frontiers | Frontiers in Built Environment

TYPE Original Research
PUBLISHED 03 October 2023
DOI 10.3389/fbuil.2023.1264368

OPEN ACCESS

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RECEIVED 20 July 2023
ACCEPTED 25 September 2023
PUBLISHED 03 October 2023

CITATION
Maciá-Torregrosa ME, Camacho-Diez J and González-Lezcano RA (2023), Strategies for integral rehabilitation and improvement of the energy efficiency of Lagos Park building in Madrid.
Front. Built Environ. 9:1264368.
doi: 10.3389/fbuil.2023.1264368

Strategies for integral rehabilitation and improvement of the energy efficiency of Lagos Park building in Madrid

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As a primary goal, Inadequate energy consumption and outdated construction systems are causing financial losses for homeowners. Spain's failure to meet European guidelines on CO_2 emissions highlights the urgent need to address the energy inefficiency of buildings, responsible for 40% of such emissions. This article presents a comprehensive refurbishment project undertaken in the Lagos Park residential building in Madrid. The paper offers a detailed analysis of common building issues related to excessive humidity in the surrounding areas and deficiencies in the energy performance of the building envelope, including facades and roofs. Precise measures for achieving compliance with the Spanish Technical Building Code (CTE), as well as enhancing energy efficiency and functionality, are explained through the renovation of the building envelopes. The study also encompasses improvements made to the domestic hot water supply systems and the air-conditioning system, which contribute to the building's attainment of an optimal energy rating (energy Class A). The extensive renovation undertaken in the complex has transformed Lagos Park homes into "zero energy consumption" residences. The strategies employed, ranging from electrical appliances to the house's structural design, are all geared towards maximizing energy usage efficiency, resulting in significantly reduced monthly electricity bills by 65%–75%.

KEYWORDS
architecture, refurbishment, sustainability, energy evaluation, energy saving

1 Introduction

Existing buildings consume an inordinate amount of energy worldwide. This consumption negatively affects the environment and the economy, so there is a need to improve the energy performance of buildings by retrofitting existing buildings (Mejjaouli and Alzahrani, 2020). Many cities are striving to develop an urban transformation strategy to move from traditional cities to sustainable cities. Improving the energy efficiency of buildings, especially existing buildings, is key to combating climate change (Gupta and Gregg, 2018).

1.1 Background

On 25 September 2015, world leaders gathered at the historic Sustainable Development Summit adopted the 2030 Agenda containing 17 Sustainable Development Goals (SDGs) that govern the efforts of the countries that are part of the United Nations system in order to achieve a sustainable world by 2030 (Gil, 2018).

Among the goals set out, with specific targets to be achieved in the next 15 years, SDG No. 9 aims to "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation" and more specifically SDG No. 11, which seeks to "Make cities and human settlements inclusive, safe, resilient and sustainable." In relation to building, these goals pursue technological progress that should underpin efforts to achieve environmental goals, such as increasing resource and energy efficiency, reducing carbon dioxide emissions and ensuring people's access to safe, adequate, affordable and sustainable housing.

By achieving these two SDGs, the aim is to improve the quality of life of citizens, the prosperity of cities in economic terms, as well as care for the environment.

The European Directive 31/2010 and its 2020 targets have been made effective through the enactment of national laws and regulations. However, they impose complex obligations for existing buildings towards NZEB and do not take into account other real issues (Wells et al., 2018; Hu, 2019; Abrahamsen et al., 2023). It is not only important to achieve a high level of energy efficiency, but also to think about retrofitting actions to mitigate the impact of natural hazards. Nowadays, restoration interventions are conceived that seek a minimum environmental impact in recent buildings. Greenhouse gas emissions are reduced using criteria that are met within a life-cycle analysis, while energy savings are achieved with cost-effective retrofit actions that ensure higher benefits in terms of comfort (Loli and Bertolin, 2018). This issue has been neglected for years, especially in the building sector, but these phenomena are becoming more and more influential and frequent. For this reason, the idea of building resilience is being developed (Wilkinson et al., 2016), which represents the measure of their ability to recover or adapt to an unfavorable situation, an event, or a change in the use of the building (Matthews et al., 2014). The energy consumption inside our buildings comes from the different equipment and facilities in them such as air conditioning, heating, domestic hot water (DHW) generation, the entire lighting system and electrical appliances. Of all of them, heating and air conditioning are the systems that consume the most energy, followed by DHW production. Lighting and appliances take last place. A comfortable interior architecture with some good practices that help us save.

Resilience is a complex challenge at any scale, including that of building systems. In other words, buildings have to be able to survive and maintain their own functionality (Folke et al., 2004) and performance even in an uncertain future. In addition, environmental degradation accelerated by climate change and global warming and by increasing frequency and severity of disturbances. Buildings are largely responsible for global and local climate change (Santamouris, 2016) but, at the same time, they have to resist these phenomena in terms of performance and dynamic reaction.

In fact, facades play an important role in the urban context, as the surface area of facades exceeds that of roofs and sometimes streets by a huge amount of square meters. In addition, each side of a building facade must be appropriate for the environment it faces: interior and exterior (Zhang et al., 2022). Most existing building facades are in need of rehabilitation, but current practices do not require sufficient attention to designing systems that adapt to changing external conditions. Therefore, it is desirable to predict future rehabilitation needs, satisfying the principles of resilient design. In particular, façades have to mitigate the increase or decrease of temperatures in the future, although it is obvious that this function must be supported by the whole building-floor system. The influence of facades requires particular analysis at both the building and pedestrian levels. Moreover, one of the crucial elements defining the energy consumption in the building envelope are the connections between windows and facades that can contribute up to 40% to the total heat loss caused by thermal bridges in the building envelope (Misiopecki et al., 2018). This research aims to expose architectural rehabilitation strategies that favor the reduction of energy consumption of a building by increasing the maximum conditions of thermal comfort through the improvement of the building envelope, always betting on a quality architecture.

1.2 Literature review

One of the alternatives to reduce energy consumption in buildings, recognized and used internationally, is to establish standards for the evaluation and classification of buildings in terms of energy requirements (energy performance) (Fossati et al., 2016). Environmental problems, especially climate change, have become a serious global problem that citizens must solve. In the building sector, the sustainable building concept is being developed to reduce greenhouse gas emissions (Liu et al., 2015). Optimization models for the improvement of energy management are mainly aimed at minimizing the energy consumption of residential buildings during the early design phases (Elbeltagi et al., 2023). In Spanish buildings we can estimate that 55% of the existing housing stock was erected before 1980 (Serrano and Sanchis, 2015), without adequate thermal insulation in facades and roofs since there were no applicable energy efficiency regulations until 1979 (de Gobierno, 1979). Buildings often do not perform at optimal levels and often fail to meet design predictions. These failures affect energy efficiency, indoor environmental quality and occupant satisfaction. Performing energy audits determines and categorizes performance problems that lead to energy inefficiency and inadequate indoor environmental quality (Borgstein et al., 2018). Through various works (Cano-Marín et al., 2014; Cervero Sánchez and Agustín Hernández, 2015) on the rehabilitation of dwellings built during the 1970s, it is possible to observe the analysis of the common pathologies existing at that time and to verify the compliance of different constructive solutions that allow the improvement of the thermal conditions of the buildings. Likewise, it is possible to analyze how some buildings have been rehabilitated (Diaz et al., 2012) through the detailed description of functional aspects, structural safety conditions, degree of thermal insulation, acoustic conditions, fire protection, accessibility and maintenance of these, which elaborate proposals aimed at reducing the most notable differences. On the other hand, dwellings built between 1980 and 2007, before the approval of the Technical Building Code, have a thermal insulation in their construction systems that is far below what is necessary and essential for adequate thermal comfort.

