Recibido 25/08/2020
Aceptado 05/12/2020

INFLUENCE ON ENERGY PERFORMANCE IN HISTORICAL BUILDINGS CAUSED BY THE URBAN ENVIRONMENT AND PROJECT MODIFICATIONS: THE CASE OF THE DUCLÓS HOUSE

INFLUENCIA EN EL RENDIMIENTO ENERGÉTICO EN EDIFICIOS HISTÓRICOS PROVOCADO POR EL ENTORNO URBANO Y LAS MODIFICACIONES DE PROYECTO: EL CASO DE LA CASA DUCLÓS

DAVID BIENVENIDO-HUERTAS
Doctor en Arquitectura
Investigador, Departamento de Construcciones Arquitectónicas II
Universidad de Sevilla, Escuela Técnica Superior
de Ingeniería de Edificación
Sevilla, España
https://orcid.org/0000-0003-0716-8589
jbienvenido@us.es

ISIDRO CORTÉS
Doctor en Arquitectura
Profesor titular, Departamento de Expresión Gráfica
e Ingeniería en Edificación
Universidad de Sevilla, Escuela Técnica Superior de Ingeniería de Edificación
Sevilla, España
https://orcid.org/0000-0003-4541-2327
icortes@us.es

RESUMEN

Los edificios históricos constituyen parte fundamental del patrimonio cultural tangible de la sociedad actual. El cumplimiento de las exigencias de ahorro energético para mitigar el cambio climático, sin embargo, puede verse limitado aquí debido a las características propias de estos edificios. Además, en el caso de las construcciones históricas, los principios de diseño bioclimático aplicados por los arquitectos, desde principios del siglo XX hasta la actualidad, pueden haber perdido efectividad. Ello ocurre, a veces, por las modificaciones en proyecto o por efectos del desarrollo urbanístico. En este estudio se analizan estos dos aspectos en un determinado edificio histórico ubicado en Sevilla: la Casa Duclós de José Luis Sert. Este presenta modificaciones en la cubierta, cuando se compara la proyectada y la construida. Asimismo, su entorno urbano se ha transformado desde que la Casa fue edificada. Para el análisis expuesto en este artículo, se realizaron simulaciones energéticas utilizando datos climáticos correspondientes al periodo 2000-2019. Los resultados muestran la influencia que tuvieron las modificaciones de la cubierta proyectada y la expansión urbanística en el rendimiento energético del edificio, con respecto a la concepción original del inmueble.

Palabras clave
patrimonio arquitectónico, ahorro de energía, estrategias urbanas, arquitectura moderna.

ABSTRACT

Historic buildings are a fundamental part of the tangible cultural heritage of today's society. However, the energy saving requirements to limit climate change may present limitations with respect to the characteristics of these buildings. In the case of historical buildings from the early 20th century to the present, the bioclimatic design principles applied by architects may have been limited. In some cases, it may be due to project modifications or urban expansion. In this study, these two aspects are analyzed in a case of a historic building located in Seville: The Duclós House by José Luis Sert. This building presents modifications in the roof between the projected and the built one. Likewise, the urban environment is different from the one existing when it was built. The analysis was carried out with energy simulations using weather data from 2000 to 2019. The results show the influence that the modifications of the projected roof and the urban expansion had on the energy performance of the building with respect to the original idea of the building.

Keywords
Architectural heritage, energy saving, urban strategies, modern architecture

Revista Hábitat Sustentable Vol. 10, N°. 2. ISSN 0719 - 0700 / Págs. 42 -53
https://doi.org/10.22320/07190700.2020.10.02.03

INTRODUCTION

Currently, there is a clear goal of attaining energy savings in existing buildings (Akande, Odeleye, Coday & Jimenez Bescos, 2016). Although most studies have focused on the energy analysis of residential, administrative or commercial buildings, a lack of research dedicated to analyzing the energy performance of heritage buildings has been detected (Lidelöw, Örn, Luciani & Rizzo, 2019). The ones there are have focused on reducing energy consumption to guarantee suitable conditions of conservation (De Rubeis, Nardi, Muttillo & Paoletti, 2019) or the suitable inhabitability for their users (Sugár, Talamon, Horkai & Kita, 2020). However, despite these efforts, there is a lack of studies considering the impact modifications of heritage buildings have had on their energy performance. Aspects like urban expansion, can modify the energy performance of buildings, on altering their shading conditions (Lobaccaro et al., 2019). An example of this was reported by Baño Nieva and Vigil-Escalera del Pozo (2005) for a building with greenhouses that favor solar radiation capture in Madrid. Urban growth led to higher buildings appearing around it, meaning the architects' previous design will be unused. Factors like the imposition of regional traditional techniques in the construction processes for these buildings are added to this, which can lead to changes in energy performance compared to what was originally projected.

