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The energy rehabilitation programs in Barcelona within the context of the European Next Generation package

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1. Introduction

In light of the challenges posed by climate change and the degradation of the environment, and as approved in the Paris Agreement, in December 2019 the EU member states signed the European Green Pact that includes a commitment to reduce CO_2 emissions by 55% by 2030 and to become the world's first climate-neutral continent by 2050 (European Commission, 2019). Thus, given that buildings are responsible for 40% of the EU's energy consumption (European Parliament and European Council, 2012) and that cities are responsible for over 70% of the world's carbon emissions (IPCC, 2014), it is clear that the transformation of the built environment is a key element in the attaining of decarbonization targets. The reduction of atmospheric CO_2 emissions in the housing stock can be accomplished through two principal strategies: (i) improvement of the energetic requirements of buildings via passive measures (linked to the constructive characteristics of buildings) and (ii) active reduction in the consumption of non-renewable energy (linked to the efficiency of climatization systems, the origin of the energy consumed, and the demand for energy) (European Parliament and European Council, 2018).

Concurrently, the outbreak of the COVID-19 pandemic in 2020 had an unprecedented impact on society and aggravated existing states of vulnerability (Barcelona Metropolitan Housing Observatory, 2021), as well as highlighting the importance of incorporating criteria linked to restoration, resilience and social justice into the planned transformation. As a result, the European Commission mobilized the so-called NextGenerationEU funds using the Recovery and Resilience Facility (RRF) to help member states implement the proposed reforms and directives (European Parliament and European Council, 2021).

In a Spanish context, these European funds were channelled via the Transformation, Recovery and Resilience Plan in which, amongst other issues, a strategy was defined to stimulate rehabilitations that would decarbonize and improve the quality of the housing stock (Gobierno de España, 2021). Specifically, this strategy was described in Royal Decree 853/2021, 5 October, which outlined the various programmes of grants for restoration (mainly for neighbourhoods, buildings and dwellings) and the minimum requirements for receiving NextGenerationEU funding. In general terms, this legislation states that rehabilitation actions in buildings that are used as primary dwellings and have high energy efficiency ratings can opt to receive funding (Ministry of Transport, Mobility and Urban Agenda, 2021).

In the case of the city of Barcelona, an initial budgetary package of over 26 million euros was established to fund the rehabilitation of neighbourhoods and buildings, which is to be applied to whole buildings to achieve minimum reductions of 25 and 30% in the indicators of energetic demand and the consumption of primary non-renewable energy, respectively. At the same time, it was decided that all work begun after 1 February 2020 and completed before 30 June 2026, with a prolongation period of 12–18 months to complete the work, was eligible to receive this funding (Consorci de l'Habitatge de Barcelona, 2022a and 2022b).

Considering this transformation and the need to manage it properly and efficiently, it was essential to gather information on the energetic state of the housing stock in Barcelona and the possibilities of implementing improvements therein. Thus, given the lack of official data on this question (currently, only 9.02% of dwellings in the city of Barcelona have an Energy Performance Certificate[1]), the Barcelona Metropolitan Housing Observatory (O-HB) set up in 2021 the laboratory Strategies and the potential for rehabilitation. Physical state and potential for improvements in the housing stock in Barcelona[2] which, via a simulation of the energy used at plot level, generated detailed knowledge of practically all the residential buildings in the city (85.09%).

This simulation, developed with the program urbanZEB (ISO 52016-1:2017), focuses on the land registry parcels in Barcelona that are primarily residential. To perform the simulation, the selected parcels were divided up into 12 typological clusters that allow the construction of a hypothesis regarding constructive systems and their thermal transmittance[3] via the parts that form the structure of the buildings according to the ERESEE[4]. Using this information, an hour-by-hour estimate of the thermal behaviour of all the studied buildings throughout the year can be calculated based on the profiles of compliance determined by the Technical Building Code (e.g. the operating temperature, internal loads and the ventilation airflow). This estimate of the thermal behaviour provides a calculation of the useful energy needed to ensure human thermal comfort in buildings according to the temperatures established by this Code. To appreciate how the energy efficiency of these buildings can be improved, the simulation is carried out again once the three interventions proposed in this study have been implemented.

This article gathers data on the current energetic state of the housing stock in the city of Barcelona and discusses how it can be improved via the implementation of passive rehabilitation strategies and how it can be executed via public tenders for rehabilitation work financed by the NextGenerationEU funding.

After this initial presentation, the second part describes the main current constructive and energetic characteristics of buildings in Barcelona, which will act as a point of departure for the transformation of the city's housing stock. The third section discusses the potential for

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[1] Source: O-HB, taken from Land Registry Directorate General (alphanumeric data, 2021) and Catalan Institute of Energy (CEE, 2021).

[2] Available at: https://www.ohb.cat/wp-content/uploads/2022/06/O22013_Lab_Rehabilitacio_Dossier-4_comprimido.pdf [Accessed 17 April 2023].

[3] The thermal transmittance (value of U expressed in $W/m^2 \cdot K$) in terms of units of time and surface area is the heat that flows through a constructive element (consisting of one of more parallel layers) if there is a difference in temperature between the two environments separated by that element. The lower the value of U, the less energy that passes between the two sides and thus the better the insulating properties of the constructive element. Source: O-HB from CTE, DB-HE-Ahorro de Energía.

[4] Estrategia a largo plazo para la Rehabilitación Energética en el Sector de la Edificación en España -ERESEE- 2014. Source: https://www.mitma.gob.es/recursos_mfom/pdf/39711141-E3BB-49C4-A759-4F5C6B987766/130069/2014_article4_es_spain.pdf [Accessed: 17 April 2023].

energetic improvement in the city's housing via three type of passive interventions, that is, actions centred on the rehabilitation of the outer structure of buildings designed to improve their energetic demands. The fourth section analyses how these actions could be developed via grants financed by the NextGenerationEU funds (for neighbourhoods and buildings) taking into account the various regulatory conditions that have been drawn up. The final section highlights the main conclusions of this research.

