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# Net zero energy analysis and energy conversion of sustainable residential building in Muscat, Oman

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**Abstract:** The building sector is the predominant consumer of primary energy globally. The building sector accounts for around 40% of global energy production. Net Zero Energy Buildings (NZEBS) are highly suggested by energy experts as an effective option to alleviate the strain on primary energy sources caused by the building sector. The disparity between energy performance predictions provided during the design phase and the actual energy performance of residential buildings is mostly attributed to a limited comprehension of the components that influence energy consumption and the constraints of whole building simulation software. The objective of this research was to perform a comparison analysis of the expected and actual energy consumption of a prototype net-zero energy house built at the University of Technology and Applied Sciences in Muscat. The Hourly Analysis Programme (HAP V4.2) was utilised to forecast the energy consumption of a Net Zero Energy Building (NZEBS) at HCT, taking into account the availability of an Energy Recovery Ventilator (ERV) and the absence of an ERV. The newly built house underwent a one-month testing phase to fulfil many duties according to competition regulations. One of the main goals was to generate on-site energy through photovoltaic panels, producing an amount proportional to the energy consumed by the house. Upon comparing the actual energy consumption data with the simulated result, it was noticed that the actual energy demand of the house was around 20% lower than the prediction made by the simulation tool.

**Keywords:** sustainable buildings; energy conservation; ecohouse; energy demand; Net Zero energy

## 1. Introduction

The building sector is the foremost consumer of primary energy globally. The International Energy Agency (IEA) estimated in 2023 that the final energy consumption of the building industry reached 2794 million tonnes of oil equivalent (Mtoe), which is double the amount recorded between 1971 and 2019. The buildings sector is expected to increase its demand for primary energy supply by an additional 838 million tonnes of oil equivalent (Mtoe) by 2035, compared to the demand in 2019. This would put significant strain on the primary energy supply. The building sector accounts for 40% of global energy production [1]. However, according to the Internal Energy Agency [2], residential buildings in Oman consumed 47.5% of the energy produced in 2022, which is 7.5% higher than the average global demand for the building sector. There are four generally utilised definitions based on site energy, source energy, cost, and emission-based criteria. The building designer chooses the net-zero site energy option to meet the energy code criteria. A site zero energy building

(ZEB) is a building that produces an equal or greater amount of energy than it uses over the course of a year, when measured at the building's location [3].

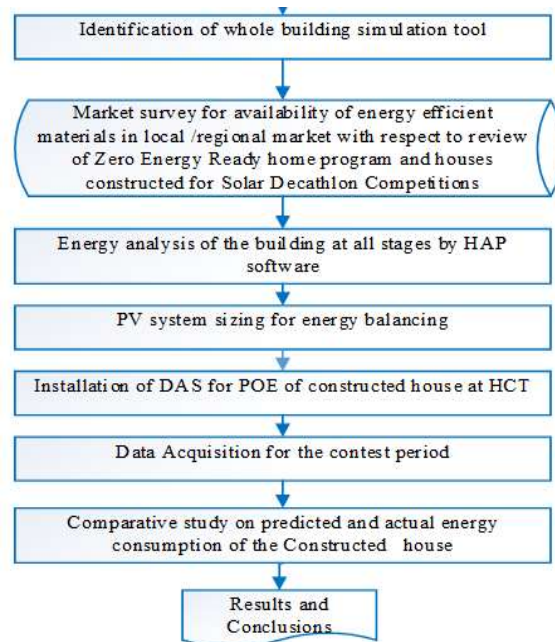
Net Zero Energy Buildings (NZEBs) are highly suggested by energy experts as an effective option to alleviate the strain on primary energy sources caused by the building sector. The significance of this solution is acknowledged universally by governments, NGOs, unions, and agencies. A number of projects and orders worldwide are focused on NZEB solutions, which aim to reduce the reliance on primary sources of energy. Some notable examples include the ENERPOS French national project [4], IEA-SHC task 40 [5], IEA task 25 [6], IEA task 38 [7], IEA-SHC task 53 [8], APEC project [9], EPBD recast 2019/31/EU [10], ASHRAE vision 2020 [11], Executive Order (EO) 135 [12], Zero Energy Ready Home Programme [13], and Solar Decathlon competitions worldwide [14]. The design of a Net Zero Energy Building involves the combination of renewable energy sources and passive house principles to minimise reliance on primary energy sources and decrease CO<sub>2</sub> emissions. The design of Net Zero Energy Buildings consists of two primary parts. The first step focuses on enhancing energy efficiency through efficient building architecture, systems, appliances, operation, maintenance, and changes in user behaviour. The second step entails meeting the remaining energy needs with on-site renewable generation [15]. Model simplifications, discrepancies between forecast and final construction, occupant behaviour, commissioning, controls, management, and maintenance are among the main factors that negatively impact the actual energy consumption of residential buildings compared to simulated results. This report provides an energy analysis of the Eco home located at HCT in Muscat, Oman. The house was specifically built to attain net-zero energy status with the installation of a photovoltaic (PV) system on the roof, in the form of a canopy. Section 2 provides an introduction to the regulations of the Eco home competition. Section 3 explains the research technique used to design the house. Section 4 emphasises the energy efficient elements incorporated into the Eco house at HCT in Muscat, Oman, in order to decrease the house's energy use. Section 5 gives the energy analysis results obtained using HAP software. It also includes a comparison between the actual energy consumption of the Eco house, as recorded by the data acquisition system (DAS), and the energy consumption anticipated by the HAP software.