Facing these circumstances, this study sets out to analyze the current energy impact of a historic building from the start of the 20th century, considering the modifications it has undergone, both from building work and urban growth. The case chosen was Duclós House built in 1930, a project by José Luis Sert, and located in Seville (Spain). José Luis Sert was one of the most important Spanish architects in the last century. Despite its importance, the work of Sert in Spain is limited. From his few Spanish constructions, Duclós House constitutes, without a doubt, the his most forgotten work on an international scale, which is why there is limited research on it (López-Rivera & Parra Bañón, 2012). Just like other famous buildings of the period, like those of Frank Lloyd Wright (Beltrán-Fernández, García-Muñoz & Dufrasnes, 2017) or Le Corbusier (Iommi, 2019), Sert's work is characterized on having a major bioclimatic component in his projects.

Concretely, there is certainty that modifications were made on the house compared to its specifications. This is likely because of a lack of direction during the works:

> In this regard, the information we have is unclear. Sert tells us that he visited the site and works on several occasions, but he does not remember the precise details about the direction […]. The owners tell us about certain modifications made during the construction […] (Delgado Pérez, Pérez Escolano, Sebastián Bollaín & Ramón Sierra, 1968, p. 177).

The building was located in an area far from the urban hub when it was built: a smallholding marked out by the architect Aníbal González on lands of the University Chancellor's farmhouse, which later became popularly known as the Nervión neighborhood (Bono Ruiz de la Herrán, García Vásquez, Pérez Escolano, Pico Valimaña & Ortega, 1996). It was an unconsolidated suburban development area, even a decade after its construction, just as can be seen in Figure 1. However, urban expansion throughout the 20th century enveloped Duclós House, leaving it located on a narrow street, surrounded by high-rise buildings (Figure 1).

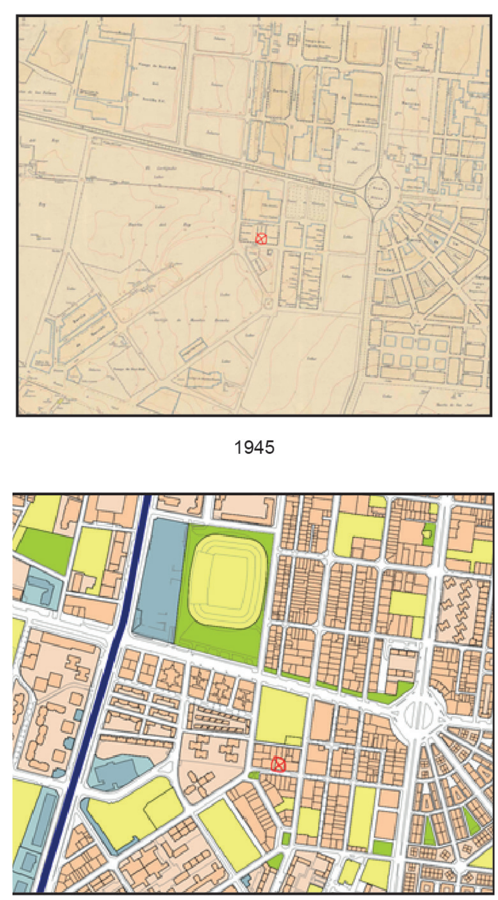

Figure 1. Plans of the area around Duclós House in 1945 (left) and today (right). Source: Preparation by the authors using plans from the map library and the Seville City Council's General Urbanistic Ordinance Plan.

As a result, the case study chosen meets the expected conditioning aspects to be analyzed. First of all, a review of the construction details is made which has differences between what was built and what was projected: the roof. After this, an energy analysis was made of the impact of the modifications made has implied, both on the roof and on the urbanistic surroundings of the building, using climate data from the last 20 years in Seville.

CONSTRUCTIVE ANALYSIS OF DUCLÓS HOUSE

Duclós House is located in Seville. It is a single-family dwelling located on a 535 m^2 smallholding (Figure 2) that occupies a surface area of 169 m^2. The house's vertical distribution comprises the following floors: semi-basement, ground floor, second floor and attic. Connection between the different levels is made through single flights of stairs (Quesada, 2008).

The ground floor has a hall, kitchen, garage, laundry and large L-shaped living room, whose initial layout formed a sitting room and the old living room. The second floor is split into four bedrooms, two bathrooms and two terraces. After a reorganization, the floor's distribution was left with 3 bedrooms, two bathrooms, a sitting room and two terraces (Lousame, 2011). The attic has a laundry room, which was closed off to leave space to hang clothes protected from the rain. It has also a box room, a bedroom, a bathroom and a terrace (Lousame, 2011).

CONSTRUCTION DESCRIPTION

The house's foundation is built from a 50 cm thick concrete slab, on which the finishing material of the basement floor was placed. The walls of this floor are 50 cm thick concrete, without any type of insulation or drainage, and the framework is made from 25 cm thick reinforced concrete (Bono Ruiz de la Herrán et al., 1996).

As for the enclosures, Sert designed the dwelling bearing in mind its bioclimatic interaction with its surroundings. For this reason, the building has two different façade setups, depending on their orientation. The north-facing façade comprises a traditional 25 cm solid wall, while the rest of the façades are built by two rows of bricks separated by an unventilated air chamber (Lousame, 2011). The building's carpentry is spread along all its façades, with different rectangular shapes. One of the aspects that most affects passive comfort strategies is the handling of the openings. At Duclós House, there are openings on most of the façades, but more so on the north-facing one. The rest of the openings have

Figure 2. Outdoor photograph of Duclós House.Source: Quesada (2008, p. 194).

