Why it's so hard? Exploring social barriers for the deployment of thermal energy storage in Spanish buildings

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Abstract

Thermal energy storage (TES) has been a prominent topic of scientific and industrial research for the last decades as TES increases efficiency, reliability and economic feasibility of solar energy systems. Several TES technologies are today feasible and competitive from a scientific-technical, sustainable and economic point of view. However, the social awareness and acceptance of TES has not followed such a development, as socio-cultural and legal aspects to be considered for their broader implementation hinder it. The main objective of this paper is to analyse social and cultural barriers to TES adoption in the Spanish context. For this proposal, we use quantitative and qualitative data provided from professionals and experts of the building sector. Hereby the main ideas arising from the analysis: the economic crisis of 2008 and the poor condition of the existing building stock prevent the adoption of extensive retrofitting measures including energy efficiency solutions such as TES' while TES is regarded as an emerging market in Mediterranean climates such as Spanish. The lack of expertise of professionals hinders the transmission of TES benefits to occupants. Besides, there is little dissemination of good practices and professionals are suspicious of the long term performance of such technologies.

Keywords: thermal energy storage, mixed methods, social acceptance, building, energy efficiency, energy retrofitting

1. Introduction

Thermal energy storage (TES) has been a prominent topic of scientific and industrial research for the last decades. The number of scientific publications has increased six-fold [1], and the installed power has increased from 0.1 GW to 3.2 GW between 2007 and 2017 worldwide [2]. Research on TES has mainly focused on its technical feasibility, moving from the characterisation and optimisation of conventional heat storage materials to the design of a next generation of TES materials with larger operation temperature ranges and greater storage capacity. With time, the focus has also been on the study of the economic viability and on the sustainability of TES [3] which has led to the emergence of several TES technologies that are currently feasible and competitive from the scientific-technical, sustainable and economic point of view.

TES is a term encompassing a wide range of technologies aimed at the storage of heat for its later use in heating and cooling applications and power generation. Depending on the storage principle, it is possible to distinguish between sensible heat storage, latent heat storage and thermochemical storage technologies. Sensible heat storage and latent heat storage are the more commercially developed to the date. In sensible heat storage, heat is stored by changing the temperature of a storage medium, generally water and molten salt mixtures. In latent heat storage, heat is stored through a phase transition, usually solid to liquid and vice versa. The so called phase change materials (PCM) such as paraffin or sugar alcohols are used in latent heat storage. Thermochemical heat storage has shown a higher potential for storage density, but further research is needed to demonstrate its feasibility [1].

The main feature of TES lies in that it can provide flexibility to solar energy systems by overcoming discordances in time, temperature, power or location between energy production and use. This improves both efficiency and reliability of such systems, leading to a significant reduction of costs and environmental impacts. This is true for both PV and thermal distributed solar energy production, as energy in buildings is mainly used in the form of heat. Although PV systems can be coupled to electric batteries, current technologies lie in scarce raw materials and involve high investment and environmental costs, which makes TES an attractive alternative. According to IRENA's last report [4], TES technologies and systems with different operational temperatures and requirements can meet a range of needs in the buildings sector. This is why TES is regarded as a key element in the energy transition towards renewable sources [5,6]. TES has also been proved to significantly reduce the energy demand of buildings if properly incorporated within building components such as walls, windows or slabs. This application is attractive as the building sector is currently responsible for 36% of global final energy consumption and nearly 40% of total direct and indirect CO_2 emissions and has a great potential for energy demand reduction [7]. These figures are a bit lower in Spain (about 20% of final energy consumption is due to buildings), but are rapidly increasing according to the predictions of the Institute for the Diversification and Saving of Energy (IDAE) [8]. This clearly underlines the relevance of introducing technologies such as TES for Spanish economy, highly dependent from external energetic sources. In consequence, construction sector has a key role in this challenge.

Although a wide range of TES technologies for buildings exist, these can be classified into two main groups, namely active storage systems and passive storage systems. Active storage systems require an energy input to force convection heat transfer. In turn, in passive storage, solar radiation, natural convection or temperature difference provide convection heat transfer. Active TES can be integrated in the core of the building (e.g. thermally activated floors and walls, where thermal energy is transferred to a slab or wall with high thermal mass -usually using water as transferring element- where heat is stored for some time -minutes or hours- before being emitted to the indoor environment), in the building envelope (e.g. suspended ceilings) or, in HVAC systems (either in ducts, in air-handling units or in other parts of the system) or in photovoltaic (PV) systems [9]. Passive TES, in turn, occurs in massive walls and floors built using high thermal mass materials (such as earth, stone or concrete); in solar walls (such as Trombe wall or solar water wall); or in building components incorporating phase change materials (PCM), either inside the material or in its porous structure, or as a separate layer in the construction solution [10]. In turn, it is possible to distinguish three groups TES technologies on the basis of their maturity: traditional technologies, which have been used in traditional architecture systems, such as massive walls, modern but mature technologies (e.g. Trombe wall) and innovative or unproven systems (such as PCM). The first are mostly passive systems while active systems are usually modern and innovative solutions.

Moreover, depending on the needs, TES for building applications can be sized for short periods (hours) to seasonal storage and in a range of scales, from domestic to local and territorial [9]. Examples of domestic set-ups are phase-change materials incorporated in building components as paints or facades, while water tanks for seasonal heat storage are an example of macro-scale TES systems. For more detailed information on these technologies see [9,10].

Despite the scientific and technological development of TES and its forefront mentioned advantages, its market penetration is not as widespread as it might be expected. According to the DOE Global Energy Storage Database, the global operational TES capacity at the time of this writing is only the 1.9% of the total world energy storage capacity. Spain is the country with a larger implementation of TES, followed by US and India, but still with a modest share of 14% of the total energy storage capacity of the country, which is estimated in 8.1 GW [2].

This mismatch between technology development and actual implementation of TES may be explained by socio-cultural factors. The analysis of socio-cultural and legal aspects influencing social acceptance of TES has been overlooked to date despite the fact that several works have pointed out its importance to boost its further implementation in the building sector [11–14]. Neglecting this aspect in energy system change strategies can lead to misguiding of policy making and practice and to a further resistance towards the assimilation of new technologies. Research has reported behavioural aspects such as the "rebound effect" [15,16] which can reduce the benefits of energy efficient interventions up to 30% if not taken into account from early stages of design. As the rebound-effect may cause demand shifting or amplifies the original system peak, the design of the TES system with the adequate control may mitigate it.

