# Chapter 3
# Eco-efficient Rehabilitation of Façades to Improve the Energy Performance of Buildings. Case Study in Seville, Spain

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**Abstract** The construction sector is one of the main contributors to climate change. According to the International Energy Agency, it is responsible for 40% of energy consumption worldwide and for 36% of its $CO_2$ emissions. Furthermore, according to the European Commission, 70% of buildings in Europe are energy inefficient, mainly since buildings employ constructive solutions that are obsolete or poorly maintained. The eco-efficient rehabilitation of buildings is essential in the fight against climate change. The purpose of this work is to improve the façade considering the energy efficiency and the life cycle analysis of the constructive solutions. The proposed solution considers circular economy criteria and is composed of materials with a high recyclability rate. A methodology is proposed for the evaluation of the direct and indirect $CO_2$ emissions, which combines energy simulation and environmental assessment by employing Building Information Modelling. A building in the south of Spain is studied. A comparison is made between the energy behaviour of the building in its original state and of that with an improved ventilated façade. Other types of representative rehabilitation solutions in Spain are also studied and compared. The embodied energy and $CO_2$ emissions of the materials are significantly reduced to one third or less with respect to other traditional solutions.

**Keywords** Circular economy · Energy rehabilitation · Eco-efficiency · Ventilated façade · Building Information Modelling

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## 3.1 Introduction

At present, climate change is evident mainly due to the greenhouse effect of $CO_2$ emissions. The construction sector is one of the biggest culprits in the global pollution process (Instituto de Tecnología de la Construcción—ITEC). In order to achieve sustainable development, it is necessary to implement low-impact constructive solutions and eco-efficient building rehabilitation. The promotion of practices such as rehabilitation, see Fig. 3.1, is essential to achieve eco-efficient development.

Another example of sustainable practice is the circular economy, in which the products participate in a closed life cycle (Gwyneth Rincón and Medina Becerra 2020). This also reduces construction and demolition waste (CDW), which accounts for 30% of the planet's total solid waste (Ginga et al. 2020). Furthermore, the construction sector is responsible for 40% of the energy consumption worldwide and for 36% of $CO_2$ emissions (IEA—International Energy Agency; EEA—Environmental European Agency). In Europe, projects are therefore being developed that share a common goal: the establishment of the circular economy model. On this topic, in March 2010, the document entitled: "Europe 2020. A strategy for smart, sustainable and inclusive growth" (European Commission 2010) was issued. It established the main strategies to achieve the objectives of Horizon 2020. In the following years, 2015 (European Commission 2015, 2016, 2017, 2019) the European Commission published reports for the implementation of the circular economy concepts. Moreover, new strategies have been defined to achieve the objectives set for 2050. Among those challenges is the construction and renovation of buildings.

In Spain, several documents have been published with the aim of fighting against climate change. In September 2017, "Pact for a circular economy" was published (Agricultura and y Pesca, Alimentación y Medioambiente 2017). This document encourages the development of the eco-design of products. Subsequently, in February 2018, the report "Spain Circular 2030" was published (Agricultura and y Pesca, Alimentación y Medioambiente 2018), whose purpose was to establish the circular economy model. In 2019, the Government of Spain published the "Action Plan for the implementation of the 2030 Agenda" (Derechos and Sociales y Agenda 2030,

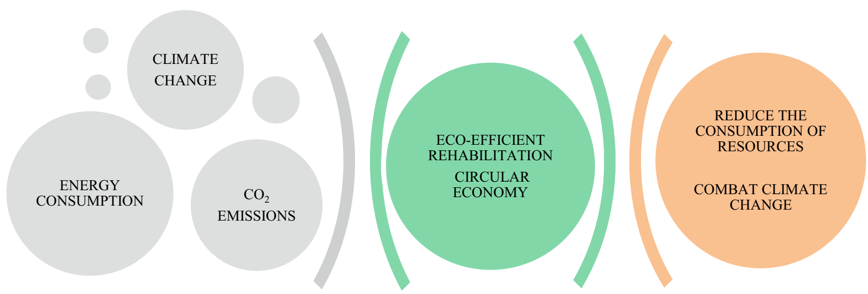


**Fig. 3.1** Current panorama and the necessary evolution to achieve eco-efficient rehabilitation of buildings

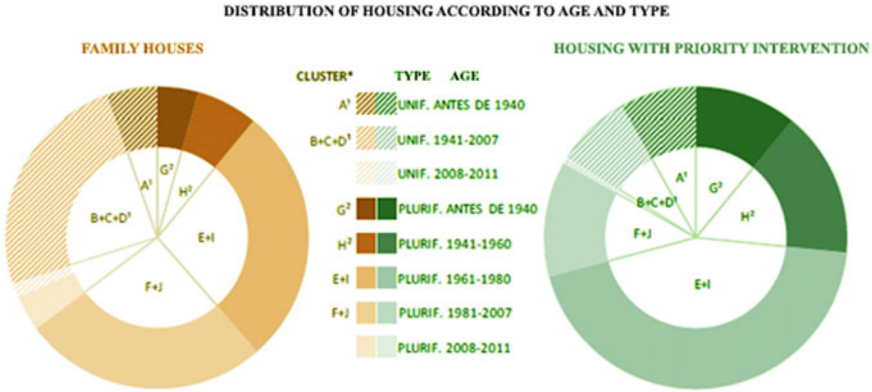


**Fig. 3.2** Distribution of the existing housing stock according to age and type. Extracted from "Analysis of the characteristics of residential building in Spain in 2011. Volume II. State and regional summary files", Ministry of Public Works, 2014 (Ministerio de Fomento 2014)

2030) in order to promote a sustainable development strategy for the country. More recently, in June 2020, the Ministry for the Ecological Transition and the Demographic Challenge issued a draft law on waste and contaminated soil (Ministerio para la Transformación Ecológica y el Reto Demográfico 2020).

In addition to the political framework, it is of interest to ascertain the current situation of the building stock in Spain, which is formed of 36 million buildings in total, 25.2 million of which are residential (INE 2011). In the Spanish housing stock, the multi-family residential typology predominates (Fig. 3.2). This is the most deteriorated typology and the one that most urgently needs rehabilitation.

Another important fact is that 51% of the housing stock was built before 1979 when the Basic Building Standard was published (NBE-CT-791979). This standard limited the energy demand of buildings for the first time. In addition, 92% of the housing stock in Spain was built prior to the drafting of the Technical Building Code of 2006. This standard tightened the energy requirements in buildings. For these reasons, a large proportion of the buildings in Spain are energy inefficient and need rehabilitation. Furthermore, energy consumption in the residential sector represents 17% of the total national energy produced (Domínguez-Amarillo et al. 2016). For these reasons, projects involving the rehabilitation of buildings are being promoted to achieve energy efficiency.

Another important aspect is the environmental impact of the construction materials employed in construction projects, which can be measured using life cycle analysis (LCA). Furthermore, buildings have their own life cycles that can be divided into stages following the nomenclature of ISO 14040 (UNE-EN ISO 2006a), see Fig. 3.3. It is also essential to promote projects based on the circular economy model applied to the field of architecture and construction. This model reduces $CO_2$ emissions and the energy incorporated in the production and manufacturing processes of construction materials (A1–A3). The extraction and manufacturing stage (A1–A3) is the stage


**Fig. 3.3** Life cycle of construction materials in stages in ISO 14040. Data extracted from. "Study of footprints in the life cycle of residential buildings" Rivero-Camacho C. (Rivero Camacho 2020)

that causes the highest energy cost for the environment. This is due to the processes necessary for the generation of the construction materials (Rivero Camacho 2020).

