Med-EcoSuRe project

Output 4.2. Cross border strategic Plan for University Building Retrofitting

Partner: SOLARTYS and University of Seville

1.1 CONTRIBUTORS

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1.2 SUMMARY

In this report on Output 4.2 for a Cross border strategic Plan for University Building Retrofitting, we report on the actions undertaken by the University of Seville and SOLARTYS, the two consortium partners based in Spain.

For this purpose, after introducing a contextualisation of the Spanish national building stock, we focus on describing the identification of cost-effective approaches to renovation. To this end, we present various data that allow us to understand the situation at the Spanish level. Then, we move on to the policies and actions towards deep renovation. To this end, we address the breakdown of existing policies and actions. After a national contextualisation, we discuss how SOLARTYS has carried out the identification of stakeholders within the public administration and stablishing relations to help them overcome the challenges. Furthermore, we also analyse the existing barriers that we have encountered when sensitising stakeholders to the results and good practices of the project. Finally, the last point of this part focuses on the action plan: including the planned measures, estimation of impact, investment needed and timeline. In it we address how to improve the thermal envelope of the buildings and how to optimise setpoint temperatures.

This report ends with the letters of commitment collected from the University of Seville.

I. Overview of Spanish national building stock

In Spain, residential buildings account for 80% of the housing stock. That is why a sample of six buildings has been generated: three buildings of single-family typology and the remaining of multifamily typology. These six buildings are defined as reference buildings of the building stock by the Spanish Directorate for Architecture, Housing and Planning, for the cost-optimal calculations report under the Energy Performance Buildings Directive (Directive 2010/31/EU). This building sample represents the new and existing buildings in Spain, such that, the reference buildings must be as representative as possible of the national building typologies and historic changes in building tradition.

Building type		N.º floors	N.º dwellings	Wall Area(a) (m^2)	Glazed Surface Ratio(b) (%)	Roof Area (m^2)	Floor Area (m^2)	Conditioned Floor Area (m^2/dwelling)	Average Ceiling High (m)	Compactness (m)
Detached Multifamily		6	18	(N) 403.0 (E) 275.9 (S) 403.0 (W) 275.9	18.1 9.4 16.5 13.3	279.1	279.1	85.3	2.3	2.0
Attached Multifamily		6	13	(N) 302.6 (E) - (S) 302.6 (W) -	22.6 - 33.6 -	214.5	163.8	89.6	2.6	3.3
Perimeter Block (Multifamily)		5	67	(N) 556.4 (E) 567.4 (S) 556.6 (W) 566.8	23.7 23.6 23.7 23.3	1 221.3	1 221.3	71.3	2.7	3.5
Detached Single-family		2	1	(N) 44.8 (E) 39.7 (S) 45.0 (W) 39.8	7.0 16.1 8.7 19.5	61.6	47.8	102.3	2.4	0.9
Attached Single-family		2	1	(N) 33.0 (E) 3.0 (S) 33.0 (W) -	19.1 - 34.3 -	53.0	57.0	99.8	2.7	1.2
Semi-detached Single-family		2	1	(N) 3.0 (E) 33.0 (S) 55.5 (W) 33.0	- 34.3 5.1 19.1	53.0	57.0	99.8	2.7	1.5

52.4% of Spanish existing dwellings were built before 1979 under no regulation focused on energy performance, and 38.1% were built following the requirements of the first building code[6,10]. To overcome the poor characterization of the oldest dwelling stock is assumed that the reference building's thermal envelope is given by the first thermal building regulation. Spain adopted its first building thermal code in 1979 under the Royal Decree 2429/1979 of July 6 (NBE-CT-79) as a consequence of the 1970s oil crisis [86]. Is not considered the dwellings built after 2006 due to the refinement of the building code and these represent only 9.6% of the dwelling stock.

Each building's thermal envelope was defined to fulfil strictly the regulation requirements, i.e, each surface U-value and air permeability defined corresponds to the maximum allowed value by the building code. The thermal envelope is defined according to the climate zone and the building's compactness(1), where lower U-values are required for colder climates and less compact buildings. It

(1) Is given by the ratio between the conditioned volume and the exterior surface area.

also accounted for the lineal thermal bridge effect by incrementing the U-value of each surface. This increment corresponds to the average increment of the building's overall U-value. The file below presents the thermal characteristics of each building attending the regulation diploma and the climate zone, and during the six different period to analyse since 1900.

Database.xlsx

The reference indoor range temperature was defined as 20-25ºC, corresponding to the comfort range present in the Spanish Building Technical Code and The final energy demand is given by the HVAC template models of EnergyPlus for the most common heating and cooling technologies of Spanish homes, being these a gas boiler (η=0.92) and an air-conditioner (split unit, COP=2.90) according to Building Technical Code Standard DB-HE0 and the housing characteristics survey.

The occupancy profile was defined according to Standard ASHRAE. Also was considered the suggested appliances and lighting usage profiles for residential buildings. Regarding the last household survey in Spain, it was assumed for each dwelling a nominal occupancy of 3 persons. The HVAC model considers a minimum outdoor airflow to ensure indoor air quality, which corresponds to 0.15 $L/s \cdot m^2$ of floor area and 3.5 L/s·personfor a ventilator with a nominal specific fan power of 1 00W/(m^3/s).

II. Identification of cost-effective approaches to renovation

The procedure developed in A4.1 for the identification of improvement measures in buildings is cost-optimal. This procedure is based on life cycle studies. A life cycle assessment allows the quantification of the cost or emissions that a building will generate according to its thermal envelope and energy systems. Applying this assessment to a set of possible improvements enables the identification of the case that minimizes the LCC or the LCE. However, this optimal case may not necessarily comply with the building legislation, so an LCA should only include the improvements packages or cases that possibilities compliance with the European and National regulations. Therefore, each optimal selection method was applied also considering the requirements of the Spanish Building Technical Code that transposes the latest version of EPBD in Spain. The refinement introduced by the integration of nearly Zero Energy Building imposes a demand limitation (heating and cooling), a minimum energy efficiency for the energy systems, a minimum quality of the thermal envelope restringing the surface U-values, the global U-value and the building air permeability and obliges integration of renewables sources.

