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ZERO ENERGY DESIGN: A CASE STUDY OF RESIDENTIAL BUILDINGS WITH SOLAR ENERGY AS ENERGY SOLUTION

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Abstract- According to International Energy Agency, existing buildings are responsible for 40% of world's total primary energy consumption and 24% of global carbon emissions. In order to protect our environment from destruction the only effective solution is to cut down the emissions of CO_2 and reduce the consumption of non-renewable energy resources. This case study is about sustainable and energy efficient development of buildings at domestic level (residential buildings) in Punjab, Pakistan. As it is about sustainable development so our main focus is Triple Bottom Line (TBL). This can be achieved through zero energy design concept. It is a case study of two different existing residential buildings in Lahore. Each building is analyzed and the yearly primary energy consumption of each building is calculated individually. Calculations are made to determine the number of solar panels based on experimentally proved formulae. Area required to accommodate these panels is also calculated. At the end recommendations are given to make optimum use of solar energy. Energy saving passive solar techniques are proposed that can highly reduce the energy demand and carbon footprint.

Keywords- Adaptation to climate change, green buildings, residential buildings, zero energy design.

1 Introduction

With an increase in population, energy demand is also increasing at an alarming rate. It has a direct impact on global warming. If energy efficiency improvements are not made in the building sector, energy consumption can increase up to 50% by 2050 [7]. Nowadays, people are inclined towards maintenance and repair instead of new construction because it is cheap, less time consuming and comparatively ecofriendly [1]. Now, designers and contractors are required to initiate energy retrofits to upgrade the energy performance of existing buildings. There is an acute need for making sustainable building retrofits to overcome the problem of global warming in the construction sector. However, building retrofits remain slow due to lack of awareness, uncertain outcomes, and state policies [1].

The solution to achieve energy efficient buildings and reduced carbon footprint related to the operation of buildings is zero energy buildings. Zero-energy buildings improve energy efficiency and reduce the energy demand through various energy-saving measures. They use combination of insulation and renewable energy to reduce and meet the energy needs, thereby achieving the goal of not consuming nonrenewable energy. As a result, there is a reduction of carbon emissions into the atmosphere. Different energy conservation technologies have been employed to realize the concept of zero-energy buildings [7].

Developing countries like Pakistan are far behind the world in contributing to sustainable development and help against the increasing global warming. We really need to work to make optimum use of our renewable resources in order to protect our environment and energy resources for the future generation. In this case study two existing residential buildings are considered. The buildings are analyzed for their yearly primary energy consumption. After analyzing the climate and associated factors solar energy is proposed to be optimum renewable energy solution in our case. Then solar energy demand is calculated with reference to the primary energy consumption of each building. Finally, the number of panels are calculated for each of the residential buildings to fulfill the solar energy demand. Solar energy has a high potential in Pakistan. The main objective of this study is to highlight the techniques we can use to cut our non-renewable energy resources and shift to solar energy as a green and renewable energy resource.

2 Literature Review

The contribution from buildings towards energy consumption, has steadily increased reaching figures between 20% and 40% in developed countries [5]. On the other hand, 40% of total carbon dioxide emitted globally is produced by construction industry only [5]. Zero energy design concept is the optimum solution to this problem. The scope of zero energy design in buildings includes energy conservation, water conservation, environment protection, material conservation and health protection and comfort of occupants [4-6].

The renewable energy e.g. solar energy, wind energy, tidal energy and soil thermal energy should be adopted instead of fossil fuels whose consumption is a direct cause of global warming. Solar energy is the most abundant renewable energy resource available on earth and is also one of the cheapest. Both active and passive energy techniques are employed in zero energy design buildings. Active solar systems involve the use of electrical and mechanical devices that can capture and store heat energy from the sun and can also convert it into electricity. They require a backup system. These systems typically include photovoltaic panels, collectors, voltage controllers, blowers and pumps that work together to process the sun's usable heat. In contrast to active solar systems, passive solar systems do not make use of electrical and mechanical devices that can capture and store energy. Passive designs rely on greenhouse principles to trap solar radiation. A few examples are sunrooms, solar chimneys, trombe walls, solariums, greenhouses etc.

Active solar systems are of three types; Off-Grid, On-Grid and Hybrid systems. Off grid system is independent of the electricity supply by the state (Pakistan Water And Power Development Authority, WAPDA in our case). It requires a backup for energy storage. On grid system requires no backup for energy storage. It is based on net metering. The surplus energy produced by the solar panels is supplied to the grid and vice versa. As WAPDA turns out, the solar power also fails. Hybrid system has a backup for energy storage and has the net metering feature as well. If electrical energy is not available from WAPDA, the load will automatically switch to the solar power and vice versa.

Solar chimney is based on the principle of stack effect. The air inside the chimney gains heat and rises, thus making space for the air beneath. It is usually used for natural ventilation. Solar chimney should be made higher than the roof so that it is exposed to direct sunlight. According to Reyes et al., the wall-roof solar chimney enhances the night time ventilation three times than the roof solar chimney [2].