There are methodologies (Alonso, 2015) for the constructive evaluation of facades in the rehabilitation of social housing. This evaluation aims to assess their impact on the quality of the indoor environment and on the reduction of energy demand for thermal conditioning. Through the analysis of some studies carried out by other authors (Peinado et al., 2012), it is possible to evaluate how ETICS (External Thermal Insulation Composite Systems) on the exterior made with mineral wool improve the acoustic performance with respect to the initial façade and also to systems made with Expanded Polystyrene (EPS) panels. There are other studies (Carbonell, 2016) on comparisons between different façade solutions for the same building. Through them, it is possible to check the percentages of improvement obtained from one solution to another. Some researchers (Negendahl and Nielsen, 2015) point out that energy optimization focuses on certain parameters of the building envelope (building energy consumption, capital cost, daylight distribution and indoor thermal environment). Thanks to comparative dynamic simulations it is possible to see the interaction between the different zones of a building in relation to the energy performance of the building as a whole (Jung et al., 2018).

It is also possible to observe how some studies link the beneficial effects on the health of the population of strategies related to the inclusion of thermal insulation in dwellings (Chapman et al., 2008) The gradual incorporation of improvements in the energy efficiency of a building, taking into account European directives, makes it possible to use the least amount of final energy to satisfy the comfort of the users (Martín-Consu et al., 2014).

Houses lose money thanks to inadequate energy consumption and anachronistic and often ill-advised construction systems. Spain is still far from complying with European guidelines to reduce CO_2 emissions, 40% of which are produced by the energy inefficiency of buildings. Moreover, as indicated in some directives (Directiva, 2010/31/UE, 2010; Directiva, 2012/27/UE, 2012; Directiva, 2018/2002/UE, 2018; Directiva, 2018/844/UE, 2018) and regulations (Reglamento, 2018/1999/UE, 2018), the measures implemented to improve the energy efficiency of buildings should not be limited only to the renovation of the building envelope but should also incorporate passive elements that are part of the techniques aimed at reducing energy needs for heating and cooling and the use of energy for lighting and ventilation. In Spanish residential buildings we can estimate that half of the energy consumption is due to heating and cooling systems (Sendra et al., 2013). Between 25% and 30% of the heating needs are due to heat losses originating from the doors and windows of the home (De La Osa, 2016).

In general, the main hygrothermal problem of the most commonly used facade solutions in the continental climate zone of Spain throughout the century is the interruption of the outer layer of the solid wall and the insulating material at the junction with the horizontal structure or the pillars. There were no movement joints between the structural components and the facades, leading to numerous cracks and fissures in the brick walls (Zaparaín, 2016). Thermal bridges and problems of interstitial condensation and water seepage appeared in the joints between the brick and mortar and cracks (Monjo, 2005). Another problematic point of façade solutions is roller shutters. Traditionally, the function of solar protection and control had been solved with cord or booklet shutters (Feijó-Muñoz et al., 2019). It is from the 1950s onwards that the use of roller shutters on the inner leaf of the enclosure became generalized, without insulation in most cases. Only in recent decades has this solution been improved with roller shutters integrated into insulated windows (Feijó-Muñoz et al., 2018).

1.3 Research gap

Currently, the European framework on energy efficiency of the building stock (Directiva, 2010/31/UE, 2010) requires a 55% reduction of greenhouse gas emissions and at least 32% from renewable energies by 2030; this should be increased to 38%–40% in accordance with the Climate Target Plan. Considering that up to 40% of CO_2 emissions in Europe come from household energy needs, the transition to clean alternatives such as this will be essential in the fight against global warming. Aerothermal will be one of the keys to the decarbonization of human activity in line with the Paris Agreement (2016) within the framework of the United Nations Framework Convention on Climate Change. All these data necessarily imply that the existing building stock must be rehabilitated and adapted to the new criteria inexorably.

Although there are numerous studies related to the use of geothermal energy in buildings (Ruiz-Larrea, 2010; Sanz et al., 2016; Sekret, 2018), the environmental and economic return problems make us consider another source of clean renewable energy alternative to fossil fuels, such as aerothermal energy (Directiva, 2009/28/CE, 2009), a system that captures energy from the air and stores it to provide domestic hot water, heating and cooling for the home. The integration of renewable energy technologies and building renovation are the two main procedures to improve the energy sustainability of buildings at the neighborhood scale (Le Guen et al., 2018).

Specifically, this article aims to expose the problems detected in the integral rehabilitation of the Lagos Park building and to present the architectural solutions carried out to provide the building with optimum energy efficiency to provide its tenants with the adequate energy comfort required by current regulations.

The work has started with a study of the building from the initial evaluation (inspection and data collection, identification of pathologies, definition of qualities, intervention strategies.), to the Rehabilitation Plan (intervention and improvement proposals, economic estimation, technical reports, rehabilitation project, execution and management of the works.) all of this from an integrated approach that seeks both the energy improvement of the building and its comfort, accessibility, use and safety. In June 2015, the developer iKasa called a restricted ideas competition in order to carry out a comprehensive functional and energy rehabilitation of one of the most relevant developments within its Residential Heritage Division. To this end, it invited some of the most prestigious architectural firms in Madrid to participate in the competition, and the winner was CMA+ Q's proposal under the slogan "Smart living in Nature."

FIGURE 1
Main image and location of the Lagos Park building.

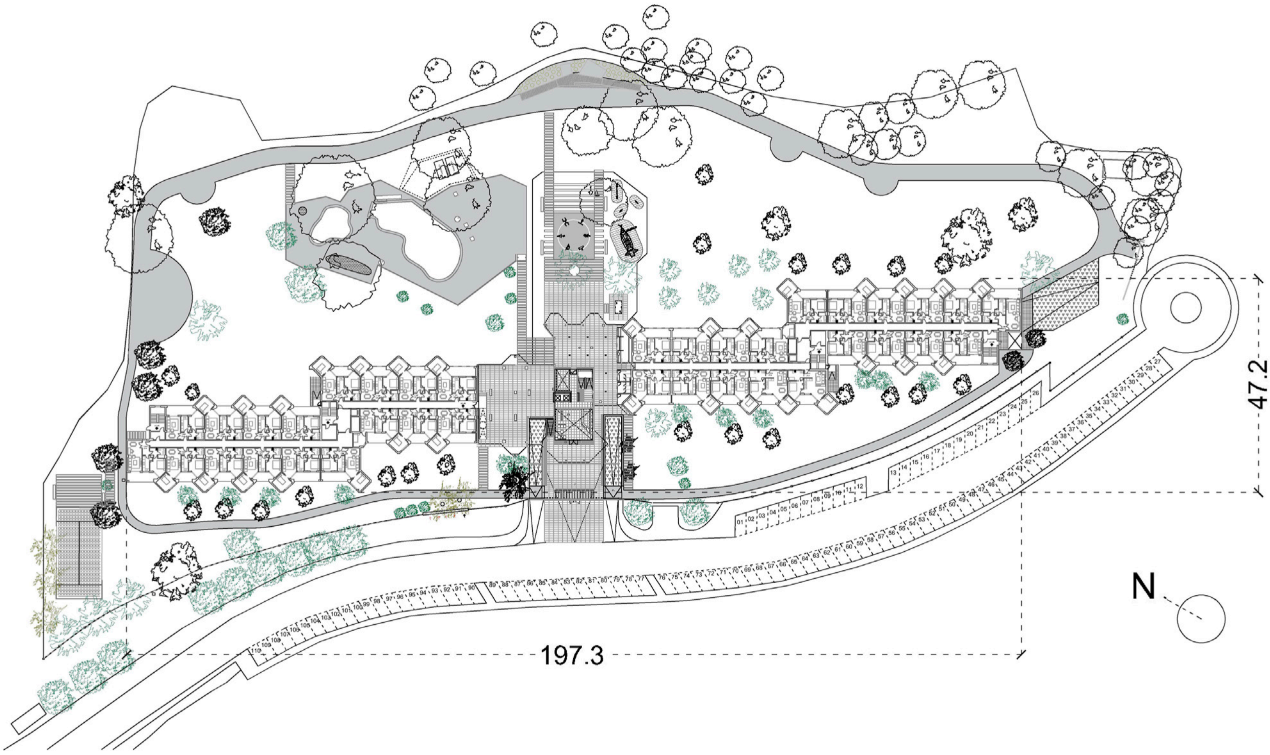

FIGURE 2
Main floor plan, general dimensions and orientation of the Lagos Park building.

