applied sciences

MDPI

Article

Energy Saving Strategies and On-Site Power Generation in a University Building from a Tropical Climate

Jaqueline Litardo [1,2], Massimo Palme [3,4], Rubén Hidalgo-León [1], Fernando Amoroso [1] and Guillermo Soriano [1,*]

1 Centro de Energías Renovables y Alternativas CERA, Escuela Superior Politécnica del Litoral ESPOL, Km. 30.5 Vía Perimetral, Guayaquil EC90902, Ecuador; jaqueline.litardo@polimi.it (J.L.); rhidalgo@espol.edu.ec (R.H.-L.); famoroso@espol.edu.ec (F.A.)
2 Architecture, Built Environment and Construction Engineering Department, Politecnico di Milano, Via Bonardi 9, 20133 Milano, Italy
3 Escuela de Arquitectura, Universidad Católica del Norte, Av. Angamos 610, Antofagasta 1240000, Chile; mpalme@ucn.cl
4 Centro de Investigación Tecnológica del Agua en el Desierto, Universidad Católica del Norte, Av. Angamos 610, Antofagasta 1240000, Chile
* Correspondence: gsorian@espol.edu.ec

Abstract: This paper compares the potential for building energy saving of various passive and active strategies and on-site power generation through a grid-connected solar photovoltaic system (SPVS). The case study is a student welfare unit from a university campus located in the tropical climate (Aw) of Guayaquil, Ecuador. The proposed approach aims to identify the most effective energy saving strategy for building retrofit in this climate. For this purpose, we modeled the base line of the building and proposed energy saving scenarios that were evaluated independently. All building simulations were done in OpenStudio-EnergyPlus, while the on-site power generation was carried out using the Homer PRO software. Results indicated that the incorporation of daylighting controls accounted for the highest energy savings of around 20% and 14% in total building energy consumption, and cooling loads, respectively. Also, this strategy provided a reduction of about 35% and 43% in total building energy consumption, and cooling loads, respectively, when combined with triple low-e coating glazing and active measures. On the other hand, the total annual electric energy delivered by the SPVS (output power converter) was 66,590 kWh, from where 48,497 kWh was supplied to the building while the remaining electricity was injected into the grid.

Keywords: energy savings; daylighting; photovoltaic system; EnergyPlus; Homer PRO; Net Zero Energy Buildings

Citation: Litardo, J.; Palme, M.; Hidalgo-León, R.; Amoroso, F.; Soriano, G. Energy Saving Strategies and On-Site Power Generation in a University Building from a Tropical Climate. *Appl. Sci.* **2021**, *11*, 542. https://doi.org/10.3390/app11020542

Received: 29 November 2020
Accepted: 31 December 2020
Published: 8 January 2021

1. Introduction

Energy consumption in buildings is a field of extensive research worldwide. Buildings are one of the fastest growing sectors in energy consumption in the last decades [1–3], which is due to population growth, industry development, expansion of cities, and improvement of living standards [4]. The aforementioned implies a growth in the demand for thermal comfort and indoor air quality [5]. This sector has a contribution between 20–40% of the global final energy consumption [6,7], where these percentages vary according to region. For example, buildings in European Union Member States represent about 40% of total final energy consumption and 36% of carbon emissions [8]. Electricity is one of the most widely used energy sources in buildings. It is estimated that buildings consume about 60% of the global electricity [9], which has increment its use in more than 19% between 2010 and 2018 [10]. The energy consumption of buildings is mainly affected by factors such as weather conditions, building characteristics, and the operating conditions of building systems [6]. Heating, ventilation, and air-conditioning systems (HVAC) are used to provide indoor thermal comfort and their demand depends mainly on local climate, building design and internal loads. These systems are the largest consumers of energy in buildings with about 40% of it [7,11]. Also, the energy demand for HVAC is affected by the thermal properties of the building envelope (walls, doors, roofs, windows, etc.) mainly in warm climate locations [12–14]. Artificial lighting is the second most energy-consuming system in buildings, ranging from 20% to 45% [15,16]. Educational buildings are among the main consumers of energy in the commercial building sector, where in countries, such as USA, Australia and UK, the energy consumption of these buildings is between 10% and 13% [7,17]. The frequency of use and occupancy of classrooms could considerably increase the energy bills [15]. In the case of Ecuador, commercial buildings account for 20.5% of the total Ecuadorian electricity demand [18,19]. Therefore, it is necessary to look for initiatives that help to improve the efficiency in the use of energy in the buildings maintaining the levels of comfort of the users, with minimum cost and reduction of their carbon footprints.

2. Literature Review

Various energy saving strategies have been modeled and implemented in buildings to reduce their energy consumption. Some of these measures are focused on increasing the efficiency of artificial lighting and their integration with daylighting through the development of improved control systems [15,16]. The latter is considering adequate lighting levels according to the type of activity of the area to be controlled and visual comfort [20]. Although the use of daylight could be exploited in the buildings, this must be done in a technical way as there could be a possible problem with heat and solar glare [21]. Several studies have shown considerable reductions in energy consumption with the use of intelligent lighting controls. A typical Greek classroom was analyzed in [15], where the results showed that from an annual lighting primary energy consumption of 90.5 kWh/m^2, it can be reduced to 0.55 kWh/m^2. Han et al. [22] reported that the control of a 200 W LED lamp and daylight exploitation could achieve savings of 174 kWh per year taking into consideration the operating conditions of the experiment. Likewise, two control algorithms were tested for the lighting of two offices, where the experiments shown savings of up to 70% [23]. In [24], three classrooms were studied over the course of a year with various types of lighting control. Here, the authors found savings between 18% and 46%.

Previous studies have shown the potential of implementing high performance windows and shading devices in buildings to reduce their energy consumption. Kunwar et al. [25] analyzed the use of shading devices, two types of glass and lighting controls in a test room, where the authors achieved energy savings of 25.4% in cooling and 48.5% in lighting. According to [13], advanced glazing technologies can achieve annual energy savings between 0.56 kWh/m^2 and 323 kWh/m^2 per window area, where these materials are capable of handling solar heat and visible light transmitted into the building. Somasundaram et al. [26] modeled a building with the use of a new type of low-emissivity glass over existing window glass and found that this replacement could achieve energy savings of up to 9% in air conditioning usage. Marino et al. [27] stated that in warm climates when the window surface occupies more than a quarter of the wall surface, the use of shading devices is crucial for energy saving purposes. Furthermore, the authors indicated that this measure is more efficient than improving the characteristics of the building envelope. Changing the size of the window façades taking into consideration the environmental conditions and building orientation has influence on the energy consumption of the building. The Window to Wall Ratio (WWR) parameter is relationship between the size of the window surface according of its wall surface [27–29]. Alghoul et al. [30] studied the influence of the WWR and window orientation on the cooling, heating and energy consumption of a small office in the city of Tripoli, Libya, where increasing the WWR resulted in increased cooling energy consumption. In addition, the increase of windows in the façade resulted in higher energy consumption between 6–181% among all the cases studied. However in [31], the use of sunshades in a comprehensive shade in the windows of a hotel in China showed a saving of 6.5% in the annual cooling load taking a reference WWR of 0.32.

The replacement of old equipment with lower consumption ones is another option to improve the efficiency of energy use in buildings. ENERGY STAR certified equipment could reduce energy consumption by 10–50% compared to standard equipment [32]. For example, a conventional desktop computer consumes 65 W against 54 W for the same ENERGY STAR equipment. In models made to an Italian office building, Luddeni et al. [33] evaluated two equipment replacement levels of 5.4 W/m^2 and 8.1 W/m^2 using 10.8 W/m^2 as a baseline. Here, the modeling of this measure allowed energy savings of over 10%.

The use of renewable energy sources in buildings is an eco-friendly solution. Some renewable sources that can be applied in buildings are photovoltaic (PV) panel modules, geothermal heat pumps, fuel cell systems, and solar thermal collectors [34]. The use of solar panel technology is convenient for buildings because apart from reducing the dependence on grid electricity and energy bills, it could not require long distances for power transmission as solar farms [35]. In addition, this technology reduces pollution levels and acts as a heat shield when it is placed on the roof. The shading effect on the thermal performance of the roof could reduce the energy consumption for indoor air conditioning in warm climates [36].

Nearly Zero Energy Buildings (NZEBs) are based on a group of regulations, energy polices, standards, and codes, which aim to ensure a higher improvement on building energy performance and also the implementation of on-site (or near-site) energy generation from renewable sources [37]. The objectives of the NZEBs are not only limited to new buildings [38], because existing buildings can be retrofitted considering energy saving measures and renewable generation. The growth of the building sector is accelerating the use of solutions to improve efficiency, to reduce the carbon footprint and to reduce energy consumption in buildings. The European Union is promoting the NZEB as a minimum standard for the new buildings in the coming years [39]. Similarly, strategies adopted by NZEBs in hot and humid climates are related to passive and active design, exploitation of technologies such as artificial lighting and HVAC systems, other energy saving measures and renewable generation [40,41]. Despite of this, the implementation of various energy saving measures could increase construction costs considerably, mainly if NZEB targets are pursued [40].

Each energy saving strategy must be planned, designed and modelled to estimate its impact on the building performance. Many authors have used the EnergyPlus software, initially to know if the strategies could achieve NZEB objectives or in the ideal scenario, if the modelling of strategies will achieve the expected zero balance [13,31,37]. Regarding onsite electricity generation, Homer PRO software is widely used by researchers to estimate the sizing, operation, economic costs, and other parameters, of power generation systems from renewable sources [42,43].

The present study aims to evaluate the potential for energy saving of different passive and active strategies for a student welfare unit located in Guayaquil, Ecuador. The case study is surrounding by a tropical climate, with two seasons: Wet and dry. All building simulations were carried out in OpenStudio-EnergyPlus. Also, we proposed a grid-connected solar photovoltaic system (SPVS) to reduce the purchase of electricity from the grid. The expected results would determine some guidelines for building retrofits in this and related climates. Also, the study can contribute to generalize energy saving strategies for tropical cities, Aw, according to the Köppen-Geiger classification [44], and improve the sustainable building design in these climates. This is a relevant issue since more than 33% of the global population lives in the tropics, and in Ecuador more than 50% of its total population [45].

3. Materials and Methods

The methodology has been divided into five subsections. Section 3.1 addresses location and climate conditions of the surroundings of the studied building. Section 3.2 describes the geometry, building materials, and the operation schedules of the modeled building. Section 3.3 describes some details about OpenStudio-EnergyPlus simulations. Section 3.4 defines energy saving strategies to be proved for the case study. Finally, Section 3.5

encompasses the on-site power generation through a photovoltaic system.

