GUIDE OF REFERENCES FOR WATER-ENERGY RENOVATION AND CONSTRUCTION IN THE SUDOE AREA

CHARACTERISATION OF RURAL TERRITORIES IN THE SUDOE AREA

APRIL 2020

AUTHORS: Patricia Borges, Oriol Travesset-Baro, Anna Pages-Ramon, Marti Rosas-Casals (Universitat Politècnica de Catalunya), Marta Gómez (University of Southern Denmark) and the Sudoe-COLEOPTER team.

CITATION: Borges, P., Travesset-Baro, O., Gomez, M., Pages-Ramon, A., Rosas-Casals, M., and the Sudoe-COLEOPTER team (2020). Guide of references for water-energy renovation and construction in the Sudoe area.

The electronic copy of this report can be downloaded at www.coleopter.eu

COLEOPTER PROJECT

The COLEOPTER (*COncertation LocalE pour l'Optimisation des Politiques Territoriales pour l'Energie Rurale*) project develops an integrated approach to the energy efficiency of public buildings that links technical, social and economic challenges. COLEOPTER addresses two energy efficiency challenges in buildings: difficulties for rural municipalities to act and carry out work despite the positive local impact (i.e., energy savings and local employment) and a lack of awareness of building challenges, which leads to irrational use of energy/water and low renovation rates.

The COLEOPTER approach has three components:

1. Territorial dialogue with local actors to co-construct work plans of public buildings.
2. Use of Building Information Modelling (BIM) as a collaborative tool to support the dialogue.
3. Consideration of water efficiency issues along with energy challenges to better consider usage.

The approach will be tested on four public buildings, three to be renovated (in Póvoa do Lanhoso, Portugal; Cartagena, Spain; and Creuse, France) and one new building (in Creuse, France). It will be replicated in Escaldes-Engordany (Andorra) to validate its transferability.

The main contributions of the project, namely the COLEOPTER approach and the work conducted on the test sites, will benefit municipalities, citizens and small and medium-sized enterprises (SMEs), leading to better planning of energy efficiency policies and increased public and private renovation rates.

The COLEOPTER project (SOE3/P3/F0951) is financed by the Interreg Sudoe Programme that supports regional development in Southern Europe, financing transnational projects through the European Regional Development Fund. The Programme promotes transnational cooperation to solve common problems in Southern Europe, such as low investment in research and development, weak competitiveness of small and medium-sized enterprises and exposure to climate change and environmental risks.

Project leader	Céline Seince – contact@rurener.eu
Axis 3	Low-carbon economy
Objective 4C1	Improving energy efficiency policies and the use of renewable energy sources in public buildings and housing through the implementation of networks and joint experimentation
Total eligible cost	1 454 944.07 €
ERDF Grant	1 091 208.06 €
Duration	36 months (01/10/2019–30/09/2022)

Partners

RURENER
Agência para a Energía (ADENE)
Asociación Empresarial Centro Tecnológico de la Energía y del Medio Ambiente de la Región de Murcia (CETENMA)
Universitat Politècnica de Catalunya (UPC)
Comunidade intermunicipal do Ave
Ayuntamiento de Cartagena
Município da Póvoa de Lanhoso
Syndicat Mixte Ferme est Creuse

INDEX

1. INTRODUCTION

The COLEOPTER project examines four case studies in the following Sudoe eligible regions: two in Nouvelle-Aquitaine (France), one in Norte (Portugal) and one in Murcia (Spain). Additionally, the methodology will be replicated in Escaldes-Engordany (Andorra) to validate its transferability.

Figure 1 shows the buildings to be renovated in Póvoa do Lanhoso (Norte, Portugal), Tallante (Murcia, Spain), Chénérailles (Nouvelle-Aquitaine, France) and the new building in Chambon-sur-Voueize (Nouvelle-Aquitaine, France).

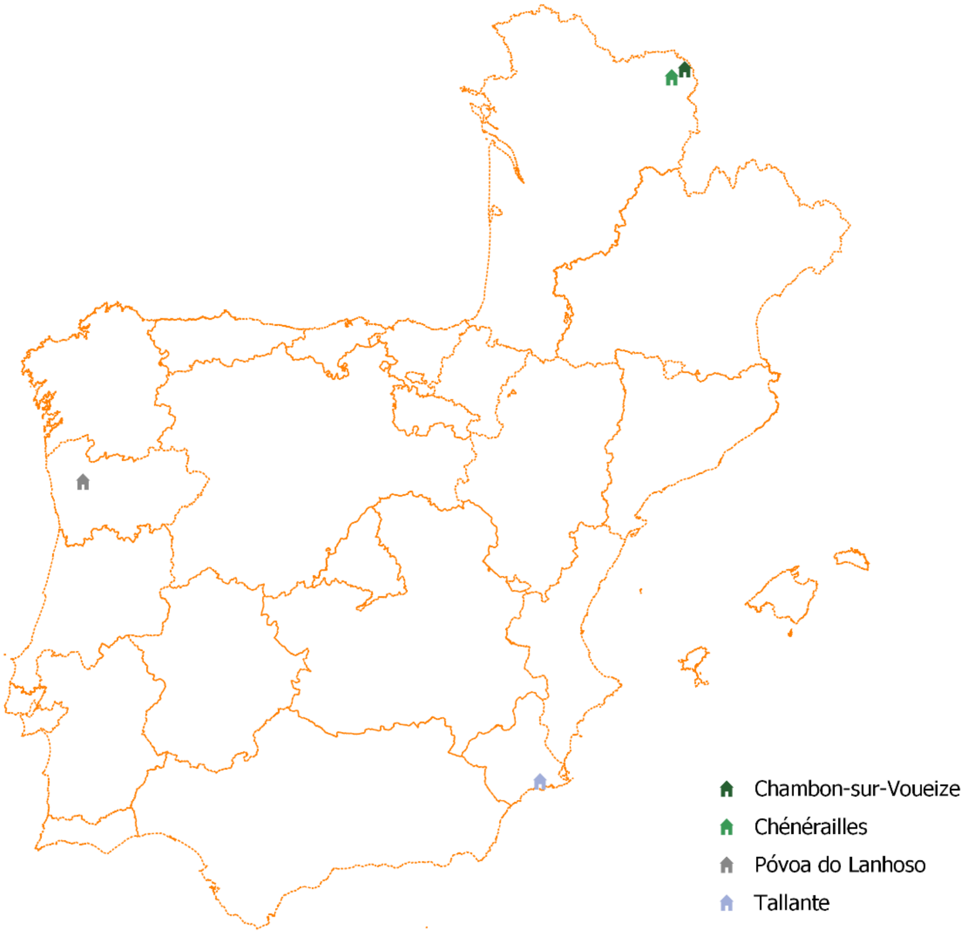


Figure 1. Location of the case studies in the COLEOPTER project

This report is divided into three main sections: a brief introduction and two main blocks of information on building renovation and construction in the Sudoe area. Section 2 contains a comparative analysis of building characteristics (including building typologies, thermal regulations and climate zones) in the COLEOPTER territories and a compilation of strategies for water-energy renovation and construction in each territory. Section 3 identifies the types and main properties of materials available in the three territories for building renovation and construction work. Finally, the document includes a guide to facilitate the selection of more appropriate materials that maximise the local impact of water-energy efficiency projects.

2. BUILDING CHARACTERISTICS IN THE COLEOPTER TERRITORIES

A significant part of a building's energy use is determined by its characteristics. In parallel, the climate severity of a territory has a considerable impact on the building heating demand (in winter) and cooling demand (in summer). As an example, Figure 2 compares the percentage contribution of cooling and heating energy demand in the climate zones of the COLEOPTER case studies (Portugal-I2V2, Spain-B3 and France-H1c). The values are based on the simulation of twelve models in each climate zone [1] (Bienvenido-Huertas, Oliveira, Rubio-Bellido, & Marín, 2019).