1.4 Objectives

The main objective of this article is to expose the construction strategies that have been carried out in the rehabilitation of the Lagos Park building, which was initially formed by 141 apartments to adapt it, not only to the new regulations in order to turn it into a building of almost zero energy consumption, but also to the architectural, compositional and design criteria that allow to update the interior and exterior appearance of the building, expanding it to 151 housing units. A zero-energy house is a dwelling that does not rely on external

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supplies for its proper functioning. This means it has very low energy consumption, and the little energy it needs is generated within the construction itself through renewable energy sources.

The specific objectives to be achieved in the comprehensive renovation of the building are as follows:

- To grant maximum energy efficiency to the building, providing it with an air conditioning system based on aerothermal energy.
- Transform the envelope of the entire facade and roof with a new thermal and acoustic insulation.
- To give a high-level residential character to the complex by providing common leisure, cultural and sports areas with an aesthetic and functional renovation.

2 Materials and methods

2.1 Previous study

The Lagos Park building was built in 1992, its main attraction being its extraordinary location in the middle of the forest park of Granja y Molino de la Hoz, its spectacular garden of 19,649 m^2 and the tranquility of its location (Figure 1). The Lagos Park building (Figure 2) is a reference in the area and was, at the time of its construction, the most representative building of the iKasa brand. Therefore, one of the objectives of the refurbishment is to adapt the building to the new iKasa image, in terms of commitment to innovation, construction excellence and the enormous importance given to energy efficiency.

2.2 Location

Lagos Park is located in a unique environment, in the municipality of Galapagar, on the banks of the Molino de la Hoz reservoir on the Guadarrama river. Molino de la Hoz is a residential area located in the northwestern end of Las Rozas de Madrid, bordering with Torrelodones and Galapagar, in the first foothills of the Guadarrama mountain range, at the foot of the Galapagar pass. This residential area has an important environmental value, since it is located next to the Regional Park of the middle course of the Guadarrama River. In the historical-artistic area, the development is located near the El Gasco dam, which was built in the 18th century as a regulating reservoir for the unfinished Guadarrama canal. Nearby is the Retamar Bridge, which was built in the same century as a work to improve the Camino Real de Castilla.

In Lagos Park (Madrid), the summers are short, warm, dry, and mostly clear and the winters are long, very cold, and partly cloudy. During the course of the year, the temperature generally ranges from 0°C to 33°C and rarely drops below −5°C or rises above 37°C.

2.3 Construction characteristics of the building

The main construction characteristics of the existing building (Table 1) are as follows (Figure 3):

The use of materials and systems, some in disuse, others obsolete, facilitate the existence of very common pathologies (cracks in walls, detachment of plaster, dirt on facades, thermal bridges in the envelope, water filtration on roofs, capillarity from the subsoil in basements).

2.4 Thermographic analysis

The main challenge was the energy rehabilitation of the existing building complex. For this purpose, an extensive thermographic study was carried out in order to detect all pre-existing pathologies. Thermographic diagnosis is a widely used technique to reveal various types of building pathologies and also to determine an energy diagnosis. The problems detected in the thermographic camera study (Figure 4) are thermal bridges in slab edges and pillars, loss of airtightness and thermal insulation in the building envelope, water seepage in roof areas and air infiltration in many areas of the building.

As mentioned above, the building suffers from innumerable problems which, specifically, can be summarized as follows:

- Lack of insulation in the facade.
- Capillary water seepage.
- Costly and inefficient heating system.
- Condensation in interior walls.
- Lack of use in common areas (possibility of storage rooms).
- Antiquity of the building and apartments (deterioration of materials, aesthetic gap, etc.).

The FLIR E6-XT infrared camera with a 3-inch 320 × 240 color LCD display has been utilized for this study. This tool boasts a thermal resolution of 240 × 180 pixels and exhibits an accuracy of ±2% for hot/cold spot measurements (temperature range extended from −20°C to 550°C). In these images, darker colors, such as blue, indicate colder temperatures (approximately −5°C), while brighter colors, like red, represent warmer temperatures (around +3°C).

3 Results

In order to achieve the overall adaptation of the building to the regulatory standards without losing sight of the architectural quality of the building, the tasks are structured around the following guidelines:

- Adaptation to the Technical Building Code (in relation to Functionality, Safety and Habitability requirements).
- Adoption of various construction strategies to thermally insulate the building's exterior envelope.
- Analysis of the energy efficiency of the rehabilitated building (to check the effect of the action).

3.1 Adaptation to the Spanish technical building code (CTE)

The following is the analysis of the existing regulations, improvement actions and results achieved in each requirement: Functionality, Safety and Habitability.

TABLE 1 Construction characteristics of existing building.

Part of existing building	Constructive system conditions
Gross floor area	14,008 m² (according to land registry)
Number of floors	Basement + 4 + under roof
Vertical structure	Reinforced concrete
Horizontal structure	Prestressed joist floor slab and ceramic vault
Facade	1/2 foot of double hollow brick, non-ventilated air chamber and double hollow brick partition plastered on the inside. Exterior finish of “garbancillo” type monolayer
Roof	Slate and stoneware tiled terraces
Domestic hot water production	Individual electric water heaters
Heating	Electric underfloor heating

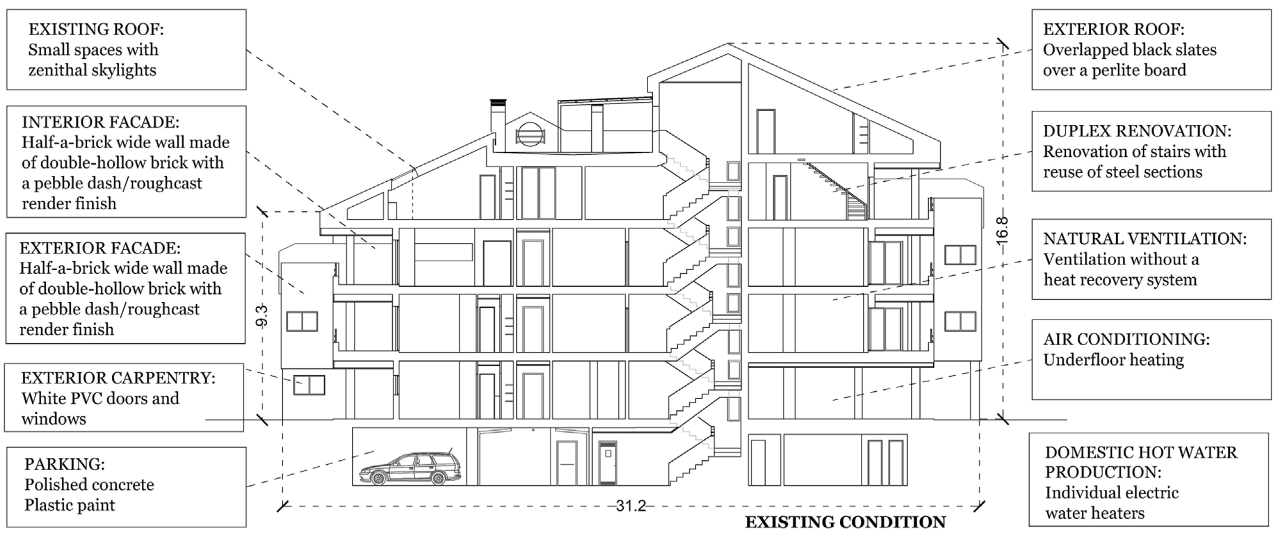

FIGURE 3
Main construction features of the building.