Figure 3. Aerial view of Duclós House and the buildings around it. Source: Preparation by the Authors.

shading elements like the windows set back from the wall on the ground floor of the south façade. With these systems, direct solar incidence in summer periods can be avoided, when it is high in the sky, as well as direct incidence in winter, when the sun is lower.

As has been indicated, the building is currently surrounded by large voluminous high-rise buildings (Figure 3), that limit the incidence of direct solar radiation on each of its enclosure elements, as such the different shading premises considered in the project's preparation may have been left inoperative, impeding, in winter, the solar incidence that can generate greater thermal comfort in the different rooms.

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David Bienvenido Huertas, Isidro Cortés
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ROOF

The roof is one of the most significant elements of Duclós House, on being the element that is most exposed to solar radiation. It was projected following the constructive typology of the Catalan roof, but the lack of site direction by the architect led to the roof being built following the construction techniques of the region at that time (Paricio Casademunt, 1998). In spite of this, the roof has a relevant solar radiation most of the year. Sert understood that the terrace was a further extension of the house and, for that reason, wanted to implement three clearly identified strategies for the protection and search of indoor comfort: the creation of a high-rise garden, the positioning of a manual awning using a metal support, and a ventilated roof. Ultimately, on facing diverse casuistries, an Andalusian roof was chosen (Lousame, 2011)

On analyzing the project's graphical documentation, the space set aside for an air chamber can be seen, on the building's floor plan (Figure 4), which corresponds to the project's original idea; although there is evidence, like the lack of vents or the 13x28 cm ceramic tiles, that indicate the terrace roof was built following the canyons of traditional Andalusian roofs (Lousame, 2011).

In this way, there are signs that show that the roof was projected with an air chamber. However, the fact that Duclós House lacks vents is one of the reasons why it is assumed that the projected roof could not be made (Paricio Casademunt, 1998). In this sense, it is worth mentioning another project of José Luis Sert which was designed at practically the same time as Duclós House: the building on Muntaner Street, in Barcelona (Spain). This building has a particular solution using the traditional Catalan roof of the time. By analyzing the graphical documentation of said project, the same type of representation seen on the plans of Duclós House can be seen (Figure 5). According to several research projects, the solution set out by Sert would use a mixed proposal of a traditional Catalan roof on honeycomb walls and the solution used by Le Corbusier and Jeanneret at the Double House in Weissenhofsiedlung, with the flooring placed on sand and filtering gravel, under which it had a waterproofed layer (Lousame, 2011; Paricio Casademunt, 1996).

The traditional Catalan roof of the time was formed by two wrought panels: one horizontal and the other with a slope of between 6% and 8%, supported on wooden or metal profile joists. But, since the beginning of the 20th century, it became a model formed by a floor tile board underpinned on honeycomb walls. The air ventilation in both cases would be produced by the façade and the indoor

Figure 4. Duclós House floor plan. Source: Preparation by the Authors.

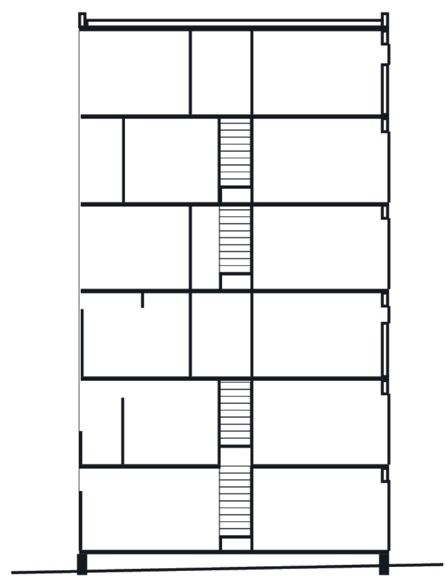

Figure 5. Floor plans of the building on Muntaner Street. Source: Preparation by the Authors.

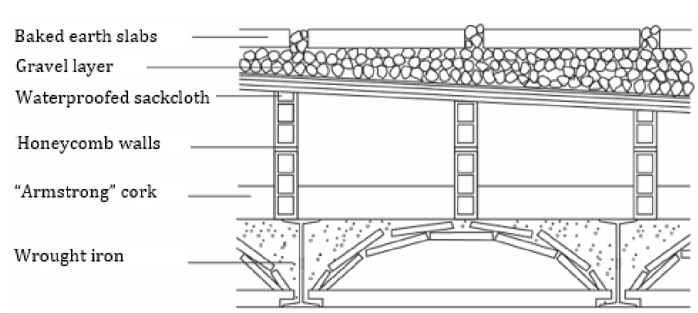

Figure 6. Floor plans of the building on Muntaner Street.Source: Paricio Casademunt (1996, p. 421).

