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Improving Thermo-Energetic Consumption of Medical Center in Mexican Hot–Humid Climate Region: Case Study of San Francisco de Campeche, Mexico

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Abstract: An assessment of the thermal refurbishment of an outpatient medical center in a tropical location, such as the City of San Francisco de Campeche, was presented with the aim to diminish its energy consumption. A year-long energy audit of the facility was conducted to formulate and validate a numerical simulation model while scrutinizing enhancement strategies. The examined improvement alternatives encompass passive adjustments to the roof (utilizing insulating materials, applying reflective coatings, and installing a green roof), modifications to active systems incorporating inverter technology, and alterations to the walls via reflective paint. The outcomes of the simulated enhancement scenarios were assessed utilizing energy, environmental, and economic metrics: key performance index (KPI), equivalent CO_2 emission index (CEI), and net savings (NS). These results were subsequently juxtaposed against TOPSIS decision-making algorithms to ascertain the alternative that optimally balances the three options. It was identified that using reflective paint on the roof provides the best energy benefits and contributes to mitigating emissions from electricity use. Furthermore, combining this passive technology with the integration of inverter air conditioning systems offers the best economic return at the end of 15 years. For its part, the TOPSIS method indicated that by prioritizing the financial aspect, the reflective coating on the roof combined with inverter air conditioning is enough. However, adding a wall with insulating paint brings environmental and energy benefits. The results of this work serve as a starting point for the analysis of other post-occupied buildings in the region and others under tropical climatic conditions.

Keywords: energy efficiency; medical building; tropical climate; thermal restauration

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1. Introduction

Global energy consumption has increased in the last 40 years by over 100%, meaning that society and governments have focused on energy efficiency and sustainability to counteract its negative effects [1,2]. The primary goal is to avoid the exhaustion of energy resources, environmental issues, and increase in energy prices; however, urbanization affects this target [3]. According to the United Nations, more than 60% of the population will reside in urban areas by 2050 [4], with buildings being one of the most critical sectors in energy consumption. So, well-designed buildings are crucial for controlling current and future electrical consumption and pollutant emissions.

Buildings represent more than 30% of global energy consumption and are responsible for 27% of CO_2 emissions into the environment [5]. According to multiple analyses, this behavior will increase the products of climate change [6]. This annual requirement is primarily for cooling, heating, ventilation, and lighting [7]. Energy management can reduce energy consumption in facilities by up to 20% and impact total energy demand [8]. However, in predicting energy consumption, there are various challenges, such as ambient temperature, area and type of building, and age of the construction, to mention a few [9,10]. In this context, health centers are important, since their operation requires an efficient and high-quality service that must be met in indoor conditions that guarantee thermal comfort. In addition, health standards are increasingly regulated and have a high impact on this type of building. Meeting these requirements carries a significant energy demand that has been overlooked for many years.

Medical centers have the highest energy consumption among the leading commercial buildings; their energy requirement is allocated to air conditioning, medical equipment, and maintenance [11]. Various studies have shown that 40% of consumption in medical centers comes from air conditioning systems [12]. This consumption is estimated to be worse in countries with warm and tropical climates, characterized by high temperatures increasing the electrical demand for indoor cooling [13]. In this context, in Mexico, the annual consumption in medical centers was 3698 MJ/m^2, where 80% of the annual demand comes from regions with warm and humid climates [14]. Furthermore, according to some studies, the public sector might present an underestimation issue [14,15]. This consumption is the product of many factors, but one of the most important is the inefficient physical state of the building and inefficient equipment; for this reason, it is imperative to study different strategies that help reduce operating costs [12].

Sun, Y. et al. [11] carried out a comprehensive evaluation through satisfaction questionnaires of users for a medical center in China, improving energy efficiency. Seo et al. [16] studied the impact of modifying the building envelope using green retrofits in South Korea. Their results demonstrated that this technique improves heating systems' energy efficiency by 30%. As and Bilir [17] focused on energy efficiency and CO_2 mitigation in a hospital building, evaluating insulation materials, building orientation, lighting efficiency and window-to-wall ratios, obtaining energy consumption reductions by 50%. Similar analyses have been reported for hospitals in Spain [18], Italy [19], and Australia [20], to name a few.

The bibliographic review in this paper establishes the importance of analyzing medical centers' energy consumption and prediction. The works presented in the bibliographic review focus on modifying operating parameters, HVAC system technologies, and modifying the building envelope. Furthermore, few works address this topic for regions with a tropical climate and coastal cities, focusing mainly on temperate or Mediterranean climates. No studies focused on the thermo-energetic behavior of medical centers in Mexico, specifically in regions with a tropical climate. That said, this study analyzes and identifies alternatives for thermo-energy improvements in an outpatient medical center located in a coastal city with a tropical climate, such as San Francisco de Campeche. This work's main objective is to identify alternatives that reduce the energy and environmental impacts of a building that operates under the real conditions of medical activity and represents a viable investment alternative in the medium term. The results represent the first approach to thermal restoration for buildings in the region linked to economic, environmental, and energy aspects. In addition, it provides an overview of actions that can be taken to make thermal restoration more attractive.

The rest of the work is divided into four sections: The second section addresses the description of the study building, the characteristics of the construction materials that compose it, and the electrical consumption equipment and operational patterns of the medical center. The third section addresses the computational methodology design for modeling, calibration, and thermo-energetic restoration of the medical center based on passive and active technologies. The fourth section presents the results of the energy, environmental, and economic analysis for the thermal improvement of the building, as well as the selection of the best option that combines the three elements. Finally, section five contains the conclusions and discussion of the work.

2. Case Study Location and Building Data

2.1. Description of the Case Study Location

The case study corresponds to an ambulatory medical center for ophthalmological care located in the historical center of San Francisco de Campeche, Mexico (19°50′41″ N, 90°32′23″ W). The city's zone is a completely urbanized area (with practically no natural vegetation) comprised of masonry buildings and concrete streets, which has fostered the heat island phenomenon. According to the Köppen climate classification, the city is characterized by a hot–humid climate with rains in summer, and an average monthly temperature between 22 °C and 31 °C, with May being the hottest month and January the coldest [21]. The average solar radiation in the city is over 16.2 MJ/m^2-day, reaching values higher than 18 MJ/m^2-day at summer. The region is also characterized by a high percentage of relative humidity throughout the year, between 70% and 98% [21]. Figure 1 illustrates the perceived heat index in the city's historical center, where the blue dots indicate the ambient temperatures recorded for 2022. More than 60% of the year, the buildings in the region are within the margin of caution, which increases dangerous heat and extreme danger indices the closer one is to the summer. In addition, it is essential to emphasize that non-operational hours (night hours) are mainly those where it is outside of this risk zone. All of them drastically impact the thermal comfort of this zone buildings' occupants and increase energy use to counteract it. Therefore, the analysis of the building is critical because it forms part of a compendium of facilities that currently perform functions for which and are susceptible to thermal restorations.

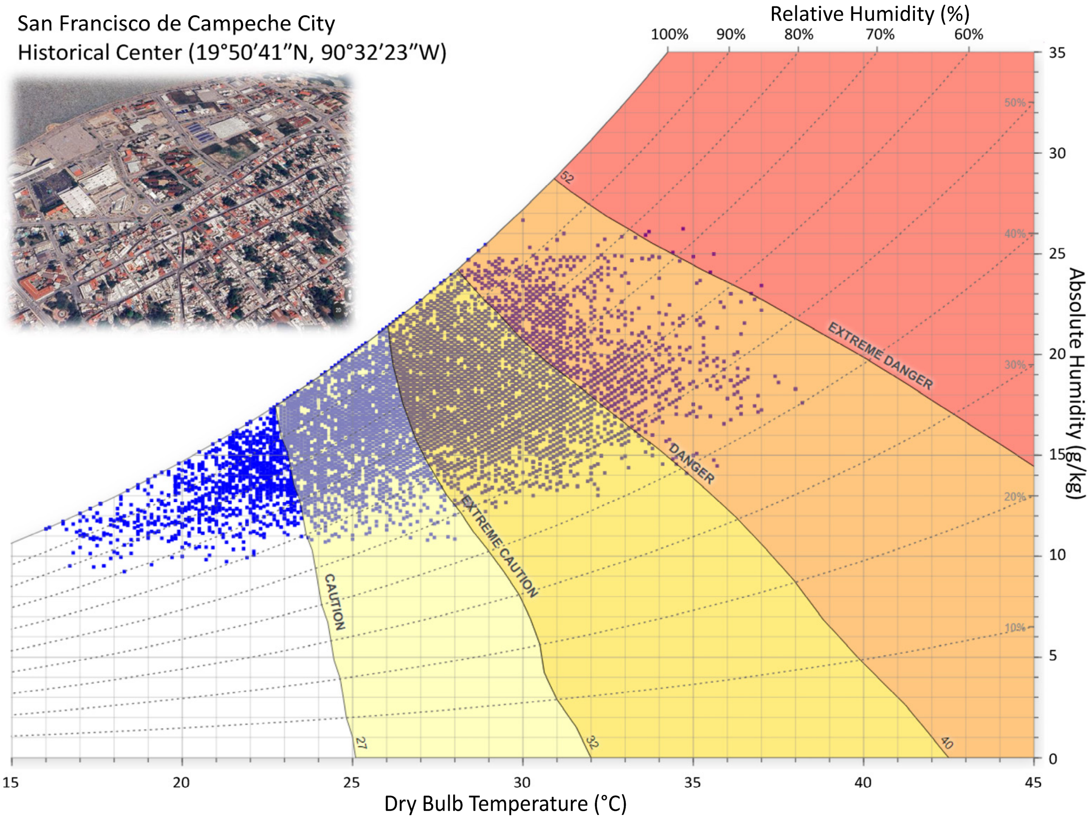

Figure 1. Psychrometric chart with the heat indices reported in the historical center of San Francisco de Campeche, Mexico for 2022.

2.2. Building Information: Outpatient Medical Center

The medical center is a single-story building facing south, divided into 11 zones with 127.63 m^2 surface construction and a volume of 521.18 m^3. A detailed description of the building's dimensions is found in Figure 2. The medical center is mainly built from masonry stone with plaster on the exterior and interior sides, a cast concrete ceiling, door and windows frames made from wood, and windows made of 3 mm clear glass (Table 1). The building is reconditioned to carry out medical consultations and specialized ophthalmological surgeries. It operates Monday to Friday from 9:00 a.m. to 1:00 p.m. and 5:00 p.m. to 9:00 p.m.; and Saturdays from 9:00 a.m. to 4:00 p.m. The facilities operate with five employees in the consulting and optical zones and six employees in the surgery zone. The medical center has an average flow of 60 to 80 monthly patients for the consultation zone and an additional 80 people who come to the operation zones. It is important to emphasize that the age of the building implies the absence of regulatory standards regarding energy saving during its construction.

