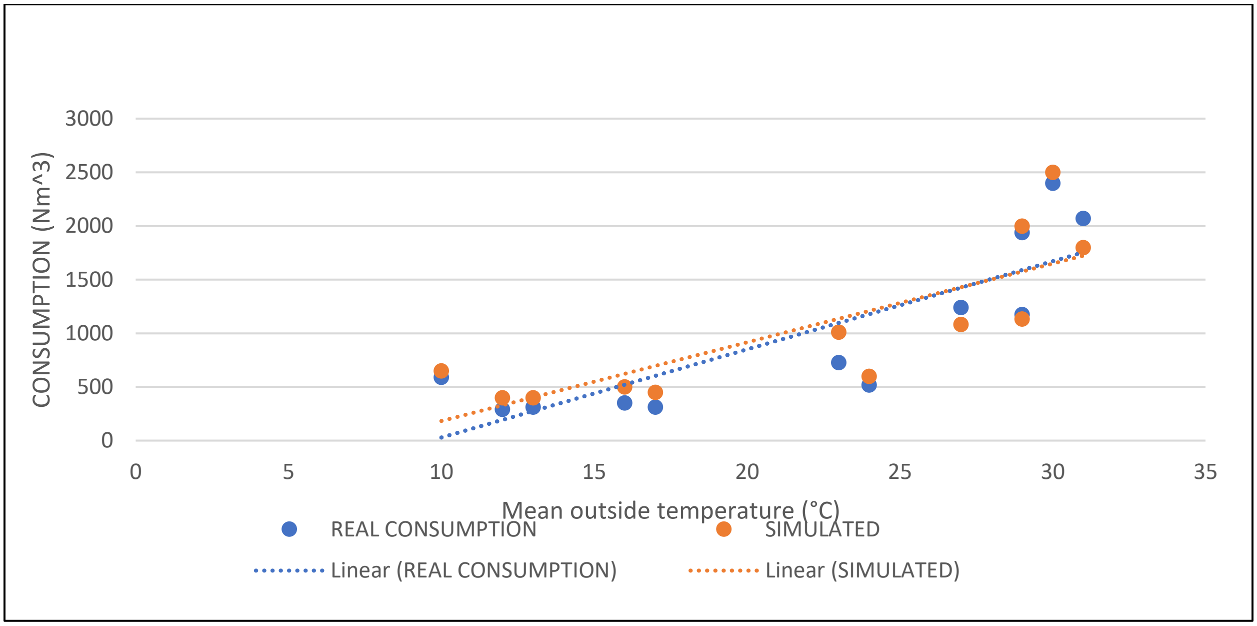

Figure 15 Calibration signature of final model

The above graph describes that the simulated model is calibrated.

Mean Bias Error

It is defined as the percent error that measure how closely the energy use predicted by the model corresponds to the metered data on monthly or annual basis. It is formulated by following formula:

$$MBE\% = \frac{\sum_{period}(S - M)interval}{\sum_{period} Minterval} \times 100\% \tag{4}$$

S= predicted energy use

M=Measured energy use

The MBE should be less than +-10% for the simulated data. If the data lies in this range, so it is calibrated. After the procedure, following are the results found.

Month	**Measured Value(m^3)**	**Simulated Value (m^3)**	**S-M**	**(S-M)^2**
January	6318.111042	8881.51188	2563.401	6571024
February	3329.739963	3400	70.26004	4936.473
March	3333.396069	4012.14	678.7439	460693.3
April	5546.003811	6870.12	1324.116	1753284
May	12554.22842	12112.7233	-441.505	194926.7
June	22116.48604	20823.847	-1292.64	1670916
July	25636.35875	26800.7892	1164.43	1355898
August	20718.36189	18617.22	-2101.14	4414797
September	13262.2134	11585.3119	-1676.9	2811999
October	7777.810712	6180.414	-1597.4	2551676
November	3751.272449	4631.22	879.9476	774307.7
December	3126.237742	3400.13	273.8923	75016.97
Total	127470.2203	126047	-1423.69	2026905

MEAN BIAS ERROR	-1.116883674

Table 3 Calculation of Mean Bias Error

The mean bias error found was -1.11 that is under the range, so the simulation is verified. We can use this simulation model to apply the EEM and make the building NZEB.

EEM

To make the building energy performance requirement as minimum as possible, passive and active measures are taken. For this purpose, there are three types of energy performance measures are taken i.e., 1st and 2nd level energy renovation and energy refurbishment. In the order of EEM it is defined which category refurbishment lies.

1st and 2nd level energy renovation

1st level energy refurbishment involves the building envelope with an incidence greater than 50% of the overall building thermal envelope gross area and the renovation of the heating and/or cooling system. The energy performance requirements are applied to the whole building and are referred to the performance of the involved energy end-use. 2nd level energy refurbishment involves the incidence greater than % of the overall building thermal envelope.

Energy refurbishment

Energy refurbishment involves an area less than or equal to 25% of the overall building thermal envelope gross area of the building and/or consist of the new installation, the renovation of a thermal system supplying the building or other partial interventions, including the replacement of the generator.