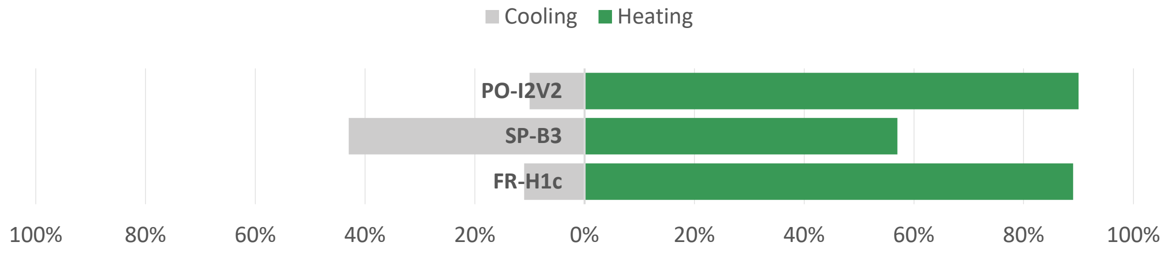


Figure 2. Percentage contribution of cooling and heating energy demand in the climate zones of the COLEOPTER case studies (based on simulations). Source: Bienvenido-Huertas et al. (2019)

Building stock analysis is the first step before sustainable water-energy renovation strategies are developed. A territory's building stock can be described in categories of building typologies. The literature provides several descriptions of building stock for countries to model their energy demand. One well-known contribution in this field is the Typology Approach for Building Stock Energy Assessment (TABULA) project, [2] which has developed residential building typologies for thirteen European countries. Each national typology consists of a classification scheme that groups buildings according to size, age and further parameters and a set of exemplary buildings representing the building types. TABULA Webtool [3] is one of the most useful outputs of the project, as it groups all the building typologies and their energy behaviour in each country.

Climate zone, construction period and building type are the parameters that tend to serve as selection criteria for building stock segmentation (Monteiro, Pina, Cerezo, Reinhart, & Ferrão, 2017). This document uses these parameters to contextualize the building characteristics in each territory. Characteristics of construction components are presented by periods to facilitate energy evaluation and to study the best saving measures. The current thermal regulations in Portugal, Spain and France, introduced as a result of transposition of Directive 2010/31/EU, are also briefly described.

Additionally, a compilation of the most common water-energy renovation and construction strategies is presented for each territory.

---

[1] Cities used for each climate zone: I2V2-Braga, D3-Mallorca and H1c-Grenoble.

[2] More information: https://episcope.eu/iee-project/tabula/

[3] More information: http://webtool.building-typology.eu/#bm

2.1 PÓVOA DO LANHOSO (PORTUGAL)

2.1.1 Thermal regulations and climate zone

In Portugal, building energy regulations are described in Decree-Law 118/2013 (2013-08-20-DRE). The regulation Portaria 379-A/2015 establishes the limit values of thermophysical properties for envelope elements. Limit values are set according to the climate zone of the building. Figure 3 shows that three climate zones are established for each season: I1, I2 and I3 in winter and V1, V2 and V3 in summer (Bienvenido-Huertas et al., 2019).

Póvoa do Lanhoso, the location of the COLEOPTER Portuguese case study, is part of the **I2V2** climate zone.

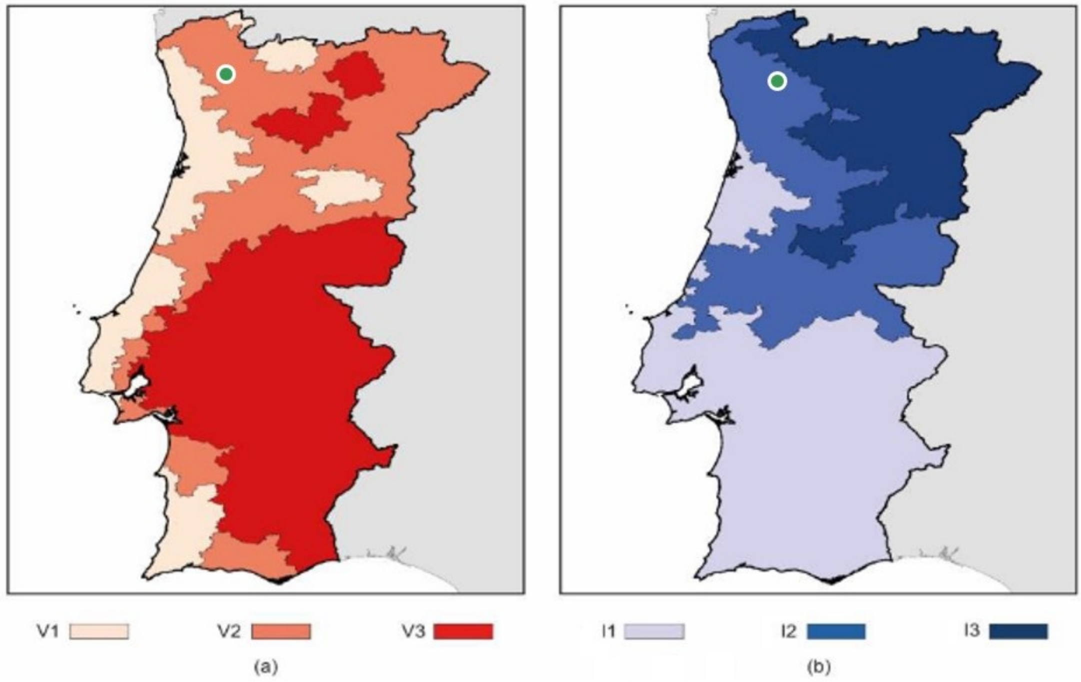


Figure 3. Climate classification in Portugal: a) summer classification and b) winter classification. Source: Bienvenido-Huertas et al. (2019)

2.1.2 Building typologies and strategies for renovation and construction

Portuguese housing stock has undergone great changes over the years. From the seventeenth century, Portuguese building evolved considerably until the use of reinforced concrete became widespread from the mid-twentieth century. As the height of buildings increased, the materials used in their construction evolved from wood to masonry (stone or brick) and finally, in the first decades of the twentieth century, to reinforced concrete.

Masonry buildings constitute a high percentage of the building stock in southern European countries, including Portugal. Given the evolution of construction practices for masonry buildings over time, variations can be found in the architecture, construction typologies and structural design. Consequently, seismic resistance varies considerably in the types of buildings that were identified. Three phases can be distinguished in masonry buildings constructed after 1755: Pombalino, Gaioleiros and Placa. Differentiation between these types of building is based not only on the time of construction, but also on the presence or absence of wooden structural elements. The existence of these elements is very important to characterize the behaviour of each type of building in relation to seismic actions. Several authors have stated that a division can be established between types of buildings according to their structural characteristics, which are directly related to the construction period and the construction technologies employed (NESDE, 2005).

Furtado, Costa, Arêde, & Rodrigues (2016) made a first attempt to divide Portuguese building stock into typologies. Unfortunately, the building typologies defined in the study were focused on reinforced concrete buildings with masonry infill walls that are vulnerable to earthquakes, which does not correspond with the goal of the present report. Monteiro et al. (2017) proposed a methodology to characterize Portuguese building stock that has certain similarities to the methodology proposed in the TABULA project. Although the study focused on how to obtain the building typologies, instead of their characterisation, the following construction periods were identified: before 1919, 1946–1960, 1961–1990, 1991–2005, 2006–2011 and after 2012.

Portugal has a range of climatic conditions, but, nowadays, the construction solutions used in buildings throughout the country are practically the same. Current construction is based on a formula that is deeply rooted and widely used throughout the country, regardless of differences in climate, geographic location, availability of raw material and lifestyle of occupants. This formula is based on a construction system in which the outer walls are double brick masonry, the interiors are simple brick masonry and the slabs consist of prestressed joists with blocks of lost formwork.

To respect European political legislation and the political commitments made over the years, several decisions have been taken that have affected buildings in Portugal. Figure 4 shows the main Portuguese energy policies that have been established to date.

