Potential for residential building renovation in the city of Barcelona in relation to the Next Generation EU funds

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Abstract

Barcelona, like many other cities in Europe, faces the challenge to reduce CO_2 emissions as defined in the European Green Deal aimed at achieving a climate-neutral continent by 2050. Hence, data-driven policies to target energy renovation of the urban built environment are key to accomplish this goal. This paper, developed in the Barcelona Metropolitan Housing Observatory, examines the potential for improving the performance of the housing stock of the city of Barcelona through different passive renovation strategies, based on a gradient of complexity in terms of management, implementation time and associated costs, and explores how these could be eligible for the Next Generation EU Funds. It relies on newly generated location-based data through energy simulation modelling based on the graphical and alphanumeric information of the Spanish land registry database. In addition, information has been included on households' income and the ownership structure of Barcelona's housing stock as to assess the socio-economic complexity behind each potential energy renovation. The results indicate an aging and energy-vulnerable housing stock that is reflected in the estimated theoretical cost of the household energy bill, placing one in four households at risk of energy poverty. Secondly, renovations targeting the entire building envelope are proven to be the most cost-effective in most of the cases. Finally, the research manifests that the designed passive strategies bring 85% of the city's buildings to surpass the consumption and demand reduction thresholds of the Next Generation EU Funds.

Keywords: Energy renovation, energy simulation modelling, passive interventions, NextGenerationEU Funds, Barcelona

Introduction

Since 2007, more than half of the world's population has been living in cities and this number is expected to increase to 68% in the next 30 years (UN, 2018). Furthermore, cities are responsible for 71-76% of global carbon emissions and more than 65% of the planet's energy expenditure (IPCC, 2014). Therefore, the renovation of the built environment represents a key element in the CO_2 emissions reduction strategy defined in the European Green Deal focused on achieving a climate-neutral continent by 2050 (European Commission, 2019).

The available data sources to examine the buildings' energy performance for the city of Barcelona are scarce and are not homogeneously represented around the urban territory. Energy Efficiency Certificates (EEC) are exclusively available for approximately 5,000 residential buildings in the city of Barcelona (9% of the total residential buildings) according to the data published by the Catalan Energy Institute. The aim of this research, developed in the Barcelona Metropolitan Housing Observatory (O-HB), is to analyse the energy performance of residential buildings in the city of Barcelona, their potential for improvement through passive interventions and the relationship between the improvement strategies and the financing options available through the European Next Generation (NGEU) Funds subsidies. This work focuses on the energy simulation of residential buildings as a new source of data for studies on renovation. By means of an energy simulator, it has been possible to analyse the energy performance of more than 50,000 residential buildings (91% of the total residential buildings of the city).

The objectives of this research are:

1. To assemble a set of indicators elaborated from official data sources related to the physical aspects of the residential buildings in the city of Barcelona and the economic characteristics of its inhabitants.
2. To calculate the current energy performance of the city's residential buildings by means of an energy simulation based on the city land registry database.
3. To design three improvement scenarios to upgrade the energy performance of the residential buildings through passive design strategies and evaluate their effect through the same energy simulation process used to determine the current state of the buildings.
4. To evaluate the hypothetical impact of the NGEU Funds subsidies on the estimated cost of the proposed passive design strategies.

All data used for the research is geolocated and available at the building level, thus providing a more extensive detail than previous studies that focus on this matter in the city of Barcelona. Therefore, the results obtained are not related to the administrative boundaries of neighbourhoods and describe the diversity of situations of the city's residential buildings with more precision. The present paper brings together the first results of this research focused on providing outcomes at the city level.

The first section of the paper focuses on the research methodology, the geographical scope of the study and presents a series of technical considerations to understand the technical framework of the study. The second section focuses on the results and the analysis of the research. Section three summarizes and evaluates the main results of the research.

I. Methodology and data

Geographical Scope

This study focuses on urban plots in the city of Barcelona that contain properties for residential use. Therefore, out of the total number of cadastral units in Barcelona (78.226 plots), a subset of 58.634 has been extracted and considered suitable for the purpose of this research. Additional data has been filtered to guarantee the data quality standards of the urbanZEB energy performance simulator in accordance with the ISO 52016-1:2017 (see table 1).