Figure 16 Energy refurbishment and 1st and 2nd level major renovation

<table>
<tr><td colspan="2" rowspan="2"></td><td colspan="3">Overall building thermal envelope gross area fraction undergoing envelope renovation (f)</td></tr>
<tr><td>f > 50%</td><td>25 < f ≤ 50%</td><td>f ≤ 25%</td></tr>
<tr><td rowspan="2">Renovation of the space heating/cooling system serving the whole building</td><td>Yes</td><td>Major renovation (1° level)</td><td rowspan="2">Major renovation (2° level)</td><td rowspan="2">Energy refurbishment</td></tr>
<tr><td>No</td><td></td></tr>
</table>

In this project, the EEM will applied to the building that lies in the category of energy refurbishment. Following are the strategies applied to building:

1. Use of insulation on the external wall
2. Use of insulation on roof
3. Use of insulation on floor
4. Windows with double glazing and shading inside
5. Use of heat pumps as a generator
6. Use of PV panels

The detailed analysis of these EEMs will be done in the results section.

CHAPTER 4: Results

After the calibration process, EEM are applied to the model to make the building NZEB. As defined before the NZEB is the building where there is no energy performance requirement. The passive measures are taken first and their NPV and DPP are calculated. The NPV is the sum of all the discounted cash flows over the considered period n. The positive NPV in the end of the period indicates that the investment is profitable, and it can be applied. In order to calculate the cash flows, we use the following formula.

$$CF = R - C = \frac{(R - C)}{(1 + r)^t}$$

(5)

- CFt is the net cash flow (i.e., revenues minus costs) at a given time t,
- r is the real interest rate, and
- t is the time of the cash flow, usually expressed in years.
- The term (1+r) -t is known as the discount factor, DF(t)

After the calculation of the cash flows, the NPV can be calculated by the following formula.

$$NPV = \sum_{t=0}^{n} \frac{CFt}{(1 + r)^t}$$

(6)

The DPP is defined as the period when the investment is equal to the revenue. The process is in the equilibrium. In DPP, the NPV is zero. For the passive measures it is compulsory to have the DPP in 30 years, for chiller/coolers 20 years and for the PV technology 15 years. Each EEM will be analyzed on the basis of NPV and DPP.

Insulation of external walls

This is the first energy efficiency measure applied to the model. The external walls of the buildings are the barrier between the conditioned space and the environment. It is necessary to have a certain insulation so that the U value of the wall is under the limit defined i.e., 0.28. The walls conductivity and resistance can be measured on the European model that uses the total 5 nodes in the whole fabric. The design builder automatically generates the value of the U. The thermal conductivity of the wall should be defined according to the environment. Some areas require high heating, should be insulated well while some others have moderate temperatures and doesn't require low conductivity. As defined before the stratigraphy of the current wall is internal plaster layer, bricks layer and the external plaster layer with U value higher than 0.316 Btu/h*ft^2*F. It doesn't imply to regulations according to the ISO standards. So, for this purpose the insulation is done on both internal and external side of the wall. After the simulations, it is seen that the insulation on the internal side of the wall is less effective than the insulation on the external side. Now for the external side insulation the stratigraphy is as, internal plaster layer, bricks layer, insulation layer and the external plaster layer. The insulation used for this purpose are the cork tiles that are available in the market of Pakistan on the basis of rupee/sq-ft. The design criteria are varying the thickness of the cork and find the best thickness with high NPV and low DPP in the end.

There is total five thickness chosen for the cork tiles as they are the only available in the market. So, the variation in the results will be on the basis of 6,8,10,12,14 inches. After the application of the insulation layer, it was seen that there are dynamic changes in the results as follows:

External wall				
Name	**Insulation layer(inch)**	**DPP**	**Annual consumption (Kbtu)**	**U value**
Cork	6	27	100331.4186	0.086
Cork	8	20	97251.70889	0.055
Cork	10	18	94313.68081	0.057
Cork	12	15	86783.49724	0.046
Cork	14(NA in market)	15	84260.52764	0.034
Without	No	0	126046.5262	0.6

Table 4 Effects of multiple thickness cork on the external wall

As seen above, the best solution is to put the 12 inches thick cork tile that has the discounted payback time in 15 years. So, following will be comparison between the previous calibrated model and the new model with the insulation.

