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Strategies for reducing energy consumption in public buildings: the Garzota Research Case

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Abstract*– In this paper, the energy modeling of the utility building Garzota in Guayaquil, Ecuador, was performed using OpenStudio tools and the EnergyPlus calculation engine. We applied the methodology defined by ASHRAE to create and validate the reference model. Then, three strategies were proposed to increase building energy efficiency. First, apply sunscreen film to the windows to reduce the solar heat input to the building envelope. Second, increase the efficiency of the building's cooling and air-conditioning systems. This is consistent with the Ecuadorian Manual on Energy Efficiency in Public Buildings recommendations. Finally, we propose installing a photovoltaic system on the roof of the buildings to generate electricity on-site while reducing heat gain from the roof. These three measures can reduce building power consumption, significantly cooling power consumption, by 9.67%. This is an added value for installing photovoltaic systems in public buildings.

Keywords-- energy efficiency; building energy modelling; thermal envelope; Heating, ventilation, and air conditioning HVAC; On-site generation.

I. INTRODUCTION

According to the [1], renewable electricity use multiplied by about 3% in 2020, as demand for all other fuels declined throughout the COVID-19 pandemic. As a result, the share of renewables in global electricity generation rose to 29% in 2020 and is expected to expand by more than 8% in 2021 to reach 8,300 TWh, of which at least two-thirds would come from solar photovoltaic (PV) and wind. In addition to renewable energy, energy efficiency is a critical factor in achieving global climate and sustainability goals. Energy efficiency strategies and the expansion of renewable energy are both part of the Sustainable Development Goals (SDGs) of the United Nations Development Program (UNDP): Goal 7: Affordable and clean energy, and Goal 9: Industry, Innovation, and Infrastructure. In Ecuador, according to a progress report on compliance with the 2030 Agenda for Sustainable Development published by the Planning Secretariat [2], renewable energy recorded a nominal capacity of 2,440 MW in 2014 and reached 5,272 MW in 2018. The share of renewable energy in final energy consumption is increasing. All are related to Goal 7, from 11.1% in 2014 to 16.1% in 2017.

About Goal 9, CO2 emissions per unit of gross value added (GVA) is an indicator of the relationship between production and pollution. This ratio indicates the amount of CO2 the energy consumed produces to produce one unit of GVA. The lower the index, the more efficient the economy. According to [3], the 2012 index was 0.23 kg CO2/USD, and the 2019 value was 0.33 kg CO2/USD, an increase of 43.47% in just seven years, which is problematic, a problem that must be attacked with appropriate energy policies. As the policies implemented so far have not produced significant results, strategies for the efficient and rational use of energy in the composition of the energy matrix should increase competitiveness, minimize energy consumption, and reduce carbon dioxide emissions.

The Ecuadorian Construction Standard (NEC) [4] updates the Ecuadorian Construction Code, which was in force from 2001 to 2011, by establishing a set of minimum specifications organized into determine new regulations that apply to three main areas of actions: Structural Security (NEC-SE). Habitability and Health (NEC-HS) and Basic Services (NEC-SB). Recently, measures such as the National Energy Efficiency Plan (PLANEE) 2016-2035, announced in 2017, have been promoted, which aims to reduce the cost of the oil production process and optimize the use of infrastructure for power supply. Furthermore, in March 2019, the Organic Law on Energy Efficiency was enacted. It aim is to promote the efficient, rational, and sustainable use of energy in all its forms to promote the competitiveness of the national economy and culture concerning the environment [5]. However, the use of OpenStudio and EnergyPlus in Ecuador is shallow, as no regulation requires the implementation of building energy modeling.

Among the few Ecuadorian studies in this area stands out a study developed by Soria [6] evaluating the energy efficiency of the building envelope of three office buildings constructed in the city of Quito since 2011. However, this work does not consider PV system placement an efficiency strategy. According to [7], rooftop solar systems are more profitable when there is a separation between the roof and the solar panels to avoid overheating due to ventilation. Similarly, the slope and distance between the modules are important factors affecting the thermal performance of the building. These studies do not consider roofs that are internally insulated.

The remainder of this paper is organized as follows: The second section shows the methodology used for the energy modeling of the building. The third section presents the possible results of implementing the three proposed energy efficiency strategies. In the fourth section, the main findings of this research are discussed, and in the last section, the conclusions of this work are stated.