The next figure illustrates the identification of the optimal case for the optimal methodologies among all the possible combinations for the improvement packages of the thermal envelope (grey circles) and the initial stage of the building (red cross). From all combinations, a filter is applied and selected cases that fulfil the Spanish build code requirements that are represented by the green points, and inside of that set of data is selected that case that presents the lowest value possible for the LCC or the LCE. This figure also presents the theoretical optimal case (orange circle) obtained without legal constraints. Next table presents the optimal case with and without legal requirements for the example of the next figure where is possible to see that the optimal theoretical cases have a higher global U-value (Ug), i.e., a lower insulation level of the building envelope. Having a minimum level of insulation leads to having a building with a higher LCC or LCE. Nevertheless, the floor cost-optimal is the method where a major difference can occur due to the additional cost introduced by the floor area loss.

Table. Impact of introducing the legal requirements in the definition of the optimal case. An example case for a multifamily detached building in Madrid (D3 climate zone) and XPS insulation system based.

Method	Legal Requirements	U_G ($W/m^2 \cdot K$)	E_p[a] ($kWh/m^2 \cdot year$)	LCC (€/m^2)	LCC_f (€/m^2)	CO_2 (kg CO_{2eq}/m^2)
Cost-optimal	complies	0.65	36.7	145.7	295.3	216.7
	not complies	0.89	33.9	94.1	206.4	190.4
Floor cost-optimal	complies	0.65	37.2	180.0	254.9	202.6
	not complies	1.35	52.2	123.7	123.7	263.2
CO_2 optimal	complies	0.62	35.4	188.6	300.9	199.6
	not complies	0.83	33.0	137.3	230.9	182.5

[a] Total Primary Energy Demand.

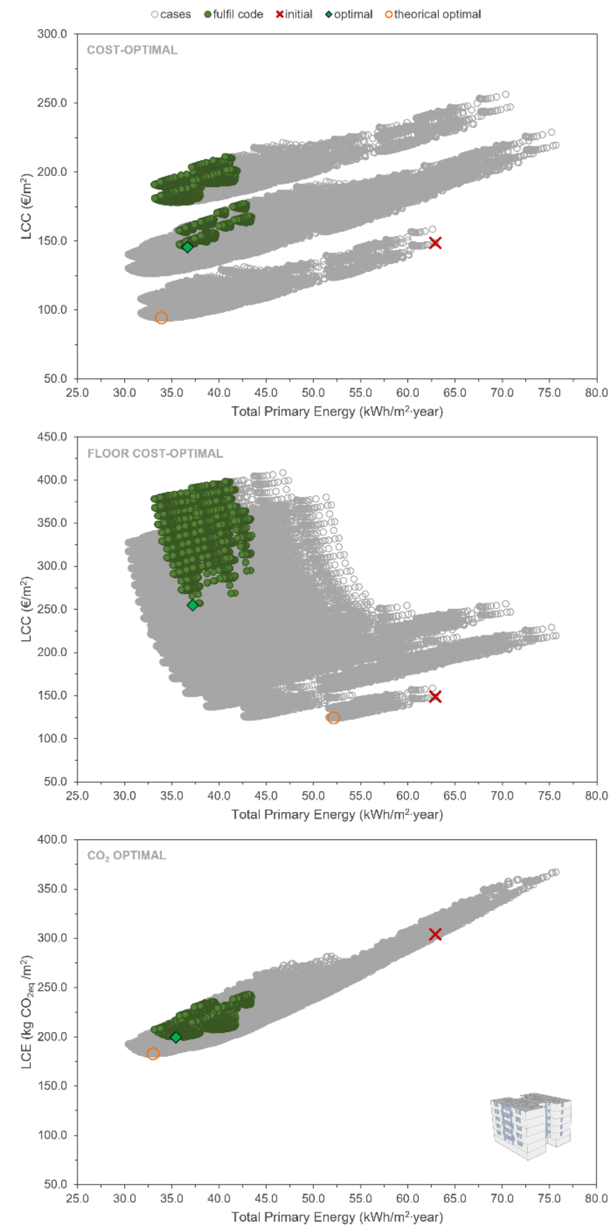

Figure. Example of optimal case selection for the three optimal selection methodologies: multifamily detached building in Madrid (D3 climate zone) and XPS insulation system based.

III.Policies and actions towards deep renovation:

3.1 Breakdown of Existing policies and actions

The state regulations applicable to buildings – from the perspective of Real Estate Law – are constituted by Law 38/1999, of 5 November, on Building Regulations (LOE), which has been developed with regard to technical aspects by the Technical Building Code, approved by Royal Decree 314/2006, of 17 March. In the Valencian Community, Law 3/2004, of 30 June, on the Regulation and Promotion of Building Quality (LOFCE) also governs, as a development of the LOE.

The Technical Building Code (CTE) is the regulatory framework that establishes the basic quality requirements that buildings must meet in relation to the basic safety and habitability requirements established in Law 38/1999 of 5 November, on Building Regulations (LOE), i.e. for the basic requirements of "structural safety". "fire safety", "safety of use", "hygiene, health and environmental protection", "noise protection" and "energy saving and thermal insulation".

The CTE also deals with accessibility as a result of Law 51/2003 of 2 December, which deals with equal opportunities, non-discrimination, and universal accessibility for people with disabilities (LIONDAU).

The CTE is also an instrument for the transposition of European directives. Thus, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings has been partially transposed into Spanish law through the amendments to the Basic Document DB-HE carried out by orders FOM/1635/2013, of 10 September, and FOM/588/2017, of 15 June. For its part, Council Directive 2013/59/Euratom of 5 December 2013 has been partially transposed by Royal Decree 732/2019 of 20 December 2019, which introduced a new basic health requirement for radon protection in the CTE.

