Low-carbon retrofits in social housing: Energy efficiency, multidimensional energy poverty, and domestic comfort strategies in southern Europe

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1. Introduction

Housing accounts for approximately 25% of all energy consumption in Europe [1], and is therefore an important target for low-carbon transitions. In this field, social housing offers unique opportunities to address both energy efficiency and social inclusion, through potential economies of scale and the reduction of social and financial costs for residents [2]. However, a whole series of economic, technical, legislative, social and organizational barriers makes the social housing stock resistant to change [3].

These barriers are salient in Spain and Portugal, due to the particular configurations of energy poverty drivers in the social housing stock and beyond. Firstly, much of the social housing stock is obsolete in energy terms, and the socio-economic profiles of the residents, with precarious households predominating, differ from those in northern European countries [4]. Secondly, the deep impacts of the 2008 socio-economic crisis have made large segments of the population more vulnerable to the important increase of gas and electricity prices [5]. Thirdly, mild winters have contributed to the invisibilisation of the problem, which has been largely overlooked by decision-makers until the end of the 2010 decade [6,7]. In these Spanish and Portuguese contexts, retrofitting policies based on standardized user patterns have drawn criticism from architectural and engineering teams supporting pilot projects [8–10]. While limitations with regard to the energy savings achieved by upgrading buildings have been well documented as resulting from a rebound effect [11,12], these southern Europe assessments record the ubiquity of a "prebound effect" [13], whereby residents consume less energy than the projections of the standardised patterns, thus invalidating energy efficiency gains and reductions in CO_2 emissions as well as the economic models relying on selling renewable energy to low-income residents. This difference between theoretical models and a low actual consumption can be attributed in part to the overestimation of domestic consumptions in the calculation methodology used for the buildings energy performance certification [14], and in part to the widespread nature of energy deprivation situations in southern Europe [15]. These situations, known as energy poverty, occur when households living in energy-inefficient homes are unable to afford adequate indoor thermal conditions. Conceptual developments about these conditions have widened the scope beyond an initial focus on thermal comfort to include a much broader range of daily services requiring energy, such as cooking or domestic hot water (DHW). These developments have conceptualised an inability to attain a socially and materially necessary level of such domestic energy services, emphasising the driving forces of energy deprivation and the multidimensional nature of these energy services [16–18].

This paper takes this widened notion of energy poverty as a starting point to characterise registered social housing providers (RPs) in the southern European contexts of Spain and Portugal as stakeholders at the nexus between contradictory missions when conducting retrofits of the built estate. European, national and municipal expectations for RPs are set on energy efficiency gains, but this ambition is hindered by the socio-economic and material reality of a low-consumption social housing estate. This contradiction adds to the primary missions of RPs, which are to secure housing affordability and tackle social exclusion issues. We argue that RPs follow a sociotechnical approach to the built environment that considers energy poverty as a central and unchangeable plight for their tenants, a choice leading to widespread adoption of retrofitting policy designs aiming for passive thermal comfort.

This paper also reflects these policy choices through a survey on the energy poverty situations experienced in broadly defined Portuguese and Spanish social housing, taking into account different forms of housing accommodating low-income households and including housing owned by private citizens whose inhabitants are facing severe energy poverty. The nature of these hidden domestic situations is receiving growing attention in southern Europe contexts, with a steady production of indicators showing the somewhat counter-intuitive prevalence of energy poverty in Spain and Portugal [19–21,15,22], albeit with fewer empirical academic studies [23,24,5] than policy reports from civil society organisations [25–28]. We argue that bringing an empirical focus to Spanish and Portuguese energy poverty situations will contribute to a better understanding of the challenges and limits of RP policies.

We begin with a brief background on energy efficiency in the built environment and in social housing in Spain and Portugal. Then the methodology for empirical data collection on RPs and low-income households is described, followed by a results section divided into three main findings on RP policies, on the situations of energy poverty and on the limits of RP incursions into the domestic spaces of households. The paper concludes with some reflexions on the findings and their policy implications, followed by suggestions for future studies.

2. Understanding the context of energy poverty in the social housing estates

This section provides contextual elements on the energy efficiency, consumption profiles and energy poverty issues and policies in Spain and Portugal, before addressing the lessons from the pilot retrofitting projects with strong energy efficiency components that have been conducted in social housing estates.

2.1 Three challenges for social housing providers

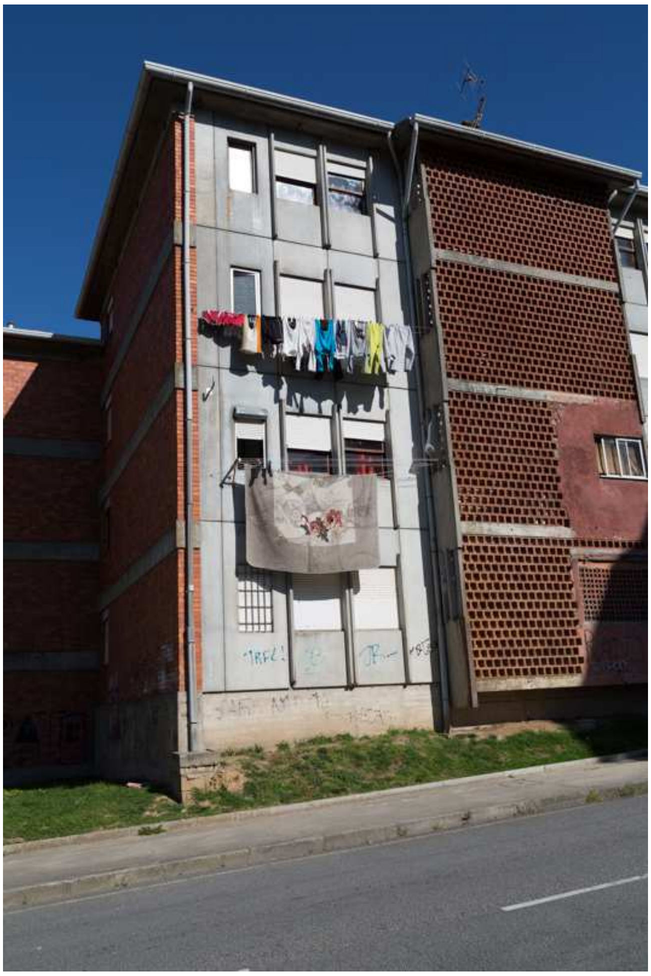
Southern Europe contexts raise three significant challenges for energy efficiency retrofits. One of them is the socio-economic profile of social housing residents, a largely homogeneous population dominated by low-income and vulnerable households. This phenomenon is the result of the constant promotion of private ownership in national strategies, which has concentrated precarious households in social housing [29]. Social housing estates represent a small fraction of the total value of national housing, 5% in Portugal and 2,8% in Spain [30], and mostly accommodate low-income residents, whereas larger estates in northern European states accommodate other social groups [4]. While rent levels differ between the two contexts[1], in both cases these rents exclude utility costs, which are borne by the residents of social housing.