II. METHODOLOGY

As a starting point, building energy simulations should create a model that is as close as possible to the real building in terms of the dimensions and characteristics of the construction materials. This geometry must then undergo a simulation process, run the necessary algorithms to debug the model, and finally analyze the results to make decisions to improve the building's energy efficiency. The processes and sub-processes required to model Garzota public building are described below.

A. Definition of standards for building modeling

In Ecuador, the Ecuadorian Institute for Standardization (INEN) is responsible for issuing technical regulations in engineering, including those related to energy efficiency. The following are the ones used for the development of the research: NEC-HS-EE: Energy Efficiency in Residential Buildings [4]; NTE-INEN-ISO-7730: Ergonomics of the thermal environment [8]; NTE-2-506:2009 Energy Efficiency in Buildings [9]; ASHRAE 189.1-2017 [10], ASHRAE 90.1-2007 [11], and ASHRAE 90.1-2007 for Energy Simulation Aided Design for Buildings Except Low-Rise Residential Buildings [12].

The requirements of the 189.1 and 90.1 standards for insulation, U-factor, and solar heat gain coefficient (SHGC) vary by climate zone. For Ecuador, the NEC [4] on Residential Energy Efficiency was based on zones defined in the United States to classify climatic zones in provincial capitals and other major cities. For example, Guayaquil is very hot and humid, and Quito is continental with lots of rain (see Table I).

TABLE I.
LOCATIONS ECUADOR'S CLIMATIC ZONES [13]

Climate Zone	**Climate Zone (ASHRAE 90.1)**	**Type**	**Thermal Criteria**
1	1A	Very Hot Humid	5,000 < CDD10ºC
2	2A	Hot Humid	3,500 < CDD10ºC<=5,000
3	3C	Continental rainy	CDD10ºC<=2,500 and HDD18ºC<=2,000
4	4C	Continental Temperate	2,000 < HDD18ºC<=3,000
5	5C	Cold	CDD10ºC<=2,500 and HDD18ºC<=2,000 2,000 < HDD18ºC<=3,000 3,000 m < Elevation (m) <= 5,000 m
6	6B	Very Cold	CDD10ºC<=2,500 and HDD18ºC<=2,000 2,000 < HDD18ºC<=3,000 5,000 m < Elevation (m)

Table I shows that climate zones are defined based on the location's heating degree days (HDD), cooling degree days CDD, and elevation above sea level. A degree day is a difference between the hourly's average air temperature and the base temperature, typically 18 degrees Celsius, discarding any hours for which the outdoor air temperature is greater than the base temperature. CDD is calculated similarly with a different base temperature for cooling (typically 10 degrees Celsius), as seen in Equations (1) and (2) [14].

$$HDD = \sum_{i=1}^{8760} \left(\mathrm{MAX} \frac{(T_{base\ heating} - T_{i,0})}{24} \right) \tag{1}$$

$$CDD = \sum_{i=1}^{8760} \left(\mathrm{MAX} \frac{(T_{i,0} - T_{base\ cooling})}{24} \right) \tag{2}$$

B. Energy Building Information

This research is being developed in the Garzota utility building in Guayaquil (see the building with the blue roof in Figure 1). The building has three floors, with a construction area of 2,100 square meters per floor.

Fig. 1 Location of the Garzota building from Google Earth™

Data about the consumption of electricity, water, gas, and other utilities are added to the building model. Information for this project was obtained from the monthly electricity consumption bill provided by Garzota employees and is shown in Table II.

TABLE II
GARZOTA BUILDING ENERGY CONSUMPTION INFORMATION

Month	**Cost ($)**	**Energy (kWh)**	**Peak Demand (kW)**
January	6,043.98	82,950.00	322.00
February	6,432.56	88,550.00	336.00
March	6,809.41	93,800.00	350.00
April	6,437.49	90,300.00	294.00
May	5,978.51	83,300.00	290.50
June	6,111.11	85,400.00	287.00
July	6,338.90	88,550.00	294.00
August	6,417.01	89,250.00	297.50
September	6,336.68	86,450.00	346.50
October	6,773.01	91,350.00	350.50
November	6,652.63	94,850.00	268.80
December	6,574.13	91,700.00	315.00
Total	**76,905.42**	**1,066,450.00**	

C. Building energy modeling

Building energy modeling (BEM) is a design tool that helps to estimate, through thermodynamic simulations, the energy performance that the building will have under scenarios defined by the systems that compose the building, the climatic environment of the building, its orientation, the design and even the materials that constitute the envelope [14]. To do this, the variables that define the building must be previously introduced, such as the walls that form it, the climatic equipment it contains, and the materials that make up each envelope. The definition of these variables and obtaining results change depending on the program used; in this project, OpenStudio will be used, allowing users to create the necessary geometry for the EnergyPlus simulation engine quickly.