One of the main novelties of the CTE with respect to the previous legislation on building in Spain was the performance approach. Thus, the CTE sets out the criteria that buildings must meet but leaves open the way in which these rules must be met. This particularity, which is present in the regulations of most of the countries around us, allows the configuration of a more flexible regulatory environment. In this way, the CTE favours the development of research, development and innovation (R+D+i) tasks and an increase in the use of new technologies in the construction sector by integrating more directly the advances achieved thanks to these activities. Thus, the performance approach allows the use of technical innovations without losing sight of the traditional elements of the construction method.

In addition to the basic regulations, the EU has launched the renovation wave which aims to double renovation rates over the next 10 years and ensure that renovations result in greater energy and resource efficiency. This is what the European Commission intends to do with the Renovation Wave, its strategy to improve the energy efficiency of buildings in the Old Continent.

The Renovation Wave will focus on three areas. The first is the decarbonization of heating and cooling. The second is fighting against energy poverty and improving less efficient buildings. And the third is the renovation of public buildings, such as schools, hospitals, and administrative buildings.

Once it is known in which areas it will act, it is the turn of the main actions established by the EC in its strategy, which are 6:

1. Adopt stronger regulation and standards, as well as provide information on the energy performance of buildings, to establish better incentives for renovations in the public and private sectors. This includes the gradual introduction of mandatory minimum energy performance standards for existing buildings, updated standards for energy performance certificates and a possible extension of building renovation requirements for the public sector.
2. Ensure accessible and well-targeted financing, notably through the Recovery and Resilience Facility's "Renovate" and "Power Up" initiatives under Next Generation EU, simplified rules to combine different funding streams and multiple incentives for private finance.
3. Increase capacity to prepare and implement renovation projects, from technical assistance to national and local authorities to training and skills development for workers in new green jobs.
4. Expand the market for sustainable building products and services, including integrating new green materials and solutions, and review legislation on the marketing of construction products and material reuse and recovery targets.
5. The creation of a new European Bauhaus is an interdisciplinary project jointly led by an advisory committee of external experts, including scientists, architects, designers, artists, planners and civil society. The goal is the formation of a network of five founding Bauhaus by 2022 in different EU countries.
6. The development of proximity approaches for local communities to integrate digital and renewable solutions and create 0 energy districts, in which consumers become prosumers (at the same time producers and consumers) selling energy to the grid. The strategy also includes what they call an Affordable Housing Initiative for 100 districts.

Taking into account the existing policies and in relation to the actions taken towards deep renovation of buildings, SOLARTYS has focused in identifying stakeholders within the public administration and stablishing relations to help them overcome the challenges.

Framework and context of the actions related to Catalan Public Administration:

Within Med-EcoSuRe project, at the Tunis meeting & "workshop on energy efficiency action plans for the Higher Education Building Stock in the Mediterranean" held in May 2023, MEDREC asked SOLARTYS to be able to close the Med-EcoSuRe project in Barcelona, given the political problems in Palestine around Spring/Summer 2023.

SOLARTYS accepted the proposal, and thought of being able to capitalize on all the knowledge generated during the Med-EcoSuRe project based on the search of energy efficiency solutions for university buildings, and extend the event by inviting as many representatives as possible of the Catalan Public Administration. The reason for inviting the Administration derives from the fact that the solutions developed during the project are replicable to all public buildings.

The following public entities were invited and attended the Final Med-EcoSuRe event "Towards efficiency and sustainability in the Mediterranean: from universities to public buildings":

- Barcelona City Hall;
- Catalan Government;
- Barcelona Provincial Council
- Girona Provincial Council;

- Sant Cugat del Vallès City Hall;
- BaixLlobregat County Council.

After the event, until date the following meetings have been held:

General Directorate of Heritage. Head of the Property Management and Support Services Implementation Area. Department of Economy and Finance

We held a first meeting to explain the Med-EcoSuReproject and invite them to attend TESMed. They explained us that the main objectives of where to invest European funds will be in measures aimed at the efficiency and sustainability of public buildings owned by the Generalitat of Catalonia; This plan is foreseen between 2030 and 2050, with a first action extended to all buildings to place photovoltaic panels to generate renewable energy.

Due to the success of the event, they asked us to hold a second meeting now to try to explore ways for collaboration. In this meeting we continue discussing the different challenges, needs and problems on which we can develop a proposal. The General Directorate of Heritage tells us that the next intervention they wish to carry out in some of the buildings they manage is the implementation of artificial intelligence in buildings to reduce energy consumption by 30%.

The total number of properties of the Generalitat of Catalonia that can be candidates and that are occupied by uses of the Department, and that have a type of use compatible with an AI proposal to maximize energy efficiency is 1,100, disaggregated by type of use:

Offices = 89

Schools = 252

Institutes = 357

Universities = 4

Residences and homes = 71

Based on this information, at Secartys/Smartech we have worked together to identify the companies in our ecosystem that can respond to the pilot project. We have worked together on the design of a pilot based on the following technologies:

- **Artificial Intelligence** to be able to make autonomous decisions to optimize energy consumption, collecting historical and real-time data from both the building and the exterior.
- **IoT**, deployment of a sensor network of different types for the measurement of environmental variables, space occupation, lighting and air conditioning control.
- **Digital twin**, to understand the dynamic behavior of the building and with the purpose of managing it so that it is more intelligent and sustainable.
- **Blockchain**, implementation of a tokenization and digital asset management system to optimize the energy consumption of public buildings.
- **Intelligent lighting/Human Centric Lighting**, with the aim of automating the dynamic control of both artificial and natural lighting, to increase user well-being and energy savings.

Barcelona's City Hall. Directorate of Services and Environmental Quality

We invited the chief engineer of Barcelona City Council, who could not attend TESMed; However, we decided that it was interesting to send him the information and content worked on in a digital file that was made to document the event. A few days later he contacted us since he found it very interesting and proposed to have a meeting with the Department of Energy and Environmental Quality Services of the Barcelona's town hall.