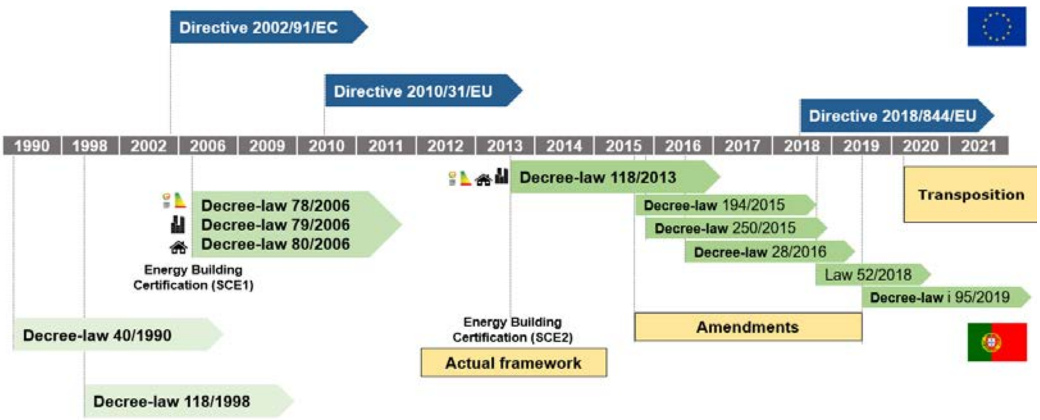
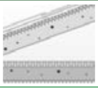
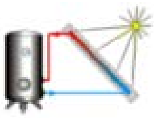


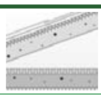
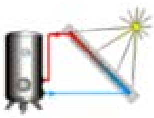
Figure 4. Main Portuguese energy policies

Decree-Law 40/90, which approved the Regulation of Thermal Behaviour of Buildings (RCCTE), was the first legislation that imposed requirements on the design of new buildings and major renovations. Its main objectives were based on guaranteeing thermal comfort requirements inside buildings without excessive energy needs, even if the construction elements did not suffer from pathologies due to condensation. Eight year later, Decree-Law 118/98 was issued, which approved the Regulation of Energy Systems for Building Climatization (RSECE). Like the previous law, this regulation focused on the thermal quality of the envelope, but with more demanding requirements. However, the main difference and objective was to define the rules of design and installation of air conditioning equipment. In 2006, after the publication of EPBD Directive 2002/91/EC, Portugal proceeded to its transposition and launched a legislative package that contained Decree-Law 78/2006 Energy

Certification System (SCE 2006), Decree-Law 79/2006 Regulation of Energy Systems and Building Climate Change (RSECE) and Decree-Law 80/2006 Regulation of Thermal Behaviour Characteristics of Buildings (RCCTE). Subsequently, buildings have tended to be more efficient. In 2013, Decree-Law 118/2013 (SCE 2013) was introduced with more demanding requirements. This is the current framework, with some amendments.

Table 1 presents the main construction elements and facilities in the Portuguese buildings since 2006, when the first SCE was approved.

2006-2013		**SCE 2006**			
Element	**Construction detail**	**Description**	**U (W/m²K) I1**	**U (W/m²K) I2**	**U (W/m²K) I3**
Roof		Concrete sloping roof with insulation (60 to 70mm)	1.25	1	0.9
Wall		Double brick masonry wall with insulation (40 to 50 mm)	1.8	1.6	1.45
Floor	-	-	-	-	-
Windows	-	-	-	-	-
Heating system		Thermal solar panel or heat pump			
Domestic hot water system					

2013-2015		**SCE 2013**			
Element	**Construction detail**	**Description**	**U (W/m²K) I1**	**U (W/m²K) I2**	**U (W/m²K) I3**
Roof		Concrete sloping roof with insulation (70 to 80mm)	1.25	1	0.9
Wall		Double brick masonry wall with insulation (50 to 60 mm)	1.75	1.6	1.45
Floor	-	-	-	-	-
Windows	-	-	-	-	-
Heating system		Thermal solar panel or heat pump			
Domestic hot water system					

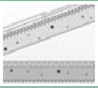
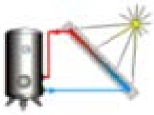
After 2015	SCE 2013 with amendments				
Element	**Construction detail**	**Description**	**U (W/m²K) I1**	**U (W/m²K) I2**	**U (W/m²K) I3**
Roof		Concrete sloping roof with insulation (60 to 70mm)	1.25	1	0.9
Wall		Double brick masonry wall with insulation (40 to 50 mm)	1.75	1.6	1.45
Floor	-	-	-	-	-
Windows		Aluminium frame, double glazed with thermal; or PVC frame with double glazed	2.8	2.4	2.2
Heating system		Thermal solar panel or heat pump			
Domestic hot water system					

Table 1. Main construction elements and facilities in Portugal (2006-2020)

Portuguese legislation proposes some changes in the composition and materials to be used in buildings' water networks that must be applied to new and refurbished buildings. Materials must be chosen according to the specifications of use, the characteristics of the distributed water (e.g. considering its fouling or aggressive power), the location of pipes and equipment, the accessories to be applied and the heterogeneous mix of materials (according to the Portuguese Institute of Quality; IPQ 2019). If the existing building network has lead sections, they must be fully replaced according to legislation on the quality of water for human consumption (Decree-Law 306/2007, 27 August).

Materials that can be used in building water networks are iron or galvanised steel, stainless steel, cast iron, plastics and semi-plastics. All selected materials and installation systems must be suitable for contact with water and for human consumption, in accordance with the legislation.

The accessories and constituents of piping systems should follow the norms. Products made from galvanised malleable cast iron should be produced in accordance with NP EN 10242 and pipes made from galvanised steel should be produced in accordance with NP EN 10255 and NP EN 10240 standards (the latter is specific to galvanised coating).

The selection of materials must be made considering:

- The characteristics and their range of applicability.
- The type of use for which they are intended, as well as the desired levels of performance and comfort.
- The operating conditions such as flow speed, water temperature, sun exposure and possible mechanical actions.
- The areas at risk of hydrocarbon contamination (benzene, toluene, ethylbenzene, xylene, etc.), and areas 50 metres around (minimum radius) fuel supply pumps. In these areas, ductile cast iron or steel piping should be installed. If plastic tubing is used, the installation should be carried out using shirting.
- Plastics, or other combustible materials, are not permitted for pipes that affect the fire network. Standing water is often present in firefighting systems, which promotes rapid aging of pipelines. The use of certain materials in galvanised irons should prevent corrosion.

Each material choice should consider the advantages and disadvantages of each material, which are summarised below.

Ferrous alloys: there are several ferrous alloy compositions that can be used in pipes and accessories of water networks. We can group them into: steel, galvanised steels, ductile cast irons and stainless steels. The use of metal pipes has decreased considerably with the increasing abandonment of the use of galvanised steel. However, metal pipes still constitute a relevant group of materials, especially for accessories (faucets, showers, etc.). They are used to transport hot and cold water and are mandatory in firefighting systems, as they enable water to be driven even with high temperatures outside.

Non-ferrous metal alloys: in addition to their enormous electrical conductivity, non-ferrous metal alloys, like copper, have characteristics such as algicide and fungicide capacity. These alloys have good resistance to atmospheric corrosion.

Polymeric materials: this family of materials consists of natural or synthetic compounds. They are obtained by polymerisation (such as polyethylene, PE), polycondensation (such as Bakelite or resin and polyester resin), polyaddition (such as vinyl polychloride, PVC) or similar processes of molecules with low molecular weight or resulting from chemical modifications of natural molecules. In this group, thermoplastic polymers are used primarily in the pipe base material and accessories, and thermosetting for coatings and elastomers when elasticity is necessary. Most of this family of materials should not be directly exposed to sunlight, as it degrades polymers.

Cementitious materials: these products are used in contact with water, mainly in reservoirs.

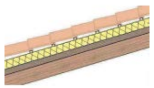
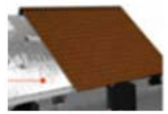
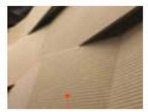
Composite materials: these materials are derived from the connection between two or more types of materials that are chemically compatible and have complementary mechanical properties, for example, ceramic and polymer, metal and polymer, and metal and ceramic. The best characteristics of the individual materials are enhanced, to obtain physical characteristics that may be superior to those of the constituents.

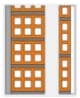
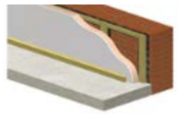
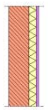
In order to complement Table 1, Adene [4] has provided data on buildings' energy certificates in CIM do Ave. [5] These data have been used to characterize construction elements and facilities. Although the data are limited to sports centres, [6] the construction elements, facilities and renovation strategies can generally be extrapolated to other public building types.

Table 2 presents the main construction elements and facilities in current sports centres in CIM do Ave based on Adene's data. The characteristics are complemented with the most common water-energy renovation strategies available for application to construction elements and facilities.