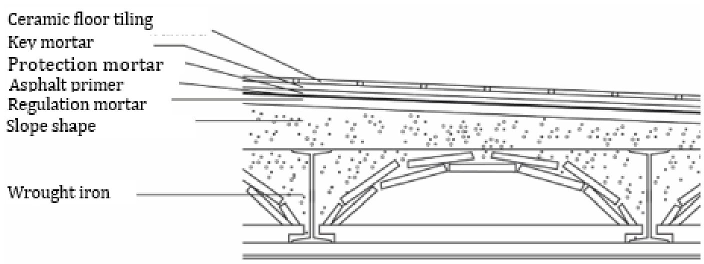

Figure 7. Construction detail of the roof implemented at Duclós House. Source: Preparation by the Authors.

patios, creating air circulation that dries up any leaks produced by the deck.

Therefore, although the type of roof projected for Duclós House is unknown, due to the complete lack of literature, the construction details of the roof on Muntaner Street are known accurately (Figure 6). It is made from a floor tile laid on honeycomb walls, on which a waterproofed sackcloth was laid, a layer of regularization gravel that acted as a drainage layer and a finish using 43 x 43 cm slabs, with a 2.5 cm joint between pieces. Inside the ventilated chamber, between the honeycomb walls, compressed cork from the Armstrong Cork Company was used as insulating material (Olona, 2015; Paricio Casademunt, 1996).

Now, the roof actually made was not the one projected. It is worth clarifying that there are not data about the construction details of the roof implemented. Facing the impossibility of determining its composition through any other type of tests, destructive or non-destructive, an estimation of is composition was made through the analogy with other similar constructions of the time (Ficco, Iannetta, Ianniello, D'Ambrosio Alfano & Dell'Isola, 2015). In this way, it is agreed that the type of roof constructed is built by a lightened concrete slope shape with a variable thickness, on which a mortar regulation layer was applied for the later asphaltic primer. Over said primer, at the same time, a layer of protection mortar was applied and the ceramic finish were placed with their corresponding key mortar. As a result, it can be stated that the roof does not have any element with a low thermal conductivity that can be used as insulation.

METHODOLOGY

The methodological flow of the research consisted in an energy simulation process performed using DesignBuilder, the main steps of which

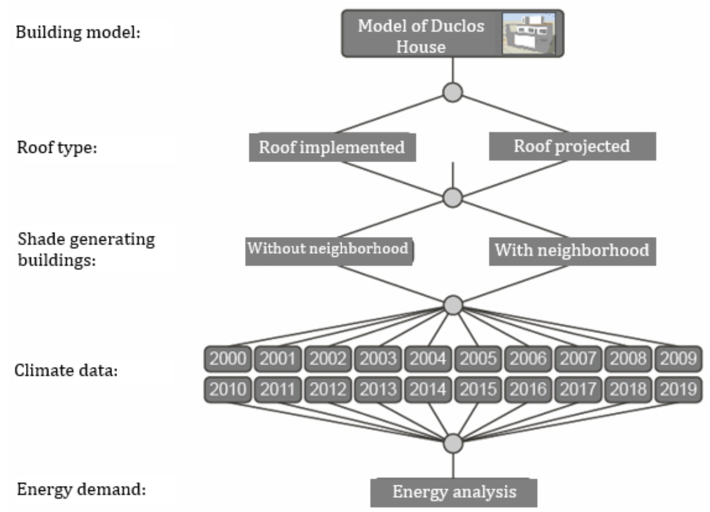

Figure 8. Work flow followed in the research. Source: Preparation by the Authors.

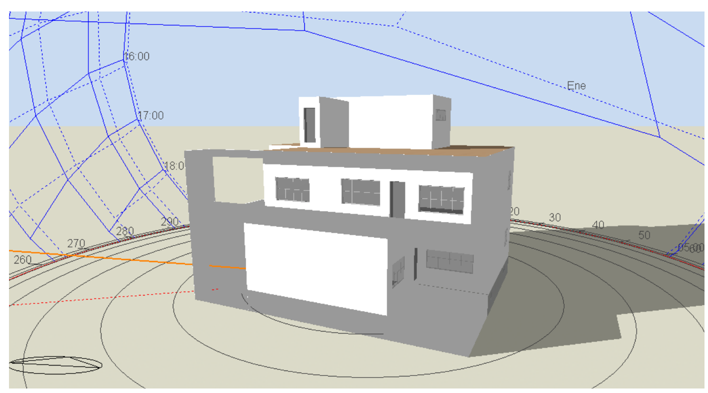

Figure 9. Model of Duclós House in DesignBuilder. Source: Preparation by the Authors.

are summarized in Figure 8. Just as can be seen, Duclós House was modeled first (Figure 9). For this, the available planimetric data of the project was used and the enclosures were defined using the construction details described in the previous sections. Table 1 indicates the thermal conductivity values and the thicknesses of the layers of the main elements of the envelope. The thermal conductivity values used are those established in the Construction Elements Catalog and in the energy certifications tools in Spain. It is worth highlighting that two models were defined considering the roof type: projected roof (with chamber) and implemented roof (flat Andalusian). In Table 2, the thermophysical properties set out for each roof are detailed.

