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Zero Carbon Ready Metrics for a Single-Family Home in the Sultanate of Oman Based on EDGE Certification System for Green Buildings

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Abstract: A single-family house was designed as a new middle-income green residential building in the Sultanate of Oman, according to criteria defined by the green building certification system EDGE (Excellence in Design for Greater Efficiencies), developed by the International Finance Corporation (IFC), which is a member of the World Bank Group (WBG). The design was accomplished through the free cloud-based tool of EDGE. With respect to a base design for the Sultanate of Oman, the green home design achieved savings of 40.86%, 20.22%, and 26.39% in energy, water, and materials (Embodied Energy), respectively. In addition, a saving of 35.48% in greenhouse gas (GHG) emissions was estimated. Based on the completed green building design, four green building-normalized metrics were used to quantify the efficiency of the base case and the design case in terms of the consumption of resources and polluting emissions. These efficiency metrics are: Carbon Emission Index (CEI), Energy Performance Index (EPI), Water Consumption Index (WCI), and Embodied Energy Index (EEI). Out of these green building performance metrics, the EPI is directly provided by EDGE, while the other three are introduced here as additional useful indicators that allow fair evaluations and comparison with other buildings, due to their less stringent dependence on the floor area or the number of occupants.

Keywords: EDGE; green building; zero carbon; zero carbon ready; Oman

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1. Introduction

1.1. Background

According to the Department of Economic and Social Affairs (DESA) in the United Nations (UN), the urban global population (those living in urban areas rather than rural areas) was 55% in 2018, and is expected to grow to 68% by 2050. Thus, the urban population is expected to grow from 4.1 billion in 2018 to 6.7 billion in 2050. This growth is driven by a normal population increase, as well as by a social change with a gradual shift in residence from rural communities to urban communities. The level of urbanization is not equal globally, varying in 2018 from 43% in Africa to 82% in Northern America [1]. Examining the historical change in the global percentage of urban population shows that it increased nearly linearly from 33.6% in 1960 to 56.6% in 2021, giving an average increase rate of 0.38% per annum. Oman (officially Sultanate of Oman) in particular already has a high urbanization level, which reached 87.0% in 2021 (compared to only 16.4% in 1960). This big change initially followed a steady profile from 1960 and 1993, reaching 71.0%, thus achieving an urbanization rate of about 1.65% per annum. This first phase of rapid urbanization was followed by a period of a nearly fixed urbanization level till 2005, when it started to grow again at a slower rate than the earlier urbanization phase, but still faster than the global rate. This historical growth in the national (Omani) and global (worldwide) urbanization levels is demonstrated in Figure 1.

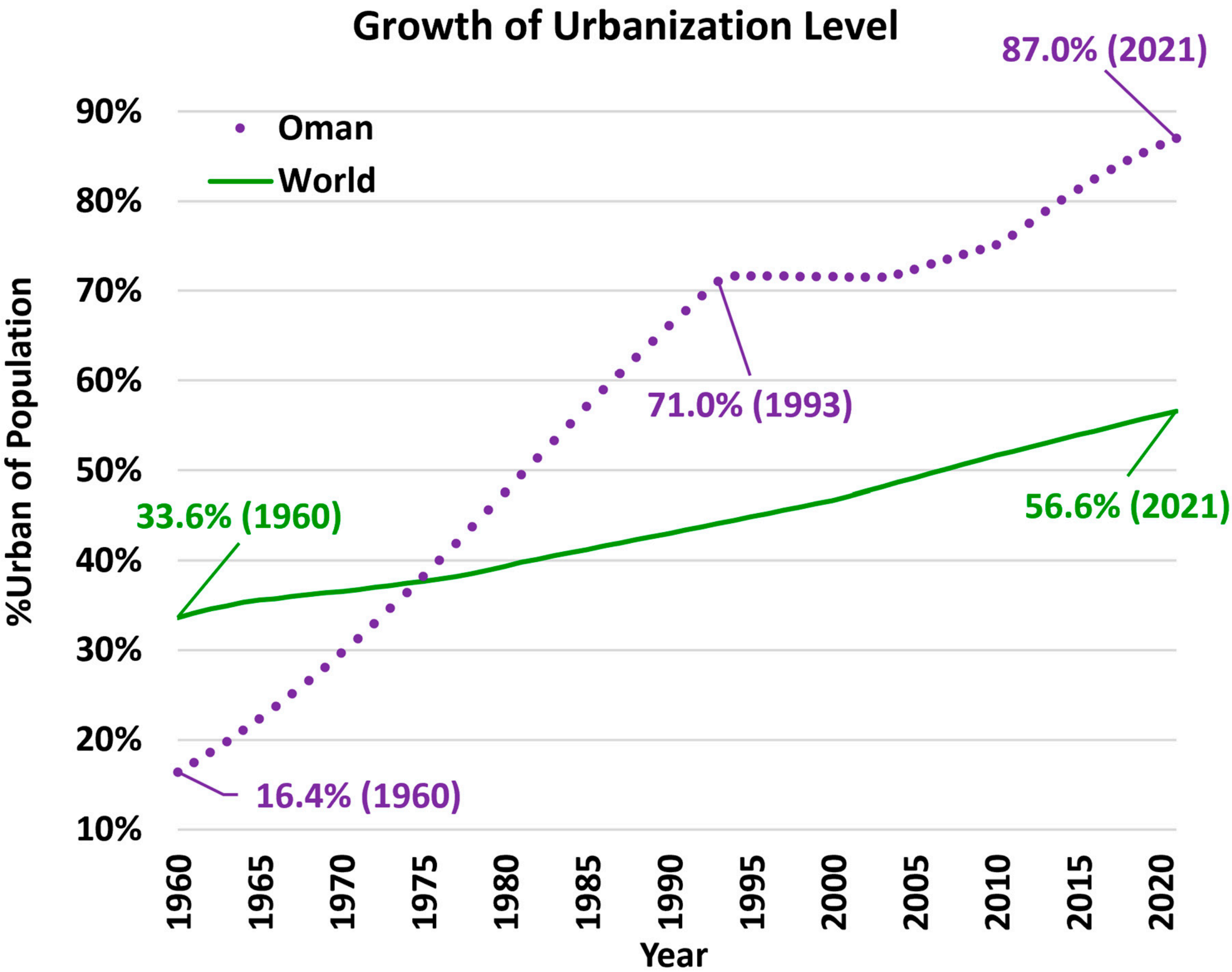

Figure 1. Historical data for the urbanization level from 1960 to 2021. Data source: The data were made publicly accessible from the World Bank Group [2,3].

In 2018, the buildings and the construction sector accounted for 39% of carbon dioxide emissions (11% of which were due to produced construction products and materials such as cement, steel, and glass), and also accounted for 36% of the final energy use [4]. This contribution to carbon emissions and energy consumption shows the environmental benefit of transitioning from conventional buildings to green (sustainable) buildings, which are characterized by the efficient use of energy, the reduced or even eliminated release of greenhouse gas emissions, less demand placed on natural resources for both ongoing operation and initial construction, and suitability for smart cities [5–9]. These environmental benefits from green buildings are even emphasized in countries with high urbanization levels, such as the Sultanate of Oman. In particular, green buildings help achieve carbon neutrality or zero carbon emissions, such that any amount of carbon dioxide released to the atmosphere is counteracted by a same amount removed from it [10,11]. Reductions in emitted fossil fuel-based carbon dioxide and other greenhouse gases are an important step to slow down climate change, as observed by global warming [12,13].

A number of green building certification systems were established, which include criteria and rating structures to clarify the necessary attributes of a green building, as well as the various levels of attaining these attributes. Such green building certification systems include the LEED system (Leadership in Energy and Environmental Design), set out by the U.S. Green Building Council–USGBC [14,15]. As of 10 September 2022, there were 18 projects (buildings) that were successfully certified under the LEED program in Oman, such as the Mall of Oman in Muscat, and the City Centre–in Suhar [16]. This is a relatively small number, given that the total population (citizens and non-citizens) in Oman in August 2022 was 4,796,112 [17], and the number of issued building permits from 2011 to 2020 (during 10 years) was 336,616 [18].

EDGE (Excellence in Design for Greater Efficiencies) is another green building certification system. EDGE is an innovation and a registered trademark of the International Finance Corporation (IFC), which is one of the five institutions of the World Bank Group (WBG). EDGE is not just a certification system, but offers a free cloud-based application for designing a green building with several available categories for the usage type (such as home, hotel, office, retail shop, hospital, and school). The user can utilize this cloud-based EDGE software application to explore various options for savings in (1) energy consumption, (2) water consumption, and (3) materials (embodied energy), compared to a base case. The term "embodied energy" for a construction product means the demanded energy for extracting and processing the raw materials required to make that product. It is an indirect form of energy consumption that is not accounted for when measuring or predicting the direct energy consumption reflected in the operational energy [19,20]. It is worth mentioning that a recent (July 2023) technical update in the EDGE software changed the style of reporting savings in the Material category from embodied energy to embodied carbon per internal floor area [21], expressed as $kgCO_{2e}/m^2$. However, the former embodied energy style is used in the current work. EDGE received funding from the UK Government, with original funding from the Switzerland State Secretariat for Economic Affairs (SECO). It also received additional support from other sources, including Austria, Canada, Denmark, European Union, Finland, Hungary, and Japan [22].