---

[4] Agência para a Energia (Portuguese Energy Agency).
[5] Póvoa do Lanhos belongs to the Comunidade Intermunicipal do Ave (CIM do Ave).
[6] The COLEOPTER case study in Póvoa do Lanhoso is a sports centre.

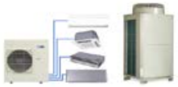
Existing state							Refurbishment measures	
Construction detail	Description	Share of current buildings (%)	Insulation information	%	Insulation U *(W/m²K)*	Element U *(W/m²K)*	Construction detail	Description
CONSTRUCTION ELEMENT: Roof								
	Sloped roof without thermal insulation	16%						**Energy efficiency** Thermal insulation installation is fundamental to ensure good energy performance
	Flat roof without thermal insulation	33%						**Waterproofing** Roof waterproofing prevents infiltration that could damage it
	Sloped roof with thermal insulation	7%	Stone wool	24%	0.034-0.04	0.35-0.43		**Fire resistance** Check the fire resistance and reaction of the materials. Request the respective technical sheet. Ideally, choose products with class A1 of reaction to fire and E in resistance
			Glass wool	1%	0.045	0.44		
	Flat roof with thermal insulation	44%	Extruded polystyrene	7%	0.037	0.44		**Acoustics** In air traffic areas or similar, information should be requested on the acoustic attenuation of the proposed materials
			Sandwich panel	14%	0.0224-0.037	0.42-1.05		

Existing state							Refurbishment measures		
Construction detail	Description	Share of current buildings (%)	Insulation information	%	Insulation U *(W/m²K)*	Element U *(W/m²K)*	Construction detail	Advantages	Disadvantages
CONSTRUCTION ELEMENT: Wall									
	Single wall without thermal insulation	7%					 Exterior insulation	- Surfaces and interior areas are not reduced - Waterproofing duration increases - It is one of the most effective methods to reduce thermal losses and increase thermal comfort inside the home	- Not recommended if the facade is not smooth and vertical - Scaffolding installation - It can change the appearance of the exterior façade - Investment
	Single or double plastered wall	25%							
	Single wall with exterior thermal insulation	55%	Expanded Polystyrene	55%	0.031-0.04	0.22-1.3	 Exterior insulation	- Easier to install than outside insulation - Keeps the appearance of exterior walls - Cheaper than applying insulation from the outside - One of the easiest methods to reduce thermal losses	- Can reduce the interior area - Increases the risk of condensation and should be avoided in very humid areas - Although the costs are lower than insulation, it requires investment capacity
			Stone wool	16%	0.04	0.42-0.53			
			Mineral wool	8%	0.04	0.46			
	Single wall with interior thermal insulation	25%	Extruded polystyrene	7%	0.037	0.38-1.02			
			Sandwich panel	14%	0.037	0.31-0.5			

COLEOPTER www.coleopter.eu - contact@rurener.eu
Project funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF)

Existing state				Usual refurbishment			Advanced refurbishment		
Construction detail	**Description**	**Share of current buildings (%)**	**U *(W/m²K)***	**Construction detail**	**Description**	**U *(W/m²K)***	**Construction detail**	**Description**	**U *(W/m²K)***
CONSTRUCTION ELEMENT: Floor									
	Flooring without thermal insulation	13%	-						
	Flooring with thermal insulation	87%	-						

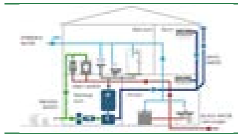
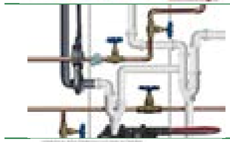
Existing state				Refurbishment				
Construction detail	**Description**	**Share of current buildings (%)**	**U *(W/m²K)***	**Construction detail**	**Description**	**U *(W/m²K)***	**Advantages**	**Disadvantages**
CONSTRUCTION ELEMENT: Window								
	PVC frame, single glazed	2%	-		Metal frame, double glazed with thermal break	2.1-2.9	- Heat losses reduction - Sound insulation improvement - More resistant than PVC (it is better for huge windows)	- Investment
	Metal frame, single glazed, with thermal break	16%	4-6.2					
	Double glazing, metal frame without thermal break	17%	2.8-4.5					
	Double glazing, metal frame with thermal break	64%	-		PVC frame with double glazed	1.1-2.4	- Heat losses reduction - Sound insulation improvement	- Investment
	Curtain wall	1%	-	-	-	-	-	-

<table>
<tr><th colspan="3">Existing state</th><th colspan="4">Refurbishments</th></tr>
<tr><th>Construction detail</th><th>Description</th><th>Share of current buildings (%)</th><th>Construction detail</th><th>Description</th><th>Advantages</th><th>Disadvantages</th></tr>
<tr><td colspan="7">FACILITIES: Heating/cooling system</td></tr>
<tr><td></td><td>Fixed radiators</td><td>5%</td><td rowspan="2"></td><td rowspan="2">Heat pump</td><td rowspan="2">- The most efficient and effective equipment to use in a home
- Significantly improves thermal comfort in the summer and allows heating in winter</td><td rowspan="2">- Initial investment</td></tr>
<tr><td></td><td>Chiller</td><td>5%</td></tr>
<tr><td></td><td>Multisplit</td><td>20%</td><td rowspan="2"></td><td rowspan="2">Chiller</td><td rowspan="2">- It is the most efficient and effective equipment to use in service buildings
- Significantly improves thermal comfort in the summer also allows heating in winter</td><td rowspan="2">- Initial investment</td></tr>
<tr><td></td><td>VRF</td><td>15%</td></tr>
</table>

Existing state			Refurbishments			
Construction detail	**Description**	**Share of current buildings (%)**	**Construction detail**	**Description**	**Advantages**	**Disadvantages**
FACILITIES: Domestic hot water						
	Conventional boiler	34%		Condensing boiler	- More Efficient	- Investment
	Water heater	7%		Solar thermal panels	- Renewable energy with zero emissions - Low operating costs - Long lifetime	- High initial investment - Additional costs for installation
	Thermal accumulator	27%		Biomass boiler	- Carbon neutral - Renewable energy source - Reduced cost of biomass compared to competitors (gas, diesel or electricity)	- More expensive than heaters or condensing boilers - Requires more space for its installation and additional space for biomass storage - Needs more careful maintenance
	Solar thermal panel	32%		Heat pump	- One of the most efficient pieces of equipment - Useful life up to 25 years - Easy installation - Low maintenance cost	- Substantial initial investment

Project funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF)

OTHER REFURBISHMENT MEASURES			
Construction detail	**Description**	**Advantages**	**Disadvantages**
FACILITIES: Lighting and other electrical equipment			
	Light replacement	- Reduced electricity consumption - Improved light quality	- The LED lamp has to fit the casing - The new lamp assembly and old luminaire may not provide the lighting foreseen in the design
	Light retrofitting	- Reduced electricity consumption - Improved light quality	- Greater investment than LEDs
	PV panels	- Reduced energy bills - Use of a free renewable energy source - Production of emission-free energy	- Investment - Period of return on investment - A suitable area needs to be available for the installation

OTHER REFURBISHMENT MEASURES			
Construction detail	**Description**	**Advantages**	**Disadvantages**
FACILITIES: Water			
	Flow reducers/aerators	- Water consumption reduction - Reduced investment and ease of implementation	- Sometimes the flow may be too low - Reduced pressure
	Alternative water sources – rainwater harvesting system	- Reduced freshwater consumption - Reduced stormwater production - Reduced surface runoff - Source of water for greywater systems	- Not viable in low rainfall regions
	Alternative water sources – greywater system	- Reduced freshwater consumption - Reduced wastewater	- High investment costs - Usually installed during the construction phase
	Piping system – design and renovation	- Leakage reduction - Reduced system net head	- Need for masonry and plumbing work
	Piping system – leakage control system	- Leakage reduction	- Need for plumbing works

Project funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF)

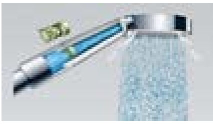
OTHER REFURBISHMENT MEASURES			
Construction detail	**Description**	**Advantages**	**Disadvantages**
FACILITIES: Water			
	Piping system – smart water meters	- Leakage reduction - Consumption profile control	- Need for plumbing works
	Efficient showers	- Reduced water consumption - Same comfort - Easy to install - Low maintenance	
	Efficient taps	- Reduced water consumption - Same comfort - Easy to install - Low maintenance	
	Dual flush toilets and auto stop urinals	- Reduced water consumption - Easy to install - Can be installed in old devices	

Table 2. CIM do Ave sports centres typologies and water-energy efficiency strategies. Source: Adene (2020)

2.2 TALLANTE (SPAIN)

2.2.1 Thermal regulations and climate zone

Royal decree 314/2006 regulates the energy efficiency of buildings in Spain (BOE-A-2006-5515). This latest royal decree is divided into several standards, including an energy saving document, which is also known as CTE-DB-HE.

