ENERGY EFFICIENCY INTERVENTIONS IN THE CONVENT OF CARMEN IN GEA DE ALBARRACÍN

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Abstract. This text focuses on the intervention project carried out at the convent of El Carmen, located in Gea de Albarracín, twenty kilometres west of Teruel, Spain. The commission was established as a result of the Ministry of Transport, Mobility, and Urban Agenda's grant of aid for the promotion of public building rehabilitation (PIREP). This programme introduces as conditions that the intervention must be comprehensive, responding to criteria of sustainability, inclusion and aesthetic quality; it must include actions aimed at improving energy efficiency with a climate contribution coefficient of 100%; as well as a management plan for at least 70% of the non-hazardous waste generated in the work. Finally, it is worth mentioning that the actions are based on the concepts of minimum intervention with reuse of the structural system, acting only occasionally with current materials and designs, essentialised, so that they are integrated into the quality of permanence, while showing their commitment to the current time and culture.

Keywords: Environmental sustainability, Architectural Intervention, Conservation, Restauration

Introduction. The climate emergency at the end of 2019, coupled with the effects of the COVID-19 pandemic, led to the European Commission launching a Recovery and Resilience Facility, as well as the Fit for 55 package of measures, which proposes reducing greenhouse gas emissions by at least 55% in 2030 compared to 1990 levels, requiring member states to develop strategies for renovating their building stock. In Spain, one of the mechanisms proposed has been the Programme to Promote the Renovation of Public Buildings (PIREP), which aims to provide comprehensive intervention based on criteria of sustainability, inclusion and aesthetic quality and must include actions aimed at improving energy efficiency with a climate contribution coefficient of 100% (Secretaría General de Agenda Urbana y Vivienda, 2022). As part of this programme, in 2023 the Ministry of Transport, Mobility and Urban Agenda awarded a grant for the renovation of the Convento del Carmen in Gea de Albarracín, Teruel.

The project proposes a series of actions aimed at regenerating the building and reusing it for socio-cultural purposes, organised into five blocks: improving energy efficiency, focusing on improving the building's thermal envelope on the one hand and improving the thermal and electrical installations on the other; improving environmental sustainability, which includes aspects such as water, use of materials, waste management, adaptation to climate change and protection of biodiversity; improving physical and environmental accessibility; improving habitability and safety; and, finally, actions for the conservation of the building.

Among all the actions taken, it is worth highlighting those related to energy efficiency, which exceed the 30% target set by the PIREP, achieving the goal of zero consumption by improving the insulation of the building envelope, installing a photovoltaic system for use in the building, and improving the heating, electrical and water consumption systems. This text focuses on describing the actions taken in the building to meet the energy efficiency requirements outlined in the PIREP.

Description of the building. The building is located at the eastern end of the town, bordered to the north by the main street and to the west by Plaza del Carmen. It was founded by the Order of Discalced Carmelites in 1673, with construction completed in 1705, and follows the compositional laws of the conventual type, with a rectangular floor plan measuring 46x36m with perimeter naves arranged around a central cloister, built with stone masonry walls. The convent features a church on its north side, accessible from the west façade facing the square, and is divided into three floors, with an additional floor on the south side due to the uneven terrain. The building is sober, massive and closed to the outside, with an architecture where the relevant spaces are concentrated in the interior (Figure 1).

The building has undergone various renovations throughout its history, notably the bricking up of the cloister openings during the 18th century, as well as the work carried out in recent years to adapt the complex for cultural use, which has not been particularly respectful of the original building. Currently, the building is partially in use and exhibits various signs of damage, including cracks, flaking, missing pieces, cement mortar plastering, capillary dampness, and woodworm infestations in the wooden structures.

The premises in use are heated by underfloor heating, which is powered by a boiler located in one of the basement rooms, with a heating oil burner. This same boiler supplies the domestic hot water required by the building. The average seasonal efficiency of the boiler, considering factors such as its age, the type of fuel used, which causes significant soiling of the home, and the lack of control over when it is switched on and off, is barely 72-75%.

On the other hand, the building lacks any type of mechanical ventilation and, consequently, no heat recovery from the extracted air. Currently, the only method of ventilation is through infiltration due to the poor condition of the building envelope and carpentry.

In terms of lighting, the building lacks low-energy lighting installations, such as those utilising LED technology. Many of the rooms are still lit by fluorescent lighting, and some even use incandescent lighting.