3.1. Location and Climate Conditions

The city of Guayaquil (2°11′21.89″ S, 79°53′20.64″ W) is the largest and the most populated city of Ecuador, with an estimated area of 2494 km^2 and about 2.72 million people in 2020, based on projections of the National Census Institute (INEC) [46]. Guayaquil has a tropical climate, corresponding to the Aw group from the Köppen-Geiger classification [44], with two well-defined seasons: wet (January–April) and dry (May–December). The climate conditions of Guayaquil are depicted in Figure 1. The monthly average temperatures vary between 23.4 to 26.5 °C. The monthly minimum temperatures are above 18.0 °C, while the monthly maximum temperatures are below 33.2 °C. The relative humidity values are higher during the wet season, while the annual average is about 70%. The monthly average global radiations are between the 3.5 and 5.3 kWh/m^2.

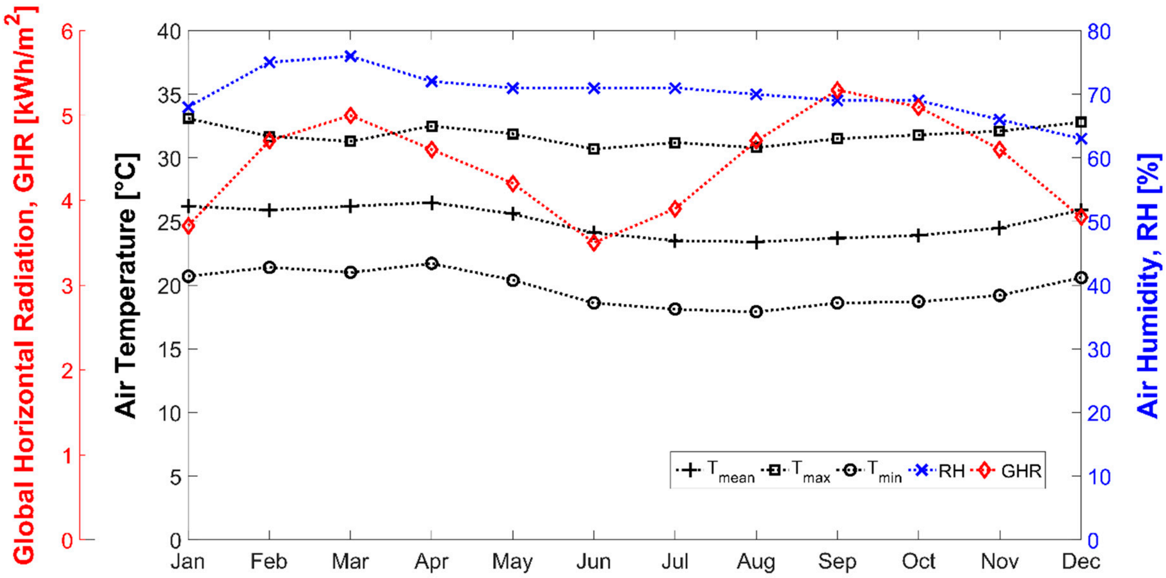

Figure 1. Climate conditions in Guayaquil, Ecuador (authors elaboration based on data from Meteonorm [47]).

Figure 2 shows the distribution of the annual climate conditions of Guayaquil (temperature and humidity) plotted on the psychrometric chart based on a Typical Meteorological Year (TMY) file. As can be observed, during almost all the year, the city presents high outdoor temperatures and humidity. It means that around 86% of the year people could experiment indoor discomfort. Therefore, efficient air-conditioning systems and/or passive energy saving strategies are required to reduce the energy demand for cooling in these climates. Some strategies suggested by the Climate Consultant v. 6.0 tool [48] for the studied climate are dehumidification, sustainable cooling, and solar shading.

3.2. Building Description

The building under study is the Student Welfare Unit of ESPOL Polytechnic University, whose campus is in Guayaquil, Ecuador (Lat. 2° 8′34.61″ S, Long. 79°58′1.76″ O) (Figure 3). It is a two-story building formed by conventional local building materials, based on masonry construction [14]. Table 1 summarizes the physical and thermal properties of the building materials that form the studied building envelope. The entire building has a total floor area of about 1086 m^2 and a floor to floor height of 4.5 m. This building has a 35% window-to-wall on the north wall, 38% on the south wall, 33% on the east wall, and 23% on the west wall.

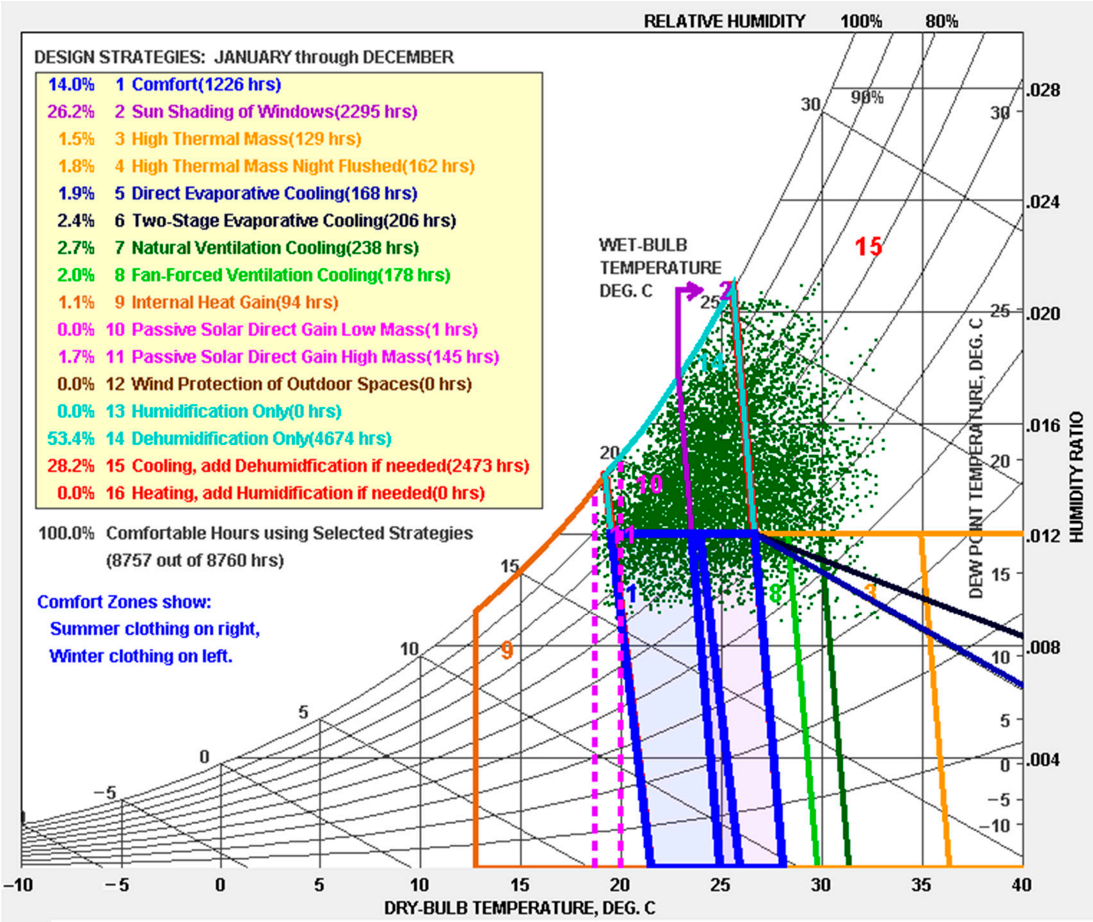

Figure 2. Hourly outdoor temperature and humidity in Guayaquil, Ecuador (obtained from Climate Consultant [48]).

Figure 3. Student Welfare Unit building of ESPOL Polytechnic University (from [49]).

Table 1. Physical and thermal properties of envelope building materials (adapted from [14]).

Construction	Density [kg/m^3]	Thermal Conductivity [W/m-K]	Specific Heat [J/kg-K]	U-Value [W/m^2-K]
Roof				
Steel sheet (1 mm)	7800	50	450	
Heavy weight concrete (30 cm)	2240	1.31	837	
Wall				
Hollow concrete block (9 cm)	1600	0.47	1000	
Plaster (1 cm)	800	0.37	340	
Floor				
Heavy weight concrete (10 cm)	2240	1.31	837	
Acoustic tile (2 cm)	368	0.06	59	
Windows				
Clear glass (6 mm) Metal frame				5.78

The building has a double use: it works as an office building and as a medical center for students and the rest of the University staff. The building operates from 8:00 to 16:30 during weekdays.

The internal heat gains of the building consist of internal (appliances, lighting) and conditioned loads (direct expansion mini splits). Table 2 summarizes the overall installed power by end-use. All the internal and conditioned loads of the building work with electricity.

Table 2. Building internal loads: installed power by end-use (from [49]).

System	Description	Installed Power [W]
Lighting	LED and saving lighting	11,974
Electric equipment	Appliances	25,716
Air-conditioning	Direct expansion mini and floor/ceiling splits	170,567 (581,999 BTU/h)

Also, the studied building has an occupancy of around 30 permanent workers, all of them performing light office activities. Therefore, the activity level value was set at 100 W/person.

The energy tariff for the building is USD$0.06/kWh from 07:00 to 22:00; the rest of the hours the electricity cost is USD$0.05/kWh. Likewise, the tariff for monthly peak demand is USD$1.57/kW. The city's public electricity company established these values for 2020 [50].

3.3. Building Energy Model in EnergyPlus

We used the OpenStudio v. 2.7 tool and EnergyPlus v. 9.1 software for the simulations. As a first step, we modeled the baseline of the building, i.e., its actual situation in terms of energy (Figure 4). For this, we considered all internal loads from Table 2, and people occupancy.

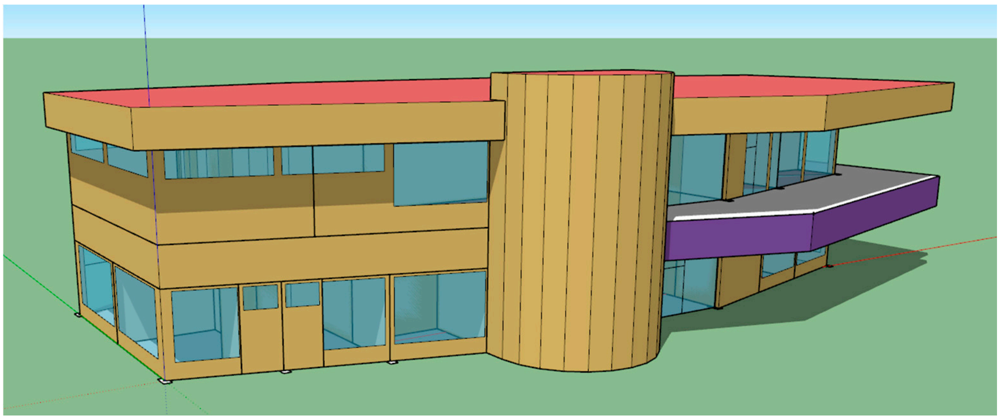

Figure 4. Student Welfare Unit building model in EnergyPlus (authors elaboration).