As a brief comparison between LEED and EDGE, LEED certification is a point-based system for validating that a building, an interior design, or an entire community is green (sustainable) and comfortable for its users. Being a point-based certification system means that the project to be certified through LEED should accumulate a certain number of points by meeting as many criteria as possible, in various categories, such as: Water Efficiency, Materials and Resources, Indoor Environmental Quality, and Location and Transportation. LEED has four levels of certifications: Certified (minimum level), Silver, Gold, and Platinum (best level). It is not necessary for a project in LEED to focus on a certain category over another, because the points in the different categories are treated equally. On the other hand, EDGE certification is a saving-based system for validating that a building is green (sustainable) with conserved natural resources during its construction and its operation. Being a savings-based certification system means that the building project to be certified through EDGE should achieve a certain percentage of reduced consumption with respect to a base case that depends on the location and type of the project (such as a 20% reduction in the annual energy consumption). EDGE offers three certification levels, which are EDGE Standard, EDGE Advanced, and EDGE Zero Carbon. EDGE has a large advantage over LEED, which is the availability of a free online interactive self-assessment tool that any person can utilize after making a free online user account, to explore the possibility of a building design (as per data entered by the person into the online tool) receiving an EDGE certification, before starting any official registration for actual certification and before an official evaluation (which requires an EDGE auditor to review submitted building documents, and to perform a site visit). It is this big advantage in EDGE that justifies its selection in the present study.

The base case in EDGE is formed automatically based on the location of the project and its type, through a built-in database of information. The web-based EDGE application also provides cost analysis, such as the estimated monthly utilities cost for the base case and the reductions expected due to modifications made in the design case. The term "design case" in the present study refers to the improved building design after applying certain sustainability measures within the EDGE application. Therefore, the design case is the final green building design reached after modifying the starting building design representing the base case (the baseline building) as described by the EDGE software application.

The EDGE website lacks an all-inclusive database of all certified projects. However, it has a database of some project studies that were submitted by EDGE clients, which received EDGE certification (at any of its three levels) worldwide. As of 11 September 2022, this project studies database contained 610 projects. These include airports, educational institutions, homes, hospitals, hotels, industrial facilities, offices, places of worship, retail shops, and warehouses. The (homes) sector is the largest one among these, with 352 projects (thus, 57.7% of all listed projects). The distribution of EDGE certifications over the various building types in this database is illustrated in Figure 2. None of these projects are in Oman.

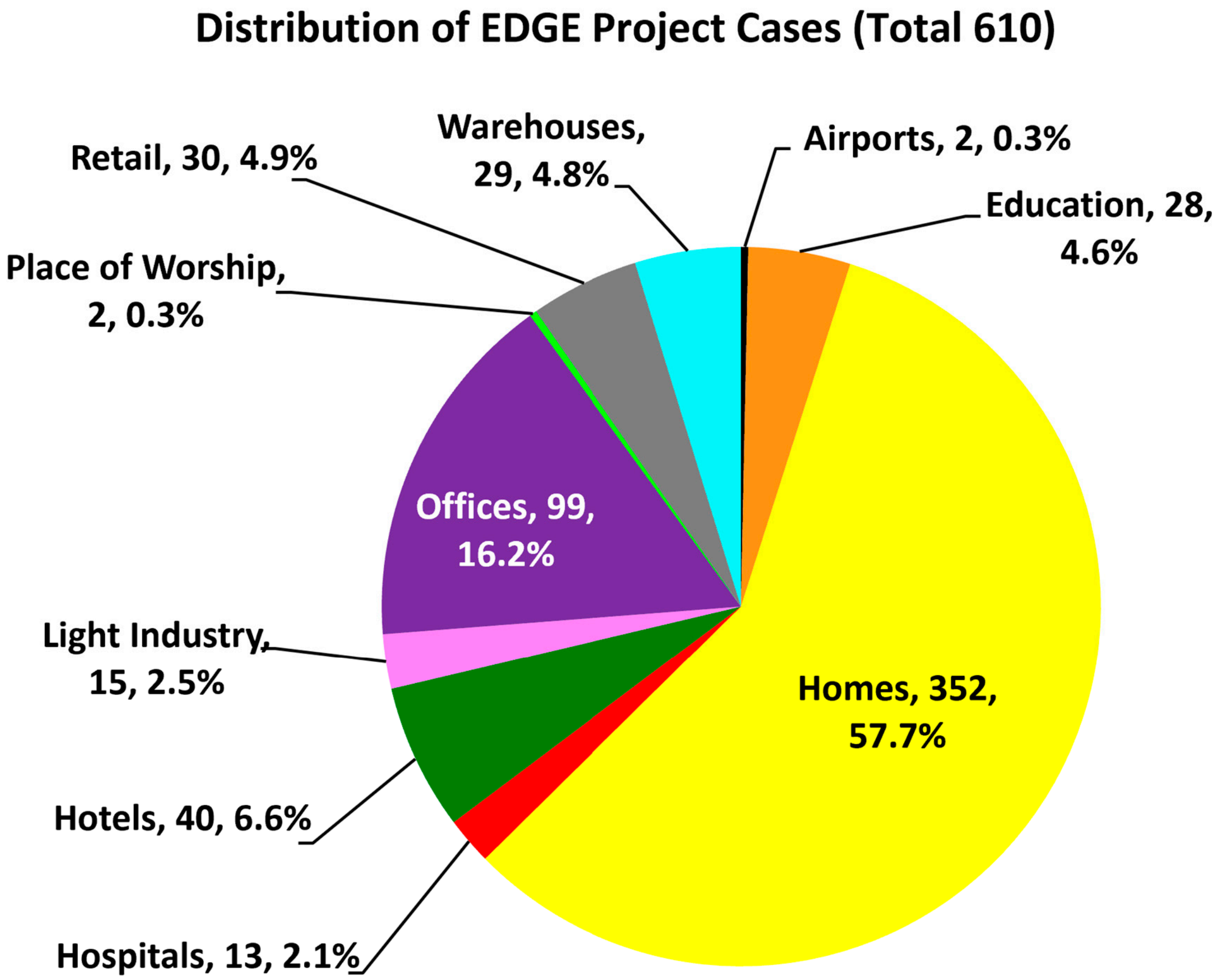

Figure 2. Number and percentage of EDGE-certified project studies in different sectors, as of 11 September 2022. Data source: EDGE.

On the contrary, LEED established a comprehensive certification database, which contained 86,709 certified projects (also as of 11 September 2022) worldwide in all of the four certification levels of LEED [23,24].

Both LEED and EDGE are renowned programs for green building certification. LEED has a wider scope and covers urban projects not addressed by EDGE, such as neighborhood-scale certification at the level of a whole community [25]. However, EDGE has some advantages compared to LEED. Perhaps the most important is the free web application provided by EDGE, which can be used for self-assessment as an initial informal stage of certification, without incurring any cost. The second advantage is the relative simplicity of the certification criteria and the condition to achieve them. The third advantage of EDGE is the built-in database of information that is customized adaptively to the location determined by the user for the green building being designed. Thus, the user does not need to make a lot of effort in collecting these data. Such data include prices and climate profiles.

The fourth advantage of EDGE is the interactive response that can be obtained instantly as the user adapts the building design online, which helps in exploring the impacts of various changes in the building to save operational energy or water needs, or optimize the construction materials. A complete green building design may be completed through the EDGE application in just one hour, although very careful and detailed designs may take much longer, through an iterative process of design. The digital design can be stored and retrieved online. It does not have to be completed in one session.

1.2. Goal and Contribution of the Study

This study may be viewed as an attempt to promote awareness about green buildings in Oman. It presents an example design of a green residential building for a family of four members, with a total gross internal area of 200 m^2 (2153 ft^2). The study provides details about four normalized green building metrics (indices) that can be used as generic targets or benchmarking levels to compare with, when assessing the level of sustainability of other buildings in Oman, either without taking sustainability measures into account (the base case) or with adopting them (the design case). The green building design presented here is classified as a ZCRB (Zero Carbon Ready Building) or a renewable energy ready building [26,27], which means that the building design does not only show satisfactory levels of savings in energy, water, and materials, but also has the potential to be a net-zero source of greenhouse gases without major retrofitting in the future, either through purchasing renewable energy from an offsite source, such as using a power purchase agreement (PPA [28,29]), or through purchasing enough carbon offsets [30,31] to counteract greenhouse gases released from operating the building. In the ZCRB design presented here, it was intended to adopt enough changes in the base building to meet the certification requirement, while minimizing the excess in compliance beyond the minimum requirements. This makes the design closer to conventional buildings, and less expensive to achieve in reality.

The concept of Net Zero Energy Building or nearly Zero Energy Buildings (Net ZEB, NZEB, ZEB, nZEB) is related to ZCRB. In NZEB, efficient low-energy building structures are combined with renewable energy utilization to allow zero (or nearly zero) energy balance on an annual basis. Thus, during a one-year period, the building generates as much energy as it consumes. However, an NZEB does not need to achieve a zero energy balance instantaneously [32–36].

For readers inside Oman or neighboring Gulf Cooperation Council members (GCC countries: Oman, United Arab Emirates, Saudi Arabia, Qatar, Kuwait, and Bahrain), with similarities in climate, culture, and economy, this study provides a complete example of what a traditional house needs in order to be classified as a green building. This study apparently contributes to the subject of green building certification in Oman, and GCC in general, which is not addressed deeply in the literature and thus warrants further studies [37,38]. The study may motivate others to either implement some of the mentioned sustainability measures, or to extend them to other building types, where savings in energy, water, and material can lead to pronounced environmental and economic gains.

For the readers outside Oman who are not familiar with the EDGE certification system or the corresponding EDGE software application, this study provides an overview supported with an example of utilizing the free web application, and the benefits it offers. The study also includes various explanations and remarks related to the EDGE reporting mechanism that can be valuable to the proper interpretation and processing of them. Readers outside Oman may also find the normalized green building metrics given here suitable for implementation in any construction project in general, in order to assess and compare the performance of the project with regard to environmental impacts.