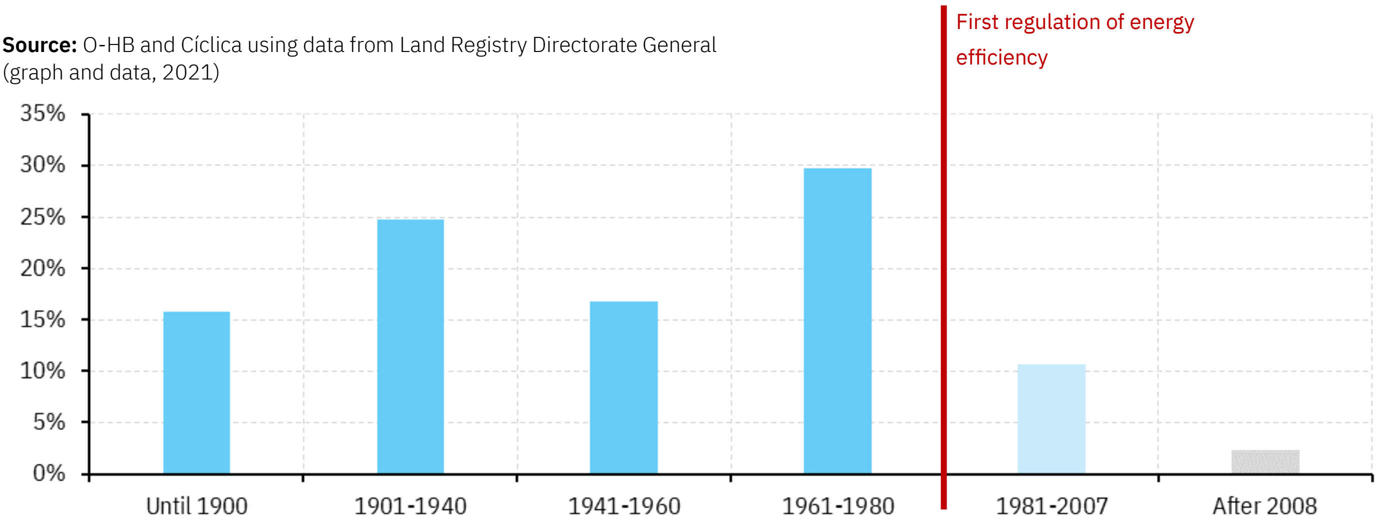
2. Point of departure: the energetic condition of the housing stock

In 2021, the city of Barcelona's housing stock had 58,643 land registry parcels with a majority of residential dwellings[5], which give a heterogeneous mix of single (28.44%) and multi-family (71.56%) buildings.

Firstly, almost 87.06% of buildings were built before the first legislation on energy efficiency was passed in Spain (NBE-CT-79, Royal Decree 2429/79, 6 July[6] and the Regulation of Heating, Air-conditioning and Hot Water Installations in Royal Decree 1618/1980, 4 July[7]) as a response to the petrol crisis of 1976 (Figure 1). Only 2.78% of buildings were constructed after 2007, the year in which the Technical Building Code began to be enforced effectively, initially through legislation derived from European directives on energy efficiency[8].

Figure 1. Percentage of buildings by date of construction showing the entry into force of the main state regulations concerning energy efficiency. Barcelona. 2021

Source: O-HB and Cíclica using data from Land Registry Directorate General (graph and data, 2021)



Secondly, despite the appeals from professional bodies and the urgent need to improve the current housing stock, rehabilitation actions in the city of Barcelona are still outnumbered by new constructions (in the first trimester of 2022, only 23% of all constructions consisted of

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[5] Source: O-HB from the Land Registry Directorate General (2021).
[6] Source: https://www.boe.es/buscar/doc.php?id=BOE-A-1979-24866 [accessed: 31 March 2023].
[7] Source: https://www.boe.es/buscar/doc.php?id=BOE-A-1980-16729 [accessed: 31 March 2023].
[8] Source: https://www.boe.es/buscar/doc.php?id=BOE-A-2006-5515 [accessed: 31 March 2023].

restorations[9]). Indeed, in Barcelona total or full rehabilitation work – i.e. work that involved significant constructive and structural changes – was only carried out on 9% of buildings[10].

Taking into account the effective age of buildings, as well as the two residential typologies mentioned at the beginning (single- and multi-family), the city of Barcelona's housing stock can be defined in terms of 12 clusters of buildings of similar characteristics (Table 1). Specifically, and leaving architectural aspects aside, eight clusters are characterized by having no thermal insulation on their outer surfaces (back and front facades, party walls, roofs and flooring) and, in terms of their thermal quality, have low-quality woodwork (transmittance of almost 6 W/m²·K); two clusters have thermal insulation only on their back facades, roofs and flooring (thicknesses of 2–6 cm), and low-quality woodwork (transmittance of almost 4 W/m²·K); and two clusters have thermal insulation in their back façade, party walls, roofs and flooring (thicknesses of 4–7 cm) and middling-quality woodwork (transmittance of almost 3 W/m²·K).

Table 1. Classification of the housing stock into 12 clusters based on the date of construction and their residential type. Barcelona. 2021

Source: O-HB and Cíclica using data from Land Registry Directorate General (graphic and data, 2021) and the Ministry of Transport, Mobility and Urban Agenda (Long-term strategy for the Energetic Rehabilitation in the Construction Sector in Spain -ERESEE-. 2014)

Year of residential part construction	Type of residence: single-family	Constructive characteristics	Percentage in relation to total number of buildings	Type of residence: multi-family	Constructive characteristics	Percentage in relation to total number of buildings
Until 1900	**Cluster A**: U.INF 1900	. No thermal insulation . Woodwork 6 W/m²·K	34.06%	**Cluster G**: P.INF1900	. No thermal insulation . Woodwork 6 W/m²·K	53.01%
1901 to 1940	**Cluster B**: U.1901-40	. No thermal insulation . Woodwork 6 W/m²·K	34.06%	**Cluster H**: P. 1901-40	. No thermal insulation . Woodwork 6 W/m²·K	53.01%
1941 to 1960	**Cluster C**: U.1941-60	. No thermal insulation . Woodwork 6 W/m²·K	34.06%	**Cluster I**: P. 1941-60	. No thermal insulation . Woodwork 6 W/m²·K	53.01%
1961 to 1980	**Cluster D**: U.1961-80	. No thermal insulation	34.06%	**Cluster J**: P. 1961-80	. No thermal insulation	53.01%