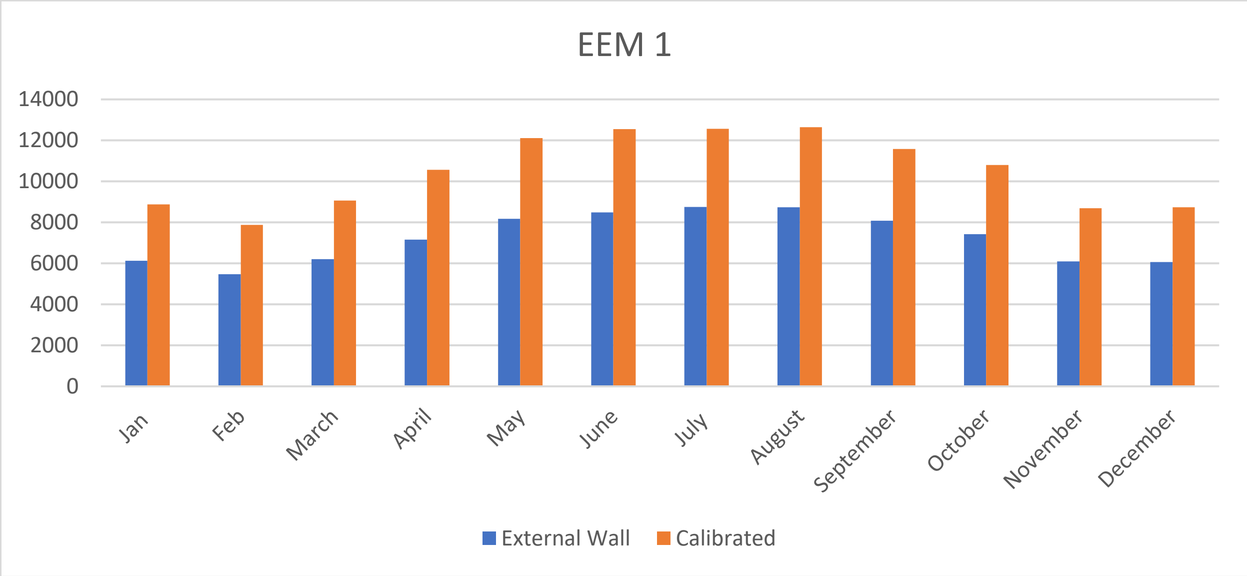

Figure 17Comparison of 12 inch insulation with calibrated

The above graph shows that after the insulation there is major decrease in the energy consumption for the house. In the month of the heating, there is decrease in the heating consumption in all of the months. In the months of the cooling, it can be observed that there is major percentage difference. The reason behind this is because there is less conductance through the wall that results in summers and fewer cooling loads are required. Along with the decrease in the consumption is the decrease in the CO2 emissions. Due to cork, the carbon footprint is negative. It provides the sound damping and non-permeability of the liquids too. The insulation is placed external so that while retrofitting, the inside environment cannot be disturbed. It has helps in thermal bridges as it doesn't affect them.

Insulation of the roof and ground

Insulation is to be applied on the roof and the ground floor in order to decrease the U value under the defined that is 0.28. On the right both figures describe the stratigraphy for the ground floor and the roof. After the application of the insulation material the U value of ground floor decreased to 0.036 and of roof to the 0.056. The total primary energy consumption after the application of the insulation strategies has been decreased to the 85000 KWh/year.

The investment doesn't provide enough NPV and DPP because of high investment cost and low reduction in the total primary energy consumption.

For the roof, XPS has been used that is the synthetic insulation and it provides much better U value and in the ground floor cork tiles are used. The slabs can be bought from the market and both the strategies applies to the external side as it is more efficient.

There are plaster ceilings used that are changed in the ceilings section of the design builder.

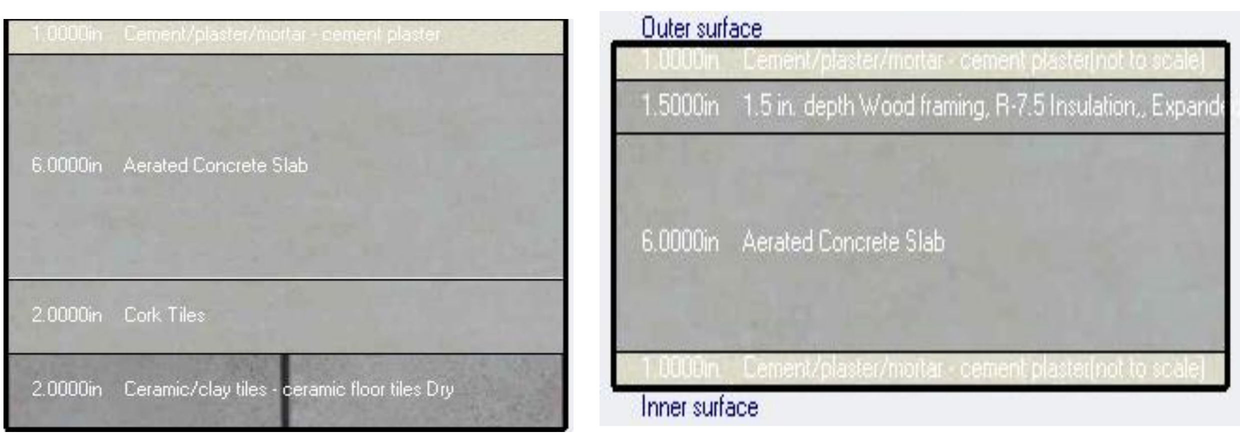

Figure 18 Left: Stratigraphy of roof Right: Stratigraphy of floor

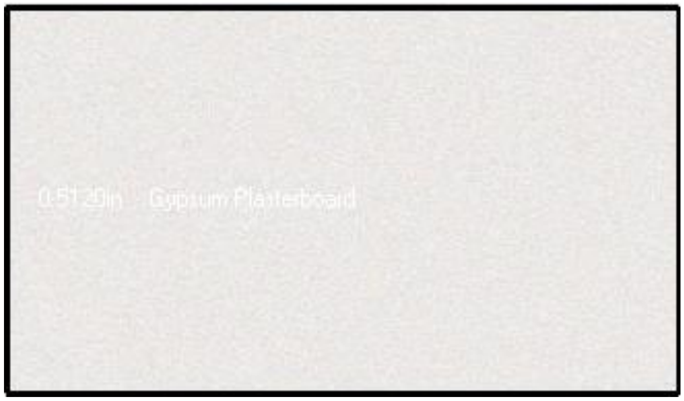

Figure 19 Stratigraphy of ceilings

Double glazing with shades

Glazing's and other transparent materials contribute high share towards the energy performance of the building. Usually in some climates the investments with the glazing's are not profitable in the required time. They are expensive with high installation charges. In our current building scenario, simple double glazing with air is used. The best financial strategy will be treatment of current windows so that not extra investment has to be paid. Current building has some overhangs over the windows but are mostly damaged. The blinds weren't used in the previous model. The U value has to be observed while choosing the glazing and also the frame. Following is the formula for the Uwindow:

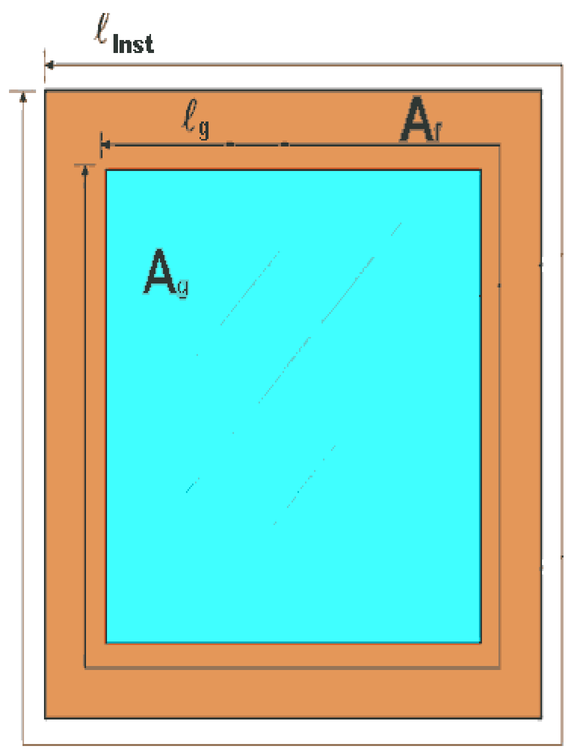

Figure 20 parts of glazing

$$Uw = AgUg + AfUf + \frac{lg\psi g(+linst\psi inst)}{Ag + Af}$$

(7)

- The glazing U-value Ug and the surface area of the glazing Ag,
- The U-value of the frame Uf and the surface area of the frame Af
- The thermal bridge coefficient at the edge of glass Ψg (essentially determined by the spacer) and the glass edge length lg
- The thermal bridge due to the installation of the window in the exterior wall ΨInst and the length lIns where the window meets the wall.

After the calculation of the U value and g glazing, following criteria should be considered for the glazing:

- The window U-value is a measure of the heat losses through the glazing and above all because the window is not to have an unpleasantly cold surface during the winter. The U-value should be as small as possible, but at least smaller than 0.8 W/(m²K).
- The glazing g-value is a measure of the possible solar heat gain. The g-value should be reasonably high; values around 0.5 are now typical

After the application of the insulation on roof and the ground floor, I used the following strategies for the glazing's in the building.

Window				
Name	**Thickness**	**DPP**	**Annual consumption**	**U value**
Dbl ref 6/6 with air	Same	26	81754.52612	0.4
Dbl glazing tinted	Same	26	81960.39098	0.4
Without	Same		86783.49724	0.469

Table 5 Effect of multiple types of windows

Above table describes two strategies with constant changes such as, use of 1m overhang, blinds with high reflectivity and scheduling of shading. The use of EEM suggests the decrease in the annual consumption by the 5.7%. We need to see the intervals changes by monitoring each month see what happened.

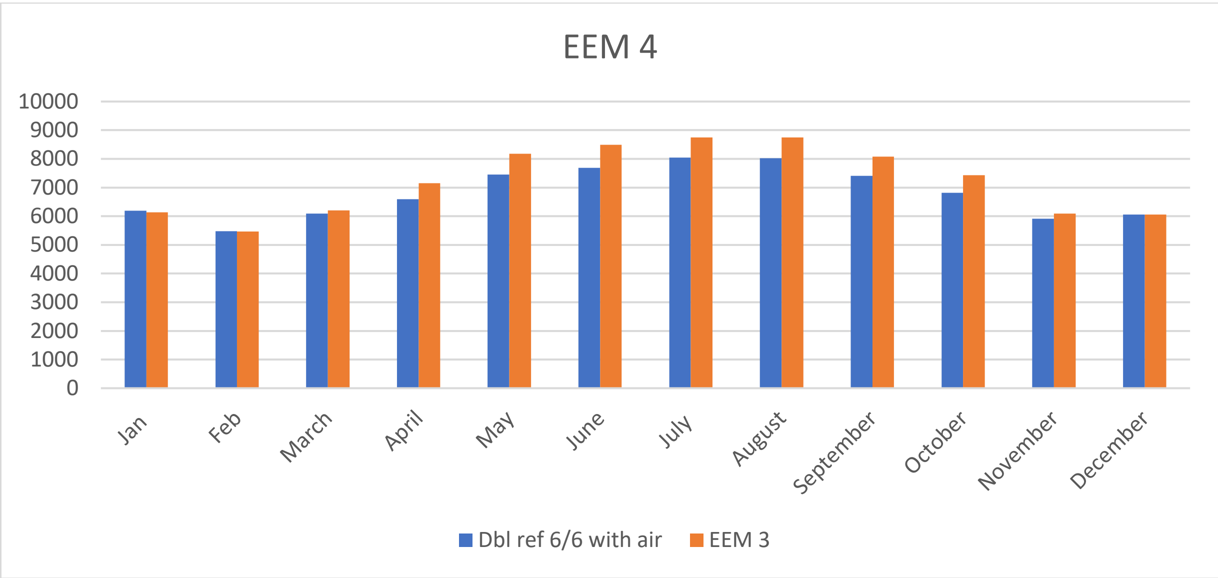

Figure 21 Comparison of Glazing with roof/ground energy efficiency

The above table describes that there is decrease in the energy consumption in the house. The energy consumption decreased in the days of the cooling because the glazing doesn't allow much of the solar gains to the thermal envelope. Most of the heat is either reflected or absorbed and there is less cooling load required in the building. The heating load increased because of the less solar gains and the azimuth angle sun is elevated low and the building requires more heat. The outdoor temperature is low, and the building requires more of the heat from outside. It also covers the limit defined that is 0.8 by ISO standards. The financial cost is low because the windows are treated with the blue tints. The blinds are used according to the schedule, and it is different in the days of summers than the days of winter. Following schedule is applied for the days of summers and winters for the specific building.