A second challenge is the low energy efficiency of existing buildings. In Spain and Portugal, 70% of the housing stock was built before the first regulations were issued to establish limitations on energy demand in buildings in Spain [31] and in Portugal [32]. Much of this stock, therefore, is not equipped with thermal insulation [33,34], central heating or space cooling, with biomass and electricity providing the majority of final energy [35]. These issues are particularly salient in social housing estates, where most large projects were built

[1] The Spanish social housing estate is covered by the "Official protection of housing" scheme, whereby subsidies are defined at the national scale and based on a Family Income Indicator. In Portugal, local authorities may adopt their own regulations according to social realities.

from the 1940s to the 1980s, with no district heating[2] and little incentive for retrofits until the 2010 decade when national priorities shifted from new constructions to retrofitting buildings [38,39]. Social housing estates combine these energy characteristics with pathologies specific to the massive use of concrete as the primary construction material [40,41], as shown in Figure 1, a photo taken in the Lagarteiro neighbourhood of Porto. Built between 1973 and 1979 to relocate households from the dilapidated city centre, this ensemble of social housing blocks has reached the highest levels of socio-economic deprivation indicators in the Porto agglomeration [42]. The concrete walls are in direct contact with the exterior and exposed to wind and rain, allowing humidity to penetrate the walls and causing pathologies aggravated by the appearance of thermal bridges between panels and the building's structure. The windows have no insulation and their frames are degraded, as are the laundry rooms protected by the red bricks on the right of the photograph.

Figure 1 – a social housing block in the Lagarteiro neighbourhood, before retrofitting



This second efficiency challenge is exacerbated by the discrepancies between energy certification procedures modelled on northern European contexts and real consumption profiles in the Iberian peninsula. Numerous studies demonstrate that certificates are built upon full occupation schedules and full climatization projections that are disconnected from local contexts [43]: deviations up to 90% between real and simulated consumption

[2] The diffusion of district heating is recent and limited in Spain [36] and absent in Portugal, where its potential has been deemed null by central administration services [37].

have been measured in Portugal, strengthening the argument of a "performance gap" distorting energy efficiency gains expectations in the design of retrofitting policies [44,45]. These observations do not contradict the widespread low efficiency levels of Portuguese and Spanish residential buildings. Rather, they point to the challenges of designing retrofitting policies in contexts where consumption profiles deviate substantially from certification standards, with low final energy consumption figures compared to the EU average[3]. They reflect specific structures in the domestic sector energy consumption, where electricity is the dominant domestic fuel, and where heating takes a lower share of energy consumption than in EU averages (See Annex 1) [47,48]. Furthermore, when compared with southern European countries, Spain and Portugal exhibit similar low levels of air conditioning, which can be justified by lower incomes, cultural habits and larger use of alternative passive measures [43].

Thirdly, the combination of poverty, low efficiency standards and low consumption practices create the conditions for pervasive and difficult to measure energy poverty situations, which represent an additional challenge for social housing providers. The prevalence of this problem in Spain and Portugal has already been documented in various policy reports based on Europe-wide surveys on income and living conditions [25–27,46,49,50], and the correlation between thermal discomfort and socio-economic conditions has been made with *in situ* measurements in case studies [51–53]. Nationwide surveys have shown how the margins of tolerance in low-income households regarding thermal comfort are higher, with heating and cooling systems either absent or unused, and households where it is "usual to forgo comfort and live in energy poverty conditions" [54,8], to the point that modelled energy costs appear as better indicators of energy poverty than actual bills [50]. In these contexts, the distinction between cultural and socio-economic explanations are somewhat blurred, with policy reports describing as "cultural habits" practices such as ventilating and changing clothes to adapt to temperature changes [35,55], when these practices could also be described as the product of deeply entrenched energy poverty.

2.2 Design of retrofitting policies in Iberian social estates and lessons from pilot projects

In spite of these challenges, RPs have the potential to achieve large-scale results because their housing stocks are typically co-located in large building complexes, known as "polígonos" in Spain and "bairros sociais" in Portugal, and managed by a small number of stakeholders. Because of this potential, national and local government players have targeted social housing sites to achieve decarbonisation targets through efficiency measures. European legislation acts as a strong incentive, from the EPBD setting minimum energy efficiency requirements for major residential retrofitting projects and translated into the Spanish [56] and Portuguese codes [57], to implementation of the nZEB norm for social housing [58]. The shift in national priorities towards retrofitting buildings in the 2020s also encompasses social housing. Portuguese governments have devised a national renovation strategy [59] based on a series of national funds and financial schemes to retrofit municipally-owned residential buildings, in coordination with the Norte 2020 European Regional Operational Program (ROP)[4]. In Spain, social housing was included in the long-

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[3] The final energy consumption averages 324 kgoe/capita in Spain and 254 kgoe/capita in Portugal, well under the EU average of 558 kgoe/capita [46].

[4] Portugal has five national funds for social housing: a social housing rehabilitation programme [60], the PROHABITA (national financing program for access to housing [61], a special rehousing programme [62] and two funds for larger rehabilitation ambitions, the Reabilitar para arrendar or "retrofit to lend"

term strategy for energy retrofits in the housing sector [38,39] with ambitious targets [68]. This policy shift also mirrors the emergence of energy poverty as a new public problem [69]. Both countries have elaborated national strategies of energy poverty mitigation, providing national definitions for vulnerable consumers and targeting both energy prices and energy retrofits, with interventions in social housing appearing as an important item in the Portuguese policy[5] [6,7].

These incentives have brought an increase in the production of policy reports and academic literature documenting the results of a decade of pilot projects with strong energy efficiency components conducted in social housing estates in Spain and Portugal. These assessments are unanimous in documenting the prevalence of a "prebound effect", which is the opposite of the "rebound effect" whereby energy efficiency improvements increase energy consumption. The prebound effect causes households to consume less energy than in the theoretical models predicting the outcomes of retrofitting projects [13]. These studies observe households in social housing who are living in thermal discomfort "100% of the time in winter", both in Spain [8] and in northern Portugal [10]. The specificity of Spain and Portugal has been further highlighted by a comparative assessment of energy retrofits conducted in social housing estates at the European scale as part of an EU Interreg programme [70]. Energy consumption in these case studies was very low, with social housing providers struggling to adapt the energy-efficiency goals of the EPBD directive to the "socio-climatic reality" of their social housing estates [9,55].

To adapt retrofitting policies to these contexts, pilot project evaluations establish a set of lessons for RPs. First, they recommend "passive" instead of "active" strategies, with "passive" solutions including "envelope treatment, thermal control, solar gain protection and night-time natural ventilation" [71,72] and "active" solutions describing renewable energy-producing installations such as solar thermal and solar PV [10,73]. They also advocate the monitoring of actual consumption, before and after retrofits, and the inclusion of this monitoring into financial incentive schemes [74], in order to analyse patterns of consumption and habits [9]. Thirdly, they recommend working and engaging with residents to understand their patterns of consumption [3], before advocating changes in energy efficiency standards for retrofits in southern European social housing [9].

