Green Roof Design for Urban Homes in Tropical Climate

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Abstract— Global warming scenario is becoming crucial day by day. Designing green buildings & lowering carbon footprints at highest became an important part of construction industry. Under such crisis, proposing a green roof for city houses will help in lowering the use of non renewable energy. This study is directed towards comprehensive study of green roof. A case of bungalow having an area of 1250 sq.ft. is been chosen for installation of the green roof. The green roof uses an area of 388 sq.ft. & roof utilizes photovoltaic panels & grid linked photovoltaic system of 5400 watts. The roof comprises of 15 solar panels with aggregate generation capacity of 4650 watts. Considered the area underneath the panels, it is noted that this space can be developed for growing microgreen / vegetables. The normal crop-time for nearly all the vegetables varies from 2 to 3 weeks, differs upon the type of plant seeds used. As the green roof continues to cover up the room area, it supports to achieve the temperature within comfort level & also allow natural air ventilation which helps in controlling the humidity. The green roof can also create alternative energy that does not contribute to CO2 emissions into the atmosphere & can generate about 300 kilowatt hours per month, which partially supports to lessen electrical expenses. The paper gives an idea about the implementation of green roof & its advantages in various terms. This green roof technique should be designed separately for individual cases.

Index Terms— Global warming, Carbon footprint, Green roof, Photovoltaic panels, micro-greens

1. Introduction:

Global climatic scenario is known to whole world. Every developed country is trying to reduce the carbon footprint & at the same time buying carbon credits from the developing countries. To control the climate manipulation, it is important to control the emission of green house gases & minimize use of non-renewable energy & more focus is on implementation of renewable energy for various purposes. One of the most important factor for reducing emission of green house gases is housing sector. Out of the total energy consumption, 22.46% is consumed by housing sector. & out of this energy, 37% energy is being used for fans & 7% is being used for AC to achieve comfortable living conditions inside the room (Scroll, 2020).

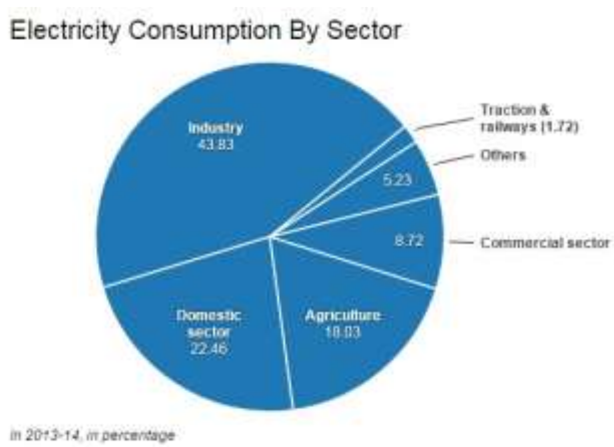

Figure i Energy consumption details

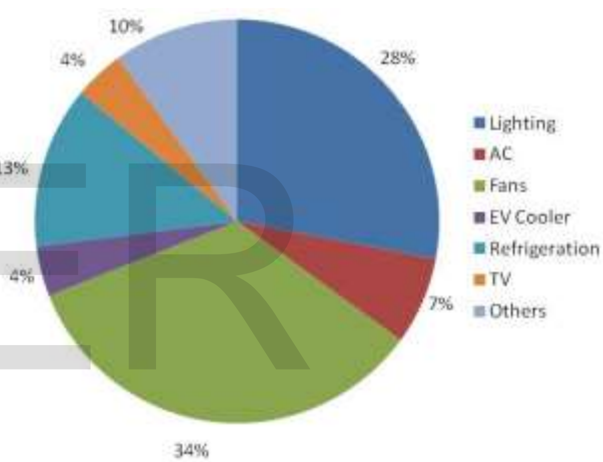

Figure ii Domestic Energy consumption details

It is essential to shield inside areas from climatic conditions like temperature, humidity, rainfall etc. guaranteeing the safety of spaces underneath, rooftops also give proper area for the installation of solar panels to produce electricity & for the farming of eatable plants for residents (Hyde, 2008). Rooftops where crops are growing, are known as green roofs. Such roofs help to mitigate the impact of urban heat island effect. (Kibert, 2013). Such roofs connect the human being & building with the nature. Green house gas emissions were reduced due to such roofs. Such idea also led to growth of zero net energy structures. A research analysis states that solar panels installed on 40 sq.m. of space generates about 3000 watts of electricity per month. This gives an suitable explanation for development of eco roof for urban homes & also serves an essential role in sustainable development. In addition to this, eco roof top also encourage good condition of life for citizens, conserves energy, enhances air condition, atmospheric conditions of cities for comfort & lessening the greenhouse gas emissions. This paper focusses on creating a set of guidelines for design of green rooftops for urban homes in Tropical climates in India considering the aim of developing sustainable rooftop which will accommodate solar panels & cultivation of eatable plats above the same.