We established the schedules of the building based on the information provided by the users. We fixed the infiltration rates in 0.54 air changes per hour (ACH) [18]. Air-conditioners were modeled with a standard COP of 3, considering that the systems installed in the case study are obsolete.

3.4. Energy Saving Scenarios

Previous studies have defined several strategies to improve energy use in buildings [33]. The optimal selection of these will depend on the final use of the building, the needs of the users (environmental comfort), the investment costs, and the climate conditions of the site. In general, energy saving measures can be divided into two large groups: passive and active strategies. Passive strategies are mainly focused on improving the thermal properties of the envelope components and/or taking advantage of the climate and surroundings to reduce the energy demand of the building. In contrast, active strategies focus directly on improving the energy efficiency of the building's internal loads and/or on the implementation of smart controls.

In this section, we propose different energy saving scenarios to analyze the feasibility of incorporating them in the retrofit of the case study. All scenarios were tested independently.

3.4.1. Integration of Daylight with Artificial Lighting

In order to take advantage of the daylight levels around the studied building, we proposed a dimming control.

Figure 5 depicts the schematic of the dimming control scenario modeled in EnergyPlus. This system uses a photosensor to monitor the lighting level (in lux) in a reference point of the studied zone. As the main purpose of these systems is to maintain the desired lighting levels within the zone, they adjust the output power of the artificial lighting systems based on the available daylight levels. We used "SplitFlux" as the daylighting method, with a minimum input power fraction and minimum light output fraction of 10% in both cases. We also defined the illuminance setpoint at each reference point as 500 lux.

3.4.2. Window to Wall Ratio (WWR-20%)

Since the optimal WWR for daylighting and natural ventilation is around the 30–40% and considering the external view as an important factor for the environmental comfort of the users, we proposed a reduction of the WWR from the base case to 20% in all façades. For this purpose, we used the "Resize existing windows to match a given WWR" measure from NREL's Building Component Library (BCL) available for OpenStudio [51]. This measure reduces the dimensions of each window around its centroid and it only works in case of WWR reduction. The result of applying this measure provides a clearer perspective about its potential against the potential of daylighting control strategy. Therefore, from this analysis we would be able to know if it is recommended to keep the current WWR to take advantage of the daylighting availability or if it is better to reduce it without considering the incorporation of daylighting strategies in this building.

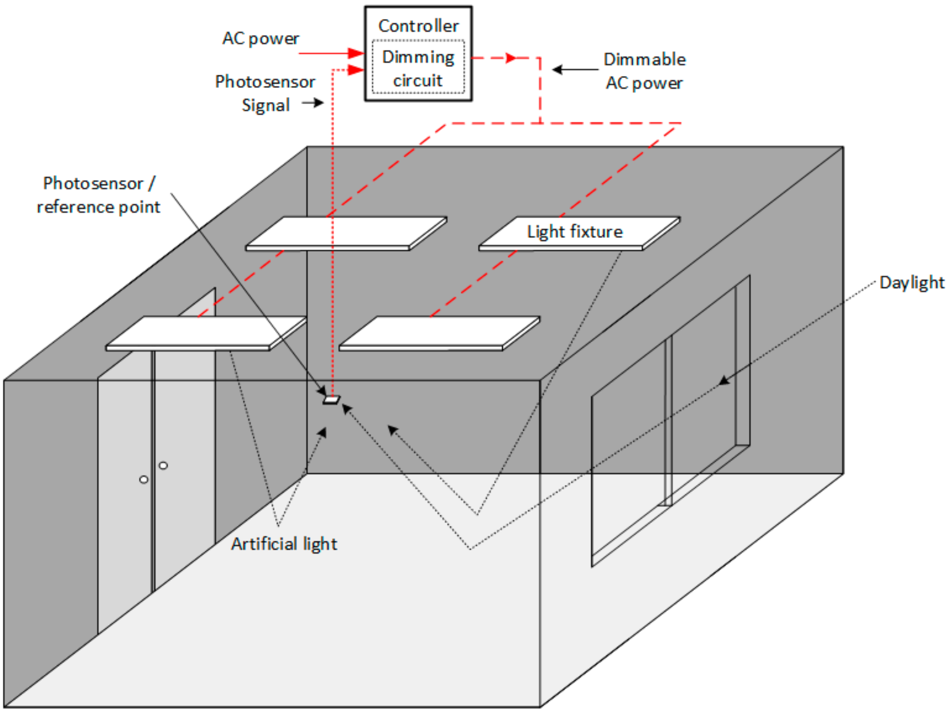

Figure 5. Schematic of a zone using a dimming control system from the integration of daylight and artificial lighting (authors elaboration).

3.4.3. Static Solar Shading

We employed static shading devices on the windows of the building in horizontal (overhangs) and vertical fins configurations, as shown in Figure 6. These configurations aim to reduce the penetration of sunlight into the building through the windows [31]. These structures were placed on the windows of all façades in the building model. The height and width of these structures are adapted to the dimensions of the windows and the depth was set at 60 cm in all windows.

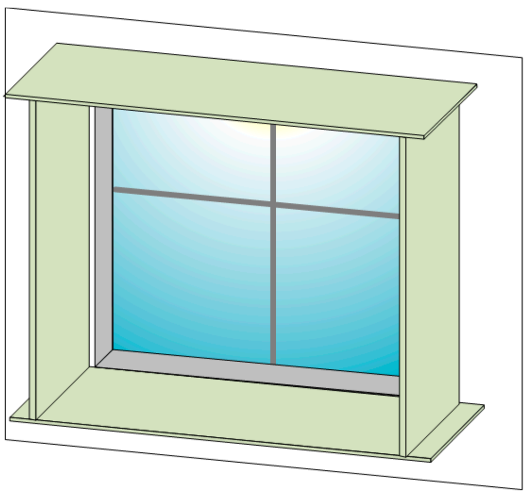

Figure 6. Horizontal and vertical shadings (adapted from [31]).

3.4.4. High Performance Windows (TrpLoE)

Static windows with triple glazing were considered in the analyses, as shown in Figure 7. This retrofit window has a thickness of 44 mm, where the glasses are in layers 1–2, 3–4 and 5–6. It has two air gaps filled with argon gas (2–3 and 4–5), as well as two low-e coating films (2 and 5). The thickness of each air gap with argon is 13 mm and 6 mm for each glazing. These retrofit windows were modeled in all façades. We proposed windows with lower thermal transmittance values (U-value = 0.785 W/m^2-K) to reduce the solar gains of the building, while admitting the entrance of daylight into the indoor spaces (visible light transmittance, τ = 0.66), with a low solar heat gain coefficient (SHGC = 0.474) to avoid overheating. Single pane windows, which are common in the façades of Guayaquil's buildings, are responsible for increasing the energy demand for cooling due to the higher solar gains. Poor window design will result in significant impacts on thermal and visual comfort and increased energy demand for cooling, and consequently, these will increase energy bills and CO_2 emissions.

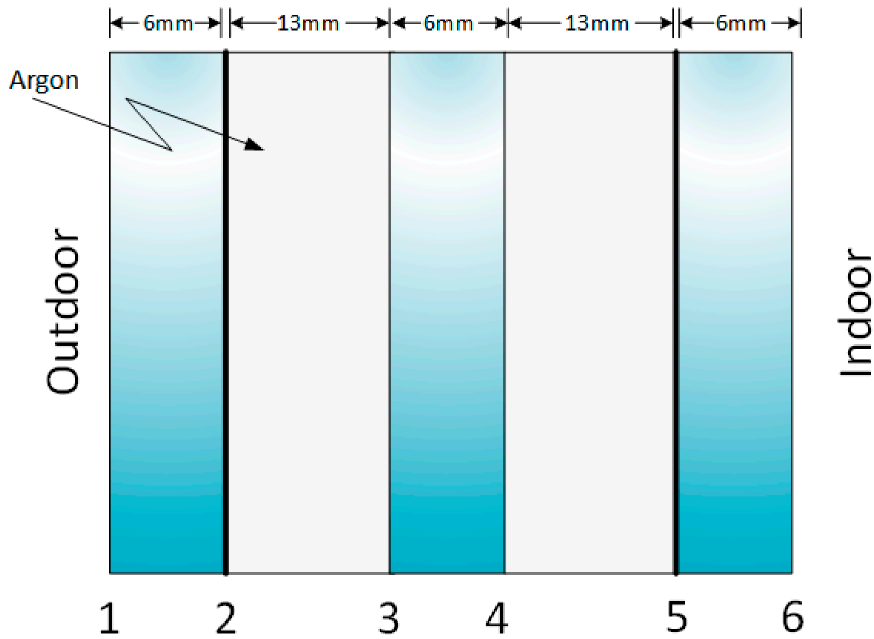

Figure 7. Triple glazing low-e coating window filled with argon, TrpLoE (authors elaboration).

3.4.5. Active Measures for Energy Saving

We analyzed three actives measures, which are: changing the cooling set point of the thermal zones, increasing the coefficient of performance (COP) of the air-conditioners, and replacing the standard electric equipment with others with ENERGY STAR certification.

In the studied case, the set points of the air-conditioners are typically fixed at temperatures between 21–22 °C. For energy saving purposes, we changed the set point temperature to 24 °C, in accordance with [45] to maintain an adequate level of comfort for all users. This measure is intended to establish a single temperature, which will reduce the excessive cooling of areas according to the needs of certain users.

For this scenario, we also considered the replacement of air-conditioners with others of higher coefficient of performance (COP). To accomplish this, we followed the recommendations of the ASHRAE 90.1-2019 Standard [52] for the U. S. Department of Energy (DOE) minimum energy efficiency requirements for HVAC systems and changed the COP values of each one in OpenStudio. Table 3 summarizes the cooling capacity ranges of the air-conditioners installed in the case study and their corresponding minimum COP based on DOE recommendations.

Table 3. Cooling capacity ranges and DOE minimum energy efficiency requirements for air conditioners (extracted from [52]).

Cooling Capacity [BTU/h]	COP
<65,000	3.45 (SEER 14)
≥65,000 and <135,000	3.55 (SEER 14.6)

The replacement of electric standard office equipment with similar but less energy-consuming equipment was another energy-saving measure proposed in this study. We proceeded to replace office equipment such as computers, printers, and copy machines by similar equipment but with ENERGY STAR certification [32,33]. This is equivalent to a reduction of about 20% in the installed power for appliances. This measure maintained the same operation profiles of the base case. The use of high-performance lighting systems was not in the scope of this study since it is considered that the lighting systems of the base case are LED.