Country climates are classified according to climate severity in winter and summer, which is calculated depending on heating and cooling degree days. As shown in Figure 5, the classification distinguishes five zones for winter (A, B, C, D and E) and four zones for summer (1, 2, 3 and 4) ordered by severity. The CTE-DB-HE also establishes limit values of thermal transmittance of envelope elements, which are assigned according to a building's winter climate zone. These limitations are applied to new buildings and to interventions in existing buildings (Bienvenido-Huertas et al., 2019).

The climate severity of Tallante, the location of the COLEOPTER Spanish case study, is **B3**.

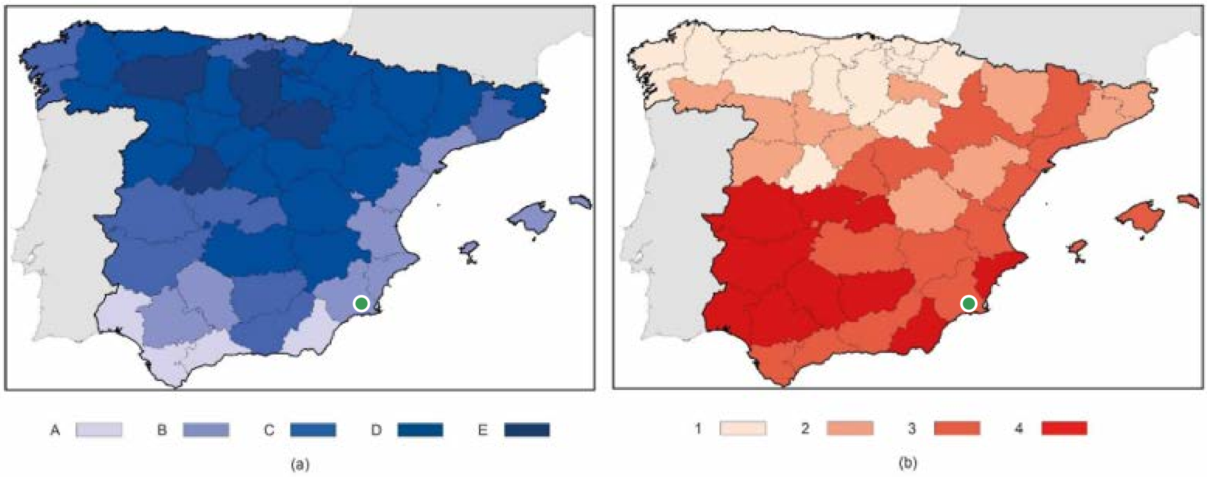


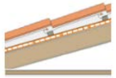
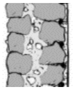
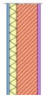
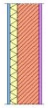
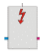
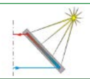
Figure 5. Climate classification in Spain: a) winter classification and b) summer classification. Source: Bienvenido-Huertas et al. (2019)

2.2.2 Building typologies and strategies for renovation and construction

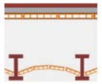
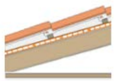
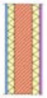
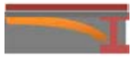
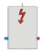
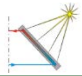
In Spain, the first thermal regulation was approved in 1979. Before that date, the energy demand of buildings was not limited by any regulations. Buildings dating from before 1979, which were mostly built without thermal insulation in their facades and roofs and with deficient carpentry with high air permeability, are real energy devourers. In general, these buildings have high energy savings potential during renovation work (IVE, 2015).

According to IVE (2016), Spanish buildings in the Mediterranean area, where Tallante is located, can be classified into six construction periods: before 1900, 1901–1936, 1937–1959, 1960–1979, 1980–2006 and after 2006.

Table 3 presents the construction elements and facilities in each construction period. Their characteristics are complemented with water-energy renovation strategies (i.e., usual refurbishment, advanced refurbishment, improved standard and ambitious standard).

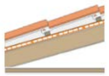
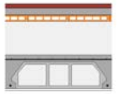
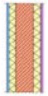
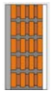
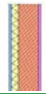
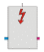
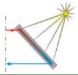
Bef. 1900	Existing state			Usual refurbishment			Advanced refurbishment		
Element	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**
CONSTRUCTION ELEMENTS									
Roof		Pitched roof, wooden frame without ventilated air chamber	5.00-5.56		Add **(1)** 12 cm or **(2)** 50 mm of insulation on the inside of the roof	**(1)** 0.25 **(2)** 0.52		Add 20 cm of insulation on the inside of the roof	0.17
		Ventilated pitched roof, wooden frame and suspended ceiling	4.17		Add 50-80 mm of insulation on the inside of the roof	0.63		Add 180 mm of insulation on the inside of the roof	0.19
		Ventilated flat roof with wooden one-way frame	1.60		Add 50 mm of insulation on the outside of the roof	0.48	-	-	-
Wall		Masonry of natural stones	0.24		Add 50 mm of insulation on the outside of the façade through ETIC	0.17	-	-	-
		Masonry of cladding bricks	2.56		Add 40-50 mm of insulation on the outside of the façade through ETIC	0.54-0.64		Add 80-120 mm of insulation on the outside of the façade through ETIC	0.26-0.36
Floor		Flooring on the ground	0.66	-	-	-	-	-	-
		Flooring on the ground	0.85		Add 10 cm of insulation	0.30		Add 20 cm of insulation	0.16
Windows		Wood frame, single glazed, bad fit	4.96-5.35		New window, metal frame and double-glazed 4-15-4	2.56		Install new windows with low-e double glazed 4-15-4 and thermal break	1.66
FACILITIES									
Heating system		Electric system		 *	Mixed natural gas condensing gas boiler heating + DHW		-	-	
Domestic hot water system		Butane gas heater						Thermal solar system contribution to the improved boiler	

* In a rural context without natural gas network, it could be replaced by a conventional biomass boiler or a condensing propane boiler.

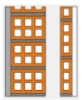
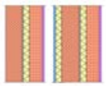
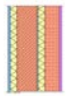
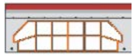
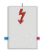
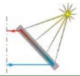
1901-1936	Existing state			Usual refurbishment			Advanced refurbishment		
Element	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**
CONSTRUCTION ELEMENTS									
Roof		Ventilated flat roof with metal frame	3.08		Add **(1)** 20 mm or **(2)** 40 mm of insulation on the inside of the roof	**(1)** 1.13 **(2)** 0.70		Add **(1)** 60 mm or **(2)** 100 mm of insulation on the inside of the roof	**(1)** 0.50 **(2)** 0.32
		Ventilated pitched roof, wooden frame and suspended ceiling	4.17		Add **(1)** 80 mm or **(2)** 100 mm of insulation on the inside of the roof	**(1)** 0.41 **(2)** 0.34		Add 180 mm of insulation on the inside of the roof	0.19
Wall		Masonry of cladding bricks	2.56		Add **(1)** 20 mm, **(2)** 40 mm, **(3)** 60 mm, **(4)** 80 mm or **(5)** 100 mm of insulation on the outside of the façade through ETIC	**(1)** 1.20 **(2)** 0.64 **(3)** 0.47 **(4)** 0.36 **(5)** 0.30		Add 120 mm of insulation on the outside of the façade through ETIC and 60 mm on the inside clad with plasterboard	0.14-0.17
Floor		Flooring on the ground	0.66-0.85	-	-	-	-	-	-
		One-way framework, metal joints	1.68	-	-	-	-	-	-
Windows		Wood frame, single glazed, bad fit	4.30-5.35		New window, metal frame with thermal break and double glazed 4-15-4	2.63		Install new windows with low-e double glazed 4-15-4 and thermal break	1.66
FACILITIES									
Heating system		Electric system		 *	Mixed natural gas condensing gas boiler heating + DHW		-	-	
Domestic hot water system		Butane gas heater						Thermal solar system contribution to the improved boiler	

* In a rural context without a natural gas network, this could be replaced by a conventional biomass boiler or a condensing propane boiler.

