*Proceeding Paper*

# The Simulation and Design of Zero-Energy Homes—A Comparison between Photo-Voltaic, Solar-Thermal, and Photo-Voltaic-Thermal Systems †

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**Abstract:** The domestic sector is the leading energy consumer in Pakistan. Due to an increase in population, urbanization, and economic development, energy demand is increasing day by day. To meet this energy demand, net-zero energy buildings provide the optimal solution. In zero energy buildings, energy demand is met by renewable energy sources, such as solar energy. This study describes techniques of home design using simulation, and energy conservation is achieved by using proper construction techniques and insulation materials in building construction. In this study, the actual climate data of different climate zones in Pakistan is being used to design zero-energy homes. The results show that there is a remarkable difference between the energy demand of standard homes and homes proposed by the simulator used. The total energy performance index of a house decreased from 94.6% to 67.6%. The comparative simulation analysis of different solar energy system solutions such as solar thermal, photo-voltaic, and hybrid photo-voltaic-thermal modules for different climate zones in Pakistan, is presented in this paper. This study also describes the best combination of solar energy systems to reach a close-to-zero energy balance and the results depend on the building design and design of building energy systems. A cost analysis based on the rate of return on investment is also presented to motivate the usage of this method.

**Keywords:** energy conservation; zero-energy homes; solar; solar-thermal

## 1. Introduction

Domestic buildings consume almost half of the total energy production in Pakistan [1]. Making buildings more energy-efficient and smart is therefore important to reduce energy demand. Zero energy homes are energy efficient and use renewable energy sources to perform all operations of life. Typically, after a couple of years, the building reaches to the energy balance of zero. The efficient utilization and conservation of energy is an important element of government methodology to meet the issues the power sector has been facing. National energy efficiency and conservation authority have been given the responsibility to conserve energy by planning and initiating different actions, making the policies nationwide.

According to geographical measures, Pakistan is situated at the latitudes between 24° N and 37° N therefore it receives high solar radiation. Due to its sunny climate and high solar radiation, the temperature in the southern areas of Pakistan remains high for 7 months of the year. Considering these realities, Pakistan is the most feasible for solar technologies [2].

Poorly designed buildings become hot in summer and to obtain a comfortable indoor temperature, the HVAC load needs to be increased. This causes greater pressure and demand on the national grid. For energy conservation and a better indoor environment, a

proper structure and the standardized architecture of residential buildings are required. The use of proper passive design techniques can make buildings more comfortable and temperature efficient [3].

The government created policies for energy conservation and Energy Conservation Cell, National Energy Conservation Center (ENERCON), and the Ministry of Water and Power convey these guidelines [4].

The efficient thermal envelope and energy-efficient houses result in the reduction of demand [5]. In [6], the authors performed a comparison between official buildings and energy-efficient buildings by using the simulation software e-Quest. It explains the effects of different structures in the building architecture such as the size of the windows, lighting material, and setting point of the thermostat for the air conditioner and refrigerators. It shows that 5% of energy can be saved by the setting size of the windows [7] and 12% to 16.4% of energy is saved by the appropriate setting of the thermostat for the air conditioners. This shows that energy can be saved when small changes are made such as the use of insulation and coating of the walls of the building and the setting up the temperature of the appliances [8].

Cavity structured walls are better for the buildings to reduce the heating effect. By building cavity structured walls, the HVAC load of the buildings and solar heat gain is reduced [9]. Moreover, it was suggested that the use of LED lights instead of traditional ones was more beneficial. In [10,11], the authors described the different energy conservation techniques for building the structure of the walls, the heating, cooling, and ventilation system design.

## 2. Energy Efficient Building Design

For the reasons stated above, a South-East oriented 5 marlas house with a flat rooftop, housing a family of 4, was designed in order to estimate the solar potential from the utilization of photovoltaic, solar thermal, and photovoltaic-thermal in an effort to achieve zero energy building. The geometry of the building is defined in Table 1. We use BEopt [12] software to design the house. BE-opt is a software that allows the user to evaluate and compare the building designs and retrofit the existing building designs as well as analyze the cost and provide a cost-optimization solution. It allows us to incorporate all the information in the simulation about the architecture, the structure, and the material used in the building as well as the use of different appliances in the household. The national renewable energy laboratory developed this software to be easily used by engineers to make the buildings zero-energy buildings.

**Table 1.** Parameters of a house.

| Geometry of the building | 1390 square feet, bedrooms: 3, baths: 2 |
| --- | --- |
| Orientation | Orientation: South-east, neighbors: 2 (left and right) |
| Walls | CMU-12inch hollow, exterior finish—cement, light |
| Ceiling | Tiles and attics insulated; floor 80% carpeted |
| Windows and doors | Windows double insulated, wood doors, 2 ft leaves |
| Lighting | CFL 34% |
| Ventilation | Natural |
| Space-conditioning | Room air conditioner: 1, ceiling fan: 2 of standard efficiency |
| Water heating | Water heater: electrical |
| Appliances | Refrigerator: 1, cooking range: gas, clothes washer: 1, dryer: 1, shift in the loads from peak hours |

For the energy supply system, we used the POLYSUN [13] software, which allows for the best template to make the design for the heat pump, solar-thermal and photo-voltaic, and their combined systems. The simulation is assisted by the metronome data. Simulation time can be set by the user.

