engineering proceedings

Proceeding Paper

Sustainable Preservation: Design of Solar Photovoltaic (PV) Panels for Listed Buildings in Scotland with Consideration of Cleaning Methods †

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† Presented at the 4th Annual Conference Solar and Wind Power, Edinburgh, UK, 4–6 June 2024.

Abstract: Improving energy efficiency in listed buildings to reduce greenhouse gas emissions (GHGs) by using a monocrystalline solar PV system with the Dar-Al-Arqam mosque in Edinburgh as a case study. Leveraging PVsyst simulation software, various solar PV design scenarios are evaluated. The results suggest the west wing of the roof is optimal for solar PV installation, demonstrating that PV panels can economically reduce emissions while preserving the building's integrity. Different cleaning methods were investigated and the one best suited for the location is the natural cleaning method.

Keywords: sustainable; preservation; listed buildings; solar PV; cleaning methods

Citation: Shobande, R.; Sellami, N. Sustainable Preservation: Design of Solar Photovoltaic (PV) Panels for Listed Buildings in Scotland with Consideration of Cleaning Methods. *Eng. Proc.* **2024**, *71*, 3. https://doi.org/10.3390/engproc2024071003

Academic Editors: Firdaus Muhammad-Sukki and Pablo Sola

Published: 29 July 2024

1. Introduction

The world is now focusing more on renewable sources of energy (RES), as indicated in the latest United Nations COP28 in Dubai [1]. The United Kingdom (UK) is also on a quest to significantly reduce greenhouse gas (GHG) emissions and has a target of net zero by 2050 [2]. However, buildings in the UK are amongst the sector producing the highest percentage of GHG emissions, amounting to about 20% [3]. This shows that GHG emissions from buildings need to be significantly reduced to move towards the transition from fossil fuel to RES. The UK has the oldest stock of buildings in Europe, with over 5.9 million houses constructed before 1919, and a further 4.3 million constructed before 1944, with some of these buildings being of historical importance [4,5]. These historic buildings are buildings with significant heritage, and they are a vital part of the UK's rich heritage and have a major role in upholding the historical pride of the nation; thus, they are listed as heritage buildings in categories A, B, and C with respect to their significance to the nation or local community [4,6,7]. These buildings are cultural assets that require protection and conservation to keep their heritage status and elongate their lifespan for future generations. This study focuses on heritage buildings in Scotland, and for context, there are about 47,000 heritage (listed) buildings in Scotland [8].

However, because of their large windows and doors and their architectural style, the energy performance of these buildings is not as good as that of modern buildings [9]. Hence, to keep these buildings sustainable, there is a need to adapt energy efficiency methods to these heritage (listed) buildings without compromising their architectural integrity.

In this study, the focus will be majorly on improving the electrical energy consumption of the Dar-Al-Arqam mosque building, which is in Edinburgh, Scotland, UK, by designing an optimized and economical solar PV system using monocrystalline solar panels.

2. Solar PV Cleaning Methods

Solar photovoltaic (PV) panels are technologies that continue to be widely adopted in the quest to tackle the human-induced climate crisis and the continuous growth in the demand for energy in the world [10,11]. However, factors like soiling, atmospheric pollution, photovoltaic (PV) panel tilt angle, and bird droppings can be detrimental to the efficiency of solar PV panels [10,12]. Soiling and bird droppings are some of the leading criteria that reduce the efficiency of solar PV panels, with a study showing that a power reduction of up to 5.66% is possible in a solar PV system that has been covered with dirt for one year [10,12]. Hence, various cleaning methods are considered, with the natural cleaning method being best suited for the location.

Natural Cleaning

Natural cleaning is the process of depending on natural phenomena like rainfall and wind to clean solar PV panels. This process can have an significant effect in removing the dirt on solar PV panels, but it is heavily reliant on weather conditions [13].

3. Methodology

To carry out the design for the Dar-Al-Arqam mosque, the methodology is segregated into the following stages: Stage 1: Constructing the database of the location. This database collection is categorized into two parts, the geographical location of the site where the solar PV system will be installed, and the energy consumption data detailing how energy is used in the mosque. These data are paramount and influence the design of a solar PV system that is economical and efficient. Stage 2: Roof space availability assessment for the solar PV system design. This part of the methodology is important in order to have a clear understanding and knowledge of the space availability, thus allowing a suitable design to be carried out for the available containing space. Stage 3: Carrying out a market survey to obtain a clear idea of prices and designing the system utilizing the PVsyst simulation software package. Stage 4: Visitation was carried out to a Passivhaus project where a solar PV system was incorporated into the design to determine whether this work conforms with industry methods.