## **2. Research methodology**

The Eco home team initiated the project by adopting an integrated building design strategy and examining the international energy conservation guidelines of 2018. The project was separated into three distinct phases: design, conceptual, and development. During the design phase, the building's conceptual energy analysis is conducted using the TAS software 'Thermal Analysis Simulation' developed by Environmental Design Solutions Limited (EDSL), available at <http://www.edsl.net/main/>. The Green Nest team took into account the following recommendations during the conceptual design and development stages for the building: The building has a rectangular shape that is expanded on the north-south axis. It is a two-story structure with a courtyard. The East and West facades have fewer openings. The building has a window-to-wall ratio of 20%, meaning that 20% of the

walls are made up of windows. The southern facade and roof are shaded to reduce sun exposure. Following the conceptual energy analysis, a comprehensive building energy analysis was conducted using HAP software to determine the energy consumption of the structure.

This analysis was based on the architectural building information model (BIM), which includes detailed information about the thermal properties of the walls, windows, floors, and roof construction. During the final phase of the design process, a comprehensive energy analysis of the building was conducted using HAP software. This software offered specific information on the annual energy consumption of lighting, electrical, and HVAC systems. The Greenest team utilised the PV Watts calculator to optimise the energy supply from solar panels and meet the energy demand of the house throughout the construction phase. The results of the HAP and PVWatts research assisted the team in identifying the most suitable HVAC equipment and optimal solar system size. The research methodology chosen for designing a Net Zero Energy Building is summarised in **Figure 1**.



**Figure 1.** Research methodology.

### 3. Eco house at HCT, UTAS Muscat, Oman

The floor space of the two-story Eco house at Higher College of Technology (HCT), University of Technology and Applied Sciences (UTAS), Muscat, Oman, is 230.7 m<sup>2</sup>. The ground floor of the house comprises a majlis, dining room, living room, and kitchen. The first level comprises a master bedroom, a children’s bedroom, and a guest bedroom. The house is equipped with a grid-tied solar energy system with a DC rating of 22.8 kW. This system is positioned on the top of the house in the form of a canopy, facing south at a fixed angle of 5°. It is designed to maintain a temperature range of 25 °C–27 °C and a relative humidity range of 50%–70% throughout the year.

The house is built using insulated concrete forms for the walls, which have a U value of 0.233 W/m<sup>2</sup>K. The roof is made of hollow core slabs with a U value of 0.339

W/m<sup>2</sup>K, and it is also covered with solar panels. The windows are double-glazed with a shading coefficient of 0.48, and their overall U values range from 3.25 to 4.1 W/m<sup>2</sup>K. The certified wooden doors have U values ranging from 3 to 3.5 W/m<sup>2</sup>K. These features help to achieve the desired energy balance during the competition period.

The house is equipped with energy recovery ventilators, with one unit for each story. Additionally, there are variable refrigerant volume heat pumps, with one unit for each floor. These systems are designed to maintain comfortable conditions throughout the year. A solar hot water system with electric backup, freezer, refrigerator, clothes washer, induction oven, dishwashers, home electronics, and internal and external lighting were installed in the house to fulfil various tasks as advised by the competition organiser.