Likewise, two types of models were designed to value the presence or absence of surrounding buildings. The lack of buildings would allow analyzing

Element	Layer	Thickness (m)	Thermal conductivity (W/(mK))
Facade	Cement mortar	0.020	1.80
	Brick wall	0.10	0.43
	Cement mortar	0.020	1.80
	Air chamber	0.05	0.025
	Hollow brick wall	0.05	0.313
	Gypsum plaster	0.015	0.57
Basement wall	Mass concrete	0.50	1.65
Basement floor	Mass concrete	0.15	1.65
	Cement mortar	0.02	1.80
	Clay floor tile	0.10	2.30

Table 1. Layers, thicknesses and thermal conductivity of the façade and the basement floor and walls considered in the energy simulation process. Source: Preparation by the Authors.

Element	Layer	Thickness (m)	Thermal conductivity (W/(mK))
Roof implemented	Finish	0.010	1.00
	Key mortar	0.01	1.80
	Protection mortar	0.015	1.80
	Asphalt primer	0.004	0.23
	Regulation mortar	0.015	1.80
	Lightened concrete	0.20	1.15
	Slab	0.25	2.5
	Gypsum plaster	0.015	0.57
Projected roof	Finish	0.010	1.00
	Layer of gravel	0.050	1.00
	Waterproofing sackcloth	0.013	0.23
	Ceramic floor tiling	0.04	0.29
	Air chamber	0.02	-
	Compressed cork	0.04	0.10
	Slab	0.25	2.5
	Gypsum plaster	0.015	0.57

Table 2. Layers, thicknesses and thermal conductivity of the roofs implemented and projected. Source: Preparation by the Authors.

Revista Hábitat Sustentable Vol. 10, N°. 2. ISSN 0719 - 0700 / Págs. 42 -53
https://doi.org/10.22320/07190700.2020.10.02.03

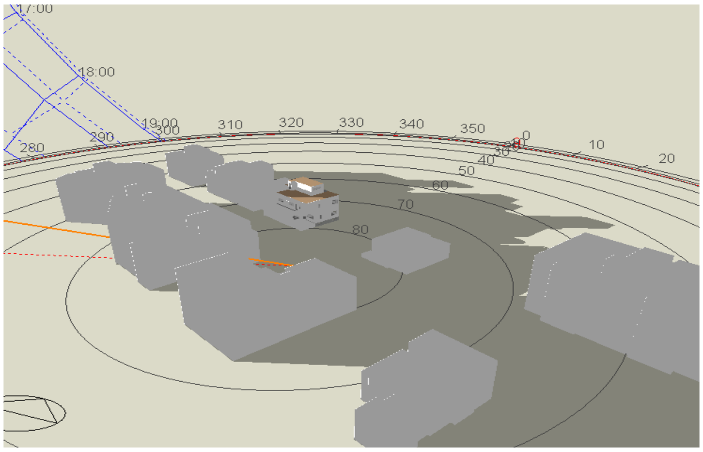

Figure 10. Model of Duclós House with the surrounding buildings in DesignBuilder.Source: Preparation by the authors.

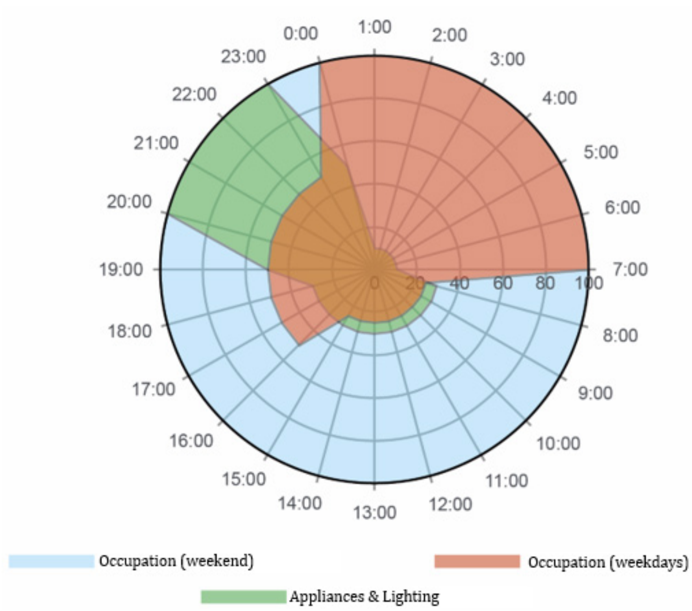

Figure 11. Percentage distribution of the residential profile loads of the Technical Building Code. Source: Preparation by the Authors.

the energy performance of the building if large buildings had not been built around it, while analysis with the surrounding buildings allows valuing the current energy performance. With this purpose, the cartographic database was downloaded to model the neighboring buildings, considering a height of 3 meters per floor (Figure 10).