2. EDGE Certification

2.1. EDGE Impact Categories

The EDGE certification of a building project is not based on accumulating credit points in various criteria such that a certain threshold is reached in order for the building to deserve a corresponding certification level. Instead, it is based on achieving a percentage of saving (relative to a base case) in three impact categories, which are the three building-related aspects that have an impact on the environment [39,40]. These three impact categories in EDGE are:

- Energy;
- Water;
- Materials (expressed as Embodied Energy).

The first two impact categories (Energy and Water) influence the operational energy and water consumptions, and thus the monthly utilities bill. They also influence the daily release of greenhouse gases. The third impact category (Materials or Embodied Energy) reflects a one-time influence on the environment, whereby some construction products to be used in the building are more favorable than others from an environmental perspective, due to consuming less energy in producing them, which typically means the release of fewer polluting emissions associated with such energy. It should be noted that the Water impact category can influence the Energy impact category in categories such as a washing machine (a water-efficient washing machine saves not only water, but also energy through less water heating). Similarly, enabling the Roof Insulation option under the Energy category results in savings in the Materials category.

2.2. EDGE Certification Levels

EDGE offers three levels of certification, depending on the amount of savings that can be attained in each of the three impact categories of EDGE, as well as the ability to have net-zero greenhouse gas emissions (expressed as carbon dioxide equivalent).

Table 1 explains the criteria required to reach each level of EDGE certification.

Table 1. Three levels of green buildings in EDGE.

Certification Level	Minimum Saving Relative to the Base Case			Operational Condition
	Energy	Water	Materials	
EDGE Standard	20%	20%	20%	-
EDGE Advanced	40%	20%	20%	-
EDGE Zero Carbon	40%	20%	20%	100% reliance on renewable energy (onsite or offsite) or Purchasing carbon offsets to counteract any emissions

The middle level is called Edge Advanced or Zero Carbon Ready. The top (most environmentally friendly) level of EDGE Zero Carbon cannot be attempted directly. The building should first officially receive the middle level certification (Edge Advanced) before applying for certification under the higher level (EDGE Zero Carbon). While the bottom and middle levels can be attempted without restrictions on occupancy or real-time use, the top level requires the availability of 12-month operational data under 75% or more occupancy. Also, the bottom and middle levels take the form of one-time certification, while the top level is subject to an expiration period of 2 years (if offsite renewable energy or carbon offsets are included) or 4 years (with 100% onsite renewable energy), and thus requires periodic renewals.

In the present work, the second (the middle) level of Edge Advanced (or Zero Carbon Ready) is considered for the green building design discussed later. This is a good choice; it is more sustainable than the basic level (first level) and enables an upgrade to the top level (EDGE Zero Carbon) without any major change in the building itself, in case of purchasing offsite renewable energy or carbon offsets (if available). On the other hand, choosing 100% onsite renewable energy as the route from Zero Carbon Ready (ZCR) to Zero Carbon (ZC) necessitates structural changes through installing a renewable energy system, such as a small photovoltaic power unit with sufficient electric batteries for energy storage [41].

3. Intrinsic Settings for the Building

In this section, some properties of the residential building that was designed, and its region, are provided. Some of these properties are suggested by EDGE (like the climate conditions), while others (such as the dimensions and number of floors) are chosen to make the design reasonable for its purpose as a single-family dwelling in a low-density urban community. All the properties discussed here are not affected by later adjustments to transform the building design from a conventional building (base case) into a sustainable building (Zero Carbon Ready). Thus, these properties are intrinsic configurations for the building and its geographic location. They are not subject to change.

3.1. Location

The geographic location of the designed green building is Oman. Oman is a medium-size coastal country belonging to the Gulf Cooperation Council (GCC) in southwestern Asia. It shares borders with the United Arab Emirates, the Kingdom of Saudi Arabia, and the Republic of Yemen.

In EDGE, the latitude assigned by default for Oman is 24°, and the elevation is 300 m. Both values suggest that they belong to Muscat, the capital of Oman.

3.2. Climate

Climate conditions have a big impact on the performance of a green building, due to the resultant heating or cooling requirements in order to maintain indoor spaces at comfortable conditions regardless of the temperature and humidity outside [42]. The temperature profiles (monthly maximum and monthly minimum) and the relative humidity (monthly average) for Oman, as suggested by EDGE, are shown in Figure 3. It shows that the climate is very hot in the summer, leading to large cooling needs. There are also heating needs in the winter, but at a smaller level.

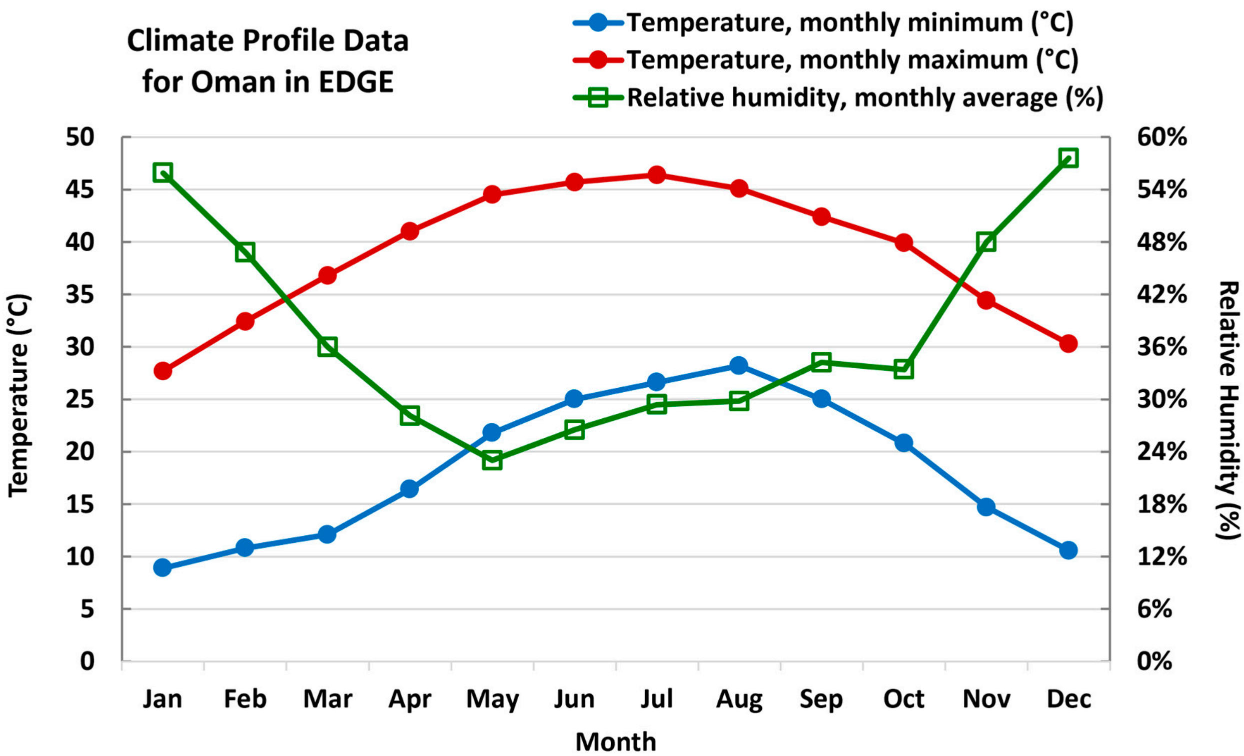

Figure 3. Profiles of temperatures and relative humidity in Oman. Data source: EDGE.

3.3. Building Layout

EDGE allows the user to define the geometric shape (layout on the ground) of the building, with up to eight sides. The selected indoor area in this study is 200 m^2. It was decided to assign a simple rectangular shape to the home, with the south/north-facing side being shorter than the east/west-facing sides. This has the advantage of reducing the heating loads caused by solar radiation to the south walls, given that Oman lies entirely in the northern hemisphere. Therefore, the south-facing walls are exposed to solar radiation more than other walls, if special external factors like significant shading due to nearby terrains or trees are excluded [43–48]. With a reasonably selected aspect ratio of 2:1, the dimensions of 20 m and 10 m for the building's side lengths are obtained, as illustrated in Figure 4. The figure also shows a possible arrangement of the internal spaces within the home. The 10 m^2 utility room is replaced in the figure by a central distribution area, where occupants can move conveniently to or from bedrooms, the kitchen, and the living/dining room.