We investigated how Spanish and Portuguese RPs respond to these many challenges when implementing energy-efficiency retrofits. Low consumption levels in social housing can jeopardise the implementation of energy-saving measures: upfront costs are high as residents are seldom creditworthy, and there is little return on investments in either insulation or renewable energy equipment. Given the absence of economic incentives, this paper is interested in the pull exerted by other motivations for RPs, and how they balance against metric-based expectations on energy efficiency set by local, national and European authorities, both in the management of pilot projects and in the translation of their inputs into measures adapted to the bulk of the social housing estate.

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programme [63] and financial schemes for retrofitting projects [64,65]. A new generation of housing policies was adopted in a 2018 legislative package to establish retrofits as a national imperative [66]. The PRBS, the PROHABITA and the IFFRU combine national funds with European funds from the Portugal 2020 scheme [67]

[5] In the Portuguese "long term national strategy to fight energy poverty" , social housing estates appears as one of the seven areas of intervention in the "energy efficiency" priority, with housing policies receiving 1,2 billion euros from the National Resiliency Program dedicated to "rebuild" the country after the economic and sanitary crises [6].

3. Methodology

To understand the agency and capacity of RPs in addressing the prebound effect in southern European social housing, two urban case studies were chosen, in Spain [ES] and Portugal [PT]. Porto [PT] and Barcelona [ES] have similar local climates, with hot summers and mild winters, and a large and ageing social housing estate under similar management. In the Metropolitan Area of Porto and the Metropolitan Area of Barcelona, most social housing is managed by local authorities, with a municipal social landlord in each case. There is also a national landlord in Portugal and a regional social housing agency in Catalonia, the latter coordinating its strategies with the municipal landlords through a consortium. There are currently 30 000 units under this scheme in Barcelona (1% of total housing in the metropolitan area) and 17 500 units in Porto (14%). In Barcelona, this public housing deficit has motivated municipal schemes aimed at capturing vacant privately-owned apartments in order to rent them at subsidised prices.

Local authorities in both contexts received strong incentives to tackle energy poverty during the 2010 decade. Reinforcing the shift from new constructions to retrofits at the national scale, the regional and municipal authorities in the metropolitan areas have set energy efficiency targets for social housing. In the Porto region [PT], the commission in charge of coordinating local development has played an influential role in securing funding for social housing retrofits from the European ROP fund [70], while municipal authorities have adopted ambitious renewable energy targets for the social housing estate in the Porto Action Plan for energy efficiency [75]. In the Barcelona region [ES], regional and municipal plans for an energy transition [76–78] have pointed to social housing as a potential target for energy retrofits, installing PV panels and promoting local production and consumption. Moreover, energy poverty became a public issue for the Barcelona local authorities at the end of the 2010 decade, thanks to a strong social movement and a politicized municipal government [5]. The Barcelona Climate Plan for 2030 places the fight against energy poverty as a central objective, an imperative that translates into the creation of a new municipal utility company [79] and local offices staffed by social workers responsible for helping households in energy poverty situations [78].

In both case studies, two methodological approaches were applied in parallel. One was based on 13 semi-directive interviews with RPs and low-carbon policymakers between January 2015 and June 2018. The interviewees were five RPs (RP1 to RP5), five architects and project managers charged with designing and evaluating retrofit projects (AR1 to AR5), two heads of missions in local NGOs conducting retrofits in social housing and the head of the Barcelona energy agency. The institutions were selected according to a preliminary survey of organizations having delivered notable retrofit schemes or completed other significant energy-related retrofits in their housing stock and among tenants. The interviews were conducted in person and audio-recorded. The audio recordings were transcribed, and quotes from the interviews were anonymised.

The second approach aimed to shed light on the socio-climatic realities underlying RP retrofitting strategies by gathering quantitative and qualitative information on low-income residents in Porto and Barcelona. Contact with interview partners was established through two NGOs. In Porto, the partner NGO provided food to low-income households and shared the individual datasheets for the 246 households they supported, comprising income and energy bills for January and February 2015. In Barcelona, the partner NGO was created to implement a pilot scheme designed to expand social housing into the private rental sector[6]. For 100 of these households, individual datasheets comprising income and energy bills covering the years 2015-2016 were collected, along with the energy certificates for each apartment, and a questionnaire on thermal discomfort was applied. Further data were collected through qualitative interviews with ten Spanish households and eight households in Porto, using an open interview guide supplemented by the individual NGO protocols for eliciting socio-demographic data. The interviews were conducted during the spring of 2015 in Porto and the spring of 2016 in Barcelona. All interviews were transcribed and analysed with a qualitative data analysis software. The socio-economic profiles giving further characteristics of the households in the survey are shown in Table 1.

Table 1 - socio-economic profile of surveyed households

	Composition of households	**Monthly household income compared to the national at-risk of poverty thresholds for single households [80]**
Porto	One person: 63	Above 515€: 44
	Two people: 73	257-515€: 109
	Three and more people: 109	Up to 257€: 87
Barcelona	One person: 3	Above to 767€: 23
	Two people: 19	383-767€: 63
	Three and more people: 81	Up to 383€: 13

This approach covers three types of social housing, all built before the adoption and application of national energy efficiency norms for residential buildings. Half of the quantitative information gathered in Porto corresponds to households living in collective buildings managed by RPs, while the other half corresponds to *de facto* social housing. According to the NGO's social workers, most of these households live in Porto's "ilhas", small degraded urban ensembles built in the 19th century to accommodate factory workers that are rented at well below Porto's market prices [81]. In Barcelona, a third type of social housing is concerned, consisting of refurbished privately-owned apartments that are managed as part of the Catalan registered social housing estate, hence rented to low-income households at a subsidised rate. Their construction periods range from the 1940s to the 1980s and energy efficiency standards are low [7].

[6] With funds from the Barcelona City Council and support from the Catalan entity federating social welfare NGOs, vacant and deteriorated apartments are refurbished and rented to low-income households that the social housing estate cannot accommodate. Under this scheme, private owners renounce rental payments in exchange for up-front payments for retrofits over a period corresponding to the repayment of the cost of the repair work.

[7] Under the CTE code [56], an apartment in Barcelona's climatic zone should consume 80kWh/m^2/year. Based on the energy certificates calculating theoretical energy consumption based on the buildings characteristics and equipments, only 10 of the 100 apartments comply with this standard and most have theoretical consumptions ranging from 100 to 270kWh/m^2/year, which do not correspond to real energy consumption. .

