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Retrofitting Approaches for Office Buildings in Tropical Climates: A Systematic Review

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Abstract*– The alarming energy crisis developing worldwide has driven investigation towards minimizing the impact of the energy sector on the global emissions of greenhouse gases (GHG). As the building sector represents 30% of global energy consumption, efforts must be made to address the increasing energy demand in buildings, especially existing buildings, since they currently represent the majority of energy consumed in the sector. In this study, a bibliometric analysis was conducted to identify research opportunities based on a literature review of energy efficiency strategies applied to existing office buildings in the tropics with the objective of analyzing the most efficient retrofit measures under this type of climate. The analysis showed little available investigation on buildings in tropical climates, especially involving office buildings. Results showed that the most studied passive strategies were related to the glazing component of the envelope, including using low-emissivity materials, semi-transparent photovoltaic modules, or electrochromic materials. However, active strategies such as efficient HVAC systems have been demonstrated to achieve higher reductions in the electrical consumption of the building when compared to passive strategies.

Keywords—energy efficiency, office building, passive design, retrofit, review.

I. Introduction

The last World Energy Outlook report emitted by the International Energy Agency (IEA) in 2022 shows that an alarming energy crisis is developing worldwide [1]. Studies indicate that climate change has had a significant impact on the energy demand and supply, especially since the integration of renewable sources into the electricity system, given these rely strongly on climate conditions. Different factors, such as wind patterns, increases in air temperature, variations in water flow levels in hydroelectric plants, and others, directly affect the operation of existing energy generation systems and hinder the planning and forecast for new ones [2]. Through studies conducted in the United States of America, it has been demonstrated that increases in global temperature due to climate change led to increases in energy demand at the national level [3], [4]. An investigation of different scenarios of climate change impacts on the national interconnected system of Greece showed that energy demand can rise between 3.60 to 55% only because of climate change effects [5]. Similarly, variations in energy consumption in China due to climate factors were estimated through regression models. Results indicated that energy consumption can increase up to 8.53% in a year because of climate change conditions [6]. These studies demonstrate the negative impact of global warming and climate change on the increase in global energy demand and emissions of greenhouse gases produced by the energy sector. Countries such as Panama, with a tropical humid climate, affected by natural phenomena such as “El Niño” y “la Niña," floodings, and droughts, tend to be more vulnerable to climate change effects, making it difficult to ensure accessibility and secure energy supply to its population [7].

At the present time, the building sector is responsible for 30% of the global energy consumption, which represents 26% of the total greenhouse gas emissions of the energy sector, including operational emissions and emissions by electricity and heat used in buildings [8]. These numbers locate the building sector as an important aim for the decarbonization of the energy sector.

In response to this problem, different studies have been conducted over the years to assess the implementation of passive and active energy efficiency design strategies in buildings. This is with the objective of benefiting from the natural resources and innovative technologies available to minimize building energy consumption while ensuring occupants' comfort.

Generally, the main passive strategies implemented in buildings focus on improving the envelope efficiency of the façade by adjusting the transmittance value (U) in order to reduce heat gains or losses according to the climatic needs of the building. For tropical humid climates, efficient envelope design usually contemplates adding insulation materials to the envelope with the aim of reducing heat gains to the interior of the building [9]. Nevertheless, there exist many passive strategies that can be implemented in buildings, including enhancing natural lighting and ventilation, choosing the appropriate orientation of the building, efficient glazing, shading devices, and others. To assess the most used passive design strategies for buildings, Balali et al. proposed a classification that shows that most research efforts have focused on strategies such as (i) selection of appropriate materials for insulation of the envelope, (ii) enhancing natural ventilation and (iii) shading devices and structures [10]. Moreover, a study conducted in Gaza, Palestina, simulated 16 different passive strategies from which shading devices, thermal insulation of the envelope, natural ventilation, and adjusting window-to-wall ratio (WWR) to 15% proved to have the best performance when applied simultaneously [11]. In the same way, a study on scientific contributions to the energy performance of buildings in Latin America highlights that most studied passive strategies in the region focused on building envelope and implementation of biomimetic-focused strategies [12]. The climatic conditions that surround a building play an important role in the decisions of the strategies to be implemented. Harkouss et al. demonstrated through a simulation of multiple passive strategies subjected to 25 different climatic conditions that in order to optimize the performance of passive design, it is important to take into consideration the climatic context of the building [13][14].