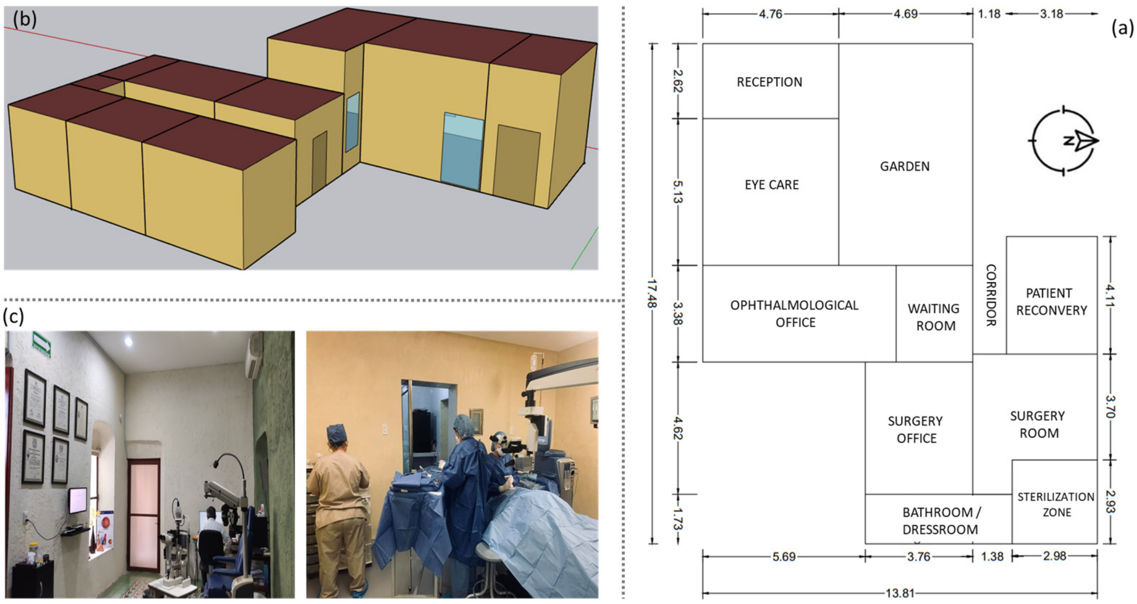

Figure 2. Dimensions and structure of the medical center: (**a**) floor plant; (**b**) computational 3D building perspective; (**c**) indoor activities of daily occupation.

Table 1. Medical center envelope elements' physical properties.

Envelope	U-Value (W/(m^2 K))	Total Solar Transmission (%)	Light Transmission (%)	Materials	Width (m)	Thermal Conductivity (W/(m-K))	Specific Heat (J/(kg-K))	Density (kg/m^3)
Outdoor walls	1.773	Na	Na	Outdoor gypsum plaster	0.01	0.4	780	1860
				Cast concrete	0.015	0.9	980	1860
				Concrete block	0.25	0.8	1000	700
				Indoor gypsum plaster	0.02	0.5	1000	1300
Indoor walls	1.628	Na	Na	Gypsum plaster	0.01	0.4	780	1860
				Cast concrete	0.015	0.9	980	1860
				Concrete block	0.25	0.8	1000	700
Roof	1.432	Na	Na	Outdoor gypsum plaster	0.01	0.4	780	1860
				Ready-mixed concrete	0.12	0.9	900	2100
				Concrete block	0.18	0.5	1000	1400
				Indoor gypsum plaster	0.02	0.5	1000	1300
Doors	2.111	Na	Na	Wood	0.045	0.2	1760	357

Table 1. *Cont.*

Envelope	U-Value (W/(m^2 K))	Total Solar Transmission (%)	Light Transmission (%)	Materials	Width (m)	Thermal Conductivity (W/(m-K))	Specific Heat (J/(kg-K))	Density (kg/m^3)
Windows	5.894	79.3	88.1	Clear simple glass	0.003	0.96	800	2500
Surface material		**Solar reflectance (%)**		**Thermal absorbance (%)**	**Solar absorbance (%)**		**Solar absorbance (%)**	
gypsum plaster		30		90	70		70	

An energy audit was conducted to identify the electricity devices with significant demand and establish the building's energy consumption baseline. Audit data was collected on the number of devices and operating hours of lighting equipment, HVAC systems, office equipment, and specialized medical practice systems. For the present study, HVAC systems only cover air conditioning devices, as due to regional climatic characteristics, the heating requirement for thermal comfort is null [22]. The energy audit information was collected through surveys carried out on staff, installed equipment datasheets, and measurements. Electrical data was captured by an AEMC 3945-B PowerGrid analyzer; it is a class S device designed to measure power frequency, magnitude of supplied voltage, voltage unbalance, interruptions, and electrical rapid changes with 5% precision concerning the nominal voltage. The measurement period ranged from January to December 2022. Energy audit results are presented in Table 2, which describes the electrical loads between the 11 zones of the ambulatory medical center, such as the energy final use of electricity. According to the data collected, higher electrical energy consumption is associated with using air conditioning to cool the spaces that patients and staff frequent to a greater extent. These results are consistent with the literature, where it is reported that air conditioning equipment represents about 66% of electricity consumption in regions with hot–subhumid or similar climates [23]. In facilities for the care of patients, health, or other small-sized related matters, it has been verified that the energy consumption for air conditioning is around 60% [24].

Table 2. Installed loads and electrical energy consumption of the medical center based on the energy audit.

Zone	Width (m)	Length (m)	High (m)	Electric Devices	Installed Electrical Loads (kW)			
					Lightning	Air Conditioning	Medical Equipment	Office Equipment
Ophthalmological office	3.38	6.69	4.60	11 plugs, 6 LED lamps 20 W, television, computer and printer, Minisplit	0.12	1.22	-	
Eye care	5.13	4.76	4.73	6 plugs, 7 LED lamps 20 W, computer and printer, fridge, Minisplit	0.14	1.28	-	
Reception	2.62	4.76	4.73	4 plugs, 6 LED lamps 20 W	0.12	-	-	-

Table 2. *Cont.*

Zone	Width (m)	Length (m)	High (m)	Electric Devices	Installed Electrical Loads (kW)			
					Lightning	Air Conditioning	Medical Equipment	Office Equipment
Patient recovery	4.11	3.00	3.53	10 plugs, 3 T8 lamps 32 W, Minisplit	0.10	1.24	-	-
Surgery room	3.70	4.36	3.53	14 plugs, 4 T8 lamps 32 W, Minisplit 2.52 kW, 3 medical equipment	0.13	2.52		-
Sterilization zone	2.93	2.98	3.53	8 plugs, 2 LED lamps 9 W, fridge, 2 medical equipment	0.02	-		-
Dressing room /bathroom	1.73	5.14	3.53	2 plugs, 2 LED lamps 9 W	0.02	-	-	-
Corridor and cellar	-	-	3.53	5 plugs, 10 LED lamps 9 W	0.12	-	-	-
Waiting room	3.38	2.76	3.63	2 T8 lamps 32 W, Minisplit	0.07	1.22	-	-
Surgery office	3.38	3.76	3.63	26 plugs, 2 T8 lamps 32 W, 2 medical equipment, computer, Minisplit	0.07	1.22		
Outside space	7.75	4.69	-	T8 lamp 32 W	0.03	-	-	-

Energy end use	Installed electrical loads		Average monthly electricity consumption	
	(kW)	(%)	(MJ)	(%)
Lightning	0.89	7.2	251.6	5.18
Air conditioning	8.69	70.3	3065.4	63.05
Office equipment	1.913	15.5	1510.2	31.06
Medical equipment	0.87	7.0	34.5	0.71

For its part, Figure 3 illustrates the baseline of electricity consumption and the final use of energy measured throughout 2022 for the outpatient medical center. According to Figure 3a, the highest energy consumption occurs from May to October, exceeding 1.4 MWh per month. This is associated with the summer season and the heatwave period, forcing an increase in the use of air conditioning to counteract thermal stress. However, it is essential to emphasize that in more than 60% of the year, the 1.2 MWh per month is easily exceeded, of which the eye care and ophthalmologic office represent about 76% and 71% in air conditioning and lighting consumption, respectively. Finally, in environmental matters, the baseline associated with said energy consumption is around half a ton of monthly average CO_2 equivalent emissions.

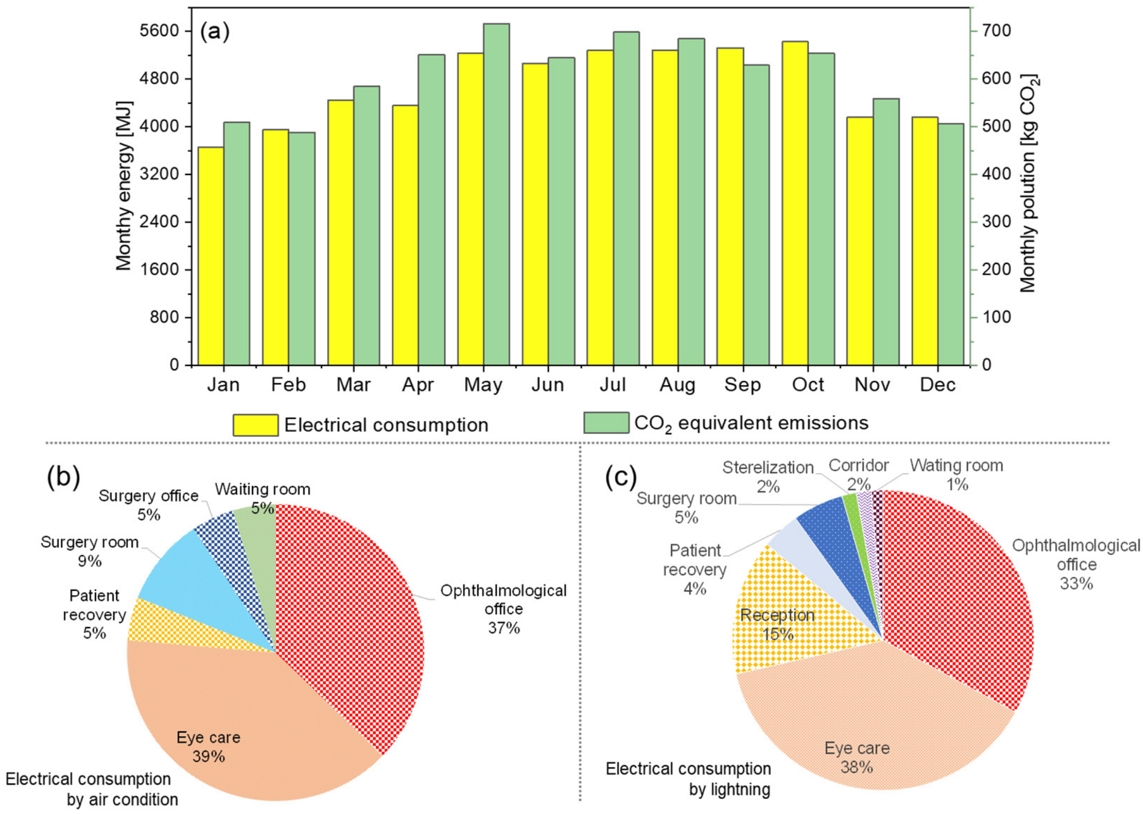

Figure 3. Summary of the results of the energy audit for the ambulatory medical center: (**a**) monthly baseline of energy consumption and equivalent CO_2 emissions, (**b**) electricity consumption associated with air conditioning equipment, (**c**) electricity consumption associated with lighting equipment.