3.4.6. Combined Scenarios

We also proved two combined scenarios that were selected at our discretion:

1. Scenario 1: Daylighting control + TrpLoE + Active measures
2. Scenario 2: Shading + TrpLoE + Actives measures

We considered the active measures in both scenarios since these strategies are the directly related to the reduction in internal loads. On the other hand, we chose to evaluate the TrpLoe windows in both cases to answer one key question: Is it better to take advantage of the solar radiation coming into the building, or is it preferable to block it partially, considering the studied climate?

3.5. On-Site Energy Generation

The building under study has a nearby total area of more than 2000 m^2, free of obstacles, where PV modules could be installed without any inconvenience in case of implementation. For the purpose of the present work, we proposed to use between 20% to 25% of the total available area. Taking into account the size and power of the selected PV module and the target area, we considered a grid connected solar PV system (SPVS) of 50 kWp for on-site energy generation.

The SPVS aims to reduce the use of the building's electrical energy from the electric power grid. In the implementation of a SPVS, its investment costs could be much higher than the execution of the other energy saving measures in the building, depending mainly on its size [33]. In the simulation it is assumed that the surfaces of the PV modules are facing north with a tilt angle similar to the latitude of the site. These last conditions are ideal for extracting the most significant PV energy in SPVSs, located in the southern hemisphere [53]. DC/AC power converters sends the power generated by the PV panels to the electric power grid, which can operate in parallel to the grid without any inconvenience.

The simulations of this system were carried out in the HOMER Pro software [54], taking into consideration the electrical load modeled in EnergyPlus. The governing equation to calculate the output power of each system is the following:

$$P_{out,PVsyst} = Y_{PVsyst} \times f_{PVsyst}\left(\frac{G_T}{G_{T,PVsyst}}\right)\left(1+\alpha_p\left(T_c - T_{c,PVsyst}\right)\right), \quad (1)$$

where Y_{PVsyst} is the nominal capacity of the PV system, f_{PVsyst} is the derating factor of the PV system, G_T is the incident radiation on the PV system [kW/m^2], $G_{T,PVsyst}$ is the irradiation under standard test conditions [1 kW/m^2], α_p is the temperature coefficient of the power [%/°C], T_c is the cell temperature of the PV system [°C], and $T_{c,PVsyst}$ is the temperature of the PV system under standard test conditions [25 °C].

The PV module considered for the calculations was 360 Wp, monocrystalline type, with a surface area of 1.77 m^2 [55]. The cost for this module in the Ecuadorian market is around USD$220.00 per unit with a lifetime of 25 years [56]. In addition, we considered a derating factor of 90%, where 10% represents the losses such as dust on the surface of the panels, wiring, shading, and others [57]. Likewise, the cost of the 6 kW DC/AC power converter was USD$5,000.00, with an efficiency of 95%. The replacement costs of these two equipment are not considered in this simulation.

Figure 8 shows the configuration of SPVS, which was simulated in Homer Pro. It is composed of PV panels, DC/AC power converters, electric power grid and the electrical load of the building.

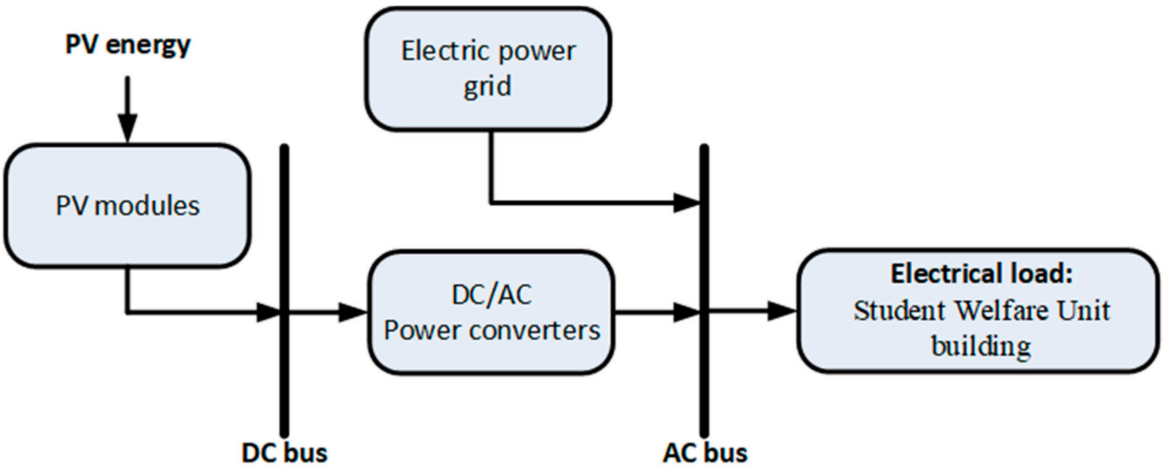

Figure 8. Configuration of grid-connected solar PV system of 50 kWp to be simulated in Homer PRO (authors elaboration).

4. Results

In order to provide a better understanding of this section, it has been structured as follows. The first subsection encompasses the estimated results of the annual energy consumption of the building and its energy consumption by end-use. These results represent the baseline of the model. The second subsection presents the results of the energy saving strategies and analyzes their feasibility to improve the energy use in the studied building. The third subsection presents the results of the combined energy saving scenarios. The forth subsection regards to the costs related with each of the strategies. Finally, the fifth section shows the results from the SPVS and its related costs.

4.1. Baseline

We estimated the energy consumption of the Student Welfare Unit model related to the annual operational activities of the building. Considering all internal gains and conditioned loads, the estimated annual energy consumption resulted in 97,958 kWh. The estimated Energy Use Index (EUI) was 90.17 kWh/m^2-year. The 44% of the total energy consumption corresponded to the use of HVAC systems. Lighting and electric equipment occupied 31% and 25% of the total, respectively. The results are consistent with analysis conducted in similar buildings of the Coastal Region of Ecuador [58,59].

Figure 9 shows the estimated monthly energy consumption by end-use. As can be observed, the energy consumption exhibited a seasonal behavior being higher during the months of the wet season and lower during the months of the dry season. This is an expected result since outdoor temperatures during the wet season are higher causing heat gains through the envelope and through infiltration to be more significant than during the dry season.

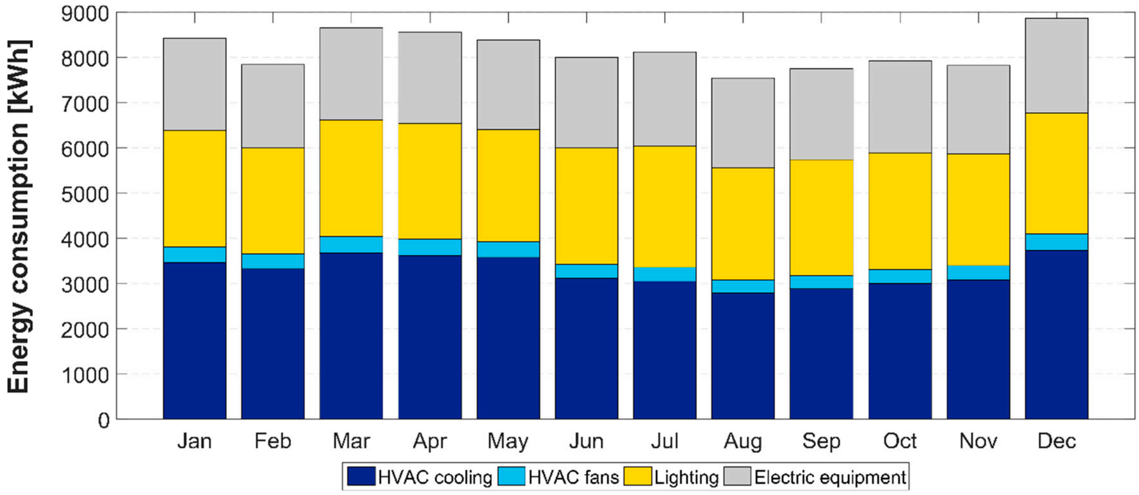

Figure 9. Estimated monthly energy consumption by end-use (authors elaboration).

Since energy consumption for cooling and lighting are the largest, measures should be taken to reduce electricity consumption mainly in these sectors, without affecting the comfort levels of the indoor environment (thermal, visual, and others). Regarding electric equipment, their replacement with their equivalent ENERGY STAR could lead to a relevant reduction in the annual energy consumption of the building. Also, energy efficiency policies could be addressed to improve the energy use in this type of buildings. The introduction of common dinning spaces and user training are other initiatives that can contribute to reduce the energy consumption and consequently, the carbon footprint of the building.

4.2. Energy Saving Scenarios

Figure 10 shows the results from the simulations of the energy saving scenarios proposed for the case study. We analyzed the savings strategies in the figure separately. As can be seen, daylighting control strategy had a highest impact on the total energy consumption in comparison with the other studied strategies. It provided a higher reduction in the annual building consumption by decreasing the energy for lighting in 42% compared with the base case. This strategy exhibited a EUI of 72.09 kWh/m^2-year. Next, active measures were in second place, providing the highest reduction in energy for HVAC systems and equipment. This is an expected result since active measures directly increased the energy efficiency of the HVAC systems, and also, the replacement of obsolete equipment with their ENERGY STAR equivalent reduced the final energy consumption for equipment in 15%, which can increase if it is applied to other type of buildings such as offices. The resultant EUI of this strategy was 77.07 kWh/m^2-year. The other saving strategies showed similar percentages of reduction. The main reason why the daylighting strategy had the highest impact among all strategies is due to the exploitation of daylight in the lighting of the building areas. This contribution of daylight to artificial lighting reduces energy consumption considerably compared to the case where there were not dimmable control systems on the light fixtures. Also, the application of all strategies reduces the energy demand for cooling of the building so that there was a reduction in cooling compared to the base case. Likewise, there was a slight reduction in the use of HVAC fans. These results help to estimate how much electrical energy can be saved by implementing these five strategies.

Figure 11 shows the energy saving percentages and the impact of each energy saving strategy on the total building electricity consumption and cooling. As can be observed, WWR-20% showed the smallest reduction in the annual total energy consumption (only 5.6%) but provided a reduction of about 12% in cooling loads. The solar shading and TrpLoE strategies showed reductions in energy for cooling of around 15–16%. The implementation of the WWR and Daylighting strategies should be carefully analyzed in building modeling. This is because while window reduction also reduces internal heat gains, this measure primarily affects the input of daylight and natural ventilation. As can be seen, the daylighting strategy showed a reduction of 20%, being the one that provided more savings in annual energy consumption. Despite daylighting controls decrease the energy for cooling in 14.3%, active measures provided a higher saving in cooling load of about 24.2%. In the case of the building under study, the daylighting strategy would be the ideal choice (between the two strategies mentioned) that would represent a considerable energy savings, in this particular case in electricity, and at the same time, a decrease in the energy bills.