**Figure 2.** Eco house at University of Technology and Applied Sciences, Muscat, Oman.

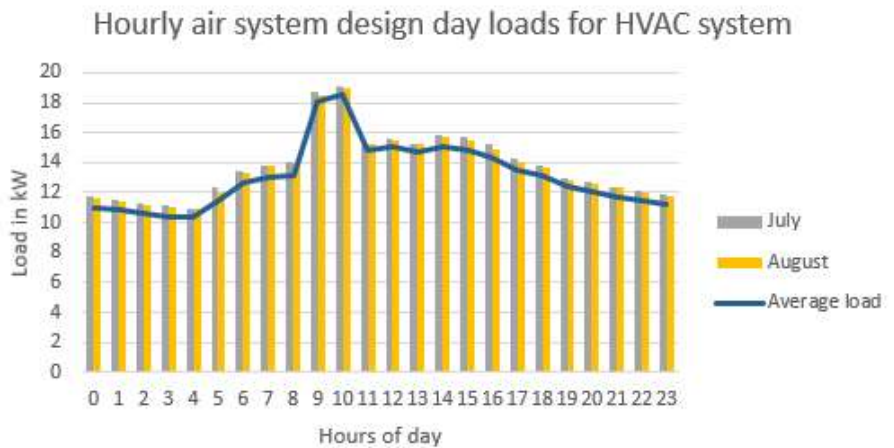
The house is outfitted with a data acquisition system (DAS) that monitors and records performance and administrative measurements for various contests related to comfort zone, refrigerator, freezer, hot water, clothes washer, cooking, dishwasher, lighting, home electronics, and energy balance. This is illustrated in the accompanying **Figure 2**. The completed Eco house at the University of Technology and Applied Sciences in Muscat incorporated several sustainable elements, as outlined in **Table 1**. The Eco house team successfully achieved the goal of creating a Net Zero Energy Building for the competition duration, thanks to these groundbreaking innovations.

**Table 1.** Sustainable features of the house.

S/No	Sustainable feature description	S/No	Sustainable feature description
1	Appropriate sizing/ number of floors	11	Cross flow ventilation
2	North-South oriented building	12	Certified wood (FSC certified)
3	Insulation of wall (NADURA ICF), roof and floor	13	Vertical green wall (west wall)
4	Double glazed windows	14	LED lighting
5	External shading	15	5-Star energy efficient appliances
6	Food and low water plants	16	Solar hot water system
7	Eco friendly refrigerant	17	Energy generation onsite by solar panels
8	Energy recovery ventilator	18	Solar mobile charging station
9	Grey water treatment system	19	Real-time energy and water usage display
10	Rainwater collection	20	Paints with low toxicity

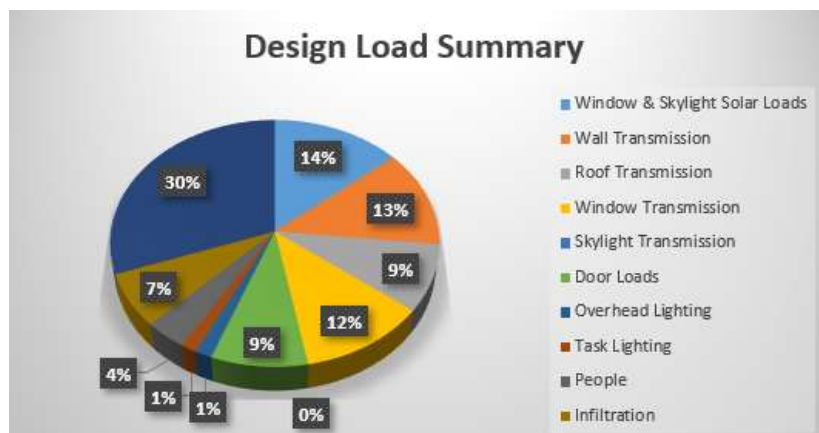
#### 4. Energy analysis results

The graphic displays the mean HVAC load on the central cooling coil. The summer profile was derived using the mean data collected from May to October 2023, including the months of July and August 2023. This is illustrated in the accompanying **Figure 3**. The significant surge observed between 8:00 am and 10:00 am can be attributed to the arrival of six students who engaged in various activities such as cooking, water heating, turning on electric lights, and operating home appliances.