D'Oca et al. [14] analysed the outcomes of several EU funded projects dealing with energy retrofitting of buildings. The authors identified technical, financial and social barriers that explain why, despite the efforts made, only 1% of the EU existing building stock has been energy retrofitted to the date. These barriers were identified thanks to the outcomes of a focus group joining several stakeholders that took place at the Sustainable Places Conference 2018. Among the social barriers identified are (1) complex decision-making processes; (2) misunderstanding between residents; (3) disturbances during the site works; (4) limited awareness on energy and non-energy benefits; and (5) poor communication between stakeholders. The authors pointed out the need to create a demand from the market and the project level to boost investment in building renovation. In this vein, other studies also pointed out an "information deficit" and the "not in my back yard" position as important social barriers for energy system change strategies [17,18].

Devine-Wright et al. [13] suggested an interdisciplinary methodology for the analysis of social acceptance of energy storage taking into account the role of the diverse actors at local, national and international scale. Authors stress the significant role played by belief systems from key actors, in our case, practitioners, to understand and argue social acceptance in renewable energy storage solutions. Their approach followed the triple dimension of social acceptance proposed by Wüstenhagen et al. [19] (that is governance and regulation, markets and innovation and socio-cultural and public acceptance aspects) but put more emphasis on the analysis of the interrelations between the stakeholders at different geographical scales.

Hu et al. [15] conducted an online survey on about 5.000 households in China to investigate, among others, the awareness and reaction of end users to existing energy efficiency policies. The survey revealed that energy efficiency behaviour and awareness is shaped mainly by what users have learned from their academic and professional environments and from their traditional energy-saving habits. It is remarkable that these factors were found to be more influential than economic concerns.

The main objective of this paper is to identify existing barriers, especially social, hindering the implementation of TES in buildings. The authors' hypothesis is that having such a diagnosis should help to define paths to overcome these limitations and boost the widespread use of TES in buildings. In Section 2 we describe the quantitative survey and the focus group designed to gather quantitative and qualitative information from stakeholders related to TES. In Section 3 the penetration of TES in the Spanish building sector is discussed, while in Section 4 we outline the main barriers to a wide adoption of TES. Finally, the conclusions resulting from the field work are presented in Section 5.

2. Methodology

Aiming at the identification of social barriers of TES, we undertook a mixed perspective. From one hand, a quantitative survey among the professionals of the building sector, specially building engineers and architects, which are the decision makers regarding the energy strategies implemented in buildings. From the other hand, a focus group involving experts from the private and public sector, representatives of professional associations and teaching institutions. The analysis was limited to the region of Catalonia, Spain.

We designed a web-based questionnaire to collect the experience of professionals in the building sector on the use of TES (see Table A1 in the Annex). The focus was put on finding out the main barriers for implementation of TES among the professionals in the building industry. The questionnaire was carried out on-line and distributed through the communication channels of professional associations in Catalonia (CAATEEB and COAC)[1] from May to October 2018. The snowball sampling method implemented took advantage of the existing networks within the sector, aiming at any participant regardless their professional role or position [20]. The survey was divided into three sets of questions. The first was aimed at the collection of data showing what the general awareness in TES technologies was, and building energy efficiency of the respondents. In the central part, professionals were asked about their personal experience regarding the use of TES, thermal insulation and other available technologies for the energy efficiency of buildings. Special emphasis was made on energy retrofitting as this was the main activity for most professionals in Spain after the economic downturn that severely hit the sector in 2008 [21]. The final part was focused on getting some demographic information of the respondents such as age, professional profile or educational background to construct a sociodemographic of the sample.

In order to complement the quantitative perspective, a focus group was organised. This participatory method from qualitative approach is suitable to discuss new fields and gain insights through the reactions from interpersonal dynamics identify reactions from each participant [22]. It took place on the 14th March 2019 and gathered together eight practitioners with distinct profiles and contrasted experience on TES and building energy performance. The discussion was organised in three major parts (see Table A2 in the Annex): a) Energy refurbishment policies. In this block, the discussion was focused on identifying barriers to the implementation of building energy refurbishment policies as well as unravelling the reasons behind the scarcity of energy rehabilitations undertaken so far in Spain; b) Energy refurbishment practice. The experts where asked to share their experiences in energy refurbishment stressing common difficulties and potential improvement measures. Finally, c) Thermal energy storage (TES). In this block, the use of TES was discussed. The debate was centred on how these technologies are being assimilated by the sector, the awareness of practitioners and the factors that may prevent the widespread use of such technologies in construction. The focus group was recorded (under permission) and was transcribed literally. Content analysis was done in order to obtain relevant information following the previous identified concepts (theoretical saturation).

2.1. Demographic and social profile of the participants

The survey obtained a sample of 146 respondents. Mostly of them were professionals actively practicing while 5% were retired. Most of the respondents (56%) were in a mature period of their

[1] CAATEEB: Col·legi d’Aparelladors, Arquitectes Tècnics i Enginyers d’Edificació de Barcelona (Association of Building Engineers of Barcelona) and COAC: Col·legi d’Arquitectes de Catalunya (Catalonia Association Architects).

professional careers (between 40 and 60 years), while young architects under the age of 30 and senior architects over the age of 60 were the populations with lower number of respondents (6% and 15% of the total respectively). Regarding their professional activity, 25% of the respondents were project designers or engineers, 20% construction managers and 11% project managers, all of them roles with responsibility regarding the definition of the energy efficiency strategies in buildings. We found that 14% of the respondents were from academia or gave courses in training institutions, which doubles the Spanish ratio among architects (7%) [23].

From the point of view of the background training and specialization it was found that most of the respondents were experts or had a high awareness in issues related to energy efficiency of buildings. The majority of them (76%) declared to have been following some kind of training related with this issue, a percentage much higher than the Spanish average (37%) [23]. This is probably due to the fact that professionals already interested in this topic were more motivated to take the survey.

Participants of the focus group are eight practitioners with distinct profiles were chosen for their level of knowledge and contrasted experience on TES and building energy performance, and do necessarily represent the overall population of stakeholders [20]. The profiles chosen were: two representatives from the professional order CAATEEB, from the technical and training areas (P1 and P2); an academic teaching at the school of architecture of Barcelona (P3); a representative from the Housing Agency of the Catalan administration (P4); a practitioner from a company specialized in facade renovation (P5); a representative of a building sustainability consulting firm (P6) and two researchers in the field of TES and energy efficiency of buildings (P7 and P8).

3. Penetration of TES in the construction practice

Aiming at the evaluation of TES implementation, the focus was put on the experience from practitioners in building retrofitting rather than on new construction. This profile is predominant after the bursting of the real estate bubble in 2008, when Spanish construction sector was hit by a dramatic downturn. The number of new building licenses reduced from 96,626 in 2007 to 35,692 in 2010. As a result, building retrofitting took on greater prominence, from 25% of total building licenses (excluding demolitions) in 2007 to 46% in 2010 and 52% in 2017 [21].