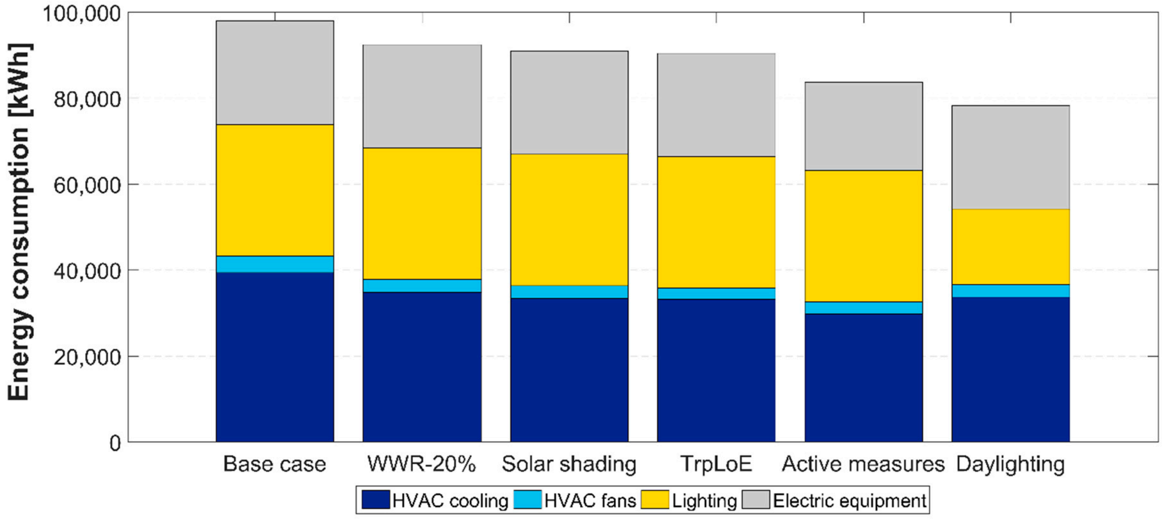

Figure 10. Annual energy consumption by end-use estimated for each proposed scenario (author's elaboration).

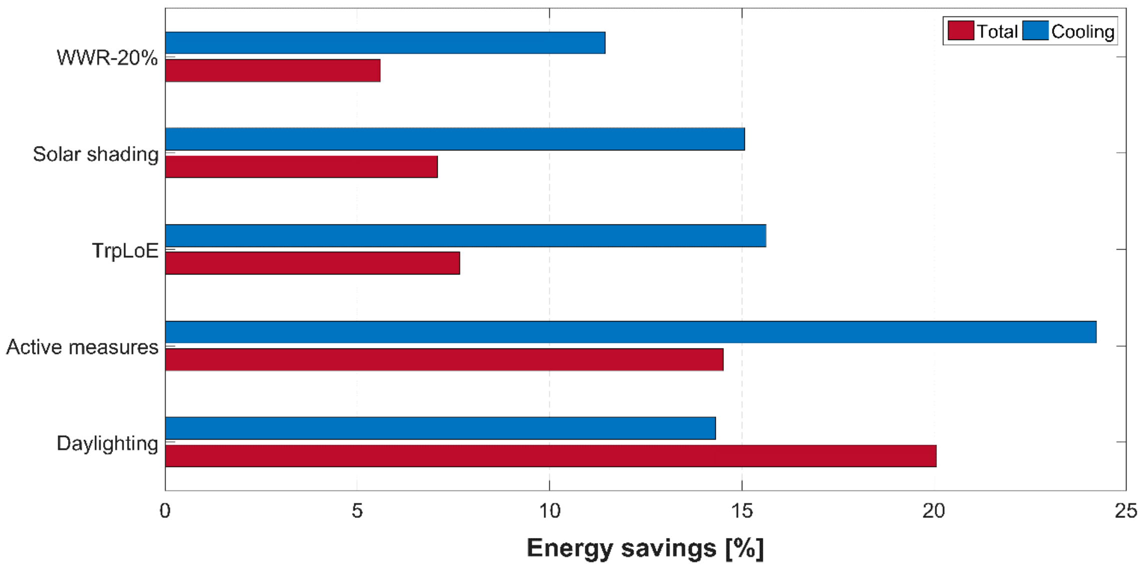

Figure 11. Annual energy saving percentages for cooling and total loads obtained from each proposed scenario (authors elaboration).

4.3. Combined Scenarios

In this section, we simulated two scenarios consisting of two groups of strategies. Scenario 1 consists of the application of solar shading, TrpLoE and active measures, while Scenario 2 consists of the application of daylighting, TrpLoE and active measures in the building model. Results from the simulations of these scenarios can be observed in Figure 12. In the Figure 12a, scenario 1 showed an annual energy consumption of 75,203 kWh

(EUI = 69.22 kWh/m^2-year) and scenario 2 of 63,713 kWh (EUI = 58.64 kWh/m^2-year). Figure 12b showed the percentage savings in total energy consumption and in cooling in the modeling of the two scenarios. Scenario 1 reduced total energy consumption by 35% and scenario 2 by 23% compared to the base case. The impact of both scenarios on building cooling is about 43%.

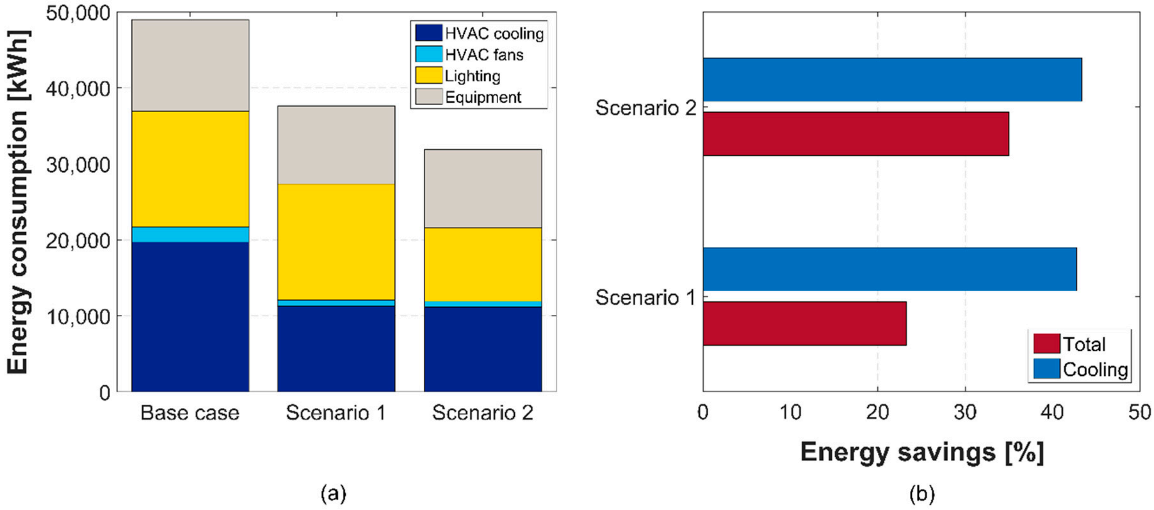

Figure 12. Estimated annual; (**a**) energy consumption; and (**b**) savings obtained from combined scenarios (authors elaboration).

4.4. Investment Cost of the Proposed Energy Saving Scenarios

In this section, we present the investment costs related to each of the proposed energy saving scenarios. Table 4 lists the approximated costs taking into account the suggested costs from the Ecuadorian construction sector [60,61]. As can be observed, the costs related to implementation of high performance windows are the highest and also, it presented the highest payback (more than 100 years). On the other hand, the installation of daylighting controls provided the lowest costs and a payback of more than 2 years. For this, daylighting solutions could be considered as the most cost-effective strategy to provide energy savings in this building according to the present analysis. Also, changing the cooling setpoint of the building should not be ignored since this strategy does not present an investment cost. Other strategies as WWR-20% and the use of static shadings presented paybacks of less than 50 years. The implementation of this strategies should be carefully analyzed, especially due to the cost of the energy in this building, which is subsidized. Therefore, this decision would probably lie on the availability of external investors.

Table 4. Investment costs of the proposed energy saving scenarios (authors elaboration based on costs established in [60,61]). All costs are presented in USD$.

Energy Saving Scenario	Investment Cost	Unit	Total	Payback
Daylighting controls				
Dimming controller Photosensor	From $100.00/unit From $60.00/unit	20 20	From $3200.00	2.34 years
Window to wall ratio reduction				
WWR-20% Windows desmounting Cement filling New windows installation	From $4.25/m^2 From $10.00/m^2 From $31.00/m^2	310 m^2 181 m^2 129 m^2	From $7126.50	18.7 years

Table 4. *Cont.*

Energy Saving Scenario	Investment Cost	Unit	Total	Payback
Static shading devices				
Overhangs and vertical fins from aluminium	From $118.76/m^2$	211 m^2	From $25,058.36	47.16 years
TrpLoE				
Triple glazing (6 mm) with double low emissivity films and aluminum profile	From $174.80/m^2$	310 m^2	From $54,188.00	103.8 years
Active measures				
Changing the cooling setpoint temperature	-	-	-	63.7 years
Replacement of obsolete air-conditioners with their higher efficiency equivalent	Mini split 12,000 BTU/h: from $500.00/unit Mini split 18,000 BTU/h: from $700.00/unit Floor/ceiling split 36,000 BTU/h: from $950.00/unit Floor/ceiling split 60,000 BTU/h: from $1200.00/unit	10 7 6 2	From $18,000.00	
Replacemet of obsolete electric equipment with their equivalent ENERGY STAR	Computer: from $1100.00/unit Copy machine: from $1200.00/unit Printer: from $200.00/unit	31 9 1	From $45,100.00	

4.5. On-Site Power Generation

Figure 13 shows the estimated monthly electricity generation of the SPVS of 50 kWp projected by HOMER Pro. The electrical load of the building was 97,958 kWh/year, whose monthly distribution can be seen in Figure 5. The total annual electric energy delivered by SPVS was 66,590 kWh where 48,497 kWh served to feed the building and the remaining 18,093 kWh were introduced into the electric power grid. This last amount is the excess energy produced by the SPVS when the building's electrical load is already covered [62]. The energy purchased from the grid during one year for the building's operation was 47,080 kWh. The month of July showed the minimum reduction of 44.20% in the use of energy purchased from the grid compared with the baseline modeling. October showed the highest reduction with 59.96%. The average monthly reduction was 51.98%.