In summary, it is estimated that the low energy efficiency of the facilities, together with thermal losses in various areas of the building, leads to high energy expenditure on heating the property (62.14 kWh/m² per year) and lighting the premises (97.86 kWh/m² per year) which, added to the costs of heating water, amounts to a total of 172.05 kWh/m² per year.

Improving energy efficiency. Criteria. Improving the building's energy efficiency is approached through three main groups of actions: firstly, improving the building's thermal envelope; secondly, improving the thermal installations; and thirdly, improving the building's electrical installations (Figure 2). To this end, a balance has been sought between energy improvement and heritage restoration. In this regard, the research carried out by Besen et al. (2022) is interesting, in which they study various intervention scenarios with different degrees of insulation, and in which it is demonstrated that scenario 5, corresponding to an intervention similar to that used in the present project, achieves a good balance between energy performance and impact on heritage.

Improvement of the thermal envelope. Regarding the thermal envelope, it is worth noting that the building features thick stone masonry walls, varying in thickness from 80 to 90 cm, which provide good thermal stability within the spaces (U = 0.52 W/m²K). Therefore, in the opaque parts of the walls, the intervention focuses on conservation tasks, including replacing missing stone (ashlars, small ashlars, rubble) or brick (window frames), stitching cracks, and removing inappropriate elements to replace them with lime mortars. The installation of thermal insulation inside the walls is therefore avoided, as, apart from the loss of aesthetic value, it can lead to a loss of water vapour permeability and thermal inertia, with the associated problems. (English Heritage, 2012).

Regarding hollow sections, it has been decided to replace the joinery in cases where the opening is modified to restore its original dimensions or where the existing joinery is in poor condition and does not provide adequate insulation. To this end, it is proposed to install new tilt-and-turn windows made of solid iroko wood, with a 90 mm thick frame featuring a European triple seal profile, prepared to receive triple glazing (4/16/4/16/6) and solar control. The windows will also be equipped with solid interior shutters made of the same wood, 5-6 cm thick. Similarly, it is proposed to improve the watertightness and insulation of the joints between the joinery and the lintel, jambs and flashings by installing perimeter insulation with elastomeric seals (Historic England, 2024). All of this makes it possible to achieve a transmittance of less than 1.5 W/m²K, which is superior to what can be obtained with other energy improvement systems in historic windows, as observed in the study conducted by Mauri et al. (2022).

Thirdly, it is proposed to install thermal insulation in the roof by installing a sandwich panel with 120 mm XPS insulation, a 16 mm board, and a 10 mm fir frieze, resulting in a total thickness of 146 mm and a transmittance of 0.27 W/m²K. Although this solution requires the roof to be dismantled, it yields better thermal performance than other partial solutions (Historic England, 2016-A).

Finally, it should be noted that the floor in contact with the ground is thermally insulated with underfloor insulation consisting of a 4 cm thick expanded polystyrene insulation panel, which, together with the other layers, achieves a transmittance of 0.5 W/m²K. Aware that insulation reduces the breathability of the ground and that this can cause different problems (Historic England, 2016-B), various measures are taken: the permeability of exterior walls has been improved by removing coatings, helping reduce the risk of condensation, and a new 20 cm layer of gravel under the flooring prevents rising damp from reaching the base of the walls. In addition, installing a wireless anti-damp electro-osmosis system prevents moisture from rising through the walls by inverting the polarity of the water, gently and steadily channelling it into the subsoil (Mestre, 2026).

Improvement of thermal installations. For the improvement of thermal installations, it is proposed to modify the heating, domestic hot water production, and ventilation systems for thermal conditioning.

Regarding the domestic hot water production system, the proposal is to install aerothermal heat pumps, which have average seasonal efficiencies of over 250%, compared to the 72-75% currently achieved by the installed boiler system. Furthermore, to completely eliminate ring losses, which can account for more than 100% of the energy required for DHW production, the installation of a fully decentralised preparation system is proposed, bringing production closer to the points of consumption (less than 15 metres away).

As for the heating system, underfloor heating is proposed for the garden level, ground floor, mezzanine, first floor, and second floor, complementing the existing underfloor heating on the ground floor, which is powered by the aerothermal system. However, to cope with the extreme conditions in the area where the building is located, a parallel installation of a condensing boiler for low-temperature operation is proposed. This boiler will operate only 5% of the time when outdoor conditions prevent the heat pump from functioning. All energy distribution and transport ducts will be insulated with 2.5-3 cm thick shell insulation. The machinery is located in a space on the garden level, which is easily accessible and acoustically insulated, although it requires the opening of new holes in the façade to allow outside air to enter (Figure 3b).