Hours of the day	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
North	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√
North-East	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√
East	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√
South-East	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√
South	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√
South-West	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√
West	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√
North-West	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√
Horizontal	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	-	-	√	√	√	√

√ Closed blinds - Open blinds

Table 6 Scheduling of blinds in winters

Hours of the day	00	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23
North	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	-	√	√	√	√	√	√	√
North-East	√	√	√	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	√	√	√	√
East	√	√	√	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	√	√	√	√
South-East	√	√	√	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	√	√	√	√
South	√	√	√	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	√	√	√	√
South-West	√	√	√	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	√	√	√	√
West	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	√	√	√	√	√	√	√
North-West	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	√	√	√	√	√	√	√
Horizontal	√	√	√	√	√	√	√	√	√	-	-	-	-	-	-	-	-	√	√	√	√	√	√	√

√ Closed blinds - Open blinds

Table 7 Scheduling of blinds in summers

Above two schedules shows when the blinds will be closed and when will be opened. In winters, blinds are opened most of the time to get the maximum solar gains and decrease the heating load. In summer, the blinds are closed most of the time to decrease the solar gains and decrease the cooling loads. These strategies can be inhabited to the people and blinds can be controlled automatically. It contributes towards the thermal comfort of the people. After the application of these strategies, we have decreased the total primary energy consumption.

Improvements in HVAC

Heating and cooling loads of the building contributes major share towards the primary energy consumption. HVAC systems in building should be efficient and have least losses. In the current building scenario AC with split are used for cooling and heaters with natural gas are used for heating. For forced ventilation, fans are used in all of rooms except bathrooms. The HVAC systems are important for the thermal comfort of the users. As defined before the cutoff and cut in temperatures for the HVACs, the systems automatically keep the temperature. There are five main systems on which the HVAC systems work i.e., generation, storage, distribution, control, and emission.

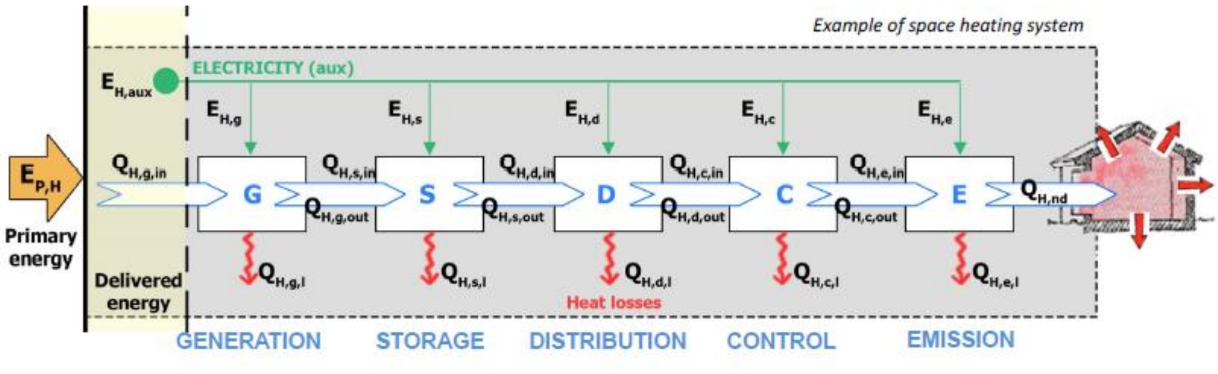

Figure 22 Primary energy conversion process

Above figure explains that first the primary energy is converted into the heat in the generation phase and then it is stored to work on the peak energy hours. There are the distribution systems such as pipes and pumps that distribute the heat to the thermal envelope. The systems are controlled by the climatic control sensors that measure the indoor temperature and then work according to that. The emission systems are fans, radiators that emits the heat to the environment. The efficiency of the systems can be calculated by the following formula:

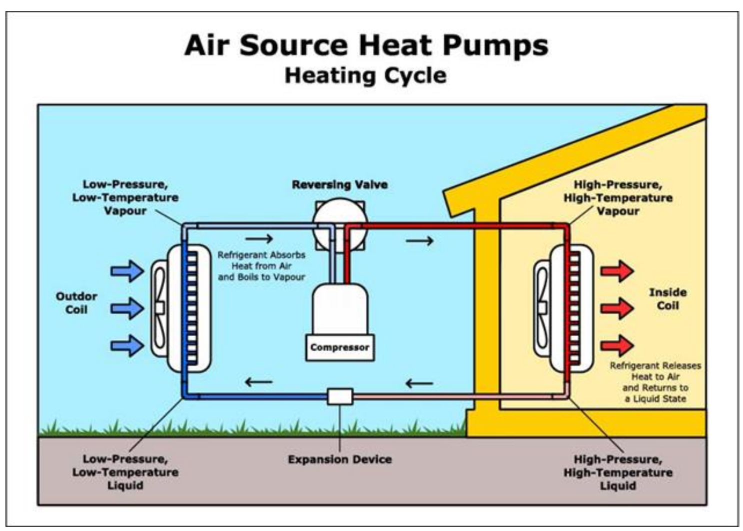

Figure 23 Air to water heat pump

$$\eta H, gl = QH, \frac{nd}{EP, H}$$

(8)

$$EP, H = QH, g, in * fP, g, in + EH, aux * fp, el$$

(9)

Where the fp are the conversion factors for the gas and the electricity. The HVAC systems should have high efficiency around 90% but the current building has the old cooling and heating systems. They are not that efficient and only few rooms have access to them. In order to have the futuristic approach all of the thermal envelopes should have access to the HVAC systems. After the application of different energy efficiency measure, following are the approaches adopted and their results in the HVAC systems.