The architectural plans provided by the building staff served as a reference for creating the geometric model of the building. From these plans, the dimensions of the three floors, as well as the room distribution and the identification of rooms with ventilation and air conditioning systems (HVAC), were derived. This information was used to define the thermal zones within the model, which represent spaces or sets of spaces with similar conditioning requirements and the same heating and cooling set point. Fig. **2** illustrates a representation of the thermal zones in the building.

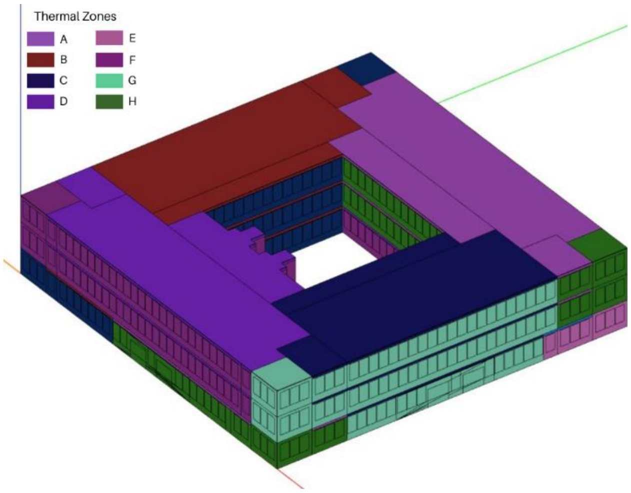

Fig. 2 Garzota building thermal zone rendering.

Material changes to the building envelope must comply with the MIDUVI [4] requirements for thermal insulation, reflectivity, air infiltration, and translucent elements that apply to the affected parts of the building. Due to the lack of detailed information about the building's electrical installation and interior lighting systems, the heat is modeled using the standard model defined in ASHRAE 189.1-2017 [10] for an office building located in climate zone 1A.

The Garzota building schedule is work-related, i.e., schedules of people entering and leaving the facility (customer service, offices, and others). There are also lighting and equipment schedules, usually in the same timeframe as the occupational schedules. Other defined schedules include cooling thermostat schedules that define metabolic activity types, clothing, and design temperatures.

D. Energy Model Validation Method

To determine the consistency of the data obtained from the model, methods of validating the results must be applied. Criteria for determining whether an energy model is appropriate are set out in ASHRAE Guideline 14 and are based on available data to estimate electricity consumption (kWh), electricity demand (kW), and all other fuels used in the facility [10].

ASHRAE Guideline 14 uses two statistical measures to characterize the accuracy of a calibrated model: the mean biased error (MBE) and the coefficient of variation of the root mean square error CV(RMSE). These indices allow us to quantify deviation between measurements and simulations. For example, MBE shows how well the model predicts energy consumption compared to the measured data. A positive value indicates that the model overestimates the actual value. A negative value indicates that the model predicts a decrease in the actual value. Using monthly data, the MBE should be ± 5%, and the RSME should be <= 15% [15]. In a study developed by [13], Equations (3) y (4) are used to determine the mean normalized bias error (NMBE) and CV(RMSE).

$$\mathrm{NMBE} = \frac{1}{\overline{M}} \cdot \frac{\sum_{i=1}^{n}(M_i - S_i)}{n} \times 100 \tag{3}$$

$$\mathrm{CV(RMSE)} = \frac{1}{\overline{M}} \sqrt{\frac{\sum_{i=1}^{n}(M_i - S_i)^2}{n}} \times 100 \tag{4}$$

Where *M*, *S* and *n* represent the measurement, simulation, and the number of data, respectively. The top bar represents the statistical mean.

E. Energy Efficiency Strategies

Once the model has been validated, three strategies are proposed to reduce the energy consumption of buildings. Note that strategy two is combined with strategy one, and the third is combined with the first two, so the strategies are complementary.