To complement the passive design, it is common to implement active strategies that involve the reduction of internal loads associated with electromechanical systems [15]. In a study conducted in Israel´s humid climate, the integration of active strategies such as lighting and window automation and forced ventilation with fixed temperature setpoints proved to achieve a reduction of the energy consumption of the building up to 15 kWh/m^2 [16]. Similarly, a university building in Singapore replaced luminaires with more efficient ones, air conditioning units for variable speed systems, and integrated a personal ventilation system with underground air distribution. Each of these active strategies achieved energy savings that represented a payback period of 2, 10, and 28 years, respectively [17]. A study conducted in the metropolitan area of Korea simulated, along with different passive strategies, a lighting automation system coupled with dynamic curtains. Lighting control proved to achieve energy savings of up to 28.07%, while dynamic curtains were 6.57% [18].

The simultaneous integration of active and passive strategies can achieve a significant reduction in the energy consumption of a building in a way that the remaining energy demand can be supplied by renewable energy generation. Buildings under this concept are called Zero Energy Buildings (ZEB) [19]. However, the economic development of countries, as well as the creation of a robust legal framework and the development of research programs, play an important role in the implementation of this type of building. Consequently, more than 90% of ZEB projects are located in developed countries such as the United States of America or countries part of the European Union [9][20]–[22].

In response to this problem, Chen et al. conducted a review of studies related to Zero Energy Buildings (ZEB) in Latin America and current regulations and policies in Panama. The objective was to propose a definition of Zero Energy Buildings applicable to the climatic and regulatory context of Panama. A SWOT analysis conducted at the end of the study suggested that applying the nZEB (nearly zero energy buildings) definition in Panama represents an opportunity to achieve national goals of improving energy efficiency in the building sector. However, this requires strengthening research and developing policies on the subject, especially in developing countries with climatic conditions comparable to those in Panama [23].

As existing buildings still account for the majority of energy consumed in the sector [24], applying energy-efficient retrofits or improvement techniques to existing buildings represents a crucial strategy for energy savings and sector decarbonization. Additionally, the Energy Transition Agenda (Agenda de Transición Energética, ATE, in Spanish) of Panama describes how implementing different strategies for the public sector can achieve significant energy consumption savings at the national level [25].

To support the development of research towards sustainable buildings in Panama's climatic context, this article aims to conduct a systematic literature review on retrofitting active and passive energy efficiency strategies for existing office buildings in tropical climates. The aim is to analyze and compare the reviewed strategies to comprehend which techniques have been demonstrated to be the most efficient in improving the energy performance of the buildings within the scope of the investigation.

II. Methodology

The methodology implemented for the systematic review consists of a bibliometric analysis based on passive and active strategies implemented in office buildings and their respective performance indicators for tropical climates.

A. *Search strategy*

The search strategy employed for this research consists firstly of gathering data related to scientific advancements in the field of sustainable buildings up to the present date. To achieve this, a keyword search was conducted using various search engines and databases such as Google Scholar and Science Direct. Once preliminary data was collected, exclusion criteria were applied to select papers within the scope of the investigation, including only those whose topic refers to energy efficient strategies that have been applied as retrofits to office buildings in tropical climates that have proven to improve energy performance and comfort of buildings. This search strategy is displayed in Fig. 1, and Table 1 presents the different combinations of keywords connected through Boolean operators such as AND and OR that were used for the preliminary research.

B. *Bibliometric Analysis*

In order to identify and examine research trends and needs, a bibliometric analysis of the publications collected through keyword research was carried out, using the co-occurrence of keywords as an indicator. This study was conducted through the VOSviewer software, which provides visual connection networks among the found keywords, facilitating the analysis of research trends by occurrence.

III. Results analysis and discussion

A. *Current state and tendency of the specific fields*

From the literature research, a total of 8229 keywords were identified by the VOSviewer software, from which 1164 met the threshold of a minimum of five occurrences by keyword.

As observed in Fig. 2, different clusters were obtained from the selected literature, with the most representative group being the one where the term "Energy efficiency" appears most frequently (a total occurrence of 869). In this map, although the term "Office building" is connected to

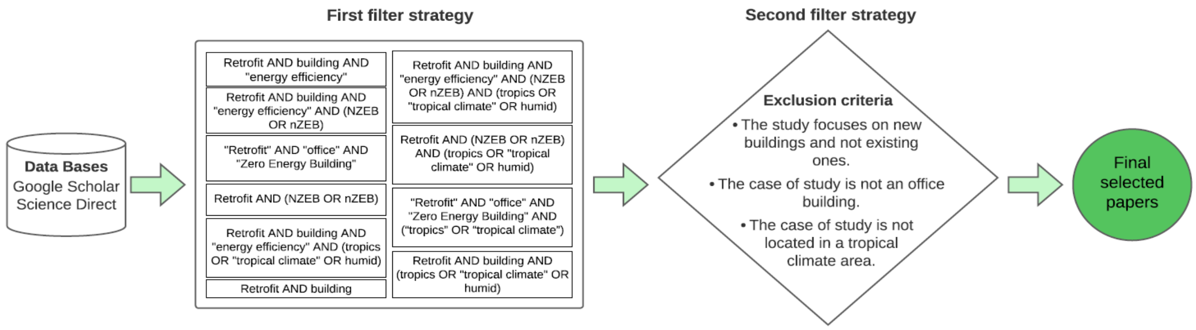

Fig. 1 Implemented search strategy.

terms such as "Net Zero Energy Building," "Near Zero Energy Building," "Energy Efficiency," and "Retrofit," there is no direct connection between "Office building" and "Tropical climate" (Fig. 3). Additionally the term "Tropical Climate" has a considerably smaller level of co-occurrence than the others mentioned. This highlights the limited research and literature on renovation strategies implemented in office buildings in the tropics that have allowed them to achieve Net or Near Zero status.