We held a meeting, where they explained their challenges and problems summarized in these three points:

- ✓ Increase in the city's energy self-sufficiency levels, increasing the production of endogenous energy and reducing the demand of consuming spaces as much as possible without affecting the level of well-being.
- ✓ Improvement of the lighting sensation of the city, incorporating criteria of energy efficiency and functional operability.
- ✓ Improvement of air quality and reduction of noise pollution.

Two main challenges emerged from the meeting that we at SOLARTYS/Secartys can work on in a project:

- ➢ Rehabilitation of buildings in both the tertiary and residential sectors.
- ➢ Need to increase renewable energy generation from public space.

From there we have followed the same process as with the Generalitat. We decided to start with the challenge of renewable energy generation in public spaces; We identify those companies from our ecosystem, to solve this goal of integrative and innovative generation of renewable energy.

The City Council has determined an urban space for us to study the feasibility of integrating photovoltaic technology. In this way, it is intended to study other architectural-energy solutions to create outdoor spaces that are self-sufficient in their consumption, creating the basis for the creation of a local energy community.

The challenge we have to work on is an urban space that has two small green areas and a paved area, partially covered by a pergola.

The pergola is a rectangle 22m long by 6.30m wide and can serve as a surface on which to place photovoltaic panels and produce enough energy to illuminate the public space and for the connection to electric mobility.

<u>Barcelona's City Hall. Directorate of Services for city town buildings</u>

We met with the Director and manager of the Directorate of Services for city town buildings, who had previously attended TESMed event.

They manage the maintenance and renovation of the buildings owned by the City hall. In the last year they have developed plenty of projects to improve the energy efficiency and sustainability of these buildings.

Actions and projects developed have been focused mainly on the installation of solar energy panels in the building rooftops and in improving energy efficiency, by measuring energy consumption and defining strategies to reduce it. Moreover, a big effort has been made and is being made in raising awareness among employees that work in these public buildings about making good use of resources to decrease the negative impact on the environment.

The main challenge they have nowadays is that they need to maximize the renewable energy generation and green areas in the building' rooftops. As we are doing with the other Administration departments, the next steps will be to identify companies' members of our ecosystem with innovative solutions to solve this challenge and make a collaborative proposal to the City Hall.

These solutions can be related to agrovoltaic (combination of agriculture and photovoltaic), biophotovoltaics (generation of energy through the photosynthesis process of plants) or other innovative technologies that allow the production of renewable energy combined with plants.

Sant Cugat City Hall. Department of Environment and Urban Quality

We met with two representatives of Sant Cugat City Hall that explained to us the different challenges and projects that they are currently working on in the Department of Environment and Urban Quality.

They shared with us that the Sant Cugat City Council has among its mandate objectives to fulfill the commitments made in the Sustainable Energy and Climate Action Plan PAESC approved on July 19, 2021. For this reason, its will is to work towards a resilient, sustainable and environmentally friendly city to contribute to this task of moving towards decarbonisation in 2050:

- Per capita emissions will be reduced by 62.5% in 2030, compared to 2005;
- On the way to achieving climate neutrality by 2050, promoting decarbonisation and resilience policies;
- Access to affordable, clean and safe energy will be guaranteed;
- Situations of energy poverty and inequality will be tackled;
- Work will be done for a fair adaptation and transition.

The PAESC (Energy and Climate Action Plan 2021-2030) includes 61 mitigation and adaptation actions to climate change, where the City Council has the power to act, either directly or indirectly (except the primary and industrial), collecting data available from the competent bodies and from the following sectors:

- Transport (public and private)
- Domestic
- Services (including the City Council)
- Waste treatment
- Water cycle
- Local energy production

They shared with us European projects they are involved, in order to identify synergies and collaborations for the future.

The 3 European projects in which they have participated at the level of implementation of new technologies in municipal facilities in the municipality:

- Project at the Pins del Vallès school: GEOFIT (https://geofit-project.eu/)
- Project at the Mirasol cultural center: SUNHORIZON (https://www.sunhorizon-project.eu/)
- Project at the sports halls PAV1,2 and 3: CHESS-SETUP Grant agreement identifier: 680556 https://cordis.europa.eu/project/id/680556/es

We conclude al those meetings with the compromise to pursue collaboration in the future by participating together in European projects related to renewable energy and smart cities and smart buildings technologies.

3.2 Analysis of existing barriers

As developed above, at the time of implementing the strategy around output 4.2 of the Med-EcoSuRe project at Spanish level, we have come up against different barriers, which we will detail below. This detection was born thanks to the dynamics of the University of Seville itself, and specifically of its Thermotecnia group, in taking advantage of its educational actions with the other faculties of the University of Seville itself or other universities with which it maintains relations, as well as the activities developed between the University of Seville and SOLARTYS - such as the training carried out at the end of June and the beginning of July 2023 - or the two events organised by the University of Seville and SOLARTYS. Likewise, the two events organised by SOLARTYS within the framework of the project: the Barcelona University Business Forum (held by SOLARTYS in May 2022) and the Towards Efficiency and Sustainability in the Mediterranean (final event of the project organised by SOLARTYS in July 2023) or the relations with our partners (which include universities and research centres linked to universities), allow us to nourish this observation.

In general terms, we have identified an interest on the part of the Spanish universities and public administrations with which we work and collaborate in SOLARTYS, as well as with other universities closer to the University of Seville. This interest is rooted in the fact that the solutions and pilots implemented throughout the development of the project are easily transferable to other Spanish universities, and therefore to public administrations, due to their similar nature to universities: underfunding, old and unsustainable buildings both in terms of energy consumption and efficiency, the need to be renovated, etc.

This interest has materialised in the strong participation of universities and public administrations in the two major events organised by the Med-EcoSuRe project in Spain. Specifically, the Barcelona University Business Forum (organised by SOLARTYS in May 2022) and the Towards Efficiency and Sustainability in the Mediterranean (final event of the project organised by SOLARTYS in July 2023).