4. RP strategies and the challenges of energy poverty in social housing

On the following pages, the three main results of the paper will be described, linking RP strategies for implementing energy efficiency measures in registered social housing with the energy poverty situations observed in low-income households in broadly defined Portuguese and Spanish social housing.

4.1 Passive comfort as a new retrofitting strategy for RPs

All of the RPs expressed normative aims of providing thermal comfort for social housing residents. They recognised that it is their responsibility to ensure that vulnerable people are protected from extreme summer and winter temperatures. RP1 summarized this approach as follows: "we decided that, if nothing else, we would bring thermal comfort to these families". This choice, formulated here as a compromise due to the prevalence of energy poverty situations, is the result of a learning process common to both Spanish and Portuguese RPs.

This responsibility is recent, as thermal comfort and the management of energy poverty was not part of RP missions until 2010. As stated by RP1 in Portugal: "retrofitting has largely been empirical, the experience was new, in the early 2000s we mostly painted façades, and energy questions only appeared at the end of that decade". This statement on energy poverty is mirrored by RP5 in Catalonia: "we were receiving a lot of complaints, people saying that they were paying too much for energy, our technicians finding illegal connexions to the grid, but it took [the pilot retrofit project] for us to really understand the depth of the problem".

These energy poverty situations came to light through the use of metrics during the implementation of pilot projects designed to increase energy efficiency and meet European, national and municipal imperatives. Situations previously hidden in the domestic space, known to but not tackled by RPs, became visible, as temperature, hygrometry and CO_2 concentration levels were measured over monthly and yearly periods. As stated by a Catalan architect in 2016 (AR1): "when we started the retrofit project five years ago and started talking about energy poverty, the social housing provider did not understand what we were talking about. First, we monitored thermal comfort, with spectacular results. Residents only turned up the heat when the temperature dropped to 14°C, and there were apartments with 9°C during the whole winter. And yet, for 70% of the households, the percentage of energy expenditure in their income was more than twice the national average". This observation echoes the discourse of all five RPs following pilot projects, summarised by RP5 as: "we had an idea of what was *fuel poverty* [*sic* and pronounced as such in English], we knew about the context… but when we saw it, it was frightening… and we learned that in the UK they had been working on it for years".

Along with measuring thermal discomfort, the pilot projects highlighted the underuse of domestic hot water (DHW), thus invalidating energy efficiency gains to be achieved by equipping social housing buildings with renewable energy equipment. For the Barcelona RP2 : "in 2009, we were planning and building new social housing apartments with energy-producing installations: solar thermal and PV panels and even a district heating and cooling network[8]. We wanted to create comfort at a cheaper price for our users. But when the first installations were completed, the residents had very little use for them and we had lots of

[8] This pilot project was part of the 22@ neighbourhood, a showcase for municipal involvement in energy efficiency in the 2000s [82]. This vast urban renewal project included the construction of a 53-apartment block dedicated to social housing.

issues with their maintenance. The obvious fact was that this kind of energy efficiency was not suited to their needs". The same conclusions were drawn from the failure of the Porto [PT] energy efficiency action plan to attract private investors. None of the 50 000m^2 of solar thermal panels planned for 2020 [75] have been financed by the initial public-private financing scheme due to the lack of investment returns. The exception is the installation of solar thermal panels for DWH on a social housing block that was entirely financed by public funds, for which maintenance remains a liability as stated by RP1: "in this case, we do not have to expect returns on investments and tenants will not have to pay for DHW, but problems will arise when we have to repair the pipes, the heaters, the tanks: we are no specialists and have few financial resources for this".

Faced with the reality of the lack of investment returns, there is little financial incentive for RPs to invest in low-carbon retrofitting activities, either for the RPs themselves because utility bills are paid by residents, or for residents who consume little energy for their domestic daily activities. The same observation can be made for CO_2 emissions reduction targets. For RPs charged with achieving climate change mitigation targets under European, national and municipal policies, this impasse is summarised by the Portuguese partner of the EU-funded Social Green project [73], AR4: "energy retrofits only translate into a theoretical reduction in consumption, and in these conditions, choosing energy consumption reduction as a criterion for evaluating projects and expecting returns on investments for energy-producing installations is ill-advised".

Instead, the retrofitting strategies devised by the Porto and Barcelona RPs are based on a redefinition of the priorities to focus instead on measures that have no maintenance costs for the large bulk of the built estate. The term used to describe these measures is "passive", which encompasses the thermal control, ventilation and insulation interventions on the built envelopes that have grown into a new internal policy for RPs. The chosen indicators have also been adapted to shift the imperatives from reducing consumption to achieving internal temperature targets in the social housing apartments without operating heating or cooling systems. As stated by RP5 in Catalonia: "we chose to secure an internal temperature of 17°C or 18°C to avoid respiratory problems, because we have accepted that they will never turn on their heating systems, regardless of how efficient we choose them". This focus on domestic temperatures is theorised by a chief architect in Porto (AR2) as follows: "what is important is to calculate and mitigate passive discomfort: how buildings behave when they are not heated or cooled". This is translated as follows by the corresponding RP1: "if we manage to raise winter temperatures from 14°C to 16°C in the retrofitted buildings, this will already be a success as residents will have more comfort". For RP3 in Catalonia, this choice amounts to a profound "paradigm shift" in RP goals and practices, as the conclusions reached by pilot projects are deemed to be applicable to the majority of the social housing estate. We summarised this change in the following table, distinguishing between what RPs see as an "efficiency" paradigm and a "comfort" paradigm and the implications in terms of objectives and technologies. However, this shift still accommodates energy-producing equipment when additional funds are available, in the form of European funding schemes or public-private partnerships made possible by the inclusion of private real-estate operations in the retrofitting projects[9].

[9] This is for example the case in Porto, where the retrofitting of the Rainha D Leonor social neighbourhood in 2019 included the sale on the private market of one third of the retrofitted apartments.

Table 2 – Efficiency and comfort paradigms in RPs' retrofitting strategies

	Efficiency paradigm	**Comfort paradigm**
Objectives	Reach emission reductions objectives measured in CO_2	Secure a minimum temperature in winter and a maximum temperature in summer with little or no use of heating or cooling systems
Technologies	All systems producing energy for social housing tenants: solar thermal and photovoltaic panels as well as heating and cooling systems	Install or improve existing insulation and ventilation of built envelopes, reduce thermal bridges

4.2 The multidimensional presence of energy poverty in social housing

The RPs' choice of a passive approach follows the recommendations given in the literature and project analyses accompanying the Spanish and Portuguese pilot projects. However, other suggestions made in this literature regarding monitoring and understanding consumption practices, in line with a wider understanding of energy poverty than thermal comfort alone [16], are not as closely followed. The results of the surveys on low-income households in Porto and Barcelona reiterate the scientific evidence that energy deprivation situations are multidimensional, adding empirical observations on an under-studied southern European context, but their main contribution is to explore the discrepancies between these conditions and RP policies. Three main findings can be drawn from this research, lead in coherence with the literature striving to measure energy poverty in different contexts of the EU though three main methods of measurement [83].