3.1.1 Functionality

In relation to Usability, the existing vertical and horizontal communication elements have not been substantially modified, except for the incorporation of independence vestibules in the protected stairways and two new evacuation exits in the central stairways to comply with the CTE (Técnico de la Edificación, 2018).

Regarding Accessibility, existing elements of architectural barriers on the first floor have been corrected, resulting, both the access to the building and its common areas, in a suitable way for the accessibility of people with reduced mobility, according to the provisions of Decree 19/2000 approving the Accessibility Regulations in relation to urban and architectural barriers in development of Law 5/1994 (Espínola, 2018). Regarding Access to Audiovisual and Information Telecommunication Services, the existing telecommunication installations are adapted to the current regulations (Valdivia, 2007).

With respect to the Facilitation of access to postal services, the first floor of the postal lockers is renewed, and several Smart-Boxes are provided for the collection of parcels for users of the urbanization.

3.1.2 Safety

In relation to Structural Safety, the main structural elements have not been modified. The only structural reinforcements that have been made are the new roof installation benches, and those corresponding to the variation of the slopes of part of the roofs (630 m²) and the new slabs that replace those demolished in the restaurant area (360 m²).

Regarding fire safety, the existing fire detection installations have been improved and the DB-SI requirements have been adapted. With regard to safety in use, the configuration of the spaces and the fixed and mobile elements installed in the building have been designed in such a way that they can be used for their intended purpose within the limitations of the building’s use without posing a risk of accidents to the building’s users.

FIGURE 4
Thermographic images of different areas of the existing building.

3.1.3 Habitability

With respect to Hygiene, Health and Environmental Protection, the existing conditions have not been modified. In the specific actions of distribution changes, the requirements of habitability and salubrity have been met. All of the projected building envelopes have been provided with means to prevent the presence of water or inadequate humidity from atmospheric precipitation, from the ground or from condensation, and have been provided with means to prevent its penetration or, if necessary, its evacuation without causing damage.

The apartment building complex and the basement parking lot have been provided with a forced renovation so that their enclosures can be adequately ventilated, eliminating the contaminants that are normally produced during their normal use, so that a sufficient flow of outside air is provided and the extraction and expulsion of the air fouled by contaminants is guaranteed (Técnico de la Edificación, 2017).

- Regarding Noise Protection, an acoustic improvement has been sought in the elements where intervention is carried out (facades and roofs), and in the vertical separating elements between dwellings (Técnico de la Edificación, 2009).
- Regarding Energy Saving and Thermal Insulation, the projected building has an envelope suitable for limiting the energy demand necessary to achieve thermal comfort depending on the climate of the site, the intended use and the summer and winter regime. The inertia and insulation solutions, air permeability and exposure to solar radiation adopted have solved the pre-existing pathologies of surface and interstitial condensation humidity. Special consideration has been given to an improvement in the treatment of thermal bridges through a ventilated facade solution with continuous insulation, in order to limit heat losses or gains

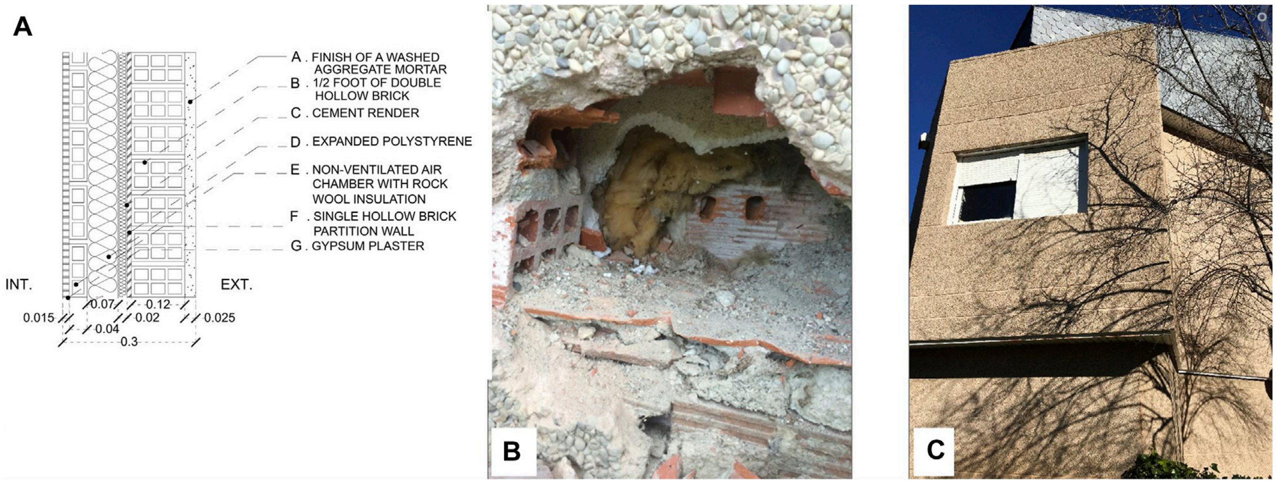

FIGURE 5
(A) Construction section of the existing façade. **(B)** Site images and **(C)** appearance of the initial exterior of the façade.

and avoid hygrothermal problems in them (Técnico de la Edificación, 2012).

- The projected building has lighting installations that meet the needs of its users and at the same time are energy efficient, with a control system that allows adjusting the lighting to the actual occupancy of the area, as well as a regulation system that optimizes the use of natural light in areas that meet certain conditions (Técnico de la Edificación, 2012). In particular, the current incandescent lighting has been replaced by LED type solutions.
- The current underfloor radiant air conditioning has also been replaced by a much more sustainable air-water system with centralized production.

3.2 Construction strategies adopted to resolve deficiencies related to insulation and thermal sealing

From the analysis of the existing deficiencies and pathologies in the building and thanks to the thermographic images of the building, the lack of thermal insulation at the junction of the vertical structure (supports) and the enclosures, at the junction of the horizontal structure (slab edge) and the enclosures, at the junction of the lower floors (landscaped first floor) and the enclosures, under the living spaces over open porches, under the living spaces over the parking basement and in the walkable terraces over the living spaces is detected. In addition, thermal bridges are noted in jambs and lintels of exterior openings.

The following is a description of the existing situations prior to the intervention and the solutions adopted to ensure compliance with the regulations in relation to airtightness and thermal insulation in the building envelope: facades and roofs.

The transmittance values meet the requirements of the Technical Building Code (Técnico de la Edificación, 2012) for climate zone D to which Madrid belongs, which is where the project is carried out.

The main constructive characteristics of the building facades are described in Figure 5A. The existing constructive system and the initial external façade appearance are shown in Figures 5B, C.

A decisive renovation of the perceived representativeness of the Lagos Park development is proposed through the implementation of a new skin (ventilated façade) that will give the current development a modernized and technologically advanced appearance, while allowing the implementation of a new coat of continuous thermal insulation on the façade, thus avoiding the existing thermal bridges (Figure 6).

A solution of large-format polished extruded porcelain ceramic tiles (H) is presented, in two tones, white for the emerging facade bodies and anthracite gray for the recessed planes and interior of terraces by including extruded aluminum battens (I) for anchoring the facade. Legends A–G shown in Figure 5 are valid for Figure 6.

A renovation of the exterior carpentry is also proposed, implementing an updated solution using aluminum carpentry with thermal bridge break, in anthracite gray tones and Climalit type thermal and acoustic double glazing. A system of compact pvc blinds with thermal aluminum slats has been chosen.

It is proposed to replace the terrace parapets with a 5 mm + 5 mm laminated safety glass railing solution with colorless butyral and polished edges.

The false terrace ceilings are replaced by a metal ceiling solution of perforated steel trays lacquered in anthracite gray.

A continuous insulation (J) of 1.2 m × 0.6 m × 0.08 m double density rigid rock wool panel is installed, fastened to the facing by means of polypropylene plastic fasteners.