2. Green Architecture & Solar electric system for solar roofs:

2.1 Sustainable Architecture concept for Urban homes:

Structural work, erection & nature are combined to increase leafy spaces in the ecosystems such as across the cultivation of food crops & decorative plants across houses & use of open courtyards to offer natural air circulation (Ratanamart, 2014). This is bio-climatic house design concept that benefits urban homes in Tropical climate. Renewable energy is preferred, while trash & waste are minimized to promote good quality of life for inhabitants. This idea is taken as a practical set of standards for sustainability-oriented architectural models. It is also the issue for eco-roofs, which hold natural balance via its link with residents, expanding green space for urban areas & giving a source of energy in the form of photovoltaic solar systems. (Guilherme Carrilho da Graça, 2012)

2.2 **The purpose** is to construct roofs that provide renewable energy which will help to cut the carbon emissions & will provide a space for increasing greenery in the urban environment. A green roof is a component of green building design concept geared for sustainability. The roof qualities & elements are described as follows :

i) Flat roof installed on the top of house or high-rise building that directly receive sun-light radiation & heat. They are to be constructed of steel reinforced concrete & should be covered with glazed outdoor tiles to prevent rain from seeping into buildings. These tiles also provide additional heat insulation for building.

ii) Steel reinforced flat roofs can support the weight of plants, planting equipment & solar panel fittings.

iii) Photovoltaic solar panel systems are to be mounted on top of concrete roofs to produce electricity.

iv) The ideas of green roofs & solar roofs can be merged into the similar system known as solar energy system building integration.

2.3 Solar cell, Solar energy & Photovoltaic system:

Solar cells or photovoltaic cells help to directly alter solar energy into electricity. Solar cells are mass-produced from 2 key groups of semiconductors. The 1st group is crystalline silicon. It uses silicon as key material & is split into mono crystalline cells & poly crystalline cells. The 2nd group is identified as thin-layer cells or thin-film solar cells (TFSC). This cluster of solar cells uses variable semiconductors onto glass or alternative material that eases the conversion of solar energy into electricity, trailed by placing numerous thin layers of film on top of each other. Henceforth, they are known as thin-film solar cells. So, many unlike matters are used in these layers, so thin-film solar panels can have various names depending on materials. Samples of materials are amorphous silicon (a-Si), cadmium telluride (CdTe), copper indium gallium selenide (CIS/CIGS), & Organic Photovoltaic cells (OPC). The efficiency of thin-film solar cells ranges between 7 to 13 % on average liable on film materials. (Solar, 2019)

2.4 Electricity generation from Rooftop solar panels:

Usually known as solar rooftop or photovoltaic rooftop, solar panels proficient of generating electricity are installed on top of the buildings. By locating them at the top, residential & commercial structures can earn the profits from the solar panels. Solar rooftops can generate only minor quantity of electricity, generally around 5-20 kilowatts, when related to ground-mounted solar panels or solar farms, which are proficient of producing a middling of at least 1 Mw of electricity. Additionally, commercial solar installations overseas are generally capable of generating minimum 100 Kw of electricity, which is more than numerous residential houses combined. Solar rooftops are combination of 3 sub-systems.

i) Electricity Generation System: 1 side of solar panels work to directly alter solar energy into direct current electricity. This side must be directly visible to sun light. Both thin-film & crystalline solar panels have tags that define the normal test circumstances of the manufacturer.

ii) Energy utilization system: This system consists electricity load generated & its usage in line with necessities.

iii) Balance of System (BOS): While both of the above-mentioned systems are working, this third system helps as a device to support electricity generated from photovoltaic solar panels be directed for uses as appropriate & in line with needs. Part of the BOS system contains of a assembly for supporting solar panels. This assembly is usually assembled along the roofing material or above the flat roof & creates an slant that improves daily sunlight contact year-round. Additional part of the system is an electricity translation scheme such as one which changes direct current DC into alternating current AC. The BOS system also includes backup batteries for times when climate circumstances are non-conducive to electricity generation such as at night.

iv) Solar panels & Sunlight Captivation Direction – These depend on the fixing position, the essential quantity of electricity to be generated & the strength of sunlight. In order to make the most of electricity generation, solar panels should be installed such that they are upright to the sun at all times. (Anselm, 2006)

2.5 Growing Micro Greens, Sprouts & Seedlings:

These can be full-grown to deliver a source of nutritious food comprising nutrients that the body needs. Approximately can be grown & reaped for eating in only 1.5 to 2.5 weeks, & they also raise a decent price when sold.