Table 1. Geographical scope depending on filtering criteria

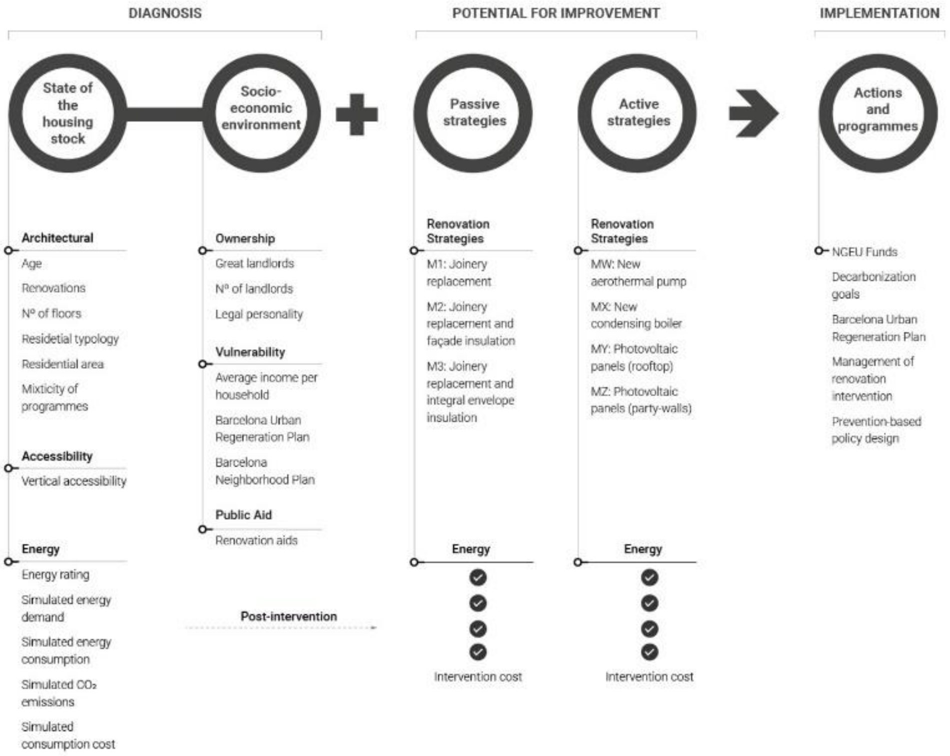
Name of the geographical scope	Filtering criteria	Plots [nº]
Barcelona land registry	Land registry references containing graphical and alphanumerical information	78.226
Residential land registry	Land registry references with housing over street level	58.643
Energetic land registry	1. Land registry references with consistent graphical and alphanumerical information 2. Land registry references with housing over 20 sqm 3. Land registry references erroneously indexed as single home buildings	53.368

Source: Barcelona Metropolitan Housing Observatory based on the report "Architectural Characterization" by Cíclica [space-community-ecology].

Methodology outline

With the aim of approaching the challenges to renovate the residential building stock with a holistic and data-driven perspective, a large database containing multiple data sources has been created. It is based on a research scheme divided into three sequential sections: it starts from a diagnosis, followed by an associated potential for improvement, and concluded with an analysis of its implementation within the existing policy framework (see figure 1). A brief description of the three sections and the contained dimensions and variables is described below.

Figure 1. Research scheme



Source: Barcelona Metropolitan Housing Observatory.

Diagnosis: this section comprises data to elaborate a diagnosis of the current situation, considering both the physical state of the residential housing stock and the socio-economic environment of the inhabitants. In addition, these aspects are further divided into sub-dimensions: architecture, accessibility, and energy in the first case, and ownership, vulnerability, and public aids in the second.

Potential for improvement: this section proposes a series of building renovation strategies designed to improve their energy performance. The research scheme considers both passive as well as active renovation interventions The firsts improve the building's global demand for heating and cooling, and the seconds contribute to reducing its non-renewable primary energy consumption. As for the purpose of this paper, only passive interventions will be analysed.

Passive intervention strategies have been designed to offer a gradient of complexity in terms of management, implementation time and associated costs. The interventions include the replacement of existing joineries (M1), the insulation of the two main building façades (M2), and the insulation of the entire building's envelope (M3).

Implementation: All the information from the previous sections is evaluated to extract data insights relevant in the framework of existing policy plans and agendas (e.g., subsidies derived from the NGEU Funds, the strategies towards a decarbonized city by 2050, etc.).

Data selection and treatment

Geolocated data has been collected from various available sources to ensure that the described related information is available at the building level. The database contains a wide range of variable types, integrating quantitative and qualitive data.

Most of the data within the architectural dimension is extracted from the 2021 Spanish land registry database. Data processing includes combining the available information from the alphanumerical and graphical sets, removing duplicates, and discarding all records without housing units or with housing units only present below the ground. Building ages have been aggregated intro 6 tranches predefined by the Long-term strategy for energy rehabilitation in the building sector in Spain, Known as ERESEE 2014 (Ministerio de Fomento, 2014)). Information on building permits has been generated by combining official data from the Barcelona City Council for the 2008-2019 period and the 2021 land registry database.

Data on energy performance are generated through UrbanZEB, a standardized thermal- and zonal simulation model according to the ISO 52016-1:2017. It calculates the hourly building energy performance throughout one complete year by considering a large list of factors related to both the building itself and the theoretical user standards as defined by the Spanish Technical Building Code, concretely the CTE DB-HE document (Ministerio de Vivienda, 2006). Some of these factors include the climate zone, the building's orientation, its distribution and neighbouring elements, its construction characteristics, its heating and cooling system, and data on the user's behaviour and standardized minimum living conditions for thermal comfort. Data on the building's construction characteristics is not available in any of the existing data sources, which is why a definition of 12 typological clusters has been hypothesized. These result from combining two available building attributes: the residential typology (2 categories to differentiate between one-family or multi-family buildings) and the building age, which is linked to different historical construction processes (6 categories, according to the classification defined in the ERESSEE 2014 (see table 2).