Regarding the operational patterns of air-conditioning systems and load profiles, the profile defined for residential buildings in the Technical Building Code was used. This considers three load types (occupation, equipment and lighting) and establishes two different distribution types depending on the type of day (working day and

System	Months	Setpoint temperature/period of the day			
		0:00-6:59	7:00-14:59	15:00-22:59	23:00-23:59
Heating System	October – May	17	20	20	17
Air-conditioning system	June - Sept	27	-	25	27

Table 3. Hourly values of the setpoint temperatures defined in the residential profile of the Technical Building Code. Source: Preparation by the Authors.

weekend). In Figure 11, the percentage load distributions of said profile are shown. The maximum load value of the equipment and lighting systems is 4.4 W/m^2; while, for occupation, a maximum value is established for the sensitive load and for the latent load of 2.15 W/m^2 and 1.36 W/m^2, respectively. As for the operational pattern of the air-conditioning systems, the Technical Building Code distinguishes two periods of operation considering the time of the year. In Table 3, the temperature setpoint values and hours considered in said residential profile are indicated. It is important to clarify that by including, in the comparisons, the status of the buildings without the neighborhood does not cover the objective of determining the energy performance in 1930, as at that time there were no active systems for these purposes; what is intended is to evaluate the consequences urban expansion has had on the building's energy performance, considering the demands of users in the 21st century.

As for the climate data, the hourly temperature and relative humidity values were compiled from 2000 to 2019 in Seville, using the Spanish State Meteorology Agency's data. With these hourly data, specific EnergyPlus Weather files were designed for each year, so that energy simulations could be made that would simulate the energy performance of the case study every year. It is worth mentioning that the years prior to 2000 were not simulated because of the lack of hourly data in Seville. Finally, given that the case study was analyzed combining the roofs and urban surroundings with climate data of the last 20 years, the results of this analysis are based on a simulation process comprising a total of 80 simulations.

RESULTS AND DISCUSSION

The analysis of the results was based on the modifications detected in the building's annual energy demand. These data are expressed, first of all, in Figure 12, where the