Micro green or sprouts are small & the newly developed plantlets that have yet to develop into trees. Suring this phase of growth, significant nutrients are collected to nurture the plants as they grow older, so consuming them can deliver the body with many valuable nutrients. The procedure of rising these sprouts requires only 1 to 2 weeks, & taking care of them is easy, since only irrigating is needed. Because the farming of these small & fast developing sprouts are simple & easy, it is only suitable that farming of these plants on rooftops or under roofs. Some sprouts with possible for growing to progress human nutrition include gehu rop, mataki sprouts, hirewe mug, chavali sprouts, sunflower sprouts & others.

3 Measures:

The location for the installation of a mock-up model was studied & chosen appropriately for the sustainable roof experiment. This research selected a single-story home located in tropical climate near Navi Mumbai. Since the house has open courts in interior & exterior.

The eco-roof mock up model was designed & constructed as follows:

i) A rooftop space of 388 sq.ft. was prepared

ii) Grid system solar panels for the eco-roof were installed. First, solar panels & an inverter were chosen from Vikram solar which are durable & reliable & for which clear electricity generation conditions are shown on the producer's site. In addition, the connecting firm had to be expert & skilful at providing facilities & solving issues at the work site. A total of 365 to 385-watt capacity solar panels were used in the research. The shuttle brand model SOMERA VSM.72.AAA.05 was used. Each panel was 992 X 1966 mm in dimensions i.e. 1.96 m^2. The total combined electricity generation capacity was 6750 watts. However, on average, the maximum capacity was diminished by 14%, so the capacity was about 315 to 330 watts per panel. The inverter was a parallel on-grid inverter. The inverter converted direct current from the solar panels into alternating current, which was then supplied to the house. The parallel on-grid inverter model SUNNY BOY 3600 TL of the Vikram solar brand was chosen.

iii) For the plants cultivated on solar rooftops, in case to adjust to the rainy climate, this research choose numerous potted plants because of the ease in their care & activities & absence of long-term difficulties related with leak-proofing efficiency due to planting apparatus. The plants chosen for farming in the experiment were eatable plants appropriate for periodic cultivation.

iv) Temperature & humidity were recorded to generate values for study in determining suitable conditions. The temperature & humidity gadgets used for measurements belongs to the Testo brand. Readings were taken over two times in all. The first period lasted from 1 January 2020 to 31 January 2020 in which readings were taken at a 1point of eco-roof. The second period was lasted from 1 May 2020 to 31 May 2020, when temperatures & humidity were measured at 3 places. The 1st point of measurement was at the sustainable-roof. The second was at the underside of the garage above which solar panels were installed upon its fibre cement tiles. The third location was inside the kitchen under the eco-roof. The measurements were taken to compare the suitable weather conditions. (Supalux Jairueng, 2019)

The results from the design & installation of the eco-roof were analysed. Analysis was conducted using temperature, humidity & wind speed measurements in contrast to the comfort scores for New Mumbai uses of space under the eco-roof for vegetable farming & relaxation. The suitable weather conditions were also distinguished between under the garage roof & the eco-roof along through comparisons of the electricity generation of the eco-roof with structure addition installation & solar roof with solar-mounted roof installation on the roof of the main building & the roof of the garage, as all 3 roofs were positioned in way that they were at dissimilar slants to the sun. The inverter was connected to alter electricity, & the electricity generation outcomes were recorded. The 3 D drawing shown below in fig. no. i & the real home for case study are shown in fig. no. ii, iii & iv