3. Computational Methodology

Figure 4 presents the simulation process to identify the merge of passive and active technologies to improve the building's energy performance. This methodological approach is comprised of six stages. The first phase consists of developing a 3D model based on the construction properties of the medical center and the information gathered from the energy audits. Subsequently, a calibration stage is executed where the model's electric consumption simulations are contrasted with the grid analyzer measurements. Once medical center calibration was carried out, passive building technologies were evaluated to improve the building's energy performance. In the same way, active systems are integrated with high-efficiency air conditioning to maximize energy savings. At this stage, various configurations were analyzed, looking for the optimal combination for the location. Finally, in the fifth and last stage, the energy performance index (according to the ISO 50001:2018 standard) pollution mitigation, and the techno-economic feasibility of investment are contrasted through a decision-making tool to quantitatively identify the trade-off where the three indices converge. A more detailed description of the six phases is provided in the following subsections.

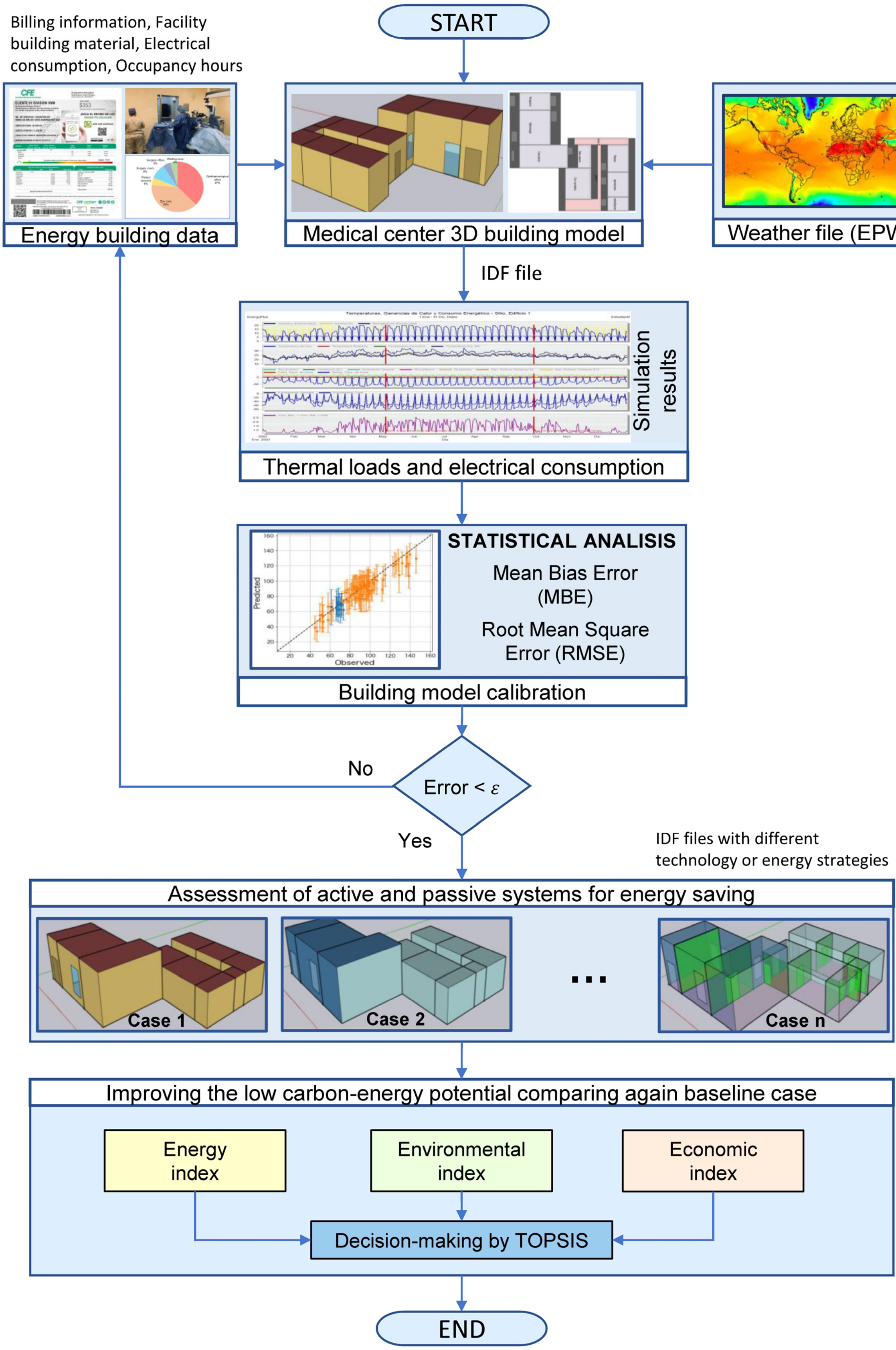

Figure 4. Computational methodology implemented to improve thermal performance in a medical center under hot-humid climate conditions.

3.1. Building Modeling

To carry out the energy analysis, a 3D model of the medical center was built aided by the simulation software Open-Studio(v. 3.4) and Energy-plus(v. 9,4). These are based on BIM methodology, specialized in predicting the indoor environment and energetic behavior of the building through heat transfer calculations and assumptions. They are designed for energy improvement, from advanced envelope strategies to developing air conditioning systems. For this purpose, the software calculates the thermal loads of the built environment and the thermal/electrical load of operation systems by using a transient heat balance [25].

For simulation, the software requires data of the building materials' thermophysical properties, schedule operation, characteristics of HVAC and lighting systems, and the weather information of the location. The model of the medical center was developed using the envelope materials properties reported in Table 1. Regarding electrical devices, it was given the information collected by energetic audits. Similarly, based on the flow of people and patients served by the medical center (described in Section 2.2), information on the occupancy percentages and hours of activity of the building linked to energy loads was programmed, as is presented in Table 3. The configuration of the HVAC systems was adjusted to a set point of 22 °C under current regulations in hospitals and health centers [26]. Finally, the climatic file used in the study comprises hourly meteorological data for 2022 obtained through the software METEONORM (v. 8.1.1) [27].

Table 3. Percentage distribution of loads in the process of energy simulation.

Loads	**Period**					
Occupancy	**Weekdays**					
	Schedule	00:00–7:59 h	8:00–13:59 h	14:00–16:59 h	17:00–20:59 h	21:00–23:59 h
	Percentage	0%	100%	0%	100%	0%
	Weekend (Saturday)					
	Schedule	00:00–7:59 h	8:00–15:59 h	16:00–23:59 h		
	Percentage	0%	100%	0%		
Equipment and lighting	**Weekdays**					
	Schedule	00:00–7:59 h	8:00–13:59 h	14:00–16:59 h	17:00–20:59 h	21:00–23:59 h
	Percentage	0%	100%	0%	100%	0%
	Weekend (Saturday)					
	Schedule	00:00–7:59 h	8:00–15:59 h	16:00–23:59 h		
	Percentage	0%	100%	0%		
Natural Ventilation	**Weekdays**					
	Schedule	00:00–7:59 h	8:00–13:59 h	14:00–16:59 h	17:00–20:59 h	21:00–23:59 h
	Percentage	100%	10%	10%	10%	100%
	Weekend (Saturday)					
	Schedule	00:00–7:59 h	8:00–15:59 h	16:00–17:59 h	18:00–23:59 h	
	Percentage	100%	10%	30%	0%	

3.2. Building Model Calibration

Since building energy models are complex and comprise a large number of input data, it is necessary to carry out calibration processes to corroborate and verify that they represent the actual behavior and performance of the building. The literature reports two statistical approaches commonly used to assess the quality of model calibration: the mean bias error (MBE) and the coefficient of variation of the root mean square error (Cv(RMSE)) [28].

MBE measures the overall systematic error of the building energy model and is defined as follows:

$$MBE = \frac{\sum_{i-1}^{Np}(m_i - s_i)}{\sum_{i-1}^{Np}(m_i)} \quad (1)$$

where m_i and s_i represent the measured and simulated energy data, respectively; with Np as the number of measurements analyzed. The acceptable ranges of MBE for analysis with monthly data are between 0–5%, while for hourly or daily data the tolerance is up to 10% [29]. On the other hand, the CV(RMSE) is used as a complement to prevent calibration errors due to the compensation between positive and negative values used in the MBE. The CV(RMSE) is computed following the equation:

$$CV(RMSE) = \frac{\sqrt{\sum_{i-1}^{Np}(m_i - s_i)^2/Np}}{\sum_{i-1}^{Np} m_i/Np} \quad (2)$$

According to ASHRAE and the International Performance Measurement and Verification Protocol (IPMVP), the acceptable range for CV(RMSE) using monthly data is from 0 to 15%, while hourly and daily data this extends up to 30% [29].

Figure 5 illustrates the results of the outpatient medical center model calibration concerning the cumulative monthly energy consumption over a year. In general, the overall systematic error of building model (MBE) is close to 1%, and the CV(RMSE) is 7.75%. This implies that the model balances well between overestimation and underestimation, and the CV(RMSE) confirms acceptable uncertainty range below the limit, indicating a good accuracy according to the regulations. It is essential to highlight that the largest monthly difference occurs in May, without exceeding 10%, and that, on average, the monthly differences of the model do not exceed 6%. Furthermore, the differences presented in the warmer months overestimate the monthly demand when analyzing the integration of passive technologies.

