energies

MDPI

Article

Integrated Energy and Social Retrofit Strategies for Lima's Central Market: Balancing Cost and Sustainability

Patricia Aguilera-Benito [1,*] and Karla Soto-Florez [2]

[1] Departamento de Tecnología de la Edificación, Universidad Politécnica de Madrid, 28040 Madrid, Spain
[2] Facultad de Arquitectura, Universidad Peruana de Ciencias Aplicadas, Santiago de Surco 15023, Peru
* Correspondence: patricia.aguilera@upm.es

Abstract

There is an urgent need to implement sustainable solutions in the construction sector, particularly within the Peruvian context, where regulations on energy efficiency and building rehabilitation are still under development. This study addresses the energy and social rehabilitation of the Mercado Central in Lima, with the aim of identifying the most effective interventions from both energy and economic perspectives while promoting urban sustainability. A detailed assessment of the building's original state—covering the thermal envelope and technical systems—was conducted, followed by fifty energy simulations using Ce3X© v.2.3. software. Based on the obtained energy rating, several envelopes and system improvements were proposed and evaluated in terms of energy savings, cost-effectiveness, and social benefits. The most advantageous option, Measure M9, combines interventions in roofs, openings, and installations. It achieved a global energy rating of 17.6 A, with a projected lifespan of 75 years and an investment of EUR 1,642,457.01, recoverable in just 1.4 years. The results highlight the potential of integrated retrofitting strategies to simultaneously improve energy performance and social impact. Measure M9 emerges as the most viable solution, providing a replicable model for sustainable urban rehabilitation in Peru and other regions facing similar challenges.

Keywords: energy simulation; renovation; commercial building; economic analysis

check for updates

Academic Editor: Paulo Santos

Received: 19 July 2025
Revised: 4 September 2025
Accepted: 5 September 2025
Published: 15 September 2025

Citation: Aguilera-Benito, P.; Soto-Florez, K. Integrated Energy and Social Retrofit Strategies for Lima's Central Market: Balancing Cost and Sustainability. *Energies* **2025**, *18*, 4903. https://doi.org/10.3390/en18184903

1. Introduction

Sustainability in the construction sector has become a global priority, driven by the urgent need to reduce environmental impacts, conserve natural resources, and promote more responsible and environmentally conscious development [1]. Moreover, the adoption of sustainable practices in construction not only contributes to the protection of the environment but also improves the quality of urban life, creating healthier, more efficient, and comfortable spaces for its inhabitants.

1.1. Challenges in Implementing Sustainable Solutions in Developing Countries

Many developing nations continue to grapple with a complex mix of structural barriers that hamper the adoption of sustainable building practices. Regulatory frameworks for energy efficiency are often fragmented, inconsistently enforced, or underdeveloped. Without clear standards, performance targets, and predictable timelines, investments in efficient technologies and materials struggle to compete with lower upfront costs or quick fixes that yield limited long-term gains. Moreover, incentives such as subsidies, tax benefits, or financing mechanisms are frequently misaligned or inadequately funded, reducing the appeal of retrofitting projects that require higher initial capital.

The retrofitting of existing buildings emerges as a particularly stubborn hurdle. Many structures were designed without energy efficiency in mind, and retrofits involve technical complexities, higher upfront costs, and disruptions to occupants. Inadequate data on building stock, limited technical expertise, and constraints in access to financing further impede progress. Appliances, systems, and envelopes that could dramatically reduce energy use are often outdated or unavailable locally, slowing the pace of modernization. Additionally, the lack of robust consumer awareness and demand for energy-efficient options means that market signals do not sufficiently reward sustainable choices.

These combined challenges hinder cities from fully leveraging the benefits of sustainability. When energy efficiency improvements stagnate, cities miss significant opportunities for energy savings, lower greenhouse gas emissions, and enhanced social well-being, including improved indoor comfort and health. A coherent, well-funded strategy that aligns regulations, incentives, financing, and technical capacity is essential to unlocking the potential of sustainable, resilient buildings and to translating environmental advantages into tangible improvements for residents [2].

A clear example is Peru, a great biosphere for the planet, rich in biodiversity and natural resources, whose environmental dynamics have a global impact. However, it faces an enormous task in moving towards sustainable development and greater energy efficiency. The country has a historical legacy of great heritage value, but its buildings do not always receive the maintenance and rehabilitation they require [3]. When assessing the state of conservation, energy consumption, and efficiency of these properties, many historical structures are found to be prone to deterioration and disproportionate energy consumption. While private companies are significantly driving the construction of new buildings and environments in developed economies, historic centers and national heritage sites, when dependent on public funding, often lag behind, without adequate rehabilitation or energy efficiency upgrades.

This gap between the modernization of new buildings and the conservation of old ones creates significant imbalances: greater vulnerability of historic sites to climatic events, higher maintenance costs, and loss of cultural and tourist value. The lack of incentives and technical capabilities to intervene in historic buildings hinders the implementation of energy efficiency and sustainable rehabilitation solutions that respect architectural identity and heritage value. As a result, sustainability efforts are misaligned with the country's cultural and tourist wealth, limiting the positive impact on emissions reduction and community well-being.

The 2020 pandemic exacerbated the economic situation, causing a recession and relegating sustainability to a secondary level in the face of immediate needs. This blow highlighted the urgency of comprehensive strategies that connect heritage conservation, sustainable urban development, and energy efficiency, supported by public and private financing, clear regulatory frameworks, and technical capabilities. To convert Peru's biospheric potential into tangible benefits for its people, cohesive policies are needed that prioritize the respectful rehabilitation of historic buildings, the modernization of existing infrastructure, and the strengthening of demand for efficient solutions, without losing sight of the cultural wealth that characterizes the country.

1.2. Greater Environmental Impact During the Building's Occupancy Phase

To address these challenges effectively, it is essential to understand at which stage of a building's life the greatest environmental impact occurs. Studies assessing energy costs at each stage of a building's life cycle reveal that, although the material extraction, construction, and demolition phases consume a significant amount of energy, their contribution to total energy consumption is relatively small compared to the building's occupancy phase [4]. The latter, which includes daily use, maintenance, and operation, accounts for most of the long-term environmental impact. This knowledge is key to guiding design, management, and policy strategies to promote more sustainable and responsible construction [5]. Furthermore, depending on the lifetime of a building, the percentage of energy consumption allocated to the construction phase alone represents 9% of the total for a building with a lifetime of 50 years, and it decreases to 5% for a building with a lifetime of 100 years. This demonstrates the importance of efficient resource management in the occupancy phase of the building [6]. For this reason, it is essential to understand that one of the resources that can decrease the current pressure on the environment is the retrofitting of existing buildings [7].

In this context, retrospective analyses should emphasize the role of heritage-listed and historically significant buildings, which often exhibit architectural features that limit straightforward retrofits yet hold substantial cultural and economic value. Case studies integrating energy retrofits with preservation objectives can illuminate pathways to improve energy performance, without compromising historical integrity, by leveraging passive design principles, high-performance envelope assemblies compatible with conservation guidelines, and targeted retro-commissioning of legacy systems. Such approaches require multidisciplinary collaboration among conservation professionals, engineers, and policymakers to establish adaptable standards and funding mechanisms that align with both conservation ethics and modern energy performance targets [8].

Additionally, adopting a life-cycle assessment framework tailored to historic urban cores can quantify the trade-offs between conservation intervention, retrofit intensity, and long-term energy savings. This involves probabilistic modeling of uncertainty in material durability, climate exposure, and occupancy patterns to optimize retrofit sequences and maintenance scheduling. The resulting evidence base can inform policy instruments—such as targeted subsidies, performance-based financing, and regulatory relief for historic districts—that incentivize progressive energy upgrades while preserving the architectural and cultural identity that drives tourism, education, and community resilience.

1.3. Energy Consumption in Commercial Buildings: Previous Studies

On the other hand, MINEM (2020) [9] has an "Energy efficiency and energy diagnosis guide for large stores", where markets and supermarkets are considered large-scale buildings. These buildings are equipped with more electrical equipment, consume more energy, and have greater demands than other types of buildings. Accordingly, in the informative part on energy efficiency and sector characteristics of this guide, it is mentioned that large shopping centers use electricity as their main source of energy. In addition, the distribution of the energy consumption of electricity that is demanded in a large shopping center may depend on the following factors: type of products it stores, operating hours of refrigeration, and air-conditioning and lighting equipment [10]. The distribution of electrical energy is led by lighting (44%), followed by air conditioning (43%) [9].

The retail sector in Europe is characterized by high energy consumption, with supermarkets being particularly significant, with one of the highest rates of energy consumption in this sector. Given their impact, supermarkets represent a key element in Europe's efforts to meet its greenhouse gas reduction target of 10% by 2020 [11,12]. On the other hand, in the United States, the commercial building sector consumes almost 30% of all energy in the country [13], hence the importance of analyzing this building typology.

In Peru, persistent poverty and economic constraints have significantly conditioned infrastructure and sustainability priorities. Investment in retrofitting existing buildings and in environmental awareness campaigns is low, as the focus is mainly on immediate economic savings [14]. This reality contrasts with the situation in many European countries, where energy efficiency policies and campaigns are closely linked to environmental awareness and the promotion of sustainable practices [15,16]. In the Peruvian context, especially in the commercial sector, this is reflected in high energy consumption in buildings that, for the most part, have not been refurbished or modernized to improve their efficiency. The lack of investment in upgrading these spaces not only perpetuates high energy consumption but also limits opportunities to reduce costs and reduce environmental impact in the long term. This scenario underlines the need to rethink energy management strategies in Peruvian commercial buildings, considering the economic and social realities of the country, in order to promote a more efficient use of energy and move towards more sustainable development [17–19].

Several international studies have highlighted the potential of retrofitting measures in markets and commercial buildings. For instance, Salgueiro (2021) analyzed the Atarazanas Market in Málaga, focusing on envelope upgrades and system improvements compatible with heritage preservation, achieving reductions in heating demand by 50% and a significant decrease in carbon footprint [20]. Calado (2023) studied the San Cristóbal Market in Madrid, evaluating roof insulation and installation improvements, with payback periods ranging from 1.2 to over 40, depending on the intervention [11]. Echevarría (2023), in turn, examined La Paz Market in Madrid, proposing user behavior changes and envelope optimization, again showing the importance of glazing and skylight interventions [19]. These works confirm that envelope measures and installations can yield meaningful results, yet they also show that cost-effectiveness strongly depends on context [21].

Beyond market typologies, the retail sectors in Europe and the US have been widely studied due to their high energy intensity [13,14,22]. Integrated retrofit approaches—those combining envelope, systems, and renewable generation—are increasingly recommended because they unlock higher savings and better economic returns than isolated measures [15,16]. However, most peer-reviewed evidence for integrated strategies comes from high-income contexts with consolidated regulatory frameworks. By contrast, in Peru, the few existing references highlight the predominance of basic efficiency measures (e.g., LED lighting, improved HVAC) [9,23,24] and show that broader integrated retrofits remain underexplored. Importantly, while previous studies have examined packages of measures targeting a simple element (e.g., only roofs or only façades), there is a lack of systematic analyses of hybrid packages that combine roofs, openings, and installations with explicit economic evaluation in markets of developing countries. This constitutes the specific knowledge gap that the present study addresses.

This research focuses on the energy and social rehabilitation of the Mercado Central of Lima, a landmark building with significant commercial and cultural relevance. The main objective is to identify retrofit strategies that maximize energy savings, economic viability, and social impact. The central hypothesis is that integrated packages combining interventions in roofs, openings, and installations achieve superior performance compared to isolated measures, both in terms of energy efficiency and cost-effectiveness, while also enabling social reuse of building spaces.