The main construction characteristics of the building's roofs are described in Figure 7A. The existing external roof envelope is shown in Figure 7B.

The existing roof solution has a very low insulation thickness for the desirable habitability requirements, resulting in real interior temperature conditions, far from comfort conditions, and requiring excessive energy inputs for air conditioning. The waterproofing of the system works adequately thanks to the

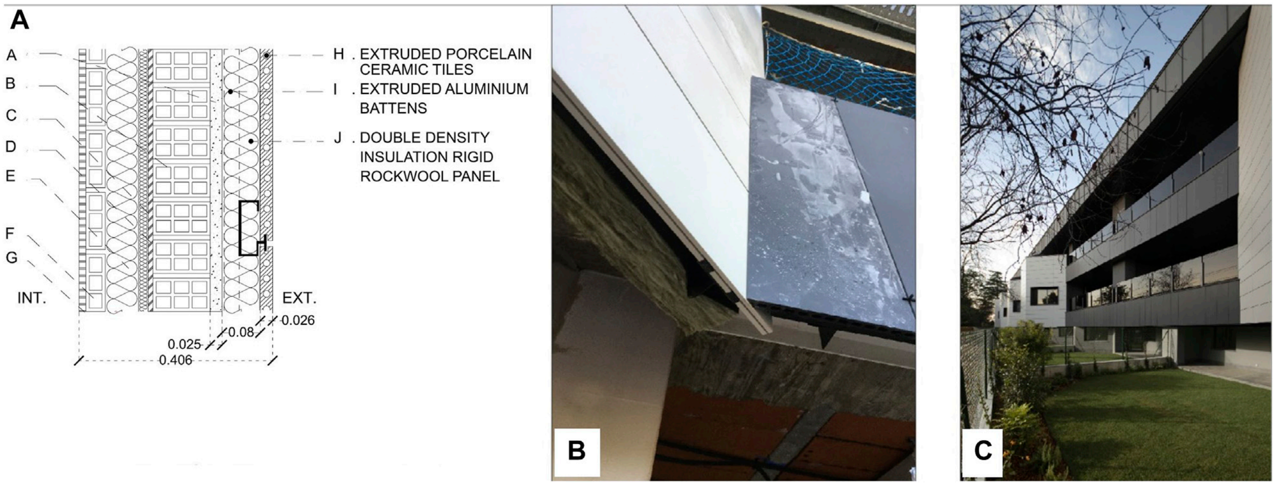

FIGURE 6
(A) Construction section of the rehabilitated façade. Images of **(C)** the construction site and **(B)** final exterior appearance of the façade.

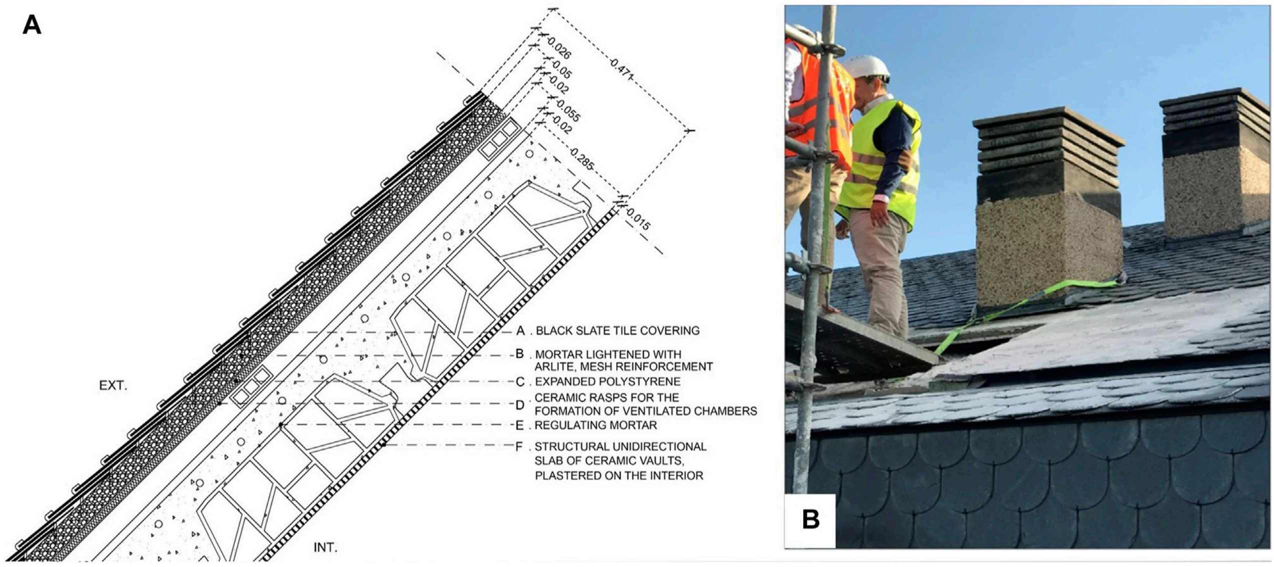

FIGURE 7
(A) Construction section of the existing roof. **(B)** Site image of the initial exterior appearance of the roof.

high slopes (close to 45%) and only occasional problems have been detected, due to clogging of the hidden gutters, caused by the accumulation of leaves.

The new roof solution (Figure 8) proposes the implementation of a new 8 cm layer of insulation in rigid closed-pore extruded polystyrene panels (J), mechanically fixed to the floating reinforced lightweight mortar slab (H) and coated with a zinc finish (G) in a standing seam over battens and wood decking (I), generating a new ventilated chamber. Legends B–F shown in Figure 7 are valid for Figure 8.

This solution significantly improves the energy saving performance of the envelopes, in addition to generating an aesthetic improvement in accordance with the renovation of the facades.

3.3 Strategies for energy efficiency compliance of the refurbished building

With the aim of obtaining the energy efficiency certificate with an optimal classification, the challenge of making an installation that complies with the current regulations both RITE and CTE and that at the same time is a sustainable and efficient installation is faced. For this purpose, a study of the system has been carried out in order to achieve an installation that complies with the following premises:

- Centralized production of heating, cooling and Domestic Hot Water (DHW).

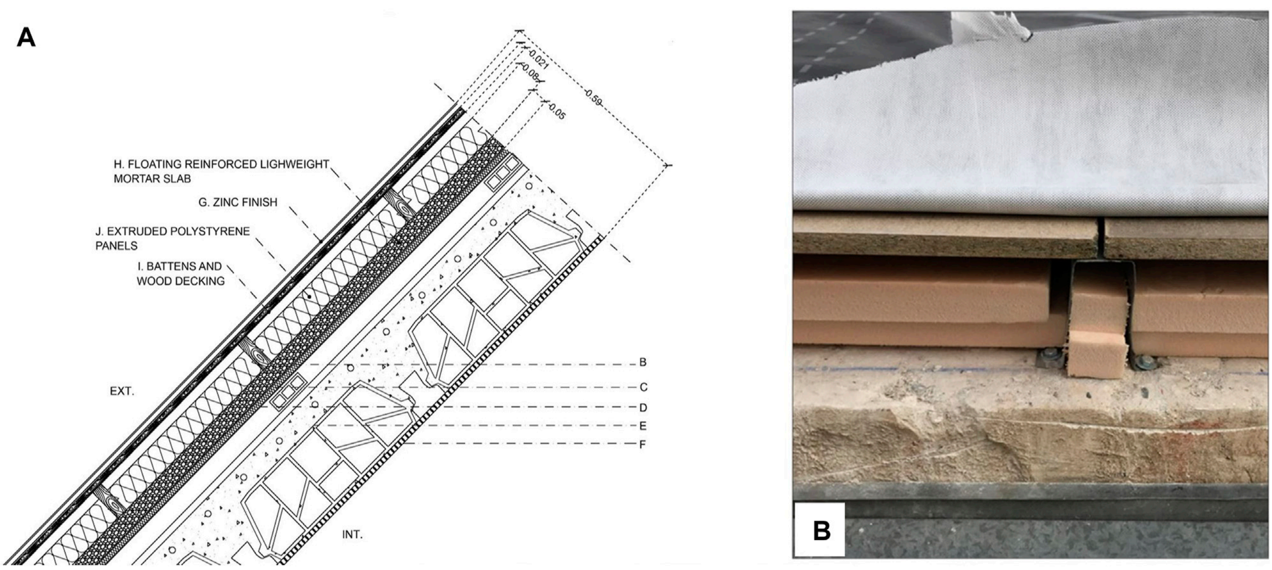

FIGURE 8
(A) Construction section of the rehabilitated roof. **(B)** Image of the final exterior appearance of the roof.