First, the results of a direct measurement method have shed light on the discrepancies between the level of energy services and a set standard. Indeed, the households surveyed have low consumption levels when compared to national averages. In Barcelona where the partner NGO gave us access to monthly electricity bills over two years, the annual consumption per household was 2100kWh/year, well under the 3 490kWh/year national average measured by the 2011 survey on Spanish residential sector consumption [84]. Furthermore, the results emphasise the discrepancy between actual energy consumption of the households surveyed including all end uses (92kWh/m^2/year) and the theoretical levels established by the building's energy certificates if the households were only to attain WHO standards of thermal comfort and DHW use (182kWh/m^2/year), omitting other end uses such as washing machines and refrigerators.

Second, a consensual approach based on self-reported assessments has shown that these low consumption figures are the result of austere domestic practices. Indeed, domestic temperatures in the homes are constantly controlled, with a focus on areas where heat is deemed more important, such as children's rooms. As stated by RES1: "All my life I have been careful with bills. I have a small electric heater and that's all. If it is very cold, I turn it on, and I move it around to save on the bills, I put it in my son's room before he goes to bed, and then in my room for an hour". This monitoring is not limited to electricity use, as in the experience of RES2 "we installed a butane heater, but only in the kid's room, or in the living room when he's with us". This behaviour is mirrored by the results of secondary indicators covering thermal comfort: in Barcelona, where a survey was designed to answer the research questions, households declared feeling too hot or too cold in higher percentages than the mean national values measured in the 2016 EU-SILC [80]. 40% feel uncomfortably cold during the winter (well over the 10% national mean) and 40% uncomfortably hot in the summer (also over the 20% mean). This discomfort could be enhanced by the impacts of climate change on this Mediterranean city, as only 20 out of the 40 households equipped with air conditioning declared not turning it on during the warmer months.

This meticulous monitoring goes well beyond heating needs to encompass water heating, lighting and cooking needs, which are not taken into account by the passive strategy adopted by RPs. For these needs, energy vectors are often described as having an influence on how appliances are used: domestic electricity in Spain and Portugal is more expensive than natural gas, and as such is more rationed. RES2 described her fear of using the electric boiler for DHW: "to wash the dishes, I try to use as little hot water as possible, when I give my children a bath, I use the water several times, including for me. Before the crisis, when we were living in an apartment connected to the gas network, where we would each have our own bath, but now with an income of 300€, it has become very difficult". For RES5 in Porto: "I needed a dehumidifier to absorb humidity, but I couldn't install one, because it consumes a lot of electricity, it's easy for them [RPs] to advise us residents to compensate for damp homes, but it costs 100€ upfront plus the electricity it uses". Cooking practices are also closely monitored, as stated by RES3 "I am afraid because of the oven. There is no gas network in this apartment, and as I use the oven to bake cakes that I sell, every time I receive a bill, I get scared. Even 60€, it seizes us by the throat". A strategy adopted by households interviewed is to rely on gas bottles, which allow them to keep track of the expenses, as for RES4: "a bottle of butane costs 14€ and it lasts a month, I can cook large pots of soup, whereas the last electricity bills have scared me. The only problem is to buy them at the petrol station and bring them up to the apartment, door-to-door salesmen sell them for 18€". In all the households interviewed, this constant monitoring has a strong gendered component, as women appear to bear the responsibility of keeping track of domestic expenses and negotiating between family needs. This result echoes wider surveys on day-to-day coping strategies in households experiencing energy poverty in Catalonia [85].

A third dimension of energy poverty can be approached through an expenditure method, confronting the surveys' results with absolute and relative thresholds. In Porto and Barcelona, we measured three primary indicators, the high share of energy expenditure in income (2M), the low absolute energy expenditure designed to identify households dangerously underconsuming energy (M/2) and the arrears on utility bills due to financial difficulties[10]. These indicators draw a portrait of a low-income population heavily affected by rising energy prices, with the majority of households positive on at least one indicator of energy poverty. The 2M indicator represented in Figure 2 reaches 57% in the Barcelona case study and 71% in the Porto households. Both figures are well above the national

[10] The 2M indicator is the proportion of households whose share of energy expenditure to income is twice the national median share. This median share has been measured for Spain by the Spanish NGO ACA, estimating the mean share as 4,9% of energy expenditure to income [49]. This methodology was replicated by Desvallées [69] for the Portuguese income/expenditure survey [86] and resulted in a similar figure: the Portuguese median threshold is also 4.9% of energy expenditure to income. The M/2 is the low absolute energy expenditure indicator, presenting the share of households whose absolute energy expenditure is below half the national median expenditure. Similary, this indicator has been measured for Spain by the NGO ACA and replicated by Desvallées in Portugal. In both countries, the national median expenditure for domestic energy is 48€ per month and per household setting the threshold for energy poverty under 24€ per month and per household.

means, already placing Spain and Portugal at the top of European comparisons on this indicator [87].

The low absolute energy expenditure indicator (M/2) is above the national average by a smaller margin than the 2M indicator. This gap can be traced to different expressions of energy poverty in the households surveyed, as shown in Figure 3, a Venn Diagram representing the overlap between the indicators. 2M and M/2 appear as complementary, distinguishing households with a high share of expenses from households with low consumption. For the thirty-three Spanish households and the one Portuguese household validating both indicators, the available income is low enough for even limited gas and electricity bills to weigh heavily in the domestic budget.

Figure 2 – Values for energy poverty indicators: local surveys and national Portuguese and Spanish averages