The participants were asked if they had been involved in any building retrofitting project including energy upgrades in the last five years. 60% of professionals confirmed their participation in such projects, three out of five of which were in the preceding two years. The refurbished buildings were dwellings in most of the cases, mostly single-family dwellings privately owned. Public facilities corresponded to 20% of the cases. Almost all the interventions were made on buildings built before 2006, when the Spanish Building Code (CTE) entered into force, of which 52% were on buildings built before 1960.

Of the 71 energy renovations reported, 75% included thermal insulation of envelopes and window replacement. Only 12.6% of the reported refurbishments included seven or more of the intervention activities proposed in the questionnaire (see Figure1), which points out a scarcity of in-depth refurbishments. As shown in Figure 1, which shows the frequency of the most common activities in building energy refurbishment, other improvements of great impact on energy efficiency such as control of thermal bridges and control of ventilation and infiltration rates were undertaken only in 4.3% and 10.4% of the cases. The use of TES is even rarer, as it can be deduced from the fact that only 3% of the interventions included any consideration to the thermal inertia of the building. The incorporation of renewable energy sources, which commonly includes the use of thermal storage in water tanks, was found not to be any common either.

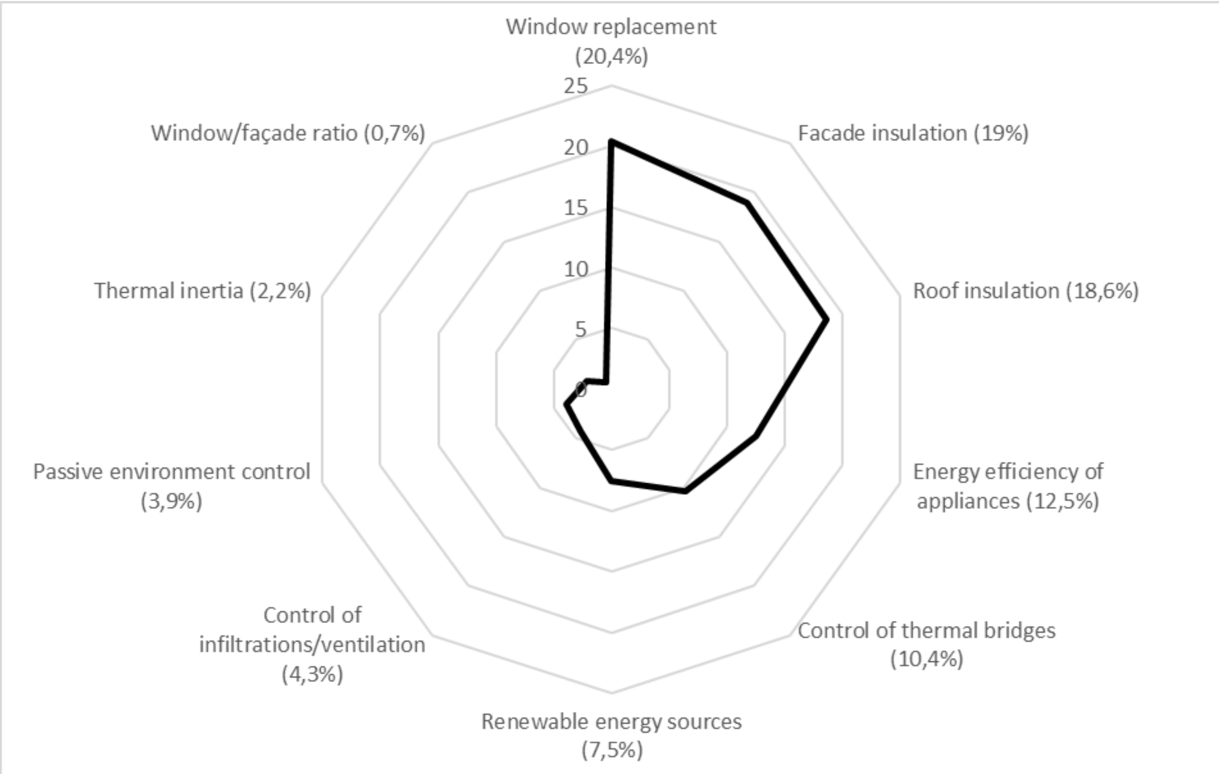

Figure 1. Most common energy refurbishment interventions. Source: Survey on TES awareness, 2018 (% of responses).

Regarding the application of TES, the professionals were asked about three specific technologies: water tanks, phase change materials and Trombe walls. The results showed that only 42% of the respondent had used water tanks in any of their projects, mainly in sanitary hot water facilities (50%) and solar energy systems (36%).

In brief, the results of the survey show that most of building energy retrofitting activities are small (mostly single-family dwellings) and limited, mostly including envelope insulation and window replacement only. Other interventions, such as control of ventilation or the use of TES, are not considered in the strategies for energy improvement. These results are aligned with the ideas raised by the focus group, in which the participants noted a low adoption of TES and, in general of building energy retrofitting in the Spanish context and pointed out some possible reasons behind this fact, which are discussed in the next section.

4. Barriers to TES acceptance

The analysis of the data from the focus group led to the identification of two groups of barriers. A first group referred to TES technologies but also to other technologies that also aim at the energy performance of buildings, but are not based in TES. A second group was specific for technologies based on TES. The first are depicted in sub-section 4.1 and the second in 4.2.

Notice that TES is a generic term that clusters various types of technologies, from PCMs in plaster panels to water tanks in solar energy systems. The barriers presented may apply in some of the cases but not the others. For instance, a technical barrier highlighted was the large space demanded by these technologies. This is true for water tanks or walls with high inertia, but obviously not for plaster panels incorporating PCMs.

4.1. General barriers for technologies aiming at energy efficiency of buildings

Several barriers to the widespread adoption of energy efficiency technologies (EET) were identified during the focus group. These were clustered into three groups: economic, technical and social barriers (see Figure 2). This clustering is proposed by the authors based on the results of the field work and adapting the classifications proposed by Devine-Wright et. al. [13] and Wustenhagen et al. [19]. Notice that although the focus of this research was on social barriers, economic and technical barriers were also included for contextualization and to provide an integral approach to the complexity of the object of study. In turn, social barriers were grouped into three levels according to the degree of proximity to the occupants, which were considered as final beneficiaries of EETs: contextual, regulatory and project level. The contextual level clusters macro difficulties derived from the economic, social and structural context. The regulatory level is a meso level including barriers related with the role of the administration and other stakeholders not in direct contact with the final beneficiaries. Finally, the project level includes all barriers related to the design and construction of specific projects, which directly affect the final beneficiaries.