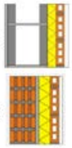
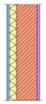
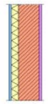
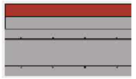
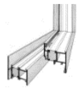
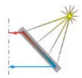
COLEOPTER www.coleopter.eu - contact@rurener.eu
Project funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF)

1937-1959	Existing state			Usual refurbishment			Advanced refurbishment		
Element	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**
CONSTRUCTION ELEMENTS									
Roof		Ventilated flat roof with metal frame	1.60		Add 50 mm of insulation on the outside of the roof	0.48	-	-	-
		Ventilated pitched roof, wooden frame and suspended ceiling	4.17		Add **(1)** 80 mm or **(2)** 100 mm of insulation on the inside of the roof	**(1)** 0.41 **(2)** 0.34		Add 180 mm of insulation on the inside of the roof	0.19
		Ventilated flat roof with concrete horizontal framework	1.67		Add 20 mm of insulation in the ventilated chamber of the roof	0.86	-	-	-
		Flat roof with one-way concrete horizontal framework, prestressed joint	1.37		Add 50 mm of insulation on the inside of the roof	0.46	-	-	-
Wall		Masonry of cladding bricks	2.56-2.94		Add **(1)** 40 mm, **(2)** 50 mm, **(3)** 60 mm or **(4)** 100 mm of insulation on the outside of the façade through ETIC	**(1)** 0.64 **(2)** 0.54 **(3)** 0.47 **(4)** 0.30		Add 120 mm of insulation on the outside of the façade through ETIC and 100 mm on the inside clad with plasterboard	0.14
		Masonry of perforated cladding bricks	2.27		Add 60 mm of insulation in the ventilated chamber of the roof	0.62		Add 100 mm of insulation in the ventilated chamber of the roof	0.30
Floor		Flooring on the ground	0.66-0.85	-	-	-	-	-	-
		One-way framework, metal joints	1.83	-	-	-	-	-	-
		One-way framework with prestressed joint	1.26-1.27	-	-	-	-	-	-
Windows		Wood frame, single glazed, bad fit	4.59-5.35		New window, metal frame with thermal break and double-glazed 4-15-4	2.63		Low-e double glazed 4-15-4 window	1.46-1.66
FACILITIES									
Heating system		Electric system		 *	Mixed natural gas condensing gas boiler heating + DHW		**-**	-	
Domestic hot water system		Butane gas heater						Thermal solar system contribution to the improved boiler	

Project funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF)

1960-1979	Existing state			Usual refurbishment			Advanced refurbishment		
Element	**Construction detail**	**Description**	**U** *(W/m²K)*	**Construction detail**	**Description**	**U** *(W/m²K)*	**Construction detail**	**Description**	**U** *(W/m²K)*
CONSTRUCTION ELEMENTS									
Roof		Ventilated pitched roof, wooden frame and suspended ceiling	4.17		Add 12 cm of insulation on the inside of the roof	0.28		Add new waterproofing, 20 cm of insulation and gravel	0.19
		Ventilated flat roof with metal frame	1.61-1.67		Add 20 mm of insulation inside the cavity of the roof	0.44	-	-	-
		Flat roof with one-way concrete horizontal framework, prestressed joint	1.37-1.92		Add new waterproof, 50 mm on the outside of the roof	0.46-0.51	-	-	-
Wall		Brick cavity wall without insulation	1.33-1.64	 1 2	Add insulation **(1)** inside the cavity and **(2)** 20 mm to 40 mm of insulation on the outside of the façade, through ETIC	**(1)** 0.53-0.57 **(2)** 0.40-0.45		Add insulation inside the cavity and 140 mm of insulation on the outside of the façade, through ETIC	0.12
Floor		Flooring on the ground	0.85	-	-	-	-	-	-
		One-way framework with prestressed joint	1.07-1.72	-	-	-	-	-	-
Windows	 1 2	**(1)** Wood frame, single glazed, bad fit **(2)** Metal frame, single glazed, no thermal break	**(1)** 4.59 **(2)** 5.70		New window, metal frame with thermal break and double-glazed 4-15-4	2.63		Low-e double glazed 4-15-4 window	1.46-1.66
FACILITIES									
Heating system		Electric system		 1-2	**(1)** Mixed natural gas condensing boiler heating + DHW, **(2)** conventional biomass boiler		-	-	
Domestic hot water system		Gas heater						Thermal solar system contribution to the improved boiler	

COLEOPTER www.coleopter.eu - contact@rurener.eu
Project funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF)

1980-2006	Existing state			Usual refurbishment			Advanced refurbishment		
Element	**Construction detail**	**Description**	**U** *(W/m²K)*	**Construction detail**	**Description**	**U** *(W/m²K)*	**Construction detail**	**Description**	**U** *(W/m²K)*
CONSTRUCTION ELEMENTS									
Roof		Flat roof, one-way framework with prestressed joint and insulation	0.52-0.60	-	-	-	-	-	-
Roof		Pitched roof, one-way framework with prestressed joints and insulation	1.92		Add 20 mm of insulation on the inside of the roof	0.88		Add 40 mm of insulation on the inside of the roof	0.59
Wall	1 2 	Cavity wall of **(1)** concrete block or **(2)** brick, with insulation inside the cavity	0.58-0.72		Add **(1)** 20 mm or **(2)** 40 mm of insulation exterior side of the façade through ETIC	**(1)** 0.51 **(2)** 0.36-0.39		Add **(1)** 60 mm or **(2)** 80 mm of insulation on the outside of the façade through ETIC	**(1)** 0.31 **(2)** 0.25
Floor		Flooring on the ground	0.89	-	-	-	-	-	-
Floor		One-way framework with prestressed joint	1.61-2.94	-	-	-	-	-	-
Windows		PVC frame, double glazed, thermal break	3.09-3.37		Install new windows, metal frame with thermal break and double glazed 4-6-4	2.83		Low-e double glazed 4-15-4 window	1.46-1.66
FACILITIES									
Heating system	 1  2	**(1)** Conventional mixed LPG boiler, **(2)** electrical equipment by pipes, **(3)** natural gas DHW system		 1-2	**(1)** Conventional mixed biomass boiler, **(2)** natural gas condensing boiler		-	-	
Domestic hot water system	 3							Thermal solar system contribution to the improved boiler	

COLEOPTER www.coleopter.eu - contact@rurener.eu
Project funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF)

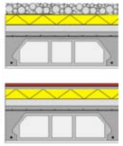
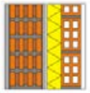
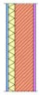
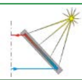
After 2006	National minimum requirement			Improved standard			Ambitious standard		
Element	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**
CONSTRUCTION ELEMENTS									
Roof	1 2 	Flat roof, one-way framework with prestressed joints and insulation, **(1)** gravel or **(2)** ceramic tile finish	0.45-0.48	-	-	-	-	-	-
Wall		Cavity or brick wall with insulation inside the cavity	0.47-0.52		Add 40 mm of insulation on the outside of the façade through ETIC	0.31		Add 80 mm of insulation on the outside of the façade through ETIC	0.19
Floor		One-way framework with prestressed joint with insulation	0.44-0.56	-	-	-	-	-	-
Windows		PVC frame, double glazed, thermal break	3.09-3.37	-	-	-		Low e double glazed 4-15-4 window	1.46-1.66
FACILITIES									
Heating system		Conventional mixed natural gas boiler heating + DHW		-	-		-	-	
Domestic hot water system					Thermal solar system contribution to the existing boiler		-	-	

Table 3. Mediterranean Spanish building typologies and water-energy efficiency strategies. Source: IVE (2016).

2.3 CHAMBON-SUR-VOUEIZE AND CHÉNÉRAILLES (FRANCE)

2.3.1 Thermal regulations and climate zone

In France, the regulations establishing building requirements are the *Code de la construction et de l'habitation.* The levels of thermal and energy performance that are described in Article R 131-28 of the code were updated in the decree *Arrêté du 22 mars 2017.*

Unlike other regulations based on transmittance, the limitations of the thermophysical properties of the envelope in France are based on thermal resistance and depend on the climate zone of the building. Climate is divided into three zones for winter (H1, H2 and H3) and four for summer (a, b, c and d). As shown in Figure 6, eight climate zones are obtained from the combinations of winter and summer zones (Bienvenido-Huertas et al., 2019).