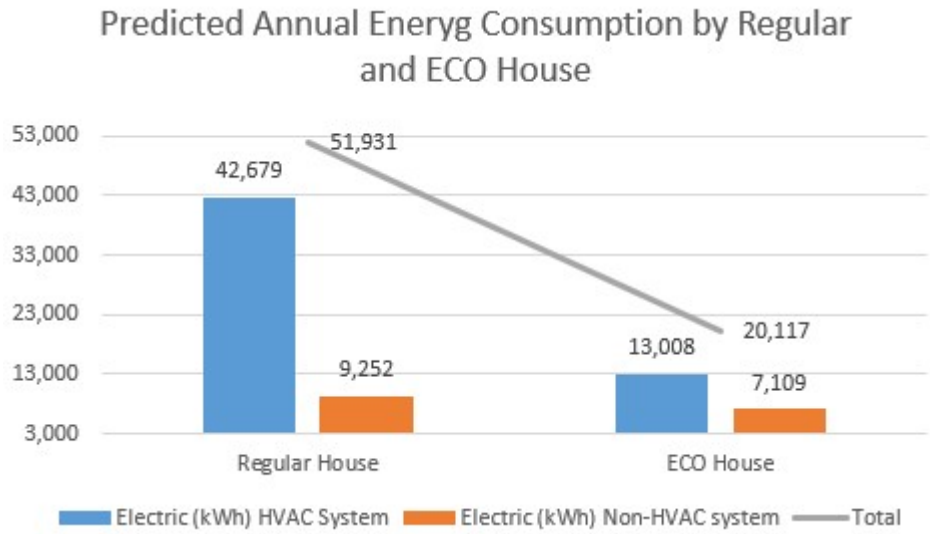
**Figure 3.** Hourly air system design day loads for HVAC system.

**Figure 4** displays the simulation results for the zone design load of the building envelope, lighting, people, and electric equipment. The findings revealed that electric equipment contributed 30% of the overall cooling load, while windows, walls, roofs, and the lighting system collectively accounted for 7% to 14% of the load.



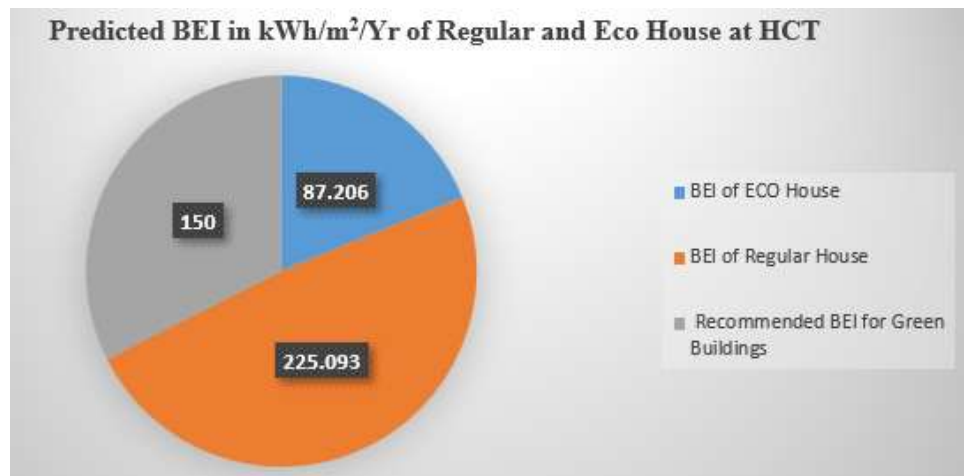
**Figure 4.** Zone design load summary.

The data presented in **Figure 5** demonstrate the energy requirements of a standard-sized house and an eco-friendly dwelling in Muscat. The projected findings indicate that the energy consumption of the Eco house is 61.2% lower than that of a standard house, mostly due to a reduction of 69.5% in HVAC load and 23.16% in non-HVAC load.



**Figure 5.** Annual Energy Consumption by Regular and Eco house.

The Building Energy Index is a metric that quantifies the overall energy use of a residential property over the course of one year, divided by the entire floor area of the property. In this instance, the analysis solely projected the BEI values for the regular house and Eco house while also providing the suggested BEI for green buildings (see **Figure 6**). This was due to the lack of available data on the Eco house’s energy consumption for a complete year under the same operating conditions specified in the competition criteria in **Table 1**. The Building Energy Index (BEI) of the Zero Energy House at HCT is 87.20 kWh/m<sup>2</sup>/year, which is significantly lower than the BEI of 225 kWh/m<sup>2</sup>/year for a conventional house of the same size in Muscat. This information is based on the predictions made by the simulation tool and aligns with the suggested BEI for green buildings in Malaysia [15].