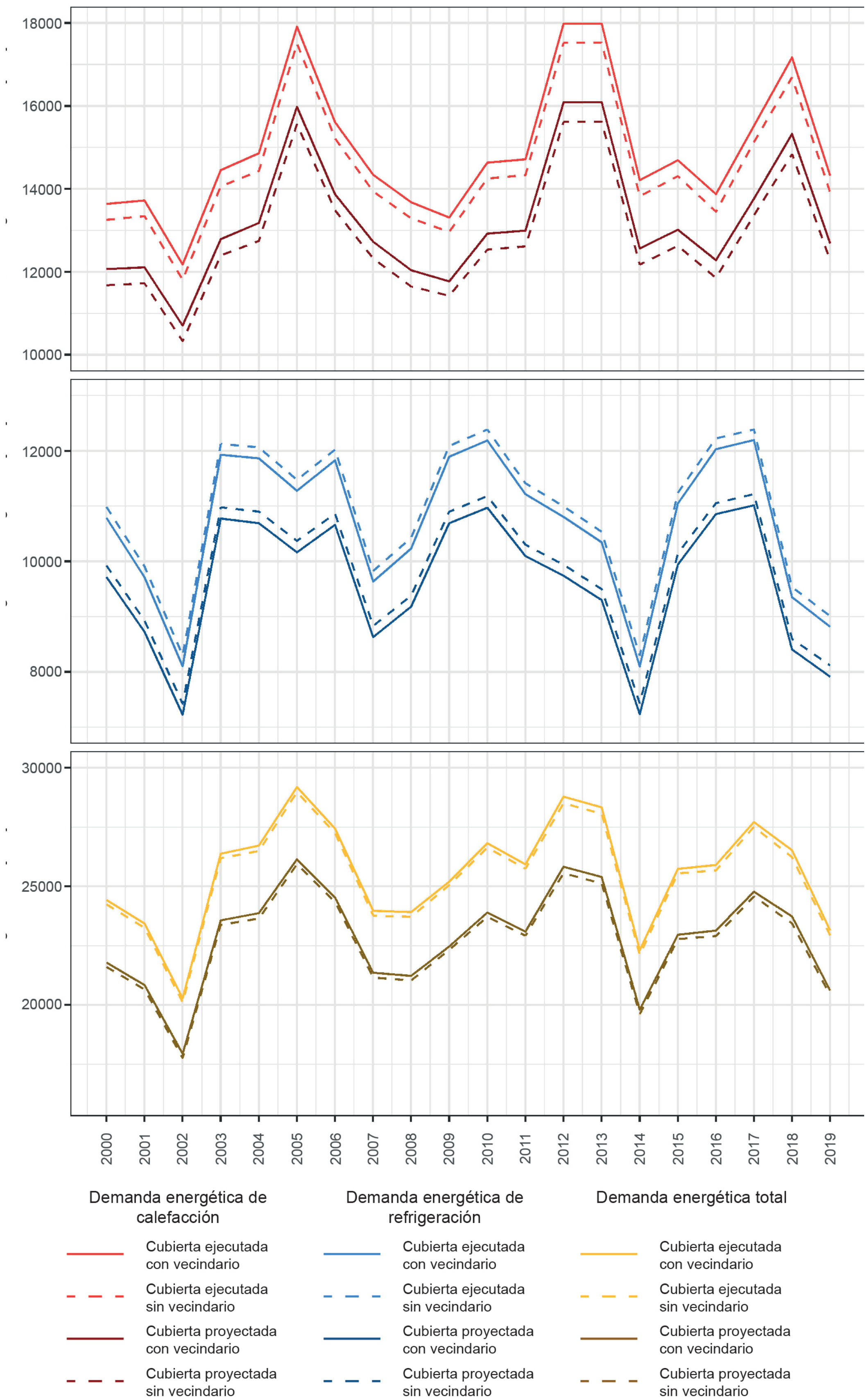

Figure 12. Annual energy demand values obtained with the different assumptions considered. Source: Own Preparation

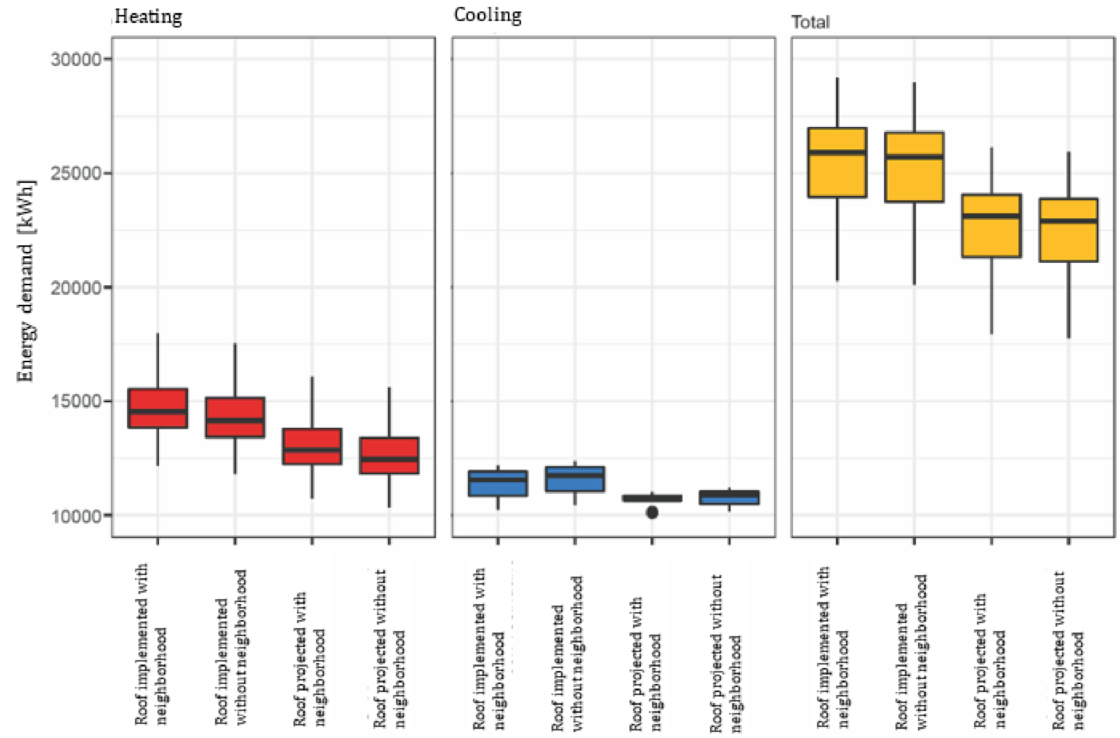

Figure 13. Box plot of the annual energy demand distributions of each assumption considered for Duclós House. Source: Preparation by the Authors.

time series obtained of the energy demands with the different assumptions of Duclós House are included. Just as can be seen, the roof style projected by Sert constitutes a roof typology with a lower energy demand. However, the urbanistic expansion phenomenon has altered the case study's energy performance, although this modification depends on the type of energy demand: with respect to the heating energy demand, the projected case study, without a neighborhood, had lower values; while, the cooling energy demand, had higher values. Despite this, the higher percentage contribution of the heating energy demand in the total energy demand (as it obtained higher values than the cooling energy demand throughout the year) means that the most suitable combination is the projected house without a neighborhood.

To see this aspect in greater detail and in a quantified way, the values of quartiles obtained in the annual energy demand distribution of recent years (i.e., 2000-2019), are presented in Figure 13. In this way, the case with neighborhood is the one that has the highest quartile values in the heating energy demand. Concretely, there is a higher value here of between 386.5 and 412.38 kWh compared to the current case without neighborhood, and of between 1,597.93 and 2,149.35 kWh in the different assumptions of the projected case study. This same trend is detected in the total energy demand, with values over 204.62 kWh compared to the building implemented without neighborhood and of up to 3,104.14 kWh in comparison with the building projected by Sert. This means significant percentage deviations (Figure 14) and proves the worse energy performance that Duclós House currently has.