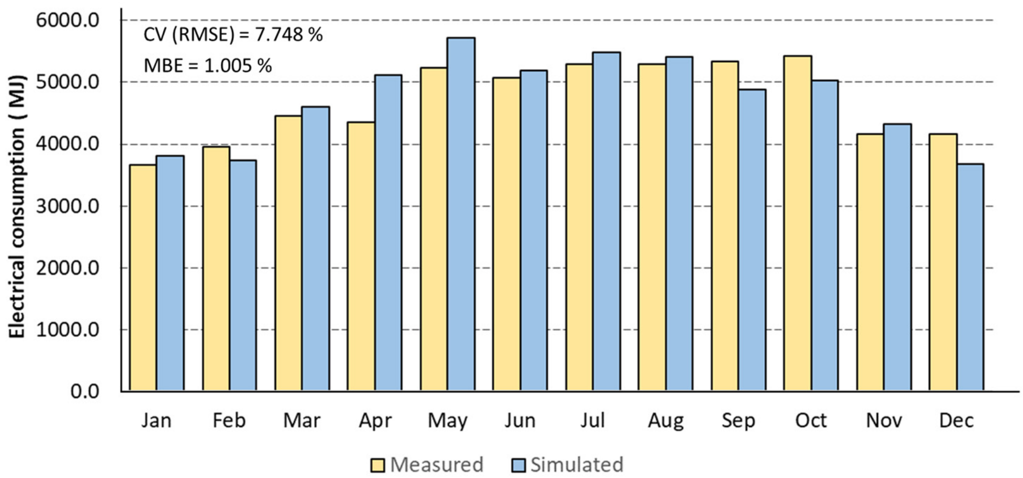

Figure 5. Comparison between measured electricity consumption data and calibrated results from the outpatient medical center.

3.3. Energy Efficiency Proposal Using Passive and Active Technologies

The integration of passive and active technologies search reduces CO_2 emissions and improve the medical center's electrical energy performance. In the case of passive systems, the literature reports various strategies to improve the energy efficiency of buildings under hot or tropical climate conditions [30]. In this work, we opted for assess thermal insulation panels, reflective coating, and green roofs because they are readily available materials in the region, require few or no structural modifications, and thermally have demonstrated advantages of use at high temperatures.

Thermal insulation using construction material was evaluated considering the expanded polystyrene (EPS) panel, a light, rigid, and formable thermoplastic. These panels are installed on the roof using plugs or adhesives and are protected with a fiberglass mesh covered with plaster. Although the labor of this material is not expensive, the price of the panels and masonry work considerably increases the initial investment cost [31]. In the case of reflective coatings, these are special paint (usually white) designed to be applied on the envelope and increase the reflectance of the roof and walls. This represents the most direct way to reduce incident solar energy and is considered the most straightforward passive measure because most of these coatings can be installed the same way as regular paint, which implies reduced implementation and labor costs [32]. In the case of green roofs, the structure consists in vegetation, soil layer, filter and drain membrane, root barrier and waterproof layer (Figure 6) The vegetation type affects the leaf area index (LAI), leaf reflectivity, leaf emissivity, and stomatal resistance [33,34]. For this study, the green roof analyzed is one of the most applied in Mexico, considering a LAI of 3.75, the reflectivity of 0.25, emissivity of 0.9, and a stomatal resistance of 175 [34].

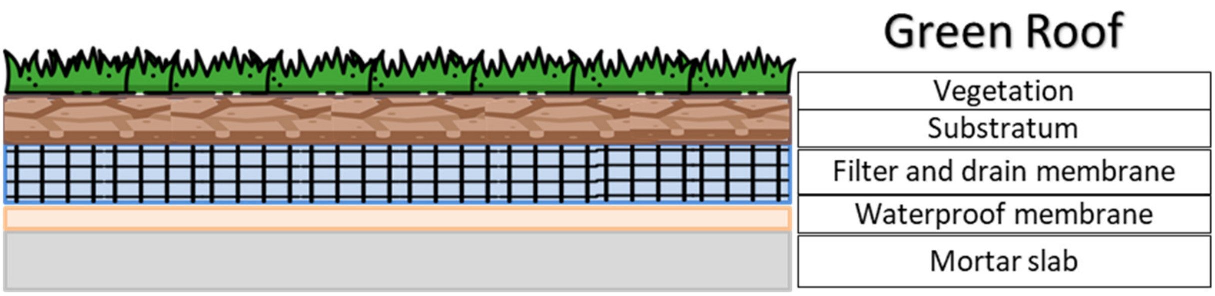

Figure 6. Typical structure of green roof layers.

Table 4 summarizes the optical and thermophysical properties of the materials considered, as well as their market and installation prices. The three materials were assessed on the calibrated model considering their application on the roof (and the exterior walls for the cases of reflective coating). Regarding active strategies, replacing conventional air conditioning equipment (on–off technology) with inverter technology was considered an energy efficiency measure. Based on this, the improvement in energy performance and economic savings were evaluated. This strategy was combined with the passive alternatives to identify the best cost–energy choice. Table 4 also contains detailed information on the current and replacement devices and their respective technological replacement costs.

Table 4. Passive and active strategies used to improve building energy efficiency and achieve thermal restauration.

Passive Thermal Restoration Technologies								
Proposed Envelope Material	**U-Value (W/(m² K))**	**Width (m)**	**Conductivity (W/(m-K))**	**Specific Heat (J/(kg-K))**	**Reflectance (%)**	**Annual Maintenance**	**Unitary Price [a] (MXN/m²)**	**Ref.**
White reflective coating	1.278	0.025	0.40	780	90	-	160	[35]
Expanded polystyrene	1.760	0.050	0.04	1400	-	-	469	[31]
Green roof	1.161	0.200	0.30	1000	25 [b]	1200 MXN	550	[36]
Active thermal restoration technologies								
Building zone	**TOR [c]**	**A/C Power (kW)**	**Average consumption (MJ/month)**	**TOR [c]**	**A/C Power (kW)**	**Average consumption (MJ/month)**	**Electrical device cost (MXN)**	**Maintenance cost (MXN/year)**
	Current conditions			Technological replacement				
Ophthalmological office	1.0	1.22	839	1.5	1.7	774	7500.00	1400.00
Eye care	1.0	1.28	882	1.5	1.71	779	7500.00	1400.00
Patient recovery	1.0	1.24	246	1.0	1.18	155	6000.00	1400.00
Surgery room	2.0	2.52	501	2.0	2.4	315	9900.00	1400.00
Surgery office	1.0	1.22	242	1.5	1.72	226	7500.00	1400.00
Waiting room	1.0	1.22	242	1.0	1.16	152	6000.00	1400.00

[a] Including installation cost; [b] Considering a LAI of 3.75, emissivity of 0.9, and a stomatal resistance of 175; [c] TOR: Tons of refrigeration.

The passive and active technologies were assessed systematically, dividing them into lots containing the thermal restoration scenarios. Lot A comprises restoration scenarios with passive modifications to the roof (insulating material, reflective coating, and green roof) or reflective paint on the walls. Lot B includes passive changes in the roof combined with efficient air conditioning systems (inverters). Finally, in Lot C, the reflective coating on the walls is added to the active and passive modifications. Table 5 enlists the 15 thermal restoration scenarios, whereas Figure 7 depicts the layer distribution of material of the 5 essential changes in the envelope from which the scenarios are derived. In the green roof, simulation is important considerer the irrigation process [37]; however, energy plus software does not have enough information to model that process. To consider the effect of irrigation, the model contemplates a scheduled irrigation once a month with an irrigation rate of 0.3 m/h, according to similar studies [36].

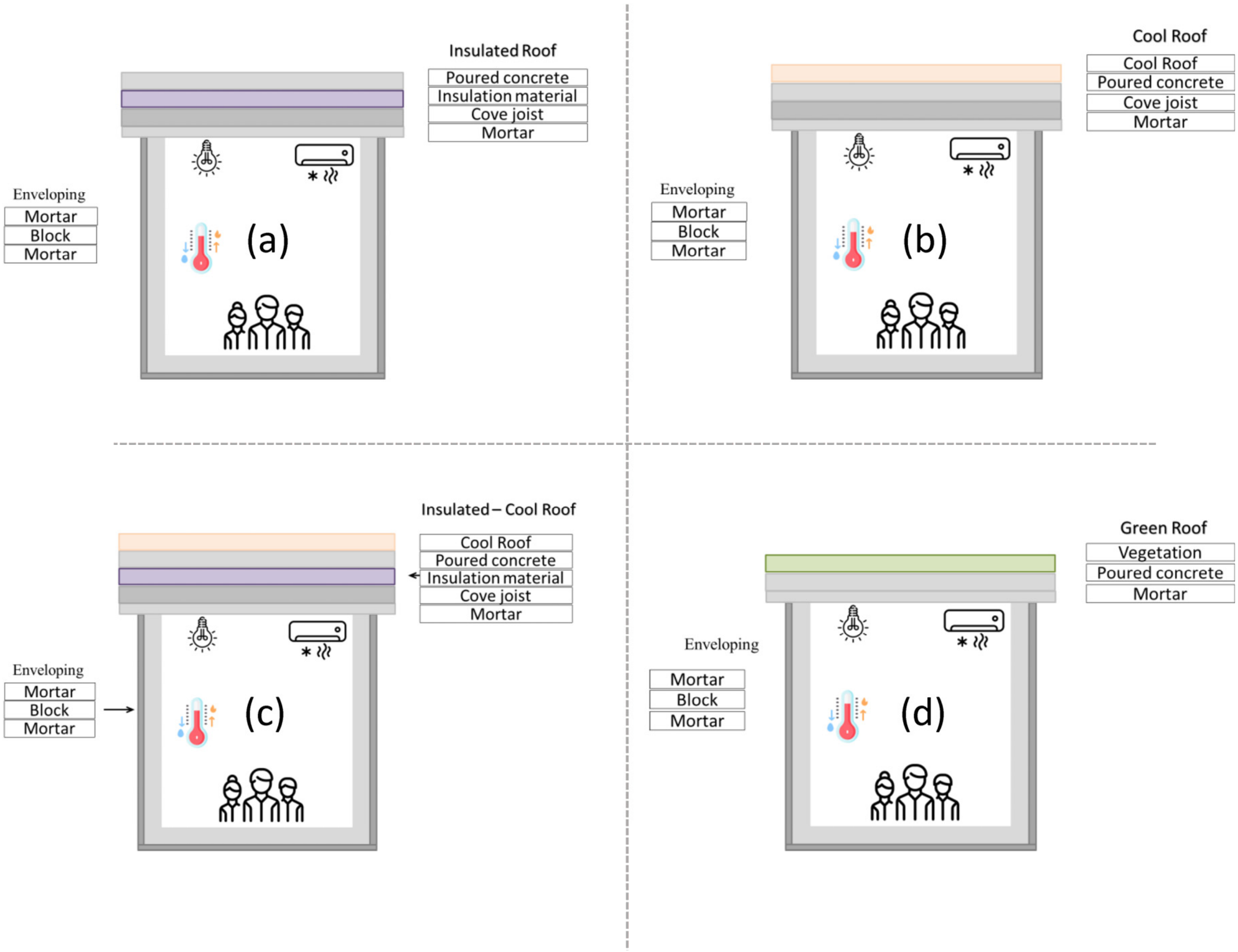

Figure 7. Description of passive modifications implemented in the envelope of the medical center: (**a**) roof with polyurethane insulation; (**b**) roof with reflective coating (This is the same material implemented in the case of the walls); (**c**) roof with polyurethane insulation and reflective coationg; (**d**) green roof.