Figure iii - 3 D drawing for case study

Figure iv - The real home for Case study

Figure v - The roof under construction part a

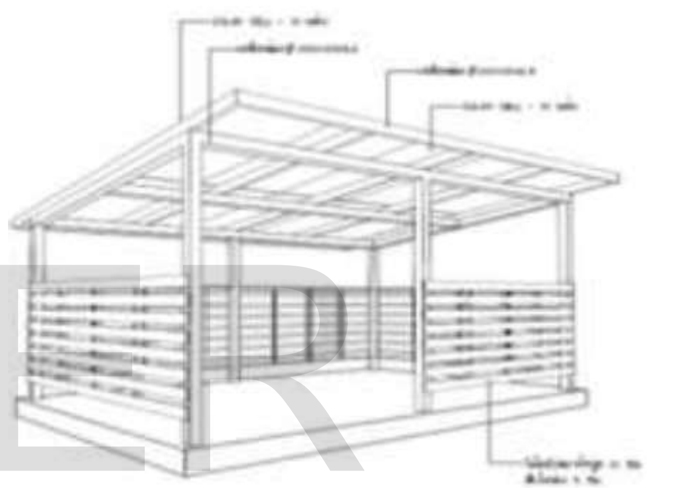

Figure vi- The roof under construction part b

The outcome of the tests was abridged & number of design strategies were shaped to simplify application & innovation.

4 Results:

The research outcomes are segregated into 2 sections. The 1st section covers the solar roof electricity generation effectiveness, cost & the 2nd section covers cultivation outcomes of micro greens. Temperature, humidity & airstream speed measured at the terrace level. For the temperature & humidity, over 24 hours after the period spanning 1 to 31 January 2020, the lowermost recorded temperature arisen around 5.00 am. Afterward, temperatures consecutively rose due to rising solar radiations. Heat peaked around 2.00 pm & began to decline at around 3.00 pm. Temperatures continued to reducing until the lowest levels at around 5.00 am of the next day. For humidity, the extreme humidity was observed at 5.00 am. After that time, humidity slowly reduced due to increase in solar radiation in the same manner, recording its lowest levels around 2.00 pm. Starting at around 2.00 pm, humidity increased consecutively until the sun left the skyline & sustained to rise till the extreme measurements at around 5.00 am of the next day. For wind speed, wind speed was recorded hourly from morning 6.00 to evening 6.00. The average wind speed was 0.99 m/sec. to 13.0m/sec.

Temperature, humidity & wind speed were recorded at the eco-roof, under the garage roof, & the kitchen below the eco-roof. Records of temperature & humidity figures over a day from the period 1 to 31 may 2020 states that the minimum temperature recorded at about 5.00 am. Afterwards, temperature consecutively risen up due to variation in solar radiations. Temperature peaked at around 1.30 pm. By 3.30 pm, temperature began to lower down until the sun leaves the skyline & reaching at the minimum point at morning 5.00 am of the next day. When temperature between January & May were equated, the time at which temperature peaked changed from 1.00 pm in January to 1.30 pm in May. However, the lowest temperatures last to succeed at about 5.00 am. Moreover, average daytime temperature was maximum compared to the temperatures in January. Thus, the daily temperature of October was minimum than those in May. The highest humidity happened about at 5.00 am. Afterwards, it gradually reduced due to increase in solar radiation in similar way as temperatures. Humidity reached at risen to up point about 12.00 pm. Starting at 2.00 pm, humidity slowly rose until the sun left the sky & constantly increase until the maximum levels were reached by about 5.00 am of the next day. The period changes in the lowest relative humidity values were the same as for temperature. In other words, time changed from 1.00 to 12.00 pm. This shows high temperature means low relative humidity & low temperature means high relative humidity. Trends of time & average of temperature from 1 January to 31 January 2020 are shown in fig. 5