Methodologically, the study conducts an initial assessment of the building's envelope and systems, followed by parametric simulations of retrofit measures using Ce3X©. This tool, although simplified, provides an effective basis for comparative energy rating and cost–benefit analysis. Complementary tools include PVGIS for solar potential assessment and CYPE© for cost estimation. We acknowledge, however, the limitations of certification-based software such as Ce3X©, particularly its inability to capture sub-hourly dynamics, occupancy variability, and time-dependent interactions. For this reason, we incorporate a discussion of the value of dynamic simulation and calibrated models, which recent studies have successfully applied to building retrofit assessments [17,19]. Such approaches can enhance precision in evaluating scenarios with complex temporal interactions, internal loads, or passive strategies and represent an important avenue for future research in the Peruvian context.

The contribution of this article is threefold: it provides the first systematic evaluation of hybrid retrofit packages (roofs + openings + installations) in a Peruvian market; it integrates energy simulations with economic analysis to identify cost-effective and replicable solutions for contexts with limited resources; and it incorporates social rehabilitation considerations, such as the potential reuse of roof and communal spaces, highlighting the broader cultural and economic value of sustainable retrofitting in historic urban centers.

2. Methodology

Modeling required a preliminary analysis of the building, studying its spatial, structural, and architectural configuration. On this basis, the input parameters for the energy simulation were established, as well as the conditions of the building's environment.

2.1. Preliminary Development: Architectural Configuration

The Central Market is located in the district of Cercado de Lima, province and department of Lima, Peru. It was built in 1967. The district of Cercado de Lima is the oldest, most historic and monumental district of Lima, as it is home to a series of monuments of great relevance characterized by their historical, religious, and cultural value.

The mixed building consists of a parallelepiped that occupies the entire block and is surrounded by a commercial perimeter ring. This volume is divided into three main levels, the first of which is subdivided into two platforms separated by half a level; all these levels are connected by ramps. Above the market volume is the nine-story office tower, which is supported by columns that create an open floor plan (Figure 1).

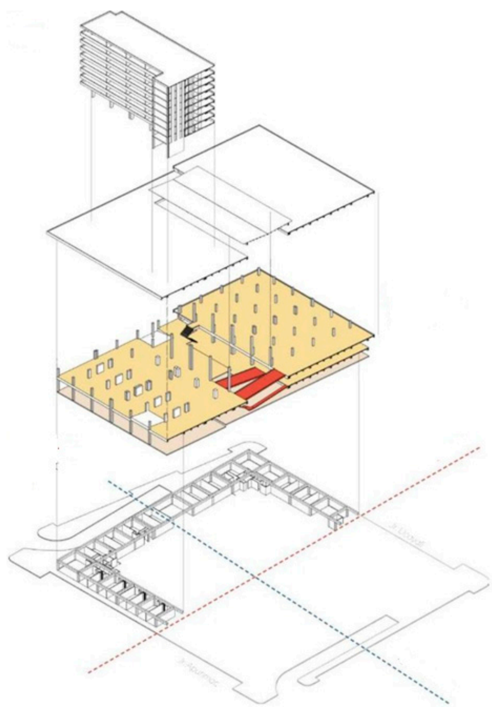


Figure 1. Exploited isometry of formal analysis of the Central Market. Source: Tolentino, 2019 [25].

Inside, the market is composed of a free floor plan with a central triple-height void that becomes the organizer of the main circulation of the complex and where the ramps connecting the different levels are located. This void is covered by a raised metal roof structure that differs from the concrete roofs used in the rest of the building (Figure 2).

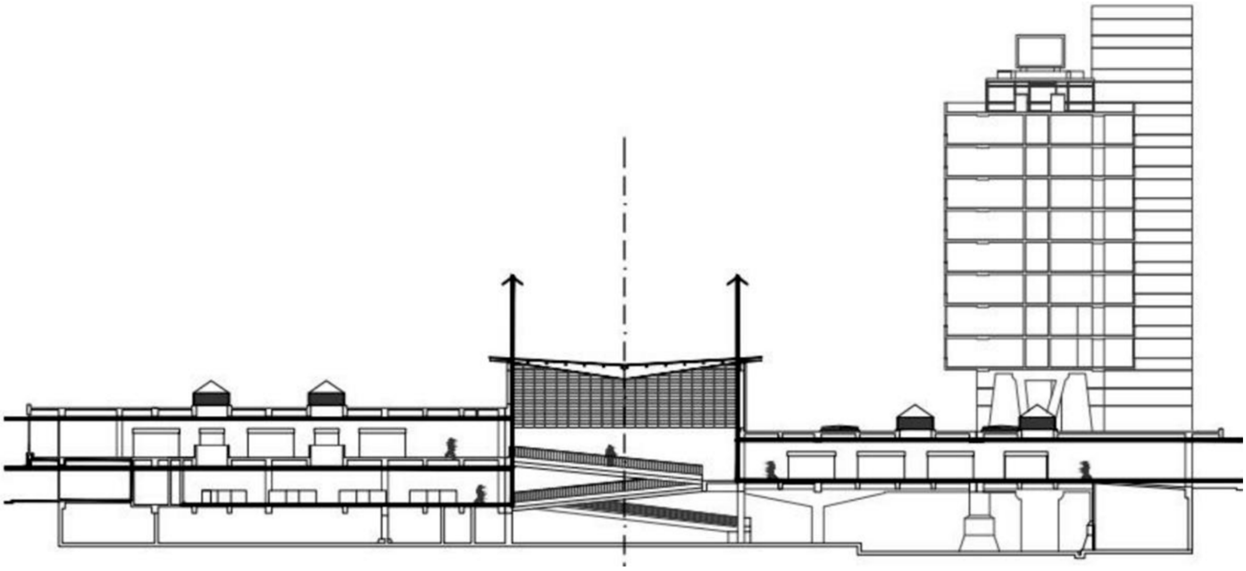


Figure 2. Section of the Central Market. Source: Tolentino, 2019 [25].

In general, the building has an arcade system of reinforced concrete columns and beams. The perimeter walls of the building are also made of this material, while the interior divisions of most of the commercial premises are simple masonry partition walls. The parallelepiped volume is made up of nine blocks separated by 5 m seismic joints. The office tower is supported on blocks A1 and A2, so the columns are replaced in this case by reinforced concrete slabs 60 cm thick and 3 m long (Figure 3).

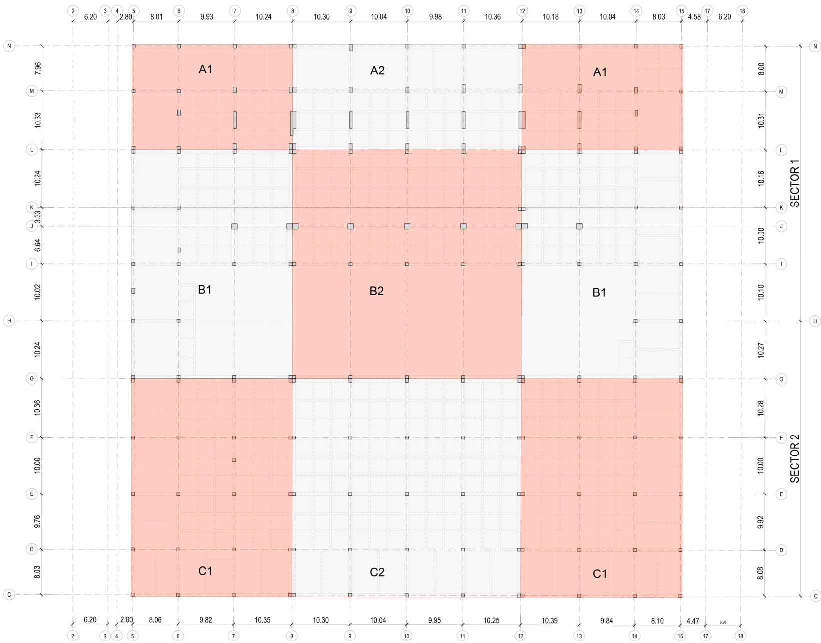


Figure 3. Schematic plan of structural modulation of the Central Market. Source: Tolentino, 2019 [25].

The slabs are 20 cm thick and are supported on secondary beams with a section of 35 × 50 cm. On the other hand, the ramps are structurally supported on trapezoidal section beams that are continuations of the main structure. Likewise, the central void is covered by a metal roof that rests on a structure made up of full-section steel scissors with a variable section, which in turn rests on reinforced concrete columns.

2.2. Initial Building Analysis

This section outlines the construction characteristics of the building envelope and the facilities available for conducting an initial energy analysis (Tables 1–3).

Table 1. Characteristics of market envelopes.

Elements	Name	Dimensions	Area (m^2)	U (W/m^2k)
Roof	Market flat roof Market pitched roof	variable variable	8745.00 1838.00	4.23 7.04
Walls: Northeast façade Huallaga	F.M. Huallaga first level F.M. Huallaga central space F.M. Huallaga skylights Wall in contact with terrain	variable variable variable variable	550.82 517.80 69.30 576.31	2.36 4.00 5.88 0.66
Walls: Northwest façade Ayacucho	F.M. Ayacucho first level F.M. Ayacucho second level F.M. Ayacucho central space	variable variable variable	458.35 215.63 123.55	2.36 4.00 4.00
Wall in contact with ground	Wall in contact with ground	variable	410.53	0.85
Southwest façade Ucayali	F.M. Ucayali central space F.M. Ucayali skylights Wall in contact with ground	variable variable variable	338.44 69.30 302.81	4.00 5.88 1.01
Walls: Southeast façade Andahuaylas	F.M. Andahuaylas first level F.M. Andahuaylas second level F.M. Andahuaylas space central	variable variable variable	433.72 215.63 123.55	2.36 4.00 4.00
Wall in contact with ground	F.M. Andahuaylas skylights Wall in contact with ground Andahuaylas	variable variable	69.30 410.53	5.88 0.85
Soil	Soil in contact with ground Floor in contact with outside air	97.68 × 97.50 variable	9523.80 1059.00	1.00 3.18
Walls	F.M. Ucayali first level F.M. Ucayali second level	variable variable	288.19 540.09	2.36 4.00

Table 2. Characteristics of the office tower enclosures.

Elements	Name	Dimensions	Area (m^2)	U (W/m^2k)
Office flat roof	Office flat roof	variable	1465.00	4.23
Walls: Northeast façade avenida Huallaga	F.O. Huallaga	variable	2501.14	4.00
Walls: Northwest façade avenida Ayacucho	F.O. Ayacucho	variable	722.43	4.00
Walls: Southwest façade avenida Ucayali	F.O. Ucayali	variable	2441.48	4.00
Walls: Southeast façade avenida Andahuaylas	F.O. Andahuaylas	variable	772.43	4.00
Soil	Soil on contact with outside air	variable	1378.00	3.18

Table 3. Characteristics of the office tower enclosures.

Characteristics of Office Tower Enclosures	
Heating	It does not have a heating system because the temperatures are not very low, so this equipment is not indispensable.
Cooling	The building does not have this type of system; however, some premises on the perimeter ring on the first level have air-conditioning equipment for private use.
Sanitary Hot Water	The building does not have domestic hot water (DHW). The commercial stalls belonging to the semi-wet and wet areas, as well as the toilets, only have cold water.
Ventilation	There is no ventilation system, so no data is entered in the program for this.
Lighting	In terms of lighting equipment, linear fluorescent-type luminaires predominate in the market, both in the whole of the outer perimeter and in most of the interior of the market. It is estimated that 80% of the surface area of this area has these types of luminaires. The remaining parts of the interior of the market, specifically the sales stalls located near the main entrances, have linear LED tube luminaires, covering 20% of the area's surface. The office tower, which is currently used as a warehouse, has incandescent luminaires due to the age of this sector.