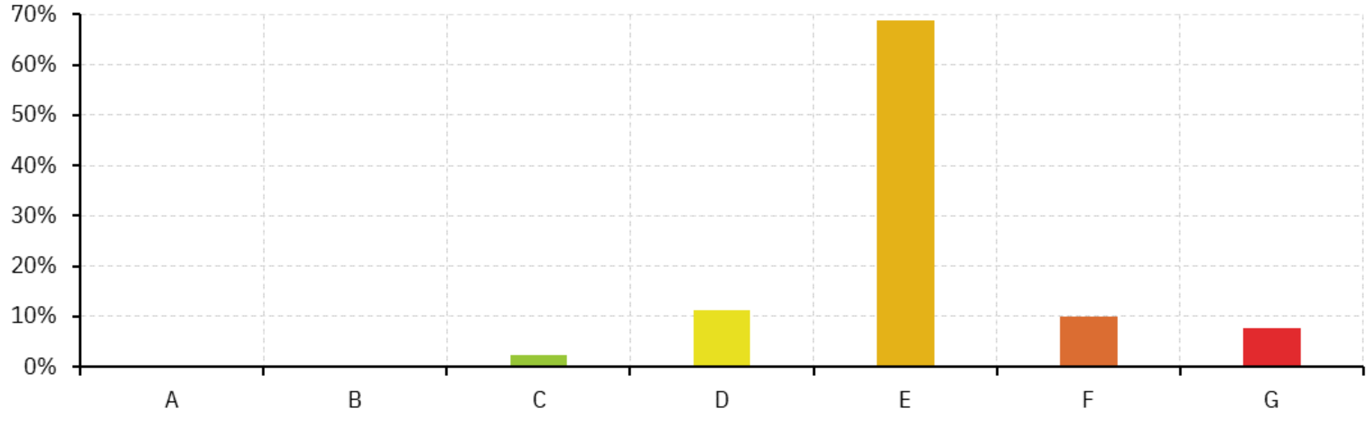
[9] Source: https://www.arquitectes.cat/ca/suport/actualitat/edificacio-catalunya-1semestre-2022 [Accessed: 31 March 2023]-
[10] Source: O-HB from the Land Registry Directorate General (alphanumeric data) and Barcelona City Council (Licences OMA, 2008-2019).

		. Woodwork 6 W/m²·K			. Woodwork 6 W/m²·K	
1981 to 2007	**Cluster E**: U.1981-07	. Thermal insulation in back facades, roofs and flooring (2–6 cm) . Woodwork 4 W/m²·K	2.49%	**Cluster K**: P. 1981-07	. Thermal insulation in back facades, roofs and flooring (2–6 cm) . Woodwork 4 W/m²·K	8.14%
After 2008	**Cluster F**: U.SUP2008	. Thermal insulation in back facades, party walls, roofs and flooring (4–7 cm) . Woodwork 3 W/m²·K	0.75%	**Cluster L**: P. SUP2008	. Thermal insulation in back facades, party walls, roofs and flooring (4–7 cm) . Woodwork 3 W/m²·K	1.54%

The distribution of the city's buildings in terms of these clusters (Table 1) confirms that Barcelona's housing stock is chiefly (97.70%) old and of low constructive quality, a fact that has a direct impact on its energetic status. Indeed, the energetic simulation performed to obtain an overview of this issue shows that in 2021 86.38% of buildings in the city would be classified with an 'E' or less in the scale of CO_2 emissions according to the Energy Performance Certificate[11]. Conversely, only 0.20% of dwellings could be qualified as 'A' or 'B, the two categories that most closely meet the objectives of decarbonization (Figure 2).

Figure 2. Percentage of buildings according to the classification of their current simulated energetic performances (CO_2 emissions). Barcelona. 2021

Source: O-HB and Cíclica using the urbanZEB and the Ministry of Ecological Transition and Demographic Challenge (Calificación eficiencia energética de los edificios. 2015)