In carrying out this design, some mathematical expressions were used in the simulation software and they include the following:

Calculation of the energy consumption: $E = P \times (t/1000)$,
where E = energy measured in Joules or kilowatt-hours (kWh), P = power units in watts, and t = time over which the power or energy was consumed;
Payback period: Total installed cost/(estimated annual energy produced kilowatt hour) $\times$ (grid price per kilowatt hour);
Levelized Cost of Energy (LCOE) = Lifecycle cost / net energy output [14];
Performance ratio (PR): $PR = Yf/Yr$,
where Yf = Final Yield and Yr = Reference Yield [15].

4. Results and Discussion

Three solar PV design scenarios were considered, which are the design of the full roof capacity, the east design, and the west angle design, as shown in Figure 1. Going by the designs, the west angle seems to be the most suitable system for the building, although the east angle produced more energy. More of the energy has been exported than used, which further increases the payback period; Figures 1 and 2 give more insight into this. Also, designs with storage and without storage were carried out to verify which was most suitable for the building, as shown in Figure 3.

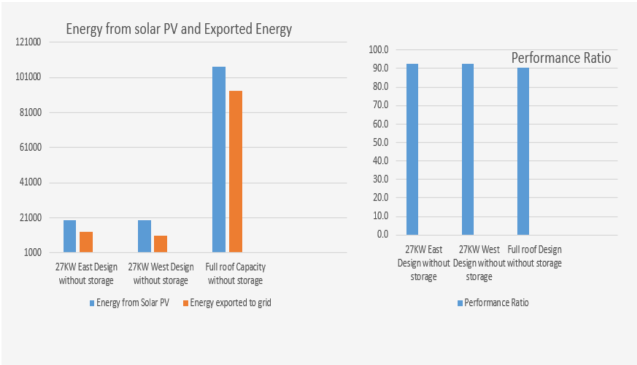

Figure 1. All design scenarios.

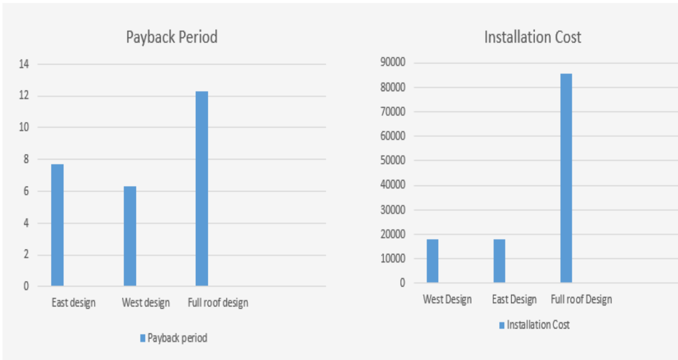

Figure 2. The three design scenarios' payback period and installation cost.

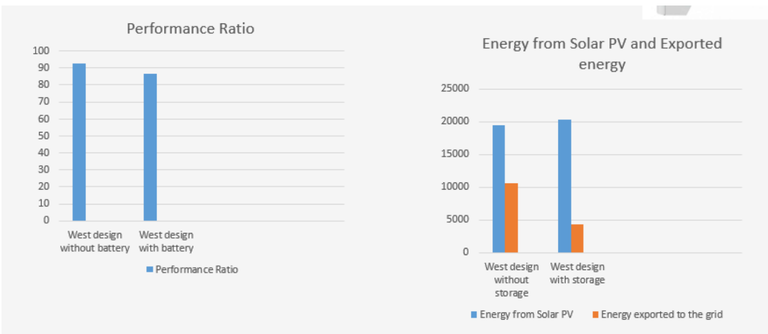

Figure 3. Battery system vs. no-battery system.

5. Future Work and Conclusions

Some of the energy utilized by the mosque is for hot water to perform ablutions, which is also a core part of the day-to-day activities in the mosque. Hence, by analyzing the energy exported to the grid, if it can be shown that this energy can be used to heat up the water instead, this will not only increase the fraction of renewable energy in the energy mix but also help in the economical aspect.

This work highlights that improving the energy efficiency of a listed (heritage) building can be a daunting task but not impossible, and it is paramount to adapt these historic buildings to reach the energy efficiency goals and keep them sustainable for the next generations; and there cannot be a one-method-fits-all approach in retrofitting these buildings, as doing so can result in impacting their structural integrity. Also, a solar PV system is a suitable energy source that can be integrated into the building as there is typically a roof space in which to install it. With cleaning methods, there is also no one method that fits all needs as it all depends on the geographical location.

Author Contributions: Conceptualization, R.S. and N.S.; methodology, R.S. and N.S.; software, R.S.; validation, R.S., and N.S.; formal analysis, R.S.; investigation, R.S.; resources, R.S.; data curation, R.S.; writing—original draft preparation, R.S.; writing—review and editing, R.S. and N.S; visualization, R.S.; supervision, N.S.; project administration, N.S. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

Conflicts of Interest: The authors declare no conflict of interest.

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