Figure 14 shows the distributions of the annual hourly electrical power. As can be seen in the figure, the distribution of the power from the SPVS (output power converter) and electric power grid to cover the electrical load can be clearly observed. It should be emphasized that the operation of the SPVS is given according to the following cases. First, when there is a high solar resource and certain power consumption of the building at a specific time during daytime, the power of the converter could exceed this consumption and the surplus is introduced into the grid. The highest levels of power injection to the grid take place between 11:00 and 17:00, given that the electrical load is completely covered. In contrast, if there is a low solar resource and certain power consumption of the building in a certain time during daytime, the power of the converter is completely injected into the building and the difference to complete the load is taken from the grid. During the nighttime, the power consumption of the building is completely taken from the grid.

Furthermore, since the building does not operate on weekends, the power delivered by the SPVS is almost entirely injected into the grid. The results show that there are a significant number of hours of daytime per year that present the first case of operation.

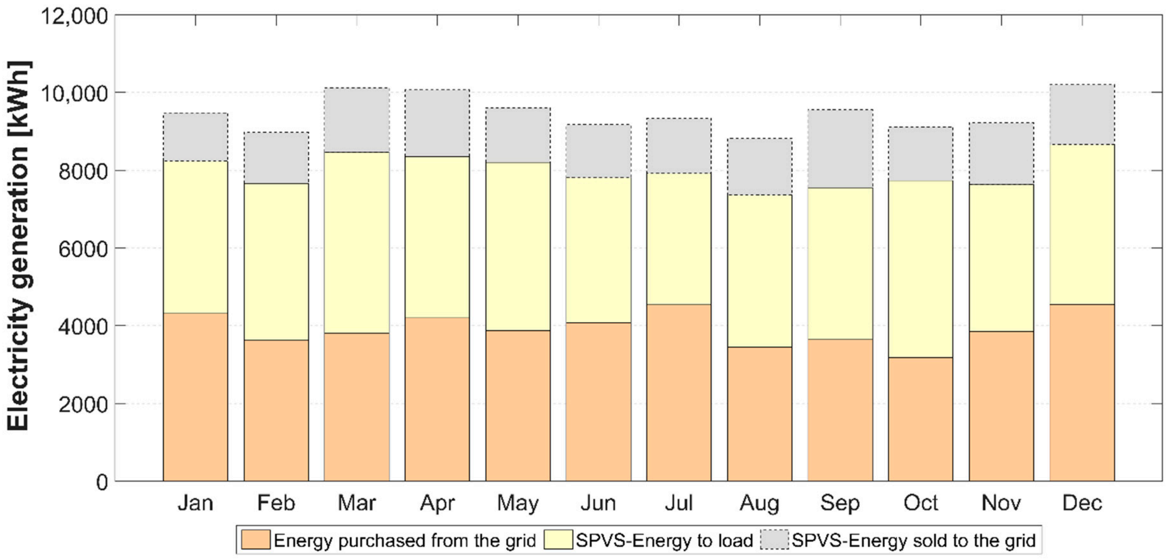

Figure 13. Estimated monthly electricity generation for a 50 kW PV system (authors elaboration).

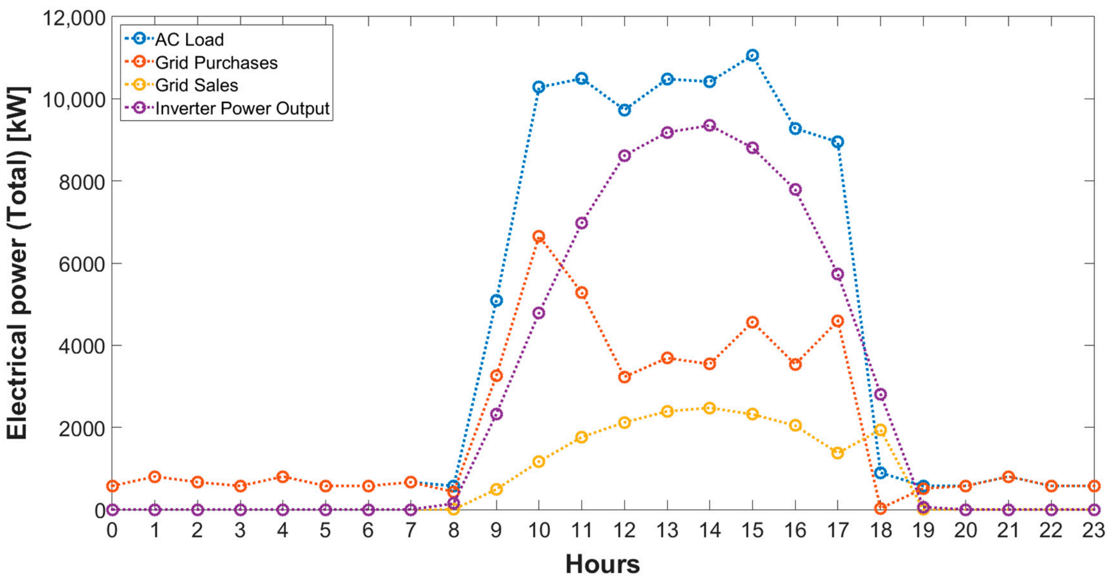

Figure 14. Distributions of the total annual electrical power of the load, SPVS, and electric power grid (author's elaboration).

The initial capital cost of the SPVS was USD$72,222.00 with an operation and maintenance cost of USD$3211.00. This last cost is related to the payment of energy purchased from the grid. In the present work, the SPVS was analyzed for one year of operation and the costs of assembly and installation of the system had not been considered.

5. Discussion

Energy savings strategies based on windows retrofits are one of the most expensive according to literature [33,63]. In our analysis, this strategy provided a reduction of about 16% and 8% in cooling loads, and total building consumption, respectively. The use of daylighting controls compared with the above exhibited a higher potential for savings that can lead to reductions of around 20% or more, depending on the control technology [64]. In equatorial zones, as in the case of Guayaquil, daylighting strategies can be very effective as stated in literature [65,66] since more direct solar radiation is received in this areas. This alternative could also present superior cost benefits when compared with the implementation of higher performance windows (doble reflective or triple pane low-e windows) or the replacement of obsolete equipment with more energy-efficient devices. The introduction of higher COP air-conditioners in old buildings could represent an important investment that should not be neglected, even when this measure could allow for energy savings ranging from 6 to more than 30% for different SEER values [67]. Therefore, this should be rethought for being used in new building projects and prioritize other low-cost measures for retrofitting purposes.

For minimizing the costs of implementing these measures in retrofits, some zero-cost strategies should be considered to improve energy use in buildings. Papadopoulos et al. (2019) [68] showed an example of this by changing the thermostat setpoint without compromising the occupants thermal comfort levels. When varying the cooling occupied setpoint between 24.3 to 26.9 °C, they found reductions up to 60% in HVAC loads depending on the climate. In this study, we included this strategy between the active measures and obtained that around 1/3 of the reduction provided by this strategy corresponded to the case when thermostat was set at 24 °C. This is equivalent to a decrease of 4% in the annual building electricity bills, which can be used to partially meet the implementation costs of other strategies. Despite the benefits of setting a higher static temperature for cooling control, some studies suggest that adaptive setpoints for summer and winter could reduce the building annual energy consumption even more [69,70]. In the case of Guayaquil, it is required to deepen this analysis to determine its effectiveness since the climate of this city could be a challenge for this approach.

Other strategies, such as the installation of static shading devices have been widely studied for researchers worldwide and despite their limitations [71], their use in hot and humid climates could account for reductions between 10% and even more than 20% in building cooling loads, depending on the shading design [72,73]. Even though our results are in accordance with this range, more effort should be devoted to exploring the optimal design of these element to decrease the energy demand for cooling in Guayaquil buildings, considering its climate, the type of building, and also, the amount of solar radiation on each façade. Full shading in all façades is recommended for tropical climate cities as Guayaquil [72,74]. However, to determine the best shading configuration for each façade could allow for relevant reductions in cooling, while decreasing the costs related to the application of this strategy.

The power of SPVS does not reduce the energy consumption of the building like other energy saving strategies. This power is consumed by the building during the daytime on-site and the surpluses sent to the power grid [33]. According to the legislation in Ecuador, these surpluses could generate an energy credit in favor of the consumer but with no money back from the electric company [75]. Guayaquil is a city that has a considerable solar resource [76], where the implementation of SPVSs could considerably reduce the electricity bills and the carbon footprint of buildings. However, the expansion of these systems is limited by the subsidies that have certain countries on electricity tariffs [77], as in the case of Ecuador.

The obtained results from EnergyPlus simulations could present uncertainties of around ±10% [78,79], which is in accordance with the ASHRAE Guideline 14 [80]. These uncertainties depend on external errors related to weather data, schedules, and others, but also, internal errors such as the difference between actual HVAC and its simplified model in the simulation, and the inaccuracies of the mathematical models [81].

Overall, this study showed the potential for energy savings of various passive and actives measures applied in a university building from Guayaquil, Ecuador. From these results, some research questions emerged that could be addressed in future works:

- What could be the best shading configurations to be applied in Guayaquil taking into account the incident solar radiation in each façade?

- What could be the best cooling set point to save energy considering the thermal comfort of the occupants in these type of buildings?
    - Should this cooling set point change depending on the season (wet/dry)?
- What could be the best cooling strategy to provide energy savings and reduce the building's carbon footprint without compromising indoor thermal comfort in this climate?
- Apart from the implementation of daylighting controls, what could be another low-payback alternative to reduce energy in this climate?

6. Conclusions

This paper analyzed the potential for the implementation of some energy saving strategies in building retrofits from the tropics. The base case, which was a student welfare unit from an Ecuadorian university campus, and all the proposed energy saving strategies were modeled in OpenStudio-EnergyPlus. This study also evaluated the opportunities of the implementation of a SPVS in the studied building, which was simulated in Homer PRO software.

The analysis of the proposed strategies suggested energy savings between 10 and 25% in cooling loads and between 5 and 20% in the annual building consumption when were evaluated independently. Whereas the combination of some strategies resulted in savings of around 43% in cooling and from 23% to 35% in annual building consumption.

Daylighting control strategy was the one that provided the more energy savings independently and even when combined with other strategies such as TrpLoE windows and active measures. The results suggested that it would be more cost-effective to use daylighting strategies in building retrofits located in hot and humid climates.

The use of SPVS reduces the carbon footprint and the electricity bills of the building; however, its implementation is subjected to local regulations and the total costs of the project.

The combination of the energy saving strategies with the proposed PV system could approach the case study into a NZEB.