The openings have different thermal properties that vary according to their typology, which is defined according to the type of enclosure they have. In order to organize their typologies, they have been named as follows: ROM, nomenclature for openings with a roll-up enclosure; REM, nomenclature for openings with a static vertical louvered or slatted enclosure; HM, nomenclature for openings without a defined enclosure; VO and VM, for window openings with a glass enclosure; and MO and MM, for partition openings with a glass enclosure. The thermal properties of the openings are defined as estimated values.

The building has been designated for commercial use, which predetermines its occupancy. Its intensity of use has been estimated as high, and its daily operating hours have been set at 12 h. All of this data is crucial for defining its operation. The equipment that affects the building's operation is detailed below.

2.3. Instruments for Evaluating Energy and Economic Improvements

In order to carry out this study, several tools and approaches were used to comprehensively assess possible energy improvements in the building under analysis. Firstly, the Ce3X© software was used, a platform specialized in energy analysis of buildings, in which all the data related to the thermal envelope of the building was entered, including walls, windows, doors, and other construction elements, as well as the existing installations. This process allowed an initial energy rating of the building to be obtained, serving as a baseline for future improvements.

Ce3X© was selected because it is widely applied for preliminary energy certification and retrofit assessment, especially in contexts where comprehensive building energy datasets are scarce and regulatory frameworks are under development, such as in Peru. Compared to dynamic simulation tools [26–29], such as Energy Plus©, TRNSYS©, or Design builder©, Ce3X© offers simplified calculations with reduced computational time, which allowed the evaluation of fifty different retrofit scenarios. Its limitations include the monthly resolution of results, the absence of sub-hourly dynamics, simplified internal load representation, and lack of advanced control strategies. These limitations are acknowledged in the discussion as potential sources of uncertainty.

Although Ce3X© provides a simplified and certification-oriented assessment of building energy performance, it does not capture the time-dependent dynamics of occupancy, climate, and internal loads. In the broader context of building energy analysis, dynamic simulation tools calibrated with real data can provide more accurate insights, especially when evaluating retrofit scenarios involving passive strategies and complex interactions over time. Nevertheless, the choice of Ce3X© in this study is based on feasibility, data availability, and its certification-driven purposes.

Subsequently, different individualized improvement measures, such as additional insulation, window replacement, lighting improvements, and more efficient air-conditioning and ventilation systems, were incorporated into Ce3X©. In addition, combinations of these measures were analyzed to identify the most favorable configurations in terms of efficiency and energy savings. To assess the economic viability of each option, the costs associated with each measure and combination were entered, using data provided by the program itself, which calculated the corresponding payback years, thus facilitating a comparison between the different alternatives.

In addition, the SketchUp© software (v.2023) was used to carry out a detailed study of the building's sunlight. This analysis made it possible to determine which façades receive the greatest amount of solar radiation throughout the day, which is crucial information for defining improvement measures related to orientation and solar protection, thus optimizing the efficiency of solar installations and other passive strategies. To dimension the PV installation, the PVGIS-5 application© was used, which provides precise data on solar yields based on geographical location and climatic conditions. With this tool, the required power of the solar panels to cover the energy demands of the building was determined, ensuring that the proposed solutions are technically feasible and efficient.

Finally, the CYPE© software, a price generator that allows for obtaining the updated costs of the different improvement measures proposed, was used. This resource facilitated the accurate estimation of the budgets required for the implementation of each alternative, thus complementing the technical analysis with a sound economic evaluation. Together, these tools and methodologies allowed for a comprehensive and informed analysis for the selection of the best energy improvement strategies for the building under study.

According to all of the above, the integration of the software tools followed sequential logic. SketchUp© was employed to create the 3D model and conduct the solar incidence study. Geometric and envelope data were transferred into Ce3X© for energy simulations. PVGIS© was used to estimate solar photovoltaic potential, and its results were incorporated into Ce3X© for renewable energy scenarios. Finally, CYPE© was applied to calculate the implementation costs of each measure, ensuring that technical and economic analyses were consistently integrated.

2.4. Climate Data

The district of Cercado de Lima is located in the Lima region. In the report "Climas del Perú: Mapa de clasificación climática Nacional", the climate is classified as E (d)B, which means that this province is located in a desert with an annual rainfall of 8 mm in the form of drizzle, mainly between July and September. Temperatures are influenced by the adjacent sea to the west, with maxima between 18 °C in August and 26.7 °C in February, and minima between 13.5 °C in August and 19 °C in February [30]. With respect to altitude, the city of Lima has an altitude of 101 m above sea level. According to Weather Spark, the average relative humidity in Lima is 81%, while the average minimum humidity is 66% and the maximum humidity is 92% [20].

In addition, a sunlight study of the building was carried out to evaluate the incidence of the sun on the dates of the autumn equinox, 21 March 2024; the spring equinox, 23 September; the summer solstice, 21 December 2024; and the winter solstice, 21 June. Through the project modeled in 3D in the Sketchup©, its geolocation and data such as latitude of -12.0453 and latitude $12°02'57'$ South and longitude $77°01'31'$ West can be entered in this file, and the following is obtained:

- The northeast façade receives more hours of light and sunshine in the morning at the autumn equinox, spring equinox, and winter solstice.
- The southeast façade receives more hours of daylight and morning sun at the autumnal equinox, spring equinox, and summer solstice.
- The northwest façade receives more hours of light and sunshine in the afternoon at the autumn equinox, spring equinox, and winter solstice.
- The southwest façade receives more hours of daylight and afternoon sun at the autumn equinox, spring equinox, and summer solstice.

2.5. Model Verification and Limitations

The model was not calibrated with measured energy consumption data, as no historical utility records were available for Mercado Central. Nevertheless, internal consistency checks were performed, such as verifying energy balances within Ce3X© and comparing demand values with benchmark studies of similar commercial markets in Peru and Spain. These cross-checks suggest that the model produces results of reasonable magnitude. We acknowledge, however, that the absence of a quantitative validation or calibration process represents a limitation of this study.

3. Results

This section presents the results obtained in the evaluation of the energy improvement measures. Firstly, an individual analysis of each improvement measure is carried out, assessing its impact on the energy consumption, emissions, and demand of the building. Subsequently, those measures that have shown the best results for these parameters are selected and combined to form different intervention configurations. Finally, an economic and payback analysis of the combinations with the best energy performance is carried out, considering the associated costs and payback periods. This process makes it possible to identify the most efficient and viable solution from a technical and economic point of view, thus optimizing the improvement strategies for the building under study.

3.1. Evaluation of Individual Improvement Measures with the Ce3X© Software

In this first stage of evaluation of individual improvement measures, the objective is to determine which of these proposals will be the ones that can be finally implemented in the project. In this case, only those measures that have the highest percentage of savings and qualification compared to the original situation of the building will be prioritized. For improvement measures involving the thermal envelope, i.e., roofs, façades, and openings, the percentage of demand savings is more important; on the contrary, for improvement measures involving installations, the percentage of consumption savings will be the determining factor for the choice of the most suitable improvements.

3.1.1. Roof Improvement Measures

The results with respect to these measures show that, individually, the ones that produce the greatest savings in terms of consumption, emissions, and demand are those that have thicker thermal insulation. Regarding the proposals for improvements in the flat roof of the market, it can be determined that the proposal to install XPS thermal insulation with a walkable finish in one sector and a vegetation finish in another sector generates greater savings than the proposal to install thermal insulation with a non-walkable finish. With regard to the pitched roof on the market, it can be seen that incorporating PUR thermal insulation of the sandwich panel type does not generate any energy savings for the building, at least as an individual measure, and worsens the rating in the three factors analyzed (Table 4).

Table 4. Savings and rating of individual improvement measures on roofs.

Savings and Ratings of Individual Improvement Measures on Roofs Compared to Original Situation			
Measures	**Consumption**	**Emissions**	**Demand**
Original Rating	487.5 E	129.4 E	78.5 D
Incorporate 80 mm thick XPS thermal insulation in flat market roof with walkable and vegetated finish.	Cooling: 4.8% Lighting: - 481.98 E	Cooling: 4.8% Lighting: - 127.91 E	Cooling: 4.8% 74.73 C
Incorporate 40 mm thick XPS thermal insulation in flat market roof with walkable and vegetated finish.	Cooling: 4.5% Lighting: - 482.24 E	Cooling: 4.5% Lighting: - 127.98 E	Cooling: 4.5%. 74.91 C
Incorporate 80 mm thick XPS thermal insulation in flat roof of market with non-trafficable finish.	Cooling: 3.4% Lighting: - 483.55 E	Cooling: 3.4% Lighting: - 128.33 E	Cooling: 3.4% 75.8 C
Incorporate 40 mm thick XPS thermal insulation in flat roof of market with non-trafficable finish.	Cooling: 3% Lighting: - 484.01 E	Cooling: 3% Lighting: - 128.45 E	Cooling: 3% 76.12 C
Incorporate 80 mm thick XPS thermal insulation in flat roof of offices with non-trafficable finish.	Cooling: 0.4% Lighting: - 486.91 E	Cooling: 0.4% Lighting: - 129.22 E	Cooling: 0.4% 78.1 D
Incorporate 40 mm thick XPS thermal insulation in flat roof of offices with non-trafficable finish.	Cooling: 0.4% Lighting: - 486.96 E	Cooling: 0.4% Lighting: - 129.24 E	Cooling: 0.4% 78.1 D
Incorporate 80 mm thick PUR (sandwich panel) thermal insulation in pitched market roof.	Cooling: −0.2% Lighting: - 487.62 E	Cooling: −0.2% Lighting: - 129.41 E	Cooling: −0.2% 78.59 D
Incorporate thermal insulation of PUR (sandwich panel) of 30 mm thickness in pitched market roof.	Cooling: −0.3% Lighting: - 487.72 E	Cooling: −0.3% Lighting: - 129.44 E	Cooling: −0.3% 78.66 D

The most suitable improvement measures are to incorporate 80 mm thick XPS thermal insulation into the flat roof of the market, with one sector with a walkable finish and another sector with a vegetated finish, and to incorporate 80 mm thick XPS thermal insulation into the flat roof of the offices with a non-walkable finish. All the chosen measures are then carried out (Tables 5 and 6).

In this case, if all the improvement measures are carried out on roofs with 40 mm thermal insulation, the savings and ratings in terms of consumption, emissions, and demand improve by 1% compared to the original situation. This means that for the climatic conditions in which the building is located, it is preferable to have improvement measures with thinner insulation, because when the temperature rises, a thicker thermal insulation material retains more heat inside the building and therefore causes a greater cooling demand.

According to the analyses indicated, in building envelopes, the greatest savings come from measures that increase thermal inertia and reduce heat gains and cooling demand, with insulation thickness being the key factor. The greater the insulation thickness, the lower the heat gain, and when accompanied by a thermal mass, it can moderate temperature peaks and reduce demand, while in the flat roof of the market, the combination of 80 mm of XPS with a walkable finish in one zone and a vegetated finish in another generates greater savings than a non-walkable finish. In gable roofs, the incorporation of PUR sandwich panel insulation does not provide significant savings and can worsen the ratings by increasing the interior heat gain without improving the overall thermal resistance; therefore, the optimal sizes are 80 mm of XPS in the market's flat roof with a walkable and a vegetated sector, and 80 mm of XPS in the office's flat roof with a non-walkable finish, balancing demand and heat gains through permeability and solar exposure. If all the improvements are applied to roofs with 40 mm, the improvements in consumption, emissions, and demand are around 1% with respect to the original situation, indicating that, under these climatic conditions, it is preferable to seek greater thickness when the outside temperature rises to avoid greater cooling needs. As indicated in the limitations, this value could be adjusted with a heat flow and interaction analysis.