The present research focuses on these phases of the life cycle. The extraction and manufacturing stage (A1–A3) directly affects the rehabilitation stage (B5). This phase is fundamental in this study, since, when making an improvement on an existing building, the consumption of resources is obviated. A detailed study is carried out of each of the materials involved in the construction of the various façades. The objective is to reflect the most relevant values and to extract general data on the energy cost. In this way, it will be possible to study façades and to reduce their environmental impact.

## 3.2 Materials and Methods

Having analysed the situation presented herein, the need to promote new, more efficient projects becomes evident. These projects should focus on the study and development of constructive solutions that improve buildings from the point of view of eco-efficiency and sustainability. In this research, a ventilated façade is developed for the rehabilitation of those buildings whose energy behaviour is inefficient. The design is based on the concepts of the circular economy and uses materials with a low environmental impact.

In order to achieve the main objective of this work, it is necessary to carry out the study in detail. To this end, a methodology is defined in several stages, which are described in Fig. 3.4.

In Stage 1, the building model is defined. To this end, statistical studies carried out in Spain are consulted. In Stage 2, the study of the energy behaviour is carried out with the HULC computer program (Results viewer of the Unified Tool for verification of DB-HE 2019). For the development of this research, the characteristics of the building's façade and the rehabilitation proposal are defined in accordance with the current construction period.

In Stage 3, the products that make up the façades for the rehabilitation of the building are defined. The proposed façade includes materials with low environmental impact. This represents progress in terms of sustainability and eco-efficiency. The bill of quantities is obtained using Building Information Modelling, with the Open

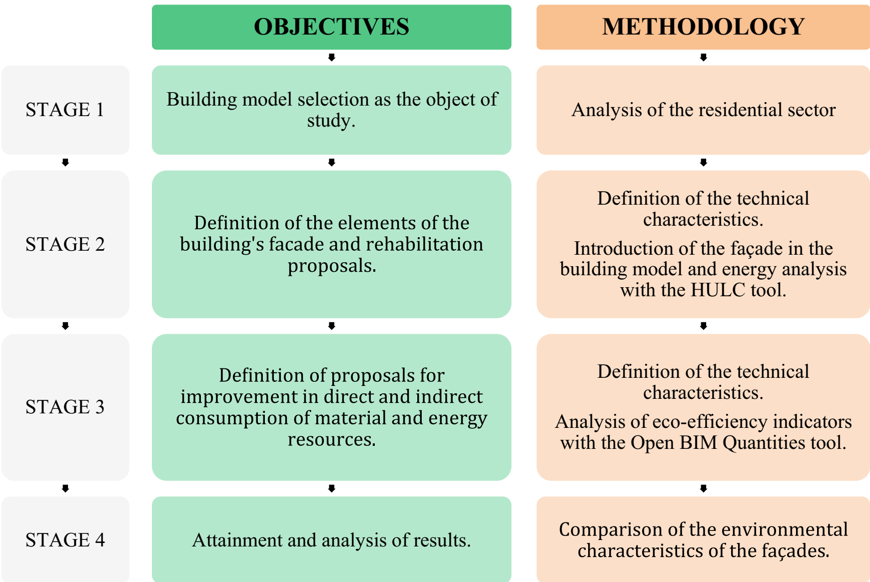


**Fig. 3.4** Outline of the project development stages related to the proposed objectives and the methodology

BIM Quantities tool (Ingenieros and S.A. Software para Arquitectura, Ingeniería y Construcción 2021a). Finally, in Stage 4, the results are analysed. In this stage, a comparison is made of the characteristics of the materials in the construction solutions, and of the energy behaviour of the emissions and recycled product.

## 3.3 Definition of the Building Model

The building is in a warm climate zone since, in hot climates, more than 30% of all consumption in the residential sector is due to the need for thermal comfort (Comisión Nacional para el Uso Eficiente de la Energía 2019). A model is defined to study the performance of the different façades proposed. The building, built in 1962, is in the San Pablo district in Seville, Spain and has 4 floors (ground floor plus three upper floors) with two homes per floor. The floor area is rectangular and measures 22.30 m by 7.50 m. The building has a central communication shaft. Each apartment covers approximately 72 $m^2$ and has a living/dining room, kitchen, laundry room, bathroom, toilet, and 3 bedrooms (Fig. 3.5).


**Fig. 3.5** Planimetry of the simulated building. From top to bottom: front views (north and south) and standard. *Source* Authors' own with data extracted from. "Typological analysis of linear social housing blocks: Spain 1950–1983. The case of Western Andalusia", Guajardo, A. (2017)

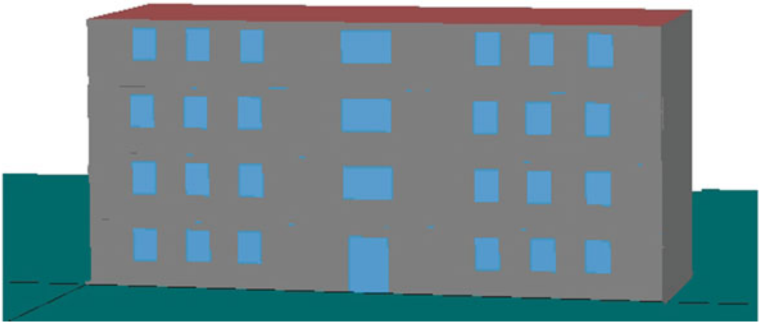

**Fig. 3.6** Building monitored in the HULC program (Results viewer of the Unified Tool for verification of DB-HE 2019). Results viewer of the Unified Tool for verification of DB-HE. *Source* Authors' own with images extracted from "LIDER-CALENER Unified Tool" (2019)

The energy performance of the building is evaluated using the Unified Tool LIDER/CALENER (HULC) (Results viewer of the Unified Tool for verification of DB-HE 2019). See Fig. 3.6. This software enables the energy certification of buildings in Spain, and the verification of the CTE DB-HE 2019 (Db-He 2019).

The constructive characteristics of all the elements that make up the building are subsequently assigned. This enables verification to be made that comply with the CTE-DB-HE1 Conditions for the control of energy demand (Db-He 2019). In this document, the values of thermal transmittance and solar factor are limited.

The roof of the building is accessible and composed of unidirectional slabs with concrete interbeams. The flooring is composed of a concrete screed. Neither the roof nor the flooring has thermal insulation.

The building's façade is defined as a conventional façade, Fig. 3.7. The characteristics of this façade are obtained from the database of the HULC tool, which is representative of the construction period (Results viewer of the Unified Tool for verification of DB-HE 2019). In Fig. 3.7, the composition of the conventional façade is shown together with the thermal conductivity values of its materials.

- Conventional façade with exterior finish of grey granite slabs, dimensions of the pieces of 40 × 40 × 2 cm, glued to the main layer with cement mortar.
- Main layer made of waterproof perforated ceramic brick, 24 × 11.5 × 5 cm, compressive strength 25 N/mm$^2$. Horizontal and vertical joints of 10 mm thick, received with industrial cement mortar M5 CEM II/A-L 32.5 N.
- Busbar layer composed of cement mortar CEM II/B-P 32.5 N type M-2.5.
- Insulation of rigid polyurethane foam, 50 mm thick, 45 kg/m$^3$ density.
- Double hollow brick 21 × 11.5 × 7 cm, compressive strength 5 N/mm$^2$.
- Inner coating by means of a C6 thin-layer gypsum plaster on a previously lined surface.
- Lacquered aluminium carpentry forming an aluminium window, hinged to be opened towards the interior (Table 3.1).