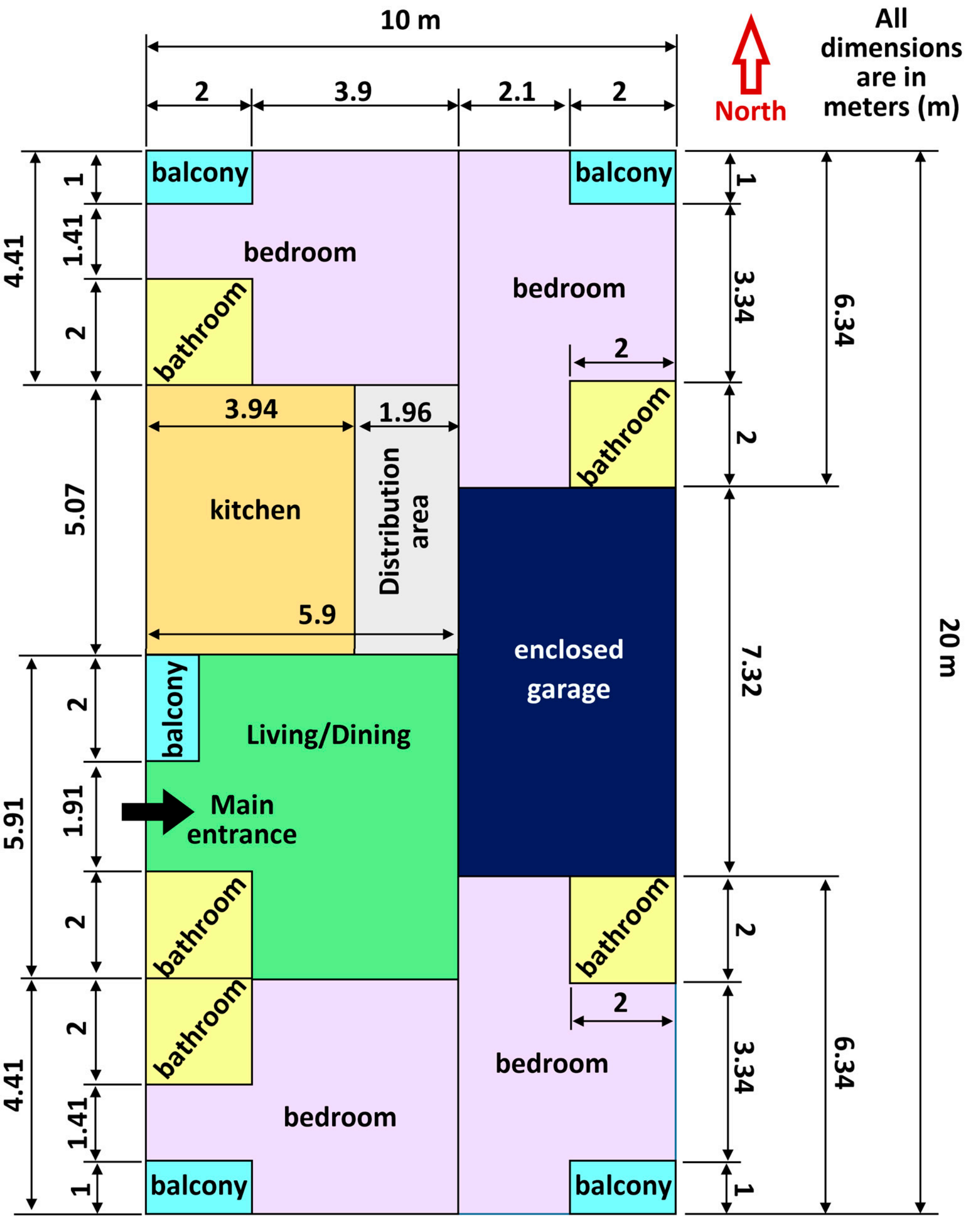

Figure 4. Selected layout of the residential building.

All the external walls are assumed to be exposed to outside air (not shared with a neighbor building). This is consistent with the type of the building set as a family residence, with an attached illuminated courtyard that allows outdoor social activities with a private garden covering part of that outdoor space.

3.4. Occupants

The expected number of occupants for this green home is four, representing one family. It may also be viewed as four tenants who are renting the home from the owner, using it as a temporary residence during study or work. This alternative utilization scenario (four individual tenants instead of a single family) is plausible given that the building design has four equally-sized bedrooms, with a private bathroom and a private balcony for each bedroom.

Table 2 lists the areas assigned to the bedrooms and other parts that collectively constitute the total floor area of 200 m^2. These areas are based on some modifications of initial values suggested by EDGE. For example, the initial total balcony area was only 2 m^2, which was increased to 10 m^2, such that each of the four bedrooms has its own balcony with an area of 2 m^2, and there is an additional common balcony with the same area of 2 m^2 in the living room. Also, the dining room (initially 10 m^2) and the living room (initially 40 m^2) were merged together as a single space with an intermediate area of 30 m^2. This is considered a more efficient utilization of space, avoiding oversizing or functional redundancy, while prioritizing privacy in the personal spaces in which the occupant might be spending more time. In addition, the bathrooms' total area was originally 10 m^2. However, this was increased to 20 m^2, allowing each room to have its own bathroom (with an area of 4 m^2) and an additional common bathroom attached to the living area, for use by guests.

Table 2. Break-up of the gross internal area (GIA).

Space Type	Number	Area (m^2) per Unit	Total Area (m^2)
Bedroom	4	20	80
Bathroom	5	4	20
Balcony	5	2	10
Kitchen	1	20	20
Living/Dining	1	30	30
Utility	1	10	10
Enclosed garage	1	30	30
	Total area		200

There is one floor, with a height of 3 m. The roof area is equal to the indoor area (200 m^2). There is no swimming pool. However, an outdoor space with exterior lighting is added, with an area of 200 m^2. Half of the outdoor space (thus, 100 m^2) is irrigated.

3.5. Energy Sources

It is possible in EDGE to select the energy source for water heating, space heating, and cooking from a number of options. The source can be electricity or fuel (natural gas, diesel, or liquefied petroleum gas (LPG)). In the present design, electricity was selected as the energy source for all the three functions. This is helpful for transitioning in future into a zero carbon building, because electricity can be generated from a clean renewable natural resource without greenhouse gas emissions, while the other fossil fuels always release greenhouse gases when burned.

3.6. Utility Tariffs

In order to perform a financial analysis and estimate the average cost of monthly utilities (energy and water) of the building, the tariffs of these utilities must be known. The default values for the electricity tariff in EDGE for Oman was OMR 0.040/kWh. Although this can be suitable for large corporate consumers, for small residential consumers, this tariff is too high. The value was thus reduced to OMR 0.014/kWh. This tariff is the announced tariff (as of September 2022) for residential users in the first tier, ranging from 0 to 4000 kWh/month [49]. The postulation that the monthly electric consumption of the design does not exceed 4000 kWh/month needs to be confirmed after the design is completed. If it is violated, a different (higher) electricity tariff should be entered. For example, in the second tier of consumption, from 4001 to 6000 kWh/month, the residential electricity tariff increases to OMR 0.017/kWh. The built-in tariff in EDGE for Oman for water was OMR 0.36/m^3, which is lower than the current rate for residential consumers (OMR 0.66/m^3). Thus, the default underestimated value in EDGE was replaced by the accurate higher value.

To express the consumption costs later in U.S. dollars, the currency exchange rate of OMR 0.38/USD suggested by EDGE was kept as it is. This value is correct [50], and the Omani rial is pegged to the U.S. dollar [51].

3.7. CO_2 Emission Factors

To estimate the released carbon dioxide due to the green building design, EDGE assigns a CO_2 Emissions Factor for each energy source, which is a number representing the released mass of carbon dioxide for each kWh of energy from that energy source. In the present design, since electricity is the only energy source used, only one Carbon Emission Factor is effectively utilized. The default value of 0.32 kgCO_2/kWh for Oman was retained. This value was found to be a reasonable estimate for the Sultanate of Oman because the CO_2 Emissions Factor for combined-cycle power plants (or combined-cycle gas turbines) is about 0.35 kgCO_2/kWh [52]. This type of gas-fired power plant is popular in Oman [53], and natural gas is the dominant fuel used for electricity generation nationally [54].

4. Methodology

This section lists the specific modifications made in the baseline home design in order to convert it into a Zero Carbon Ready version, through the green building software application EDGE. The modifications are categorized by the three impact categories (Energy, Water, and Materials) of EDGE. While modifying the design, it was desirable to keep the changes as limited as possible, enabling the design to meet the minimum requirements without a large excess of compliance. This simplifies the design, and reduces the expected cost of sustainability changes to be incurred, which increases the chance of constructing a sustainable home in reality. One modification can be made at a time to assess the resulting calculated savings in the impact categories. Then, a decision may be made regarding whether or not additional or alternative modifications are needed.

4.1. Energy Modifications

The threshold saving level in energy consumption relative to the base case for a ZCRB in EDGE is 40%. This was achieved through four modifications in the base case (the conventional building design), as listed in Table 3, leading to a final energy saving of 40.86%.

Table 3. Energy saving measures, totaling 40.86%.

Energy Feature	Base Case (Original)	Design Case (Modified)
Reflective Roof	Solar Reflectance Index 45	Solar Reflectance Index 85
Reflective Exterior Walls	Solar Reflectance Index 45	Solar Reflectance Index 85
Insulation of Roof: U-value 0.12 $W/m^2{\cdot}K$	Disabled	Enabled
Onsite Renewable Energy	No Onsite Renewable Energy	40% of Annual Energy Use (Solar Photovoltaic)

The Solar Reflectance Index (SRI), which was increased from 45 (base case) to 85 (design case), is a numerical value that combines the effects of two solar characteristics of a surface. The first solar characteristic included in SRI is the solar reflectance, which is the fraction of incident solar radiation that is reflected. The second solar characteristic included in SRI is the thermal emittance or thermal emissivity, which is the fraction of infrared radiation emitted compared to the maximum possible emitted radiation at the same temperature [55–57]. A standard white surface (solar reflectance 0.80, and thermal emittance 0.90) has an SRI value of 1 (alternatively 100% or 100), while a standard black surface (solar reflectance 0.05, and thermal emittance 0.90) has an SRI value of 0 [58–60]. It is even possible for a special surface to have an SRI value above 100 because that value of 100 does not correspond to a theoretical maximum, but corresponds to an arbitrary reference condition [61]. A surface with high reflectance and high thermal emittance tends to have a lower temperature than a surface with low reflectance and low thermal emittance, due to the lower amount of absorbed radiation combined with a better ability to dissipate the absorbed heat by emitting it away [62]. High SRI values help in avoiding surface overheating when subject to solar radiation, reducing heat gains through the envelope of a building [63].