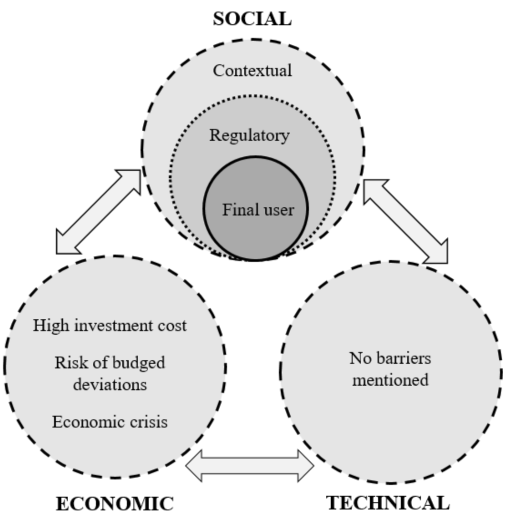

Figure 2. Clusters of identified barriers for EET.

4.1.1. Economic and technical barriers

The main economic barrier mentioned was the high initial cost of the interventions, which results in long pay-back periods. According to the focus group, even if rigorous calculations on energy savings and pay-back periods can be made in the design phase, a poor construction quality control can add a considerable degree of uncertainty to such calculations, which reduces owners' willingness to put in energy retrofitting. This reluctance is reinforced in a context of economic crisis such as the one hitting Spain since 2008, which has heavily affected the construction sector. It is also more common in the case of neighbourhood communities where the need to reach an agreement between all parties often tilts the choice towards the cheapest budget.

Technical barriers, in turn, do not seem to be a main concern among the professionals as these were not highlighted in the focus group.

4.1.2. Social barriers

The social barriers compiled from the discussion group are summarised in Table 1. As mentioned before, these are classified into macro, meso and micro levels according to their direct influence on final users.

Table 1. Social barriers for Energy Efficiency Technologies (EES).

a. Contextual level	b. Regulatory level	c. Project level
Ownership type. Tenure is strengthened against rent which hinders coordinated interventions	**Confusing regulation and unclear objectives.** Generating confusion among professionals in the sector.	**Need of an integral approach.** Professionals need to work in multidisciplinary teams to deal with complexity.
Economic recession (2008). Occupants and landlords adopt more conservative attitudes. Public funding support is constricted.	**Poor coordination between administrations.** Hinders a holistic view of the stakeholders.	**Not a prime concern.** Energy efficiency and associated technology is not a priority for the stakeholders in the construction sector.
Building stock ancient and poorly maintained. Addressing structural and safety interventions is regarded as a priority.	**Regulations not adapted to the context.** They are directly transposed from European directives without any debate on the contextual specificities.	**Lack of knowledge**. The awareness of the key actors (promotors, practitioners and administration) on building energy efficiency is low.
	Lack of awareness. Lack of a clear commitment to improve the energy efficiency of the building stock.	**Poor motivation.** Key actors are not convinced and are not encouraged to promote energy efficiency of buildings.

a. Contextual level: the influence of Spanish tenure system

One of the cited barriers in the contextual level was the Spanish tenure system, in which users are encouraged to own rather than to rent their homes. This hinders the possibility of a coordinated intervention in the existing stock. In multi-family dwellings, it is often challenging for the communities of neighbours to coordinate interventions. The intervention in common areas, the ownership of which is shared, is not regarded as an individual priority. Administration only manages public housing, which represents in Spain less than the 2.5% of the dwellings [24]. Stablishing a minimum consensus is the first step and it is probably the most challenging one for the communities.

Another added contextual factor was also considered: the influence of the economic recession that took place in 2008. Since then, the investment in building retrofitting has been dramatically reduced. In such context, only the most urgent structural deficiencies are addressed due to budget constraints and the lack of subsidies offered by the administrations. Energy efficiency retrofitting measures are set aside, as they are not considered essential.

> *(...) Energy refurbishment is a very small part of our list of works (...) I wonder if it's due to a lack of awareness in the communities, obviously we come out from a time of crisis which has done much harm in the type of works undertaken in retrofitting and refurbishment. (...) The fact of going only minimums has made it hard to envisage these kinds of refurbishments, which are very expansive, of considerable cost, when it comes to existing buildings. (P5)*

To this economic context must be added the fact that the existing building stock, both public and private, present severe structural and safety deficits that need to be addressed. While this could be an opportunity for EET, the reality is that refurbishments are done only when the need is urgent and often EET do not fit in the budget.

> *What the Agency is doing now,* (refers to the Housing Agency of the Generalitat de Catalunya) *besides making housing policy, is promoting rehabilitation through the ITs, technical inspections* (of buildings). *They are aimed at urgent cases or buildings aged over 40. Raising issues of energy rehabilitation there I think is complicated, because communities of neighbours have a lot of work to do in agreeing to repair the damage they have and the pathologies showing up after 40 years. (P4)*

b. Regulatory level: drawing a confusing scenario/background

This intermediate level refers to the role of administrations and other stakeholders that react to the contextual effects and, with their actions (generally regulatory), generate an effect on the final users. Four major barriers were found at this level, interacting with each other: (1) confusing regulation and unclear objectives; (2) poor coordination between administrations, (3) a regulation body not adapted to the context and (4) lack of awareness of the importance of building energy retrofitting.

According to the focus group, Spanish professionals have to deal with a confusing regulation framework arising from a refurbishment policy with unclear objectives. This condition was also mentioned by Wüsternhagen et al. [19] when analysing other contexts, and it is mostly due to the existence of many administration bodies with competencies in the energy retrofitting sector. The diverse levels of administrations concerned (local, autonomic and national) are poorly coordinated and communicate ineffectively, which hinders the implementation of comprehensive energy efficient measures.

> *(...) Then a further issue that we should be clear about our country: is the level of segmentation of administrations which makes it very difficult to know who it who, who has said what, where the funding will come from, etc. Things are at the state level, others at the regional, and others at the municipal... this is tricky. Above all with regard to a key issue: financing. (P2)*

Indeed, the outcomes of the survey showed that despite the high cost of energy retrofitting, public financial support was asked in only 25% of the cases reported, from which the half where finally granted.

Professionals also miss a clear regulation adapted to the Mediterranean context. They claim that the models of Northern Europe should not be directly adopted, as the climatic and cultural conditions differ. At the same time, a clear role is called for from the administrations, which should clearly establish the goals to be achieved. In addition, a greater dissemination of the best practices is requested, as a complement of the existing regulatory frame.