Figure 14 shows the average saving obtained between the different assumptions of Duclós House compared to the existing case. In this way, it can be seen that the changes in the design and the surroundings have led to a worse energy performance. In this sense, although the urbanistic growth has implied an improvement in the cooling energy demand (with an average saving of 193.70 kWh), the effect on the total energy demand is negative (with an average increase of 207.68 kWh in the energy demand). However, where the highest difference is detected is between the type roof typologies analyzed: the roof projected by Sert implies significant average savings in all energy demands (of 2,762.91 kWH in the case with neighborhood and of 2,966 kWh without it). As was to be expected, the surrounding buildings have a different saving effect in terms of the energy demand, but, due to the operational criteria established by the Technical Building Code, this generates a better performance, when this is a setting without buildings. In any case, this performance could change in the coming years, on facing a progressive increase of the outdoor temperature as a result of climate change.

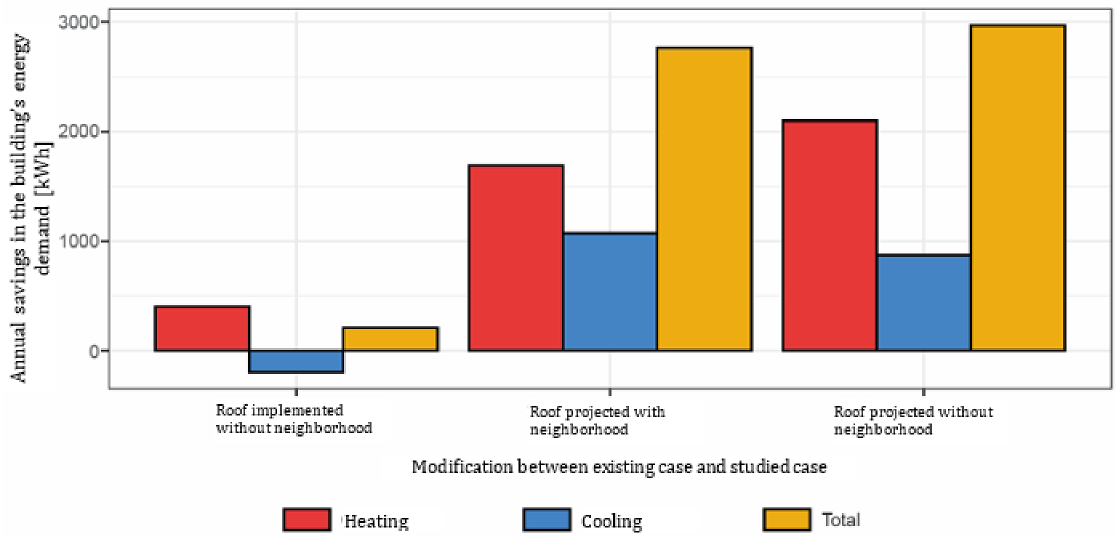

Figure 14. Average saving in energy demand between the current status of Duclós House (executed roof and surrounding buildings) and the other models considered. Source: Preparation by the Authors.

CONCLUSION

The results of this study reveal the great effect that urbanistic growth can have on the energy performance of heritage buildings. The results show how the bioclimatic strategies designed by Sert for openings are nullified with the bigger surrounding buildings. It is a good idea to analyze this aspect, which a priori could be negative, in a longer temporal context, as it could be foreseeable that, through the 21st century when considering climate change, this greater shading is beneficial for users of the house. In any case, it is essential to examine existing surrounding elements and their status at the time of its construction to know in detail the energy transformations the building has experienced throughout its history. This factor could explain the possible measures adopted by users of the dwelling throughout its history. For example, in the case of Duclós House, the reasons that led its residents to not place the awning projected by Sert are unknown, although one possibility, in this sense, is that greater shading was achieved with the surrounding buildings.

Likewise, the importance that the detailed study of the constructive and projected characteristics of heritage buildings may have to establish energy savings measures is proven. Specifically, in this research, the analysis of graphical documentation and later energy analysis reflected that the characteristics projected for Duclós House present a better energy performance than those which were finally implemented following traditional local construction techniques. This can be used as a starting point to design improvement measures in this type of buildings. In addition, the repercussions of urban growth on historic buildings have been shown. Although it is obvious that the design patterns of historic buildings did not seek energy efficiency, it is also true that the architects and designers could seek suitable thermal comfort conditions. By using sunlight techniques through the openings, they could effectively have sought to increase thermal loads in cold periods and improve thermal conditions indoors. Despite this, it has been shown that urban growth, without considering the integration of existing historic buildings, may affect their energy performance. Summarizing, the results of this work show the affectations that, at an energy level, urbanistic growth may represent for this type of buildings, as well as the need to make this type of assessment on facing the possible limitations in retrofitting that these properties have, on being protected by public institutions.

To finalize, it must be added that, beyond the results of this research, analysis of the energy performance of these buildings to face the climate evolution expected throughout the 21st century is left outstanding. Performing studies with climate data designed following the climate change scenarios foreseen by the Intergovernmental Group of Experts on Climate Change, would allow more suitably establishing the energy savings measures needed to reach the category of almost zero energy consumption buildings in these constructions.

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