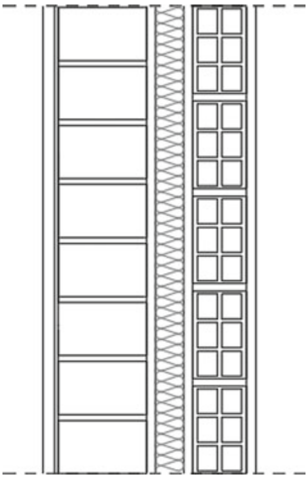

**Fig. 3.7** Conventional façade type section. Catalogue of Constructive Elements of the CTE (Costes and de la Construcción en Andalucía (BCCA) 2017). Specifications according to BCCA (Torroja and de ciencias de la construcción con la colaboración de CEPCO y AICIA 2018) and Construction cost generator—CYPE Ingenieros (Ingenieros and S.A. Software para Arquitectura, Ingeniería y Construcción 2021b)

**Table 3.1** Constructive elements of the conventional façade

| Construction element | Thickness (cm) | Thermal conductivity (w/m k) | Thermal transmittance (w/m$^2$k) |
|---|---|---|---|
| Natural stone | 2.00 | 2.800 | 0.37 |
| Perforated brick | 11.50 | 0.395 | |
| Cement mortar | 2.00 | 0.550 | |
| Cement mortar | 5.00 | 0.025 | |
| Double hollow brick | 7.00 | 0.432 | |
| Plaster coating | 2.00 | 0.570 | |

Data extracted from the LIDER-CALENER Unified Tool (Results viewer of the Unified Tool for verification of DB-HE 2019).

The conventional façade presents constructive deficiencies, such as the absence of insulation or the poor performance of the window frames. A detailed study is carried out to ascertain the energy gains and losses of the property, see Fig. 3.8.

The quantification of energy gains and losses is studied for heating (cold months) and cooling (warm months). Regarding heating, the most relevant data involves its losses, since, in the cold period of the year, it is of interest that energy losses are lower. In contrast to this, in warmer months, the energy gain values carry greater importance. This is because the lower the energy losses in winter and the lower the

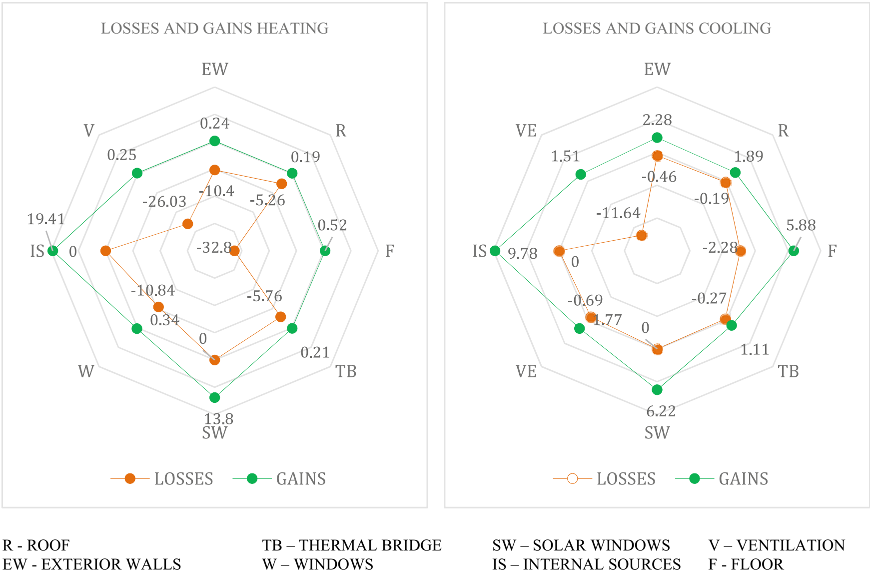


**Fig. 3.8** Distribution of gains and losses with the conventional façade for heating (left-hand side) and cooling (right-hand side). Extracted from the "LIDER-CALENER unified tool" (Results viewer of the Unified Tool for verification of DB-HE 2019)

gains in summer, the greater the reduction in the use of systems for heating and air conditioning in buildings.

The total losses due to heating the building are −88.50 kWh/m$^2$·year. The amount of −10.40 kWh/m$^2$·year corresponds solely to the façade (12% of the total heating losses of the building) and −10.84 kWh/m$^2$·year correspond to the windows. Ventilation, which also occurs through the gaps in windows frames, accounts for −26.03 kWh/m$^2$·year. The façade accounts for almost 50% of the losses.

The gains in summer are mainly attributed to internal sources, with 9.78 kWh/m$^2$·year. In second place is solar incidence on the windows, with 6.22 kWh/m$^2$·year. Therefore, in cooling and heating, the façades and the gaps constitute two determining elements. It is essential to propose a façade that improves the energy performance of the building in order to reduce energy consumption.

The rehabilitation of the building is performed by employing three different façades. First, the façade that is developed in this work, a ventilated façade, and also an external thermal insulation composite system (ETICS), façade containing XPS or extruded polystyrene, and another façade with expanded polystyrene (EPS) as thermal insulation. These façades were defined in the TABULA-EPISCOPE (EPISCOPE-TABULA 2016) as the most commonly used façades in Spain due to their ease of placement in Spanish buildings. The three façades have been set to the same thermal transmittance value. In this way, the values obtained in the energy analysis of the three façades for the rehabilitation are identical. These values are reflected in Fig. 3.9. The following tables show the thickness and thermal conduc-

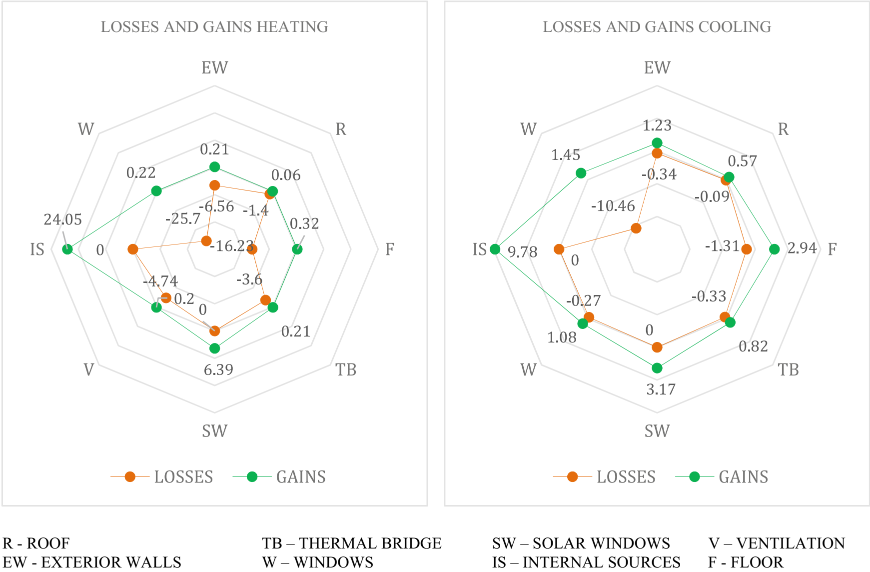


**Fig. 3.9** Distribution of gains and losses with the rehabilitation façade for heating (left-hand side) and for cooling (right-hand side). Extracted from the "LIDER-CALENER unified tool" (Results viewer of the Unified Tool for verification of DB-HE 2019)

tivity values of the materials that make up the façades for rehabilitation. The thermal transmittance e of all the new façades is 0.26 W/m$^2$K.