TABLE 1
KEYWORD COMBINATION FOR THE PRELIMINARY RESEARCH

Keywords	Number of documents	Period
Retrofit AND building AND "energy efficiency"	5107	2018-2024
Retrofit AND building AND "energy efficiency" AND (NZEB OR nZEB)	504	2018-2023
Retrofit AND building	10488	2018-2024
Retrofit AND (NZEB OR nZEB)	550	2018-2024
Retrofit AND building AND "energy efficiency" AND (tropics OR "tropical climate" OR humid)	812	2018-2024
Retrofit AND building AND "energy efficiency" AND (NZEB OR nZEB) AND (tropics OR "tropical climate" OR humid)	130	2018-2023
Retrofit AND building AND (tropics OR "tropical climate" OR humid)	1131	2018-2024
Retrofit AND (NZEB OR nZEB) AND (tropics OR "tropical climate" OR humid)	138	2018-2023
"Retrofit" AND "office" AND "Zero Energy Building"	855	2007-2024
"Retrofit" AND "office" AND "Zero Energy Building" AND ("tropics" OR "tropical climate")	27	2007-2023

Examining trends over the years reveals that research related to "Tropical Climate" has not shown significant development in more recent years but has rather remained consistent between 2019 and 2021 (Fig. 4).

Once the research opportunities were identified based on the trends studied through bibliometric analysis, a literature review was conducted to identify strategies implemented in existing office buildings in the tropics through which energy efficiency has been demonstrated to achieve low-consumption or Zero Energy Building (ZEB) status. The results of this review are presented hereafter.

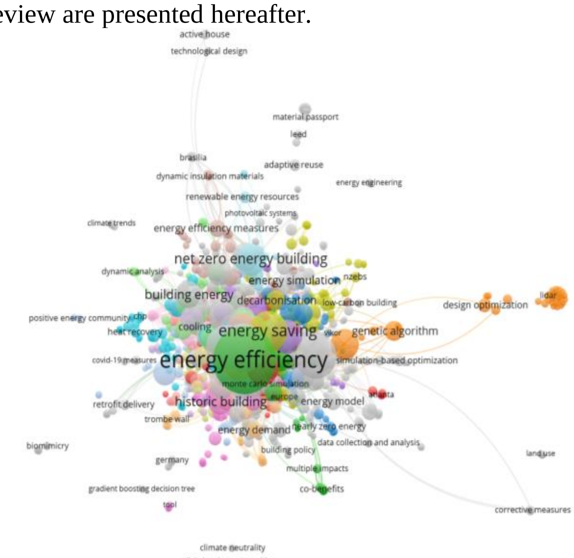

Fig. 2 Co-occurrence analysis results.

B. *Passive and active strategies for buildings in tropical climate*

As mentioned in the literature, to design effective strategies for reducing energy consumption in a building, it is essential to consider the climatic conditions in which it is located. In the case of buildings in tropical climates, it is common for energy demand to increase due to the frequent use of cooling systems to maintain occupants' thermal comfort [26]. This represents a challenge to achieving zero energy in buildings in this type of climate. Another significant challenge for countries in tropical regions is that many are considered developing countries and, therefore, lack a robust framework of regulations and policies on zero energy buildings. Consequently, most studies related to Zero Energy Buildings (ZEB) in the tropics are in the simulation stage, and data associated with experimental studies are limited, hindering the development of zero energy buildings in these regions [21], [27].

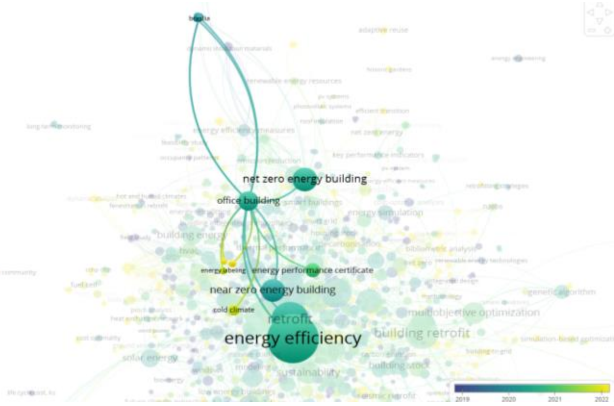

Fig. 3 "Office building" connection network.