Strategy 1. Improving the building envelope.

One of the points where an energy improvement can be achieved is in the thermal envelope since, by selecting insulating materials with low conductivity, energy losses can be reduced. The building envelope is defined by the parts that delimit the habitable interior space from the exterior, like roofs, floors, envelopers, windows, and doors [16].

Building energy consumption can be reduced through the replacement or upgrading of the building envelope. Considering that the outer envelope of the Garzota building consists mainly of opaque glass, the application of thin films as a glazing coating can effectively combat excessive air conditioning usage in hotter climates like Guayaquil. These windows are particularly beneficial in regions with high temperatures, as they allow visible light to pass through while reflecting infrared light to maintain a cooler indoor environment.

Several second-generation thin-film solar cells recently use single- or multi-layer PV elements on a glass, plastic, or metal substrate. The most common thin-film solar cells, Copper Indium Gallium Selenide solar cell and Cadmium Telluride solar cell-based PV technologies have maximum power-conversion efficiency (PCE) of 22.6% and 22.1% at the laboratory scale and 19.2% and 18.6% at the module level, respectively. Thin-film solar control is proposed by [17] to reduce the energy consumed by the HVAC system to maintain the temperature inside the building. The implementation of thin-film solar control is proposed as a means to reduce energy consumption by the HVAC system, thereby maintaining optimal indoor temperatures.

Strategy 2. HVAC system efficiency.

When ventilating an enclosure, there is an exchange of fluids and heat, so the temperature tends to decrease, and consequently, energy has to be consumed to replace the losses. The introduction of the airflow affects the demand; therefore, it is advisable to introduce the lowest airflow to guarantee the area's healthiness. A solution could be using ventilation with a variable flow rate or heat recuperators in HVAC systems, thus minimizing energy losses [16].

The maximum allowable average air velocity depends on the local air temperature and turbulence intensity. For spaces with mixed-flow air distribution, the turbulence intensity can range between 30% and 60%. However, in spaces with displacement ventilation or without mechanical ventilation, the turbulence intensity may be lower (NTE, 2014). To enhance the energy efficiency of the building and compare it to the first strategy, we propose two combined criteria. Firstly, we aim to improve the efficiency of motors connected to the HVAC fans. Secondly, we suggest increasing the thermostat setting on the cooling system to 25°C.

Strategy 3. On-Site Generation.

Replacing conventional energy sources with on-site generation from renewable sources can improve building energy efficiency. The most common applications for energy savings are associated with heating and electricity systems. Solutions can be solar photovoltaics for electricity production, reducing energy dependence and CO2 pollution. The benefits of solar energy are not only limited to environmental and economic factors; rooftop installations of solar photovoltaic modules reduce the thermal load of buildings [18]. As a strategy to reduce the building's energy demand, this section proposes to address the installation of photovoltaic panels on the roof to generate electricity on-site while reducing the thermal load.

In 2019, the latest solar map of Ecuador was released [19] and it was concluded that the annual global horizontal irradiance (*GHI)* ranges from 2.9 kWh/m^2-day to 6.3 kWh/m^2-day. The higher elevation areas generally have higher radiation levels, and the coastal and eastward transition areas have the lowest radiation levels. In the first case, the reduced thickness of the atmosphere is less and fewer clouds allow more radiation. In the second case, atmospheric pressure causes clouds to form, increasing diffuse radiation. The annual *GHI* for Guayas is 4.8 kWh/m^2-day, while the annual diffuse horizontal radiation (*DHI)* is 2.6 kWh/m^2 per-day.

The PVsyst^{TM} software is used to design the photovoltaic system for this project, considering site latitude and longitude, building electricity consumption, orientation, and nearby shading. We use 782 JA Solar Polycrystalline Silicon 260 Wp modules and eight Fronius USA 20.0 kW ac inverters.

III. RESULTS

This section presents energy modeling results for the Garzota building. First, we validate the model by comparing the actual state of the building with simulation results in OpenStudio. This base case is a reference model for analyzing the three strategies described in the previous section.