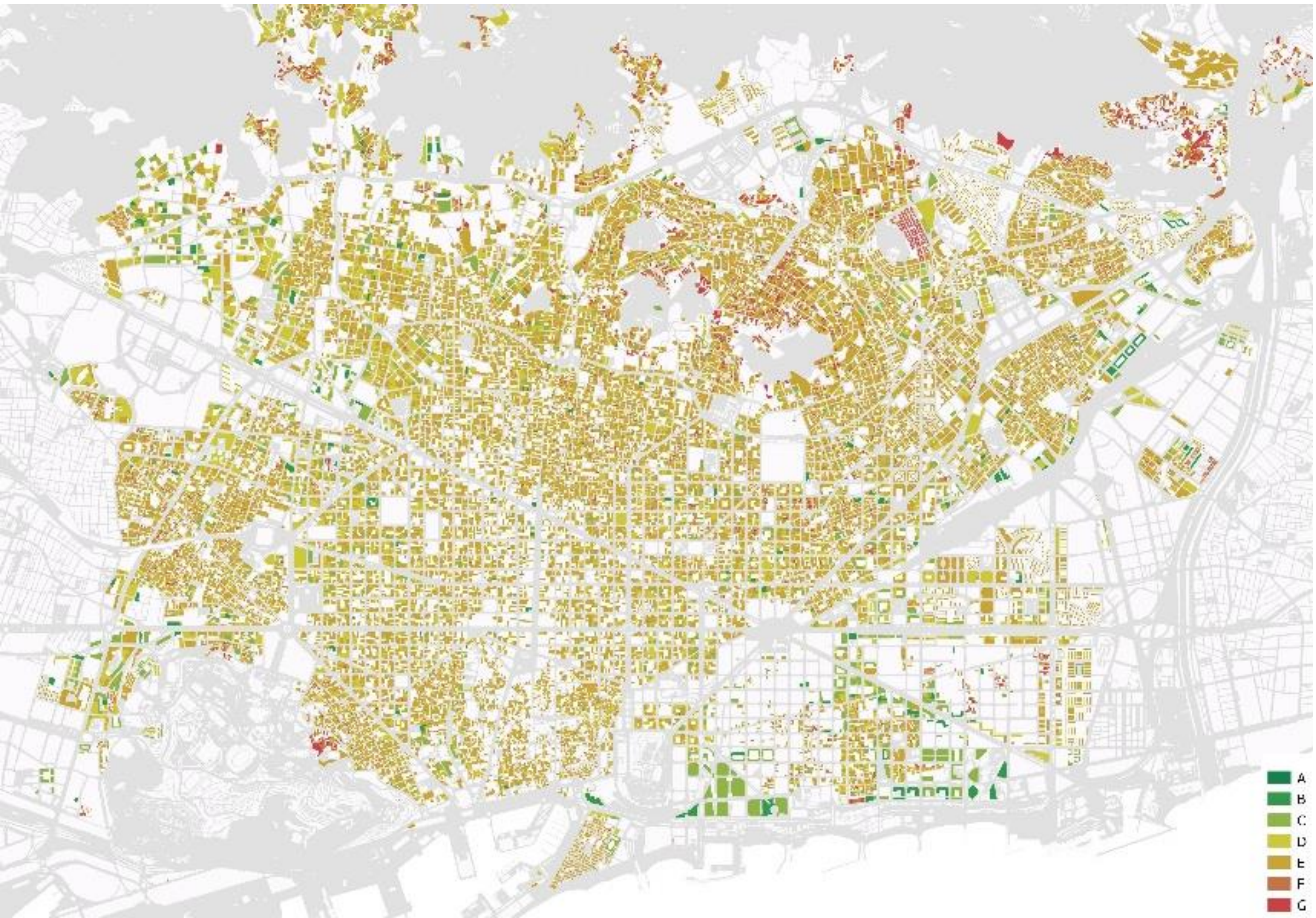
[11] The Energy Efficiency Certificate (EFC) for buildings is an official document that contains information on the condition of the building in terms of its energy demands (related to its constructive characteristics), energy consumption (related to the demand for heating and hot-water systems), and CO_2 emissions (related to the energy consumption and the use of renewable sources). In general terms, this document classifies buildings into one of seven classes ranging from 'A' (the most favourable situation) to 'G' (the worst situation) linked to the three indicators mentioned (ICAEN).

These results highlight the fact that the housing stock in Barcelona is energetically vulnerable as, due to its constructive characteristics, large amounts of useful energy are required by heating and refrigeration systems to ensure that minimum legal temperatures are maintained in winter (17–20oC) and summer (25–27oC).

Finally, a simulation of the energetic performance of buildings in Barcelona highlights the city's generalised energetic vulnerability (Figure 3). The theoretical economic costs of paying energy bills for heating and climatization that ensure a minimum level of thermal comfort rise to 393 €/month for single-family homes and 201 €/month for dwellings in multi-family buildings. These figures give an idea of just how many homes in Barcelona are at risk from energetic poverty[12].

Figure 3. Distribution of buildings according to the classification of their current simulated energetic performances (CO2 emissions). Barcelona. 2021.

Source: O-HB and Cíclica using the urbanZEB and the Ministry of Ecological Transition and Demographic Challenge (Energetic efficiency classification of buildings. 2015)



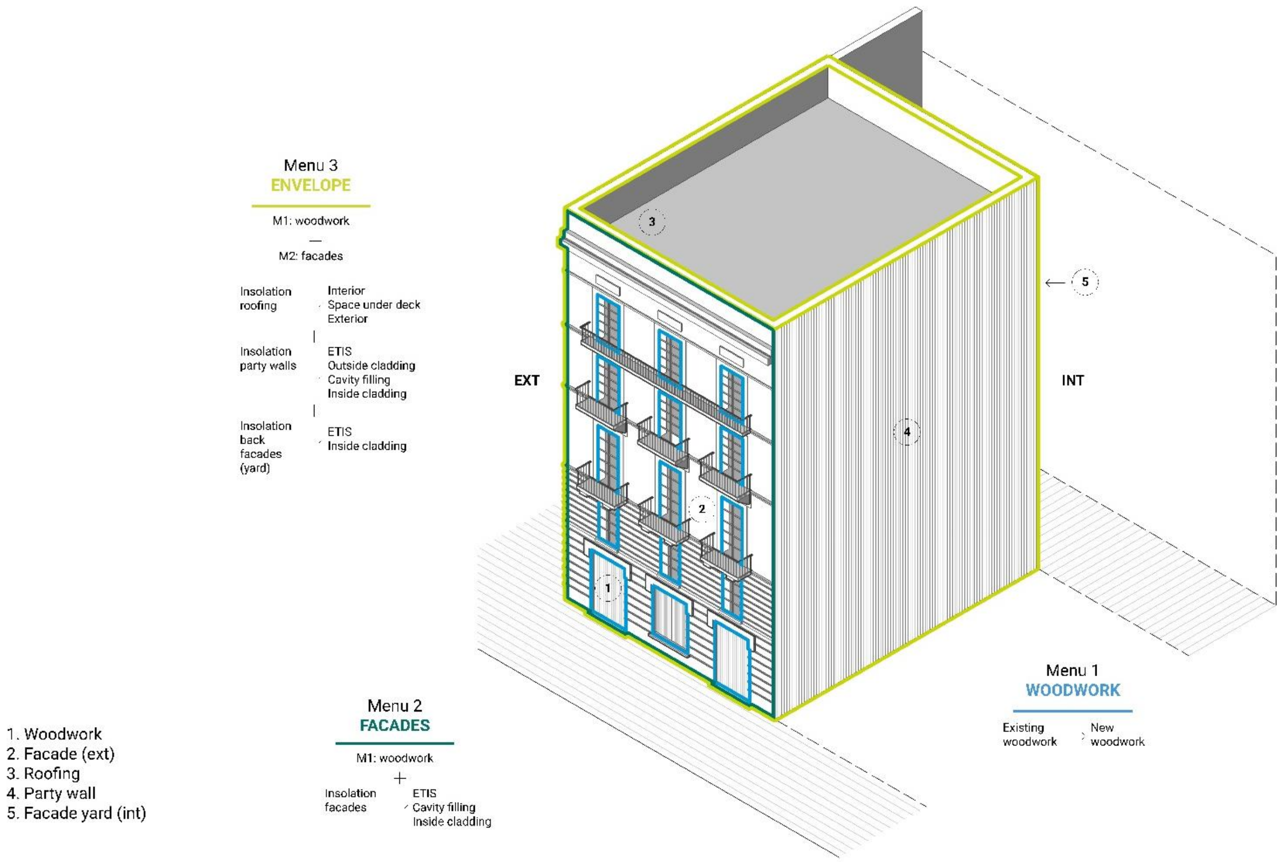
[12] Households that spend 10% or more of their monthly income on energy bills (heating, cooling, etc..). Source: O-HB based on the document Propuesta metodológica de evaluación de la pobreza energética en España by Carmen Sánchez-Guevara.