Table 2. Typological cluster classification

Age of the residential part of the building	Single-family building	Multi-family building
Construction before 1900	Cluster A: U.INF1900	Cluster G: P.INF1900
Construction from 1901 to 1940	Cluster B: U.191-40	Cluster H: P.1901-40
Construction from 1941 to 1960	Cluster C: U.1941-60	Cluster I: P.1941-60
Construction from 1961 to 1980	Cluster D: U.1961-80	Cluster J: P.1961-80
Construction from 1981 to 2007	Cluster E: U.1981-07	Cluster K: P.1981-07
Construction after 2008	Cluster F: U.SUP2008	Cluster L: P.SUP2008

Source: Barcelona Metropolitan Housing Observatory based on the report "Construction scenarios" and “Methodological document” by Cíclica [space-community-ecology].

Since data on the heating systems is not available, two hypotheses have been considered for this research: electric heating and gas boiler systems, leaving out other minor solutions such as butane cylinder usage or biomass boilers. Consequently, all results are calculated for both scenarios.

At the same time, we have also considered the use of conventional materials and materials with low embodied carbon as a mean to undertake the renovation strategies we propose. The first exploitations presented in this document have been delimited in two scenarios, the gas boiler as a heating solution and passive measures with ecological materials. This decision was motivated, firstly, to respond to the reality of Barcelona in terms of consumption of basic supplies (according to Barcelona City Council in 2020, gas consumption represented 99.9% of the total) and, secondly, to align ourselves with the decarbonisation strategies for the 2050 horizon defined in the European Green Pact.

As for the socio-economic variables, data from the Spanish National Institute of Statistics has been downloaded and combined with the results from the energy performance simulation. Energy poverty vulnerability is calculated combining the energy performance data, current energy prices and housing disposable income data. Data on the Barcelona’s ownership structure calculated by the Barcelona Metropolitan Housing Observatory (Barcelona Metropolitan Housing Observatory, 2020) is also included.

The potential for improvement of the city’s housing stock is calculated following these steps: first the energy simulation on the building’s current state is applied. The energy performance is then simulated again for each of the three proposed renovation interventions (M1, M2, M3) (see table 3 and figure 2). Finally, pre-intervention and post-intervention data are compared. As for the economic costs, data includes the project, works, and permits and is based on publicly available materials and construction databases.

Table 3. Renovation strategies

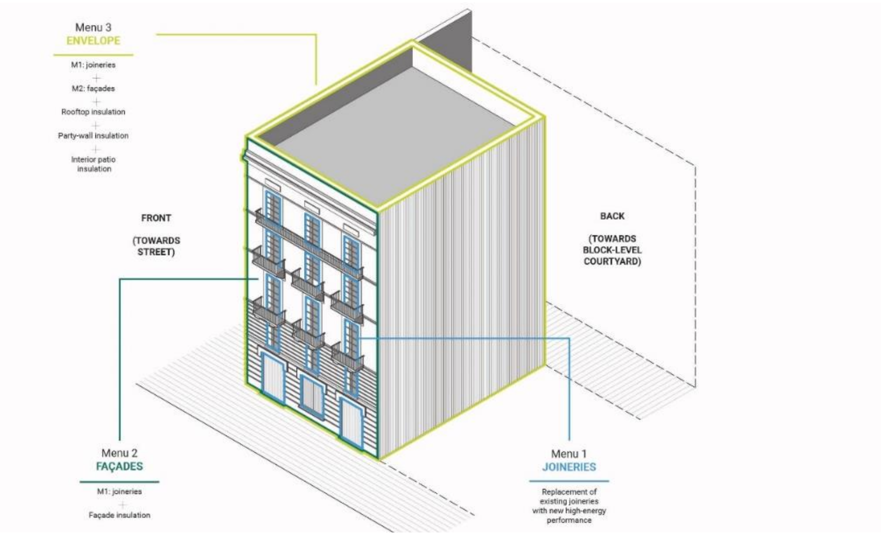
M1: Replacement of existing joineries	Existing joineries are replaced with new ones, characterized by improved thermal transmittance and thermal bridge break. Two scenarios have been calculated to differentiate between conventional and low embodied carbon materials: aluminium joineries (M1A) and wooden joineries (M1B)

M2: Façade insulation and replacement of existing joinery	M1 strategy combined with the insulation of the existing front and back façades. SATE systems (6 cm), interior linings (6 cm) and the filling of existing air chambers are chosen depending on the typological cluster to which the building belongs. Two scenarios have been calculated to differentiate between conventional and low embodied carbon materials: expanded polystyrene, blown cellulose and aluminium joineries (M2A) and rock wool, blown cellulose and wooden joineries (M2B)
M3: Integral envelope insulation	M1 and M2 strategy combined with insulation of the rooftop and other secondary walls, such as party walls and walls facing interior patios. SATE systems (6 cm), interior cladding (6 cm) and the filling of existing air chambers are chosen depending on the typological cluster to which the building belongs. Two scenarios have been calculated to differentiate between conventional and low embodied carbon materials: expanded polystyrene, blown cellulose and aluminium joineries (M2A) and rock wool, blown cellulose and wooden joineries (M2B)

Note: all described interventions include the necessary different execution processes (e.g., in the case of menu 1, the removal of the existing window frames, the installation of the new ones, as well as the costs derived from the industrial benefits, the transport of materials and rubble, among other technical issues, are foreseen).