Table 5. Savings and ratings of the set of improvement measures for roofs, case 1.

Savings and Rating of All Roof Improvement Measures Compared to the Original Situation Original Situation			
Measures	**Consumption**	**Emissions**	**Demand**
Original Rating	487.5 E	129.4 E	78.5 D
Incorporate XPS insulation Roof thickness 80 mm Market flat roof Passable finish and garden	Cooling: −1.3% Lighting: - 488.96 E	Cooling: −1.3% Lighting: - 129.77 E	Refrigeration: −1.3% 79.51 D
Incorporate insulation XPS insulation 80 mm thick in flat roof Flat roof of offices with non-trafficable finish			

Table 6. Savings and ratings of the set of improvement measures for roofs, case 2.

Savings and Ratings of Combined Improvement Measures on Roofs Compared to Original Situation Original Situation			
Measures	**Consumption**	**Emissions**	**Demand**
Original Rating	487.5 E	129.4 E	78.5 D
Incorporate 40 mm thick XPS thermal insulation in flat market roof with walkable and vegetated finish.	Cooling: 1% Lighting: - 486.23 E	Cooling: 1% Lighting: -	Cooling: 1% 77.63 C
Incorporate 40 mm thick XPS thermal insulation in flat roof of offices with non-trafficable finish.			

3.1.2. Façade Improvement Measures

The results with respect to these improvement measures show that, individually, those that contribute the most are the incorporation of 60 mm thick XPS thermal insulation on the inside for both the northwest and southwest façades, which generates savings of 1.2% in consumption, emissions, and demand (Table 7).

The best-performing improvements involve interior installation of 60 mm of XPS thermal insulation on the northwest and southwest façades. Their effectiveness stems from enhanced thermal inertia, which dampens temperature fluctuations and reduces conduction losses, coupled with a higher overall thermal resistance that moderates solar gains and convective heat losses. By increasing effective permeability and thermal mass, these measures lower cooling demand and, in turn, reduce energy consumption and associated emissions.

Table 7. Savings and ratings of individual improvement measures on façades.

Savings and Ratings of Individual Improvement Measures on Façades Compared to Original Situation			
Measures	**Consumption**	**Emissions**	**Demand**
Original Rating	487.5 E	129.4 E	78.5 D
Incorporate 60 mm thick XPS thermal insulation on the inside of NW and SW façades (most solar radiation received).	Cooling: 1.2% Lighting: - 486.03 E	Cooling: 1.2% Lighting: - 128.99 E	Cooling: 1.2% 77.5 D
Incorporate 20 mm thick XPS thermal insulation on the inside of the NW and SW façades (more solar radiation received).	Cooling: 1% Lighting: - 486.32 E	Cooling: 1% Lighting: - 129.07 E	Cooling: 1% 77.7 D
Incorporate 60 mm thick XPS thermal insulation on the inside of NE and SE façades (less solar radiation received).	Cooling: 0.2% Lighting: - 487.16 E	Cooling: 0.2% Lighting: - 129.29 E	Cooling: 0.2% 78.27 D
Incorporate 20 mm thick XPS thermal insulation on the inside of NE and SE façades (less solar radiation received).	Cooling: 0.2% Lighting: - 487.22 E	Cooling: 0.2% Lighting: - 129.3 E	Refrigeration: 0.2% 78.32 D

3.1.3. Improvement Measures in Openings

The results with respect to these improvement measures show that, individually, those that contribute the most are replacing the glass and frames of the northwest and southwest façades with low-emissivity 4-12-4 double glazing in the vertical position that has a thermal transmittance of 1.6/Wm^{2}k and PVC frames with three air chambers that have a thermal transmittance of 1.8/Wm^{2}k, generating savings of 6.7%. Regarding skylights, the measure that generates the greatest savings, exactly 2.6%, is the replacement of the current material with low-emissivity 4-6-4 double glazing in the horizontal position that has a thermal transmittance of 2.6/Wm^{2}k and PVC frames with three air chambers that have a thermal transmittance of 1.8/Wm^{2}k. Finally, the replacement of the building's static vertical louvers with movable louvers has a better result if only applied on the northwest and southwest façades, producing savings of 7.8% in building consumption, emissions, and demand (Table 8).

Table 8. Savings and ratings of individual improvement measures in opening.

Savings and Ratings of Individual Improvement Measures in Openings Compared to Original Situation			
Measures	**Consumption**	**Emissions**	**Demand**
Original Rating	487.5 E	129.4 E	78.5 D
Replace windows and screens with low-emissivity 4-6-4 double glazing and PVC frames with three air chambers on NW and SW façades.	Cooling: 6.5% Lighting: - 479.97 E	Cooling: 6.5% Lighting: - 127.38 E	Cooling: 6.5% 73.35 C
Replace windows and partitions with low-emissivity 4-6-4 double glazing and PVC frames with three air chambers on NE and SE façades.	Cooling: 4.6% Lighting: - 482.15 E	Cooling: 4.6% Lighting: - 127.96 E	Cooling: 4.6% 74.85 C

Table 8. *Cont.*

Savings and Ratings of Individual Improvement Measures in Openings Compared to Original Situation			
Measures	**Consumption**	**Emissions**	**Demand**
Replace windows and partitions with low-emissivity 4-12-4 double glazing and PVC frames with three air chambers on NW and SW façades.	Cooling: 6.7% Lighting: - 479.76 E	Cooling: 6.7% Lighting: - 127.32 E	Cooling: 6.7% 73.21 C
Replace windows and partitions with low-emissivity 4-12-4 double glazing and PVC frames with three air chambers on NE and SE façades.	Cooling: 4.4% Lighting: - 482.43 E	Cooling: 4.4% Lighting: - 128.03 E	Cooling: 4.4% 75.04 C
Replace skylights with low-emissivity 4-6-4 double glazing and PVC frames with three air chambers.	Cooling: 2.6% Lighting: - 484.4 E	Cooling: 2.6% Lighting: - 128.55 E	Cooling: 2.6% 76.39 C
Replace skylights with low-emissivity 4-12-4 double glazing and PVC frames with three air chambers.	Cooling: 2.6% Lighting: - 484.44 E	Cooling: 2.6% Lighting: - 128.57 E	Cooling: 2.6% 76.41 C
Replace static louvers with movable louvers on NW and SW façades.	Cooling: 7.8% Lighting: - 478.54 E	Cooling: 7.8% Lighting: - 127.0 E	Cooling: 7.8% 72.37 C
Replace static louvers with movable louvers on NE and SE façades.	Cooling: 7.1% Lighting: - 479.32 E	Cooling: 7.1% Lighting: - 127.21 E	Cooling: 7.1% 72.91 C

Table 9 presents the ratings after selecting the measures that maximise savings for the building, focusing on the openings.

Table 9. Savings and qualification of the set of improvement measures in openings.

Savings and Qualification of the Set of Improvement Measures in Openings			
Measures	**Consumption**	**Emissions**	**Demand**
Original Rating	487.5 E	129.4 E	78.5 D
Replace windows and partitions with low-emissivity 4-12-4 double glazing and PVC frames with three-chambered glass on NW and SW façades.	Cooling: 17.4% Lighting: - 467.45 E	Cooling: 17.4% Lighting: - 124.06 E	Cooling: 17.4% 64.79 C
Replace skylights with low-emissivity 4-6-4 double glazing and PVC frames with three air chambers.			
Replace static louvers with movable louvers in in NW and SW façades.			

The most notable improvements come from modifications to key openings, such as replacing the glazing and frames on the northwest and southwest façades with low-emissivity double glazing. This change reduces unwanted solar heat gains and lowers the total transmittance of the envelope, moderating thermal peaks and reducing conduction losses. The result is a lower cooling demand and, therefore, savings of about 6.7% in consumption, emissions, and demand.

As for skylights, the most cost-effective improvement is to replace the current material with low-emissivity double glazing, which operates by reducing both excessive solar gain and thermal losses, achieving approximately 2.6% savings.

Replacing static vertical louvers with movable louvers offers the highest performance when applied on the northwest and southwest façades only, with an estimated 7.8% savings in consumption, emissions, and demand, by improving solar gain control and ventilation (air intake) according to orientation.

The combination of these improvements in openings achieves total savings of 17.4% for consumption, emissions, and demand by achieving solar gain reductions, reduced transmission through the openings, and increased dynamic ventilation control capability.

3.1.4. Improvement Measures in Installations

The results with respect to these improvement measures show that individually, those that contribute most are the incorporation of an air-conditioning system, with savings of 80.3% in cooling consumption and 100% in lighting; the incorporation of solar panels, which generates savings of 47.8% in cooling consumption and 100% in lighting; and, finally, the replacement of current luminaires with LED luminaires, a measure that allows savings of 42.1% in cooling and 88% in lighting (Table 10).

Table 10. Savings and qualification of individual improvement measures in installations.

Savings and Rating of Individual Improvement Measures in Installations Compared to the Original Situation			
Measures	**Consumption**	**Emissions**	**Demand**
Original Rating	487.5 E	129.4 E	78.5 D
Incorporate air-conditioning equipment	Cooling: 80.3%. Illumination: 100%. 27.14 A	Cooling: 80.3%. Lighting: 100% 6.96 A	Cooling: 47.8% 40.98 C
Incorporate ventilation equipment	Refrigeration: 37.5% Lighting: 100% 75.65 C	Cooling: 37.5% Lighting: 100% 19.86 C	Cooling: 37.5% 49.05 C
Replace existing luminaires with LED luminaires	Cooling: 42.1% Lighting: 88% 115.06 A	Cooling: 42.1% Lighting: 88% 30.32 A	Cooling: 42.1% 45.46 B
Incorporate solar panels	Cooling: 47.8% Lighting: 100% 59.73 C	Cooling: 47.8% Cooling: 47.8% 15.61 C	Cooling: 47.8% 40.98 C

Once the measures with the greatest savings for the building in terms of installations have been chosen, these are then taken as a whole (Table 11).

Table 11. Savings and ratings of all improvement measures for installations.

Savings and Ratings of Set of Improvement Measures in Installations Compared to Original Situation			
Measures	**Consumption**	**Emissions**	**Demand**
Original Rating	487.5 E	129.4 E	78.5 D

Table 11. *Cont.*

Savings and Ratings of Set of Improvement Measures in Installations Compared to Original Situation			
Measures	**Consumption**	**Emissions**	**Demand**
Incorporate air-conditioning equipment	Cooling: 78.1% Lighting: 88	Cooling: 78.1% Lighting: 88%	Cooling: 42.1%
Replace existing luminaires with LED luminaires	68.96 A	18.09 A	45.46 B
Incorporate solar panels			

Together, these improvements in installations produce savings of 78.1% and 88% in cooling and lighting consumption and emissions, respectively. The savings in cooling demand are 42.1%.

3.2. Analysis of Combined Improvement Measures with the Ce3X© Software

Table 12 analyzes all combinations derived from the previously obtained sets for each thermal envelope element and installation, identifying those that optimize consumption, emissions, and demand reductions alongside the measure rating.