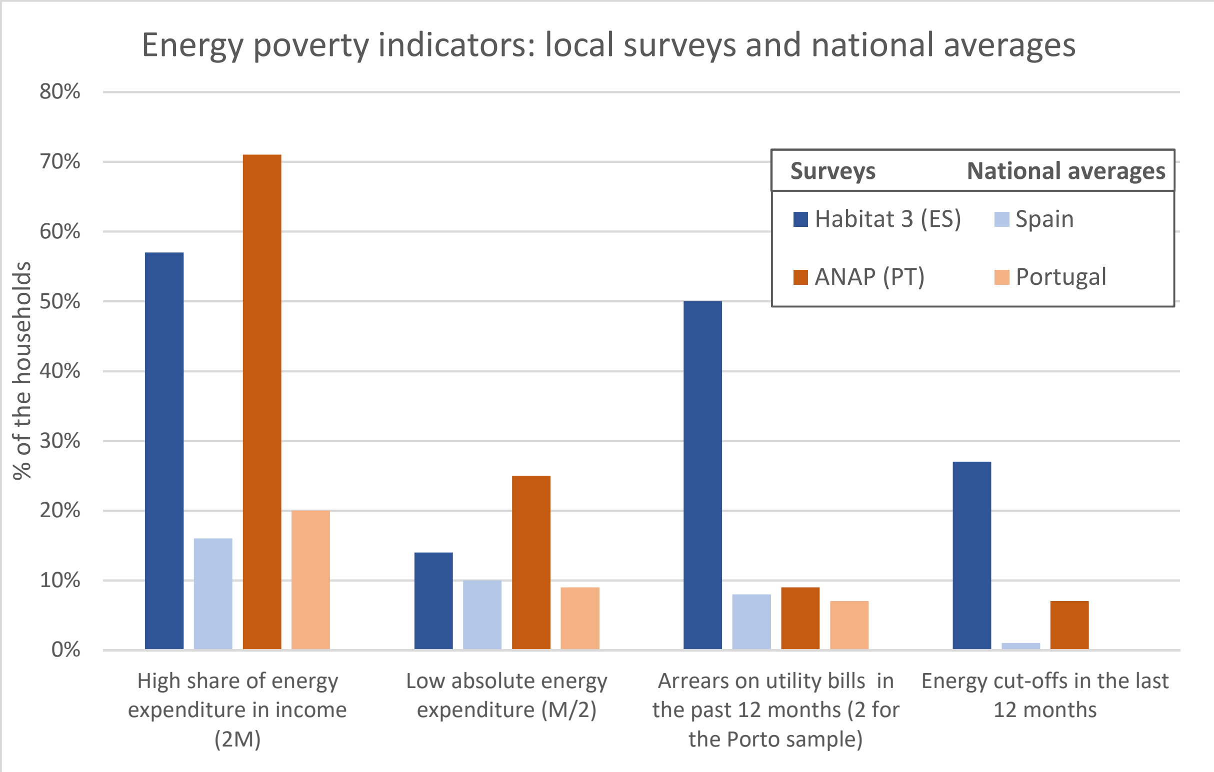
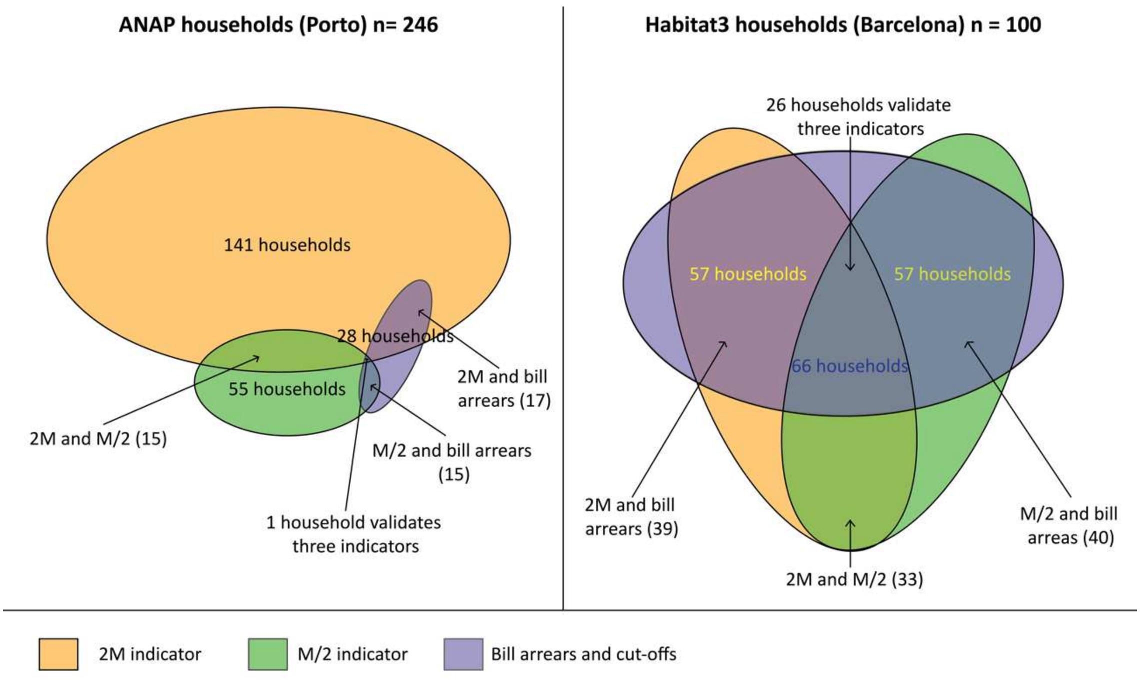


Figure 3 – Venn diagram for overlap between three energy poverty indicators



Following this expenditure method, the survey was also designed to identify arrears on utility bills due to financial difficulties. This indicator is more prevalent for low-income households than in the mean national values, as shown in Figure 2. Half of the Barcelona households experienced bill arrears in the past 12 months, well above the national mean, and 10% of Porto households experienced bill arrears in the two months covered by the data provided by the partner NGO. When repeated, these arrears can lead to electricity and gas cut-offs, again with a high prevalence measured in Barcelona with 27 respondents having experienced one or more cut-offs in the twelve months preceding the survey.

Following cut-off operations, and being unable to pay for accumulated debts and reconnection fees, households can turn to illegal connections to the electricity network. These frauds are difficult to approach through surveys, but they are recurrent in RPs interviews, who deal with them on a case-by-case basis when technicians encounter them during interventions, as stated by RP4 in Porto: "our response is to declare these situations [to the utility companies] when we encounter them, but as there are now several utilities, we don't know who to contact", because no protocols were established to deal with contracts with energy utilities in the liberalised market from 2006 onwards. This observation highlights the status of energy retail as external to the scope of RPs, only becoming visible during crises such as the regularisation operation conducted in the Porto neighbourhood of Lagarteiro in October 2013. Technicians from the utility company Energias de Portugal (EDP) entered this large district with a police escort and identified several dozen electricity frauds, before distributing fines and suspending illegal connections, prompting a fatalistic response from the RP1: "there is a lot of fraud, then the utility intervenes and regularises the situations, but they always find new ways, for example setting up illegal connections from equipment in common areas. When one of them does it, others follow, and it is a very harrowing task for us to intervene in situations where fraud is the general rule".

In the light of these energy poverty situations, the strategy adopted by RPs to focus on thermal comfort appears limited, as it only addresses the thermal component of a problem that concerns not only other daily needs but also causes conflicts with energy utilities. Interviews with RPs help to shed light on the complexities of extending their scope of action and their normative aims beyond thermal comfort.

4.3 The challenges of RPs incursions into domestic energy consumption

RPs in Porto and Barcelona are aware of the prevalence of bill arrears and low consumption practices, but we argue that they do not respond to these energy poverty situations with a structured approach beyond passive thermal envelopes, and choose to develop discrete programs illustrating the limits of their technical and legal competences and of their financial means.