The climate zone of Chambon-sur-Voueize and Chénérailles, which are the locations of the French COLEOPTER case studies, is **H1c**. According to simulations carried out by Bienvenido-Huertas et al. (2019), buildings located in zones with a summer classification of type c (H1c and H2c) are those with a greater annual energy demand.

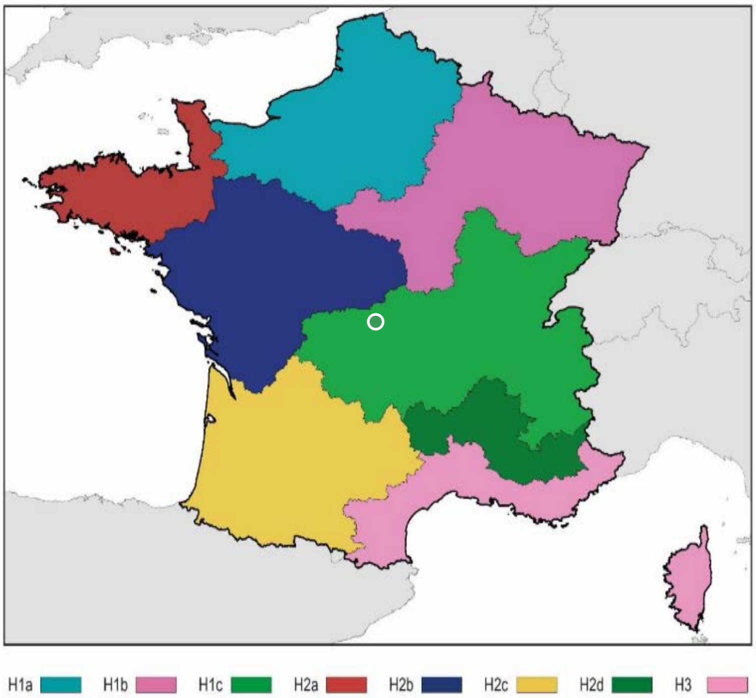


Figure 6. Climate classification in France. Source: Bienvenido-Huertas et al. (2019)

2.3.2 Building typologies and strategies for renovation and construction

The first thermal regulation in France was approved in 1974. At this time, there was a major change in energy efficiency of new buildings. According to the exhaustive study *Analyse détaillée du parc résidentiel existant* by PACTE (2017), French construction can be divided into four long periods:

Before 1948. In 1948, the massive post-war reconstruction period began.

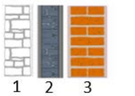
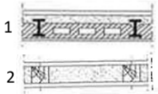
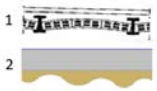
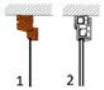
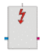
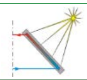
1948–1974. These two dates mark the distinction between ancient buildings built before 1948 and recent buildings built after 1974.

1975–2000. In 1975, the first thermal regulation was implemented. Before this date, buildings were often not insulated. The 1974 regulation imposed a minimum level of insulation.

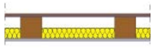
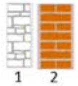
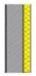
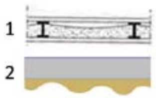
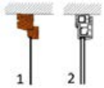
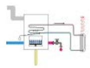
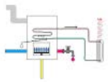
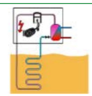
After 2000. The energy weight of buildings built after 2000 is not studied in detail.

In this report, the main construction periods are divided into subperiods to provide more detail on building stock characteristics. Based on Rochard, Shanthirablan, & Brejon (2015), French buildings can be classified into ten construction periods: before 1915, 1915–1948, 1949–1967, 1968–1974, 1975–1981, 1982–1989, 1990–1999, 2000–2005, 2006–2012 and after 2012. The subperiods before 1974 correspond to historical dates that reflect significant changes in construction methods and the subperiods after 1974 correspond to changes due to the evolution of regulations.

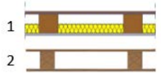
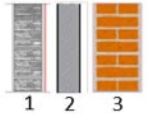
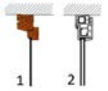
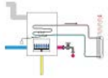
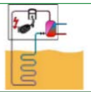
Table 4 presents the construction elements and facilities in each construction period. Their characteristics are complemented with water-energy renovation strategies (i.e., usual refurbishment, advanced refurbishment, effinergie+ and passive level).

Bef. 1915	Existing state			Usual refurbishment			Advanced refurbishment		
Element	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**
CONSTRUCTION ELEMENTS									
Roof		Wooden sloping roof **(1)** with insulation and tiled roofing, **(2)** with zinc roofing	**(1)** 1.35 **(2)** 2.40		Add 12 cm of insulation between rafters + 10 cm of wood fibre	0.36		Add 12 cm of insulation between rafters + 18 cm of wood fibre	0.20
Wall		Masonry of: **(1)** rubble stone, **(2)** hewn stone, **(3)** solid bricks	**(1)** 1.50 **(2-3)** 1.70		Add 6-11 cm of insulation on the inside of the façade	0.26-0.37		Add 10-12 cm of insulation on the inside of the façade	0.23-0.24
Floor		**(1)** Metal beams, flooring and brickwork, **(2)** in solid brick vaults between metal joints	**(1)** 2.30 **(2)** 1.20		Add 10 cm of sub-slab insulation	0.32		Add 14 cm of sub-slab insulation	0.23
		**(1)** Floor in solid brick vaults between metal joists, **(2)** concrete floor on solid ground	**(1)** 3.55 **(2)** 2.90		Add 7 cm of sub-slab insulation	0.32		Add 10 cm of sub-slab insulation	0.23
Windows		**(1)** Wood frame, single glazed, **(2)** wood or PVC frame, double glazed, 4/12/4, air	**(1)** 4.80 **(2)** 2.60		Wood or PVC frame, double glazed, with reinforced thermal insulation for glazing (Ug = 1.1)	1.40		Wood or PVC frame, double glazed, with reinforced thermal insulation for glazing (Ug = 0.8)	1.00
FACILITIES									
Heating system		Electric system			Gas condensing boiler, individual system		-	-	
Domestic hot water system		Electric heater, individual distribution without looping			Instantaneous DHW by individual boiler			Thermal solar system contribution to the improved boiler	

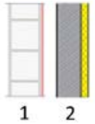
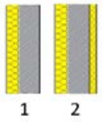
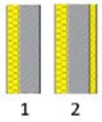
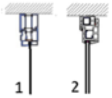
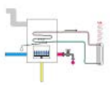
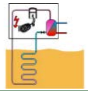
Project funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF)

1915-1948	Existing state			Usual refurbishment			Advanced refurbishment		
Element	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**
CONSTRUCTION ELEMENTS									
Roof		Wooden sloping roof **(1)** with insulation and tiled roofing, **(2)** with zinc roofing	**(1)** 1.35 **(2)** 2.40		Add 12 cm of insulation between rafters + 10 cm of wood fibre	0.36		Add 12 cm of insulation between rafters + 18 cm of wood fibre	0.20
		Wooden roof with 1 cm of insulation on the inside of the roof	2.42		Add 22 cm of insulation on the outside of the roof	0.14		Add 30 cm of insulation on the outside of the roof	0.10
		Concrete flat roof without insulation	3.00-3.60		Add 10 cm of insulation on the outside of the roof	0.23		Add 20 cm of insulation on the outside of the roof	0.14
Wall		Masonry of: **(1)** rubble stone, **(2)** solid bricks	**(1)** 1.80-2.10 **(2)** 1.70-1.80		Add **(1)** 11 cm or **(2)** 12 cm of insulation on the inside of the façade	**(1)** 0.26 **(2)** 0.24		Add 16 cm of insulation on the inside of the façade	0.19
Floor		**(1)** Metal beams flooring and brickwork in solid brick vaults between metal joints, **(2)** concrete floor with heavy aggregates	1.70		Add 10 cm of insulation underneath	0.32		Add 14 cm of insulation underneath	0.23
Windows		**(1)** Wood frame, single or double glazed, **(2)** wood or PVC frame, double glazed, 4/12/4, air	**(1)** 4.80-2.80 **(2)** 2.60		Wood or PVC frame, double glazed, with reinforced thermal insulation for glazing (Ug = 1.1)	1.40		Wood or PVC frame, triple glazed, with reinforced thermal insulation for glazing (Ug = 0.8)	1.00
FACILITIES									
Heating system		Standard oil boiler			Gas condensing boiler, individual system		-	-	
Domestic hot water system		Electric heater, individual distribution without looping			Instantaneous DHW by individual boiler			Thermal solar system contribution to the improved boiler	