HVAC			
Name	**COP**	**DPP**	**Annual consumption**
Air to water heat pump	2.5	10	63678.15262
Unitary heat pump	3	17	86028.23827
Without	No		81754.52612

Table 8 Effect of multiple types of HVACs

Above table explains that the air to water heat pumps decreases the major amount of the primary energy consumption. Heat pumps are very efficient systems with low electricity consumption. The most common type of heat pump is the air-source heat pump, which transfers heat between our building and the outside air. Today's heat pump can reduce your electricity use for heating by approximately 50% compared to electric resistance heating such as furnaces and baseboard heaters. High-efficiency heat pumps also dehumidify better than standard central air conditioners, resulting in less energy usage and more cooling comfort in summer months.

A heat pump's refrigeration system consists of a compressor and two copper or aluminum coils (one indoors and one outside), which have aluminum fins to aid heat transfer. In heating mode, liquid refrigerant in the outside coil removes heat from the air and evaporates into a gas. The indoor coil releases heat from the refrigerant as it condenses back into a liquid. A reversing valve, near the compressor, can change the direction of the refrigerant flow for cooling mode as well as for defrosting the outdoor coil in winter.

The COP of the heat pumps are around 2.5-3.5 and can be calculated by the following formula:

$$COP = \frac{Qcold}{Qhot} \tag{10}$$

The heat pumps are scheduled according to the use of the tenants. The investment is giving the PBT in 10 years because of the high installment costs, majorly on the distributions systems. Each room will have a radiator that will be controlled by the climatic control sensors.

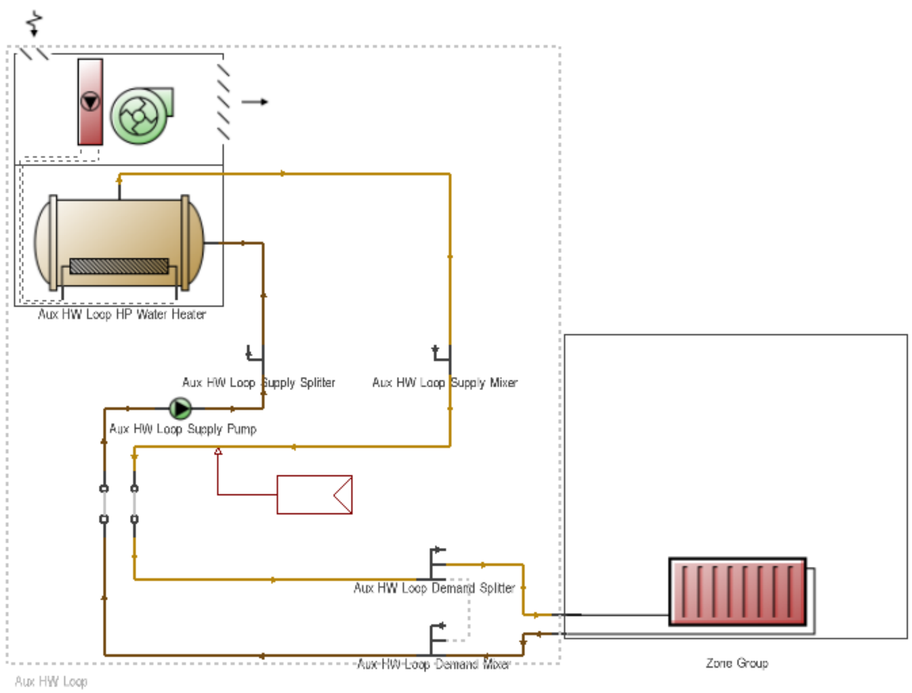

Figure 24 HVAC system of house

The above image describes the detailed HVAC system in which the refrigerant will be circulated in the whole building. For the domestic hot water purpose, the traditional boiler will be used in each bathroom that will provide the hot water. With this hybrid strategy there can be decrease in the primary energy consumption.