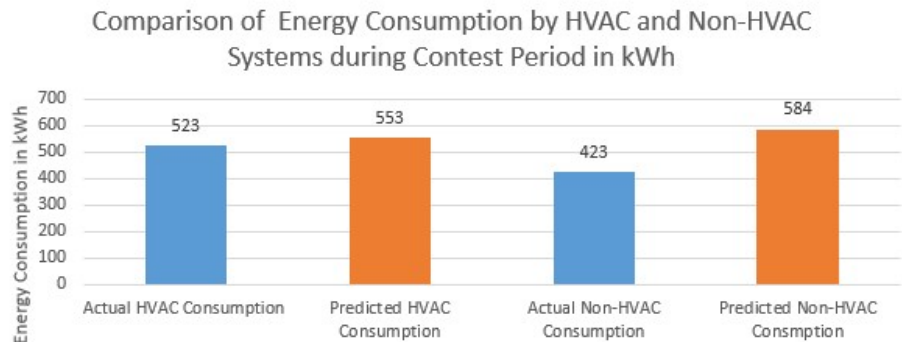


**Figure 6.** Building Energy Intensities of different houses.

The figure displays the energy consumption results of both HVAC and non-HVAC systems over the competition period, including both the actual and forecasted values (see **Figure 7**). A comparison of the results showed that the energy consumption predicted by the HAP software for the HVAC system was only 5%

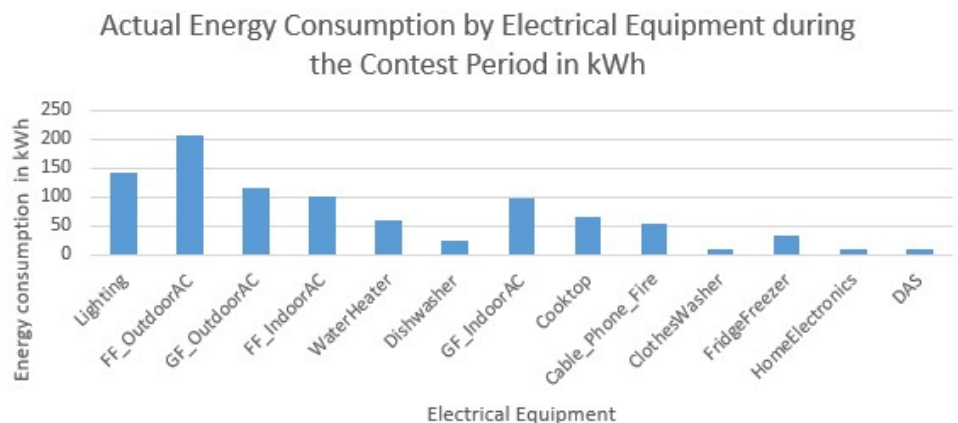


higher than the actual energy consumed during the competition period. However, the energy consumption predicted by the HAP software for the non-HVAC system was 27.56% higher than the actual energy consumed by the house. This difference can be attributed to the non-operation of the Energy Recovery Ventilator and Grey Water Pump during the competition period. The HVAC system of the house accounted for 44% of the overall energy consumption during the contest time, while the non-HVAC system accounted for the remaining 56%.



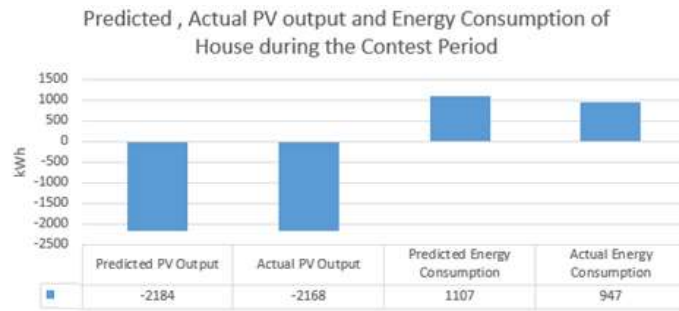
**Figure 7.** Comparison of energy consumption by HVAC and Non-HVAC system during contest period in kWh.

The graphic displays the real energy consumption of electrical equipment throughout the contest period. The energy consumption breakdown is as follows: HVAC system accounted for 55.26% of the total energy, lighting system for 14.95%, cook top for 6.84%, water heater for 6.31%, fridge-freezer for 3.8%, dishwasher for 2.68%, clothes washer for 0.95%, home electronics for 1.06%, DAS for 1.08%, and unmeasured electrical load for 1.57% (see **Figure 8**).