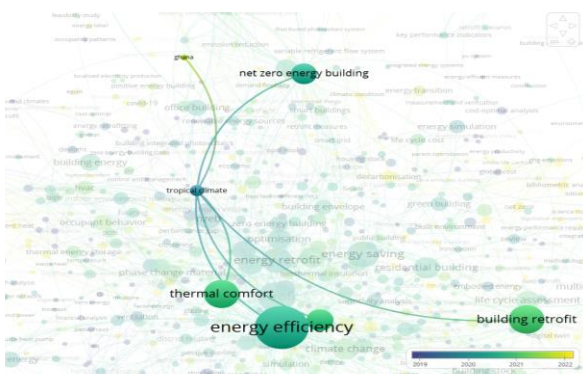

Fig. 4 "Tropical Climate" connection network.

However, studies have been conducted on strategies with the greatest impact on reducing the electrical consumption of buildings in tropical climates. A state-of-the-art review by Gupta and Deb demonstrated that, according to the literature, the strategies with the highest energy-saving potential in tropical climates, in order, are (i) envelope insulation, (ii) appropriate glazing materials, (iii) coating, and (iv) window-to-wall ratio. The energy savings from these strategies can reach up to 60% when implemented simultaneously. The same study suggests that increasing the thermal mass of the building in this type of climate may be counterproductive for energy consumption [28].

Regarding appropriate insulation for building envelopes in the tropics, Nematchoua et al. calculated the optimal thickness for buildings in the climatic context of Douala, Cameroon (Am in Koppen climate classification) in terms of energy reduction and total economic benefit. The study found that energy costs decrease with an increase in the thickness of the insulation used. For Douala, the optimal thickness was found to be between 0.092-0.102 m, and according to a literature review conducted in the same study, for tropical climates like Malaysia (Af), the optimum thickness is 0.040-0.100 m. However, the selected insulation thickness value should vary depending on the material used [29]. Additionally, Nematchoua conducted research to study different Phase Change Materials (PCM) and their integration with an expanded polystyrene insulation layer applied, through simulation, to an office building under different tropical climate conditions in Madagascar (transition tropical, humid tropical and hot tropical). Applying PCMs was shown to have a significant effect on reducing energy consumption, and when combined with 0.05 m of polystyrene insulation, it was possible to achieve comfort temperatures on the three climatic zones according to ASHRAE parameters [30].

For the study of roof insulation in tropical climates, Samah and Banna proposed different models of insulating materials, including vegetative cover for buildings in the country of Togo (Aw Koppen climate). The results of this study showed that bioclimatic covers like green roofs outperform plaster, earth layers, and polystyrene in reducing heat gains [31]. Similarly, an experimental study in Indonesia (Af) evaluated the effects of integrating zinc and concrete green roofs in low-rise residential buildings. The study demonstrated that concrete performs better than zinc in reducing incoming heat flux, and this performance can improve with the integration of vegetation into the roof. In terms of comfort, green roofs were shown to have the potential to decrease temperature and humidity enough to provide a comfortable indoor environment [32]. Expanded polystyrene was also studied as an insulating material for roofs in Ratmalana, Sri Lanka (Af) and although it improved the building's energy performance and was an eco-efficient material, the research highlighted the need to combine it with another insulating material to achieve optimal thermal conditions [33].

On the other hand, research conducted in Malaysia on existing zero-energy buildings in tropical regions (such as Enerpos Building and the Building Construction Authority) suggests that, for this type of climate, up to 29% thermal comfort can be achieved using window shading devices in combination with natural ventilation, without the need for super insulation of the building envelope or low-emissivity glazing [34].

To study the feasibility of using natural ventilation as a resource to ensure occupant comfort in tropical climates, Liping and Hieng analyzed meteorological data from Singapore (Af Koppen climate) for a full year. This analysis concluded that by increasing airspeed and integrating an efficient facade design with shading devices, up to 80% comfort can be achieved according to ASHRAE parameters [35]. Furthermore, a survey conducted in Singapore on occupants of naturally ventilated residences resulted in an average comfort index between "just right" and "slightly warm" [36]. However, the overlap of these strategies must be properly analyzed beforehand. In another study conducted in Singapore, the effects of shading devices on natural ventilation and sunlight utilization were evaluated. Seven different configurations of window overhangs were simulated, and illuminance and ventilation parameters were studied. The study's results showed that the implementation of vertical overhangs can be counterproductive for the enhancement of natural light and ventilation. Nevertheless, when done correctly, the implementation of shading devices in tropical rainforest climates (Af) can be useful to minimize heat gains without reducing natural lighting to levels below recommended standards [37].