Table 3.2 summarizes the characteristics of the façade developed in this work. Table 3.3 shows the values of the ETICS with XPS and Table 3.4 the ETICS with EPS.

Data extracted from the LIDER-CALENER Unified Tool (Results viewer of the Unified Tool for verification of DB-HE 2019).

**Table 3.2** Constructive elements of the ventilated façade for rehabilitation

| Construction element | Thickness (cm) | Thermal conductivity (W/m k) |
|---|---|---|
| Stone cladding | 4.00 | 3.000 |
| Ventilated air chamber | 3.00 | – |
| Rock wool panel | 3.70 | 0.031 |
| Perforated brick | 11.50 | 0.395 |
| Cement mortar | 2.00 | 0.550 |
| Polyurethane foam | 5.00 | 0.025 |
| Double hollow brick | 7.00 | 0.432 |
| Plaster coating | 2.00 | 0.570 |

**Table 3.3** Constructive elements of the rehabilitated façade ETICS (XPS)

| Construction element | Thickness (cm) | Thermal conductivity (W/m k) |
|---|---|---|
| Stone cladding | 4.00 | 3.000 |
| ETICS products | 3.00 | 1.800 |
| Extruded polystyrene (XPS) | 4.50 | 0.042 |
| Perforated brick | 11.50 | 0.395 |
| Cement mortar | 2.00 | 0.550 |
| Polyurethane foam | 5.00 | 0.025 |
| Double hollow brick | 7.00 | 0.432 |
| Plaster coating | 2.00 | 0.570 |

**Table 3.4** Constructive elements of the rehabilitated façade ETICS (EPS)

| Construction element | Thickness (cm) | Thermal conductivity (W/m k) |
|---|---|---|
| Stone cladding | 4.00 | 3.000 |
| ETICS products | 3.00 | 1.800 |
| Expanded polystyrene (EPS) | 4.50 | 0.046 |
| Perforated brick | 11.50 | 0.395 |
| Cement mortar | 2.00 | 0.550 |
| Polyurethane foam | 5.00 | 0.025 |
| Double hollow brick | 7.00 | 0.432 |
| Plaster coating | 2.00 | 0.570 |

Data extracted from the LIDER-CALENER Unified Tool (Results viewer of the Unified Tool for verification of DB-HE 2019).

Data extracted from the LIDER-CALENER Unified Tool (Results viewer of the Unified Tool for verification of DB-HE 2019).

The HULC (Results viewer of the Unified Tool for verification of DB-HE 2019) program carries out the energy analysis of the building for the renovation proposal, and important improvements are achieved, see Fig. 3.9.

The data referring to energy gains and losses shows that the total losses due to heating decrease to −66.73 kWh/m$^2$·year with the improvements made, which represents a 10% reduction, of which −6.56 kWh/m$^2$·year corresponds to the façade, although the greatest losses occur through the floor and through the ventilation of the building. The total gains are 31.65 kWh/m$^2$ year, 20% of which corresponds to the gaps found in the façade, at 6.39 kWh/m$^2$ year.

Regarding cooling, the greatest gains are produced by internal sources at 9.78 kWh/m$^2$·year, while 3.17 kWh/m$^2$·year is due to solar incidence on the windows; the remaining elements exert minimal influence.

## 3.4 Evaluation of the Construction Elements

In the present work, the materials that make up the façades for the rehabilitation of buildings are also evaluated. There are many tools available to assess the environmental impact of construction materials: through certification and standardization companies; through the promotion of international standards to promote the use of eco-labelling of construction products (UNE-EN ISO 2002, 2006b, 2017; UNE-EN 2012a); through the development and application of life cycle analysis (LCA) in this sector (UNE-EN ISO 2006a, c; UNE-EN 2012b); and via the environmental management of buildings from a life cycle perspective (UNE-EN ISO 2015; ISO 2017). However, the implementation of these standards is seldom straightforward, due to economic, technical, practical, and cultural limitations (Giesekam et al. 2016, 2014).

Most recent studies propose: LCA methodologies for the estimation of the environmental impact of buildings or for the application of ecological indicators to the case studies (Buyle et al. 2013); the assessment of the energy consumption during the life cycle (Ramesh et al. 2010) or the carbon footprint (CF) of the life cycle (Schwartz et al. 2018); or a combination thereof (Cabeza et al. 2014; Chau et al. 2015). The carbon footprint is an indicator of the greenhouse gas emissions generated by a given process (Weidema et al. 2008). It stands out for its simplicity and direct relationship with the main objectives of the Kyoto Protocol (Cagiao et al. 2011), together with its easy application in decision-making and environmental policy (Bare et al. 2000). Numerous literature reviews are related to the use of the CF indicator in construction (Geng et al. 2017), although the results are not always comparable. This lack of comparability is due to the absence of a methodology that follows international standards (Dossche et al. 2017). For this reason, studies have also been carried out in recent years to establish scales that make it possible to define reasonable ranges of $CO_2$ emissions in construction and material manufacturing processes (Chastas et al. 2018).

In Spain, a variety of these tools use the CF indicator in the construction of buildings. For example, SpainGBC presents the GREEN tools (SpainGBC VERDE tool website Available online 2018), and ECOMETRO is an open-source tool on the web that measures the environmental impact of a building (Ecometro and LCA tool website Available online, (n.d.). 2018). This latter tool is like an environmental product declaration (EPD), but it is applied to entire buildings, instead of a single product. Highly specialized platforms allow the detailed calculation of $CO_2$ emissions according to the project budget and its bill of quantities. On one hand, there is BEDEC, which was developed by the Catalonia Institute of Construction Technology (ITeC). This tool uses environmental data for construction materials obtained from the Ecoinvent LCA database (Ecoinvent centre 2016). It is known for being one of the most complete databases in Europe and for its integration with the Simapro LCA software. The SOFIAS tool, on the other hand, uses data from the OpenDAP database (SOFIAS project SOFIAS project website Available online 2018). As an intermediate solution, there is E2CO2Zero (e2CO2cero tool website Available online 2018), from the Basque Government, software that enables the embodied energy and the CF of a building to be estimated in terms of the materials consumed and the construction processes used (e2CO2cero tool website Available online 2018).

An open-source software tool OERCO2 (Solís-Guzmán et al. 2018) estimates the environmental impact of architectural projects from the design phase (accessible at http://oerco2.eu/). This is an online application that enables the carbon emissions produced in the construction of residential buildings to be estimated. It is derived from several previous research studies developed by the authors (Solís-Guzmán et al. 2015; Martínez-Rocamora et al. 2017) and includes the evaluation of $CO_2$ emissions for the construction process of 140 different residential building typologies. Studies carried out on more than 100 homes in Spain determined that the materials that make up the façade carry the greatest impact in terms of carbon footprint (Vallejo et al. 2020).

This work studies the façades and determines the embodied energy and equivalent $CO_2$ emissions of the cradle to door of the factory processes of the construction products used. The percentage of recycled material contained therein is also identified. In order to obtain this data, manual calculations are carried out to compute volume and density.