The table above shows that eleven possible combinations of all sets of improvement measures can be obtained, which are M1, improvement measures in roofs and façades; M2, improvement measures in roofs and openings; M3, improvement measures in roofs and installations; M4, improvement measures in façades and openings; M5, improvement measures in façades and installations; M6, measures to improve openings and installations; M7, measures to improve roofs, façades, and openings; M8, measures to improve roofs, façades, and installations; M9, measures to improve roofs, openings, and installations; M10, measures to improve façades, openings, and installations; and finally, M11, measures to improve roofs, façades, openings, and installations. Below is a table showing the eleven proposed improvement measures combined; the percentage of savings in consumption, emissions, and demand compared to the original situation; and the new rating that would be obtained after applying each average (Table 13) for subsequent analysis.

- M1: Improvement measures on roofs and façades

It can be seen that if the improvement measures on roofs and façades are combined, the percentage of savings in cooling is −10.1%. This means that it generates greater demand than the current situation, which is reflected in the negative ratings of the three factors analyzed; therefore, the overall rating worsens to 132.4 E. One of the most important factors is the use of the roof and façade improvement measures.

One of the reasons for this is that warm air tends to rise, as it is less dense air, concentrating on the roofs and inside the building. While it is true that the set of individual measures on roofs generated savings of 1%, which in itself is a low percentage, when combined with the set of individual measures on façades, the hot air concentrated in the building becomes very high, creating a greater need for cooling in the building. From an energy point of view, this combination is not favorable for retrofitting. It should be mentioned that, as analyzed in the previous section, the two sets of improvements in this combination represent the lowest percentage savings in cooling demand for the building.

Table 12. Combined improvement measures.

ELEMENTS		FACADE	ROOMS	FACILITIES
MEASURES		- Incorporate 60 mm thick XPS thermal insulation on the inside of the NO and SO façades.	- Replace windows and partitions with low emissivity 4-12-4 double glazing and PVC frames with three air chambers on NO, SO façades. - Replace skylights with low-emissivity 4-6-4 double glazing and PVC frames with three air chambers. - Replace static louver with movable louver on - façades NW, SW	- Incorporate air conditioning equipment - Replace existing luminaires with LED luminaires. - Incorporate solar panels
ROOF	- Incorporate 40 mm thick XPS thermal insulation on flat market roof with walkable and vegetated finish. - Incorporate 40 mm thick XPS thermal insulation in flat roof of offices with non-trafficable finish.	**●M1**	**●M2**	**●M3**
FACADE	- Incorporate 60 mm thick XPS thermal insulation on the inside of NW and SW façades.		**●M4**	**●M5**
ROOMS	- Replace windows and screens with low-emissivity 4-12-4 double glazing and PVC frames with three air chambers on NW, SW façades. - Replace skylights with low emissivity 4-6-4 double glazing and PVC frames with three air chambers. - Replace static louver with movable louver on NW, SW facades			**●M6**
ROOF-FAÇADE	- Incorporate 40 mm thick XPS thermal insulation in flat market roof with trafficable and vegetation finish. - Incorporate 40 mm thick XPS thermal insulation in flat roof of offices with non-trafficable finish. - Incorporate 60 mm thick XPS thermal insulation on the inside of the NW and SW facades.		**●M7**	**●M8**

Table 12. *Cont.*

ELEMENTS	FACADE	ROOMS	FACILITIES
ROOF-OPENINGS	- Incorporate 40 mm thick XPS thermal insulation in flat roof of market with trafficable and vegetation finish - Incorporate 40 mm thick XPS thermal insulation in flat roof of offices with non-trafficable finish. - Replace windows and partitions with low emissivity 4-12-4 double glazing and PVC frames with three air chambers on NW, SW façades. - Replace skylights with low emissivity 4-6-4 double glazing and PVC frames with three air chambers. - Replace static louver with movable louver on NW, SW façades.		**●M9**
FAÇADE-OPENINGS	- Incorporate 60 mm thick XPS thermal insulation on the inside of NW and SW facades. - Replace windows and partitions with low emissivity 4-12-4 double glazing and PVC frames with three air chambers in NO, SO façades. - Replace skylights with low emissivity double glazing 4-6-4 and PVC frames with three air chambers. - Replace static louver with movable louver on NW, SW façades.		**●M10**
ROOF-FAÇADE-OPENINGS	- Incorporate 40 mm thick XPS thermal insulation in flat market roof with walkable and green finish. - Incorporate 40 mm thick XPS thermal insulation in flat roof of offices with non-trafficable finish. - Incorporate 60 mm thick XPS thermal insulation on the inside of NO and SO façades. - Replace windows and partitions with low-emissivity 4-12-4 double glazing and PVC frames with three air chambers in NW and SO façades. - Replace skylights with low-emissivity 4-6-4 double glazing and PVC frames with three air chambers. - Replace static louver with movable louver in NO, SW façades.		**●M11**

Table 13. Savings and ratings of the combinations of improvement packages compared to the original situation.

	Consumption (%)	Emissions (%)	Demand (%)	Energy Rating ($KgCO_2/m^2$)
Original	114.7	30.4	78.5	129.4
M1	−10.1	−10.1	−10.1	132.4
M2	2.8	2.8	2.8	128.5
M3	78.9	78.9	44.1	18.1
M4	18.8	18.8	18.8	123.6
M5	78.4	78.4	42.6	18.9
M6	82.4	82.4	36.5	17.6
M7	−6.8	−6.8	−6.8	131.4
M8	77.0	77.0	39.1	18.6
M9	80.5	80.5	48.4	17.6
M10	82.9	82.9	54.7	17.3
M11	78.9	78.9	44.2	18.1

Note: The blue rows show the best solutions.

- M2: Roof and cavity improvement measures

In this case, combining roof and cavity improvements generates cooling demand savings of 2.8%; consequently, the overall rating improves, and a rating of 128.5 E is obtained. Although this rating is an improvement, it is not a combination that generates high energy efficiency in the building, as the difference from the original rating of 129.4 is small. In any case, it can be determined that the set of measures that contributes the most in this combination is the one applied to the openings, which prevents solar gain towards the interior in summer, thus representing savings in cooling demand. From an energy point of view, this combination is favorable for the renovation of the building.

- M3: Improvement measures on roofs and installations

Combining the set of roof improvement measures with the roof installation measures results in savings of 78.9% and 87% in cooling and lighting consumption and emissions, respectively; on the other hand, the cooling demand has savings of 44.1%. In addition, the overall rating improves to a value of 18.1 A. It can be determined that, despite the fact that this combination includes the set of measures on roofs, which leads to 1% savings in the three factors analyzed, the improvements in installations make the greatest contribution in this combination and tend to improve the energy efficiency and therefore the overall rating of the building much more. On the other hand, although implementing roof improvements can concentrate heat inside the building and generate greater cooling demand, incorporating energy-efficient air-conditioning equipment helps to counteract this demand; i.e., it minimizes the need for cooling and, in the process, helps to maintain the building's internal comfort conditions. In addition, this cooling equipment generates a percentage savings in the energy consumed. In terms of lighting, the contribution of solar panels and new LED luminaires also means that less energy is consumed from non-renewable sources. From an energy point of view, this combination is favorable for building refurbishment.

- M4: Improvement measures in façades and openings

It is observed that combining the improvement measures in façades and openings generates savings of 18.8% in energy consumption and cooling demand. This is reflected in the overall rating improvement to 123.6 E. In this combination, the set of measures that contributes the most is the one applied to the building's openings, as analyzed in the previous section. From an energy point of view, this combination is favorable for the renovation of the building.

- M5: Improvement measures on façades and installations

Combining the façade improvement measures with the installation measures results in savings of 78.4% and 87% in cooling and lighting consumption and emissions, respectively; on the other hand, cooling demand has savings of 42.6%. In addition, the overall rating improves to a value of 18.9A. In this case, similar to Measure M3, a set of improvements in the thermal envelope is proposed, this time in façades, which, despite showing savings of 1.2% in cooling demand, when combined with the improvements in installations, greatly improves the energy efficiency and therefore the overall rating of the building. On the other hand, although implementing façade improvements can prevent heat from entering the building, if only this measure is applied, there is still a considerable cooling demand that is countered by the incorporation of energy-efficient air-conditioning equipment, thus minimizing the need for cooling and, at the same time, helping to maintain the internal comfort conditions of the building. In addition, these cooling units generate a percentage savings in energy consumed, as do the panels and the new LED luminaires. From an energy point of view, this combination is favorable for building refurbishment.

- M6: Improvement measures in openings and installations

In this case, combining improvements in openings and installations generates savings of 82.4% and 87% in cooling and lighting consumption and emissions, respectively; on the other hand, cooling demand has savings of 53.5%. These high savings percentages are reflected in the overall rating of the building, which improves to 17.6A. It is worth mentioning that, as discussed in the previous section, the two sets of improvements in this combination represent the highest percentage savings in cooling demand for the building. From an energy point of view, this combination is favorable for the refurbishment of the Central Market.

- M7: Improvement measures on roofs, façades, and openings

It can be seen that, if the improvement measures on roofs, façades, and openings are combined in the building, the percentage saving in cooling demand is −6.8%. This means that it generates greater demand than the current situation, which is reflected in the negative ratings of the three factors analyzed; hence, the overall rating worsens to 131.4 E. As mentioned in the analysis of the previous measures, this is due to the fact that hot air tends to rise and concentrate on the roof, which, having thermal insulation, causes it to concentrate more inside the building. This, together with the thermal insulation applied to the façades, means that the hot air concentrated in the building is very high, creating a greater need for cooling in the building. In this case, the measures applied to the openings, which prevent solar gains towards the interior, are not sufficient to obtain better cooling of the building.

- M8: Improvement measures on roofs, façades, and installations

If all the improvement measures on roofs, façades, and installations are combined, savings of 77% and 87% in cooling and lighting consumption and emissions, respectively, are obtained; on the other hand, the cooling demand has savings of 39.1%. In addition, the overall rating improves to a value of 18.6A. In this case, similar to Measures M3 and M5, a set of improvements in the thermal envelope is proposed, this time in roofs and façades, which, despite showing savings of 1% and 1.2%, respectively, in cooling demand, when combined with the improvements in installations, greatly improve the energy efficiency and therefore the overall rating of the building. On the other hand, it was determined that hot air from inside the building is concentrated on the roofs and that the thermal insulation of the façades, while preventing heat from entering the building, also retains the heat that has already been generated. These two situations mean that there is still a considerable demand for cooling, which is counteracted by the incorporation of energy-efficient air-conditioning equipment, thus minimizing the need for cooling, while at the same time helping to maintain the internal comfort conditions of the building. In addition, these cooling units generate a percentage savings in energy consumed, as do the panels and the new LED luminaires. From an energy point of view, this combination is favorable for building refurbishment.

- M9: Improvement measures in roofs, openings, and installations

It can be observed that, if all the improvement measures in roofs, openings, and installations are combined, savings of 80.5% and 87% in cooling and lighting consumption and emissions, respectively, are obtained; on the other hand, cooling demand has savings of 48.4%. In addition, the overall rating improves to a value of 17.6A. In this case, similar to Measures M3, M5, and M8, a set of improvements in the thermal envelope is proposed, this time in roofs, which, despite demonstrating savings of 1% in cooling demand, when combined with the improvements in installations, achieves a much greater improvement in energy efficiency and therefore the overall rating of the building. It should be noted that, as analyzed in the previous section, it is the combined improvements to openings and installations that represent the highest percentage of savings in cooling demand. For this reason, although this combination includes the roof improvement package, which, if applied individually, still creates a considerable cooling demand, this time it is offset by the incorporation of energy-efficient air-conditioning equipment, thus minimizing the need for cooling and, at the same time, helping to maintain the internal comfort conditions of the building. In addition, these cooling units generate a percentage savings in energy consumed, as do the panels and the new LED luminaires. From an energy point of view, this combination is favorable for building refurbishment.