First, interviewed RPs recognize the limitations of available financial and technical resources to streamline the process of monitoring everyday practices and turn the results into meaningful interventions in domestic spaces, as summarised by RP5: "we do not know how to gather and interpret the data on users' consumption [from the pilot projects], there are data privacy concerns, and we need tools to do that and time and money that we don't have…". This technical challenge is also illustrated by the close monitoring of a retrofitting project in Porto advertised as "the best social housing complex in Portugal" [88], where a university-led research team did not manage to take into account the real consumption of the households, instead highlighting theoretical consumption reductions that are quite unconnected with the experiences of the households [55]. The same observations are raised by the reports drawn by the EU Interreg program designed to develop regional energy efficiency policies in the social housing sector, recognizing the "key challenge" in the "lack of monitoring" of households consumptions across a range of European social housing case studies including the Porto social housing estate [73]. Beyond the metrics for temperature and kilowatt hours gathered during pilot retrofitting projects, energy patterns in social housing therefore remain a "black box" [89]. Without precise knowledge of user practices, policies designed by RPs lack comprehensiveness and focus only on structural interventions for passive envelope retrofits.

Secondly, when aiming beyond advice on everyday behaviour, the authority of RPs in domestic energy consumption is faced with legal barriers in the regulatory framework of the energy sector. Along with retrofitting the envelope of a social building and the installation of solar PV, the pilot project merged groups of four individual 4kW meters into collective 10kW meters, for which the provider established a contract with the utility company, thus saving the monthly 30€ fixed connection charge corresponding to the subtraction of 6kW. Small individual meters were installed in each apartment by the RP to measure individual consumption and charge the households along with other rental costs. "We provide one more service", states RP5, "we already rent the apartments with the utility costs, this would be another service that we provide". However, this experiment was limited to one retrofitted building in the Catalan countryside: energy retail is not within the competencies of Spanish social housing providers, and the merging of smart meters was dependent on negotiations with local energy distributors, a scheme described by RP5 as "not illegal, not legal either, provided that there are no complaints from the Spanish government". This exception was made by a historic local energy distributor who agreed to sign a contract with the RP, but it could not be replicated for the majority of the social housing estate in more densely populated areas where larger energy distributors rejected the scheme. "Users were very happy, recalls RP5, but not the companies, and starting conflicts with utilities is highly problematic, even for public institutions like ours".

Thirdly, adding to the absence of leverage on energy retail, RPs lack financial means to conduct large-scale interventions in domestic interiors other than for EU-funded projects. As stated by RP5, "the pilot had a 90% investment from the EU [for solar thermal and PV installations] and we could invest 20 000€ for each of the twenty apartments, which is a very large sum. Now we have to retrofit 2500 apartments, and our choice to focus on envelope efficiency allows us to invest only 9000€ per apartment, which it is still a high level of investment for us". Because of this, interventions in homes are secondary for RPs, and take the form of low-cost pilot projects designed to cut down electricity and gas bills by promoting careful monitoring of everyday consumption practices[11]. They are part of a larger dynamic targeting individual households and aiming to help them afford energy bills through low-cost tools and protocols, as implemented by the Barcelona municipality on 40 000 low-income households in both private and social housing. This piecemeal approach contributes to blurring of individual and collective responsibilities, individualizing energy poverty by reframing it as a problem of household consumption, and serving the interests of RPs and local authorities neither willing nor able to bear the cost of more expansive schemes [5].

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[11] For example, a scheme to tackle energy poverty in social housing led by RP1 in Porto was entrusted to the municipal energy agency, resulting in minor investments in 400 homes such as low-energy lightbulbs and a leaflet giving a set of consumption guidelines that showed little awareness of the socio-economic and material conditions of the households, in line with the little attention given to real benefits for users: low-income households are advised to buy highly efficient domestic energy appliances, are expected to spend time choosing a suitable energy deal in the liberalised market and are given recommendations on the use of irons, microwaves, ovens and refrigerators [90].

5. Discussion, policy implications and future research steps

By cross-analysing the conclusions obtained from the surveys on RPs and on consumption practices in low-income households, this study investigated the manifestations of energy poverty and how they are perceived and treated by social housing providers. The results show that RPs respond to the ubiquity of low-consumption practices in the social housing estates of Porto and Barcelona with a focus on passive measures designed to provide thermal comfort without heating and cooling appliances, thus placing energy poverty at the core of their retrofitting strategies for social housing. However, as these conditions exceed thermal needs [16], energy-poor households also keep a close track of their cooking, lighting and DHW use, while still struggling to afford gas and especially electricity bills, leading to frequent cut-offs and frauds. The avoidance by RPs of the multidimensional expression of energy poverty can be traced to the limitations of their budgets and technical and legal competences, which restrict their capacity to understand and act in indoor domestic spaces. However, our results suggest three possible directions for policymakers.

First, energy poverty situations appear as a central characteristic for tenants living in social housing in Porto and Barcelona, shaping the design of RP retrofitting policies. However, the nature of these situations is still little understood by RPs beyond their assessment of low-consumption practices, leading to flawed interventions aiming for closer monitoring of household habits that are unlikely to mitigate energy poverty. In line with the literature [8], we argue that RP policies would benefit from *in situ* assessments of user consumption profiles including, but not limited to, thermal comfort, and covering monthly expenses as well as perceptions regarding the fulfilment of social needs. Such assessments would help to shed light on the differences between practices stemming from cultural traits and practices that are themselves the result of economic deprivation. They could establish a foundation for the definition of new, context-based indicators of energy poverty situations to anchor the design and evaluation of retrofitting policies in real user profiles.

Secondly, these indicators could be established as criteria for applying to European and national funds, in the design of which RPs have a role to play as "process innovators", as conceptualised by Cauvain and Karvonen, whereby retrofit processes involve engagement with policies and financial instruments [91]. Portugal's Region Norte stakeholders have already demonstrated their capacity to align funding opportunities for retrofitting social housing, combining energy efficiency upgrades with urban development measures into place-based financing schemes [74]. The project implementation process could be improved further by adapting the regulatory frameworks to allow flexibility in the design of EU-funding criteria and promote structural changes in standards, in order to acknowledge specific southern European contexts, characterized by both inefficiency and lower-than-standard energy consumption practices, where recouping energy costs in social housing retrofits is near-unachievable.

Thirdly, acknowledging this reality could serve as an incentive for redefining the missions of social housing providers in Spain and Portugal, and challenging the limits of their legal competences in the energy retailing sector. There have been successful experiments of social housing institutions taking on a role in energy retail for their vulnerable tenants, at once reducing households energy bills and protecting them from cut-offs. Such incursions into retail, with possible synergies with the nascent municipally-led local energy companies like the Energía Barcelona [79] could lead to new missions for RPs, ensuring that social housing tenants can continue to have access to affordable energy in the context of both climate change and rising energy prices.

Further research could follow these directions, by further monitoring the evolution of energy consumption in the social housing estates and by comparing Spanish and Portuguese RPs energy poverty mitigation strategies with their European counterparts. We argue that these future lines of investigation will be more concerned with summer cooling issues, in the context of climate change projections predicting temperature increases that exceed peoples' – and social landlords? – capacity to take adaptive actions [43].