> *You talk about consciousness at the bottom, but what about the top? Are energy refurbishment policies clear? Which ones are they? They're not clear indeed. Let me explain. First, if we focus on Catalonia and look at the Energy Plan or the National Energy Transition Agreement ... I do not know yet what the priority is: is it mobility? Energy rehabilitation? I see that they talk about many things, in the Energy Plan for Catalonia for example, it describes what happening in England and what Shell says, but what about we want, in our framework, which is the Mediterranean and is so different from Northern Europe? I have no idea. Then we will have to talk about how we have to do it. But if we are not clear about the What first, we will hardly discuss the How. (P2)*

The forefront mentioned elements add to a lack of awareness at the administration level. This lack of awareness is reflected in uncomprehensive priorities and regulations non adapted to the contextual needs. This leads to a lack of clear commitment to energy sustainability of buildings.

c. Project level: not a prime concern

Barriers observed at the project level can be organized in two groups: at the side of practitioners, a lack of holistic viewpoint, as well as a lack of building maintenance and management planning were highlighted. Deficits in training on how to raise awareness on energy innovations were also mentioned. At the level of occupants, the main barrier noticed was the fact that energy efficiency is not considered a priority. Finally, lack of awareness was common to both groups and results in poor motivation.

The discussion group pointed out the need of multidisciplinary teams capable to deal with the complexity that energy retrofitting interventions demand. Contributions from multiple disciplines allow for more efficient projects where all kind of aspects, not just the technical ones, are taken into account:

> *(...) I think that one of the barriers identified is that energy refurbishment needs multidisciplinary teams. If we each stay in our own field, it is hard to overcome it (*referring to energy efficient interventions). *Since the funding is so high, you need to have bankers on your team. (P4)*

This lack of integral vision has a direct impact on the end users. Often their needs in terms of how they will use the building are ignored and so is the management of the building after the intervention:

> *(…) one of the most important points related to motivation or awareness is that not enough thought is given to the ones that will manage the building. (P2)*

The above mentioned aspects are related to a further challenge: benefits of undertaking energy upgrades, which includes energy and economic savings but also improved thermal comfort, are not effectively passed from the experts and practitioner s to the owners, which is key in raising social awareness. As a result, owners often disregard energy efficiency interventions compared to other upgrades considered of higher priority, namely reparations and maintenance.

> *Currently no-one shows them [referring to occupants]: if we do so, what will you save? In the short term? In the long term? We are not trained to do this. According to my experience, neither the project managers nor the construction companies. Then, when it comes to works, it is nowadays hard to apply. You may do an ETICS and little else. (P5)*

Two other closely related barriers where brought up: the general lack of awareness and the lack of motivation of both practitioners and occupants. This idea is reinforced by the results yielded in the survey. It is not only a shared vision (74% of the respondents believe that the building sector does not give priority or is neutral to issues related to energy efficiency), but also an attitude in the daily practice of most of the respondents.

For example, when respondents were asked about what are and how they select the insulation materials for their projects, in most cases environmental aspects lag far behind technical aspects. Polystyrene and mineral wool are the insulators most commonly installed and are also the most commonly recommended by manufacturers and installers. When asked about the factors considered in the choice, thermal conductivity and cost were the most cited factors. In third place were fire performance (14%), durability (12%) and acoustic properties (9.3%). The respondents attached little or no attention to environmental aspects such as bio-degradability, fume or dust emissions or embodied energy of insulation materials, which fell to the bottom of the list.

This contrasts with their ideological positioning. When asked in general terms, the respondents argue that environmental aspects should be given more attention. For instance, in 68% of the cases they considered that waste disposal of building materials is a highly relevant issue that should be considered more seriously. The mismatch between the ideological positioning and the factors influencing design choices does not seem to be due to the influence of other decision makers, as the respondents claimed to be in charge of making this decision in 60% of cases. The explanation given in the focus group to this situation is a generalised poor motivation to tackle the existing challenges.

> *(...) But when it comes to energy improvements in a project, my colleagues find that it is adding complexity, more work, obviously, and as it does not have immediate results, as it does not translate into a higher revenue per square meter when the work is finished, it does not make sense. And this has happened in façade interventions, window substitution, energy recovery... We had the money… (...) Therefore, I would say that we need more awareness and that the key word is motivation. (...) It is challenging: it is not training, it is not just the role of the administration or the* [lack of a] *roadmap, which I find very important; it is something more personal. (P6)*

4.2. Specific barriers to TES technologies

In section 4.1 the challenges of energy efficiency interventions in buildings (including the use of TES but also other technologies) were discussed. In this section specific barriers to TES are introduced. As in the previous section, barriers are classified into three main groups: economic, technical and social (see Figure 3).

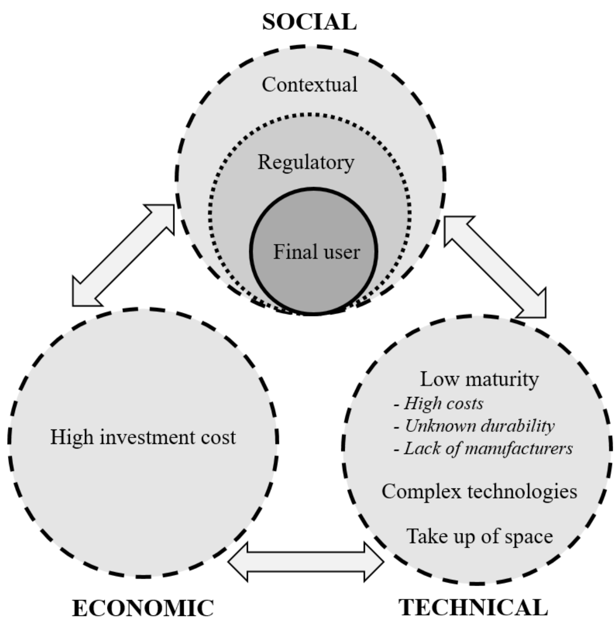

Figure 3. Clusters of identified barriers for TES.

4.2.1. Economic and technical barriers

According to the focus group, the main barriers hindering a wider implementation of TES are related to the fact that it is incorporated in technologies that have been in the market for a short time. The implications are two-fold: higher costs, due to underdeveloped economy of scale and little evidence about long-term performance and durability.

> *(...) I think that we still have some way to go to deploy these options. For [thermal] storage, some studies exist, and as far as I know the issue is cost and durability (...). How many times can a material change* [phase] *before being damaged? This must be taken into account in designs too. (P3)*

Another consequence derived from an immature market was identified in the survey: the scarcity of manufacturers and distributors offering TES technologies was placed in sixth place in the list of barriers for TES, as shown in Figure 4.