Table 5. List of passive and active strategies to reduce energy consumption in the outpatient medical center.

Lot	Scenarios	Passive Systems		Active System
		Roof	Walls	
A	A-I	polyurethane insulation	None	Conventional air conditioner
	A-II	reflective coating	None	Conventional air conditioner
	A-III	polyurethane insulation/reflective coating	None	Conventional air conditioner
	A-IV	green roof	None	Conventional air conditioner
	A-V	None	Reflective coating	Conventional air conditioner
B	B-I	None	None	Inverter air conditioner
	B-II	polyurethane insulation	None	Inverter air conditioner
	B-III	reflective coating	None	Inverter air conditioner
	B-IV	polyurethane insulation/reflective coating	None	Inverter air conditioner
	B-V	green roof	None	Inverter air conditioner
	B-VI	None	Reflective coating	Inverter air conditioner
C	C-I	polyurethane insulation	Reflective coating	Inverter air conditioner
	C-II	reflective coating	Reflective coating	Inverter air conditioner
	C-III	polyurethane insulation/reflective coating	Reflective coating	Inverter air conditioner
	C-IV	green roof	Reflective coating	Inverter air conditioner

3.4. Energy, Environmental, and Economic Performance Indices

The improvement in building energy performance was evaluated based on energy baseline in conjunction with the key performance indicators for energy (KPI) determined by the ISO 50001:2018 standard [38], which is given as:

$$KPI = \frac{\sum_{i=1}^{a} E_{m,i}}{\sum_{i=1}^{a} E_{s,i}} \quad (3)$$

where E_m represents the actual energy consumption measured in the medical center (corresponding to the baseline) and E_s the results of electrical energy consumption estimated from the computer simulation. The comparison period is usually conducted over a month with daily or hourly "a" values. If the KPI < 1, it means that in said month, technologies implementations improve energy performance regarding the energy baseline. On the other hand, values above unity indicate that the implemented strategies are counterproductive.

Regarding the reduction in environmental impact, the carbon equivalent emissions index (CEI) was used [39]. For this work, this was defined as the monthly polluting agents emitted to the atmosphere (translated into kilograms of CO_2) derived from electrical consumption to satisfy the medical center's operational and thermal comfort needs:

$$CEI = \sum_{i=1}^{a} E_{x,i} EF \quad (4)$$

where subscript x represents the building electrical energy consumption either for the baseline (E_m) or for the energy improvement simulations (E_s). In the same way, EF is defined as the emission factor of the electric power supplied by the Mexican federal government. The emission factor (EF) value used in this study is reported in Table 6, with information obtained from the Mexican Energy Regulatory Commission (CRE).

Table 6. Costs, energy, and environmental assumptions for performance indices of the medical center.

Parameter	Value	Unit	Reference
Electricity price	1.07	MXN /MJ	[40]
Emission factor	0.012	kg CO_2/MJ	[41]
Electricity inflation rate	4.0	%	[42]
Annual discount rate	1.0–20.0	%	[43]
Maintenance annual increase rate	6.0	%	[42]
Life cycle	15	years	[31]

Finally, the cost-effectiveness of energy efficiency strategies adopted was evaluated by quantifying the economic indicators: net saving (NS). It estimates the economic benefit considering the evolution of savings and costs over time. According to Hernández-Pérez et al. [35], NS is given by:

$$NS = -I_O + \sum_{t=1}^{N} \frac{S_t(1+e_s)^t}{(1+d)^t} - \sum_{t=1}^{N} \frac{C_t(1+e_c)^t}{(1+d)^t} \quad (5)$$

where I_O is the initial investment, S_t is the saving difference in the year t, C_t is the cost difference in the year t, N is the number of years in the life cycle, d represents the discount rate, and e_s and e_c are the annual inflation rate for saving and cost, respectively. Positive values of NS indicate a most cost-effective strategy, while negative values economically favor the energy baseline. Table 6 summarizes the information on electrical and economic parameters required for the implementation of both indicators, while investment cost is described in the passive and active technologies presented in Table 4.

3.5. Selection of Best Alternative Based on Decision-Making Algorithm

A numerical tool for decision making was implemented to identify the trade-off that ensures the best overall performance of the environmental, energy, and economic aspects. For this purpose, the Technique for Order of Preference by Similarity to Ideal Solution algorithm, known as TOPSIS, was used. It works by choosing the best alternative based on the shortest and furthest Euclidean distances from the positive (v_j^+) and negative (v_j^-) ideal solutions, respectively. The ideal solution is represented by the maximum value of the proximity coefficient (CC) [44].

$$\max[CC_j] = \frac{\sqrt{\sum_{j=1}^{k}\left(v_{ij} - v_j^+\right)^2}}{\sqrt{\sum_{j=1}^{k}\left(v_{ij} - v_j^+\right)^2} - \sqrt{\sum_{j=1}^{k}\left(v_{ij} - v_j^-\right)^2}} \quad (6)$$

For this purpose, the TOPSIS algorithm requires identifying whether the variables will be improved by increasing (+) or reducing (−); also, the degree of priority of the variable needs to be indicated, where the sum of these must equal 100%. In this work, the KPI, CEI, and NS indicators were considered as the variables to be analyzed, forming a 15 × 3 decision matrix. It was instructed that the best results aim to reduce the KPI and CEI and increase the NS. The evaluation was carried out by varying the priority percentage of each variable from 80 to 50% in steps of 10%. The calculations were implemented in the Python programming environment through the PyTOPS tool [45].

4. Results

4.1. Improving the Energy Performance of the Outpatient Medical Center

Once it was verified that the model satisfactorily estimates the building's electrical demand and computed the desirable indices, the passive and active substitution scenarios were analyzed in three lots: Lot A, corresponding to cases where there are exclusively passive modifications to the roof or wall; Lot B, where passive modifications to the roof are combined with efficient air conditioning systems (inverters); and Lot C, where, in addition to the active and passive modifications, a reflective coating is added onto walls. Figure 8 illustrates the KPI results both monthly and annually for the three analyzed lots linked to electricity consumption.

For the scenarios with modifications exclusively on the roof or wall (Figure 8a), only applied passive technologies are feasible to reduce the medical center energy consumption between 5% and 11% for the hottest months (April–September). Green roof was detected as the least effective (annual KPI of 96.3%), followed by polyurethane insulation (annual KPI of 94.3%). In the case of selective coating on the façade, during the hottest months, its contribution is almost zero; however, it demonstrates exemplary performance in energy saving for winter days. Furthermore, the annual advantages in energy savings are not negligible, decreasing by around 9% annually. For its part, the analysis of the annual KPI indicates that reflective coating on the roof (Case A-II) and its combination with expanded polyurethane (Case A-III) are the ones that have the most significant benefit for the building, reducing electrical demand by 10.09% and 10.19%, respectively. It is important to highlight that the contribution of including the expanded polyurethane layer can represent a higher cost when modifying the envelope with an almost zero energy benefit of 0.1% annually and barely 1% for the hot month of the year. It is also important to emphasize that although the lower consumption in the warmer months is obtained in Case A-III, the monthly curve of Case A-II is more constant throughout the year, obtaining even better energy benefits for the winter season (November to February).

The scenarios in Lot B demonstrate the benefits of combining passive and active technologies. According to Figure 8b, the effect of passive technologies in the envelope is better appreciated when introducing inverter air conditioning systems. In summary, it is possible to reduce the electrical consumption of the outpatient medical center for the hottest months from 22% (Case B-I) to 31% (Case B-IV). Excluding Case B-I, which proposes using an inverter system without modifications to the envelope, again, selective coating on the walls (Case B-VI) and green roofs (Case B-V) have the least favorable results. At the same time, the reflective coating on the roof and its combination with insulating material were again the best thermal options, obtaining practically the same performances (KPI of 72.2% and 72.05%, respectively). The expanded polyurethane on the roof is benefits from using inverter technology, differing only 3.5% from the best Case. Finally, the results of Lot C (Figure 7c) show that the integration of selective coating on the walls improves the energy performance of the medical center by 2.45% concerning theirs homologous of the Lot B. The above implies that a white reflective coating provides the greatest thermo-energetic advantage to the envelope.

4.2. Environmental Pollution Mitigation Analysis

For its part, Figure 9 shows how the use of passive and active technologies reduces CO_2 equivalent emissions. The monthly results of Lot A are exhibited in Figure 9a. In the case of commercial thermal insulator (Case A-I polyurethane foam) or green roof (Case A-IV), both options are characterized by being mainly thermal barriers that increase resistance to heat flow from radiation. Therefore, their mitigation capacity depends on thickness, which is reflected in the figure where they express an intermediate mitigation level concerning the other cases of thermal restoration. The combinations with reflective paint on the roof (Case A-II and a-III) present the best performance in reducing emissions, with almost identical mitigation potential. In quantitative terms, implementing technologies based on the reflection of solar radiation incidents on the roof can represent mitigations above half a ton of CO_2 equivalent annually, between 719 kg and 725 kg, compared to the baseline.