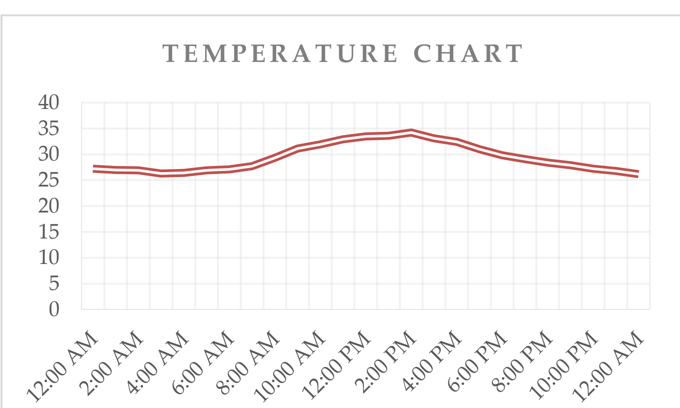

Figure vii Time & average temperature in **January**

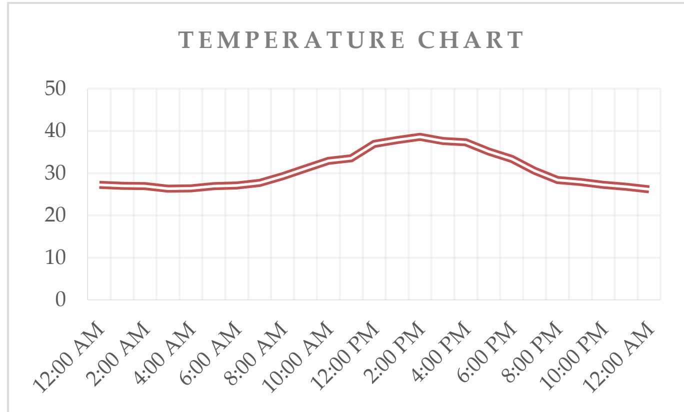

Figure viii Time & average temperature in **May**

As for the electricity generation of the eco-roof, the eco-roof was installed on the southern side where the roof height from the ground was approximately 5.40 meters. The solar panel area was 18 X 1.96 = 35.28 m^2. In total, 18 solar panels were installed. An on-grid parallel inverter sized 5400 watts was installed. The combined electricity generated for the month of January was 1012.50 Kwh or 1012.50 units in electricity costs per month when average 5 hours are considered for generation of energy. The southern side in which eco-roof solar panels were fixed enabled electricity generation better than other places at house. As an outcome of this research, this home can be called as "bioclimatic structure". Solar panels were mounted in various directions in the study, namely, at the norther side at the house's roof, at western side at the garage roof & at the south side at the eco-roof. The chart illustrates that from 1 to 21 January 2020, the garage roof produced the most electricity, followed by the eco-roof, while the house's roof generated the minimum electricity. However, from 22 January to 31 January 2020, the eco-roof generated the most electricity, followed by the garage roof & the house's roof.

For the farming of the vegetation at eco-roof, the eco-roof was fixed using solar panels as the roofing material & fixed on the roof top of the single floor bungalow. The area on the roof-top under solar panels is location where significant eatable vegetation were cultivated, namely micro-greens & vegetable sprout. As study was led from May to July 2020, the research happened throughout rainy season, so the crop of micro greens was outstanding with 99% germination rate & good sprout production.

5 Conclusions:

5.1 Urban eco-roof for the home design in Navi Mumbai :

The roof was designed to use a photovoltaic solar system as roofing material. The roof provided space for growing edible plants to feed the house's inhabitants. Plants flourished under the solar system, & no pesticides were used. Thus, the vegetables were safe for human consumption & toxic-free. This research experimented with the cultivation of micro greens or sprouts, which produced highly nutritious vegetables such as sunflower sprouts, morning glory sprouts etc. The area under the eco-roof was also used for leisure. It connected the inhabitants with the nature & greenery against the urban backdrop, since the roof was located on the top floor of the house.

5.2 This is a sustainable roof innovation:

This eco-roof was designed in the study to be installed to a bio-climatic house, & it functioned as a source for the production of renewable electricity, which lowered carbon emission & greenhouse gas, so this roof is also a green roof. Considering that edible plants were grown on this roof, the roof can be seen as being green in green.

5.3 Eco-roofs are suitable for urban homes:

Not much space is required for designing such roof. Just around terrace area of one room. When installed on southern side free from the shade of the trees & high-rise buildings, 1012.50 KWh or 1012.50 units of electricity could be produced per month. This means that around 12,150.00 units electricity cost could be cut per year.

5.4 Eco-roof are cost effective:

The cost of installation of 18 photovoltaic panels costs around Rs. 6,30,000 lacs only, whereas in comparison, it saves 12150.00 units X 7.5/- = 91,125 Rs per year. So, the payback period for construction of this roof is only 7 years. And also there tis 10 years warranty for this complete set & 27 years of linear power output warranty is also provided by dealer.

5.5 Recommendations:

Eco-roofs for urban homes in Navi Mumbai can be expanded to become part of an emergency backup power system using battery storage. In addition, when used in other regions the installation angles of solar cells as well as the plants cultivated should be appropriate for the climatic conditions.

Such green-roofs will benefit the customers in various ways.

- It will reduce the electricity bills
- It will help in reducing the carbon footprint & emission of greenhouse gases.
- The cultivation of sprouts & micro-greens will help in supplying nutritious food for the owner.
- At same time, these green vegetables will help in controlling the humidity in surrounding & will improve the wind speed by creating pressure difference in air.
- This green vegetable will also help in reducing the heat gain from the roof top. Which will result in minimum use of fans for cooling & ventilation. This will result in reducing the carbon footprint.
- As the payback period is 7 years, after which it will benefit the owner in many ways.

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