From the results of the survey it is noticeable that, in contrast to what was observed for energy efficiency technologies, the technical aspects are a concern among professionals. In particular, one half of the respondents argued that the fact that TES usually takes up more space limits their implementation, especially in renovations; and more than one third highlighted complexity in design as a remarkable technical barrier for TES. These results match with the opinions expressed in the focus group, where space requirements and complexity in design were also pointed out as main technical barriers.

Experts from focus group argued that complexity is due to the fact that the performance of TES is closely related to climate conditions and must be evaluated taking into account daily and seasonal evolution of environmental conditions or the time that it takes to the building to come into operation, among others.

4.2.2. Social barriers

Although technical barriers mentioned above were identified as relevant impediments for the use of TES, the barrier mentioned by most of the respondents of the survey was the lack of knowledge of the practitioners. The participants were asked about the main reasons for the limited use of TES in façades (such as PCM, massive walls or Trombe walls) compared to the use of alternative technologies such as thermal insulation. The results are shown in Figure 4. Three quarters identified lack of knowledge as the main impediment. Lack of regulations and lack of demand from customers and promotors were also chosen in 34% of the cases. The same was asked in the case of roofs (that is technologies such as PCMs, rain tank roofs and green roofs) yielding similar results.

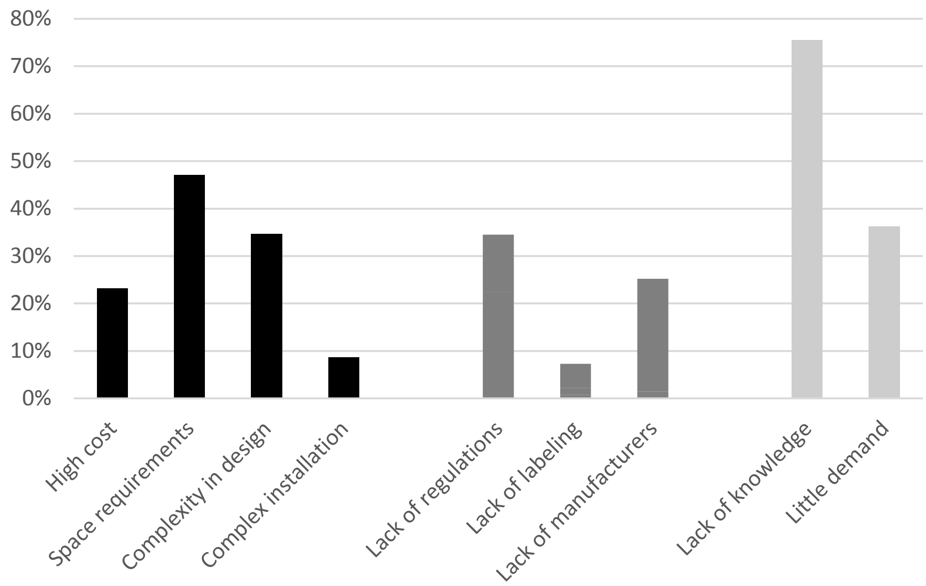

Figure 4. Main reasons for the limited use of TES highlighted in the survey (multiple choice, percentage of responses). Barriers are clustered from left to right into economic and technical (black), social - regulatory level (dark grey) and social – project level (light grey).

The above mentioned social barriers, together with the ones highlighted by the focus group, are clustered into three categories, as shown in Table 2.

Table 2. Social barriers of TES

a. Contextual level	b. Regulatory level	c. Project level
Specificity of the Spanish climate. TES being highly dependent on climatic conditions, direct transposition of the European Directives is not suitable for its development. **Cultural values and habits.** TES often require an active participation of final users which is generally overlooked.	**Lack of adapted regulations.** TES is rarely taken into account in the regulatory framework. **Lack of tools to manage complexity.** Overregulation and lack of examples of best practices.	**Lack of technical knowledge.** And even loss of knowledge compared to traditional building practices. **Poor dissemination of best practice cases.** Unexperienced practitioners find troubles in learning from previous cases. **"Technical indolence".** Rare proactive attitude from practitioners.

a. Contextual level: Spanish climate constrictions

The responsiveness of TES to climatic conditions requires the development of specific regulation for each climate zone. Most of the existent regulations at the European level are aimed at continental climates that are not so prevalent in Mediterranean countries. In addition, climatic conditions also influence the cultural context. These arguments led the focus group to argue that direct transposition of European Directives hinders the development of TES in Spain.

> *What I have seen (...) especially in research, is that we try to mirror ourselves in countries like Germany, France and the Nordic countries, and (...) what they used there [in Europe] and is intended to be transferred here into regulations, is not valid! (...) is a technology that is more complex and must be adapted to the place where it is to be*

implemented, so it must be in the design from the beginning. Because what is valid here [Barcelona] is not valid in Perpinyà or Lleida! This is the issue. (P8)

Another contextual factor that is often disregarded is the cultural. occupants and their life styles and habits are rarely taken into account in design and construction phases. This is relevant when TES are used in a project, as the performance of TES often depend, as other so called passive systems, on the active participation of users in its management. This is the case, for instance of Trombe walls and greenhouses. Such implication is becoming less common in our postmodern societies.

Trust in foreign models? No way! The Mediterranean is the Mediterranean, and so it has always been said. It is true that we are changing as a society: I also have children who do not pull the blinds. (P4)

b. Regulatory level

At the regulatory level, the lack of specific regulations was highlighted as one of the main barriers for TES both in quantitative and qualitative methods. For example, the regulation fixes minimum values for thermal transmittance of building envelopes, but it does not give any indication for thermal inertia. It just mentions that it should be taken into account in calculations. The professionals claim that there is lack of guidelines for the use of TES, especially in bioclimatic strategies where TES is not part of an industrialised product.

The one who bets on it must be highly motivated. For sure. Someone who knows the technology, who trusts it, and to whom it appeals in some way. And for it to spread, we need success stories. (P4)

Successful cases, which are currently rare and badly communicated according to the focus group, are regarded as an effective tool to deal with the complexity of TES technologies and provide robust guidance for their use. In this sense, a more active role of the administration in providing simplified and adapted standards and examples is requested, as it has been done in northern European countries.

c. Project level

As mentioned before, regarding social barriers, professionals have put the emphasis on the lack of knowledge among practitioners. Many professionals are reluctant to use TES in their projects due to their unfamiliarity with these technologies. They tend to believe that using TES will be a constraint on their choices in terms of space use and compatible construction systems.