4.2. Water Modifications

While reducing water consumption is not directly connected with carbon dioxide emissions from a building, EDGE still demands a minimum 20% saving in water consumption relative to the base case in order for the building to be qualified for any of the three levels of EDGE certifications. In the current study, a final water saving level of 20.22% was achieved after taking five measures, as indicated in Table 4.

Table 4. Water saving measures, totaling 20.22%.

Water Feature	Base Case (Original)	Design Case (Modified)
Efficient Water Closets for All Bathrooms	Single flush, 8 L/flush	Dual flush, 6 L/high-volume flush and 4 L/low-volume flush
Water-efficient Faucets for Kitchen Sinks	10 L/min	4 L/min
Water-efficient Dishwashers	8 L/cycle	3.75 L/Cycle
Water-efficient Washing Machines	55 L/Cycle, no rinse water reclaimed	35 L/Cycle
Water-efficient Landscape Irrigation System	6 $L/m^2/day$	4 $L/m^2/day$

It may be important to add that the presence of an irrigated outdoor area in the building provides an opportunity with regard to achieving water savings, through using water-efficient landscape irrigation, without impacting the water needs of the people living in the building or the indoor plumbing system. A related strategy for reducing landscape water needs is to select plants that naturally do not have heavy-water needs. Cultivating an area as a special garden or landscape that requires little or even no irrigation is a subject referred to as xeriscaping, and it is particularly beneficial in arid environments [64].

4.3. Materials Modifications

Similar to water savings, material savings (expressed as reductions in the Embodied Energy) do not necessarily impact the ongoing release of carbon dioxide due to daily operations. However, a minimum saving of 20% in construction materials (with respect to the base case) is required to claim any level of EDGE certification. In the present study, a saving of 26.39% for materials was reached after taking three measures, as indicated in Table 5. It was difficult have a saving level close to the threshold (20% for this impact category), despite this successfully occurring for the Energy and Water impact categories.

Table 5. Materials (Embodied Energy) saving measures, totaling 26.39%.

Materials Feature	Base Case (Original)	Design Case (Modified)
Bottom Floor Construction	Concrete Slab | In-situ Reinforced Conventional Slab	Concrete Slab | In-situ Reinforced Slab with >25% GGBS
Interior Walls	Brick Wall | Solid Brick (0–25% voids) with External and Internal Plaster	Brick Wall | Cored Brick (25–40% voids) Exposed with no Plaster
Roof Insulation	Polystyrene Foam Spray or Board Insulation	Glass Wool | Fiberglass Batt

The term GGBS stands for ground granulated blast-furnace slag. It is derived from blast-furnace slag, which is a by-product of blast-furnaces (industrial furnaces used to produce iron from its ore). GGBS has cementitious properties [65]. Therefore, it is used in making concrete as an environmentally friendly alternative material that can partially substitute conventional (Portland) cement [66]. The production of Portland cement involves large emissions of carbon dioxide [67], whereas the production of GGBS involves almost zero emissions of carbon dioxide [68], and even without the consumption of natural raw materials, and also helps in removing a waste stream from the iron industry.

5. Results

Before discussing the results, it is mentioned here that the web application of EDGE that was used in the modeling in this study is version 3.0.0. This was the latest version when the analysis was performed (September 2022).

5.1. Assessment Report Summary Outputs

This part lists some numerical values provided directly by the EDGE application in a generated assessment report, as a PDF file that can be saved and viewed offline, independently of the web application. This EDGE assessment report contains 21 numerical summary results, along with more information such as input parameters and sustainability modifications used in modeling.

Seven results in the assessment report are financial, related to costs or a monetary saving. Two of them are the Total Building Construction Cost, and the Incremental Cost. There is a third financial result reported by EDGE, which is the Utility Cost Savings in Local Currency. The summary assessment results include the Subproject Floor Area; the term Subproject here refers to the building (single home). This is actually an input parameter, with the value of 200 m^2. Despite this, it is a commended behavior of EDGE to display this value within the summary results due to its importance and its role in interpreting some of the results. Similarly, the result named Number of People Impacted was actually an input parameter, and it refers to four occupants in the current study.

Other than these 5 discussed output values, the remaining 16 output results in the offline assessment report are provided in Table 6. The values are ordered here in a specific way such that they are grouped into four collections. The results related to emissions come first, with a total of four values. Then, another four energy-related results are listed, followed by two water-related results, and then come the two results relevant to the materials (through Embodied Energy). Finally, the table lists the remaining four financial results.

Table 6. Summary results from EDGE for the designed ZCRB.

Serial Number	Result Name	Result Value	Result Unit
1	Final Operational CO_2 Emissions	0.14	tCO_2/month
2	Operational CO_2 Savings	1.15	tCO_2/year
3	Base Case—Refrigerant Global Warming Potential (Refrigerant Emissions)	0.3	tCO_{2e}/year
4	Improved Case—Global Warming Potential (Refrigerant Emissions)	0.3	tCO_{2e}/year
5	Final Energy Use	438	kWh/month
6	Energy Savings	3.60	MWh/year
7	Base Case EPI	45.0 (44.25)	kWh/m^2/year
8	Improved Case EPI	27.0 (26.23)	kWh/m^2/year
9	Final Water Use	33 (33.3)	m^3/month
10	Water Savings	101.56	m^3/year
11	Final Embodied Energy	3103	MJ/m^2
12	Embodied Energy Savings	222.49	GJ
13	Final Utility Cost	26	OMR/month
14	Utility Cost Savings in USD	387	USD/year
15	% Increase in cost	3.60%	%
16	Payback in Years	23.2	year

It is important to point out that the Final Energy Use of 438 kWh/month validates the postulation made earlier when setting the electricity tariff as an input parameter. It was presumed that the monthly energy (electricity) consumption does not exceed 4000 kWh/month, so that the first tier of the tariff (the cheapest rate) is applicable.

5.2. Carbon Emissions Index (CEI)

In the summary of the results reported by EDGE in the assessment report (illustrated in Table 6), the Global Warming Potential (GWP) mentioned for the refrigerant refers to a common environmental metric. It compares the time integrated global warming impact of a refrigerant or any greenhouse gas (GHG) in general to the impact of carbon dioxide if both gases have the same mass, considering an impact duration of typically 100 years [69]. Therefore, carbon dioxide by definition has a GWP of 1 [70]. Despite this, the Refrigerant Global Warming Potential reported by EDGE refers simply to the equivalent mass of carbon dioxide released in the atmosphere due to the refrigerant of the HVAC (heating, ventilation, and air conditioning) system of the building. The true GWP is dimensionless (does not have a unit), whereas the value reported by EDGE has a unit of tCO_{2e}/year. To obtain the value reported by EDGE, the true dimensionless GWP is still needed to convert the mass of refrigerant to an equivalent mass of CO_2. The other information needed is the lifetime of the refrigerant and its charge (its mass within the HVAC system). Therefore, the Refrigerant Global Warming Potential in EDGE is replaced by a better term (Refrigerant Emissions) in Table 6. Regardless of the name, the base case and the design case (improved case) have the same value of 0.3 tCO_{2e}/year. This is expected because no sustainability measures were taken regarding the refrigerant while setting the energy modifications.

The Final Operational CO_2 Emissions and the Operational CO_2 Saving are expressed over different intervals, being 1 month for the final values (after subtracting the savings from the baseline emissions) and 1 year for the savings. In a dedicated graph showing the Net Carbon Emissions in the EDGE application, the base case and the design case are compared visually and numerically in terms of the annual emissions (in tCO_{2e}/year) due to electricity consumption (operational emission) and due to the refrigerant. Fuel-based emissions are not presented here, because electricity was selected as the sole source of energy in the current study. The graph is referred to here as an "inventory graph" because it shows the aggregate value (total annual emissions) as well as a break-up of the constituents of that value (electricity and refrigerant). Therefore, it resembles an itemized inventory list. The refrigerant contribution is the same in the base case and in the design (improved) case, as was already shown in the assessment report (reflected in Table 6), with a common value of 0.3 tCO_{2e}/year. For the annual operational emissions, the inventory graphs displayed them as 2.80 tCO_{2e}/year for the base case and 1.70 tCO_{2e}/year for the design case. Dividing the annual value of 1.70 tCO_{2e}/year by 12 (months per year) gives 0.14167 tCO_{2e}/month, which matches the value in Table 6 (up to the two decimal places displayed). The assessment report shows a value of 1.15 tCO_2/year for the Operational CO_2 Savings result, as given in Table 6.

The emission results from EDGE (either in the assessment report or the Net Carbon Emissions inventory graph) are for the entire building project, which is one particular incident with a specified floor area. In order to make the results useful in benchmarking with other buildings in Oman (or even abroad), a normalization is needed based on the Gross Internal Area (which is 200 m^2 in the current study). This normalization yields an emission metric expressed in tCO_{2e}/m^2/year, which is too small for convenient use. Thus, the unit tCO_{2e}/m^2/year is replaced by the smaller unit of $kgCO_{2e}/m^2$/year, which effectively scales up the numerical values by a factor of 1000, making them easy to express. This final emission metric introduced here is assigned the name Carbon Emission Index (CEI), representing the share of 1 m^2 of indoor floor area in the greenhouse gases released due to both energy consumption and HVAC, over one year. The value of the CEI for the base case (the conventional building) here was found to be 15.5 $kgCO_{2e}/m^2$/year, and for the design case (the green Zero Carbon Ready building), it was found to be 10.0 $kgCO_{2e}/m^2$/year. Thus, there is a saving of 35.48% in GHG emissions in the design case relative to the base case.

Figure 5 illustrates the two CEI components that make up the total CEI, for the conventional building and for the green ZCR building.