The ventilation system is currently uncontrolled, causing thermal dissatisfaction due to draughts resulting from infiltration through the walls and windows. The installation of a controlled ventilation system with heat recovery is proposed, as indicated and required by the Regulations on Thermal Installations in Buildings. Two air duct networks are installed for each ventilation system, one for fresh air injection using thermally insulated ducts and another for extracting stale air, which does not require thermal insulation. Before being released into the corresponding rooms, the ventilation air is thermally treated to avoid sudden temperature changes. In the Albarracín area, daytime outdoor temperatures can easily reach 10 degrees below zero, while the indoor temperature of the premises will be around 20-22 °C. Hence, the need to thermally treat the air, as it cannot be discharged into air-conditioned premises at outdoor air temperatures. On the other hand, the installation of a heat pump, as already mentioned, allows this ventilation air to be treated during the summer, lowering the temperature by between two and four degrees to achieve pleasant room temperatures without actually cooling the air (Figure 3a).

In addition, a centralised and interconnected automation and control system is planned to optimise energy consumption management in the aforementioned facilities.

The design of the heating installations aims to minimise the impact of

ducts, registers, and grilles, ensuring that the heritage value prevails over the presence of the installations. This issue is consistently present in this type of intervention (Serraino et al., 2017).

Improvement of electrical installations. To improve electrical installations, the first proposal is to implement a photovoltaic plant that utilises energy from a renewable source, with the goal of achieving a zero-energy building. To this end, a photovoltaic solar field is being designed on a plot of land belonging to the council itself, dedicated exclusively to the building. The field consists of 275 panels with a capacity of 500 W each, representing a peak installation of 125 kW and an average annual production of 200,000 kWh. This solution mitigates the potential impact of installing solar panels on the building or in its immediate surroundings, while achieving a peak power output that covers 100% of the new electricity consumption of the renovated building.

Secondly, it is proposed to replace the current lighting system, consisting of fluorescent and incandescent lamps, which, with luck, achieves a lighting ratio of over 25 W/m², with LED technology, offering lighting ratios of 2 and 3 W/m². Likewise, the installation of a lighting control system is proposed, whereby the system will detect the presence of people and regulate the lighting intensity according to the amount of lumens received from solar radiation. The lighting system is integrated into the reinforcement of the wooden joists in the floors, allowing the structural order of the historic building to be highlighted (Figure 3c).

In addition, it is proposed to install a system to harness natural light and illuminate the area under the east, west, and south wings of the cloister, on the garden level. This will bring natural light in from the cloister courtyard at twelve points, thereby reducing the need for artificial lighting and energy consumption.

Thirdly, the new lift installed to provide access to all floors of the building is designed with a hydraulic system featuring high-energy efficiency machinery and systems

Comparison of energy efficiency certificates. If we compare the energy efficiency certificates before and after the intervention, we can see how the measures implemented in the building have made it possible, firstly, to go from a D rating with 36.15 kgCO2/m2 per year of global emissions to zero emissions; secondly, from an E rating with 172.05 kWh/m2 per year in overall non-renewable primary energy consumption to zero consumption; and thirdly, from a heating demand of 42.42 kWh/m2 per year, corresponding to a D rating, to a demand of 5.38 kWh/m2 per year, equivalent to a B rating. The last figure illustrates the energy required to maintain comfortable internal conditions in the building, showing that the warmer the building is, the fewer resources and energy are needed to heat it to the ideal conditions.

Conclusions. This project aims to enhance the overall energy efficiency of the building while preserving its historic heritage value. To this end, the aim is to ensure that the work carried out does not alter the appearance and material value of the historic building. We therefore propose a solution that achieves an adequate level of energy savings without compromising the architectural values of the monument or significantly altering the building's hygrothermal behaviour. Based on the results of the energy efficiency certificates, we can conclude that the actions planned in the project have provided a significant improvement in the building's energy efficiency.

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Figures.