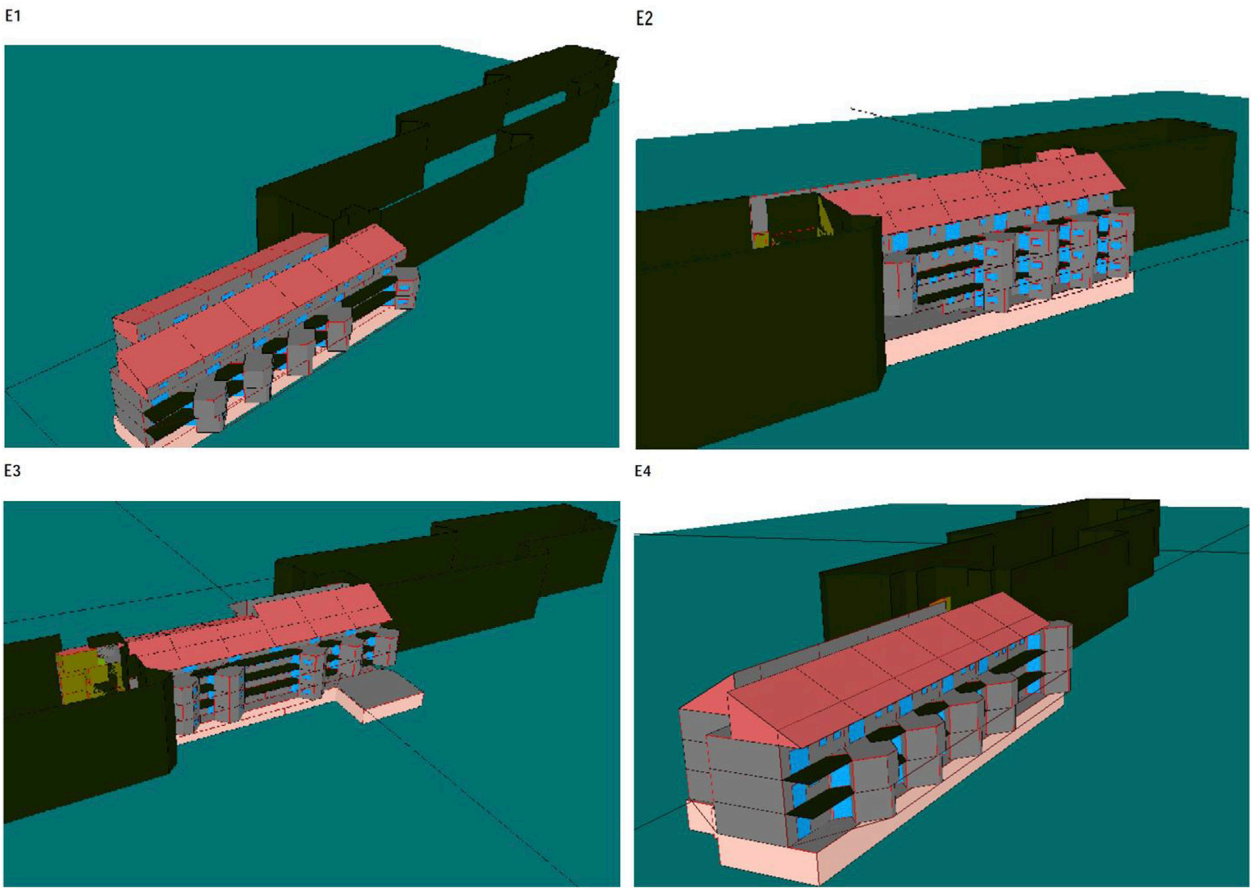

FIGURE 9
Division of the building into four sectors E1, E2, E3 and E4 for energy simulation of building performance (HULC Software).

TABLE 2 Percentage and centralized heating production in each module.

Building	Percentage (%)	Heating capacity (kW)
E1	22.0	158.1
E2	27.8	200.1
E3	28.3	203.6
E4	22.0	158.1

- Possibility of detailed regulation of each room and of the whole installation.
- Economy of the energy used.
- Ease of maintenance operations.
- Adequate acoustic levels.
- Protection of the environment.
- Less architectural impact on the building.

Regarding the air conditioning system, the building has a heating and cooling system with two heat pumps of 360 kW nominal power each for production and radiators and fan coils as terminal units. In turn, each dwelling has a heat recovery unit for ventilation.

As the building is divided into four modules (Figure 9) and has centralized heating production, it has been distributed on the basis of the radiator power of each module (Table 2).

The thermal fluid chosen is water and the working conditions are as follows:

- Cooling, air inlet temperature 27 CBS and air outlet temperature of 19 CBS with a supply air temperature of 7°C and return air temperature of 12°C.
- Heating, air inlet temperature of 20 CBS in heating and 50°C supply air and 45°C return air.

From each unit, a network of black steel pipes carries hot or cold water, depending on the time of year, to a buffer tank located in the boiler room in the basement of the building. From there, an air conditioning circuit made of black steel in general and polyethylene pipe that distributes the water to each of the houses in which a fan-coil has been installed in the false ceiling. The pipes in the boiler room, the general pipes that run through the garage floor and those that run through the interior of the skirting boards are properly insulated in accordance with the provisions of the RITE and the overall thermal losses in all the pipes do not exceed 4% of the maximum power transported and are hydraulically balanced.

The efficiency of the production of air conditioning water by these pumps is 3.01 for cooling (EER), and 3.25 for heating (COP).

The Lider-Calener Unified tool does not allow the definition of fan-coils in residential dwellings. Therefore, the cooling and heating system using fan-coils has been modeled using constant performance equipment with the aforementioned parameters.

In compliance with the Technical Building Code, section HE 4 Minimum solar contribution for domestic hot water, the installation must have a system for the production of DHW by means of solar thermal collectors that can be partially or totally replaced by an alternative installation of another renewable energy, for which it is documented that the carbon dioxide emissions and the consumption of non-renewable primary energy are equal to or lower than those produced by a similar solar thermal installation and its auxiliary support system.

Once the study was carried out, it was found that the DHW needs of the installation, taking into account the occupancy of the building, were approximately 8,000 L per day at 60°C. In order to achieve this heating, a sufficiently large surface area was required for the installation of the solar panels. For this reason, it was finally decided to replace the solar field with a 30 kW CO_2 aerothermal heat pump with a COP of 4.5 and a 100 kW natural gas boiler to heat the domestic hot water return network "radiant air conditioning system" (RACS). In addition, the work of the heat pumps and the volume of the storage tanks was distributed proportionally to the demand (Table 3).

The thermal installation has been equipped with all the necessary automatic control systems to maintain the premises in the design conditions foreseen according to RITE for heating and cooling with a THM-C 3 category control, since it has water variation according to the outside temperature, room temperature control and thermostatic valves in the terminal units to control the environment of each thermal zone, as well as the variation of the water temperature according to the outside conditions, which is carried out in the secondary air-conditioning circuit. The indoor design conditions are established as follows:

- Winter: operating temperature between 21°C and 23°C with relative humidity between 40% and 50%.
- Summer: operating temperature between 23°C and 25°C with relative humidity between 45% and 60%.