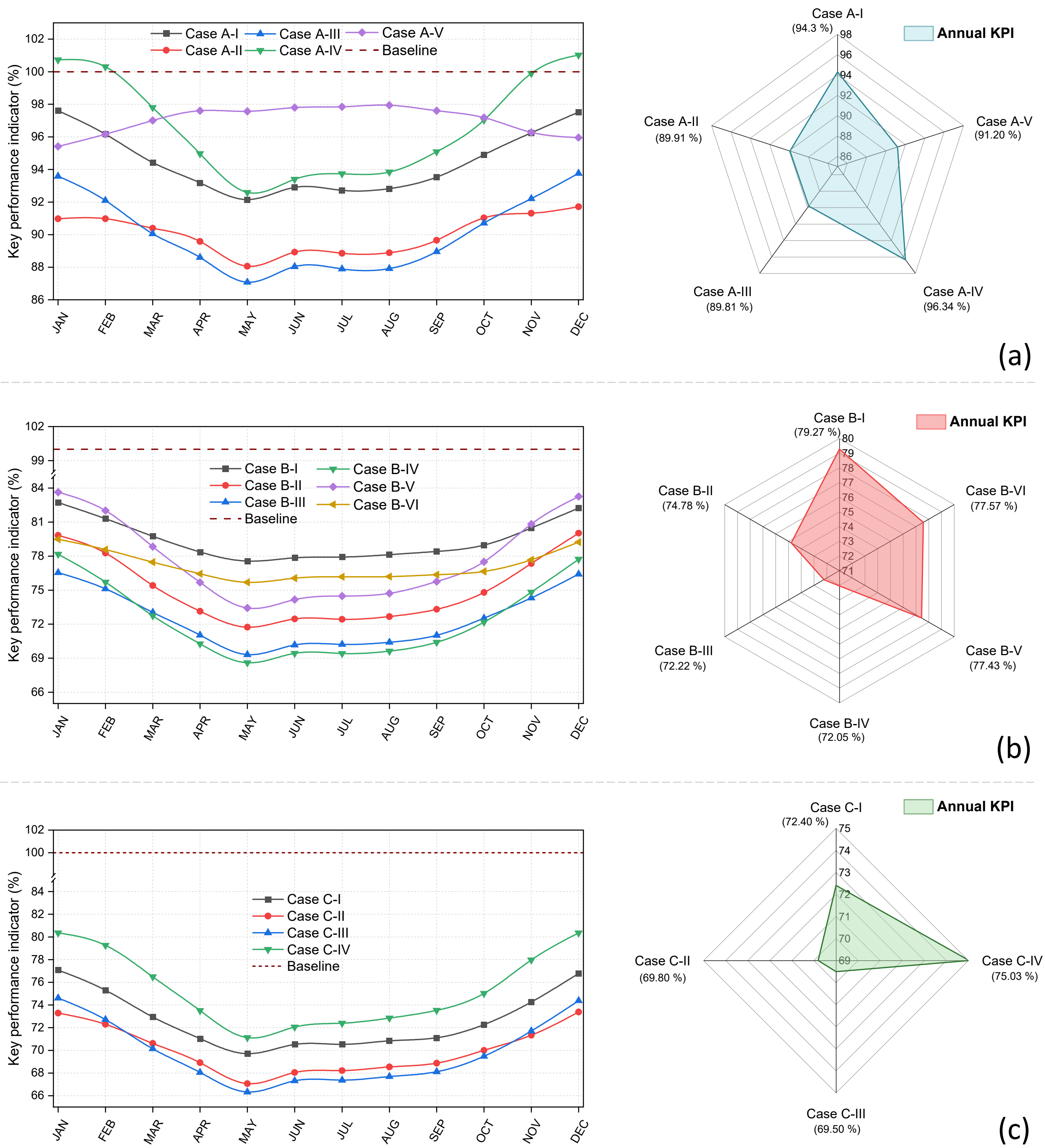

Figure 8. Monthly and annual electricity key performance index for the scenarios: (**a**) Lot A: exclusively passive modifications on the envelope; (**b**) Lot B: envelope modification combined with inverter air conditioning systems; (**c**) Lot C: active and passive modifications combined with a reflective coating on the façade.

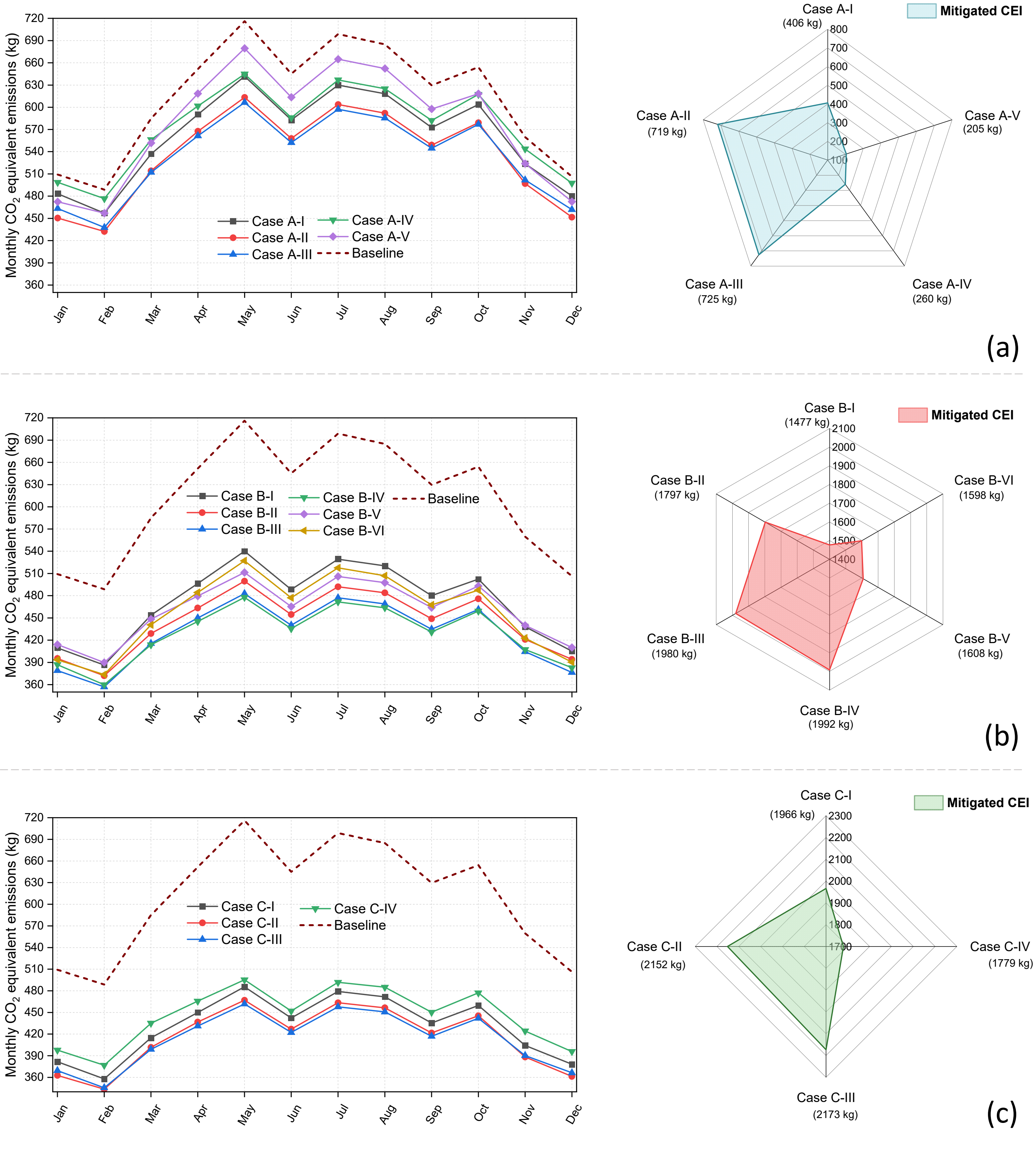

Figure 9. Monthly and annual equivalent CO_2 emission index for the scenarios: (**a**) Lot A: exclusively passive modifications on the envelope; (**b**) Lot B: envelope modification combined with inverter air conditioning systems; (**c**) Lot C: active and passive modifications combined with a reflective coating on the façade.

Regarding Lot B (Figure 9b), implementing the inverter air conditioning dramatically reduces the CEI. In the worst scenario (Case B-I), only inverter technology can mitigate nearly a ton and a half of CO_2. Under this same analysis, the integration of reflective paint on the façade or the green roof barely improves the effect achieved by the simple replacement of the active system, where although improvements in the reduction of the CEI are always desirable, it may not be economically justified to invest. For its part, by using the reflective coating on the roof with and without thermal insulation (Case B-III and B-IV, respectively), the mitigation potential can be improved by up to 26%, reaching close to two tons of reduction in CO_2 equivalent per year. This implies the impact that selective coating has on buildings in the study area. Finally, the results of Lot C (Figure 9c) show that integrating the façade with selective coating would barely reduce between 169 and 180 kg of CO_2 equivalent per year compared to its simile, presented in Figure 9b, which would not represent an attractive option from an investment perspective.

4.3. Building Net Saving Analysis

Figure 10 analyzes the economic feasibility of the scenarios. The analysis considered a discount rate range from 1% to 19% to observe the minimum rate at which it is not considered profitable to make the investment. For the case where modifications are made exclusively to the envelope of the medical center (Figure 10a), it appears that the use of reflective paint is the most attractive option. The best results are obtained with this material used on the roof (Case A-I), façade (Case A-V), and combined on the roof with thermal insulation (Case A-III), in that order. For its part, the use of the green roof proposal did not show the feasibility of implementation. The above can be explained by the reflective coating being the cheapest material of the three technologies evaluated. In addition, the Campeche area has high solar radiation, so reflecting about 90% of direct radiation contributes significantly to energy savings. It is important also to analyze the discount rate results. Given that discount values below inflation (6%) do not represent a real benefit from the investment approach, the moderate viability region was proposed, enclosed in the yellow rectangle, which is between 6 and 7%. According to the image, the use of polyurethane insulation and its simile combined with the reflective coating are not only below Cases A-II and A-V, but it is also seen that they are susceptible to falling within the zone of infeasibility upon reaching the region of moderate viability. Therefore, it may not represent an attractive investment option.

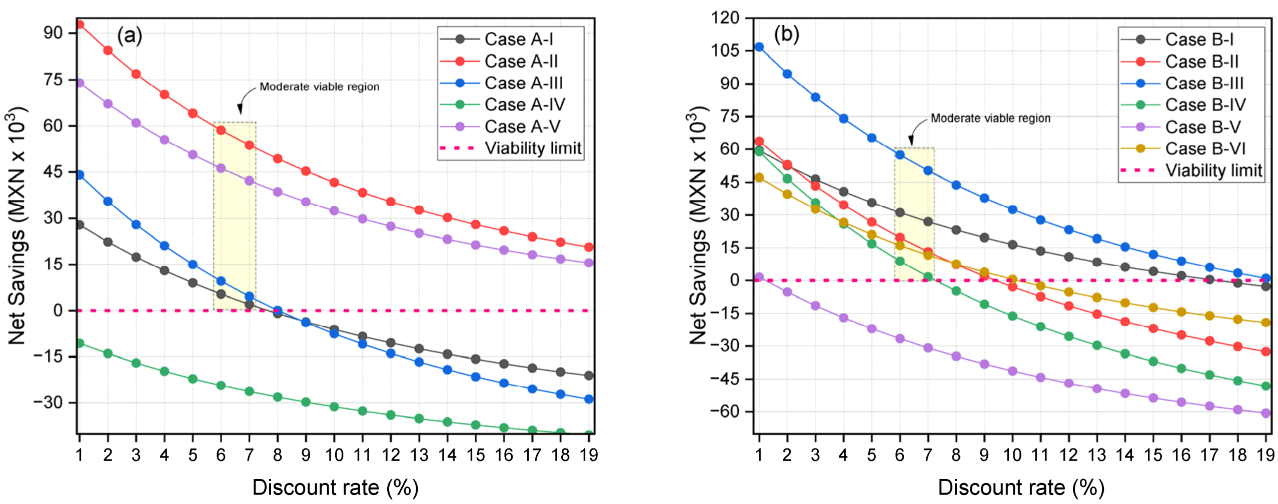

Figure 10. *Cont.*

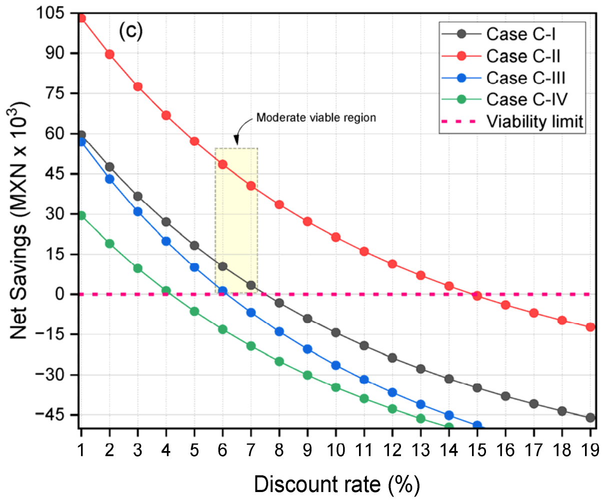

Figure 10. Net savings benefits respect discount rate for the scenarios: (**a**) Lot A: exclusively passive modifications on the envelope; (**b**) Lot B: envelope modification combined with inverter air conditioning systems; (**c**) Lot C: active and passive modifications combined with a reflective coating on the façade.