Figure 3 compares measured (Actual) electricity consumption data recorded at the Garzota building in 2021 (see Table II) with OpenStudio simulation results, which we call the Reference Model. The maximum deviation between the measured and simulated data corresponds to -11.63% in January 2021 and -13.86% in May 2021. This is because, according to NASA [20], the simulated temperatures recorded in the historical data of the repository of free climate data for building performance simulation [21] were higher than the measured temperatures recorded in 2021.

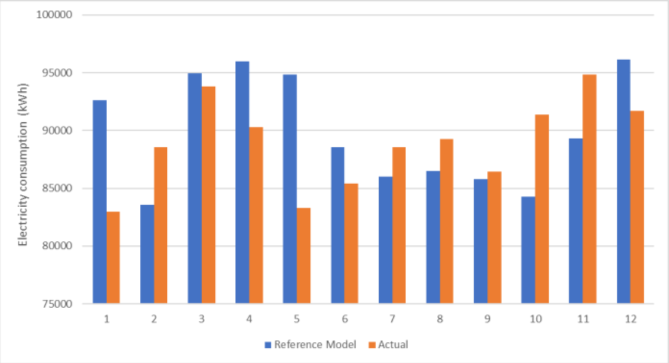

Fig. 3 Electricity consumption of the Garzota building in 2021

Applying Equations (3) and (4) yields values of -1.13% and 3.92% for NMBE and CV(RMSE), respectively. Both metrics fall within the limits allowed by ASHRAE Guideline 14. To further validate the simulation, utility database values from October 2020 to September 2021 were utilized. For consistency, the months of October, November, and December 2020 were used as the reference for the year 2021 in OpenStudio. The difference between the simulated cost of $75,706.56 and the measured cost of $76,905.42 is only 1.6%, equivalent to $1,198.86, indicating that the reference model is deemed acceptable.

Strategy 1: Improving the building envelope.

The effect of adding a commercial grade Solar Control film [22] to the windows is that the normal incidence transmittance averages 0.2349 across the solar spectrum, 38.2% lower than the reference model case (0.3801). The annual electricity consumption is reduced 1.93% compared to the reference model. Peak electricity demand also decreased in all months, reaching 308.20 kW in March 2021. Electricity bills were also reduced by 2.1%, from $ 75,706.56 to $ 74,147.63 annually.

Strategy 2: HVAC System Efficiency

In this section, we propose reducing the ventilation system's energy consumption. First and foremost, to reduce the energy consumption of the HVAC system, we suggested using higher efficiency motors for the cooling system air supply fans, replacing the 90% efficiency motors with 95% efficiency motors. Then, according to the Manual on Energy Efficiency in Public Buildings recommendations [23], we consider increasing the temperature by one-degree Celsius to the reference value used in the reference model case (24 degrees Celsius), setting the thermostats to 25 degrees Celsius. Therefore, the annual energy consumption will decrease by 4.62%, from 1,078,519.03 kWh to 102,8650.24 kWh compared to the reference model, and the electricity bill will decrease by 6.3% to $ 75,706.56.

Strategy 3: On-site generation

The results from PVsyst™ were compared with those from the OpenStudio energy model. TABLE III shows that the energy generated by the OpenStudio PV array is 0.68% higher than the PVsyst™ design, so we consider the OpenStudio model valid for the third strategy.

TABLE III
COMPARISON OF ENERGY PRODUCED BY THE PHOTOVOLTAIC ARRAY

	OpenStudio Annual Energy Generated (kWh)	PVsyst Annual Energy Generated (kWh)	Variation (%)
Photovoltaic	255,275.00	253,560.00	0.68%

Compared to the Reference Model, the annual electricity consumption is reduced by 9.67% from 107,8519.03 kWh to 974,235.87 kWh. Regarding peak electricity demand, the values obtained from OpenStudio show an average monthly reduction of about 5.00% (see Figure 4).

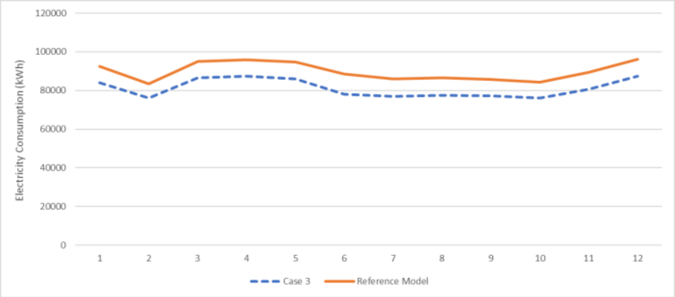

Fig. 4 Garzota Building electricity consumption in 2021 - Strategy 3

The electricity bill can also be reduced by 45.3% compared to the annual electricity bill in the reference model. This is primarily due to the significantly reduced peak power penalties. Considering that the electricity consumption in this scenario is 974,235.87 kWh per year and the energy generated in 2021 by the OpenStudio PV system in 2021 is 255,275.00 kWh, the electricity consumption from the grid will decrease to 718,960.87 kWh, that is, 26.20% decrease.