Thus, as detailed above, the realisation of the final event of the project has allowed to give a more expansive blow to the results and good practices developed by the project, taking them to the field of public administrations and specifically, the Catalan ones. As a result of this, meetings were held with various public bodies. During these meetings, we have been able to perceive the need of many public administrations to be accompanied and guided in their process towards sustainability and energy efficiency. However, despite this good predisposition in general terms, we have detected a series of barriers.

One of the first barriers (and perhaps the most conditioning one) is the apprehension on the part of universities and public administrations to implement measures external to their own institutions. This factor, which is extremely important given the output that we are dealing with here and the activities derived from it, has strongly marked the deployment of the strategy at the Spanish level.

Complementary to this first point, we have also detected another barrier that strongly hinders the application of the project's results and good practices. Specifically, due to internal processes. It must be said that this barrier has been more palpable at university level than on the part of public administrations. This internal limitation is due to different factors that we will address below.

The first of these points is the fact that universities have a very different perception of what sustainability or energy efficiency is and what is encompassed by these terms. For some, it is only about controlling costs linked to energy use, for others it is about raising awareness among their students, some apply a cross-cutting vision that includes factors such as improving insulation, reducing their CO2 footprint, installing photovoltaic panels, geothermal energy, among other examples of parameters. It is very clear when visiting the respective websites of the universities how they address this issue.

The previous point is also complemented by the fact that some universities already have their own energy efficiency management systems for their buildings, as well as energy saving plans, articulated through different axes and actions. Although it must be said that not all have the same level of progress, two universities stand out in Catalonia: the University of Vic - Central University of Catalonia (UVic-UCC) and the Universitat Pompeu Fabra (UPF). It is not necessary here to develop the different measures implemented by the two universities and how they differ, but only to mention that there is a great disparity in terms of parameters and actions between all the universities.

This factor can also be complemented by a strong management and/or political influence on what actions should be carried out by the respective universities. We have seen this clearly in the contact between universities for the preparation of training for university managers. In fact, the management of some universities delegate the information we have given them to employees lower down the university hierarchy, regardless of whether or not this person is competent in the matter in question. Similarly, others excuse themselves in their higher hierarchies to say that this information is not relevant to them or applicable to their buildings.

Finally, even in some cases, some universities do not simply have an energy manager or energy efficiency or sustainability specialist on their staff, but this function is carried out by maintenance staff or staff with cross-cutting functions within the universities.

Against this background, we have been guided by two principles: to try to raise awareness among the actors with whom we have the closest relations and to focus on a small number of actors. The strategy proposed by the project was certainly ambitious but difficult to achieve. This is not due to a lack of will on the part of SOLARTYS and the University of Seville, but rather to a lack of vision of the Spanish reality, since given the strong decentralisation of state organisation, each Autonomous Community may have policies that differ from the others, a fact that is reflected in the universities themselves.

3.3 Action Plan: including the planned measures, estimation of impact, investment needed and timeline

Two performances have been selected. The first contemplates the improvement of the quality of the envelope, which is the sum of a set of interventions (wall insulation, improvement of windows, improvement of thermal bridges, etc...). And the second, a non-intrusive improvement measure, is modifying air conditioning instructions. The information presented here has been extracted from A4.1 (A4.1.3 and A.4.1.4).

1.2.1 Improve of thermal envelope

Description

It consists of the installation of insulation in the walls, improvement of the qualities of the windows and the treatment of thermal bridges. The joint treatment in the form of improvement packages is proposed, with the installation of insulation being the key element.

In the case of walls, the measurement is usually not relevant to the cooling regime. On the contrary, it can be very effective in buildings with 1 or 2 floors on roofs and terraces.

In the case of roofs, the measure is of interest for buildings with 1 or 2 floors.

The reduction of the overall coefficient should only be a priority in enclosures that are in contact with occupied spaces in a sufficiently continuous way. In other words, it should be initially discarded for enclosures that make up corridors, toilets, elevator shafts, warehouses, etc.

The energy demand for transmission through walls and roofs is reduced proportionally to the decrease in its overall coefficient.

Implementation

The overall coefficient is reduced by incorporating rigid walls of insulation to the exterior or interior faces of the walls, or by filling any air chambers with polyurethane foam or granular insulation.

For roofs, the insulation (rigid walls or projected foams) is usually placed on the exterior surface, and it must be covered with tape (to avoid possible displacement by suction due to gusts of air) or passable pavement, depending on the use.

Limitations and other considerations

The type of material used as insulation for facades, roofs, and floors depends strongly on its place.

In exterior insulation, EPS or Mineral Wool materials should not be placed due to their degradation and loss of properties in humid environments, or they must be protected from the outside with some other element, such as the final finish of the enclosure.

PUR materials should not be placed inside insulators without internal protection with non-flammable materials since PURs emit toxic gases when burning.

It is necessary to foresee in solutions with rigid panels and air chamber the possible sagging of the panel, and/or sliding on the chamber, losing the continuity initially foreseen.

Other considerations

When choosing the position of the insulator, the following must be taken into account:

- On the outside faces, installation is reasonably easy in buildings with 1 or 2 floors. For buildings of higher heights increases the difficulty of access and therefore the cost.
- On the interior faces, the placement interrupts the building's normal operation, implies a loss of space, and forces the relocation of plugs or other elements (such as radiators) that were incorporated into said surfaces.

In all cases, protection against water and the incorporation of anti-vapor barriers must be guaranteed, taking special care with the finishes with doors and windows.

Regarding the thickness of the insulation, it should be remembered that the cost of the material is generally low compared to that of installation.

Improving the habitability and energy performance of a building rely primarily on upgrading the thermal behaviour of the building envelope. The proposed surface insulation solution aims to explore the cases where the wall and floor only can be insulated by the interior, on the other side it is assumed that external insulation can be applied on the roof. This work does not explore the possibility of filling wall air gaps with insulation to quantify the maximum expected impact of internal wall insulation on floor loss and property value. Along with the surface insulation strategies and windows improvement, the most common additional strategies identified in the reviewed studies for conceiving a high-performance building are the integration of solar shading systems (movable or fixed) and natural ventilation systems. A movable solar shading system is considered in the improvement packages, as well as a natural night cooling system that takes advantage of the outdoor air low temperatures during nighttime to cool the thermal mass of the building to reduce the cooling needs and the possibility of overheating events.