Regarding the effects of natural ventilation on energy savings in buildings, a study by Haase and Amato mentions that the potential of natural ventilation in energy savings depends considerably on the building's location. For a tropical monsoon climate as in Manila, Philippines, the maximum potential for consumption reduction through natural ventilation is 50% since it prevents the use of air conditioning systems while maintaining comfort [38]. Similarly, a study in the tropical savanna climate of Bangkok, evaluated the effect of implementing a ventilation shaft in a tall residential building to increase indoor airspeed and, therefore, occupant comfort. The results showed that the ventilation shaft can increase the comfort percentage from 38% to 56%, equivalent to energy savings of approximately 2700 kWh in terms of air conditioning use [39].

To study the natural light resource in the tropics and how it can be harnessed to reduce electrical consumption in buildings, a field study was conducted on the integration of natural light into tall buildings in Johor Bahru, Malaysia. On-site measurements and questionnaires were conducted on a representative sample to assess visual comfort in naturally illuminated offices. From this study, it was concluded that, despite having a high natural light resource, countries in tropical regions risk perceiving high levels of glare that can be uncomfortable for office occupants if natural light is not adequately regulated through shading devices [40]. As a solution to the issue of proper light distribution, a simulation in the hot, humid tropical climate of Malaysia, studied the optimization of light shelves in office spaces to redirect sunlight and distribute it in a way that ensures occupants' visual comfort. The study's results indicated that, among the proposed models, parametrically controlled light shelves perform better in providing adequate light levels for offices [41]. Similarly, in Bangkok, a light duct mechanism for deep spaces was proposed. This study demonstrated that, under the right configurations, the light duct could be useful for contributing to the utilization of natural light in wide buildings with light spaces not easily accessible through windows [42].

C. Zero-Energy Buildings in Tropical Climates

The simultaneous integration of passive strategies appropriate for tropical climates, in addition to the previously mentioned active strategies and proper occupant behavior, has led to the development of low-consumption buildings in the tropics. An example of this is the Building and Construction Authority Academy in Singapore, a zero-energy building achieved through renovations and retrofits. Additionally, the Enerpos Building, a university building located on the island of La Reunion (As, savanna tropical climate), significantly reduced its energy consumption through the implementation of natural ventilation during class hours. Another successful case in La Reunion is the Ilet du Center in San Pierre, an office building created with a double envelope layer surrounded by green areas to reduce internal heat gains. Furthermore, there are other low-consumption buildings, such as the American Samoa EPA Office in Utulei, NUS SDE4 in Singapore, and the Zero Carbon Center in Hong Kong, China, among others. These buildings demonstrate the opportunity that countries in tropical regions have to leverage natural resources to achieve energy neutrality through savings and electricity generation from renewable sources [27].

D. Retrofit strategies for office ZEBs in the tropics

Despite the recent global efforts to construct new energy-efficient buildings, existing buildings still account for the largest share of energy consumed in the sector [24]. This is why applying remodeling or improvement techniques to these buildings represents a crucial strategy for energy savings and decarbonization of the sector. Literature reveals examples of buildings in tropical climates that have achieved low or zero-energy status through passive and active strategies implemented during remodeling.

One such example is the Building Construction and Authority (BCA) in Singapore, which underwent renovations to reduce electricity consumption and become a Net Zero Energy Building. The renovations included a solar chimney system operating on the buoyancy effect, expelling solar-heated air while drawing ambient air into the building. The installation of this chimney improved natural ventilation, changing occupants' thermal perception from "unacceptable" to "acceptable" according to a survey using PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) comfort indicators. Variable-speed air conditioning systems were installed based on specific space demand. Modifications to the building envelope, such as adding a "cooling skin" for shade and, in some cases, generating electricity through photovoltaic modules, were also implemented. Ducts in the building structure were added to collect zenithal light from the roof and other facade areas, redirecting it to spaces where needed. Although this strategy improved natural lighting, it raised the average radiant temperature by 0.5 °C. New window modifications, including adjustable curtains, electrochromic coatings, and semi-transparent photovoltaic modules, were also evaluated. Only the semi-transparent modules showed poor performance based on Daylight Autonomy (DA) indicators. Horizontal and vertical shading devices were added to the west facade, and photovoltaic panels were installed along the roof area. With the installation of photovoltaic panels, a positive balance of electricity generation versus consumption was achieved for most of the year 2014, thus attaining Net Zero Energy Building status. The complete renovation of this building cost USD $7,639,000 [43].