On the other hand, the total heat loss at the roof plane for the reference case (206,946.40 kBtu) is 9.96% higher than Strategy 3. Additionally, a review of the results in Figure 5 shows that the roof area heat gain for the third case is 267,968.00 kBtu in 2021, 11.10% lower than the reference model. This directly affects the cooling load, which is reduced by 18.14% compared to the reference model, from 52,963.33 kWh to 44,126.67 kWh.

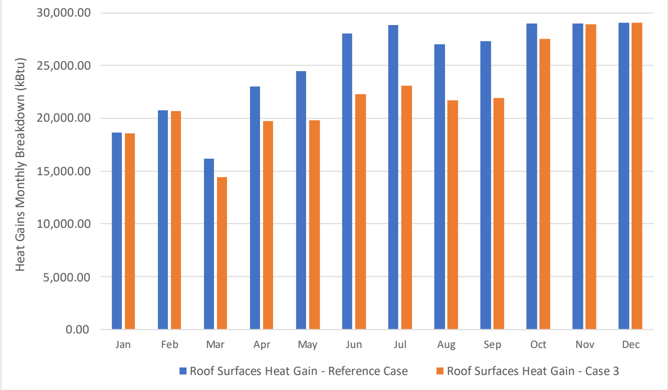

Fig. 5 Summary Monthly Breakdown of Heat Gain in Garzota Building

III. DISCUSSION

This section discusses the results for each case proposed as an energy efficiency strategy for the Garzota building and relates them to similar studies developed locally and internationally.

Strategy 1: Improving the building envelope

One of the buildings analyzed by Soria [6] is an urban plaza with a glazed envelope, suggesting that it is less efficient than the Mirage building with an opaque and transparent envelope. Optimizing the use of coefficient glass in the urban plaza building's architectural envelope reduced cooling needs by 31% and increased insulation capacity. In addition, the use of solar shading in the Mirage and Urban Plaza buildings reduced the amount of solar radiation in the front of the office by 30%.

For the Garzota building, improving the insulation of the exterior windows reduced the building's energy gain, reduced heat flow from the exterior to the interior, reduced cooling consumption, and reduced electricity consumption from 1,078,519.03 kWh to 1,057,692.40 kWh, a reduction of 1.93%. However, the savings in Soria [6] are more significant, as the modeled buildings are in Quito, which is classified as a continental zone by the NEC [13]. This significantly reduces the cooling load.

Strategy 2: HVAC system efficiency

Soria [6] argues that the thermal properties of materials, thermal inertia, and transparency reduce the cooling demand. In his work, applying skylight ventilation to the Mirage and Urban Plaza buildings reduced the surface radiant temperature by three degrees Celsius.

Our research identifies that the strategy two application reduces 8.35% of the electricity consumption for cooling concerning the reference model. This last result is significantly lower than the 42% obtained by Soria and raises two possible reasons. On the one hand, it can indicate the building's low energy efficiency as analyzed by Soria, or it can represent the more significant impact of other efficiency measures (solar protection, material replacement, and others), which were not considered in the Garzota building. The focus of this work is to propose technically and economically feasible measures.

Strategy 3: On-site Generation.

Various studies have been developed to determine the difference in cooling load between buildings with bare roofs and buildings and those with photovoltaic panels on the roof. A case study by Dominguez [18] used photovoltaic panels to reduce the cooling loads by up to 38% at the University of California Powell Structural Laboratory. In [24] attributed this to the PV-shaded surface where long-wave radiation was trapped between the roof and the back of the PV array, reducing emissivity while at the same time, the higher the visibility of the roof exposed to the night sky, the faster it cools, at least in the upper and outer layers of the roof.