The surface insulation strategies explore the three most common insulation materials for interior applications (mineral wool, extruded polystyrene and expanded polystyrene) and a new insulation material (Polyisocyanurate Hydrofluoroolefin) with low thermal conductivity (0.018 $W/m^2{\cdot}K$). All internal insulation solutions consider a plasterboard panel suitable for interior retrofits with a low moisture accumulation capacity as a finishing layer. The improvement was defined by combining all levels of improvement. Nevertheless, only the improvement package that allowed the building to comply with the U-value requirements of the building code was considered for simulation.

Table 1 details the considered strategies and the respective cost of implementation and **Table 2** details de insulation material's properties and cost. The considered costs were obtained from national databases, price inquiries to manufacturers and installers, and real experiences of building renovation. Insulation material properties correspond to the average properties value found in the literature.

Table 1. Packages and levels of improvements and their costs.

Packages	Levels of improvements and costs
Surface Insulation	Roof: external (material cost in **Table 2** + 1.948 €/m^2) [(a) (b)] Floor: internal (material cost in **Table 2** + 2.380 €/m^2) [(a) (b)] Wall: internal (material cost in **Table 2** + 2.004 €/m^2 for MW and 5.00 €/m^2 for others) [(a) (b)]
Windows	Double glazing + PVC frame: U_{wind} = 2.60 W/m^2/K + $g_\perp$ = 0.78 (291.6 €/m^2) [(c)] U_{wind} = 2.00 W/m^2/K + $g_\perp$ = 0.65 (311.0 €/m^2) [(c)] U_{wind} = 1.80 W/m^2/K + $g_\perp$ = 0.61 (319.2 €/m^2) [(c)] Low emissivity double glazing + PVC frame: U_{wind} = 1.40 W/m^2/K + $g_\perp$ = 0.45 (340.0 €/m^2) [(c)] U_{wind} = 1.30 W/m^2/K + $g_\perp$ = 0.39 (346.5 €/m^2) [(c)] Low emissivity triple glazing + PVC frame: U_{wind} = 0.75 W/m^2/K + $g_\perp$ = 0.43 (662.4 €/m^2) [(c)] All windows have a c_{q100} of 3 m^3/(h·m^2) (class 4 of air permeability)
Night Ventilation System	ACH = 10 h^{-1} (8 €/m^2) [(d)] ACH = 15 h^{-1} (12 €/m^2) [(d)]
Solar Control of Southern Windows	Reflective shade (ρ=50%, 90€/m^2) [(c)] High reflective shade (ρ=70%,140€/m^2) [(c)]

[(a)] Insulation material thickness varies from 20mm to 200mm.
[(b)] Costs in euros per square meter of insulated surface.
[(c)] Costs in euros per square meter glazed surface.
[(d)] Costs in euros per square meter of usable floor.

Table 2. Properties of the most used building insulation materials.

Insulation Material	Density (kg/m^3)	Thermal Conductivity (W/m·K)	Specific Heat (J/kg·K)	Embodied Energy (kWh/m^3)	Embodied Emissions (kg CO_2/m^3)	Material Cost (€/m^3)
MW Mineral Wool	120.0	0.039	900	564.0	126.0	79.43
EPS Expanded Polystyrene	32.5	0.035	1 275	939.3	221.0	68.75
XPS Extruded Polystyrene	36.0	0.031	1 575	889.2	271.8	98.24

PIR HFO Polyisocyanurate Hydrofluoroolefin	37.5	0.018	1 400	727.5	206.3	315.01

Energy impact

The next figure presents the primary energy demand for each building model studied in its initial stage and with the new thermal envelope obtained by the cost-optimal method. This figure evidences the importance of renovating a building regardless of the possible architectural limitations. Also, is possible to see the most expressive demand reduction occur in single-family homes. This effect is justified by the significant improvement of buildings with lower compactness introduced by the latest version of the Spanish building code.

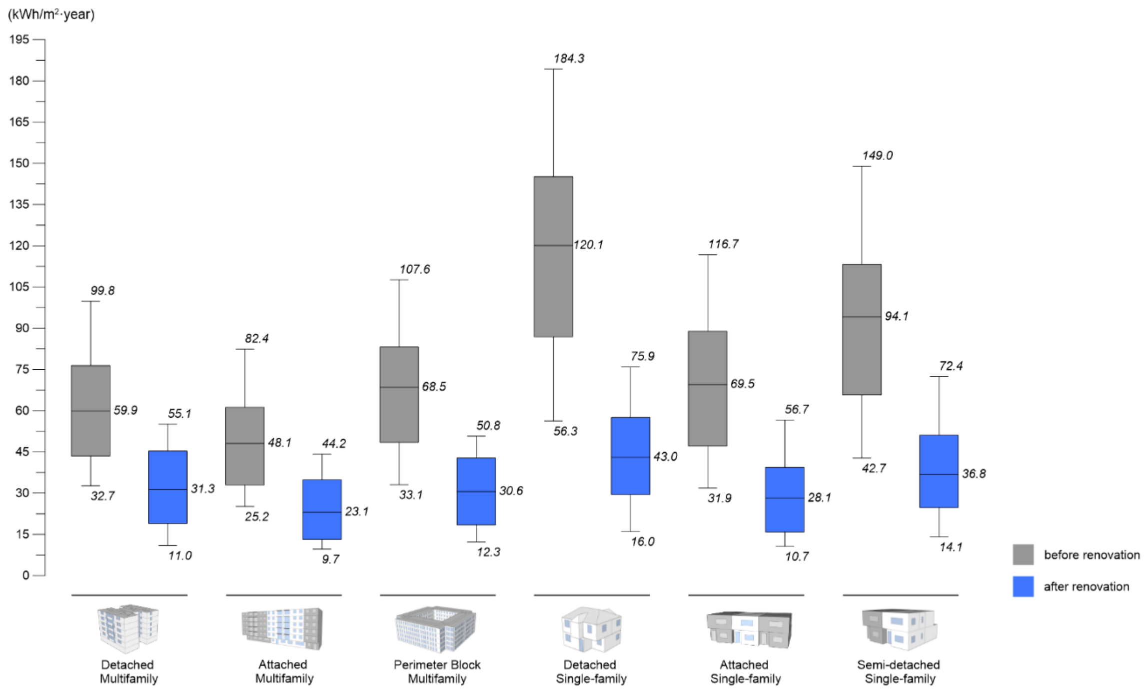

Figure 1. Total primary energy demand for each building model before and after renovation in Peninsular Spain.