For its part, integrating technological substitution with inverter equipment and passive strategies (Figure 10b) increases the range of total net savings and the profitable alternatives for energy savings. Five of the six cases that make up Lot B may be in the moderate viability region. Of these, it is interesting that Case B-III, corresponding to the reflective coating on the roof linked to the inverter system, provides better economic performance than the simple integration of the new HVAC system alone (Case B-I). Despite case B-III, the above is a more significant initial investment by the medical center's administration. This demonstrates the economic benefits of using the correct passive system for the envelope. Finally, for Lot C, although there are certain benefits from the energy and environmental perspective, its integration entails a higher cost that is not solved in the long term, as seen in Figure 10c.

4.4. Implementation of TOPSIS Algorithm

Table 7 presents the results of decision making using TOPSIS. According to the results, giving up to 60% priority to the economic aspect over the environmental and energy factors means that the integration of reflective coating (especially on the roof) and inverter air conditioning represents the most attractive option. As mentioned previously, this is a product of the shrinking of the material implemented in the envelope. When the energy aspect is almost on par with economic interests, the reflective coating on the roof and wall, and inverter air conditioner (Case C-II) become more critical. For its part, all the priority percentage options converge in Case C-II for both the environmental and energy aspects. The above means in terms of compensation, the joint integration of reflective paint on the walls and ceilings together with air conditioning would represent a better environmental and energy option; it may even be a viable option as long as the medical center administrators reduce the emphasis on economic interests a little. However, in practice, the above is not very viable, as suggested by [36], promoting interest in strategies with greater impact on the thermal efficiency of the envelope that can only be developed through incentives such as carbon credits, which would help to present interest in aspects such as CEI.

Table 7. Results of integrating the TOPSIS method to identify the trade-off of the environmental, energy and economic indices.

Priority Percentage			Best Active/Passive Technological Strategy
KPI	CEI	NS	
10	10	80	Reflective coating on roof with inverter air conditioner (Case B-III)
20	10	70	Reflective coating on roof with inverter air conditioner (Case B-III)
30	10	60	Reflective coating on roof with inverter air conditioner (Case B-III)
40	10	50	Reflective coating on roof and walls with inverter air conditioner (Case C-II)
80	10	10	Reflective coating on roof and walls with inverter air conditioner (Case C-II)
70	10	20	Reflective coating on roof and walls with inverter air conditioner (Case C-II)
60	10	30	Reflective coating on roof and walls with inverter air conditioner (Case C-II)
50	10	40	Reflective coating on roof and walls with inverter air conditioner (Case C-II)
10	80	10	Reflective coating on roof and walls with inverter air conditioner (Case C-II)
10	70	20	Reflective coating on roof and walls with inverter air conditioner (Case C-II)
10	60	30	Reflective coating on roof and walls with inverter air conditioner (Case C-II)
10	50	40	Reflective coating on roof and walls with inverter air conditioner (Case C-II)

5. Discussion

As the results show, the implementation of passive systems, with a particular focus on roofing solutions, emerges as an effective strategy for enhancing the thermo-energetic performance of a building. Passive systems harness natural elements like sunlight, ventilation, and insulation to reduce the building's energy consumption. However, it is essential to acknowledge that their success is subject to a multitude of considerations. Thus, while passive systems offer great potential for energy efficiency, careful planning and the consideration of various factors are imperative for optimizing their performance in a specific context. As results show, these characteristics are predominantly evident in green roofs and polyurethane insulation performance, making them the least effective in reducing energy consumption for air conditioning. The green roof is an innovative solution with benefits; however, the high temperature and humidity that characterize Campeche affect the type of vegetation that needs to be considered, the depth of sub-stratum, and the inheriting maintenance cost. For that reason, it is essential to study aspects of inheritance vegetation that could survive extreme temperatures and humidity without requiring periodic maintenance, decreasing the cost of the system. The government has allocated multiple resources and policies in the case of polyurethane to increase their implementation as a passive measure. This is based on the hypothesis that the reduction of the global heat transfer coefficient contributes to reducing the thermo-energetic behavior of the building and is not supported by quantified data on the impact of climatic conditions on the thermophysical properties of the material. Principally, the humidity of the region is critical to consider in the application of this material because it affects the insulation effectiveness, creates a conducive environment for mold and mildew growth, and degrades the material, affecting its durability.

6. Conclusions

An analysis of the thermal restoration of an outpatient medical center in a tropical region like the City of San Francisco de Campeche was presented to reduce its energy consumption. An energy audit of the building was carried out, collecting data for one year to design and validate a numerical simulation model and verify improvement strategies. Among the improvement options analyzed are passive modifications to the roof (insulating material, reflective coating, and green roof), alterations to active systems integrating inverter technology, and changes to the walls using reflective paint. The results of the simulated improvement scenarios were analyzed using energy, environmental, and economic indicators, which were subsequently contrasted with TOPSIS decision-making algorithms to identify the alternative that best compensates the three options.

Energetically, the results showed that adding passive technologies increases energy efficiency by 11%. Under this scenario, the most significant energy savings are modifying the roof, compared to placing reflective materials on the walls. However, combining both strategies improves the building performance mainly in the winter season. Integrating inverter technology in air conditioning equipment and roof coatings improved energy performance, with inverter-reflective coating technique being the most attractive, with 28% savings. This saving results in the mitigation of around two tons of CO_2 per year from an environmental perspective. The economic results indicate that all the options that integrate reflective paint generate the best net savings. The above is derived from the affordable value of this passive technology. However, many options that have energy and environmental benefits do not achieve economic rewards. The above is an indication of the need to implement strategies that promote better use of energy with an environmental perspective through carbon credits as in other countries, which Mexico currently does not have.

Finally, the TOPSIS approach indicates that integrating reflective paint on the roof and walls with inverter air conditioner would represent the most attractive option in most cases. However, by prioritizing the economic aspect, it remains in the background.

Based on these results, the following conclusions are drawn:

- Due to the climatic conditions of high temperature and humidity, the green roof and polyurethane insulation present the lowest energy savings.
- Green roofs present multiple advantages from the environmental perspective; however, the installation cost, maintenance, irrigation, and the region directly affect their performance.
- Implementing inverter technologies in air conditioning significantly improves the energy consumption in buildings, specifically in medical centers where a stable temperature is necessary.
- Although there is a national policy regarding target temperatures in medical spaces, a range is not established according to the region's conditions, which is why it is imperative to promote a policy that results in better energy consumption practices.

The study results make it straightforward for a coastal city in a tropical climate such as San Francisco de Campeche; the reflective paint on the roof is the best option, not only from an economic perspective. However, it is better than energy-saving strategies currently being implemented at the national level, such as using expanded polystyrene for roofing buildings, where service benefits are both energetic, economic, and environmental. The study results are the first approach to analyzing structures under actual operating conditions in coastal cities with a tropical climate and allow us to provide an overview of where to promote specific technologies and regulations of regional passive strategies for energy saving in the region.