Since the thermal installation serves more than one beneficiary, the necessary meters have been installed to distribute the expenses corresponding to each service (heating, cooling and DHW) among the different users, which will be housed in a cabinet on the outside of the house, making it possible to regulate and measure the consumption of each one of them, as well as to interrupt the service. Likewise, the boiler room will have meters for the thermal energy generated for the production of hot/cold, primary and return of sanitary hot water.

In order to comply with the indoor air quality requirements, we have taken into account the provisions of section HS3 "Indoor air quality" of the CTE and we have gone a step further by installing heat recovery equipment. With them, adequate ventilation is achieved with the minimum energy consumption in the dwellings, eliminating the pollutants that are normally produced in the use of the building, considerably improving the indoor air quality, ensuring the necessary supply of outside air and obtaining a recovery of up to 95% of the energy used for air conditioning of the building. It is possible to recover up to 60% of the heat that would be lost in a mechanical ventilation system in which the intake and exhaust air flows are independent, allowing energy savings that can reach over 40% of the consumption of this equipment.

4 Discussion

The following is a summary of the most relevant aspects that have allowed Lagos Park to become a reference within the rental

TABLE 3 Domestic hot water demand, work of heat pumps and volume of storage tanks in each module.

Building	Domestic hot water demand (L/day)	Nominal power (kW)	Volume storage (L)
E1	1.8	12.6	3,362
E2	2.4	16.3	4,350
E3	2.7	18.1	4,822
E4	1.9	13.0	3,465

building typology in the Community of Madrid, thanks to the rehabilitation and functional, aesthetic, regulatory and energy adaptation that allow it to be at the forefront in this type of projects.

One of the characteristics that undoubtedly gives added value to Lagos Park has been the use of quality construction systems such as ventilated facade and ETICS. In this way, a new envelope has been created that has solved the thermal bridges and, at the same time, has provided the building with a new insulation and ventilation chamber. A new exterior skin has been created based on three materials: porcelain tile, ETICS and Zinc. These have been used to solve the ventilated facades, the interiors of terraces and roofs creating the color palette that defines the entire intervention to enhance the geometry of the architectural ensemble (iceberg white, graphite gray and natural zinc).

It is worth mentioning that the houses now have aluminum carpentry with thermal bridge break and double glazing of low emissivity, which causes that the temperature maintenance inside is total (no heat enters in summer and stays inside in winter) and also significantly reduces the acoustic impact.

On the other hand, the old air conditioning system has been replaced in one of the most ambitious interventions of the project by creating a centralization of air conditioning and DHW in order to obtain an A energy rating.

The COVID-19 pandemic has changed the technical and engineering approach to building and facility design. This fact implies that any facility engineering project is really complex. Starting from the current sanitary measures for reopening in the COVID-19 era and the crucial current research on this issue, the feasibility of plant retrofit/retrofit solutions through efficient ventilation and air quality is investigated (Balocco and Leoncini, 2020). For this purpose, each apartment has been equipped with an air conditioning system through centralized heat pump with individual heat recuperators. This means that the hot or cold air generated in each room of the apartment is transmitted through a circuit to come into contact with the outside air. By having this contact in a natural way, this new air enters the house renewed, but with a similar temperature to the air that has left. In this way the air will always be "clean" and this confers an important energy saving to the tenant in the air conditioning of his home.

The HULC tool was used to calculate the hot water demand. The DHW supply for this building has been solved with a system of two air-to-water heat pumps of 30 kW each, centralized, with a COP performance of 4.5 and storage tanks of 16,000 L total volume.

The choice of the ventilation system through an individual heat recovery unit per dwelling with a free-cooling bypass unit with an efficiency of more than 95%, guaranteeing the renewal of air in the dwelling with minimum impact on the ambient temperature of the dwelling, thus certifying the maximum energy efficiency of the dwelling.

Thanks to the refurbishment carried out and taking into account the energy characteristics of the building, the thermal envelope, its installations, operating conditions and occupancy, it has been possible to obtain an A energy rating for the building by means of the Lider-Calener Unified Tool (HULC) according to the scale of values referred to in Royal Decree 235/2013.

Below, a recreation of the results offered by said Tool is detailed (Table 4). The overall rating of the building is shown after weighting the partial values. To facilitate the calculation, the building has been divided into four blocks based on the different positions they occupy in the building as a whole. Four units are thus formed, which have been named: E1, E2, E3, E4, taken from north to south.

The result of the entire system installed makes the Lagos Park building a model of sustainable and efficient system (Figure 10), since both the energy consumed and the CO_2 emissions to the atmosphere generated by this installation are much lower than any other installation used as a reference, even with the installation of solar thermal panels for the production of DHW, in strict compliance with all the requirements of welfare and hygiene (IT 1.1), the requirement of energy efficiency (IT 1.2) and the requirement of safety (IT 1.3).

Thanks to the refurbishment carried out and taking into account the energy characteristics of the building, the thermal envelope, its installations, operating conditions and occupancy, it has been possible to obtain an A energy rating for the building. In this way, and given that it is a rental apartment building, the tenants have obtained energy savings of more than 70% as a result of all the strategies implemented. Below (Figure 11) we can see a summary of all the action strategies that have enabled the comprehensive rehabilitation of the existing building, achieving energy, spatial and environmental performance appropriate to the new desired sustainability parameters.

Table 5 shows the results extracted from the Unified Tool program. The projected building complies with all the requirements of the Basic Document HE1 (Limitation of Energy Demand) of the technical building code in terms of energy demand limitations for heating and cooling.

Research (Brandão de Vasconcelos et al., 2016) on the best cost-effective thermal retrofit measures has concluded that i) roof thermal retrofitting produces the largest variation in building primary energy consumption (and floor measures the smallest), ii) the combination of thermal envelope retrofit measures creates synergy effects that lead to better results than individual measures (in relation to overall costs and primary energy consumption), and iii) it is more advantageous to proceed with a package of thermal retrofit measures than to do nothing.

TABLE 4 Non-renewable primary energy consumption and CO_2 emissions per module.

Building	Non-renewable primary energy consumption (kWh/m^2 year)	Carbon dioxide emissions (kgCO$_2$/m^2 year)
E1	35.8	6.5
E2	34.9	6.3
E3	34.7	6.2
E4	34.0	6.1
Total	34.8	6.3

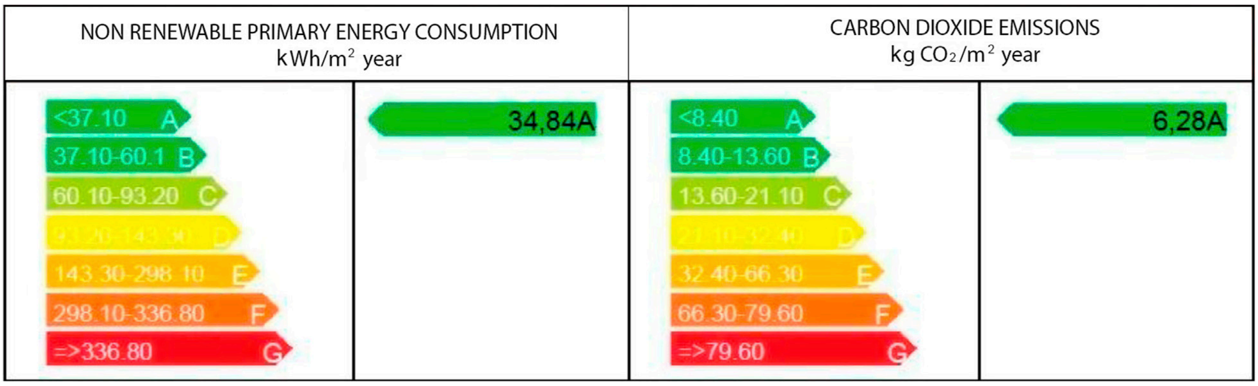

FIGURE 10
Results obtained with the HULC tool in relation to the energy rating of the building.