7. Limitations of the Study

This study presents a model of a real building located in the tropical city of Guayaquil, Ecuador. Its limitations lie particularly in the use of TMY weather files and in the power of the simulation tools. Also, the energy saving scenarios, proved in this work, are based on some strategies, which have been previously recommended by the research community for hot and humid climates.

Despite these limitations, results were congruent with the related literature and can be used by architects, engineers and/or designers for the construction or retrofit of local buildings or related.

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

Funding: This research received no external funding.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data sharing is not applicable to this article.

Acknowledgments: The authors would like to express their acknowledgements to ESPOL's Research Deanery for supporting the funding for this study.

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

References

1. IEA. *Electricity Consumption, World 1990–2018*; IEA: Paris, France, 2019.
2. GlobalABC; UNE; IEA. *Global Status Report for Buildings and Construction: Towards a Zero Emissions, Efficient and Resilient Buildings and Construction Sector*; UN Environment and IEA: Paris, France, 2019.
3. IEA. *International Energy Outlook 2019 with Projections to 2050*; IEA: Paris, France, 2019.
4. Hidalgo-Leon, R.; Urquizo, J.; Macias, J.; Siguenza, D.; Singh, P.; Wu, J.; Soriano, G. Energy Harvesting Technologies: Analysis of Their Potential for Supplying Power to Sensors in Buildings. In Proceedings of the 2018 IEEE 3rd Ecuador Technical Chapters Meeting, Cuenca, Ecuador, 15–19 October 2018.
5. Lu, T.; Lü, X.; Viljanen, M. A Novel and Dynamic Demand-Controlled Ventilation Strategy for CO2 Control and Energy Saving in Buildings. *Energy Build.* **2011**, *43*, 2499–2508. [CrossRef]
6. Li, X.; Zhou, Y.; Yu, S.; Jia, G.; Li, H.; Li, W. Urban Heat Island Impacts on Building Energy Consumption: A Review of Approaches and Findings. *Energy* **2019**, *174*, 407–419. [CrossRef]
7. Jafarinejad, T.; Erfani, A.; Fathi, A.; Shafii, M.B. Bi-Level Energy-Efficient Occupancy Profile Optimization Integrated with Demand-Driven Control Strategy: University Building Energy Saving. *Sustain. Cities Soc.* **2019**, *48*, 101539. [CrossRef]
8. Dascalaki, E.G.; Balaras, C.A.; Kontoyiannidis, S.; Droutsa, K.G. Modeling Energy Refurbishment Scenarios for the Hellenic Residential Building Stock towards the 2020 & 2030 Targets. *Energy Build.* **2016**, *132*, 74–90.
9. Manic, M.; Wijayasekara, D.; Amarasinghe, K.; Rodriguez-Andina, J.J. Building Energy Management Systems: The Age of Intelligent and Adaptive Buildings. *IEEE Ind. Electron. Mag.* **2016**, *10*, 25–39. [CrossRef]
10. Zhan, S.; Chong, A. Building Occupancy and Energy Consumption: Case Studies across Building Types. *Energy Built Environ.* 2020. [CrossRef]
11. Ramirez, A.D.; Boero, A.; Rivela, B.; Melendres, A.M.; Espinoza, S.; Salas, D.A. Life Cycle Methods to Analyze the Environmental Sustainability of Electricity Generation in Ecuador: Is Decarbonization the Right Path? *Renew. Sustain. Energy Rev.* **2020**, *134*, 110373. [CrossRef]
12. Hidalgo-León, R.; Litardo, J.; Urquizo, J.; Moreira, D.; Singh, P.; Soriano, G. Some Factors Involved in the Improvement of Building Energy Consumption: A Brief Review. In Proceedings of the 2019 IEEE Fourth Ecuador Technical Chapters Meeting (ETCM), Guayaquil, Ecuador, 11–15 November 2019; pp. 1–6.
13. DeForest, N.; Shehabi, A.; Selkowitz, S.; Milliron, D.J. A Comparative Energy Analysis of Three Electrochromic Glazing Technologies in Commercial and Residential Buildings. *Appl. Energy* **2017**, *192*, 95–109. [CrossRef]
14. Litardo, J.; Macías, J.; Hidalgo-León, R.; Cando, M.G.; Soriano, G. Measuring the Effect of Local Commercial Roofing Samples on the Thermal Behavior of Social Interest Dwelling Located in Different Climates in Ecuador. In Proceedings of the ASME 2019 International Mechanical Engineering Congress & Exhibition, Salt Lake City, UT, USA, 11–14 November 2019.
15. Doulos, L.T.; Kontadakis, A.; Madias, E.N.; Sinou, M.; Tsangrassoulis, A. Minimizing Energy Consumption for Artificial Lighting in a Typical Classroom of a Hellenic Public School Aiming for near Zero Energy Building Using LED DC Luminaires and Daylight Harvesting Systems. *Energy Build.* **2019**, *194*, 201–217. [CrossRef]
16. Wagiman, K.R.; Abdullah, M.N.; Hassan, M.Y.; Radzi, N.H.M.; Kwang, T.C. Lighting System Control Techniques in Commercial Buildings: Current Trends and Future Directions. *J. Build. Eng.* **2020**, 101342. [CrossRef]
17. Allouhi, A.; El Fouih, Y.; Kousksou, T.; Jamil, A.; Zeraouli, Y.; Mourad, Y. Energy Consumption and Efficiency in Buildings: Current Status and Future Trends. *J. Clean. Prod.* **2015**, *109*, 118–130. [CrossRef]
18. Macias, J.; Iturburu, L.; Rodriguez, C.; Agdas, D.; Boero, A.; Soriano, G. Embodied and Operational Energy Assessment of Different Construction Methods Employed on Social Interest Dwellings in Ecuador. *Energy Build.* **2017**, *151*, 107–120. [CrossRef]
19. Litardo, J.; Palme, M.; Borbor-Cordova, M.; Caiza, R.; Macias, J.; Hidalgo-Leon, R.; Soriano, G. Urban Heat Island Intensity and Buildings' Energy Needs in Duran, Ecuador: Simulation Studies and Proposal of Mitigation Strategies. *Sustain. Cities Soc.* **2020**, *62*, 102387. [CrossRef]
20. Franzetti, C.; Fraisse, G.; Achard, G. Influence of the Coupling between Daylight and Artificial Lighting on Thermal Loads in Office Buildings. *Energy Build.* **2004**, *36*, 117–126. [CrossRef]
21. Yahiaoui, A. Experimental Study on Modelling and Control of Lighting Components in a Test-Cell Building. *Sol. Energy* **2018**, *166*, 390–408. [CrossRef]
22. Han, H.J.; Mehmood, M.U.; Ahmed, R.; Kim, Y.; Dutton, S.; Lim, S.H.; Chun, W. An Advanced Lighting System Combining Solar and an Artificial Light Source for Constant Illumination and Energy Saving in Buildings. *Energy Build.* **2019**, *203*, 109404. [CrossRef]
23. Kruisselbrink, T.W.; Dangol, R.; van Loenen, E.J. A Comparative Study between Two Algorithms for Luminance-Based Lighting Control. *Energy Build.* **2020**, *228*, 110429. [CrossRef]
24. Delvaeye, R.; Ryckaert, W.; Stroobant, L.; Hanselaer, P.; Klein, R.; Breesch, H. Analysis of Energy Savings of Three Daylight Control Systems in a School Building by Means of Monitoring. *Energy Build.* **2016**, *127*, 969–979. [CrossRef]
25. Kunwar, N.; Cetin, K.S.; Passe, U.; Zhou, X.; Li, Y. Energy Savings and Daylighting Evaluation of Dynamic Venetian Blinds and Lighting through Full-Scale Experimental Testing. *Energy* **2020**, *197*, 117190. [CrossRef]
26. Somasundaram, S.; Chong, A.; Wei, Z.; Thangavelu, S.R. Energy Saving Potential of Low-e Coating Based Retrofit Double Glazing for Tropical Climate. *Energy Build.* **2020**, *206*, 109570. [CrossRef]