6. Conclusion

This study investigated the retrofitting strategies initiated by Spanish and Portuguese registered social housing providers (RPs) in Barcelona and Porto. The contribution of the paper is threefold. First, we traced the challenge faced by RPs charged with energy efficiency imperatives that appear largely unachievable in the context of widespread energy poverty situations. Pilot retrofit projects have demonstrated that upfront costs cannot be compensated by energy-saving measures, and have prompted RPs to implement new strategies targeting thermal comfort achieved through passive measures such as insulation and ventilation and limiting energy-producing equipment to well-funded stand-alone pilot projects. Secondly, we compared this strategy with the reality of energy poverty situations in a broadly defined social housing estate, showing that these situations extend well beyond thermal needs because they encompass cooking, lighting and DHW needs as well, which leads to frequent crises involving energy cut-offs and electricity frauds. This portrait also sheds light on the careful monitoring by low-income households of their own domestic practices, which is unacknowledged by RPs in their interventions beyond the implementation of passive thermal measures. The third result of the study is to have plotted the technical, financial and legal limitations encountered by RPs when designing schemes that, beyond building envelopes, target domestic spaces and the practices that take place within them. We therefore argue that the widespread nature of energy poverty situations justifiably calls into question the expectations regarding the success of retrofitting projects conducted in social housing in southern European contexts. We further argue that it points to a need to redefine the missions and competences of Spanish and Portuguese RPs, to move from awareness of the diversity of energy poverty to the adoption of new roles in the provision of energy in social housing estates.

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Appendix

Annex 1 - Share of fuels in the residential sector by end-uses

	Share of electricity	Share of heating in domestic end-uses	Share fuels in space heating uses		
			Electricity	Natural gas	biomass
Spain 2011*	**35,1%**	**47%**	**46,3%**	**32%**	**unreported**
Portugal 2020**	**46,6%**	**19,1%**	**10%**	**12,7%**	**67,1%**
EU 2019***	**24,7%**	**63,6%**	**3,4%**	**24,2%**	**unreported**

* source: national enquiry on the consumption of the residential sector in Spain [84]

** source: national enquiry on the energy consumption of the domestic sector [47]

*** source: Eurostat, Share of fuels in the final energy consumption in the residential sector by type of end-use, 2019 [92]

Annex 2 - table of interviews

Code	Organization and function	Date and place
RP1	Domus Social (Porto municipal landlord) – civil engineer in charge with implementing retrofits	April 21 2015 - Porto
RP2	Patronato municipal de la vivienda (Barcelona municipal landlord) – head of technical services and	April 29 2016 - Barcelona
RP3	Consorció de l'Habitatge (consortium coordinating social housing strategies) – head of technical services	April 27 2016 - Barcelona
RP4	IHRU, Portuguese national landlord – head of the Porto delegation	April 3rd 2015, Porto
RP5	Agencia de l'Habitatge, Catalan social landlord – head of the retrofitting programme and head of housing quality	April 27 2016 - Barcelona
AR1	Architect – in charge of the RELS retrofit project in Catalonia	Mai 16 2016 – Sabadell
AR2	Architect – in charge of Domus Social pilot retrofit projects	May 11 2015 – Porto
AR3	Architect – in charge of the monitoring of a Domus Social retrofit project	February 3rd 2015 – Porto
AR4	CEIIA, Social Green Portuguese partner – head of project	January 10 2018 – phone interview

AR5	Social Green coordinator	January 12 2018 – phone interview
	Barcelona energy agency – head of the agency	November 4th 2016 – Barcelona
	President of the NGO Habitat 3	February 23 2016 – Barcelona
	Social worker with the NGO ANAP	March 15 - Porto
RES1 to RES4	Interviews with low-income households in the Habitat3 survey in Barcelona	February to June 2015 – Porto
RES5	Interview with a low-income household living in a Porto *ilha*	March to June 2016 - Barcelona

Annex 3 - lines of questioning

LINES OF QUESTIONING

Presentation of the institution and the interviewee's position

Observations of energy vulnerabilities:

- Observations of payment difficulties, cold homes and energy disconnections (question left open to identifying other symptoms)
- Social and economic profile of households affected by these difficulties
- Material characteristics of the dwellings concerned
- Geographic location of affected households
- Observed changes in the number and extent of these situations over time
- Coverage of social tariffs for electricity (and gas for Portugal)
- Explanation of the concept of the "energy effort rate" at 10% of income and extrapolation to the population

Reception and immediate treatment of situations of deprivation

- Existing budgets of local authorities to pay electricity and gas bills
- Protocol for allocating ad hoc aid
- Changes in amounts needed in relation to citizens' requests
- Knowledge of social tariffs and their allocation criteria
- Relationships with energy companies: existence of direct telephone lines, protocols for negotiating individual cases
- Financial and organizational support from NGOs, charities and others
- Protocols in case of illegalities: energy fraud illegal occupancy

Projects involving medium and long-term preventive action in housing

- Actors and motivations behind the projects
- Methodology for identifying vulnerable households
- Nature of the interventions carried out in the dwellings
- Amounts spent on assessment projects and sources of funds
- Number of households included in programmes and projected trends
- Presence and role of NGOs in interventions

- Presence and role of universities in interventions
- Content of training on energy practices
- Number and identity of local government departments involved
- Technologies mobilized
- Tools to measure the success of projects
- Presence of an energy transition objective towards a low-carbon model

Specific issues in Catalonia regarding Law 24/2015

- Application of the protocol framing Law 24/2015
- Changes in the treatment of cases of non-payment after the adoption of Law 24/2015
- Changing relationships with energy providers
- Training administered to social assistance services (number of participants, content of training, reception of messages).

General view of energy deprivation

- Personal views on the concept of energy poverty and its evolution
- Evolution of the meaning and relevance of the concept over time

- Political support for bill payment or energy assessments

LINES OF QUESTIONING – VULNERABLE HOUSEHOLDS

Broad Introductory Questions: Major Events Leading to Habitat 3 Housing

- Family composition
- Occupational history of working household members
- Residential history (what housing the household has lived in and what work they have done on it)
- Current household income

Energy bill payments

- Average bill amount (current and past)
- Perception of the evolution of the price of electricity, natural gas and butane
- Weight of energy budget in household income
- Description of energy payment arrears, if any
- Interactions with energy suppliers in case of unpaid bills

Description of the dwelling

- Type of heating, cooling, water heating and cooking facilities
- Sunlight in the dwelling
- Insulation of the dwelling
- Change in heating/hot water/electricity needs from previous housing

Home energy deprivation

- Feeling of deprivation of heat/hot water/gas or electricity for cooking/lighting
- Practices to reduce consumption

Association support in Catalonia

- Knowledge of the Alliance against Energy Poverty and PAH networks
- Knowledge of law 24/2015