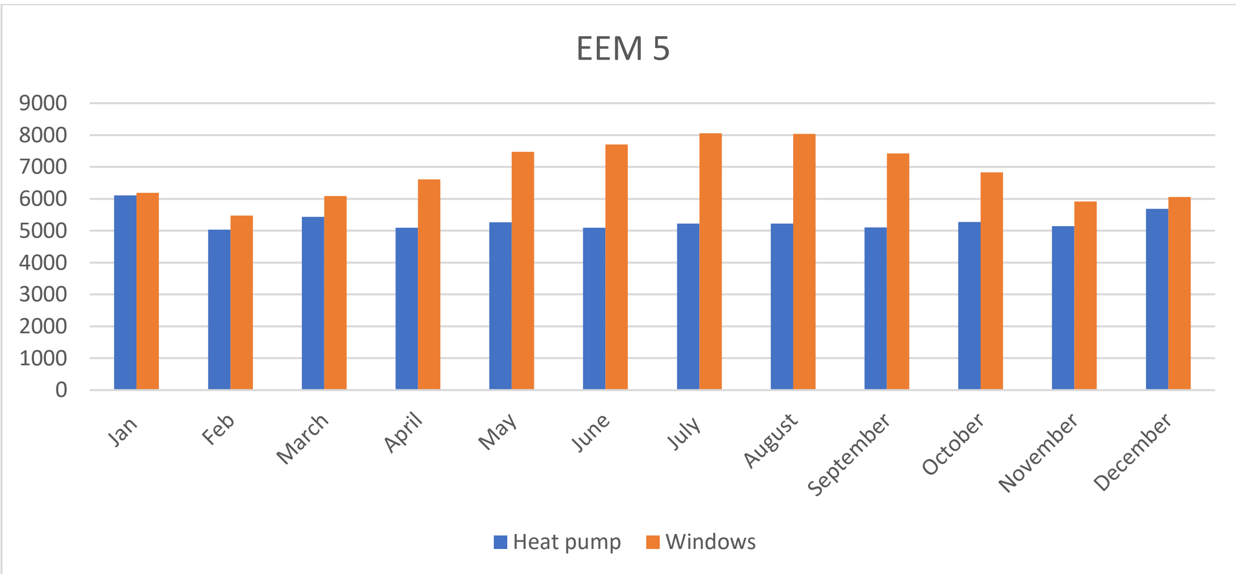

Figure 25 Comparison of Heat pump with glazing on total energy performance

Above table describes the decrease in the consumption on the monthly interval's basis. There is major decrease in the cooling period with respect to the heating periods which shows that the heat pumps are highly efficient than the other systems. Although it is an expensive investment, but it is better for the energy efficiency and sustainability.

PV panels

After the application of the energy efficiency measures mentioned before I will apply the active measure to complete the demand of electricity regardless of joules energy with no electricity from grid. One significant aspect of reducing global emissions is reducing energy demand and increasing energy storage. We are required to have energy efficiency and conservation. As, world is advancing there is more requirement of energy, and it can only be fulfilled by renewable sources that are widely available and pollution free. PV panels converts the solar energy into the electrical energy. The whole system requires multiple components like inverters, wires, and support. To understand the working of the PV panel, it is important to know the concept of the peak power that can be obtained when the irradiance is the highest. The excess energy should be stored or sent to the grid by the process of net metering in which the excess energy is paid off to the user. In net metering or net billing, the user sends the excess energy to the grid that is being measured and is adjusted with the electricity taken from the grid.

Factors contributing towards the PVs efficiency

Following are the factors contributing towards the PV efficiency:

- Global solar irradiance that is total solar irradiation per unit area of the collector
- Collectors' area that depends upon the no of panels and PVs type
- Tilt angle that is with the horizontal axis
- Azimuth angle that is the angle between the projection of the sunray to the south
- Zenith angle, declination, latitude, and hour angle
- Type of collector

Power output from the Collectors can be calculated by the following formula:

$$Psolar = G * A * n \tag{11}$$

G=Solar irradiance

A=Area of the solar PV

n=Number of PV panels

Parameters

Below tables shows the characteristics of the PV panel used for the electricity production. This model has been chosen on the basis of high efficiency and availability.

HiKu7 Mono PERC	
Parameter	**Value**
Cell type	Monocrystalline
Cell Arrangement	132 [2 x (11 x 6)]
Module Efficiency	21.20%
Open Circuit Voltage (Voc)	45.4 V
Short Circuit Current (Isc)	18.47 A
Temperature Coefficient (Voc)	(-0.26 %) / °C
Temperature Coefficient (Isc)	0.05 % / °C
Nominal Module Operating Temperature	42 ± 3°C
No of electricity load centers	1
Inverter efficiency	0.95
Rated power output	660W
Tilt angle	45 degrees
Azimuth angle	0
No of generators	5
Total PV area	626 ft^2

Table 9 List of parameters for solar panels

The PV panels have been designed on the roof of the house and will be considered as the on-site production. The PV panels have the tilt angle 45 degrees and the azimuth angle 0 so it is facing towards the sun. The distances between the panels have been set in order to not cause the shading on the previous panel. Each module is interconnected, and PV production is sent to the inverter. While designing the PV panel it is important to see the normal mean module temperature so that it works properly. The figure on the right shows the rendered view of the building in which the monocrystalline PV panel have been installed. They are facing towards the south.

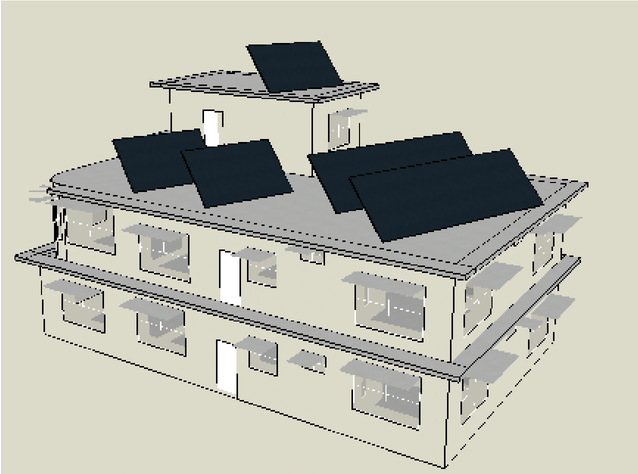

Figure 26 Building with panels

Result

The simulation results are as below that describes that there is no electricity to the utility, but the excess electricity will be paid to the user.

\

Electric Loads Satisfied

	Electricity [kBtu]	Percent Electricity [%]
Fuel-Fired Power Generation	0.000	0.00
High Temperature Geothermal*	0.000	0.00
Photovoltaic Power	96561.486	120.08
Wind Power	0.000	0.00
Power Conversion	-4828.07	-6.0
Net Decrease in On-Site Storage	0.000	0.00
Total On-Site Electric Sources	91733.412	114.08
Electricity Coming From Utility	57481.872	71.48
Surplus Electricity Going To Utility	68804.087	85.57
Net Electricity From Utility	-11322.22	-14.1
Total On-Site and Utility Electric Sources	80411.196	100.00
Total Electricity End Uses	80411.196	100.00

Table 10 Final results of solar panels

The payback time is calculated as 2 for this PV panel. This shows that it is highly profitable investment and good energy efficiency measure. The limit for PBT for the solar panels is 15 years.