27. Marino, C.; Nucara, A.; Pietrafesa, M. Does Window-to-Wall Ratio Have a Significant Effect on the Energy Consumption of Buildings? A Parametric Analysis in Italian Climate Conditions. *J. Build. Eng.* **2017**, *13*, 169–183.
28. Wang, Y.; Wang, R.; Li, G.; Peng, C. An Investigation of Optimal Window-to-Wall Ratio Based on Changes in Building Orientations for Traditional Dwellings. *Sol. Energy* **2020**, *195*, 64–81.
29. Troup, L.; Phillips, R.; Eckelman, M.J.; Fannon, D. Effect of Window-to-Wall Ratio on Measured Energy Consumption in US Office Buildings. *Energy Build.* **2019**, *203*, 109434. [CrossRef]
30. Alghoul, S.K.; Rijabo, H.G.; Mashena, M.E. Energy Consumption in Buildings: A Correlation for the Influence of Window to Wall Ratio and Window Orientation in Tripoli, Libya. *J. Build. Eng.* **2017**, *11*, 82–86. [CrossRef]
31. Xue, P.; Li, Q.; Xie, J.; Zhao, M.; Liu, J. Optimization of Window-to-Wall Ratio with Sunshades in China Low Latitude Region Considering Daylighting and Energy Saving Requirements. *Appl. Energy* **2019**, *233*, 62–70. [CrossRef]
32. Praprost, M.; Fleming, K.A.; Dahlhausen, M. *ENERGY STAR for Tenants: An Online Energy Estimation Tool for Commercial Office Building Tenants*; National Renewable Energy Lab. (NREL): Golden, CO, USA, 2020.
33. Luddeni, G.; Krarti, M.; Pernigotto, G.; Gasparella, A. An Analysis Methodology for Large-Scale Deep Energy Retrofits of Existing Building Stocks: Case Study of the Italian Office Building. *Sustain. Cities Soc.* **2018**, *41*, 296–311. [CrossRef]
34. Kong, M.; Joo, H.; Kwak, H. Experimental Identification of Effects of Using Dual Airflow Path on the Performance of Roof-Type BAPV System. *Energy Build.* **2020**, *226*, 110403. [CrossRef]
35. Aly, A.M.; Chokwitthaya, C.; Poche, R. Retrofitting Building Roofs with Aerodynamic Features and Solar Panels to Reduce Hurricane Damage and Enhance Eco-Friendly Energy Production. *Sustain. Cities Soc.* **2017**, *35*, 581–593. [CrossRef]
36. Wang, Y.; Wang, D.; Liu, Y. Study on Comprehensive Energy-Saving of Shading and Photovoltaics of Roof Added PV Module. *Energy Procedia* **2017**, *132*, 598–603. [CrossRef]
37. Aparicio-Gonzalez, E.; Domingo-Irigoyen, S.; Sánchez-Ostiz, A. Rooftop Extension as a Solution to Reach NZEB in Building Renovation. Application through Typology Classification at a Neighborhood Level. *Sustain. Cities Soc.* **2020**, *57*, 102109. [CrossRef]
38. Magrini, A.; Lentini, G.; Cuman, S.; Bodrato, A.; Marenco, L. From Nearly Zero Energy Buildings (NZEB) to Positive Energy Buildings (PEB): The next Challenge-The Most Recent European Trends with Some Notes on the Energy Analysis of a Forerunner PEB Example. *Dev. Built Environ.* **2020**, *3*, 100019. [CrossRef]
39. Asdrubali, F.; Baggio, P.; Prada, A.; Grazieschi, G.; Guattari, C. Dynamic Life Cycle Assessment Modelling of a NZEB Building. *Energy* **2020**, *191*, 116489. [CrossRef]
40. Feng, W.; Zhang, Q.; Ji, H.; Wang, R.; Zhou, N.; Ye, Q.; Hao, B.; Li, Y.; Luo, D.; Lau, S.S.Y. A Review of Net Zero Energy Buildings in Hot and Humid Climates: Experience Learned from 34 Case Study Buildings. *Renew. Sustain. Energy Rev.* **2019**, *114*, 109303. [CrossRef]
41. Sudhakar, K.; Winderl, M.; Priya, S.S. Net-Zero Building Designs in Hot and Humid Climates: A State-of-Art. *Case Stud. Therm. Eng.* **2019**, *13*, 100400. [CrossRef]
42. Ghenai, C.; Bettayeb, M. Modelling and Performance Analysis of a Stand-Alone Hybrid Solar PV/Fuel Cell/Diesel Generator Power System for University Building. *Energy* **2019**, *171*, 180–189. [CrossRef]
43. Liu, J.; Chen, X.; Cao, S.; Yang, H. Overview on Hybrid Solar Photovoltaic-Electrical Energy Storage Technologies for Power Supply to Buildings. *Energy Convers. Manag.* **2019**, *187*, 103–121. [CrossRef]
44. Peel, M.C.; Finlayson, B.L.; McMahon, T.A. Updated World Map of the Köppen-Geiger Climate Classification. In *Hydrology and Earth System Sciences Discussions*; European Geosciences Union: Munich, Germany, 2007; Volume 4, pp. 439–473.
45. Guevara, G.; Soriano, G.; Mino-Rodriguez, I. Thermal Comfort in University Classrooms: An Experimental Study in the Tropics. *Build. Environ.* **2020**, *187*, 107430. [CrossRef]
46. INEC. *Proyección de La Población Ecuatoriana, Por Años Calendario, Según Cantones 2010–2020*; INEC: Quito, Ecuador, 2020.
47. Meteotest. *Meteonorm 7.3*; Meteotest: Bern, Switzerland, 2018.
48. Energy Design Tools UCLA. *Climate Consultant 6.0 Sofware*; UCLA: Los Ángeles, CA, USA, 2020.
49. ESPOL. Escuela Superior Politécnica Del Litoral (ESPOL). Available online: http://www.espol.edu.ec/ (accessed on 22 December 2020).
50. Agencia de Regulación y Control de Electricidad (ARCONEL). *Pliego Tarifario Para Las Empresas Eléctricas de Distribución Codificado*; ARCONEL: Quito, Ecuador, 2019.
51. Fleming, K.; Long, N.; Swindler, A. *Building Component Library: An Online Repository to Facilitate Building Energy Model Creation*; National Renewable Energy Lab. (NREL): Golden, CO, USA, 2012.
52. ANSI; ASHRAE; IES. *Standard 90.1-2019 Energy Standard for Buildings Except Low-Rise Residential Buildings*; ASHRAE: Atlanta, Georgia, USA, 2019.
53. Kim, D.; Cho, H.; Koh, J.; Im, P. Net-Zero Energy Building Design and Life-Cycle Cost Analysis with Air-Source Variable Refrigerant Flow and Distributed Photovoltaic Systems. *Renew. Sustain. Energy Rev.* **2020**, *118*, 109508. [CrossRef]
54. Homer Energy. *Homer PRO*; Homer Energy: Boulder, CO, USA, 2020.
55. Maxeon Solar Technologies. *Sun Power Maxeon 2—360W*; Maxeon Solar Technologies: Singapore, 2020.
56. ProViento, Paneles Solares. Available online: https://proviento.com.ec/10-paneles-solares (accessed on 22 December 2020).
57. Jamil, W.J.; Rahman, H.A.; Shaari, S.; Desa, M.K.M. Modeling of Soiling Derating Factor in Determining Photovoltaic Outputs. *IEEE J. Photovolt.* **2020**, *10*, 1417–1423. [CrossRef]

58. Vallejo, C.; Villacreses, G.; Vásquez, F.; Godoy, F. *Evaluación Comparativa de Los Consumos Energéticos de Edificaciones Públicas En La Región Costa y Galápagos*; Instituto Nacional de Eficiencia Energértica y Energías Renovables (INER): Quito, Ecuador, 2018.
59. Litardo, J.; Hidalgo-León, R.; Macías, J.; Delgado, K.; Soriano, G. *Estimating Energy Consumption and Conservation Measures for ESPOL Campus Main Building Model Using EnergyPlus*; IEEE CONCAPAN: Ciudad de Guatemala, Guatemala, 2019; pp. 1–6.
60. Cámara de la Construcción de Guayaquil. Available online: http://www.cconstruccion.net/precios.html (accessed on 22 December 2020).
61. Compras Públicas Ecuador, Sistema Oficial de Contratación Pública. Available online: https://www.compraspublicas.gob.ec/ProcesoContratacion/compras/ (accessed on 22 December 2020).
62. Syahputra, R.; Soesanti, I. Planning of Hybrid Micro-Hydro and Solar Photovoltaic Systems for Rural Areas of Central Java, Indonesia. *J. Electr. Comput. Eng.* **2020**, *2020*, 5972342. [CrossRef]
63. Hee, W.J.; Alghoul, M.A.; Bakhtyar, B.; Elayeb, O.; Shameri, M.A.; Alrubaih, M.S.; Sopian, K. The Role of Window Glazing on Daylighting and Energy Saving in Buildings. *Renew. Sustain. Energy Rev.* **2015**, *42*, 323–343. [CrossRef]
64. Shishegar, N.; Boubekri, M. Quantifying Electrical Energy Savings in Offices through Installing Daylight Responsive Control Systems in Hot Climates. *Energy Build.* **2017**, *153*, 87–98. [CrossRef]
65. Whang, A.J.-W.; Yang, T.-H.; Deng, Z.-H.; Chen, Y.-Y.; Tseng, W.-C.; Chou, C.-H. A Review of Daylighting System: For Prototype Systems Performance and Development. *Energies* **2019**, *12*, 2863. [CrossRef]
66. Köster, H. Daylighting Controls, Performance, and Global Impacts. *Sustain. Built Environ.* **2020**, 383–429. [CrossRef]
67. Kim, H.G.; Kim, H.J.; Jeon, C.H.; Chae, M.W.; Cho, Y.H.; Kim, S.S. Analysis of Energy Saving Effect and Cost Efficiency of ECMs to Upgrade the Building Energy Code. *Energies* **2020**, *13*, 4955. [CrossRef]
68. Papadopoulos, S.; Kontokosta, C.E.; Vlachokostas, A.; Azar, E. Rethinking HVAC Temperature Setpoints in Commercial Buildings: The Potential for Zero-Cost Energy Savings and Comfort Improvement in Different Climates. *Build. Environ.* **2019**, *155*, 350–359. [CrossRef]
69. Bienvenido-Huertas, D.; Sánchez-García, D.; Pérez-Fargallo, A.; Rubio-Bellido, C. Optimization of Energy Saving with Adaptive Setpoint Temperatures by Calculating the Prevailing Mean Outdoor Air Temperature. *Build. Environ.* **2020**, *170*, 106612. [CrossRef]
70. Ge, J.; Wu, J.; Chen, S.; Wu, J. Energy Efficiency Optimization Strategies for University Research Buildings with Hot Summer and Cold Winter Climate of China Based on the Adaptive Thermal Comfort. *J. Build. Eng.* **2018**, *18*, 321–330. [CrossRef]
71. Al-Masrani, S.M.; Al-Obaidi, K.M.; Zalin, N.A.; Isma, M.A. Design Optimisation of Solar Shading Systems for Tropical Office Buildings: Challenges and Future Trends. *Sol. Energy* **2018**, *170*, 849–872. [CrossRef]
72. Alhuwayil, W.K.; Mujeebu, M.A.; Algarny, A.M.M. Impact of External Shading Strategy on Energy Performance of Multi-Story Hotel Building in Hot-Humid Climate. *Energy* **2019**, *169*, 1166–1174. [CrossRef]
73. Al Touma, A.; Ouahrani, D. Shading and Day-Lighting Controls Energy Savings in Offices with Fully-Glazed Façades in Hot Climates. *Energy Build.* **2017**, *151*, 263–274. [CrossRef]
74. Wati, E.; Meukam, P.; Nematchoua, M.K. Influence of External Shading on Optimum Insulation Thickness of Building Walls in a Tropical Region. *Appl. Therm. Eng.* **2015**, *90*, 754–762. [CrossRef]
75. ARCONEL. *Resolucion Nro. ARCONEL-042/18*; Agencia de Regulacion y Control de Electricidad: Quito, Ecuador, 2018.
76. Vaca-Revelo, D.; Ordóñez, F. *Mapa Solar del Ecuador 2019*; Escuela Politécnica Nacional (EPN): Quito, Ecaudor, 2019.
77. Korsavi, S.S.; Zomorodian, Z.S.; Tahsildoost, M. Energy and Economic Performance of Rooftop PV Panels in the Hot and Dry Climate of Iran. *J. Clean. Prod.* **2018**, *174*, 1204–1214. [CrossRef]
78. Eisenhower, B.; O'Neill, Z.; Fonoberov, V.A.; Mezić, I. Uncertainty and Sensitivity Decomposition of Building Energy Models. *J. Build. Perform. Simul.* **2012**, *5*, 171–184. [CrossRef]
79. Fumo, N.; Mago, P.; Luck, R. Methodology to Estimate Building Energy Consumption Using EnergyPlus Benchmark Models. *Energy Build.* **2010**, *42*, 2331–2337. [CrossRef]
80. ASHRAE. *Guideline 14-2002, Measurement of Energy and Demand Savings*; Technical Report; ASHRAE: Atlanta, GA, USA, 2002.
81. Judkoff, R.; Neymark, J. *Model Validation and Testing: The Methodological Foundation of ASHRAE Standard 140*; National Renewable Energy Lab. (NREL): Golden, CO, USA, 2006.