Similarly, a study was conducted on a university building in Guayaquil, Ecuador (Aw Koppen climate). Through simulation, the potential energy savings of various remodeling strategies, both active and passive, were analyzed, including the integration of a photovoltaic solar system for on-site generation. Approximately five energy efficiency measures were independently studied, one of which involved integrating a light control system based on natural light measurement through photosensors. To minimize solar radiation through windows, triple-glazed windows were configured, each separated by 13 mm of argon. The proposed model had a final transmittance value of 0.785 W/m2-K. Horizontal and vertical shading devices of 60 cm depth were added to each window, and the window size was adjusted for a 20% window-to-wall ratio. Active measures included improving the performance coefficient (COP) and temperature of air conditioners, changing electrical equipment to ENERGY STAR certified ones, and simulating monocrystalline photovoltaic panels for roof installation. The final results showed significant energy savings for each applied strategy, with natural light control being the most efficient, achieving a reduction of up to 20% in electricity consumption. The photovoltaic generation system produced an average reduction of 51.98%. Considering the investment costs in the economic context of Ecuador's construction sector, return periods were estimated for the mentioned measures. Natural light control had the lowest return period at 2.34 years, while three-layer low-emissivity glazing had the highest return period at 103.8 years [15].

To study the differences in electricity consumption trends for different types of buildings when applying modernizations, Yang et al. conducted a quantitative analysis comparing electricity consumption before and after modernizations in an office building and a classroom and laboratory building in Singapore. Thirty-four modernization scenarios were individually simulated, evaluating aspects such as solar radiation, window heat gains, air conditioning energy consumption, and occupant comfort, among others. Modernization scenarios included both passive and active techniques, such as green roofs, natural ventilation, daylighting, efficient glazing, lighting system replacements with more efficient technologies, adjustments to air conditioning temperatures, and automated control systems, among others. The study demonstrated that adjusting air conditioning temperatures to the maximum acceptable within comfort standards (around 25 °C) resulted in the best energy performance strategy. This strategy showed an average energy reduction of 6.7% per degree Celsius, supported by literature findings that a 1 °C increase in air conditioning temperature can lead to energy reductions between 5.4% and 8.0%. Comparing other scenarios, it was also shown that increasing natural ventilation and modernizing the building envelope plays a significant role in energy savings [44].

As the building envelope plays a crucial role in its electricity consumption, various studies have focused on optimizing this component of the building. In this regard, Hong et al. evaluated, through simulation, the combination of five retrofit strategies for the envelope of an office building in Malaysia. These strategies included (i) efficient glazing, (ii) wall insulation, (iii) shading devices, (iv) light ducts, and (v) reflective materials for surfaces. The study developed a decision-making tool to assess the feasibility of implementing these strategies on a real facade. The study concluded that, with available technologies for renovating existing facades, it is possible to achieve up to 50% energy savings [45].

Similarly, a study was conducted for the climatic context of Singapore, evaluating the effect of adding an additional coating layer to the glazing of an existing facade. This coating consisted of a clear glass layer of 10 and 15 mm with an air gap of 30 and 17 mm, respectively, in different orientations of the building. In this case, applying a double coating reduced the transmission of solar radiation into the interior; however, it also decreased the available light inside the space [46]. Among the most studied types of coatings for the glazing of buildings in tropical climates are semi-transparent photovoltaic modules (STPV). A simulation study conducted in Dhaka, Bangladesh, included this type of module in the windows of an office building, achieving 70% energy savings for a 60% window-to-wall ratio [47]. Similarly, research was carried out in Brazil, simulating a standard office model for tropical and subtropical climates. Five different window systems were integrated: (i) a single 6 mm window, (ii) double glazing, (iii) low-emissivity double glazing, (iv) organic photovoltaic modules, and (v) amorphous silicon photovoltaic modules (a-Si PV). The study results showed that the performance of each system varies depending on the climate and building orientation. For tropical climates, low-emissivity windows facing north achieved a higher reduction in electricity consumption [48].

The integration of shading structures into the envelope is another commonly studied strategy to prevent the incidence of solar radiation inside the building. In Malaysia, an office building located in Kuala Lumpur was selected to assess the effect of integrating awnings based on the type of building glass. Vertical, horizontal, and egg crate-shaped overhangs were simulated for both efficient double-glazed windows and simple 6 mm clear glass windows. Applying any type of overhang was shown to achieve a reduction in the building's electricity consumption. However, integrating egg crate-shaped overhangs achieved energy savings between 2.6% and 3.4%, the highest compared to the other two orientations (vertical and horizontal). It was also demonstrated that combining the integration of shading structures with double-glazed windows increased the reduction in the building's electricity consumption [49].