Solariums are the glass rooms which are used for passive solar heating. They also act as a buffer zone between the outer space and the dwelling. They permit abundant daylight. They are placed on the southern side of the building to gain maximum heat in winter season. The heat is accumulated in the solarium and is then transferred to the inner space of building through mechanical means via ducts [3].

Trombe walls are used for space heating in winter season. Its working principle is based on the principle of thermal siphon. It employs natural hot air for space heating. It is a thick concrete wall with a high heat absorbing material on its exterior surface. A glass cladding is placed at about 2 inches away from the concrete wall on the exterior side. This wall is placed on the south facing of the building. The concrete wall has vents at the floor level and at the roof level connected to the internal space of the building. During day-time the cool air from the internal space enters the trombe wall through the lower vent. Air between the concrete wall and the glass rises upon heating and escapes into the internal space through the upper vent [5].

Sunlight is used for lighting up the interior of the buildings, even those parts of the buildings which have no direct exposure to the sunlight. Now a days many countries are making use of proactive architectural lighting devices which sense and track the solar path and absorb 20%-36% more sunlight as compared to fixed solar devices [5]. Japanese sunflower fiber-optic light guide system is programmed such that it follows the solar path. Business Support Center in Duisburg, Germany is a practical example of this technology [5].

3 Methodology

Two residential buildings are considered for this study, both are in Lahore but at different locations. One is situated at Raiwind Road, Lahore and the other is located in the Bismillah Housing Scheme, Lahore. Number of occupants of the former building are 5 and the latter are 10 respectively.

Annual primary energy consumption for electricity use is calculated for each of the buildings using the data from the utility bills. Units consumed in the last 12 months have been summed up and converted into the primary energy in KWh.

There are different renewable energy resources like solar energy, thermal energy, wind energy, hydropower etc. Wind energy is not feasible in Lahore since the wind speed is usually less than 15 knots in this region. Thermal energy is an efficient renewable energy resource but it is not feasible for residential buildings as it requires a huge setup and is very expensive. For residential buildings, it is not feasible to have a thermal power plant. Same is the case for hydropower plant. Thus, the most suitable renewable energy source for the area under consideration is solar energy.

Data for solar radiations is analyzed for calculating the solar energy potential in Lahore. For this purpose a software, 'Climate Consultant' is used. This software provides ready-made graphical representation of solar radiations throughout the year based on last 30 years recorded data. The data for Lahore was not available on this software so the data of Amritsar has been used since coordinates of Amritsar (31.63˚N and 74.87˚E) are very close to that of Lahore. Also that Amritsar is approximately 50 kilometers from Lahore.

Following formula has been used for the calculation of the output of 1 solar panel.:

$$E = r \times PR \times A \times H$$

Where;

E = output of solar panel

r=efficiency of panels in percentage

PR=performance ratio

A=Total area of panel

H=annual average direct normal solar radiation on tilted panel (shadings not included)

The number of plates required to fulfil the energy demand of each of the residential building, following formula is used:

$$\text{No. of plates} = \frac{Electricity\ consumption(\frac{Kwh}{day})}{Output\ of\ 1\ plate(\frac{KWh}{day})}$$

4 Calculations and Results

Table 1 represents the covered area of each of the residential buildings in square feet and the primary energy consumption of each of the building in KWh/year. The electricity consumed by these buildings is produced by hydroelectric power plants. The hydroelectric power plants usually have efficiency of 90% [3]. So, the primary energy consumption for generating the electrical energy at hydro power plant is calculated by following conversion:

0.9 KWh of electricity consumption = 1 KWh primary energy consumption

Here electrical energy is converted to its source energy (primary energy) to make it relatable and comparable with other natural energy resources (solar energy in our case).

Table 1-Total yearly primary energy consumption

Residential Buildings	Total covered area (sq.ft)	Yearly electricity consumption (KWh/year)	Yearly primary energy consumption(KWh/year)
Raiwind Road (10 Marlas)	2846	5521	6134.3
Bismillah Housing Scheme (8 Marlas)	2949.96	12943.8	14382

Figure 1 is a graph plotted between months of the year on x-axis and solar radiations in Wh/m^2/hr on y-axis based on past 30 years data record. As indicated in the legend, yellow bar represents the direct normal radiations. Direct normal radiations are considered for the analytical calculations of solar panels. Green bar represents the global horizontal radiation and the orange bar represents total surface radiation.