Source: Barcelona Metropolitan Housing Observatory based on the report "Construction scenarios" by Cíclica [space-community-ecology] and the document "Good practices. Study of technical solutions for the treatment of party walls. 2021" of the Institut Municipal del Paisatge Urbà i Qualitat de Vida of Barcelona City Council.

Figure 2. Volumetric scheme of the renovation strategies considered for the research



Source: Barcelona Metropolitan Housing Observatory.

Implementation criteria

The information contained in the generated database has been analysed to, first, provide an in-depth description of the current state of the residential building stock and its potential for improvement and second, assess the effects of the renovation interventions within the framework of the current renovation policies and agendas. Specifically, two working scenarios have been treated: the opportunities derived from the NGEU funds and the challenges for the city of Barcelona to achieve the European Green Deal objectives.

As for the first, the conditions set by the Spanish Royal Decree 853/2021 of October 5th (RD 853/2021) have been considered. This decree regulates the aid programmes for renovation and social housing under the national Recovery, Transformation and Resilience Plan. In the case of the city of Barcelona ("Building" Programme and climate zone C), buildings are required a minimum reduction of 25% of heating and cooling annual energy demand and 30% of non-renewable primary energy consumption to be eligible for the funds. Furthermore, the subsidy amount is calculated according to the consumption reduction and is to be compared with the maximum established amounts (see table 4).

Table 4. Eligibility criteria for the NGEU funding according to the Spanish Royal Decree

Conditions	**Amount of subsidy**	
Energy savings [%]	Cost subsidy [%]	Maximum amount for housing unit [€]
Demand: 25% (minimum required)	-	-
Consumption: 30% (minimum) =<45%	40%	6.300 €
Consumption: 45%=<60%	65%	11.600 €
Consumption: >=60%	80%	18.800 €

Source: Barcelona Metropolitan Housing Observatory based on the RD 853/2021-Programm 3: Buildings (Ministerio de Transportes, Movilidad y Agenda Urbana, 2021).

As for the Barcelona 2050 horizon, the decarbonization goals derived from the European Green Deal to achieve an energy neutral continent in 28 years are taken as a premise. Consequently, the analysis has been guided by a long-term approach, introducing criteria on economic optimisation, the promotion of power generation for self-consumption and integral renovation strategies, etc.

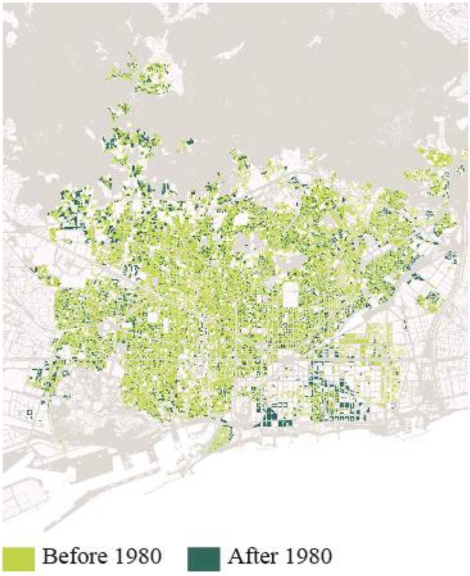
II. Results and analysis

Diagnosis

This section includes the main results of the residential building's stock.

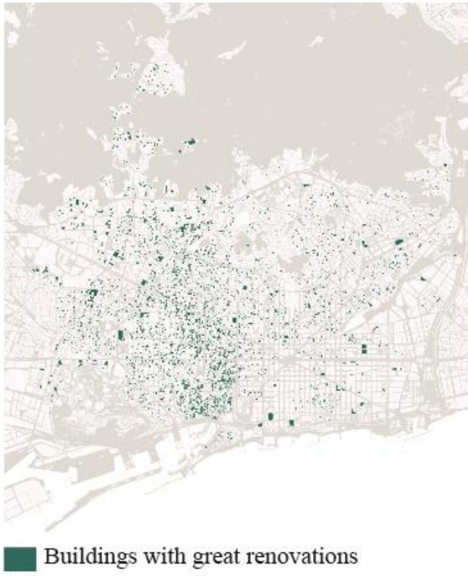
87% of the residential buildings in the city of Barcelona were built before 1980 (see figure 3) and, therefore, are exempt from the first prescriptive energy efficiency regulation of the state (NBE CT-79). According to the official renovation building permits records and the information provided by the Spanish land registry database, only 1 in 10 buildings in the city have undergone large-scale renovations. Moreover, buildings constructed between the 1960s and 1980s are the ones that have undergone the most renovations of this type (see figure 4).