On the other hand, multifamily buildings have a less expressive demand reduction due to their high level of compactness, which is also shown in Table 3. Table 3 provides the savings potential for each building typology and winter climate zone.

Table 3. Primary energy savings after renovation by building typology and winter climate zone: maximum, average and minimum value.

Primary Energy Savings (%)	Winter Climate Zone				
	A	B	C	D	E

Multifamily Buildings	min.	59.3	53.4	47.2	36.4	43.8
	avg.	65.1	59.3	53.7	44.4	49.3
	max.	70.0	66.0	59.6	51.8	54.3
Single-family Buildings	min.	64.7	59.0	57.6	52.3	51.3
	avg.	68.4	65.9	62.7	57.5	54.9
	max.	75.0	71.9	70.3	63.8	62.2

1.2.1 Optimizing setpoint temperatures

Description

Extending set-point temperatures in residential buildings has a significant impact on energy demand and thermal comfort. European governments have adopted this strategy to mitigate the energy crisis. Previous studies attempting to quantify energy savings by extending set-point temperatures were limited due to a lack of building stock characterization, poor climate representation, and the absence of uniformity in the reference set-point temperature. This study conducted a large-scale simulation that included six building models, 8034 locations in peninsular Spain, 9 Koppen-Geiger climates, and two construction periods, considering 20ºC and 25ºC as the reference heating and cooling set-point temperatures, respectively. The results show that reducing the heating set-point temperature by 1ºC can lead to an average demand reduction of 20%, while raising the cooling set-point temperature by 1ºC can lead to a 25% cooling demand reduction. The oldest building stock shows a higher absolute savings potential. Adjusting thermostats by 1ºC in Spanish homes during the winter season could represent a saved natural gas volume of 1.8 million normal cubic meters, nearly 40% of the gas demand of households in 2022.

Implementation

The reference indoor range temperature was defined as 20-25ºC, which corresponds to the definition of room temperature of ASHRAE standard. The minimum heating set-point considered was defined as 17ºC, considering the recommended lower limit by ASHRAE 55-2020 Standard. The maximum cooling set-point considered was defined as 30ºC. The two models of adaptive comfort suggest a value of 31.7ºC as the maximum acceptable indoor condition. For the authors, a value above 29ºC is too high in conditioned spaces. The value of 30ºC is studied to verify if extreme indoor conditions have comparable savings potential with the remaining cooling set-points temperature. Table 4 presents the studied set-point temperatures.

Table 4. Set-point temperatures (ºC) for heating and cooling systems.

Heating	**20**	19	18	17		
Cooling	**25**	26	27	28	29	30

A static set-point temperature was preferred since the adaptative model, at first, does not allow a quantification of the energy demand per each increment in the dead band, and secondly, assumes that all the thermostats can run a dynamic set-point or the occupants are available to change, at least, in a daily basis their set-point temperature.

The chosen set-point temperatures intents to overcome the lack of uniformity in defining a temperature set-point, as identified in the previous section and also in a recent building operator's survey.

Limitations and other considerations

The results point out that the same set-point temperature extension impacts differently on the demand savings potential due to the dependency on the climate and building envelope. Consequently, adjusting the set-point temperature to a building type and climate will ensure that each building will contribute equally to the implementation of the studied strategy. Although is not a novelty to define or adjust the set-point temperature to optimize the energy demand [30], the studies that explored the topic of extending the set-point temperature do not suggest or point to a recommended value to adopt for each building typology and climate zone. Therefore, considering a savings target of 20% and 25% for heating and cooling demand, respectively, for example, is possible to define a recommended value for residential buildings per climate zone (Table 5). The target corresponds to the average percentage savings potential by extending the set-point temperature to 1ºC.

Table 5. Set-point temperature value which reduces heating and cooling demand by at least 20% and 25%, respectively.

Set-point temperature (ºC)	Climate Zone											
	A3	A4	B3	B4	C1	C2	C3	C4	D1	D2	D3	E1
Heating	19.4	19.5	19.3	19.3	19.1	19.0	19.0	19.1	18.6	18.6	18.8	18.4
Cooling	26.0	26.1	26.0	26.2	-	26.0	26.1	26.3	-	25.9	26.1	-

Table 5 was obtained by interpolating the savings curve of each building model for every location, even so, the values per building typology presented a variation less than 0.1ºC thus an average of the obtained values is presented per climate zone. From this table is possible to settle that for peninsular Spain, during the heating season, should be required a set-point temperature of 19ºC to all residential buildings in climate zones from A to C and 18ºC for the remaining climate zones. On the other hand, during summer 26ºC could be defined as the minimum set-point temperature for all climate zones, excluding the climate zones without cooling needs.

Energy Impact

The savings potential of extending the set-point temperature is quantified for the Spanish reference buildings and is a value not neglectable, but which would be the expected savings for peninsular Spain? Table 6 gives an idea of the savings potential for Spain on thermal energy by setting 19ºC and 26ºC as the heating and cooling set-point temperatures, respectively. The presented values correspond to a weighted average, where was considered that the building stock age has a uniform distribution across the peninsula, 2% of the existing buildings can be represented by the reference buildings for the 2019 building code and assumed the remaining 98% can be represented by the 1979 reference buildings. Also, was considered the floor area for each residential building type per climate zone, obtained through the statistics for the existing floor area per building type and following the methodology proposed by the Spanish Directorate for Architecture, Housing and Planning.