In addition to the implementation of passive techniques, efficient electrical and air conditioning equipment plays a crucial role in reducing building electricity consumption, especially in tropical climates. Deb and Lee conducted research studying different variables influencing the energy consumption of 56 office buildings in Singapore based on their consumption trends before and after different modernizations. The results indicated that the most significant energy savings in the sampled buildings resulted from modernizations in air conditioning systems, reducing the energy use intensity index range from 196-303 kWh/m2 to 168-243 kWh/m2 after modernization [50]. Additionally, a study was conducted on the Island of Mauritius, Africa (tropical monsoon climate, Am), considering multiple modernization strategies for a university office building. An energy audit was conducted to identify the major consumption areas, revealing that air conditioning and lighting systems were the largest energy consumers, representing 28% and 20% of consumption, respectively. For the air conditioning system, conventional units were replaced with inverter units featuring variable-speed compressors. Occupancy sensors were installed to turn off units when offices were unoccupied, and the air conditioning temperature was set to 3°C below ambient temperature. Regular maintenance was emphasized to ensure system efficiency. Regarding lighting, existing T8 fluorescent tubes were replaced with T5 tubes, and occupancy sensors were installed to ensure lights were turned off in unoccupied spaces. The study evaluated the energy performance of these measures and their cost-effectiveness. The installation of inverter air conditioning units achieved a reduction of 31,656 kWh per year, resulting in a 36.8% annual electricity cost savings with a return-on-investment period of 6.6 years. Additionally, replacing luminaires with more efficient technology resulted in annual energy savings of 1,900 kWh and an initial investment return period of 1.2 years [51].

In addition to implementing passive and active energy efficiency strategies to reduce consumption, integrating photovoltaic modules into the building envelope is essential to meet the energy demand through renewable energy and achieve net-zero energy. Particularly in office buildings, photovoltaic generation systems have a greater influence on maximum energy demand, as their occupancy aligns with daylight hours.

To assess the role of photovoltaic systems in tropical buildings, Saber et al. conducted a study on these systems in a zero-energy building (ZEB) in Singapore. The study demonstrated that, in tropical climates, the maximum power generated by the modules is close to their nominal capacity, with peak efficiency in the early morning and decreasing throughout the afternoon due to cell temperature. The research also concluded that simulators such as EnergyPlus can predict the performance of photovoltaic systems, and the implementation of the appropriate number of modules plays a crucial role in achieving net-zero energy in office buildings [52].

As evident from the literature, modernizations, and renovations applied to office buildings have significant potential in helping buildings achieve net-zero energy. However, to achieve effective results, these remodeling strategies must be carefully selected based on the needs and climatic conditions of each building.

On buildings located specifically in tropical climates, there is an important potential for taking advantage of natural resources such as solar radiation, illuminance, and wind. Consequently, there exists a tendency to adapt the building envelope to these natural resources, enhancing its efficiency and achieving energy consumption reduction and thermal comfort for the occupants. Table 2 shows the frequency of studied passive and active strategies distributed by country.

Given the importance of the envelope of a building on its thermal and energetic performance and the broad spectrum of options of passive strategies related to retrofitting the building envelope, passive design studies highly outnumber active strategies, according to the review results. Nevertheless, some active strategies, such as efficient configurations of HVAC systems, tend to achieve higher reductions in the electrical consumption of the building when compared to passive strategies [15][44].

From the data collected through the analysis, efficient glazing systems were the most studied passive retrofit. Efficient glazing implemented in different regions with tropical climate included double and triple layers of low emissivity glass[15], [43], [45], [46] and integration of semi-transparent PV modules [43][48][47]. Semi-transparent PV modules proved to achieve up to 90% of energy savings related to illuminance for tropical climates, however, this type of glazing may interfere with the visual comfort of the occupants.

Shading devices and envelope insulation through vegetation, coating, and low U-value materials were the next most studied passive strategies. Following efficient glazing, shading devices had the highest performance in terms of total energy savings (up to 6.5%), followed by insulation of the envelope that has proved to increase total energy savings up to 5.77%, and more when combined with vegetation walls and/or roofs.

TABLE 2. Retrofit in Office Buildings Tropical and humid climate.