Figure 3. Buildings according to their period of construction: before and after application of the first energy efficiency regulation (NBE C-79).



Source: Barcelona Metropolitan Housing Observatory and Cíclica [space-community-ecology] based on Direcció General del Cadastre (graphic and alphanumeric base, 2021).

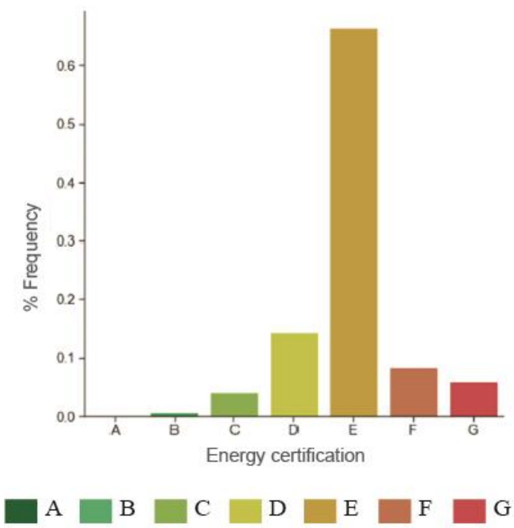
Figure 4. Buildings that have undergone large-scale renovations.



Source: Barcelona Metropolitan Housing Observatory based on Direcció General del Cadastre (alphanumeric base, 2021) and Barcelona City Council (OMA Licences, 2008-2019).

The energy simulation indicates that 81% of the residential buildings would obtain anE rating or lower in their energy rating related (global CO_2 emissions) (see figure 5 and 6).

Figure 5. Percentage of residential buildings according to simulated rating (CO_2 emissions).



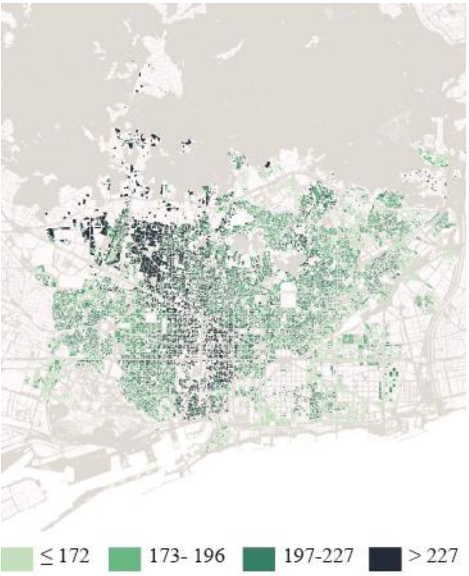
Source: Barcelona Metropolitan Housing Observatory and Cíclica [space-community-ecology] based on urbanZEB simulator.

Figure 6. Simulated energy rating of residential buildings (CO_2 emissions).

Source: Barcelona Metropolitan Housing Observatory and Cíclica [space-community-ecology] based on urbanZEB simulator.

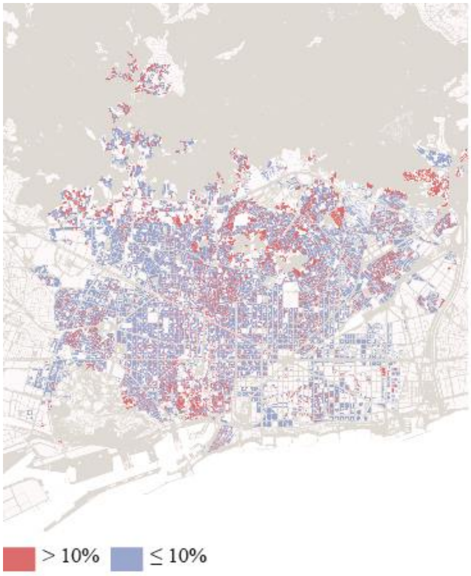
Maintaining the minimum temperature of comfort set by the Spanish Technical Building Code (CTE DB-HE) would mean a median expenditure of up to 196€/month for households living in multi-family buildings and 399€/month for single-family buildings (see figure 7). Moreover, if comfort is to be guaranteed according to the Spanish regulation standards, paying the estimated energy bill would represent more than 10% of the household income in 25% of the studied households (see figure 8), and this would result in risk of energy poverty (Boardman 1991).

Figure 7. Theoretical estimated average monthly energy bill per household in multi-family buildings.



Source: Barcelona Metropolitan Housing Observatory and Cíclica [space-community-ecology] based on urbanZEB simulator and CNMC offers (HolaLuz, 2022).

Figure 8. Buildings by percentage of disposable income used to pay the estimated energy bill



Source: Barcelona Metropolitan Housing Observatory and Cíclica [space-community-ecology] based on urbanZEB simulator,CNMC, offers (HolaLuz, 2022) and INE (lava hogares, 2019), the document "Propuesta metodológica de evaluación de la pobreza energética en España" by Carmen Sánchez-Guevara, and the National Institut od Statistics (household incomes, 20119).