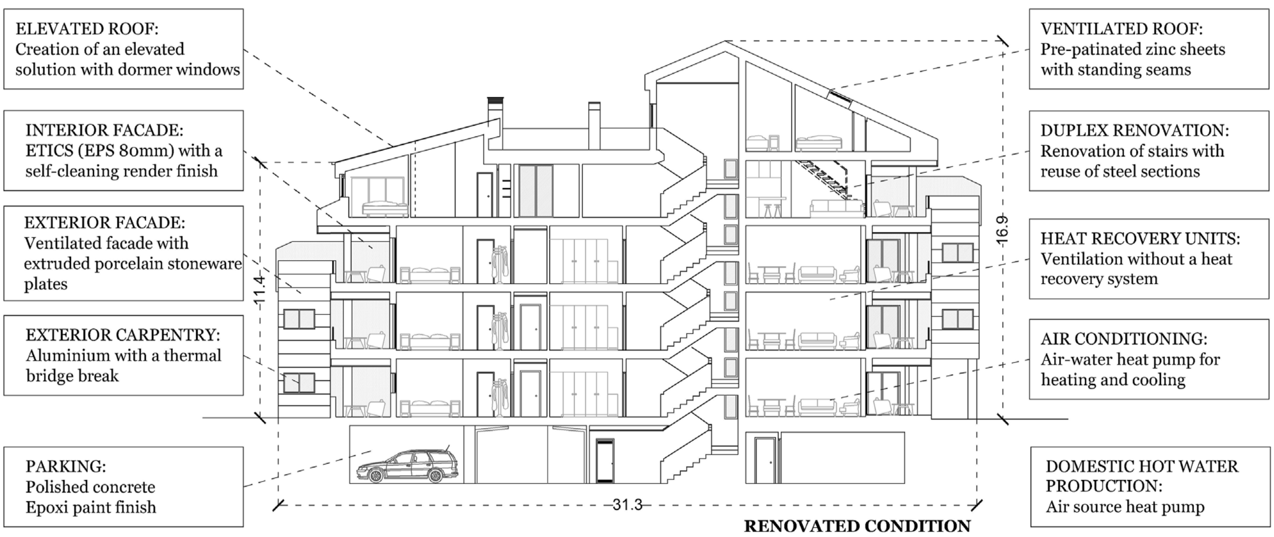

FIGURE 11
Main section of the Lagos Park building with the description of the main rehabilitation strategies.

Retrofitting residential buildings is a commitment by owners. There are economic, technical, social and political barriers, but among them high upfront costs, certainty of payback periods and inexperience are key elements that discourage owners (Pardo-Bosch et al., 2019). In order to involve owners, the following recommendations can be put forward.

- The existence of organizations offering promotion and marketing of retrofitting, comprehensive project with energy retrofitting experts, and the provision of funds and financing schemes. In this regard, the municipality plays an essential role in promoting and organizing activities to inform homeowners about the retrofit process and about

TABLE 5 Annual heating and cooling demand.

Model	Heating (kWh/m^2)		Cooling (kWh/m^2)	
	Building	Compliance	Building	Compliance
E1	18.9	27.8	10.0	15.0
E2	16.1	27.6	10.9	15.0
E3	16.6	27.6	9.7	15.0
E4	18.8	27.8	8.6	15.0
Whole Building	17.4	27.7	9.9	15.0

companies offering integrated energy and financing packages.

- In order to increase the rate of retrofitting residential buildings, the public administration could offer financing. This financing is important as an engagement strategy, especially for low-income owners and residents.
- Cities should emphasize that it is key to include owners in the decision-making processes of building retrofit strategies and interventions.

5 Conclusion

The major refurbishment carried out in the complex, with a comprehensive intervention, has allowed the Lagos Park homes to be practically "homes without consumption." From the household appliances to the structure of the house, everything is designed to optimize the energy used, which is reflected in electricity bills that reduce the monthly amount by 65%–75%. These data were provided by the building's residents through individual interviews.

Through this article we have tried to give a global vision of all those constructive aspects that have been relevant at the time of rehabilitating the "LagosPark" building in an integral way.

The rehabilitation of the building has made it a relevant work of the place, responding not only to the regulatory criteria for improving energy efficiency and sustainability in housing, but also responding to architectural strategies that are not usually taken into consideration in projects of similar characteristics.

Actually, in a short-term perspective, the benefit of the rehabilitation of a building's element condition will not result in any financial savings, which could cover an investment's costs. However, in long term this will allow one to avoid larger investments, which are necessary, when building's elements lose their functional purpose (Martinaitis et al., 2004). Such an approach to the twofold benefit of the building's renovation would stimulate the rehabilitation of a building's elements and, thereby, result in more considerable savings of the limited energy resources, the increase of the buildings' value, and a more active construction market. Already previously, other researchers presented an analysis of the trends in the rate of energy improvement per year, due to energy rehabilitations, comparing them with periods of 5 years, using a longitudinal data analysis using variables from the monitoring system (Filippidou et al., 2017).

Both the dwellings and the common areas have been favored by the use of the ventilated facade and ETIC construction systems, as well as the roof construction solution that allows the upper areas of the building not only to obtain a new spatial configuration by gaining height in the roofs, but also to favor a substantial thermal insulation in the upper parts of the building. All the apartments have had their old carpentry systems replaced with aluminium ones with thermal bridge breakage and low emissivity double glazing, which produces invaluable acoustic and thermal benefits.

In addition, each apartment has been equipped with a centralized heat pump air conditioning system with individual heat recuperators, which benefits the sustainability of the whole.

Although the choice of aerothermal energy as a system for obtaining the energy needed by the house is faced with the lack of knowledge of the system or the initial investment required for the provision of equipment, the truth is that there are many advantages and strengths of aerothermal energy:

- Its multifunctionality, since a single unit provides clean energy for the use of domestic hot water, heating and cooling.
- Savings in air conditioning, since, although they require electrical energy for their operation, they can achieve savings of 50% compared to alternatives such as diesel boilers (which were used in the homes before their refurbishment). Compared to natural gas boilers, the cost can be contained by at least a quarter.
- It generates no waste or emissions, making it the best environmentally sustainable alternative.

This study provides integrated passive and active design strategies that quantify the impact of retrofitting energy efficient building components to meet the requirements of residential building regulations. The active strategies integrated with the passive strategies seek the optimization of the demand with the integration of both; so that it can serve as a guideline for decision making on improving energy efficiency for designers and related groups, such as contractors and homeowners.

Based on the strategies established, the aim is to lay the foundations for the calculation of energy efficiency.

The main calculation methods used to determine energy demands are based on simulations and tests on the real model. The savings data provided are relatively reliable and repeatable. However, their variability should be duly completed in future research taking into consideration occupant habits and user/family profiles.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

Author contributions

MM-T: Data curation, Formal Analysis, Supervision, Writing–original draft, Writing–review and editing, Conceptualization, Funding acquisition, Investigation, Methodology, Project administration, Resources. JC-D: Conceptualization, Data curation, Formal Analysis, Investigation, Methodology, Resources, Supervision, Writing–original draft, Validation, Visualization, Software. RG-L: Data curation, Formal Analysis, Supervision, Validation, Visualization, Writing–original draft, Writing–review and editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Nomenclature

COP	Coefficient Of Performance
CTE	Spanish Technical Building Code
DWH	Domestic Hot Water
EER	Energy Efficiency Ratio
EPS	Expanded Polystyrene
ETICS	External thermal Insulation Composite Systems
HE1	Limitation of Energy Demand document
HULC	Lider-Calener Unified Tool
NZEB	Nearly Zero-Emission Building
RACS	Radiant Air Conditioning System
RITE	Spanish regulation of thermal installations in buildings
SDGs	Sustainable Development Goals
THM-C3	The system ventilates, cools, heats and deshumifies