(...) I believe that due to ignorance. And because you think: it will limit me, now I need a mass of I don't know how many cubic meters, and weight, I don't know how much storage, near to the windows, a dark pavement, some dampers, an opaque part in the facade... but the few cases that exist, they're delighted. The comfort they have: a natural comfort. (P6)

Lack of knowledge on TES and related technologies was also the main barrier identified in the survey when asked directly. But not only this, the survey also tested the actual knowledge on TES of the respondents. The participants were asked to identify TES technologies among a list of nine energy solutions. Most of the respondents successfully sorted the TES technologies, however, it is noticeably that this was one of the questions with the lowest number of answers, as only 50% of the people that undertook the questionnaire answered this question. The results are presented in Figure 5, 90% of the respondents adequately classified between five and eight of the technologies on the list and just 5% managed to sort them all out properly.

Among the TES technologies listed, the most familiar was thermal inertia of walls which was identified with TES by 83% of the respondents. Similarly, thermal stores and inertia reservoirs in heating systems were identified as TES by 73% and 66% respectively. The TES technology which respondents had more difficulties in identifying was the electric boiler. Less than 15% of the respondents identified other kind of technologies as TES. Only two respondents mistook gas tanks for TES. More confusion was found for solar panels, which were identified as TES in 24% of the cases, probably because they are installed together with thermal stores in most of the cases.

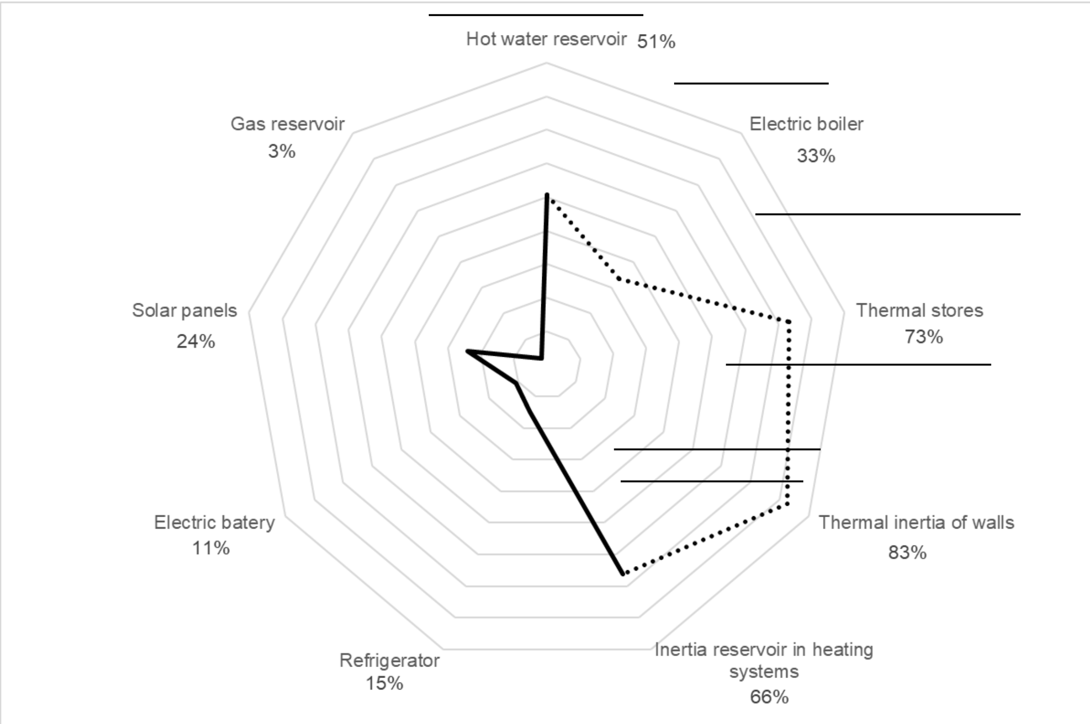

Figure 5. Energy solutions matched with TES. Note: Actual TES technologies shown to the right and with dotted line. Source: on TES awareness, 2018.

Using the correctly identification of these technologies as a new variable, a higher level of knowledge was observed between professionals who had taken some training in energy efficiency (mean 6.6) than between those who had not (mean 5.8). In relation to the professional profile, results show a higher knowledge among energy advisors and architects, with a mean of 7.6 and 6.8 respectively.

These results reinforce the general feeling that the concept of TES is not well known by professionals, even by those who are familiar with other technical concepts related to energy efficiency of buildings, such as nZEB[2]. This is considered to be a major barrier for TES implementation. The immaturity of some of the TES technologies, like the use of PCM in active or passive systems may explain, in part, this situation. A greater dissemination of their potential performance, especially at long-term, is needed.

Lack of knowledge is closely related to training shortcomings. The poor dissemination of success and best practice cases does not help to consolidate experiential knowledge, which is considered more valuable than theoretical learning.

[2] Indeed, this was tested in the survey. Most of the respondents (80%) claimed to be familiar with the concept of nZEB and the results indicated that they actually are, as their definitions matched with the ones from international institutions such as the Energy Department of EUA and the EPDB (EPBD, 2010/31/EC).

> *(...) the training of practitioners does not fit... (...) we know that these technologies exist but then when it comes to explaining exactly how to design and set some design parameters… this is where the challenge arise. (P7)*

Widespread inexperience on the part of professionals is an even more important barrier when the most reliable source of information for them is their own colleagues. In the survey, the respondents admitted to trust preferably on their own experience or the experience of their colleagues when it comes to decision making. Other sources of guarantee reported were independent certification labels and manufacturer's guarantees. Regarding the usefulness of eco-labels, opinions were divided between the 45% of the respondents believing that they are relevant and the 30% with a negative perception of them.

Another aspect was highlighted. Some experts argued that besides lack of regulations and training there is a sort of "technical indolence" among professionals, that is, low motivation in having a proactive attitude.

> *(...) motivation. Obviously it is closely related to consciousness. I have to do it, I don't have to wait for the authority, the administration, the practitioner or my head to make me do it. Why am I not motivated? (P6)*

5. Conclusions

Thermal energy storage (TES) is a term clustering a wide range of technologies with different applications and different market acceptance. Thus, they are rarely considered as a unity outside the academia. The fact that only half of the surveyed answered the questions related to the identification of TES technologies is evidence that professionals are not familiar with this terminology despite having made use of some of these technologies in their projects. The results also showed that even the professionals familiar with TES, are not always capable to identify this family of technologies, which proves that the meaning of the term TES is not clear yet. These findings are even more significant when taking into account the biased sample: most of the respondents were interested in energy efficiency but showed difficulties identifying TES.