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References

1. Li, C.; Gao, X.; Wu, J.; Wu, K. Demand prediction and regulation zoning of urban-industrial land: Evidence from Beijing-Tianjin-Hebei Urban Agglomeration, China. *Environ. Monit. Assess.* **2019**, *191*, 412. [CrossRef] [PubMed]
2. Shi, Y.; Yan, Z.; Li, C.; Li, C. Energy consumption and building layouts of public hospital buildings: A survey of 30 buildings in the cold region of China. *Sustain. Cities Soc.* **2021**, *74*, 103247. [CrossRef]
3. Sadeghian, O.; Moradzadeh, A.; Mohammadi-Ivatloo, B.; Abapour, M.; Anvari-Moghaddam, A.; Lim, J.S.; Marquez, F.P.G. A comprehensive review on energy saving options and saving potential in low voltage electricity distribution networks: Building and public lighting. *Sustain. Cities Soc.* **2021**, *72*, 103064. [CrossRef]
4. Cho, K.; Yang, J.; Kim, T.; Jang, W. Influence of building characteristics and renovation techniques on the energy-saving performances of EU smart city projects. *Energy Build.* **2021**, *252*, 111477. [CrossRef]
5. Global Alliance for Buildings and Constructuion, International Energy Agency, United Nations Environment Programme, 2019 Global Status Report for Buildings and Construction: Towards a Zero-Emissions, Efficient and Resilient Buildings and Construction Sector, Paris. 2019. Available online: https://www.iea.org/reports/global-status-report-for-buildings-and-construction-2019 (accessed on 12 October 2023).
6. Milojevic-Dupont, N.; Creutzig, F. Machine learning for geographically differentiated climate change mitigation in urban areas. *Sustain. Cities Soc.* **2021**, *64*, 102526. [CrossRef]
7. Rosas-Flores, J.A.; Rosas-Flores, D. Potential energy savings and mitigation of emissions by insulation for residential buildings in Mexico. *Energy Build.* **2019**, *209*, 109698. [CrossRef]
8. Lee, S.-J.; Song, S.-Y. Energy efficiency, visual comfort, and thermal comfort of suspended particle device smart windows in a residential building: A full-scale experimental study. *Energy Build.* **2023**, *298*, 113514. [CrossRef]
9. Zhang, Y.; Zhang, Y.; Zhang, C. Effect of physical, environmental, and social factors on prediction of building energy consumption for public buildings based on real-world big data. *Energy* **2022**, *261*, 125286. [CrossRef]
10. Guo, Y.; Uhde, H.; Wen, W. Uncertainty of energy consumption and CO_2 emissions in the building sector in China. *Sustain. Cities Soc.* **2023**, *97*, 104728. [CrossRef]
11. Sun, Y.; Kojima, S.; Nakaohkubo, K.; Zhao, J.; Ni, S. Analysis and Evaluation of Indoor Environment, Occupant Satisfaction, and Energy Consumption in General Hospital in China. *Buildings* **2023**, *13*, 1675. [CrossRef]
12. Rahman, N.M.A.; Lim, C.H.; Fazlizan, A. Optimizing the energy saving potential of public hospital through a systematic approach for green building certification in Malaysia. *J. Build. Eng.* **2021**, *43*, 103088. [CrossRef]
13. Gamero-Salinas, J.; Monge-Barrio, A.; Kishnani, N.; López-Fidalgo, J.; Sánchez-Ostiz, A. Passive cooling design strategies as adaptation measures for lowering the indoor overheating risk in tropical climates. *Energy Build.* **2021**, *252*, 111417. [CrossRef]
14. Lorentzen, D.M.C.; McNeil, M.A. Electricity demand of non-residential buildings in Mexico. *Sustain. Cities Soc.* **2020**, *59*, 102165. [CrossRef]
15. Xu, T.; Zhang, Y.; Shi, L.; Feng, Y.; Ke, X.; Zhang, C. A comprehensive evaluation framework of energy and resources consumption of public buildings: Case study, People's Bank of China. *Appl. Energy* **2023**, *351*, 121869. [CrossRef]
16. Seo, R.-S.; Jung, G.-J.; Rhee, K.-N. Impact of green retrofits on heating energy consumption of apartment buildings based on nationwide energy database in South Korea. *Energy Build.* **2023**, *292*, 113142. [CrossRef]
17. As, M.; Bilir, T. Enhancing energy efficiency and cost-effectiveness while reducing CO_2 emissions in a hospital building. *J. Build. Eng.* **2023**, *78*, 107792. [CrossRef]
18. García-Sanz-Calcedo, J.; Al-Kassir, A.; Yusaf, T. Economic and Environmental Impact of Energy Saving in Healthcare Buildings. *Appl. Sci.* **2018**, *8*, 440. [CrossRef]
19. De Masi, R.F.; Del Regno, N.; Gigante, A.; Ruggiero, S.; Russo, A.; Tariello, F.; Vanoli, G.P. The Importance of Investing in the Energy Refurbishment of Hospitals: Results of a Case Study in a Mediterranean Climate. *Sustainability* **2023**, *15*, 11450. [CrossRef]
20. Liu, A.; Ma, Y.; Miller, W.; Xia, B.; Zedan, S.; Bonney, B. Energy Analysis and Forecast of a Major Modern Hospital. *Buildings* **2022**, *12*, 1116. [CrossRef]
21. Instituto Nacional de Estadistica y Geografía, Aspectos Geográficos: Campeche 2021,Publisher by INEGI, Aguascalientes. 2022. Available online: https://www.inegi.org.mx/contenidos/app/areasgeograficas/resumen/resumen_04.pdf (accessed on 12 October 2023).
22. May-Tzuc, O.; Jiménez-Torres, M.A.; Cruz y Cruz, A.; Canul-Turriza, R.; Andrade-Durán, J.E.; Noh-Pat, F. Feasibility of the adaptive thermal comfort model under warm sub- humid climate conditions: Cooling energy savings in Campeche, Mexico. *Rev. Hábitat Sustentable* **2023**, *13*, 120–131. [CrossRef]

23. Villar-Ramos, M.M.; Hernández-Pérez, I.; Aguilar-Castro, K.M.; Zavala-Guillén, I.; Macias-Melo, E.V.; Hernández-López, I.; Serrano-Arellano, J. A Review of Thermally Activated Building Systems (TABS) as an Alternative for Improving the Indoor Environment of Buildings. *Energies* **2022**, *15*, 6179. [CrossRef]
24. Sukarno, R.; Putra, N.; Hakim, I.I.; Rachman, F.F.; Mahlia, T.M.I. Utilizing heat pipe heat exchanger to reduce the energy consumption of airborne infection isolation hospital room HVAC system. *J. Build. Eng.* **2021**, *35*, 102116. [CrossRef]
25. DesignBuilder Software LTd., DesignBuilder. 2022. Available online: https://designbuilder.co.uk/ (accessed on 15 February 2023).
26. Schurk, D. Conditioning for the environment of critical care hospital operating rooms. *ASHRAE J.* **2019**, *61*, 16. Available online: https://www.ashrae.org/technical-resources/ashrae-journal (accessed on 12 October 2023).
27. Remund, J.; Müller, S.; Schmutz, M.; Barsotti, D.; Graf, P.; Cattin, R. Meteonorm 8.1 Manual (Software). 2022, Volume 63. Available online: https://meteonorm.com/assets/downloads/mn81_software.pdf (accessed on 12 October 2023).
28. Corrado, V.; Fabrizio, E. Steady-State and Dynamic Codes, Critical Review, Advantages and Disadvantages, Accuracy, and Reliability. In *Handbook of Energy Efficiency in Buildings*; Asdrubali, F., Desideri, U., Eds.; Elsevier: Amsterdam, The Netherlands, 2019; pp. 263–294. [CrossRef]
29. Torres, M.J.; Bienvenido-Huertas, D.; Tzuc, O.M.; Bassam, A.; Castellanos, L.J.R.; Flota-Bañuelos, M. Assessment of climate change's impact on energy demand in Mexican buildings: Projection in single-family houses based on Representative Concentration Pathways. *Energy Sustain. Dev.* **2023**, *72*, 185–201. [CrossRef]
30. Hu, M.; Zhang, K.; Nguyen, Q.; Tasdizen, T. The effects of passive design on indoor thermal comfort and energy savings for residential buildings in hot climates: A systematic review. *Urban Clim.* **2023**, *49*, 101466. [CrossRef]
31. CONUEE, Catálogo de Tecnologías. Tecnologías Energeticamente Eficientes Para la Envolvente Térmica de las Edificaciones, Mexico City, Mexico. 2017. Available online: https://www.conuee.gob.mx/transparencia/nuevaestrategia/index.html (accessed on 12 October 2023).
32. Hernández-Pérez, I. Influence of Traditional and Solar Reflective Coatings on the Heat Transfer of Building Roofs in Mexico. *Appl. Sci.* **2021**, *11*, 3263. [CrossRef]
33. Mihalakakou, G.; Souliotis, M.; Papadaki, M.; Menounou, P.; Dimopoulos, P.; Kolokotsa, D.; Paravantis, J.A.; Tsangrassoulis, A.; Panaras, G.; Giannakopoulos, E.; et al. Green roofs as a nature-based solution for improving urban sustainability: Progress and perspectives. *Renew. Sustain. Energy Rev.* **2023**, *180*, 113306. [CrossRef]
34. Mousavi, S.; Gheibi, M.; Wacławek, S.; Behzadian, K. A novel smart framework for optimal design of green roofs in buildings conforming with energy conservation and thermal comfort. *Energy Build.* **2023**, *291*, 113111. [CrossRef]
35. Hernández-Pérez, I.; Xamán, J.; Macías-Melo, E.; Aguilar-Castro, K.; Zavala-Guillén, I.; Hernández-López, I.; Simá, E. Experimental thermal evaluation of building roofs with conventional and reflective coatings. *Energy Build.* **2018**, *158*, 569–579. [CrossRef]
36. De la Cruz-Uribe, A.; Jesús-Castañeda, M.; Bolívar-Fuentes, R.C.; Laines-Canepa, J.R.; Hernández-Barajas, J.R. Análisis beneficio-costo de techos verdes extensivos en condiciones del trópico húmedo en Villahermosa, México. *Ecosistemas Y Recur. Agropecu.* **2023**, *10*, 3586. [CrossRef]
37. Saraeian, Z.; Farrell, C.; Williams, N.S. Green roofs sown with an annual plant mix attain high cover and functional diversity regardless of irrigation frequency. *Urban For. Urban Green.* **2022**, *73*, 127594. [CrossRef]
38. Poveda-Orjuela, P.P.; García-Díaz, J.C.; Pulido-Rojano, A.; Cañón-Zabala, G. ISO 50001: 2018 and Its Application in a Comprehensive Management System with an Energy-Performance Focus. *Energies* **2019**, *12*, 4700. [CrossRef]
39. Torres, S.G.M.; Tzuc, O.M.; Aguilar-Castro, K.M.; Téllez, M.C.; Sierra, J.O.; Cruz, A.d.R.C.-Y.; Barrera-Lao, F.J. Analysis of Energy and Environmental Indicators for Sustainable Operation of Mexican Hotels in Tropical Climate Aided by Artificial Intelligence. *Buildings* **2022**, *12*, 1155. [CrossRef]
40. Comision Federal de Electricidad, Clasificacion Tarifaria. 2023. Available online: https://app.cfe.mx/aplicaciones/ccfe/tarifas/tarifascrenegocio/tarifas/pequenademandabt.aspx (accessed on 19 September 2023).
41. Secretaría de Medio Ambiente y Recursos Naturales, Factores de Emisión del Sistema Eléctrico Nacional 2021, Ciudad de México. 2022. Available online: https://www.gob.mx/cms/uploads/attachment/file/706809/aviso_fesen_2021.pdf (accessed on 12 October 2023).
42. OECD, Inflation (CPI), OECD Data. 2023. Available online: https://data.oecd.org/price/inflation-cpi.htm (accessed on 26 July 2023).
43. Tzuc, O.M.; Bassam, A.; Anguebes-Franseschi, F.; Ricalde, L.J.; Flota-Bañuelos, M.; Téllez, M.C. Multivariate optimization applied for the economic competitiveness analysis of photothermal systems into industrial heat production: An approach based on artificial intelligence. *J. Renew. Sustain. Energy* **2020**, *12*, 055501. [CrossRef]
44. Tariq, R.; Sohani, A.; Xamán, J.; Sayyaadi, H.; Bassam, A.; Tzuc, O.M. Multi-objective optimization for the best possible thermal, electrical and overall energy performance of a novel perforated-type regenerative evaporative humidifier. *Energy Convers. Manag.* **2019**, *198*, 111802. [CrossRef]
45. Yadav, V.; Karmakar, S.; Kalbar, P.P.; Dikshit, A. PyTOPS: A Python based tool for TOPSIS. *SoftwareX* **2019**, *9*, 217–222. [CrossRef]

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