Table 6. Potential energy savings by extending to 1ºC the heating and the cooling set-point temperature in Spain.

Building Type	Floor Area (m^2)	Avg. Savings 1979-2019 (GWh/year)	
		Heating	Cooling
Detached and Attached Multifamily Buildings	645 476 343	4.4	1.4
Perimeter Block Multifamily Buildings	1 240 064 508	9.5	2.9
Detached and Semi-detached Single-family Buildings	455 098 519	5.4	1.7
Attached Single-family Buildings	794 588 763	6.7	2.4
TOTAL	3 135 228 134	26.0	8.4

In a scenario where all Spanish residential buildings are conditioned, moving in 1ºC the thermostat of the conditioning system could lead to savings of up to 26.0 GWh/year in thermal energy for heating and 8.4 GWh/year for cooling at the peninsular level. Nevertheless, is hard to explain to non-experts what can be understood by thermal energy and the magnitude of this strategy in Spain. To have an idea of what can be expected of introducing this strategy in the Spanish residential sector highly promoted by the European Commission, Figure. Annual potential natural gas savings per heating technology for extending by 1ºC the heating set-point temperature in Spain. The next figure presents an estimation of saved natural gas volume during the winter season and a comparison with the total natural gas demand for Spanish households and small and medium-sized enterprises (SMEs) in 2022 (52.3 TWh).

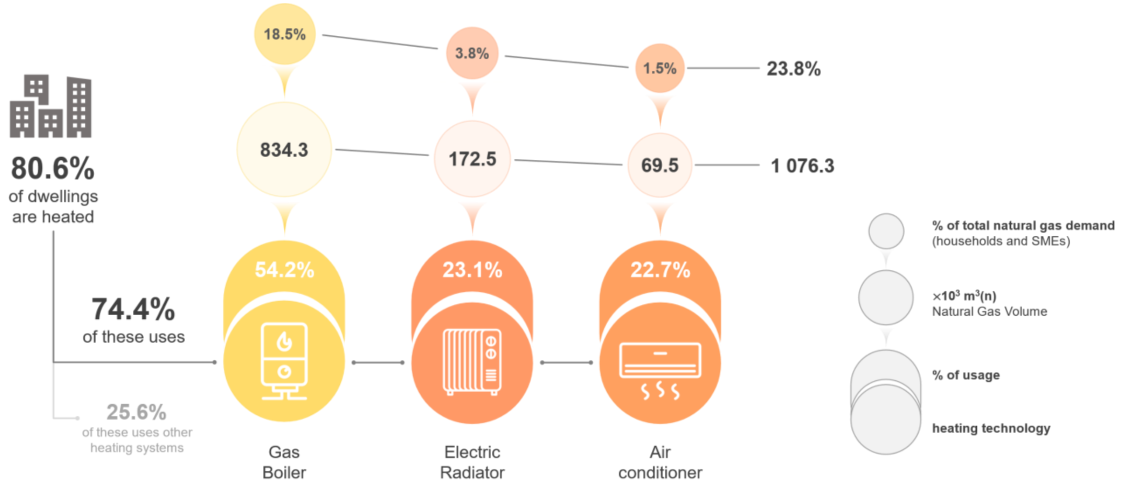

Figure. Annual potential natural gas savings per heating technology for extending by 1ºC the heating set-point temperature in Spain. Savings expressed in a normal cubic meter and percentage of total natural gas demand for households and SMEs in 2022.

According to the latest survey of housing characteristics by the Spanish Statistical Office, only 80.6% of dwellings are equipped with a heating system and 74.4% of these use a heating system based on natural gas or electricity, i.e., 60.0% of dwellings. 25.6% of the heated dwellings use oil, derivates or other fuels (biomass, coal, etc.), being excluded from the analysis of quantifying a fuel savings potential due to their irrelevance on the natural gas dependency. However, according to Building Technical Code Standard DB-HE0 [40], the Spanish dwellings are conditioned usually using three heating technologies, being these a gas boiler (η=0.92), an electric radiator (η=1.00) and an air-conditioner (split unit, COP=2.90), where the usage percentage of these heating systems was extracted from the housing characteristics survey. Considering the pointed value of gross savings of peninsular building stock in Table 6 is assumable that the gross savings will correspond proportionally to the floor area of dwellings with a heating system based on natural gas or electricity, i.e., 15.6 GWh/year on gross savings in heating demand based on electricity or natural gas.

The figure before objective is to point out the expected impact of changing the thermostats of our homes by 1ºC, where is highlighted the 1 076.3 thousand normal cubic meters of natural gas that could be saved. This value represents 23.8% of the total natural gas demand of households and SMEs in peninsular Spain in 2022. Hypothetically, if considering the same usage percentage of the typical heating systems and all Spanish dwellings use one of them, the natural gas saving could reach up to 1.8million normal cubic meters representing almost 40% of the gas demand of households in 2022. However, quantifying with an accurate number is difficult due to the diversity of heating systems, their efficiency, and the possibility of having more than one heating system in a dwelling. Also, predicting the occupant's behaviour is a hard task, especially in dwellings where the decision of turning on the heating system relies on economic factors as well as the thermal comfort perceived by each occupant. This overview does not consider the impact of the income rate of each household or the perceived thermal comfort of the occupants in each building and climate zone on the decision of not conditioning or conditioning the dwelling.

IV. LETTERS OF COMMITMENT

As a remarkable result, the commitment of the director of the Department of Energy Engineering of the University of Seville has been achieved. The director undertakes to use the results of the Med-EcoSuRe project to the extent that the University of Seville needs advice for the energy renovation of its buildings.

In addition to the above, the candidate for director of infrastructure for the new government of the University of Cadiz, Alberto Cerezo Narváez, is committed to ensuring that the energy renovation strategy of the buildings of the University of Cadiz is carried out following the principles resulting from Med-EcoSuRe.

See the attached letters signed by both.