Potential for improvement

This section presents the main results extracted from analysing the potential for improvement for the residential buildings.

A comparison between the energy consumption reduction and the cost of intervention for the three renovation strategies designed shows that, while the reduction in consumption varies substantially (between 13% and 55%), the total difference in the average costs per housing unit is 6,900 € (see table 5).

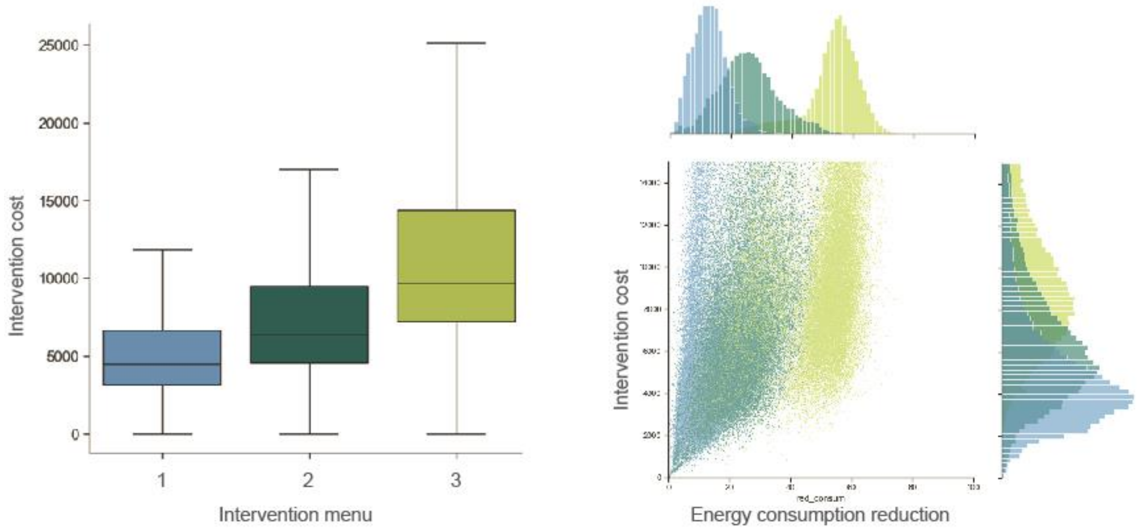
Table 5. Energy consumption reduction and associated intervention cost per dwelling. Average values for the city of Barcelona

Passive design strategy	Average energy consumption reduction over the current state	Average intervention cost
M1: Joineries	13 %	6.200 €/housing unit
M2: Façades	25 %	8.600 €/ housing unit
M3: Envelope	55 %	13.100 €/housing unit

Source: Barcelona Metropolitan Housing Observatory and Cíclica based on urbanZEB simulator

At the same time, while the range of intervention costs is wide across the three passive renovation strategies, the reductions in energy consumption concentrate around some peaks. Therefore, after applying the economic optimisation criteria, data reveals that in 90% of the cases the intervention on the building envelope is the most economically efficient (see figure 9).

Figure 9. Energy consumption reduction and associated intervention cost per dwelling.



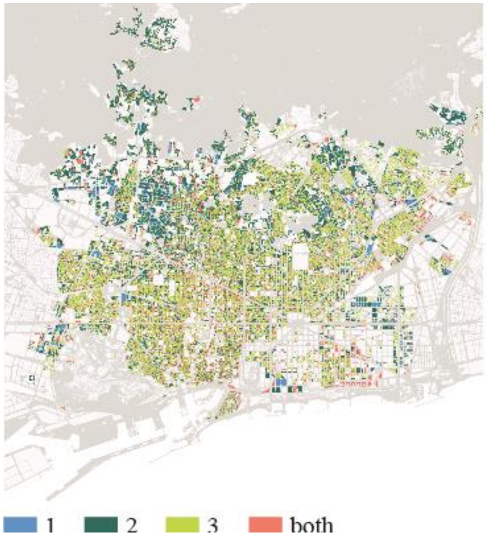
Source: Barcelona Metropolitan Housing Observatory and Cíclica [space-community-ecology] based on urbanZEB simulator and several official sources (Itec-BEDEC, HULK, GTR and ICCL)

Implementation

This section interprets the potential for fitting renovation strategies within the existing policy and agenda framework. Two scenarios have been considered: the first (NGEU scenario) considers which is the first renovation strategy (M1, M2 and M3) that meets the requirements to access NGEU funds. Thus, each building is assigned the first intervention that meets this condition. The second (optimisation scenario) considers the criterion of economic optimization which reveals that in 90% of cases it is more efficient to apply the third strategy directly (M3).

As for the NGEU scenario, the analysis indicates that 85% of the buildings studied can achieve the minimum energy consumption reduction required for the NGEU funding. Particularly, 5% of the residential buildings would be eligible for the funds by applying M1, 25% would be so by applying M2, and 55% would need M3 to be eligible for the funding (see figure 10).