Building Information Modelling tools are employed to obtain the bill of quantities of the rehabilitation projects. These are increasingly used in planning, design, and comprehensive project management, mainly in new buildings (European Commission 2010). Building Information Modelling software adds information to construction projects, and hence the designer draws construction elements and simultaneously defines their characteristics or parameters at different stages of the life cycle of the building (Cheung et al. 2012). This type of software enables the inclusion of information that can improve decision-making during the design stage (Wong and Zhou 2015; Soust-Verdaguer et al. 2017; Eleftheriadis et al. 2017). Their environmental impact assessment usually includes the consumption of energy and construction materials, greenhouse gas (GHG) emissions, and the generation of construction and demolition waste (CDW) (Kulahcioglu et al. 2012). Furthermore, evaluation systems and databases are available, both for consultants and providers (Fiès et al. 2013). However, BIM software requires designers to work with a variety of software, databases, and methodologies (Lamé et al. 2017; Chong et al. 2017). The integration of environmental impact assessment into BIM requires programming skills, since the assessment is a task in which architects, engineers, and programmers must all work together (Ilhan and Yaman 2016). For example, the integration of LCA in BIM has been addressed in recent studies (Santos et al. 2019), whereby the focus is on the construction stage.

In this work, the CYPE Architecture (CYPE Ingenieros, S.A. Software para Arquitectura, Ingeniería y Construcción 2021c) tool is used, see Fig. 3.10. In the 3D model, the façades with the corresponding door and window openings, the slabs, and the interior partitions are all defined, both in geometry and composition. In order to define the composition of the construction elements, the CYPE Cost Generator

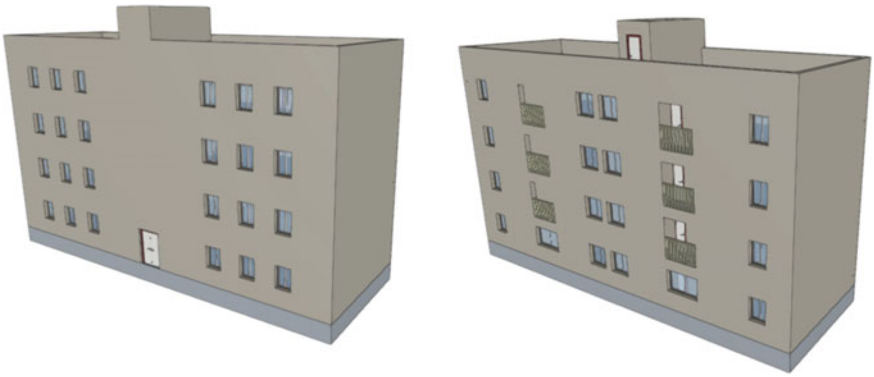

**Fig. 3.10** Building modelled in the CYPE Architecture tool. Design and 3D modelling of buildings (CYPE Ingenieros, S.A. Software para Arquitectura, Ingeniería y Construcción 2021c)

database (CYPE Ingenieros, S.A. Software para Arquitectura, Ingeniería y Construcción 2021b) is used, in which the values of embodied energy and $CO_2$ emissions of the products are included.

### *3.4.1 Façade Eco-efficiency Indicators*

Three eco-efficiency indicators are defined: Energy consumption; $CO_2$ emissions generated in the manufacturing stage of the products that make up the façades analysed; and the amount of recycled product included in the materials that make up the façades.

As a general definition, embodied energy refers to the amount of energy required to produce products from the cradle to the factory gate. In the field of construction and architecture, we will consider embodied energy as the amount of energy used in the building element. This indicator is expressed in units of $MJ/m^2$ of façade.

Emissions of $CO_2$ and equivalent gases refer to those derived from the extraction and transformation processes of materials and construction elements until they are placed and packed at the factory door. $CO_2$ emissions are quantitatively expressed in $kgCO2eq./m^2$. The square metres refer to the area of the façade.

The amount of recycled material that the façade elements contain is defined as a percentage of the total product and is the amount of recycled material in the pre-consumer stage.

These indicators are considered the most widely used in the sector when conducting a diagnosis of construction materials and products in terms of sustainability and environmental impact (Vallejo et al. 2020; Guzmán et al. 2014).

### 3.4.2 Definition of Façades for Rehabilitation

In this section, the technical characteristics of the façades for rehabilitation are defined. As previously mentioned, three façades are defined: the ventilated façade proposed for rehabilitation designed in this project (Fig. 3.11), an ETICS-type façade configured with XPS thermal insulation (Fig. 3.12), and another ETICS-type façade composed with EPS thermal insulation (Fig. 3.13).

A series of tables are configured in which the values of embodied energy, $CO_2$ emissions, and percentage of recycled product of each of the materials that make up the façades are included (Tables 3.5, 3.6 and 3.7). These values assist in the determination as to which of the three façades generates the least environmental impact. The analysis focuses on the exterior cladding, thermal insulation, and carpentry since

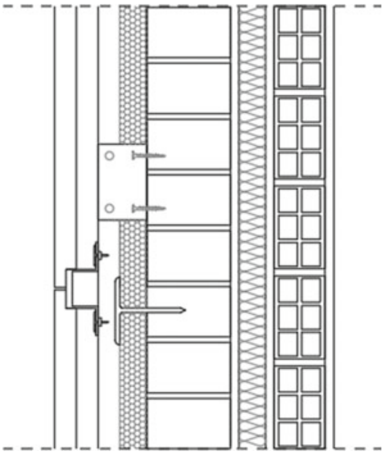

**Fig. 3.11** Section of the ventilated rehabilitated façade

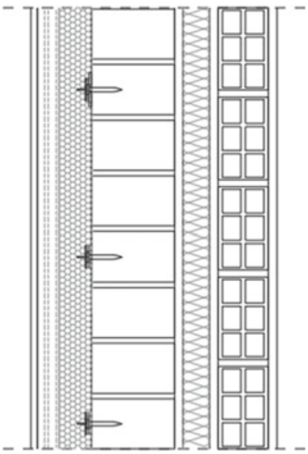

**Fig. 3.12** ETICS façade type section with XPS thermal insulation

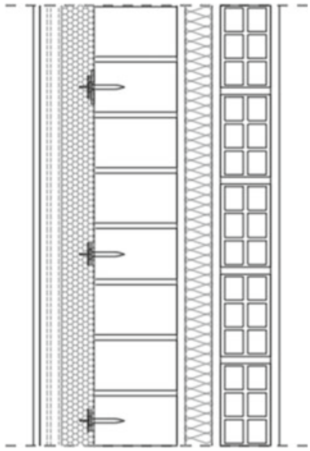

**Fig. 3.13** ETICS façade type section with EPS thermal insulation

these constitute the part of the façade layer to be added (rehabilitation), while the remaining components or substrate comprise those of the conventional façade, which functions as a base.

#### 3.4.2.1 Ventilated Rehabilitated Façade

The façade for building rehabilitation is laid on top of the conventional façade and is formed of exterior layers (Fig. 3.11). The prototype is made of materials that have an EPD (Declaración Ambiental de Productos. Página Web de AENOR).

- Exterior Coating of Capri limestone sandstone slabs, honed finish, 1200 × 60 × 4 cm. Supported by an auxiliary structure made of aluminium.
- Thermal insulation by semi-rigid rock wool panel. Thickness 37 mm. Fixed to the main layer with metal screws.
- Main layer made of waterproof perforated ceramic brick, 24 × 11.5 × 5 cm, compressive strength 25 N/mm$^2$. Joints of 10 mm thick, received with industrial cement mortar M5 CEM II/A-L 32.5 N.
- Busbar layer composed of cement mortar CEM II/B-P 32.5 N type M-2.5.
- Insulation by rigid polyurethane foam, 50 mm thick, 45 kg/m$^3$ minimum density. 21 × 11.5 × 7 cm double hollow brick partition, compressive strength 5 N/mm$^2$.
- Double hollow brick 21 × 11.5 × 7cm, compressive strength 5 N/mm$^2$.
- Inner coating by means of C6 thin-layer gypsum plaster on a previously lined surface.
- Window frames of aluminium 75R by THECNAL.