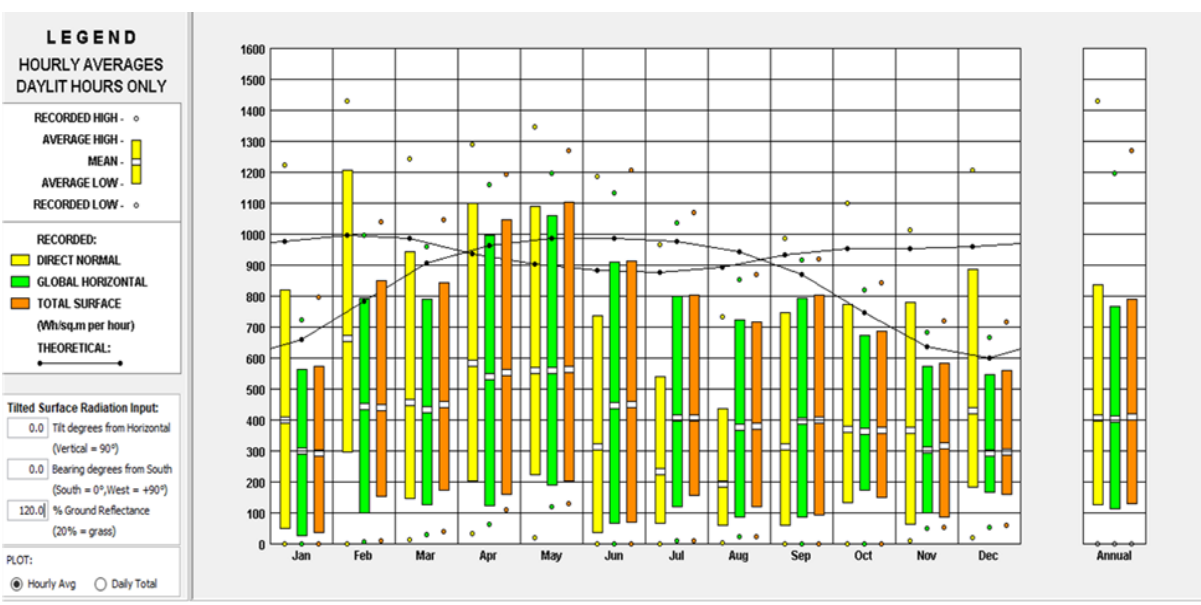

Figure 1: Graph of solar radiations vs time (Source: Climate Consultant Software)

Different types of solar panels are available in the market. Canadian Solar CS6U has been considered in this case. The same model is installed in our university campus. So we easily verified the specifications personally. It has following specifications: -

Table 2-Specifications of Canadian Solar CS6U

Peak efficiency	16.46%
Length of plate	6.43 ft
Width of plate	3.26 ft
Depth of plate	1.6 inches
Weight of plate	22.4 kg

Peak efficiency = 16.46%

Length of plate = 6.43 ft

Width of plate = 3.26 ft

Depth = 1.6 inches

Weight = 22.4 kg

Output of 1 plate denoted by 'E' is calculated as under:

E= r × PR × A × H

A = Area of 1 plate = 6.43*3.26 = 20.96 ft^2 = 1.95 m^2

r = 14% (conservatively)

PR=0.75

H= 200 Wh/m^2.h = 4.8 KWh/m^2.day(From figure 1)

E=1.95×0.14×4.8×0.75 = 0.9828 KWh/day.

For calculating the number of plates required to fulfil the energy demand:

$$\text{No. of plates} = \frac{Electricity\ consumption(\frac{Kwh}{day})}{Output\ of\ 1\ plate(\frac{KWh}{day})}$$

Table 3 gives the information of the number of plates required for each of the residential buildings to fulfil their energy demand.

Table 3-Number of solar panels

Residential Buildings	Yearly electricity consumption (KWh/year)	Daily electricity consumption (KWh/year)	Total number of plates required
Raiwind Road (10 Marlas)	5521	15.126	16
Bismillah Housing Scheme (8 Marlas)	12943.8	35.462	36

The area required for accommodation of these plates is also given in the tabular form in table 4.

Table 4-Area required for accommodation of solar panels

Residential Buildings	Number of plates required	Area required on rooftop for the accommodation of plates	Status of required space availability
Raiwind Road (10 Marlas)	16	335.36	Yes
Bismillah Housing Scheme (8 Marlas)	36	754.56	Yes

5 Recommendations

- The implementation of solar panels for our zero-energy design in the residential buildings not only reduce our nonrenewable energy resource dependency but it will also reduce the carbon footprint and will help in restoring our environment.
- Enough space should be available to accommodate the solar panels and care should be taken that there is no shading over the panels or hindrance to solar radiations.
- The angle of tilt of the solar plates should be determined by tracing the solar path to obtain the maximum efficiency of the plates.
- Hybrid solar system should be installed as we have acute problem of load shedding in our country.
- Passive solar techniques can also be employed for ventilation purposes. In Lahore there is a high cooling demand in summer. Solar chimneys integrated with earth-air heat exchangers can be used for ventilation in summer season.
- Different solar techniques can be implemented in addition to solar panels on industrial and commercial level. For example, proactive solar lighting devices can replace the electrical devices in office buildings and other workplaces.

- We can make use of earth-air heat exchangers integrated with solar chimneys in large closed spaces as in industries, schools, colleges and universities.
- Trombe walls can also be used for the ventilation purposes in winter season, where heat energy from sun is harvested and distributed to the required spaces through vents.
- Passive solar devices can be used to harvest heat energy at large scale in industries with a high demand of heat energy as for boilers in case of textiles industry.

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