3. Potential for energetic improvements: passive rehabilitation strategies

The evaluation of the potential for improving Barcelona's energetically vulnerable housing stock (97.70% of the city's buildings) can be carried out through a definition – and a subsequent simulation – of three programmes of interventions based purely on passive rehabilitation strategies (Figure 4). These strategies follow European transformation directives designed to decarbonize the housing stock via a reduction in their energetic demand, i.e. reduce the dependence on external energy sources. These programmes take into account different levels of constructive complexity, speed of execution and costs. They only use materials with low embodied carbon that can be adapted to the different types of buildings referred to in the previous section (Table 2).

Figure 4. Interventions using rehabilitation strategies (M1, M2 and M3)

Source: O-HB



In general terms, the first action programme (M1) is the cheapest and quickest to execute. It consists of the substitution of existing woodwork with new wood with better thermal transmittance (e.g. wooden window frames that break the thermal bridge and a have a transmittance of 1.55 W/m²·K). The second programme (M2) consists of the substitution of existing woodwork and the insulation of rear facades using ETIS systems (External Thermal Insulation Systems), inside cladding or cavity filling depending on the housing cluster in question (6–7 cm of mineral wool or inflated cellulose). Finally, the third programme (M3) involves substituting existing wood and the insulation of almost all the outer structure including the outer and back facades, party walls and roofing. In the case of the facades and party walls, ETIS systems, cladding and cavity filling are proposed and, in the case of roofing, actions both inside and outside, as well as under the roofing, are contemplated (6–12 cm of wood fibre panels).

Table 2. Passive rehabilitation actions to be carried out by cluster

Source: O-HB and Cíclica based on Technical Building Codes (CTE, DB-HE-Ahorro de energía), ITEC (BEDEC database) and the City of Barcelona's Municipal Institute of Urban Landscape and Quality of Life (Bones pràctiques. Estudi de solucions tècniques per al tractament de parets mitgeres. 2021)

Cluster	Wood (M1, M2 and M3)	Rear facades (M2 and M3)	Party walls (M3)	Roofing (M3)	Interior facades (M3)
Cluster A: U.INF1900	Substitution of existing wood by wood that breaks the thermal bridge (1,55 W/m²·K)	Placing of interior cladding with mineral wool insulation (6 cm)	Placing of interior cladding with mineral wool insulation (6 cm)	Reconstruction of existing and installation of wood-fibre insulation panels (12 cm)	Placing of interior cladding with mineral wool insulation (6 cm)
Cluster B: U.1901-40	Substitution of existing wood by wood that breaks the thermal bridge (1,55 W/m²·K)	Placing of interior cladding with mineral wool insulation (6 cm)	Placing of interior cladding with mineral wool insulation (6 cm)	Reconstruction of existing and installation of wood-fibre insulation panels (12 cm)	Placing of interior cladding with mineral wool insulation (6 cm)
Cluster C: U.1941-60	Substitution of existing wood by wood that breaks the thermal bridge (1,55 W/m²·K)	Placing of interior cladding with mineral wool insulation (6 cm)	Placing of interior cladding with mineral wool insulation (6 cm)	Reconstruction of existing and installation of wood-fibre insulation panels (12 cm)	Placing of interior cladding with mineral wool insulation (6 cm)
Cluster D: U.1961-80	Substitution of existing wood by wood that breaks the thermal bridge (1,55 W/m²·K)	Injection of cellulose into existing cavities (9 cm)	Placing of interior cladding with mineral wool insulation (6 cm)	Reconstruction of existing and installation of wood-fibre insulation panels (12 cm)	Placing of interior cladding with mineral wool insulation (6 cm)
Cluster E: U.1981-07	Substitution of existing wood by wood that breaks the	Injection of cellulose into	Placing of interior cladding with mineral	Reconstruction of existing and installation of wood-fibre	Placing of interior cladding with mineral