Table 3.5 shows the values of incorporated energy, $CO_2$ emissions, and percentage of recycled material of the products that form the ventilated façade for rehabilitation.

As previously mentioned, the analysis focuses on the exterior cladding, thermal insulation, and carpentry. The most unfavourable value of embodied energy is

**Table 3.5** Environmental impact generated by the elements that make up the proposed rehabilitated façade

| Construction element | Code | Incorporated energy (Mj/m$^2$) | $CO_2$ emissions (kgco$_2$/m$^2$) | Recycled product (%) |
|---|---|---|---|---|
| Stone cladding (Guzmán et al. 2014) | EC | 5.40 | 0.60 | 32 |
| Rock wool panel (Guzmán et al. 2014) | TI | 57.17 | 4.01 | 67 |
| Perforated Brick ( CYPE Ingenieros, S.A. Software para Arquitectura, Ingeniería y Construcción 2021b) | ML | 406.52 | 18.75 | 0 |
| Double Hollow Brick (CYPE Ingenieros, S.A. Software para Arquitectura, Ingeniería y Construcción 2021b) | IL | 212.22 | 11.30 | 0 |
| Plaster Coating (CYPE Ingenieros, S.A. Software para Arquitectura, Ingeniería y Construcción 2021b) | IC | 48.53 | 2.16 | 0 |
| Cement Mortar (CYPE Ingenieros, S.A. Software para Arquitectura, Ingeniería y Construcción 2021b) | U | 13.05 | 1.01 | 0 |
| Aluminium C. 75R (Guzmán et al. 2014) | WF | 85.00 | 2.30 | 75 |

Nomenclature: *EC* Exterior Coating; *TI* Thermal Insulation; *ML* Main Layer; *IL* Inner Layer; *IC* Inner Coating, *U* Unions; *WF* Window frame. Data extracted from the CYPE Price Generator database (CYPE Ingenieros, S.A. Software para Arquitectura, Ingeniería y Construcción 2021b) and EPD Certificates (Declaración Ambiental de Productos. Página Web de AENOR)

presented by the window frames at 85.00 MJ/m$^2$. The thermal insulation needs 57.17 MJ/m$^2$ and emits 4.01 kg$CO_2$/m$^2$. All the materials in the rehabilitation contain recycled material due to the selection of products of low environmental impact.

#### 3.4.2.2 ETICS XPS Façade for Rehabilitation

In this section, the characteristics of the ETICS rehabilitation are defined. In this case, the thermal insulation is XPS. The ETICS solution consists of placing thermal insulation on the exterior walls of a building. The exterior coating depends on the type of insulation installed. In this case, stone cladding is chosen in order to respect

**Table 3.6** Environmental impact generated by the elements that make up the SATE (XPS) rehabilitated façade type

| Construction element | Code | Incorporated energy ($MJ/m^2$) | $CO_2$ emissions ($kgCO_2/m^2$) | Recycled product (%) |
|---|---|---|---|---|
| Stone cladding | EC | 12.80 | 20 | 0 |
| Extruded polystyrene | TI | 144.88 | 4.61 | 20 |
| Perforated brick | ML | 406.52 | 18.75 | 0 |
| Double hollow brick | IL | 212.22 | 11.30 | 0 |
| Plaster coating | IC | 48.53 | 2.16 | 0 |
| Cement mortar | U | 13.05 | 1.01 | 0 |
| Lacquered aluminium | WF | 359.36 | 9.51 | 0 |

Nomenclature: *EC* Exterior Coating; *TI* Thermal Insulation; *ML* Main Layer; *IL* Inner Layer; *IC* Inner Coating, *U* Unions; *WF* Window frame. Data extracted from the CYPE Price Generator database (CYPE Ingenieros, S.A. Software para Arquitectura, Ingeniería y Construcción 2021b)

**Table 3.7** Environmental impact generated by the elements that make up the rehabilitated façade type ETICS (EPS). It incorporates non-recycled products

| Construction element | Code | Incorporated energy ($MJ/m^2$) | $CO_2$ emissions ($kgCO_2/m^2$) |
|---|---|---|---|
| Stone cladding | EC | 88.68 | 2.04 |
| Expanded polystyrene | TI | 100.57 | 4.25 |
| Perforated brick | ML | 406.52 | 18.75 |
| Double hollow brick | IL | 212.22 | 11.30 |
| Plaster coating | IC | 48.53 | 2.16 |
| Cement mortar | U | 13.05 | 1.01 |
| Lacquered aluminium | WF | 359.36 | 9.51 |

Nomenclature: *EC* Exterior Coating; *TI* Thermal Insulation; *ML* Main Layer; *IL* Inner Layer; *IC* Inner Coating, *U* Unions; *WF* Window frame. Data extracted from the CYPE Price Generator database (CYPE Ingenieros, S.A. Software para Arquitectura, Ingeniería y Construcción 2021b)

the aesthetics of the building and to enable the analysis of the different products in a logical and fair way.

- Exterior coating of stone cladding, honed finish, 1200 × 60 × 4 cm adhered to main layer by cement mortar.
- Mortar regularization layer, applied manually, armed with fibreglass mesh of 5 × 4 mm mesh size.
- Thermal insulation of rigid extruded polystyrene panel of dimension 1250 × 500 × 45 mm.

- Main layer made of waterproof perforated ceramic brick, 24 × 11.5 × 5 cm, compressive strength 25 N/mm$^2$. Joints 10 mm thick, received with industrial cement mortar M5 CEM II/A-L 32.5N.
- Busbar layer composed of cement mortar CEM II/B-P 32.5N type M-2.5.
- Insulation by rigid polyurethane foam, 50 mm thick, 45 kg/m$^3$ minimum density.
- Double hollow brick 21 × 11.5 × 7 cm, compressive strength 5 N/mm$^2$.
- Inner coating by means of C6 thin-layer gypsum plaster on a previously lined surface.
- Lacquered aluminium carpentry, forming an aluminium window, hinged to be opened towards the interior.

Table 3.6 shows the values of incorporated energy, $CO_2$ emissions, and percentage of recycled material of the products that make up the façade for rehabilitation ETICS (XPS).

The highest value of incorporated energy appears in the lacquered aluminium carpentry at 359.36 MJ/m$^2$ which makes this the worst value. On the other hand, stone cladding requires the least amount of energy to be manufactured. However, this product is the one that emits the most $CO_2$ in its manufacturing process. Thermal insulation is the only material that incorporates a recycled product.

#### 3.4.2.3 ETICS with EPS

In this section, the characteristics of the ETICS-type façade are defined. This façade uses a different thermal insulation, and EPS is chosen for this façade. In this case, the chosen exterior cladding is also a stone cladding in order to respect the aesthetics of the building and to be able to analyse the different products.