5.3. Energy Performance Index (EPI)

The energy saving directly reported by EDGE is 40.86%. When the individual components of the EPI (Energy Performance Index) and their total values were examined through an energy-specific detailed graph in the EDGE online application (the inventory graph for energy), more precise EPI values than those summarized in the EDGE assessment report (illustrated in Table 6) were reported, as 44.25 kWh/m^2/year instead of 45.0 kWh/m^2/year for the base case, and 26.23 kWh/m^2/year instead of 27.0 kWh/m^2/year for the design case.

Figure 6 visualizes the components that make up the total EPI, for the conventional building and for the ZCR building. There are nine components involved, which are:

1. Cooling fans;
2. Common amenities;
3. Water pumps;
4. Ceiling and ventilation fans;
5. Cooling;
6. Lighting;
7. Home appliances;
8. Cooking;
9. Hot water.

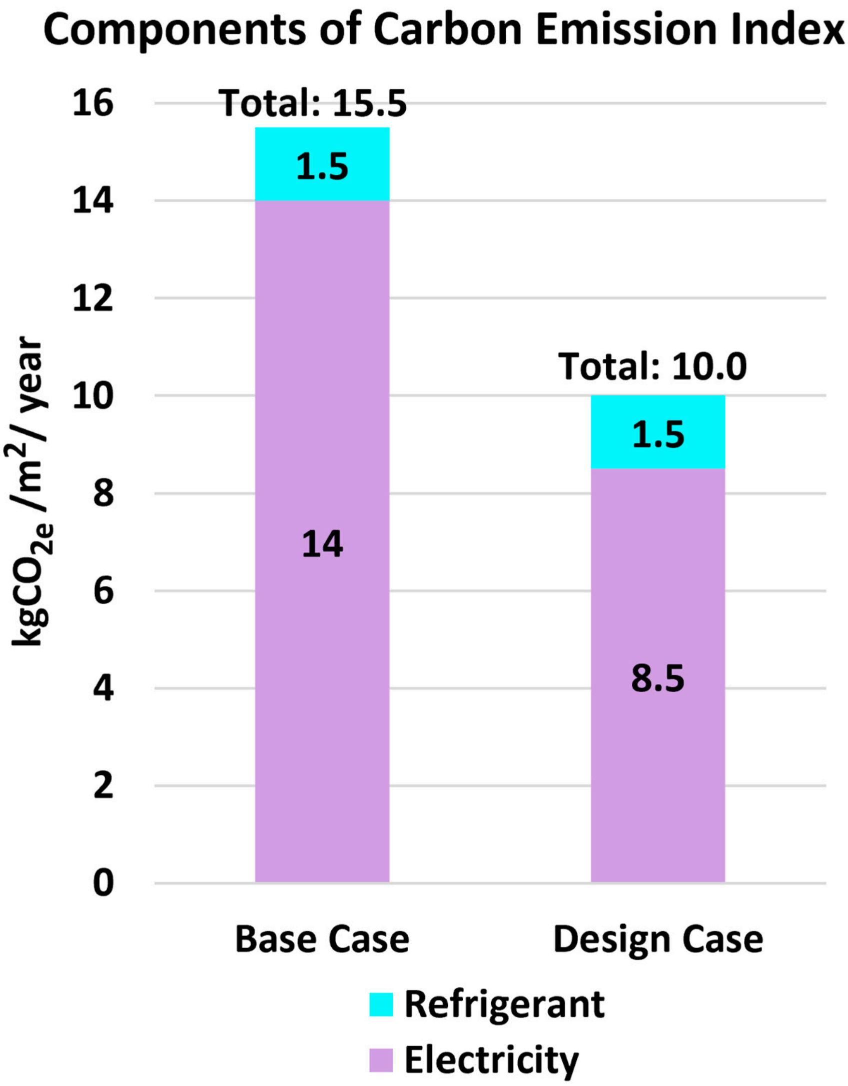

Figure 5. Carbon emission index (CEI) and its components for the conventional building (base case) and the Zero Carbon Ready green building (design case).

The energy consumption component (Common amenities) in EDGE for the Homes building type refers in general to the sewage treatment plant (STP), water treatment plant (WTP), gray water treatment plant, water pumps for recreational facilities (such as a swimming pool), and the lift (the elevator). It should be noted that not all these amenities are necessarily present in such projects. For example, the current modeled home does not have a swimming pool, which is advantageous in terms of water conservation. In both cases (base case and design case), the segments of the stacked column are ordered by size (with the biggest being at the bottom). For the house project examined here, they have exactly the same order in both cases. The biggest contributing component to the EPI in both cases is hot water, while the smallest component is the cooling fans. The energy efficiency measure of substituting 40% of the conventional electricity (purchased grid electricity) by onsite solar energy justifies the similarity in the relative contribution of consumptions by the nine energy components, before and after the energy modifications, since this partial substitution of energy source should reduce each component uniformly (each component is multiplied by a scaling factor of 0.6) without altering their sizes relative to each other.

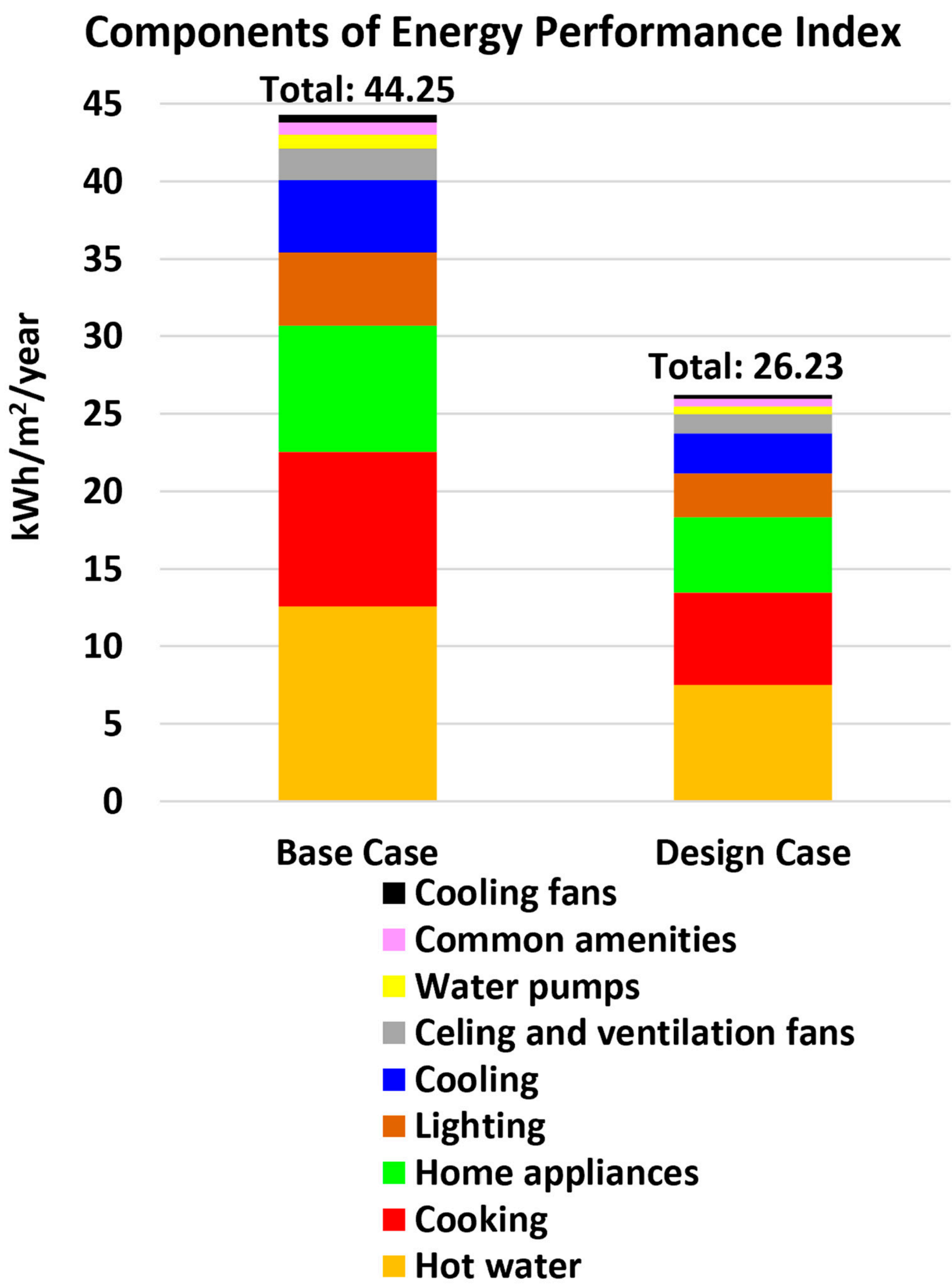

Figure 6. Energy performance index (EPI) and its components for the conventional building (base case) and the Zero Carbon Ready green building (design case).

5.4. Water Consumption Index (WCI)

The reported reduction in the annual energy use by EDGE is 20.22%. Examining a detailed water-specific graph in the online application of EDGE (the inventory graph for water) revealed that the average daily water consumption was 1.11 m^3/day for the design case, which (assuming that the month has 30 days) corresponds to 33.3 m^3/month. This is consistent with the displayed integer value in the assessment report (33 m^3/month). The more precise value for the monthly water consumption was manually added in Table 6, in parentheses after the reported rounded value in the downloaded assessment report.