Reference	Country	Climate	Type of Study	Efficiency strategy	Active/Passive	Findings
[43]	Singapore	Af	Experimental	Natural ventilation	Passive	Comfort from unacceptable to acceptable.
				Efficient HVAC system	Active	Improvement in energy efficiency from 138 to 174 kWh/m2
				Green roof	Passive	Energy savings of 70 kWh/m2
				Adjustable blinds	Passive	300-800 lux. Within ASHRAE's recommended range (>300)
				Electrochromic glazing	Passive	100-700 lux. Within ASHRAE's recommended range (>300)
				Semi-Transparent PV	Passive	100 lux. Not within ASHRAE's recommended range (>300)
				Light shelf	Passive	Not specified individually
				Shading devices	Passive	Not specified individually
				Photovoltaic generation	Generation	The energy generation covered the electric demand of the building (207 MWh/y)
[15]	Ecuador	Cfb	Simulation	Photovoltaic generation	Generation	The photovoltaic system delivered 48,497 kWh to the building while selling 18,093 kWh to the grid per year.
				Efficient HVAC system	Active	Total energy savings of 24%
				Natural lighting	Passive	Disminución de energía consumida por iluminación un 42%
				Low-e glazing	Passive	Total energy savings of approximately 8%
				Efficient lighting	Active	Energy reductions for equipment: 15%
				Shading devices	Passive	Total energy savings of approximately 7%
				Window to wall ratio	Passive	Total energy savings of approximately 6%
[44]	Singapore	Af	Simulation	Green roof	Passive	Photovoltaic generation and increase in indoor temperature setpoint are the most efficient strategies for energy reduction. Average of 6.7% reduction in energy consumption per Celsius degree.
				Natural ventilation	Passive	
				Natural lighting	Passive	
				Reflective coating	Passive	
				Envelope insulation	Passive	
				Low-e glazing	Passive	
				Efficient lighting	Active	
				Efficient HVAC system	Active	
[45]	Malaysia	Af	Simulation	Low-e glazing	Passive	Advanced green technologies available for façade retrofitting can save up to 50% of a building's energy consumption.
				Shading devices	Passive	
				Light shelf	Passive	
				Reflective coating	Passive	
				Envelope insulation	Passive	
[46]	Bangladesh	Aw	Experimental	Low-e glazing	Passive	Energy savings of up to 5.9% for the east facade
[48]	Brazil	Aw	Simulation	Semi-Transparent PV	Passive	The semi-transparent PV windows contributed 21 % of the generated electricity.
[49]	Malaysia	Af	Simulation	Shading devices	Passive	Egg-crate shading devices can achieve up to 2.6 y 3.4% of energy savings, which can increase when integrating double glazing in windows.
[50]	Singapore	Af	Numerical analysis	Efficient HVAC system	Active	Decrease in energy use intensity range from 196-303 kWh/m2 to 168-243 kWh/m^3
[51]	Isla de Mauricio	Aw	Data analysis	Efficient HVAC system	Active	Inverter AC: reduction of 31 656 kWh/yr, Payback period of 6.6 years
				Efficient lighting	Active	Payback period of 1.2 years
				Occupancy sensors	Active	Not specified individually
[47]	Bangladesh	Aw	Simulation	Semi-Transparent PV	Passive	This system can achieve up to 90% of energy efficiency

III. CONCLUSIONS

Due to the global energy crisis developing worldwide, research and development has shifted towards minimizing the building sector's impact on the global emissions of greenhouse gases (GHG). As existing buildings still account for most of the energy consumed in the sector, applying energy-efficient retrofits or improvement techniques to existing buildings represents a crucial strategy for energy savings and sector decarbonization. Buildings located in tropical climates possess a great opportunity to take advantage of natural resources to enhance the efficiency of the buildings and achieve energy consumption while maintaining comfort.

Since most countries located in tropical regions are considered developing countries, there is limited data on energy-efficient strategies that have been implemented in existing buildings, particularly experimental data. This study aims to encourage further investigation on the subject by presenting a comprehensive literature review of the data collected on retrofitting energy efficiency strategies applied to office buildings in the tropics. The goal is to analyze and compare the most efficient strategies for this specific type of buildings according to the literature.

Results showed that most studies related to retrofit strategies for office buildings in the tropics are based on analyzing the glazing component of the envelope. There is a wide range of options for configuring the glazing, including using low-emissivity materials, applying double and triple layers of glass with insulating gas, and integrating semi-transparent photovoltaic modules (STPV) for generation. It was shown that STPV can achieve up to 90% of energy consumption related to lighting. However, this type of glazing might interfere with the occupants' visual comfort. Shading devices and envelope insulation are the next most studied retrofit strategies for tropical climates. Following efficient glazing, shading devices yielded the highest total energy savings (up to 6.5%), followed by envelope insulation, which has been demonstrated to increase total energy savings up to 5.77%, and even more so when combined with green walls and roofs.

When studied simultaneously, active strategies related to cooling and lighting were shown to contribute to the energy efficiency of office buildings to a greater extent than passive strategies. Efficient HVAC systems with a high coefficient of performance (COP) and adjusted temperature setpoints proved to achieve the greatest reduction in the building's energy consumption for tropical climates. On the other hand, integrating efficient lighting systems into the building was presented as the active strategy with the lowest payback period for office buildings in the tropics.

When implemented individually, passive strategies demonstrated limited energy savings. Nevertheless, retrofitting the building envelope with simultaneous passive strategies such as insulation, shading devices, efficient glazing, and light shelves to enhance natural lighting proved to achieve energy savings of up to 50% of the building's total energy consumption.

It is important to note that most of the studies were conducted in different locations, and energy efficiency strategies were not always compared directly to each other but rather studied in combinations and under different occupancy conditions.

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