Building class

After the implementation of the energy efficiency measures, no energy is taken from the grid and the building classification changes to A4 level. This means there is no primary energy consumption of the building, and it is highly sustainable building.

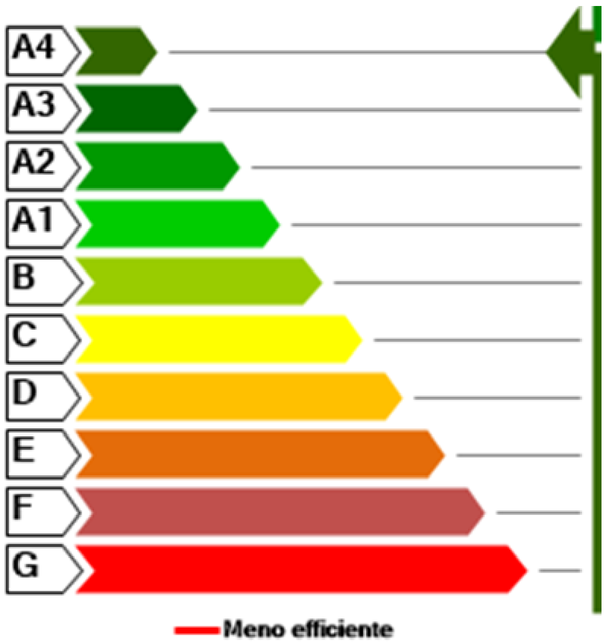

Figure 27 Energy performance grading of house

CHAPTER 5: Conclusions

The study explored the technical and financial feasibility of multiple energy efficiency measures on residential building located in sub tropic humid region to make Net Zero Energy Building. The EEMs were applied on building keeping under the energy refurbishment category. Total six energy refurbishment measures were applied which includes the insulation on external wall, insulation on roof, improvement of transparent objects, insulation on ground floor, change of HVAC system and solar PV panels.

Following are the outcomes of research work.

- Cork is one of the most beneficial insulations as it provides sound damping, liquid insulation with the decrease in the U value. It is also carbon negative.
- The installation of the insulation is more efficient on the external side of the wall than the internal side. The best solution is to put the 12 inches thick cork tile that has the discounted payback time in 15 years. There is about 31% decrease in the primary energy consumption because of the application of the insulation on the external wall. Due to low U value, heating and cooling loads are less than the calibrated model.
- The insulation on the roof and ground floor decreases the energy consumption by 2% and high discounted payback time
- Double glazing with scheduled shades contributes the decrease in the annual consumption by the 5.7%. The overhangs with 1m gives less energy consumption than the 2m. The double glazing with argon has low U value than the double glazing with air.
- Heat pumps uses less energy than the traditional boilers with joules effect. The advantage of heat pump is that it can be used for summers and winters too. It has high COP of 2.5-3.5 and in our case the air to water heat pump decreases by approximately 22%. It requires high financial input as all the five systems have to be installed in the house.
- Active measures like PV panels can be used to cover the demand of the building. In our case, the excess of the electricity can be sent to the grid and net metering can be done. Monocrystalline have high efficiency than poly crystalline PV panels. The panels can be modeled according to the area.

- The energy performance of the building can be done using the software's. After the application of the energy efficiency measure the current building lies in A4 category as it doesn't require any energy from the grid.

					EEO				
	Energy efficiency measures		Parameter	Unit	1	2	3	4	5
1	USE OF CORK AS AN INSULATION on external wall	Thermal transmittance	Uwalls	[W·m-2K-1]	0.086	0.055	0.057	0.046	0.034
		Annual consumption	P	Kbtu	100331.4186	97251.70889	94313.68081	86783.49724	84260.52764
		PBT		Years	27	20	18	15	15
		Thickness	s	Inches	6	8	10	12	14
2	Ground floor/roof with insulation	Thermal transmittance	Uwalls	[W·m-2K-1]	0.036/0.056				
		Annual consumption	P	Kbtu	85201				
		PBT		Years	28				
		Thickness	s	Inches	2				
3	Glazing with blinds and overhangs	Thermal transmittance	Uwalls	[W·m-2K-1]	0.4	0.38			
		Annual consumption	P	Kbtu	81960.39098	81754.52612			
		PBT		Years	26	26			
		Overhang length	l	m	Nil	1			
4	HVAC	COP			3.5	3			
		PBT		Years	14	18			
		Annual consumption	P	Kbtu	63678.15262	86028.23827			
		Type			Air to water heatpump	Unitary heat pump			
5	PV collector	Peak power	P	kBtu	96561.486				
		PBT		Years	2				
		Type			Monocrystalline				
		Total energy from grid	P	kBtu	-11322.22				

Figure 28: Energy efficiency measures comparison

Future recommendations

Following are the future recommendations for the modelling,

- The CVRSME should be used instead of MBE for the calibration because of the positive and negative errors
- Double glazing with argon should be used on the south facade and double glazing with air should be used in the northern facade
- Energy performance certification should be done
- Pakistan lags in the legislation regarding the NZEB, it should be considered
- No building should be sold or rented without the energy audit certification
- Solar thermal can be used with the adsorption or absorption cycle for good efficiency.
- Smart lighting control should be used
- Detailed HVAC analysis should be done

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