The online inventory graph for Water also shows that for the base case, the average daily consumption for the building (with four occupants) is 1.38 m^3/day. This value and the other one corresponding to the design case (with reduced water consumption) are further split in the graph according to the contributing components (causes of water consumption), with a total of eight components. These are:

1. Car washing;
2. Laundry;
3. Kitchen;
4. Cleaning;
5. Wash basin;
6. Flushing;
7. Shower;
8. Irrigation.

Similar to the CO_2 emissions, the reported summary water results in the EDGE assessment report are for the whole building, and thus are not normalized. This makes benchmarking with other buildings of different sizes difficult. A normalized water efficiency index is introduced here, by dividing the average daily consumption (in m^3/day) by the number of occupants, and then multiplying by a conversion factor of 1000 to express the result conveniently in L/person/day without dealing with extremely small or extremely large values. Normalization by the number of people rather than the floor area (as was the followed in CEI and EPI) is suitable here, where water consumption is strongly dependent on the consumers. On the other hand, lighting, space heating and space cooling, and the implied GHG emissions due to electricity consumption and HVAC refrigerant, are heavily affected by the floor area. In building types where there are short-term visitors as compared to regular residents or workers, an equivalence can be established between visitors or transient clients for commercial or public service buildings and regular occupants, through the estimated number of hours spent by the visitors in the building compared to regular occupants [71]. The proposed normalized water efficiency index here is given the name Water Consumption Index (WCI). It represents the average number of liters of supply water consumed by each person as part of the daily water consumption in the building.

The value of the WCI for the base case (the conventional building) here was found to be 345.0 L/person/day, and for the design case (the green Zero Carbon Ready building), it was found to be 277.5 L/person/day.

Figure 7 visualizes the eight components that make up the total WCI, for the conventional building and for the ZCR building. Either before or after the water efficiency measures, the largest water consumption component is outdoor irrigation, and then comes the showers. For either building, these two components together account for about two-thirds of the water consumption (67.39% for the base case, and 65.77% in the design case).

5.5. Embodied Energy Index (EEI)

In the summary results reported by EDGE in the assessment report (illustrated in Table 6), the embodied energy per unit area for the green building is 3103 MJ/m^2. This quantity is already a good candidate as an efficiency index due to being normalized with respect to the area. After a division by 1000 for better expressing the normalized embodied energy in terms of GJ/m^2 (to avoid numbers that are too large accompanying the original smaller unit of MG/m^2), it is to be assigned here the name Embodied Energy Index (EEI). This proposed EEI refers to the requirements of 1 m^2 of indoor area in terms of the embodied energy (in GJ, gigajoules) of the entire building project. In EDGE, the embodied energy saving is expressed as a whole building value, which is not normalized by the floor area. In the current study, the EEI is 3.103 GJ/m^2, while the total saving in the embodied energy is 222.49 GJ. Dividing the latter value by the gross internal area (200 m^2) gives a normalized saving of 1.11245 GJ/m^2. To help in comprehending the size of the GJ as an amount of energy, it is useful to state first that 1 GJ is equivalent to 277.8 kWh. In the case electric energy, 1 GJ is sufficient to run a typical split-unit air conditioner for 116 h (about 5 days continuously). Such an air conditioner is suitable for a big room with an area of about 25 m^2, and it is assumed to have a maximum cooling capacity of 1.5 tons of refrigeration (thus 18,000 BTU/h), and an energy efficiency ratio (EER) of 7.5, which leads to a maximum electric power of 2.4 kW [72].

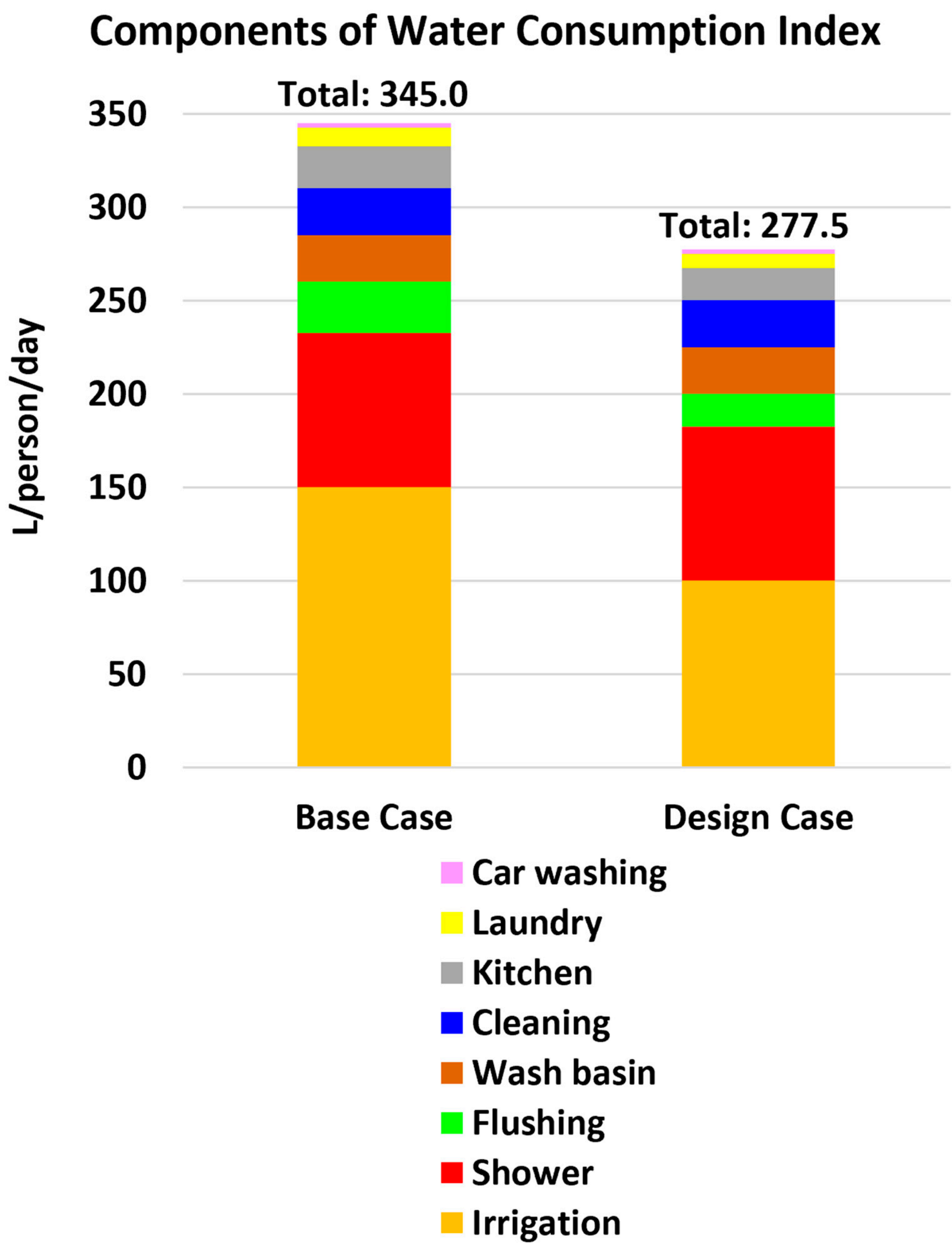

Figure 7. Water consumption index (WCI) and its components for the conventional building (base case) and the Zero Carbon Ready green building (design case).

As was the case in the Energy and Water impact categories, in the online EDGE application, there is an inventory graph for the Embodied Energy (Materials) impact category, in the form of a stacked column chart. It reveals more details about the components of the embodied energy per unit area (MJ/m^2) for the base case and the design case, by showing not only the aggregate value for the building, but also the contributions of different components. Dividing these values by 1000 converts them into EEI components. It is noted that both the total and the components of embodied energy per unit area are given with high precision in this inventory graph, expressed with six significant digits. This is a favorable feature.

Figure 8 shows the EEI components for the base case (initial building design) and the design case (final building design) based on the values displayed in the inventory graph, but after a unit conversion from MJ/m^2 to GJ/m^2. There are eight EEI components, which are:

1. Window frames;
2. Window glazing;
3. Floor finish;
4. Insulation;
5. Bottom floor;
6. Exterior walls;
7. Roof;
8. Interior walls.