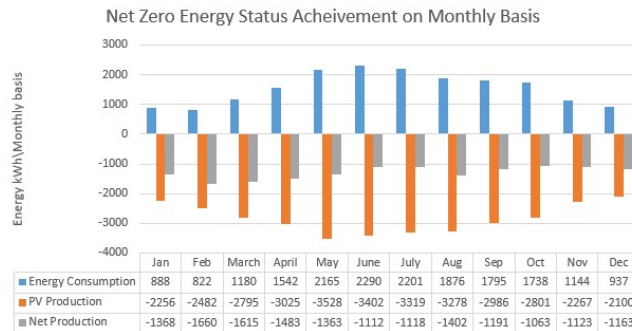
**Figure 8.** Actual energy consumption by electrical equipment during the contest.

The PV watt calculator estimated that the solar system installed in the Eco house would produce approximately 34,239 kWh of electricity in one year. The PV watts calculator forecasted a production of 2183.5 kWh for the competition month, from 18 September to 16 December 2023. However, the solar system installed on the roof only generated 2167.77 kWh during that period, which is a deviation of only 0.73% from the expected numbers, as depicted in **Figure 9**.



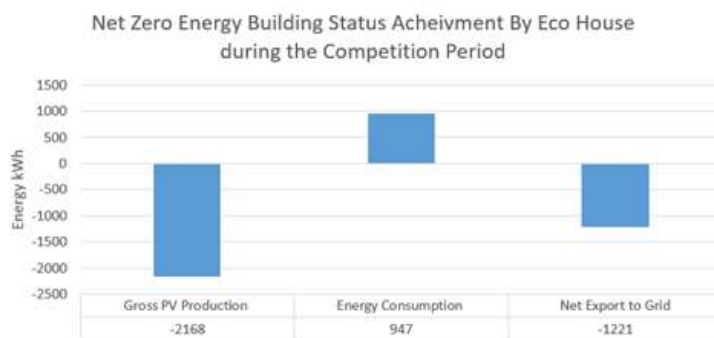
**Figure 9.** Predicted and actual PV output and energy consumption of house during the contest period.

The comparison of energy consumption and energy production data, as shown in **Figure 10**, indicates that the Eco house is able to consistently attain a net zero energy status on a monthly basis. The findings from **Figure 10** indicate that the Eco house is capable of generating an additional 32.7% of energy during the peak energy-demanding month of June and up to 64.5% extra energy during the month of February, which has the lowest energy demand. The findings indicated that by implementing a safety margin of 10%, a house can attain a net zero energy status on an annual basis while requiring a 40% smaller photovoltaic (PV) system for installation.



**Figure 10.** Net zero energy status achievement on monthly basis.

The data acquired from the installed data acquisition system in the Eco house, as shown in **Figure 11**, indicates that the building has successfully achieved the status of a Net Zero Energy Building during the contest time. Furthermore, it has exported a total of 1221 kWh of energy to the grid.



**Figure 11.** Net zero energy building status achievement in contest month.



## 5. Conclusion

The building sector is characterized by high energy consumption, and the cost of energy represents a substantial portion of its daily operational expenses. The building sector obtains energy from the grid, which is generated by thermal, hydro, nuclear, and off-site renewable energy sources, as well as on-site renewable energy sources. This study evaluated the energy consumption of a 230 m<sup>2</sup> Eco house and found that the HVAC system, lights, induction hob, water heater, and freezer are the primary energy consumers in the house. Identifying sustainable components in the design of an Eco house is considered a valuable strategy to attain a low Building Energy Index (BEI) of 87 kWh/m<sup>2</sup>/year in comparison to a typical house with a BEI greater than 225 kWh/m<sup>2</sup>/year. The analysis suggests that the amount of electricity consumed by the household was lower than the amount of electricity produced by the grid-tied solar system during the competition period. This project stands out as an early and successful endeavour to create a net-zero energy building in Muscat. The positive outcomes of this project provide strong encouragement to construct several net-zero energy buildings in the GCC region. This will help to decrease energy consumption and reduce the building sector's contribution to CO<sub>2</sub> emissions.

**Author contributions:** Conceptualization, methodology, simulation, analysis, MS; writing—original manuscript preparation, MS and HZS; introduction, HZS; review papers and method writing of the manuscript, SM; supervision, visualization, and editing of the manuscript, KA. All authors have read and agreed to the published version of the manuscript.

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**Conflict of interest:** The authors declare no conflict of interest.

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