Kolokotroni et al. [25] developed a parametric analysis to vary the roof reflectivity and insulation and ventilation rates of an office building in London, UK. They used the London summer design year as a weather file to calculate heating and cooling needs for a year. Kolokotroni et al. found that cooling demand decreased significantly, heating demand increased, and the overall energy savings relative to an albedo of 0.1 under the same conditions was found to vary between 1 to 8.5% over time. The decrease in maximum and average indoor air temperature and operating temperature was significant. No photovoltaic panels were used during modeling.

Recently, Ochoa [7] identified that using photovoltaic panels in an industrial Choloma building in Honduras reduced the building's exterior roof temperature by up to 24.3%. The resulting thermodynamic analysis showed an 83.8% reduction in total roof heat gain and a 28.1% reduction in overall building heat gain. This means that under ideal conditions, if there is no insulation inside the building, the modules will affect the heat load of the building by lowering the outside roof temperature.

Comparing the electricity used to satisfy the cooling load in the base case of the Garzota building with the electricity needed when the photovoltaic panels are installed on the roof of the building, a reduction of 22.17% is evident (see Section 3, Strategy 3), which is below the 38% of Dominguez et al. [18].

Limitations

Criteria for validating the Garzota building energy model were specified, but the ASHRAE guideline 14 MBE and RMSE indicators of (+-5% and 15%, respectively) do not imply that the model accurately predicts the building's energy performance. Instead, these percentages represent model uncertainty. Specific information about building materials, electrical and electronic equipment, lighting, and even ventilation and air conditioning systems used in the simulation correspond to templates that OpenStudio and EnergyPlus handle for the different climates according to ASHRAE 189.1-2017.

This work aimed to assess the implementation of energy efficiency strategies in public buildings. However, only the results of the three strategies were evaluated. They were enhancing the envelope, increasing the efficiency of the HVAC systems, and incorporating on-site power generation. This paper did not discuss many other strategies, such as implementing intelligent energy management systems, replacing building construction materials, and others. Future works could analyze other strategies for different climate zones and characterize the energy performance of public buildings in Ecuador.

According to the simulation results, placing polycrystalline silicon solar panels on the roof of the Garzota building was the strategy to reduce the building’s power consumption the most. Related works to this research could evaluate the results with photovoltaic cells of different technology or even determine the effect of using photovoltaic windows in buildings.

IV. CONCLUSIONS

The development of the productive sector and expected economic growth in Ecuador over the next few years will lead to a sustained increase in demand for energy services. However, increased availability and access to energy services should lead to more energy production. Therefore, it is essential to include energy efficiency measures as a strategy to ensure resource conservation and protect the environment. This research proposes three strategies for increasing the energy efficiency of public buildings, from which the following conclusions were drawn:

i. The three energy efficiency strategies proposed in this work increase the energy efficiency of the Garzota" building. The improvement of the thermal envelope reduced electricity consumption by 1.93% concerning the reference model, and the measures adopted in the HVAC system reduced electricity consumption by 4.62%. Finally, the inclusion of on-site power generation reduced total electricity consumption by 9.67%. This demonstrates the considerable potential for reducing energy consumption in public buildings in Ecuador, especially in areas with warm weather.

ii. According to the energy audit, the Garzota building consumed a total of 1,066,450.00 kWh in the period January to December 2021 of electricity and was paid $ 76,905.42. These values were compared to the reference model results of the building's energy model, yielding variations of 1.12% (electricity consumption) and -1.16% (electricity bill) when compared to actual data. Moreover, the MBE and RMSE indices were within the limits allowed by ASHRAE Guideline 14 (±5% of MBE and 15% of RMSE). Therefore, it is reasonable to assume that models developed in OpenStudio are close to the actual energy performance of the Garzota building.

iii. The thermal envelope of a building is a fundamental determinant of heat loss through walls, roofs, and floors, especially given that Guayaquil is considered a wet and hot weather zone. This is evidenced by the building model results for the third strategy (on-site power generation). In this case, implementing photovoltaic panels on the roof reduced heat losses from the roof by 9.96% compared to the reference model. This reduces electricity consumption for cooling by 18.14%, making on-site power generation an energy efficiency strategy in two respects: One related to the generation of electricity from renewable energy sources (in this case solar power) to meet the internal needs of the building, and the other is the cooling of the building, which was not have been considered in previous studies in Ecuador.

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