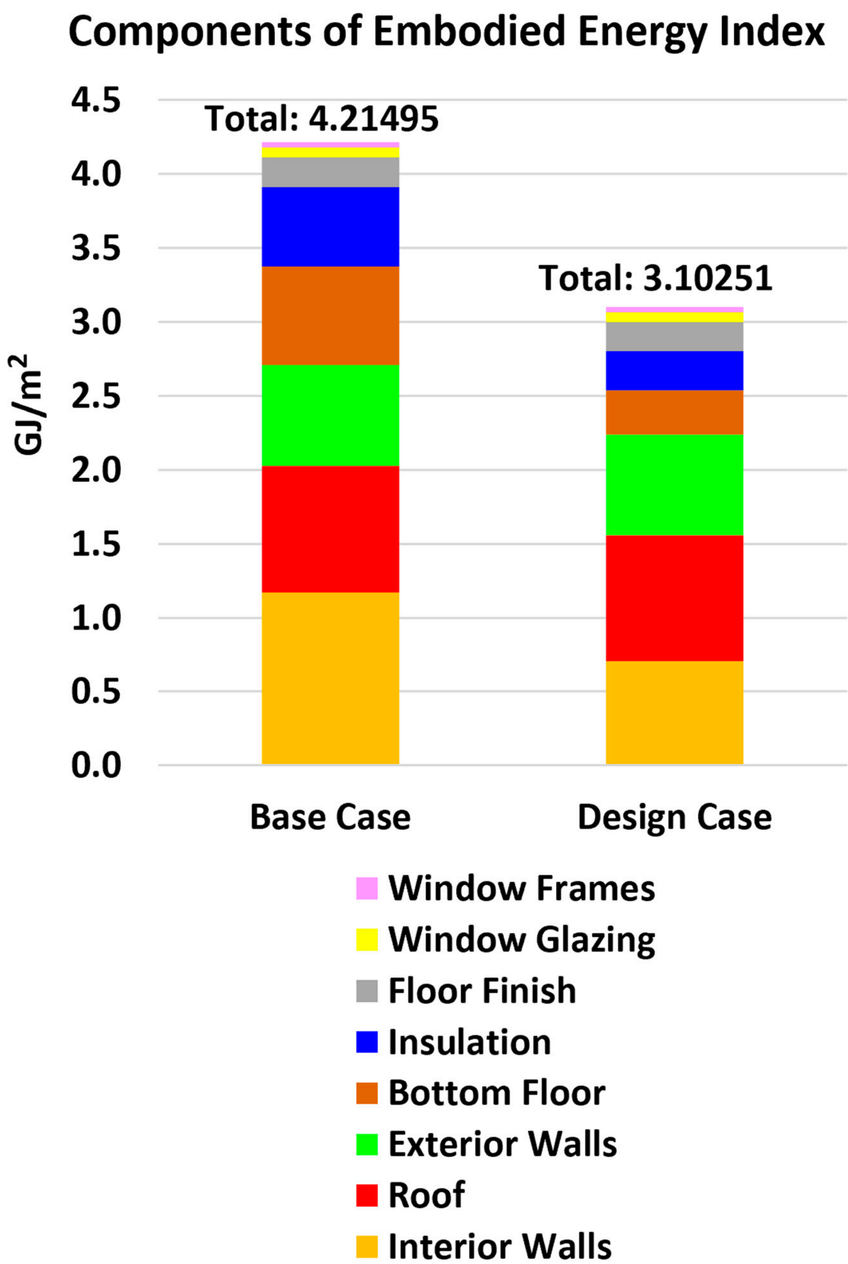

Figure 8. Embodied Energy Index (EEI) and its components for the conventional building (base case) and the Zero Carbon Ready green building (design case).

A ninth EEI component (intermediate floors) is present in EDGE but is not present in the current study, because the analyzed home here has one floor (one level), and thus does not have intermediate floors.

The EEI decreased from 4.21495 GJ/m^2 to 3.10251 GJ/m^2. The difference is 1.11244 GJ/m^2, which is consistent with the difference derived by dividing the gross embodied energy saving (222.49 GJ) by the gross internal area (200 m^2). From the two EEI values (before and after the efficiency measures), the calculated saving is 26.39%, which agrees exactly with the value directly reported by EDGE in the assessment report. The data regarding the embodied energy in the assessment report and the online inventory graph are in excellent agreement.

Out of eight EEI components, the interior walls and roof together constitute about half of the EEI value, representing 48.17% of the EEI in the base case and 50.35% of the EEI in the design case.

5.6. Financial Analysis

Based on the summary results reported by EDGE in the assessment report (illustrated in Table 6), the estimated expenses for implementing the 12 efficiency measures discussed in the previous section (4 measure for Energy, 5 measure for Water, and 3 measure for Materials) are relatively small, being only 3.60% of the base building. However, the number of years to repay that additional cost through recurrent monthly savings in the utilities bill (water and electricity) is long, being 23.2 years. This is justified by the already small value of the utilities savings (USD 387/year or USD 32.25/month). It should be noted that the final (after savings) utilities cost for the green building is OMR 26 /month (USD 68.42/month). This means that the baseline utilities cost is USD 100.67/month, and that the savings induced by the efficiency measures represents 32.0% of the baseline utilities cost. From the Utility Cost Savings in USD result and the Payback in Years result, one can infer that the incremental cost of the building due to the efficiency measures is USD 8978.4 (OMR 3412). Expressing this amount of money in million OMR gives the value of OMR 0.003412 million for the Incremental Cost item in the assessment report.

Combining this inferred (Incremental Cost) value of USD 8978.4 with the reported % Increase in cost result of 3.60%, the Total Building Construction Cost item in the assessment report may also be inferred to be USD 249,400 or OMR 94,772. Expressing this amount of money in million OMR gives OMR 0.094772 million. Finally, converting the value of USD 387/year for the Utility Cost Savings in USD result to the local currency of OMR (by multiplying it by the currency rate OMR 0.38/USD) gives OMR 147.06/year. Expressing this amount of money in million OMR gives OMR 0.00014706 million/year. As a numerical value, it is small enough such that it is not surprising that it appeared as OMR 0.00 million/year in EDGE assessment report for the item Utility Cost Savings in Local Currency. Even with three decimal places (not just two), the value is still not detected.

6. Discussion

This study addressed the question of:

- What does a single-family home in the Sultanate of Oman need in order to be qualified as a Zero Carbon Ready Building according to the EDGE (Excellence in Design for Greater Efficiencies) green building certification system?

The answer was given through a complete example of designing a new single-story home with four occupants, having an indoor floor area of 200 m^2, and an attached outdoor area of another 200 m^2. The version of the online EDGE application used here was version 3.0.0, which was the latest one available at the time of the study. Some modifications were needed in order to convert the base case (conventional building design) into a sustainable green building design (Zero Carbon Ready). These improvement modifications are expected to yield savings in energy, water, and materials (embodied energy) at levels of 40.86%, 20.22%, and 26.39%, respectively. The savings in consumption lead to a predicted savings in the monthly utilities bill such that its average is OMR 26.0/month (Omani rials per month), which is equivalent to USD 67.7/month. The annual utilities cost savings is expected to be USD 387/year, or OMR 149/year. These improvement changes cause a predicted increase in the conventional building cost of only 3.60%.

When expressing the features of the designed Zero Carbon Ready green building in a normalized way, the Omani green building design shows a decrease in the Carbon Emission Index (CEI) from 15.5 $kgCO_{2e}/m^2$/year (base case) to 10.0 $kgCO_{2e}/m^2$/year, which means that the annual greenhouse gas reduction per unit floor area is 5.5 $kgCO_{2e}/m^2$/year. The Energy Performance Index (EPI) drops from 44.25 kWh/m^2/year for the base case to 26.23 kWh/m^2/year, which means that the annual energy saving per unit floor area is 18.02 kWh/m^2/year. The Water Consumption Index (WCI) drops from 345.0 L/person/day (base case) to 277.5 L/person/day, which means that the annual water saving per person is 67.5 L/person/year. The embodied energy index (EEI) drops from 4.21495 GJ/m^2 (base case) to 3.10251 GJ/m^2, which means that predicted embodied energy saving per unit floor area is 1.11244 GJ/m^2.

7. Conclusions

According to modeling via EDGE, a new green Zero Carbon Ready home with a private garden in Oman can cost only 3.60% more than a conventional building. The expected saving in the electricity and water is about 32.0%. A total of 12 modifications with respect to a conventional design were enough to make the building design suitable for attempting a formal certification process at the intermediate (second) level—EDGE Advanced, which is a prerequisite for the next level (and highest level)—EDGE Zero Carbon.

Four normalized efficiency metrics can be useful in comparing the sustainability level of buildings of different sizes. These are: Carbon Emission Index (CEI), Energy Performance Index (EPI), Water Consumption Index (WCI), and Embodied Energy Index (EEI). They were extensively used in the present study.

Overall, this study recommends the use of the EDGE self-assessment interactive online software as a quick, simple, and free tool for modeling or evaluating green buildings. The default parameters offered by EDGE significantly simplify using it in modeling and designing green buildings. However, the electricity and water tariffs may need to be replaced by user-defined values for the more accurate estimation of utilities bills.

The use of the four charts provided in the online application of EDGE (for emissions, energy, water, and embodied energy) is beneficial if the user wants more details about the building performance.

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Conflicts of Interest: The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Nomenclature

BTU	British Thermal Unit
BTU/h	British Thermal Unit per Hour
CEI	Carbon Emission Index ($kgCO_{2e}/m^2$/year)
DESA	Department of Economic and Social Affairs (of the United Nations)
EDGE	Excellence in Design for Greater Efficiencies
EEI	Embodied Energy Index (GJ/m^2)

EER	Energy Efficiency Ratio
EPI	Energy Performance Index (kWh/m^2/year)
GGBS	Ground Granulated Blast-furnace Slag
GIA	Gross Internal Area (m^2)
IFC	International Finance Corporation
$kgCO_{2e}$	Kilogram of Carbon Dioxide Equivalent
kWh	Kilowatt-hour of Energy
L	Liter of Water
LEED	Leadership in Energy and Environmental Design
LPG	Liquefied Petroleum Gas
GCC	Gulf Cooperation Council
GHG	Greenhouse Gas
GJ	Gigajoule of Energy (1 GJ = 277.8 kWh = 1000 MJ)
GWP	Global Warming Potential
HVAC	Heating, Ventilation, and Air Conditioning
MJ	Megajoule of Energy (1 MJ = 0.2778 kWh = 0.001 GJ)
MWh	Megawatt-hour of Energy (1 MWh = 1000 kWh = 3600 MJ)
NZEB	Net Zero Energy Building or nearly Zero Energy Buildings
OMR	Omani Rial (Monetary Currency in the Sultanate of Oman)
PPA	Power Purchase Agreement
SRI	Solar Reflectance Index
tCO_2	Ton (1000 kg) of Carbon Dioxide
tCO_{2e}	Ton (1000 kg) of Carbon Dioxide Equivalent
UN	United Nations
USD	U.S. Dollar
USGBC	U.S. Green Building Council
WBG	World Bank Group
WCI	Water Consumption Index (L/person/day)
ZC	Zero Carbon
ZCR	Zero Carbon Ready
ZCRB	Zero Carbon Ready Building

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