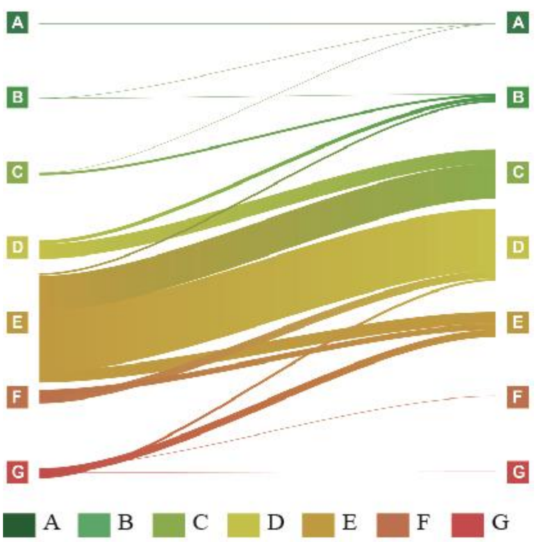
Figure 10. Buildings according to NGEU scenario



Source: Barcelona Metropolitan Housing Observatory and Cíclica [space-community-ecology] based on urbanZEB simulator and RD853/2021 (Ministerio de Transportes, Movilidad y Agenda Urbana, 2021).

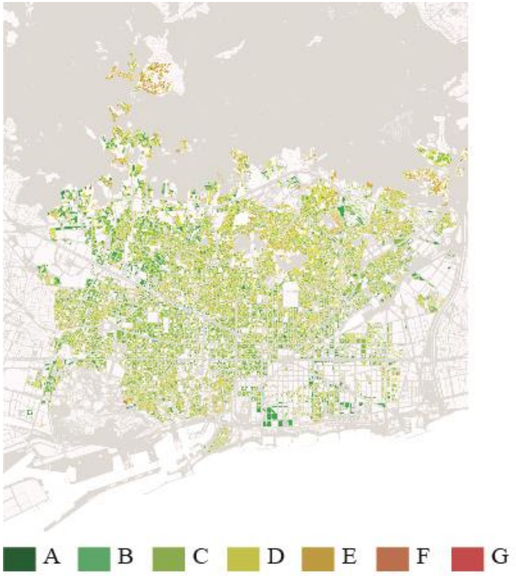
In case all the described interventions were implemented, most residential buildings with a current E rating would be upgraded to D, and most of the buildings with a current D rating would be upgraded to a C (see figure 11 and 12). This would result in an average saving of 24% on estimated energy bills.

Figure 11. NGEU scenario: Improvement of energy rating (CO_2 emissions). Current rating (left) and hypothetical post-intervention rating (right).



Source: Barcelona Metropolitan Housing Observatory and Cíclica [space-community-ecology] based on urbanZEB simulator and Ministerio para la Transición Ecológica y Reto Demográfico (Calificación eficiencia energética de los edificios, 2015).

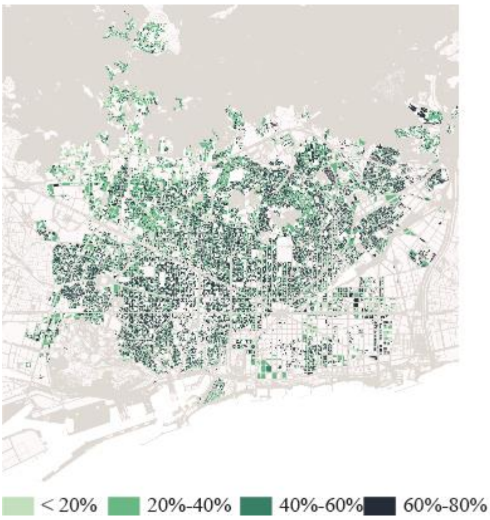
Figure 12. NGEU scenario: Hypothetical energy rating



Source: Barcelona Metropolitan Housing Observatory and Cíclica [space-community-ecology] based on urbanZEB simulator and Ministerio para la Transición Ecológica y Reto Demográfico (Calificación eficiencia energética de los edificios, 2015).

NGEU funds would cover 46% of the intervention costs derived from the described interventions. Specifically, actions on joinery and façades would obtain an average subsidy of almost 40%, while those on the envelope would be covered by 60%. This substantial increase occurs due to two factors: first, subsidy percentages are linked to consumption reduction tranches and second, interventions on the envelope effect in higher consumption reductions. It is also noteworthy that 15% of the buildings would benefit from the maximum subsidy amounts (see figure 13).