	thermal bridge (1,55 W/m²·K)	existing cavities (7 cm)	wool insulation (6 cm)	insulation panels (12 cm)	wool insulation (6 cm)
Cluster G: P.INF1900	Substitution of existing wood by wood that breaks the thermal bridge (1,55 W/m²·K)	Installation of an ETIS with mineral woollen insulation (7 cm)	Placing of interior cladding with mineral wool insulation (6 cm)	Reconstruction of existing and installation of wood-fibre insulation panels (12 cm)	Installation of an ETIS with mineral wool insulation (7 cm)
Cluster H: P.1901-40	Substitution of existing wood by wood that breaks the thermal bridge (1,55 W/m²·K)	Installation of an ETIS with mineral woollen insulation (7 cm)	Placing of interior cladding with mineral wool insulation (6 cm)	Reconstruction of existing and installation of wood-fibre insulation panels (12 cm)	Installation of an ETIS with mineral wool insulation (7 cm)
Cluster I: P.1941-60	Substitution of existing wood by wood that breaks the thermal bridge (1,55 W/m²·K)	Installation of an ETIS with mineral woollen insulation (7 cm)	Placing of interior cladding with mineral wool insulation (6 cm)	Installation of wood-fibre insulation panels (12 cm)	Installation of an ETIS with mineral wool insulation (7 cm)
Cluster J: P.1961-80	Substitution of existing wood by wood that breaks the thermal bridge (1,55 W/m²·K)	Installation of an ETIS with mineral woollen insulation (7 cm)	Placing of interior cladding with mineral wool insulation (6 cm)	Installation of wood-fibre insulation panels (12 cm)	Installation of an ETIS with mineral wool insulation (7 cm)
Cluster K: P.1981-07	Substitution of existing wood by wood that breaks the thermal bridge (1,55 W/m²·K)	Installation of an ETIS with mineral woollen insulation (7 cm)	Placing of interior cladding with mineral wool insulation (6 cm)	Installation of wood-fibre insulation panels (6 cm)	Installation of an ETIS with mineral wool insulation (7 cm)

In terms of the three proposed actions, the simulation shows that the programme M3 achieves the greatest reduction in final energy consumption, with an average decrease of 53.51% of current energy consumption. It is followed by programme M2, with a decrease of 27.93% and M3, with a decrease of 14.00%[13]. These results, predictable given the accumulative character of the proposed actions, can be linked directly to the average cost of the investment in each case: 181.48 €/m² for M3, 119.65 €/m² for M2 and 56.12 €/m² for M1[14].

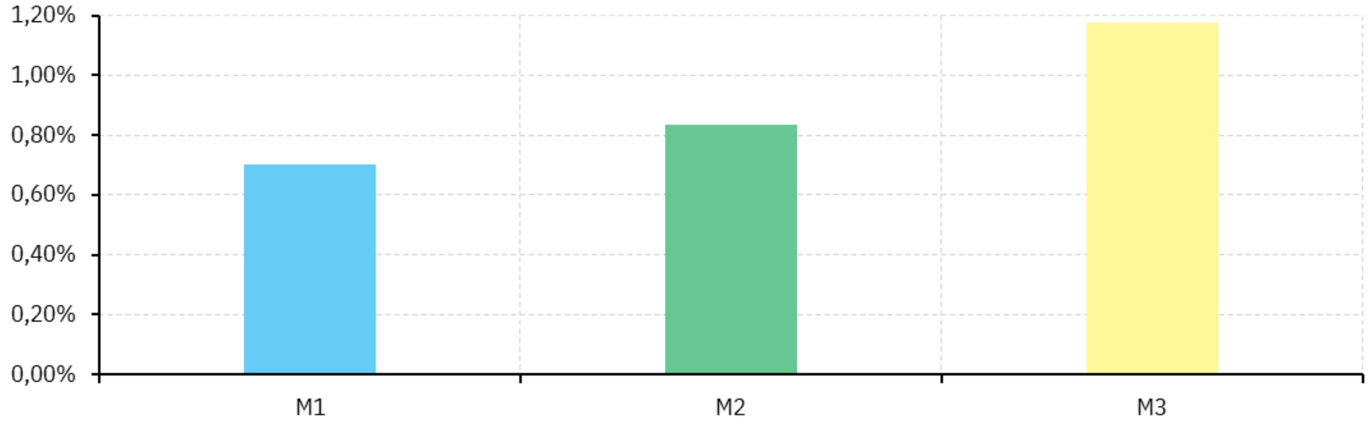
Thus, the combination of these variables (reduction in consumption and average estimated cost) allows us to study which of these programmes would give the most economic benefits or, in other words, which actions would lead to the greatest percentage fall in energy consumption for

[13] Source: O-HB and Cíclica using urbanZEB simulator.
[14] This estimated investment includes direct costs, industrial profits, fees, VAT and all other associated general and indirect expenditure that should be taken into account during the rehabilitation. Source: O-HB and Cíclica from the Technical Building Code (TBC, DB-HE-Ahorro de energía), ITEC (BEDEC database) and the City of Barcelona's Municipal Institute of Urban Landscape and Quality of Life (Bones pràctiques. Estudi de solucions tècniques per al tractament de parets mitgeres. 2021).

every 1,000€ invested. The simulation suggests that for every 1,000€ invested, the M3 programme will reduce on average the final energy consumption of a building by 1.18%, while the programmes M2 and M1 would reduce this figure by 0.83 and 0.70%, respectively (Figure 5). Moreover, the M3 programme has the best economic performance in 66.68% of cases, which indicates that the rehabilitation work affecting the whole outer surface of buildings – despite having a higher total execution cost – would lead to the proportionally higher reduction in energy consumption than the individual actions contemplated in other programmes.

Figure 5. Percentage reduction in final energy consumption of buildings for every 1,000€ invested according to the actions applied (M1, M2 and M3). Barcelona. 2021

Source: O-HB and Cíclica based on Technical Building Code (CTE, DB-HE-Ahorro de energía), ITEC (BEDEC database) and City of Barcelona's Municipal Institute of Urban Landscape and Quality of Life (Bones pràctiques. Estudi de solucions tècniques per al tractament de parets mitgeres. 2021)



4. Deployment: the opportunity offered by the NextGenerationEU funding

Grants for rehabilitation supervised by the Barcelona Housing Consortium and financed by NextGenerationEU funding represent a unique opportunity for initiating a transformation in the housing stock of the city of Barcelona. If the proposed restoration actions reach a minimum certified improvement in the energetic efficiency, these funds will cover over 40% of the execution costs of the work to be carried out –– provided costs do not exceed certain limits (Table 3).