Figure 1a shows the energy usage in different ways in a house, and, in Figure 1b, the overall energy and temperature profile of the house is presented. The energy used for cooling throughout the year and the total energy used are shown in the graph. The dark green line shows indoor temperature, the orange line shows total energy in BTU and the brown line shows energy for cooling the building.
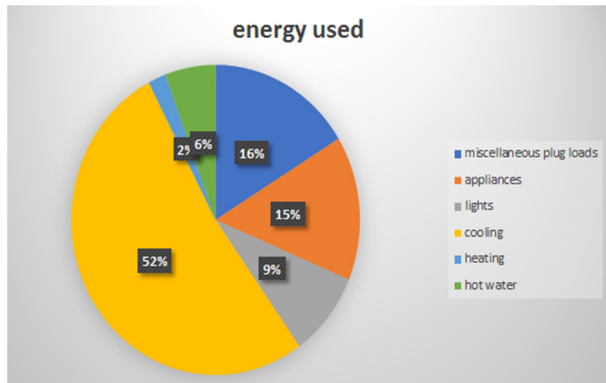


(**a**)
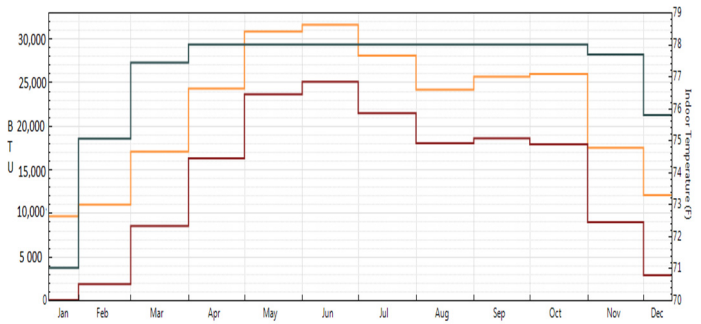


(**b**)

**Figure 1.** (**a**) Energy used in the proposed home; (**b**) Total energy and Indoor temperature graph.

We examined the different combinations of solar collectors, photovoltaic, and storage tanks to check the impact of these combinations on the total solar coverage. In order to meet the building load, each building was assumed to have a backup of natural gas. In order to meet the electrical loads of the buildings, different sized photo-voltaic systems were evaluated with different capacities.

### 3. Results

We proposed a thermal energy system, for different cities, but in this paper, we present the results for the city of Quetta. Figure 2a shows a monthly energy profile of the house and Figure 2b shows the energy deficit in the city of Quetta for the different months of the year. During the analysis of the results, the PVT shows the best results. These results are given in Table 2.
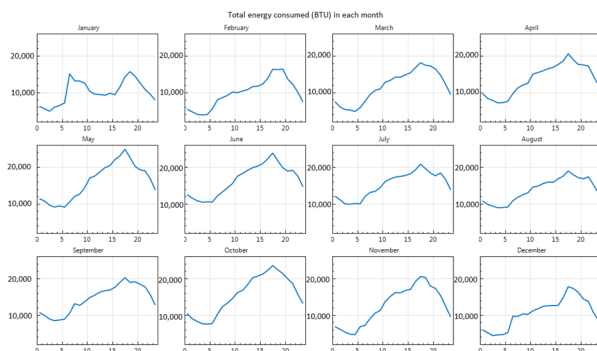


(**a**)
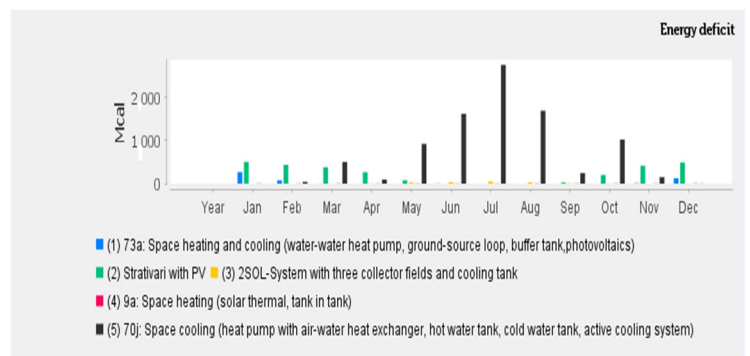


(**b**)

**Figure 2.** (**a**) Monthly profile of source energy for a new home; (**b**) Energy deficit in Quetta.

**Table 2.** Comparison for the city of Quetta.

| Type | Energy from Grid | Energy to Grid | Profit (PKR) |
|---|---|---|---|
| PV | 4823 | 3880 | −23,575 |
| PVT | 2621 | 7786 | 129,125 |
| PV + Solar-thermal | 1934 | 2716 | 19,550 |

The simulations show that more than half of the energy used in the domestic building is consumed to maintain the indoor temperature. The following graph shows the energy used in heating, cooling, domestic hot water, lights, and other usages. The indoor temperature in Fahrenheit, energy used for cooling throughout the year, and the total energy used, are shown in graph 3. The dark green line shows the indoor temperature, the orange line shows the total energy in Btu and the brown line shows energy for cooling the building. The need for energy for cooling, lighting, and heating is remarkably less. There is a noticeable effect of doing small changes in the structure and using advanced technology. The total energy index of the house transfer is from 94.6 to 67.6. This is the noticeable energy conservation as shown in Figure 2b.

## 4. Conclusions

In this paper, energy conservation and the investigation of the utilization of solar techniques such as photo-voltaic, solar-thermal, and photo-voltaic-thermal modules in typical residential buildings of different cities were carried out. This study was performed to analyze the impact of zero-energy buildings. Many factors have influenced the results such as the boundary conditions and, energy balance calculations, and the aim is either to get closer to the energy demand or fulfill the energy demand at a low cost.

Three systems are studied for the single-family house. The photo-voltaic-based energy system, the solar-thermal collector, the photo-voltaic-thermal module system, and the combination of PV and collector systems are studied for different cities. The overall aim is to conserve energy and achieve the demand for the operation of a domestic house. Through the proper insulation and construction of buildings, energy can be conserved. The energy index rating can be transferred from 94.6% to 67.6%.

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