Indeed, it seems to be a consensus that one of the main barriers for TES implementation is the lack of knowledge about these systems. The principles of thermal storage were included in several of the vernacular technologies for environmental control, such as massive walls, but this knowledge is lost in mainstream building practices. A clear commitment is needed from the practitioners, which translates into first, considering TES as a viable alternative for their projects and, second, engaging in continuous training aiming at the recovering of those traditional good practices that are being lost.

The lack of regulations might be one of the reasons why the professionals are not doing much effort in mastering this issue. In this sense, the role of the administration is key in promoting both demand and prescription of TES technologies. A clear roadmap setting building energy efficiency objectives is missed. It should be aimed at the coordination of the efforts made at local, regional and national level.

Finally, a further key issue to consider is the transversal role of training. It should not only be aimed at disseminating knowledge of the technologies themselves but also at promoting awareness among all the actors involved: from the users to the administration and the technicians. Specifically, when talking about the training of the practitioners who are to prescribe these technologies, the role of the university is stressed. It is understood that the university should be the platform providing general and basic knowledge of the discipline, but it should also promote the acquisition of practical experience which complements such knowledge. This experience must also be combined with more competence-based training, including teamwork learning, business vision and communication skills.

What is the future of TES in buildings? Different factors will play in favour of its consolidation. First, those related to the technology itself, such as durability or simplicity of application together with a lower cost. A second set of factors will be those related to the prevalent and specific social and economic structure in each area. Dominant cultural values and lifestyles, as well as climate conditions, play a key role encouraging the adoption or not of new technologies. Finally, the part played on an individual level cannot be neglected: personal values and interactions with the environment will promote certain energy efficient solutions in front of others. The prevailing pattern based on seeking short term results and a materialistic understanding of well-being play against a more wide-spread adoption of TES technologies in buildings. Authors would like to stress the prevalent individual social values over collective and long-term perspective, the first ones are based on self-interest well-being and getting immediately our (sometimes material) goals, without contemplating any possible individual endeavour in order to get a collective and long-term well-being, more sustainable in all dimensions to be considered: environmental, economic and social. Awareness on the part of all the stakeholders involved can be a catalyst helping towards a successful TES implementation.

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Annex

Table A1. Sets of questions proposed for the survey

Awareness in TES technologies and sustainability in the building sector	
1a. Are you familiar with the concept NZEB?	Y/N
1b. Which definition fits better with an NZEB building	MC
2. Which of these elements allow for the storage of thermal energy?	MC
3a. In facades, PCM, massive stone or clay walls and Trombe walls are examples of TES. Why do you think these are used less frequently than thermal insulators?	MC
3b. In roofs, PCM, water layers and green roofs are examples of TES. Why do you think these are used less frequently than thermal insulators?	MC
4. To what extend do you agree with the statement: The building sector gives priority to energy efficiency.	1-5
5. How relevant are ecolabels?	1-5
6. What is your concern regarding waste disposal of building materials?	1-5
Professional experience regarding building energy efficiency	
1a. Did you participate in any energy retrofitting in the last 5 years?	Y/N
1b. What kind?	MC
1c. Please, provide information regarding the last energy retrofitting in which you participated (year of construction and year of intervention, number of storeys, ownership, use, city, budget)	O
1d. Was it successful?	1-5
1e. Did it receive any public funding?	Y/N
1f. What percentage of the total cost did it cover?	1-4
2. What is your rate of satisfaction regarding the role of public administrations in energy retrofitting?	1-5
3. In the last 5 years, what kind of thermal insulator did you install? 1. Wool (rock or glass) 2. Polystyrene (expanded or extruded) 3. Expanded perlite 4. Cellular glass 5. Polyurethane 6. Wood fibers 7. Cork 8. Hemp or linen 9. Sheep wool 10. Cotton 11. Cellulose 12. Other vegetable fibers (coconut fiber, straw, vegetable agglomerates, etc.)	MC
4a. Who generally makes the choice on what thermal insulation to install?	MC
4b. Who decides the required thickness?	MC
4c. If you do in any of the two previous questions, from whom do you accept advice?	MC
5. What thermal insulators are the most frequently recommended by manufacturers, installers and other professionals? (same options q3)	MC
6. What are the main three qualities of a good thermal insulator? 1. Thermal conductivity 2. Price/square meter 3. Energetic production cost	MC

4. Noise attenuation	
5. Reusable	
6. Recyclable	
7. Biodegradable	
8. Durability	
9. Fire classification	
10. Fire spread contribution	
11. Smoke emission	
12. Toxicity	
13. Detachment of fibers during placement	
14. Embedded energy	
15. Physical properties (Elasticity, toughness, hardness, compressive strength)	
16. Hygroscopicity	
7a. What factors would you consider as a guarantee of confidence in a thermal insulator?	MC
1. Accumulated experience	
2. Disposal of certificates issued by manufacturer	
3. Availability of certificates issued by an independent agency	
4. Experience from other professionals	
5. Installer recommendations	
6. Manufacturer's warranties	
7. Price	
8. Other reasons	
7b. Did you have any negative experience with installing an insulation system?	Y/N
7c. Please describe the experience.	O
8a. Did you included water tanks in any of your projects?	Y/N
8b. For what purpose?	MC
9a. Are you familiar with Phase Change Materials (PCM)?	Y/N
9b. Did you use them in any of your projects?	Y/N
9c. To what element / construction system where they associated?	MC
10a. Are you familiar with the Trombe wall?	Y/N
10b. Did you use it in any of your projects?	Y/N
10c. Was it successful?	1-5
Personal information	
Gender	MC
Date of birth	MC
Profession	MC
Employment position	MC
Did you followed any training on energy efficiency?	Y/N
What kind?	MC

Table A2. Guideline designed for the focus group

Block	*Topics discussed*
A Energy refurbishment policies	*What are the barriers or limitations in making energy refurbishment policies?*

	Why are there no further buildings being energy refurbished?
B Energy refurbishment practice	*How do you evaluate your experiences in energy rehabilitation?*
	If you faced challenges, how could they have been avoided or overcome?
	How could the way in which the energy renovation of buildings is carried out be improved?
C Thermal energy storage (TES)	
Current challenges and future trends	*TES technologies have been developed for decades, why is the use of TES still so limited?*
	What are the barriers or limitations in a further use of TES?
	Do the professionals in the building sector understand these technologies effectively?
	What are the challenges to overcome in the implementation of these technologies?
	Which TES technologies do you reckon are most likely to succeed in the future and why?
	Some TES technologies where part of the traditional architecture. Today, why do professionals consider these technologies complex to apply?
Awareness and the role of training	*What role should the training play?*
	What kind of training should be addressed?
	What are the deficiencies of the current training offer?