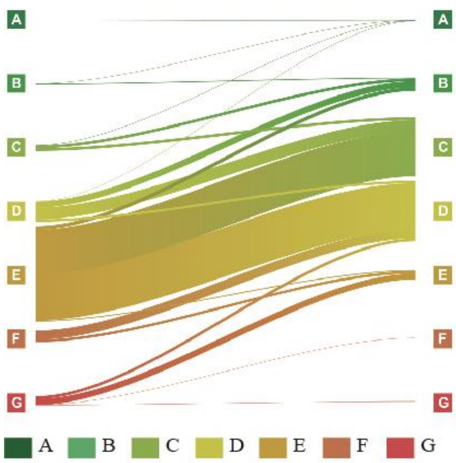
Figure 13. Buildings according to final percentage eligible for NGEU funds over the total cost of the intervention (by tranches)



Source: Barcelona Metropolitan Housing Observatory and Cíclica [space-community-ecology] based on urbanZEB simulator and RD853/2021 (Ministerio de Transportes, Movilidad y Agenda Urbana, 2021).

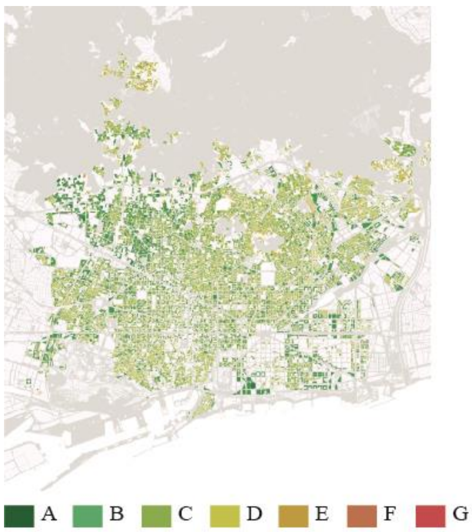
Implementing the optimisation scenario would result in 93% of the residential buildings obtaining a D rating or higher. This would lead to an average saving of 27% on the energy bills (see figure 14 and 15).

Figure 14. Optimisation scenario: Improvement of energy rating (CO_2 emissions). Current rating (left) and hypothetical post-intervention rating (right).



Source: Barcelona Metropolitan Housing Observatory and Cíclica [space-community-ecology] based on urbanZEB simulator and Ministerio para la Transición Ecológica y Reto Demográfico (Calificación eficiencia energética de los edificios, 2015).

Figure 15. Optimisation scenario: Hypothetical rating after implementing



Source: Barcelona Metropolitan Housing Observatory and Cíclica [space-community-ecology] based on urbanZEB simulator and Ministerio para la Transición Ecológica y Reto Demográfico (Calificación eficiencia energética de los edificios, 2015).

III. Conclusion

The diagnosis carried out in the city of Barcelona reveals that most residential buildings are aged and energetically vulnerable. In fact, almost 90% of the buildings were built before 1980 and, therefore, exempt from the first prescriptive regulation on energy efficiency in the country (NBE CT-79). Moreover, the energy simulation developed in this research shows that about 80% of the residential buildings would obtain E ratings or lower in the energy consumption certificates.

The current poor energy performance of residential buildings is reflected in the estimated cost of the households' energy bill for the households. Maintaining the minimum conditions of comfort as defined in the Technical Building Code would cost an average of up to almost 200 €/month and 400€/month for families living in multi-family and single-family properties, respectively. As a result, 25% of the households analysed would have to spend more than 10% of their income in paying the energy bills, and this condition places them at risk of energy poverty (Boardman 1991). In fact, Barcelona City Council's Neighbourhood Plan 2021-2024 has already launched energy renovation actions in those neighbourhoods where moderate or severe energy poverty risk has been detected.

Regarding the building's potential for improvement through passive renovation strategies, the results of the simulation show that acting on the entire building envelope is the most cost-effective action in 90% of cases when considering the relation between the economic cost of the intervention and the derived consumption decrease.

The designed passive renovation strategies would enable 85% of Barcelona's residential building stock to be eligible for the NGEU funds and meet the demand and consumption reduction criteria established in the RD. In a hypothetical scenario in which all eligible buildings were to be renovated, the NGEU Fund subsidies could cover on average up to almost 50% of the total renovation costs, and almost 70% of the buildings would be upgraded to an energy rating of D or higher. However, the mid-term future goals to decarbonize the residential stock would require larger interventions that combine both passive and active renovation strategies.

In addition to the results presented, the building-level database developed by the Barcelona Metropolitan Housing Observatory enables for a deeper diagnosis of the residential buildings. Until recently, indicators such as the annual household energy consumption were only available at the neighbourhood level. Therefore, they failed to capture complex urban realities with precision since their results were shown at a scale that only represents administrative boundaries.

Another interesting aspect of this research is that it incorporates a set of indicators to assess the complexity inherent in each proposed intervention. For instance, information on the ownership structure can help anticipate which buildings are owned by a single person, making the process of negotiating the building renovation easier for the local administration. At the same time, the research can help target the most vulnerable population and enable the local administration to assist them during the renovation process.

All in all, this project creates the first database designed to understand the current physical status and renovation potential of the residential building stock in the city of Barcelona. As such, it will enable identifying and tackling the current challenges and problems but, more importantly, it will foster prevention policies to anticipate future problems.

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