- Exterior coating of stone cladding, honed finish, 1200 × 60 × 4 cm adhered to main layer by cement mortar.
- Mortar regularization layer, applied manually, armed with fibreglass mesh of 5 × 4 mm mesh size.
- Thermal insulation of rigid expanded polystyrene panel of dimension 1000 × 500 × 45 mm.
- Main layer made of waterproof perforated ceramic brick, 24 × 11.5 × 5 cm, compressive strength 25 N/mm$^2$. Joints 10 mm thick, received with industrial cement mortar M5 CEM II/A-L 32.5N.
- Busbar layer composed of cement mortar CEM II/B-P 32.5N type M-2.5.
- Insulation by EPS polyurethane foam, 50 mm thick.
- Double hollow brick 21 × 11.5 × 7cm, compressive strength 5 N/mm$^2$.
- Inner coating by means of a C6 thin-layer gypsum plaster on a previously lined surface.
- Lacquered aluminium carpentry forming an aluminium window, hinged to be opened towards the interior.

Table 3.7 shows the values of embodied energy, $CO_2$ emissions, and percentage of recycled material of the products that make up the façade for rehabilitation ETICS (EPS).

The aluminium window frames used in this façade are the same as those used in the ETICS XPS rehabilitation solution, and hence the values of embodied energy and $CO_2$ emissions remain the same. The stone cladding has a lower value of incorporated energy, with a total of 88.68 MJ/m$^2$, which makes this the most favourable value. Finally, it should be borne in mind that none of the products contain recycled material.

## 3.5 Results and Discussion

### *3.5.1 Building Energy Performance*

In this section, a comparison is made of the energy performance of the building with the conventional façade with that after the renovation of said façade. The building complies with current regulations and the energy losses are reduced. The comparison looks at heating losses and cooling gains. These values are analysed since they represent the most relevant data and exert the greatest global impact on the energy study. In winter, the losses are examined, while in summer, the gains are examined (Fig. 3.14).

Heating losses decrease to −58.23 kWh/m$^2$·year with the improvements made. Heating losses are reduced by more than 36% thanks to the renovation of the building. The significant improvements in these losses are attained through the roof with −1.4 kWh/m$^2$·year, the floor with −16.23 kWh/m$^2$·year, and through the windows with a −4.74 kWh/m$^2$·year.

The total cooling gains reach 21.04 kWh/m$^2$·year, which represents a reduction of 30.89% of the annual gains in the warm months. The exterior walls reduce the gain to 1.23 kWh/m$^2$·year. The roof has 0.57 kWh/m$^2$·year, the floor 2.94 kWh/m$^2$·year, and the windows 1.08 kWh/m$^2$·year. The solar incidence on the windows is considerably reduced. Façade improvements reduce both losses in winter and gains in summer.

### *3.5.2 Analysis of the Eco-Efficient Characteristics of the Façade Materials*

In this section, a comparison is made between the façades from the point of view of sustainability and eco-efficiency of materials. The analysis of the materials focuses on the exterior cladding, thermal insulation, and window frames. The main objective of this analysis is to ensure that the façade for rehabilitation developed in this project (ventilated façade) represents environmental improvements in comparison with the other two façades considered for rehabilitation (ETICS-type façades).

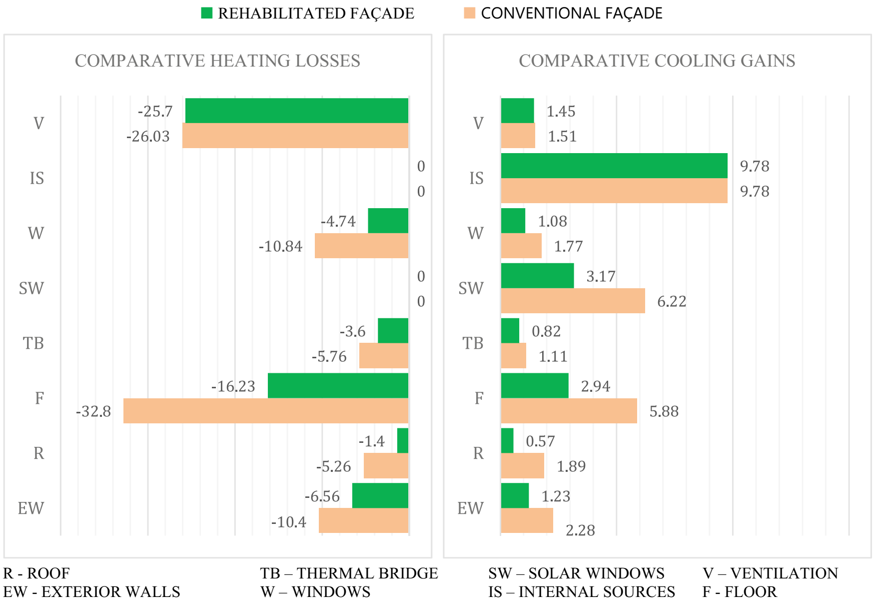


**Fig. 3.14** Comparison of the conventional and the rehabilitated solution in terms of losses due to heating (left-hand side) and cooling (right-hand side). Extracted from the "LIDER-CALENER Unified Tool" (Results viewer of the Unified Tool for verification of DB-HE 2019)

In the first place, the embodied energy values and $CO_2$ emissions of each of the materials in the façades are analysed (Fig. 3.15).

The graph in Fig. 3.15 on the left-hand side reflects the embodied energy values of the materials of all the façades. The ventilated façade presents the lowest values. The biggest difference is encountered in the window frames. The carpentry used in the ventilated façade requires 274.36 MJ/m$^2$ less energy than the carpentry of the ETICS-type façades. There are also major differences in the exterior cladding. The large amount of energy incorporated in the exterior cladding of the ETICS (EPS) façade deserves mention.

The graph in Fig. 3.15 on the right-hand side corresponds to $CO_2$ emissions. Again, the most favourable values are those corresponding to the ventilated façade. The most unfavourable value appears in the exterior cladding of the ETICS (EPS). In the case of thermal insulation, the emission values are similar, although those of the ventilated façade remain lower.

Secondly, two graphs are configured that show the total values of incorporated energy and $CO_2$ emissions per square metre of each of the façades (Fig. 3.16). These graphs allow a clear and direct view of the façade that has the most favourable values from an eco-efficiency and sustainability point of view.

In both cases, the ventilated façade developed in this project presents the most favourable values. Regarding the total incorporated energy of the materials, the ventilated façade has 147.57 MJ/m$^2$ and needs 317.76 MJ/m$^2$ less than the ETICS façade

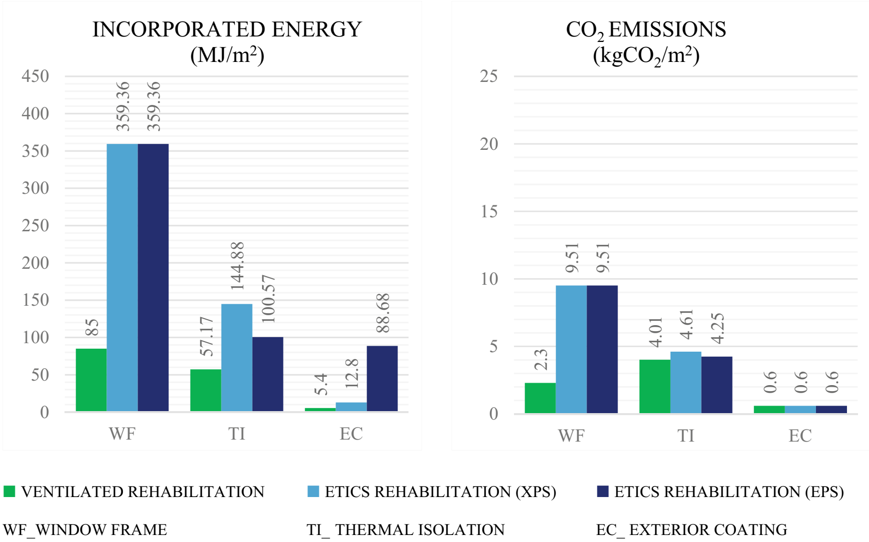


**Fig. 3.15** Energy incorporated per square metre of façade (left-hand-side) and their $CO_2$ emissions (right-hand-side)