- M10: Improvement measures in façades, openings, and installations

This time, if all the improvement measures in façades, openings, and installations are combined, savings of 82.9% and 87% in cooling and lighting consumption and emissions, respectively, are obtained; on the other hand, the cooling demand has savings of 54.7%. In addition, the overall rating improves to a value of 17.3 A, the best rating of the eleven proposed. As with Measures M3, M5, M8, and M9, a set of improvements to the thermal envelope is proposed, this time in façades, which, despite showing savings of 1.2% in cooling demand, when combined with the improvements in installations, greatly improves the energy efficiency and therefore the overall rating of the building. As analyzed in the previous section, it is the combined improvements to openings and installations that represent the greatest percentage of savings in cooling demand. Although this combination includes the façade improvement package, which, when applied individually, still has a considerable cooling demand, this time it is offset by the incorporation of energy-efficient air-conditioning equipment, thus minimizing the need for cooling and contributing to maintaining the building's internal comfort conditions. In addition, these cooling units generate a percentage savings in energy consumption, as do the panels and the new LED luminaires.

- M11: Improvement measures on roofs, façades, openings, and installations

This last proposal is the combination of the four sets of measures applied to the roof, façades, openings, and installations. If applied, savings of 78.9% and 87% in cooling and lighting consumption and emissions, respectively, can be obtained; on the other hand, cooling demand has savings of 44.2%. In addition, the overall rating improves to a value of 18.1 A. In this case, the set of measures that contribute most to this combination are those applied to openings and installations, which allow for counteracting the hot air contained inside the building that is generated by the thermal insulation applied in façades and roofs, thus reducing cooling demand. In addition, the cooling equipment, solar panels, and new LED luminaires allow high savings in energy consumption. From an energy point of view, this combination is favorable for building renovation.

The roof and façade improvement measures, when evaluated in isolation or combined, show that the roof–façade combination tends to increase cooling demand and reduce its overall energy performance, with a negative variation of −10.1% in cooling demand and an overall rating that drops to 132.4 E. This result is explained by the tendency of warm air to accumulate indoors when combining roof insulation with façade insulation, increasing the need for cooling despite slight individual reductions (1% in roofs). Therefore, this combination is not favorable for renovation from an energy point of view and should be avoided or managed with complementary strategies (Figure 4).

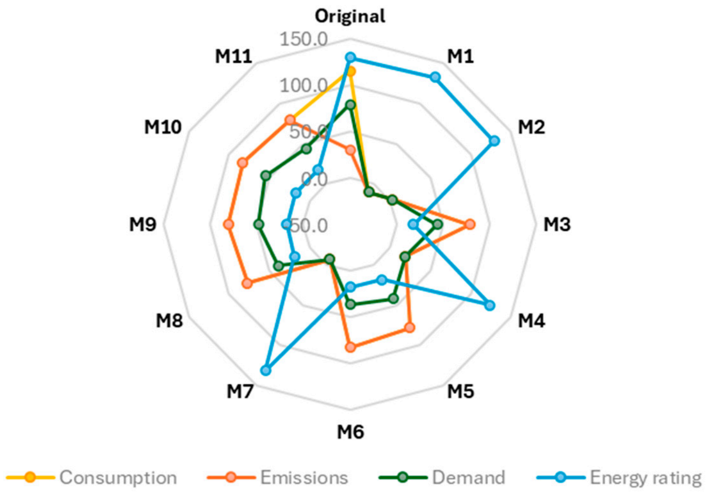


Figure 4. Radial graph of percentage improvement in consumption, emissions, and demand (%). Energy rating ($KgCO_2/m^2$).

In contrast, combinations that apply improvements to openings and installations (M6) or installations with the thermal envelope (M3, M5, M8, M9, M10, and M11) show significant improvements in cooling demand and overall performance (supported by ratings between 17.3 A and 18.6 A). In particular, the synergy between openings and installations produces the greatest cooling savings (53.5% in M6) and a notable decrease in energy consumption thanks to efficient HVAC equipment, solar panels, and LED luminaires, suggesting that strategies that prioritize improvements in installations and solar control of openings are the most effective for energy renovation.

3.3. Economic and Cost–Benefit Analysis

In this section, the economic and payback aspects for each combined measure will be analyzed in order to determine which is the most convenient and feasible according to these parameters. The criterion for this selection is that the combined measures analyzed have a low number of years of amortization, i.e., that the investment to be made to implement the measure can be recovered in a few years.

In addition, it is necessary to specify that, as this is a study on the energy and social rehabilitation of a building located in Peru, the study of the economic cost of the improvement measures will be carried out in the nuevo sol currency, which is the one used in this country, but later the conversion to euros will be carried out. The prices will be obtained through the CYPE price generator and the budget sheets of the products that will be used as part of the improvement measures. The prices of the rehabilitation measures have been set in accordance with the Peruvian economy (data provided by local construction company).

Below is a table showing the eleven proposed improvement measures combined, their useful life, their implementation costs, the years of amortization, and the new rating that would be obtained after applying each measure (Table 14), for later analysis.

Table 14. Data on the useful life, costs, and years of amortization of the combinations of the sets of measures.

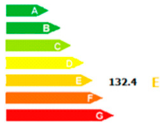
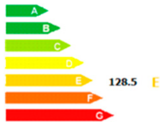
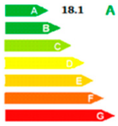
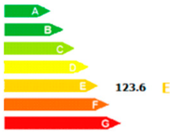
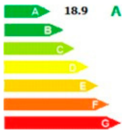
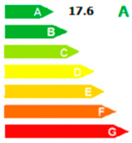
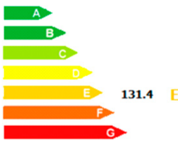
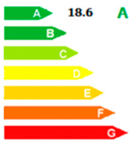
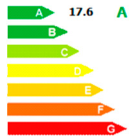
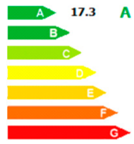
Data on the Useful Life, Costs, and Years of Amortization of the Combinations of the Sets of Measures				
Combination of Measure Sets	**Useful Life (Years)**	**Implementation Cost**	**Amortization (Years)**	**New Rating**
M1 ROOF + FAÇADES	60	EUR 416,912.51	−12.9	
M2 ROOF + OPENINGS	60	EUR 633,087.44	69.3	
M3 ROOF + FACILITIES	50	EUR 1,383,089.79	1.2	
M4 FAÇADES + OPENINGS	50	EUR 302,559.52	5	
M5 FAÇADES + INSTALLATIONS	40	EUR 1,052,261.88	0.9	
M6 ROOMS + FACILITIES	40	EUR 1,268,736.80	1.1	
M7 ROOF + FAÇADES+ OPENINGS	85	EUR 676,279.74	−31.1	
M8 ROOF + FAÇADES + INSTALLATIONS	75	EUR 1,426,282.09	1.2	

Table 14. *Cont.*

Data on the Useful Life, Costs, and Years of Amortization of the Combinations of the Sets of Measures				
Combination of Measure Sets	**Useful Life (Years)**	**Implementation Cost**	**Amortization (Years)**	**New Rating**
M9 ROOF + OPENINGS + INSTALLATIONS	75	EUR 1,642,457.01	1.4	
M10 FAÇADES+ OPENINGS + INSTALLATIONS	65	EUR 1,311,929.10	1.1	
M11 ROOF + FAÇADES+ OPENINGS + INSTALLATIONS	100	EUR 1,685,649.31	1.4	

- M1: Improvement measures on roofs and façades

This combined improvement measure has a useful life of 60 years, which is the sum of 35 years of useful life of the roof measures plus 25 years of useful life of the façade measures. The cost involved in this proposal is 416,912.51, making it the second-cheapest measure, which could be amortized over −12.9 years. This means that, all in all, if these two measures are combined, it would not be worth investing in this one because it is not cost-effective.

- M2: Improvement measures on roofs and openings

The second combined improvement measure also has a useful life of 60 years, which is the sum of 35 years of useful life of the roof measures plus 25 years of useful life of the measures in the openings of the building. The cost of this proposal is EUR 633,087.43, being the third-cheapest measure, which could be amortized over 69.3 years. It can be seen that the amortization period is very high, so in principle, this would not be a favorable measure.

- M3: Improvement measures on roofs and installations

This combined improvement measure has a useful life of 50 years, which is the result of the sum of 35 years of useful life of the measures applied to roofs plus 15 years of useful life of the measures applied to the facilities of the project. The cost of this proposal is EUR 1,383,089.79, which could be amortized over 1.2 years. This measure requires a higher amount of investment because it is composed of the two most expensive measures, which are the implementation of new roofs and installations. However, the years of amortization are ideal, as the investment could be recovered in a very short time, which indicates that it is a measure worth investing in because it is profitable.

- M4: Improvement measures for façades and openings

This fourth combined improvement measure has a useful life of 50 years, which is the sum of 25 years of useful life of the measures applied to the façades plus 25 years of useful life of the measures applied to the openings of the building. The cost of this proposal is EUR 302,559.52, which could be amortized over 5 years. The cost of this measure is the cheapest of all the options considered; the number of years of amortization is a reasonable number to be able to recover the investment made, so it would be worthwhile to invest in the measure.

- M5: Improvement measures for façades and installations

The fifth combined improvement measure has a useful life of 40 years, which is the sum of 25 years of useful life of the façade measures and 15 years of useful life of the facility measures of the project. The cost involved in this proposal is EUR 1,052,261.88, which could be amortized over 0.9 years. This measure also has a high cost because it contains improvements to installations; however, the number of years of amortization is a reasonable time to be able to recover the investment made; therefore it would be convenient to invest in the measure.

- M6: Improvement measures for openings and installations

This sixth combined improvement measure has a useful life of 40 years, which is the sum of 25 years of useful life of the measures applied to the openings of the building plus 15 years of useful life of the installation measures. The cost of this proposal is EUR 1,268,736.80 euros, which could be amortized over 1.1 years. Although it is true that the cost of the measure is high, the years of amortization are few, which means that it is worth investing in this measure.

- M7: Improvement measures for roofs, façades, and openings

The seventh combined improvement measure has 85 years of useful life, which is the sum of 35 years of useful life of the measures on roofs, 25 years of the measures on façades, and 25 years of useful life of the measures applied to the openings. The cost of this proposal is EUR 676,279.74, which could be amortized over −31.1 years. This measure is one of the cheapest of all the proposals; however, the payback period is long, so it would not be advisable to invest in the measure because it is not cost-effective.

- M8: Improvement measures for roofs, façades, and installations

The eighth combined improvement measure has a useful life of 75 years, which is the sum of 35 years of useful life of the roof measures, 25 years of the façade measures, and 15 years of useful life of the installation measures. The cost of this proposal is EUR 1,426,282.09, which could be amortized over 1.2 years. This measure has the third-highest cost; however, this amount of money could be recovered in a few years, which means that it is worth investing in this measure.

- M9: Improvement measures for roofs, openings, and installations

The ninth combined improvement measure has 75 years of useful life, which is the sum of 35 years of useful life of the roof measures, 25 years of the measures applied to the openings of the building, and 15 years of useful life of the measures applied to the installations. The cost of this proposal is EUR 1,642,457.01, which could be amortized over 1.4 years. This measure has the second-highest cost; however, the amount of money invested could be recovered in a few years, making it a favorable measure.

- M10: Improvement measures for façades, openings, and installations

This combined improvement measure has 65 years of useful life, which is the sum of 25 years of useful life of the façade measures, 25 years of the measures applied to the openings of the building, plus 15 years of useful life of the measures applied in the installations. The cost of this proposal is EUR 1,311,929.10, which could be amortized over 1.1 years. The cost of this measure is high, but the years of amortization are few; therefore, it is advisable to invest in this measure.