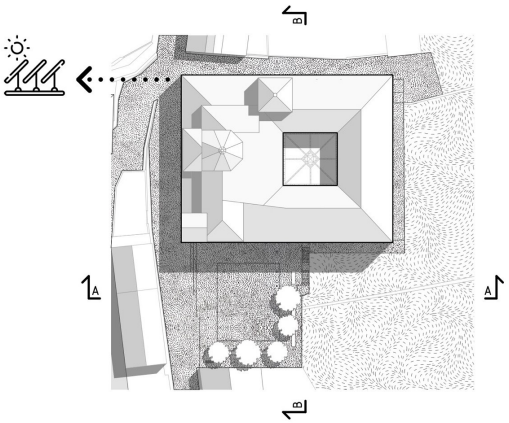
Figure 1. Plan and East façade of the convent, showing its relationship with the streets of the town to the North and East, the agricultural land to the South, and the square to the West / Elaborated by the authors with the assistance of Vanessa Komár

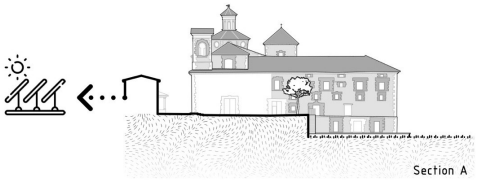
Figure 2. Diagram showing all the interventions carried out in the building to improve energy efficiency, accessibility, and environmental sustainability / Elaborated by the authors with the assistance of Vanessa Komár

Figure 3. Diagrams showing the different interventions proposed for the ventilation, thermal skin, heating system and lighting / Elaborated by the authors with the assistance of Vanessa Komár

1.

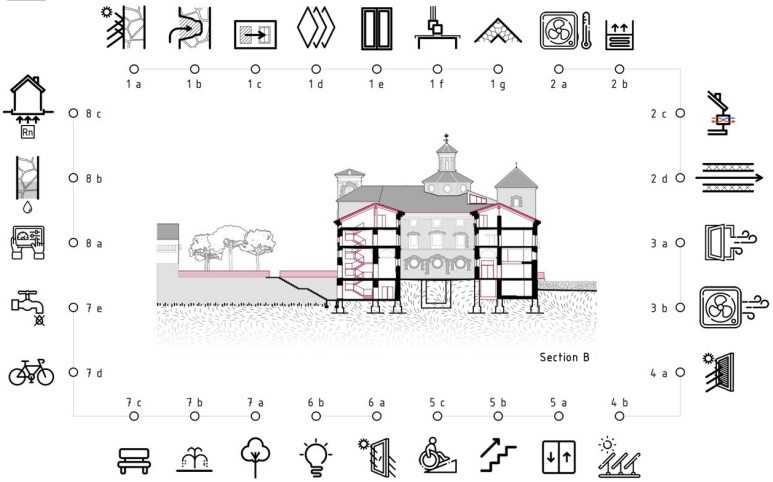
Gea de Albarracín, Spain
40°24'39.7" N, 1°20'35.2" W





0 5 10 25 50

2.



1. THERMAL SKIN
   - a wall insulation
   - b restoring walls
   - c reopening closed windows
   - d new windows (3 layered glass)
   - e restoring old windows
   - f joint sealing
   - g roof insulation

2. HEATING SYSTEMS
   - a aerothermal system
   - b floor heating
   - c pipe insulation

3. VENTILATION
   - a natural ventilation
   - b artificial ventilation
   - c heat recovery ventilation

4. SOLAR ENERGY
   - a solar protection
   - b solar panels

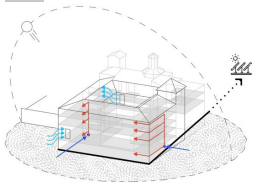
5. LIGHTING
   - a natural lighting
   - b artificial lighting

6. ACCESSIBILITY
   - a elevator
   - b stairs
   - c ramp

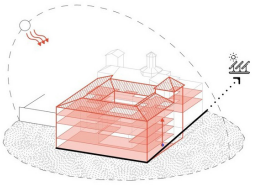
7. ENVIRONMENTAL SUSTAINABILITY
   - a trees
   - b fountain
   - c benches
   - d bicycles
   - e water saving

8. ENVIRONMENTAL CONTROL
   - a monitoring
   - b capillary water
   - c radon barrier

3.

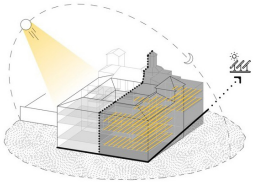


VENTILATION
- natural cross ventilation
- hot interior air
- cold exterior air
- heat recovery ventilation



THERMAL SKIN
- wall insulation
- roof insulation

HEATING SYSTEMS
- floor heating
- aerothermal system
- natural heating



LIGHTING
- natural lighting
- LED lighting