Table 3. General energetic criteria for rehabilitation work financed by the NextGenerationEU funding. Neighbourhood and building programme

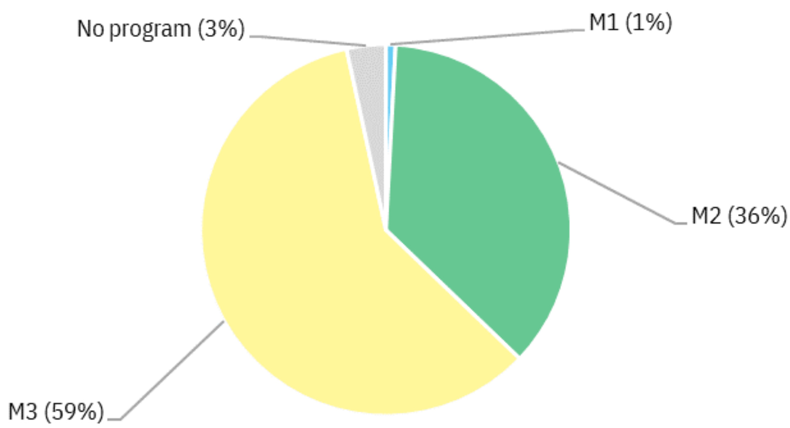
Source: O-HB and Ministry of Transport, Mobility and Urban Agenda (Royal Decree 853/2021, 5 October, regulating grants for rehabilitation of dwellings and social housing as part of the Restoration, Transformation and Resilience Plan)

Programme	Minimum energetic saving. Barcelona (%)	Part funded (%)	Limit per dwelling (€)	Local limit (€/m²)
Neighbourhoods	25% in energy demand and 30% in energy consumption	40%	8,100	72
Buildings	25% in energy demand and 30% in energy consumption	40%	6,300	56

The impact of this funding on the possibilities for energetic improvement discussed in the previous section is calculated for (i) each of the buildings that are considered part of the energetically vulnerable housing stock in Barcelona (97.70% of the city's housing) and for (ii) each of the programmes (M1, M2 or M3) that, given the simulations performed, will be able to comply with the minimum energetic savings determined by the Royal Decree. According to this minimum scenario, only 0.83% of buildings could opt for funding if they substituted only existing wood (programme M1), 36.35% would have to also insulate back facades (programme M2), 59.40% would have to act on the whole outer structure (programme M3), and, finally, 3.42% would not be able to comply with the requisites of any of the three programmes (Figure 6).

Figure 6. Percentage of buildings that, according to the first programmed action (M1, M2 or M3), would comply with the requisites for opting for NextGenerationEU funding. Barcelona. 2021

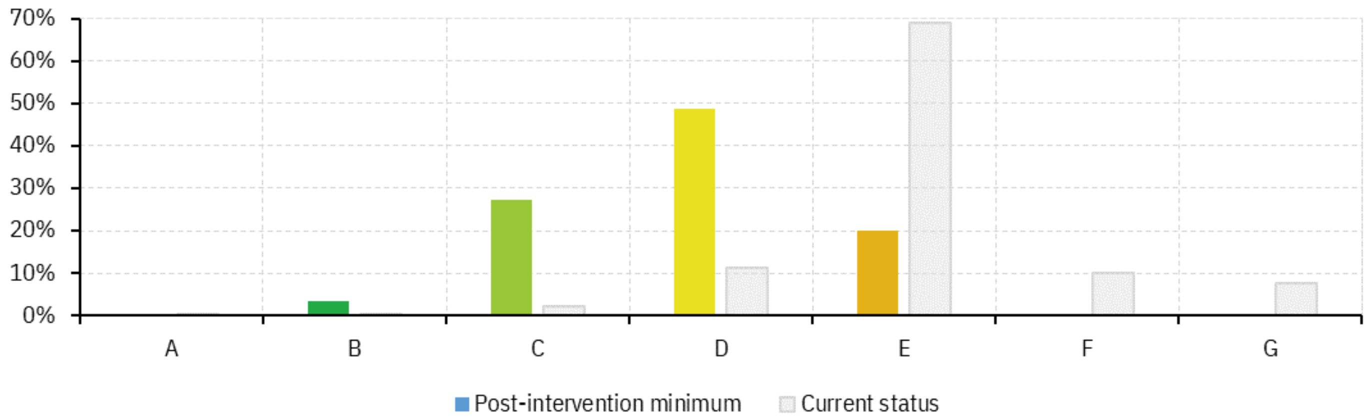
Source: O-HB and Cíclica based on urbanZEB simulator



Thus, if hypothetically all the actions regarding energetic rehabilitation according to the first programme of actions were carried out and the minimum scenario, the percentage of buildings in Barcelona with a classification of 'E' or worse in the indicator of CO2 emissions would fall from the current 86.38% to 20.26% after the completion of the work (Figure 7 and 8). Under this scenario, the NextGenerationEU funds would cover on average up to a 38.21% of the cost of the work carried out under programme M1, up to 38.77% under M2 and up to 60.94% up to M3[15].

Figure 7. Percentage of buildings in terms of their current and simulated future energetic classifications (CO2 emissions – worst-case scenario). Barcelona. 2021