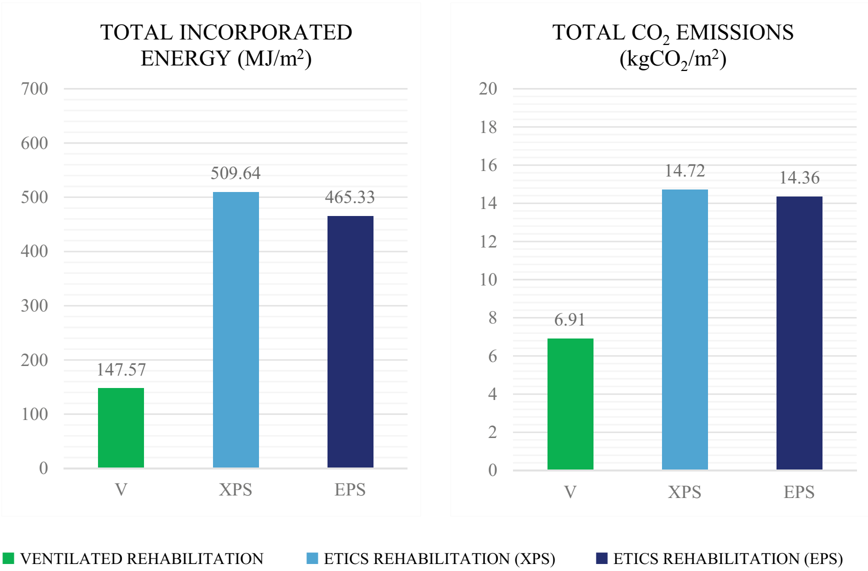


**Fig. 3.16** Total values of energy incorporated per square metre (left-hand side) and total values of $CO_2$ emissions per square metre (right-hand side)

(XPS) for its manufacture. There is an even greater difference between the ventilated façade and the ETICS (EPS): 362.07 MJ/m$^2$. The proposed ventilated façade design requires less than a third of the energy for its manufacture in comparison with the other two façades analysed.

The graph on the right-hand side in Fig. 3.16 shows the total $CO_2$ emissions per square metre of each of the façades. In this case, the proposed façade also has the most favourable value, that is, the lowest value. The ventilated façade emits a total of 6.91 kg$CO_2$/m$^2$. The ETICS façades (XPS and EPS) emit 14.36 kg$CO_2$/m$^2$ and 14.72 kg$CO_2$/m$_2$, respectively. The ventilated façade emits approximately half of that emitted by the ETICS-type façades.

It is evident, through the proposed methodology, how the benefits of the ventilated façade for rehabilitation can be clearly identified since it generates a lower environmental impact in its processes from the cradle to the factory door. This characteristic renders the ventilated façade the most sustainable, eco-efficient, and environmentally friendly façade of the three façades analysed. Finally, the lower impact is mainly due to the percentage of recycled product in each of the materials that make up the façades (Fig. 3.17).

All the materials in the ventilated façade developed in this project contain recycled material (Fig. 3.17—left-hand side). This is the only façade with this characteristic. Furthermore, the window frames present the highest percentage of recycled material, at 75%. In second place is the thermal insulation, at 67% recycled material. Thirdly, the stone cladding, has 32% recycled material. In the case of the ETICS façade (XPS),

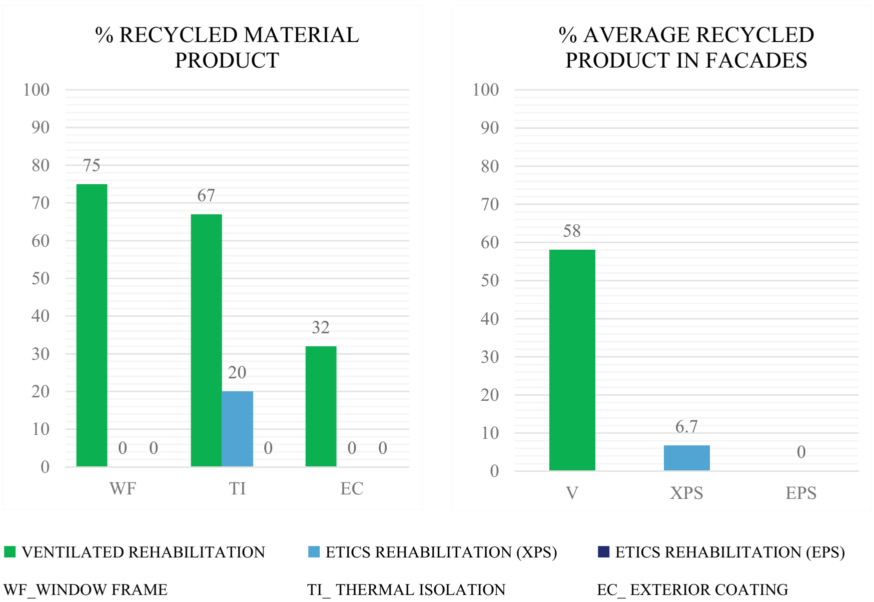


**Fig. 3.17** Percentage of recycled product of the materials that make up the façades (left-hand side) and average values of recycled product of the materials that make up the façades (right-hand side)

the only product that has recycled material is thermal insulation, at 20%. Finally, none of the materials that make up the ETICS façade (EPS) contains recycled material.

## 3.6 Conclusion

In the first place, and as a general overview, it is possible to affirm that the construction sector is a major contributor to the climate change process, due to the high volume of industry that this sector requires to carry out its activities. In addition, the production and manufacturing processes necessary for the generation of construction materials entail high energy costs, both in direct energy consumption in the building's installations, and in indirect consumption in the manufacture of construction materials and products. It is therefore necessary to include concepts of eco-efficiency and sustainability in the world of architecture and construction in the same way that it is essential to promote projects from the point of view of sustainability. Of course, a circular production model in the construction sector would imply considerable improvements of the current state.

It is verified that the rehabilitation of a façade, in which materials with low environmental impact are used, results in a significant reduction of the incorporated energy and $CO_2$ emissions, with respect to the other façades for rehabilitation.

The implementation of methodologies to carry out the analysis of the different construction solutions chosen, enables energy efficiency to be ascertained and evaluated, and, thanks to the tools used, the energy losses and gains to be quantified through both the conventional envelope and the prototype for rehabilitation. For the analysis, BIM tools, LCA, EPD, and energy simulation databases are combined.

Furthermore, it is possible to assess the potential for improvement in terms of reducing the energy demand of homes, which translates into an improvement in its habitability and a reduction in its direct and indirect environmental impact.

The rehabilitation reduces energy losses in winter and in summer, by reducing the use of heating and air-conditioning systems. It is revealed that the façade is a major contributor towards the losses and gains of cooling and heating, and hence its correct rehabilitation represents significant savings.

It should also be mentioned that other types of materials and techniques can be used in the manufacture of said elements with possible additional benefits in terms of energy consumption. In this way, the guidelines proposed in this work, beyond the specific implementation of the developed façade, can give rise to new branches of architecture that are more environmentally friendly and can facilitate the integration of these branches into the circular economy paradigm, thereby potentially reducing the environmental and economic impact of architecture.

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