- M11: Improvement measures on roofs, façades, openings, and installations

The last combined improvement measure has 100 years of useful life, which is the result of the sum of 35 years of useful life of roof measures, 25 years of façade measures, 25 years of the measures applied to the openings of the building, and 15 years of useful life of the measures applied to installations. The cost of this proposal is EUR 1,685,649.31, which could be amortized over 1.4 years. This measure is the most expensive of the eleven proposals because it combines all the possible improvements in the different elements of the building; despite this, the payback years are few, so it would be feasible and advisable to invest in this measure.

3.4. Energy and Economic Comparison Between the Initial State and the Adopted Solution

The rating of the building's thermal envelope and installations in the initial state is 129.4 $KgCO_2/m^2$ (E), and in the final state, after the selected improvements, it is 17.6 $KgCO_2/m^2$ (A).

The demand and emissions for heating and DHW are considered unquantifiable, as the program has not defined reference values for these demands. This is due to the climatic characteristics of the location, which, as it does not experience very low temperatures, does not require these systems. The opposite is true for the building's cooling demand, which is rated at 78.5 kWh/m^2 in its initial state and drops to 40.5 kWh/m^2 in its improved state. The emissions produced by the cooling system drop from 30.4 Kg CO_2/m^2 to 5.9 Kg CO_2/m^2. On the other hand, with regard to the emissions produced by the lighting system, in the initial state, they are 98.9 kg CO_2/m^2 due to the low efficiency and inadequate characteristics of the installations, and they go down to a value of 12.9 kg CO_2/m^2.

The differences between the initial characteristics of the envelope and installations and the characteristics with the improvement measures analyzed can be seen in the following Figures 5 and 6.

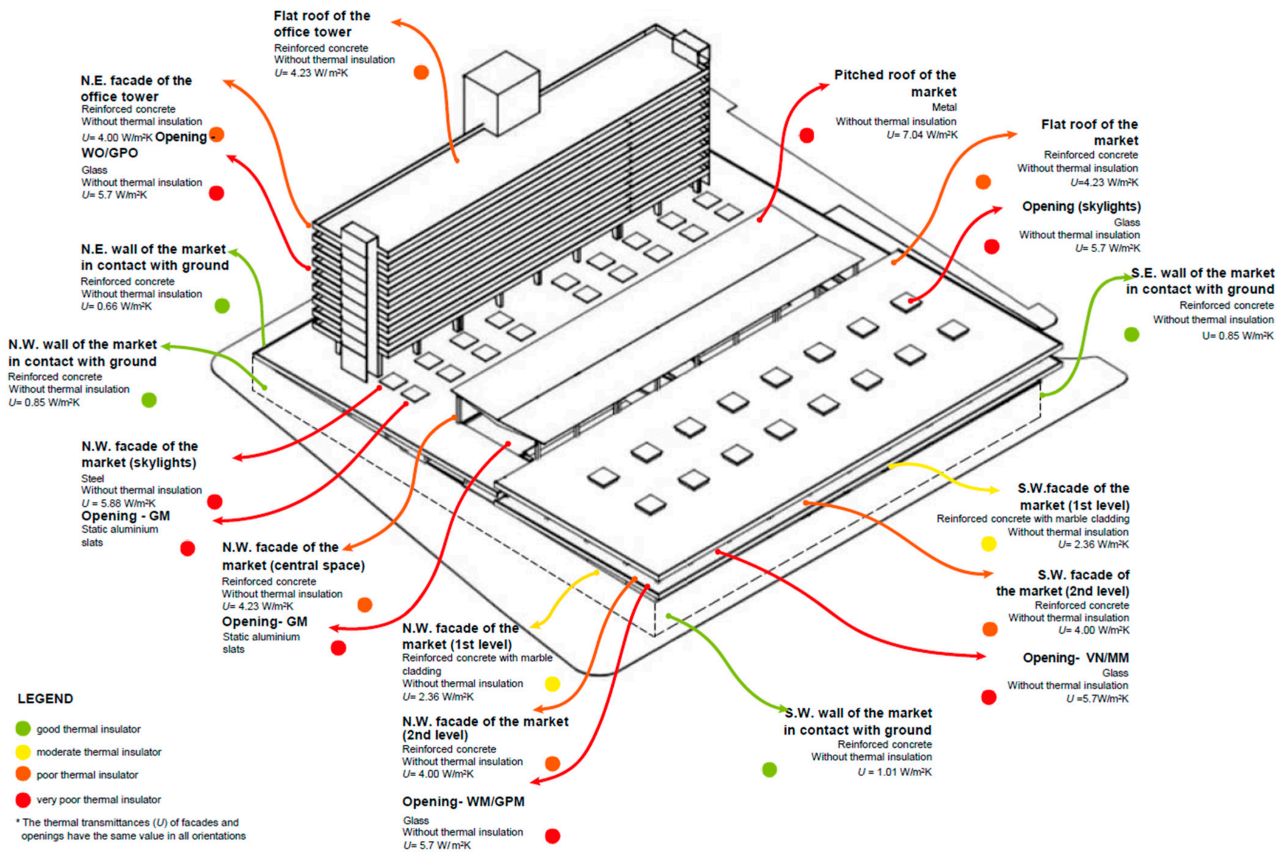


Figure 5. Isometry explaining the energy rating of the current state of the building.

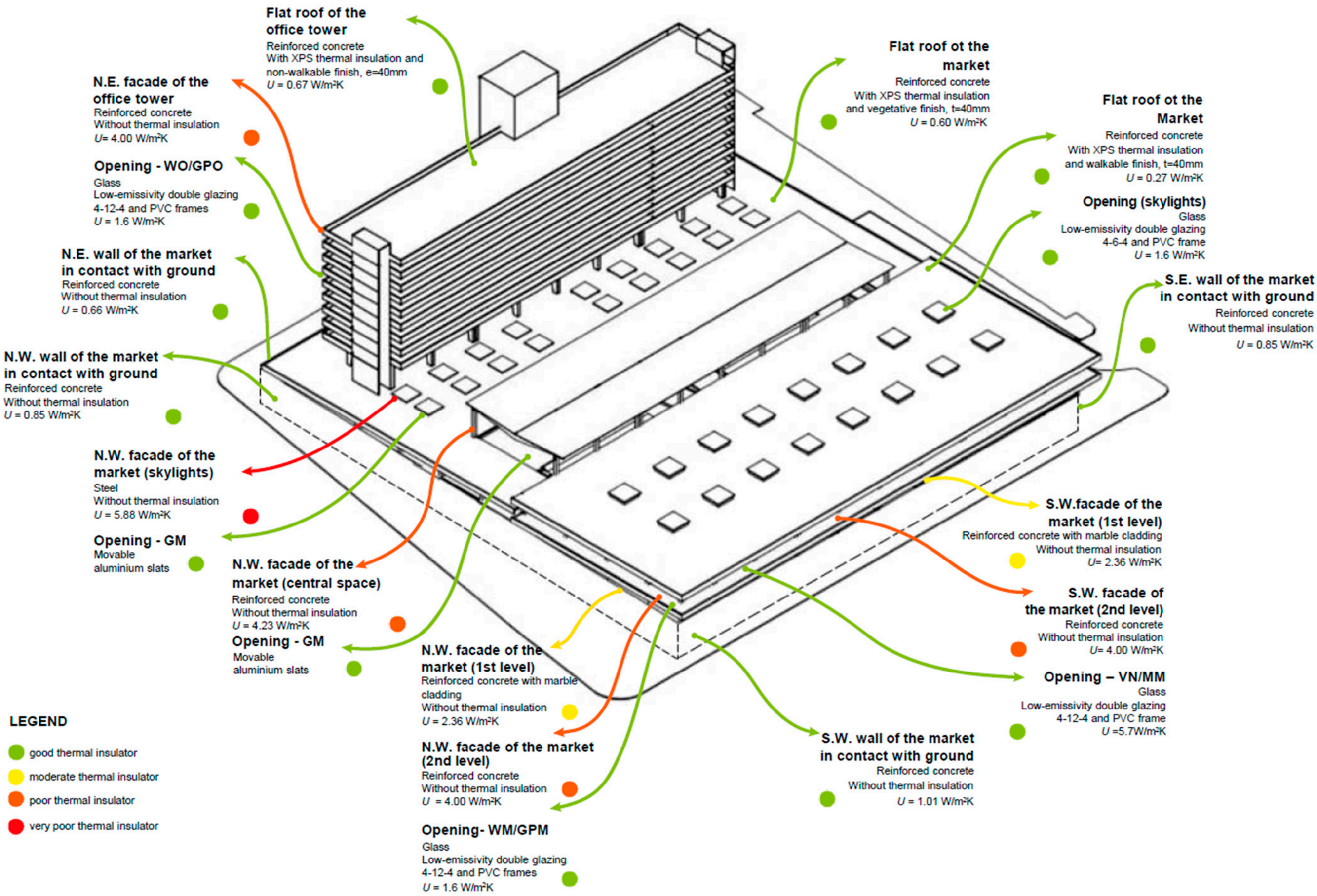


Figure 6. Explanatory isometry of the energy rating obtained by applying Measure M9.

The most energetically advantageous measure and, at the same time, the most economically viable that fits the objective of this work—to achieve energetic and social rehabilitation—is M9. This measure has an overall energy rating of 17.6 A, combines improvement measures applied to roofs, openings, and installations, has 75 years of useful life, and requires an investment of EUR 1,642,457.01, which can be amortized over 1.4 years. Although it is true that some measures also improve the overall energy rating of the building and can be amortized over a few years, this combination is considered the most favorable of all because it includes two improvement measures that are in line with the social rehabilitation of the building, which are the improvements to the roof and the installations, with the office tower refurbished by replacing the LED lights and adding an air-conditioning system.

The results demonstrate significant energy and economic gains by focusing interventions on openings and installations, especially with Measure M9, which obtains a rating of 17.6 A, a payback period of 1.4 years, and a useful life of 75 years. The evidence is consistent with similar studies, such as Salgueiro [22] and Calado [31], showing that envelope improvements and especially installations generate substantial reductions in demand and emissions when properly combined. While Salgueiro highlights the impact of insulation and renewable energy systems in reducing demand and carbon footprint, our analysis shows that improvements in windows, frames, and movable louvers can achieve similar or greater reductions in cooling demand, complemented by improvements in roofs and systems. In both cases, integrated interventions outperform isolated measures.

In terms of analysis and transferability, the results reinforce the idea that interventions targeting openings and systems are often the most energy-cost-effective, even when initial costs are high. This aligns with the findings of Calado and Echeverría [23,31], who note that improvements in installations can offer quick wins, but sustained efficiency is best achieved when acting on the envelope and combining measures. It is also noted that, as in the Spanish studies cited above, consideration of local climatic contexts is crucial to avoid solutions that, while efficient elsewhere, do not offer the same cost-effectiveness in the Peruvian location. Ultimately, the integrated strategy M9 demonstrates consistency with the literature, highlighting the need for packages of measures that combine the envelope, openings, and installations to maximize energy and social benefits.

4. Discussion

After conducting multiple energy and economic analyses in the Central Market of Lima (Peru), it is possible to conclude that the improvement measures applied to the building's openings and installations, although representing the most costly investments, are the ones that contribute most significantly to the project, since they result in a higher energy rating thanks to savings in consumption and demand for refrigeration and lighting. This highlights the importance of prioritizing these interventions to achieve optimal energy efficiency. The analysis of the thermal envelope and installations showed that interventions on openings and installations generate the greatest energy and economic impacts of all the measures evaluated. In particular, the replacement of glazing and frames on the northwest and southwest façades, the optimization of skylights, and the adoption of movable louvers offer significant reductions in unwanted solar gain, lower overall transmittance, and better control of air intakes, which translates into lower cooling demand and, consequently, lower emissions and operating costs.