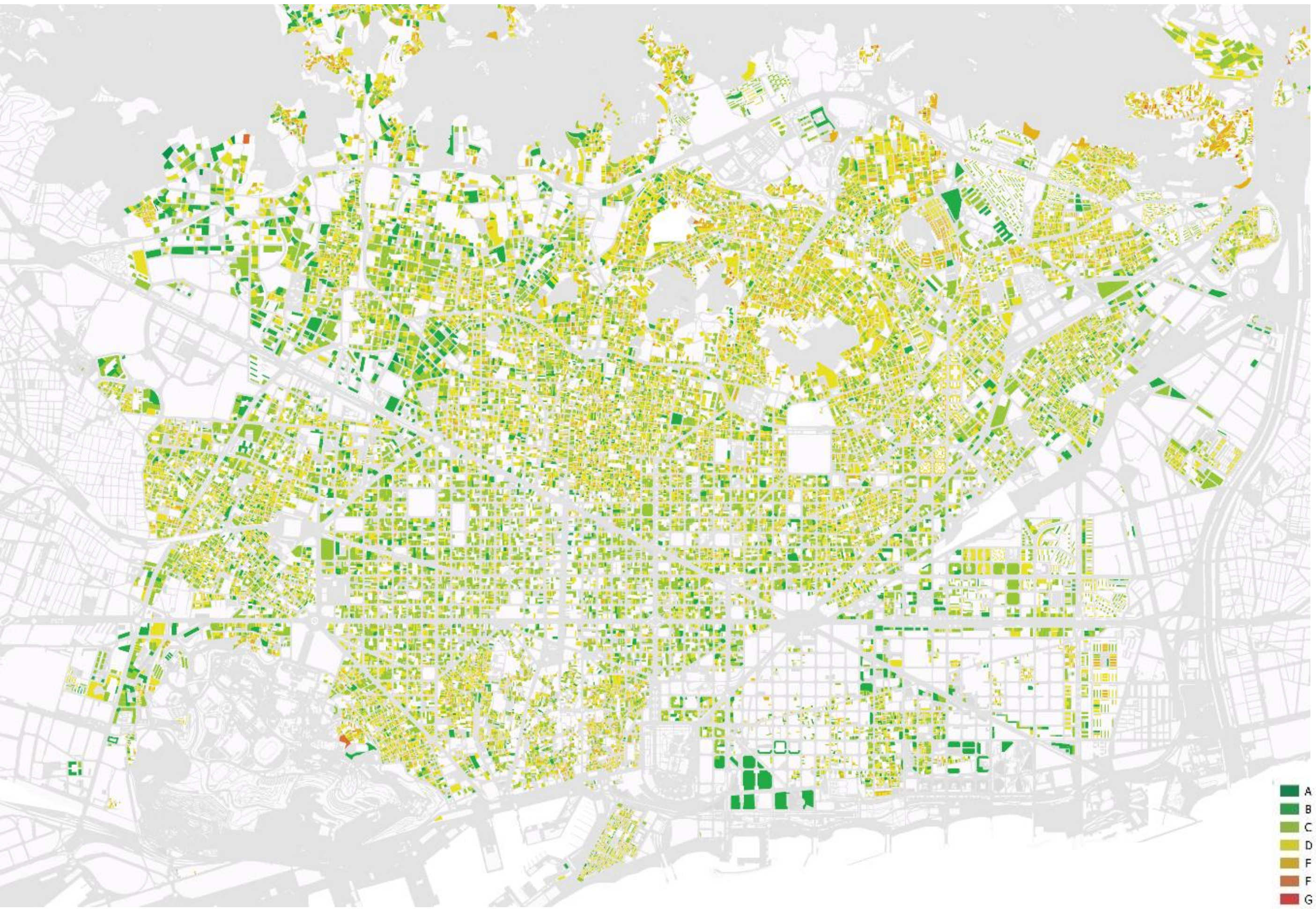
Source: O-HB and Cíclica based on urbanZEB simulation and data from Ministry of Ecological Transition and Demographic Challenge (Classification of the Energy Efficiency of Buildings. 2015)



[15] Source: O-HB and Cíclica based on data from CTE, ITEC and City of Barcelona's Municipal Institute of Urban Landscape and Quality of Life, Ministry of Transport, Mobility and Urban Agenda (RD853/2021, 5 October).

Figure 8. Distribution of buildings according to their current and simulated future energetic classifications (CO_2 emissions – worst-case scenario). Barcelona. 2021

Source: O-HB and Cíclica based on urbanZEB simulation and data from Ministry of Ecological Transition and Demographic Challenge (Classification of the Energy Efficiency of Buildings. 2015)



The results indicate that the use of passive strategies could have a highly positive impact on the energetic performance of the city's housing stock since they notably reduce energetic demands and improve energetic certification. Nevertheless, the use of active strategies such as improvements in climatization systems and energy production from renewable sources remains an indispensable part of reaching by 2050 the climate-zero target outlined in the European Green Pact.

5. Conclusions

Both the availability of information on the energetic condition of Barcelona's housing stock and the potential for improvements through rehabilitation backed by public policy are key elements in the transformation of the city's buildings and the fulfilment of the decarbonization targets established in the European Green Pact. Specifically, the energetic simulation at land registry scale enables us to improve on available official information regarding this question and cover almost all existing dwellings in the city of Barcelona (85%).

Firstly, this analysis of the current condition of the city's buildings illustrates just how much (98%) of Barcelona's housing stock is old and of low constructive quality. In all, 87% of buildings were constructed before the first legislation on energy efficiency came into force. Full or total rehabilitation work that includes significant constructive and structural changes has been performed on only 9% of buildings. Thus, the energetic condition simulator for 2021 shows that 86% of buildings would attain an 'E' classification or worse in the CO2 indicator in the EPC (Energy Performance Certificate). This will have a direct impact on the energy bills that households in Barcelona will have to pay if they are to maintain their homes within the limits of human thermal comfort (average values between 393 and 201 €/month for single- and multi-family buildings, respectively).

Secondly, passive rehabilitation actions including the substitution of woodwork (programme M1), façade insulation (M2) and the insulation of the whole outer structure of dwellings including facades, party walls and roofs (M3) would reduce considerably the final energy consumption by on average 14–54%. Compared to the individual actions contemplated in M1 and M2, the all-embracing actions in M3 would be more efficient in 67% of cases from an economic standpoint and in terms of absolute energetic improvements.

Thus, 59% of buildings in Barcelona will have to improve their whole outer structure if they are to comply with the minimum energy-saving requisites demanded by the NextGenerationEU funding (reduction by 25% of energetic demand and 30% in energy consumption). In 36% of cases, it would be sufficient to insulate the facades and substitute existing woodwork but only in 1% of cases would it be sufficient to just change window frames.

If all these potential actions were to be carried out, the percentage of buildings in Barcelona with an 'E' or worse classification in the CO2 emissions indicator would drop from a current simulated 86% to a hypothetical 20% in the future. At the same time, under this worse-case scenario, the European funds would cover on average a 38–61% of the costs of rehabilitation work. Nevertheless, these proposed passive strategies will not be sufficient to reach the climate neutral target by 2050. Thus, more active strategies including an increase in the efficiency of climatization systems and the generation of energy with renewable technology will be necessary if the aim of a complete decarbonization of the city's housing stock is to be fulfilled.

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