On the other hand, improvements to the thermal envelope, such as façades and roofs, on their own, do not generate considerable savings in cooling demand and, in terms of cost-effectiveness, are not as efficient. However, when combined with facility measures, their impact is enhanced. In addition, roof improvements can have an important social benefit, as they can be transformed into meeting and leisure spaces or even generate economic income, thus increasing the social and economic value of the property.

In the case of roofs, it was observed that a lower thickness of thermal insulation can favor a better energy rating in certain contexts, as a greater thickness can retain more heat and increase cooling demand. This underlines the need to adapt improvement measures to the specific climatic conditions of the site in order to maximize energy benefits.

Peruvian regulations currently focus mainly on improvements in installations, such as LED lighting or air-conditioning systems. However, this study shows that interventions in openings, such as the replacement of glass or frames or the incorporation of movable louvers, also offer great potential for energy savings and should be considered in efficiency policies.

The limitations of the research are concentrated in several dimensions. On the one hand the estimates of demand and emissions for heating and domestic hot water are presented as non-quantifiable within the current framework due to the absence of reference values; sensitivity analyses and long-term simulations were not performed to capture seasonal variations and cost evolution. On the other hand, no sensitivity analyses or long-term simulations were performed to capture seasonal variations and cost evolution, and furthermore, the evaluation framework could be expanded to incorporate social and economic metrics (rental value, quality of life, and use of rehabilitated spaces) and to analyze impacts on the community.

The numerical results, on the other hand, should be interpreted according to the climatic and design conditions of the site; the magnitude of benefits may vary according to orientation, occupancy, and air-conditioning demand; furthermore, the model was not calibrated with measured energy consumption data (there were no historical records of the Central Market), although internal consistency checks and comparisons with reference studies in Peru and Spain were performed; the absence of quantitative validation represents a significant limitation that will be addressed in future research. However, the proposed approach combines improvements in the thermal envelope, openings, and systems and incorporates a social dimension into decision making, demonstrating that efficiency policies can generate multiple benefits, such as energy savings, cost reductions, improvements in comfort, and opportunities for social use of rehabilitated spaces.

5. Conclusions

The conclusions reached in this research indicate that the optimal scenario is M9, which integrates improvements in roofs, openings, and installations. It emerged as the most favorable option from energy and economic points of view, with an overall energy rating of 17.6 A, an estimated payback period of 1.4 years, and a useful life of 75 years. This scenario also has a social dimension, as it provides recreational and leisure space for users, in addition to improving the comfort of the building. This result reflects the synergy between technical interventions and their appropriate alignment with the objectives of social and economic rehabilitation.

Finally, this study highlights the importance of adopting a holistic approach that combines technical improvements with social interventions. Building retrofitting should focus not only on energy efficiency but also on enhancing the social and economic environment of the building. The reconversion of spaces such as the office tower and the creation of meeting and leisure areas in renovated areas can generate a positive social impact, promoting cultural change and improving the quality of life in the community.

Author Contributions: Conceptualization, K.S.-F.; Methodology, P.A.-B.; Software, K.S.-F.; Validation, P.A.-B.; Formal analysis, K.S.-F.; Investigation, P.A.-B.; Resources, K.S.-F.; Writing—original draft, K.S.-F.; Writing—review & editing, P.A.-B.; Supervision, P.A.-B. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data are not publicly available due to privacy or ethical restrictions.

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

References

1. Wang, X.; Wang, S.; Li, T. Research on the Performance and Energy Saving of Solar-Coupled Air Source Heat Pump Heating System: A Case Study of College Dormitory in Hot Summer and Cold Winter Zone. *Energies* **2025**, *18*, 3794. [CrossRef]
2. Álvarez, A.M. Challenges for Latin America: The Agenda for Sustainabale Development and Negotiations in the Twenty-First Century. *Probl. Desarro.* **2016**, *47*, 9–30. [CrossRef]
3. Angrisano, M.; Fabbrocino, F.; Iodice, P.; Girard, L.F. The evaluation of historic building energy retrofit projects through the life cycle assessment. *Appl. Sci.* **2021**, *11*, 7145. [CrossRef]
4. Mousavi, E.; Bhattacharya, A.; Betz, F.; Lautz, R. Evolution of Ventilation Measures and Energy Performance in Buildings with High Ventilation Demands: A Critical Review. *Energies* **2025**, *18*, 3603. [CrossRef]
5. Cáceres, A.L. Análisis de Ciclo de Vida Comparativo de Edificaciones Multifamiliares en Lima. Bachelor's Thesis, Pontificia Universidad Católica del Perú, Limá, Peru, 2016; pp. 1–69. Available online: http://tesis.pucp.edu.pe/repositorio/handle/123456789/6682 (accessed on 14 January 2023).
6. Ruiz, E. El Análisis de Ciclo de Vida. Metodología de Decisión y Evaluación Ambiental en El Sector de la Edificación. Grado en Arquitectura Técnica, Universidad de Los Andes, Bogotá, Colombia, 2016. Available online: http://hdl.handle.net/10251/66016 (accessed on 16 March 2023).
7. Schittich, C. *Rehabilitación*; Walter de Gruyter: Berlin, Germany, 2013.
8. Verónica, E.; Farroñán, R.; Christiam, G.; Chilicaus, F.; Edgardo, L.; Salinas, C.; Rojas, L.C.; Katherine, L.; Cotrina, C.; Licaparedolfo, G.S.; et al. Green Finance and the Energy Transition: A Systematic Review of Economic Instruments for Renewable Energy Deployment in Emerging Economies. *Energies* **2025**, *18*, 4560. [CrossRef]

9. Caneppele, L.B.; Nogueira de J, M.C.; de Vasconcellos, A.B. Avaliação Da Eficiência Energética E Custo Benefício No Uso De Coberturas Metálicas Em Supermercados Empregando O Software Energyplus. *Rev. Eletrônica Em Gestão, Educ. e Tecnol. Ambient.* **2013**, *9*, 1971–1979. [CrossRef]
10. Ministerio de Energía y Minas. Guía de Orientación del Uso Eficiente de la Energía y de Diagnóstico Energético. *Dir. Gen. Efic. Energética.* **2020**, *2*, 1–2. Available online: https://eficienciaenergetica.minem.gob.pe/Content/fileman/Uploads/Documents/Gu%C3%ADas%202022/GUIA%20SECTOR%20RESIDENCIAL_VF3.pdf (accessed on 3 March 2023).
11. Ríos-Fernández, J.C. Economic and environmental improvements using high energy efficiency HVAC in supermarkets. *Clean Technol. Environ. Policy.* **2020**, *22*, 1417–1429. [CrossRef]
12. Cecchinato, L.; Corradi, M.; Minetto, S. Energy performance of supermarket refrigeration and air conditioning integrated systems. *Appl. Therm. Eng.* **2010**, *30*, 1946–1958. [CrossRef]
13. Sherman, R.; Naganathan, H.; Parrish, K. Energy savings results from small commercial building retrofits in the us. *Energies* **2021**, *14*, 6207. [CrossRef]
14. Cordano, A.L.V.; Balistreri, E.J. The marginal cost of public funds of mineral and energy taxes in Peru. *Resour. Policy* **2010**, *35*, 257–264. [CrossRef]
15. De la Cruz Torres, D.G.; Mazadiego, L.F.; Bolonio, D.; Pons-Esparver, R.R. Long-Term Forecast of Energy Demand towards a Sustainable Future in Renewable Energies Focused on Geothermal Energy in Peru (2020–2050): A LEAP Model Application. *Sustainability* **2024**, *16*, 4964. [CrossRef]
16. Colina-Calvo, A.O. A Comprehensive Review of Peru's Energy Scenario: Advancing Energy Access, Sustainability, and Policy Implications. *Rev. Kawsaypacha Soc. y Medio Ambient.* **2024**, *2024*, 1–24. [CrossRef]
17. Never, B.; Kuhn, S.; Fuhrmann-Riebel, H.; Albert, J.R.; Gsell, S.; Jaramillo, M.; Sendaza, B. Energy saving behaviours of middle class households in Ghana, Peru and the Philippines. *Energy Sustain. Dev.* **2022**, *68*, 170–181. [CrossRef]
18. Alva, G.; Liu, L.; Huang, X.; Fang, G. Thermal energy storage materials and systems for solar energy applications. *Renew. Sustain. Energy Rev.* **2017**, *68*, 693–706. [CrossRef]
19. Liu, P.; Pistikopoulos, E.N.; Li, Z. An energy systems engineering approach to the optimal design of energy systems in commercial buildings. *Energy Policy* **2010**, *38*, 4224–4231. [CrossRef]
20. Ren, Z. A Literature Review on the Use of Weather Data for Building Thermal Simulations. *Energies* **2025**, *18*, 3653. [CrossRef]
21. Evangelisti, L.; De Cristo, E.; De Lieto Vollaro, R. In Situ Winter Performance and Annual Energy Assessment of an Ultra-Lightweight, Soil-Free Green Roof in Mediterranean Climate: Comparison with Traditional Roof Insulation. *Energies* **2025**, *18*, 4581. [CrossRef]
22. Salguiero, M.J. *Mercados de Hierro en España: Rehabilitación y Mejora Energética*; E.T.S. Arquitectura (UPM): Madrid, Spain, 2021; pp. 49–111.
23. Echevarria, M. *Eficiencia Energética en el Mercado de la Paz (Madrid)*; E.T.S. Arquitectura (UPM): Madrid, Spain, 2022.
24. Escrivá-Escrivá, G. Basic actions to improve energy efficiency in commercial buildings in operation. *Energy Build* **2011**, *43*, 3106–3111. [CrossRef]
25. Cosio, F.P.T. *Nuevo Mercado Central de Lima: Centro Gastronómico y Residencia Para Estudiantes en el Centro Histórico de Lima*; Pontificia Universidad Católica del Perú: Lima, Peru, 2019.
26. De Cristo, E.; Evangelisti, L.; Guattari, C.; De Lieto Vollaro, R. An Experimental Direct Model for the Sky Temperature Evaluation in the Mediterranean Area: A Preliminary Investigation. *Energies* **2024**, *17*, 2228. [CrossRef]
27. González, V.G.; Bandera, C.F. A building energy models calibration methodology based on inverse modelling approach. *Build. Simul.* **2022**, *15*, 1883–1898. [CrossRef]
28. Hong, T.; Langevin, J.; Sun, K. *Building Simulation: Ten Challenges*; Springer: Berlin/Heidelberg, Germany, 2018. [CrossRef]
29. Gómez, G.; Soto, S.; Suástegui, J.A.; Acuña, A. A New Proposal for the Use of Cooling Degree Hours for the Energy Simulation of Residential Buildings in Mexico. *Energies* **2025**, *18*, 4554. [CrossRef]
30. SERVICIO NACIONAL DE METEOROLOGÍA E HIDROLOGÍA DEL PERÚ—SENAMHI, Climas del Perú—Mapa de Clasificación Climática Nacional. 2010. Available online: https://www.senamhi.gob.pe/?p=mapa-climatico-del-peru (accessed on 20 March 2023).
31. Bonnin, C.C. *Rehabilitación Energética del Mercado de San Cristóbal*; E.T.S. Arquitectura (UPM): Madrid, Spain, 2023.