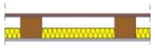
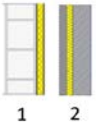
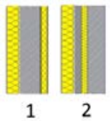
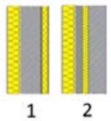
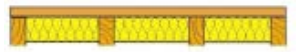
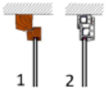
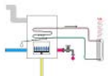
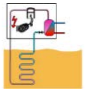
COLEOPTER www.coleopter.eu - contact@rurener.eu
Project funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF)

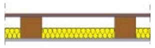
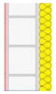
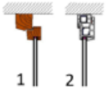
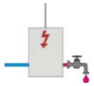
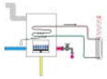
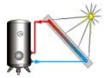
1949-1967	Existing state			Usual refurbishment			Advanced refurbishment		
Element	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**
CONSTRUCTION ELEMENTS									
Roof		Concrete flat roof without insulation	3.00-3.20		Add 10 cm of insulation on the outside of the roof	0.23		Add 20 cm of insulation on the outside of the roof	0.14
		Wooden roof **(1)** with 1 cm of insulation on the inside of the roof, **(2)** without insulation	**(1)** 2.42 **(2)** 1.45		Add 22 cm of insulation on the inside of the roof	0.14		Add 30 cm of insulation on the inside of the roof	0.10
Wall		Masonry of: **(1)** rubble stone, **(2)** concrete wall, **(3)** masonry solid bricks	**(1)** 1.50 **(2-3)** 1.70		Add 12 cm of insulation on the outside of the façade	0.26		Add 16 cm of insulation on the outside of the façade	0.19
		Concrete floor **(1)** without insulation, **(2)** with heavy aggregates	2.40-2.80		Add 10 cm of insulation sub-slab or 7 cm of insulation sub-screed	0.32		Add 14 cm of insulation underneath or 7 cm of insulation underfloor	0.23
Windows		**(1)** Wood frame, single or double glazed, **(2)** wood or PVC frame, double glazed, 4/12/4, air	**(1)** 4.80-2.80 **(2)** 2.60		Wood or PVC frame, double glazed, with reinforced thermal insulation for glazing (Ug = 1.1)	1.40		Wood or PVC frame, double glazed, with reinforced thermal insulation for glazing (Ug = 0.8)	1.00
FACILITIES									
Heating system		Standard oil boiler			Gas condensing boiler, individual system		-	-	
Domestic hot water system		Electric heater, individual distribution without looping			Instantaneous DHW by individual boiler			Thermal solar system contribution to the improved boiler	

Project funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF)

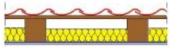
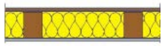
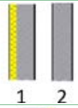
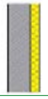
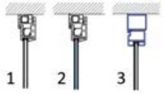
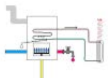
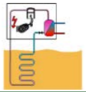
1968-1974	Existing state			Usual refurbishment			Advanced refurbishment		
Element	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**
CONSTRUCTION ELEMENTS									
Roof		Concrete flat roof without insulation	3.00-3.20		Add 10 cm of insulation on the outside of the roof	0.23		Add 20 cm of insulation on the outside of the roof	0.14
		Concrete flat roof with 4 cm of insulation	0.76		Add 10 cm of insulation on the outside of the roof	0.23		Add 20 cm of insulation on the outside of the roof	0.14
		Wooden sloping roof with insulation and tiled roofing,	1.35		Add 12 cm of insulation between rafters + 10 cm of wood fibre	0.36		Add 12 cm of insulation between rafters + 18 cm of wood fibre	0.20
Wall		**(1)** Breeze blocks wall by clay tiles without insulation, **(2)** concrete wall with 4 cm of insulation on the inside of the wall	**(1)** 2.40 **(2)** 0.78		Add 12 cm of insulation on the outside of the façade	0.26		Add 16 cm of insulation on the outside of the façade	0.19
Floor		Concrete floor without insulation	2.50		Add 10 cm of insulation sub-slab	0.32		Add 14 cm of insulation sub-slab	0.23
Windows		**(1)** Metal frame, single glazed with thermal break, **(2)** wood or PVC frame, double glazed, 4/12/4, air	**(1)** 5.60 **(2)** 2.60		Wood or PVC frame, double glazed, with reinforced thermal insulation for glazing (Ug = 1.1)	1.40		Wood or PVC frame, double glazed, with reinforced thermal insulation for glazing (Ug = 0.8)	1.00
FACILITIES									
Heating system		Standard oil boiler			Gas condensing boiler, individual system		-	-	
Domestic hot water system		Electric heater, individual distribution without looping			Instantaneous DHW by individual boiler			Thermal solar system contribution to the improved boiler	

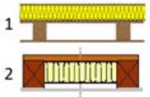
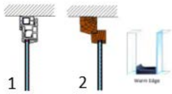
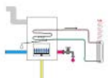
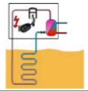
COLEOPTER www.coleopter.eu - contact@rurener.eu
Project funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF)

1975-1981	Existing state			Usual refurbishment			Advanced refurbishment		
Element	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**
CONSTRUCTION ELEMENTS									
Roof		Concrete flat roof with **(1)** 4 cm or **(2)** 8 cm of insulation	**(1)** 0.76 **(2)** 0.57		Add 10 cm of insulation on the outside of the roof	0.23		Add **(1)** 20 cm or **(2)** 30 cm of insulation on the outside of the roof	**(1)** 0.14 **(2)** 0.10
		Wooden roof with **(1)** 8 cm or 10 cm of insulation on the inside of the roof	0.49		Add 22 cm of insulation on the inside of the roof	0.14		Add 30 cm of insulation on the inside of the roof	0.10
Wall		**(1)** Breeze block wall and clay tiles with 4 cm of insulation on the inside of the wall, **(2)** concrete sandwich panel with 4 cm of insulation	**(1)** 0.61 **(2)** 0.79		Add 12 cm of insulation on the outside of the façade	0.26		Add 16 cm of insulation on the outside of the façade	0.19
Floor		Concrete floor with 5 cm of sub-screed insulation and 3 cm of fibralith	0.46		Add 10 cm of sub-slab insulation	0.32		Add 14 cm of sub-slab insulation	0.23
		Wooden floor with 4 cm of insulation between beams	0.90		Add 12 cm of sub-slab insulation	0.27		Add 16 cm of sub-slab insulation	0.21
		Concrete floor with 2 cm of sub-screed insulation	1.25		Add 7 cm of sub-screed insulation	0.32		Add 10 cm of sub-screed insulation	0.23
Windows		**(1)** Wood frame, double glazed 4/6/4, air, **(2)** PVC frame, double glazed, 4/6/4, air	**(1)** 2.80 **(2)** 3.10		Wood or PVC frame, double glazed, with reinforced thermal insulation for glazing (Ug = 1.1)	1.40		Wood or PVC frame, double glazed, with reinforced thermal insulation for glazing (Ug = 0.8)	1.00
FACILITIES									
Heating system		Standard oil boiler			Gas condensing boiler, individual system		-	-	
Domestic hot water system		Electric heater, individual distribution without looping			Instantaneous DHW by individual boiler			Thermal solar system contribution to the improved boiler	

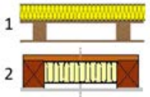
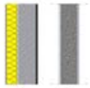
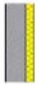
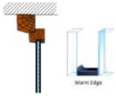
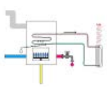
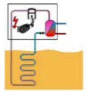
1982-1989	Existing state			Usual refurbishment			Advanced refurbishment		
Element	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**
CONSTRUCTION ELEMENTS									
Roof		Concrete flat roof with 6 cm of insulation	0.62		Add 10 cm of insulation on the outside of the roof	0.23		Add 20 cm of insulation on the outside of the roof	0.14
		Wooden roof with 10 cm of insulation on the inside of the roof	0.32		Add 22 cm of insulation on the inside of the roof	0.14		Add 30 cm of insulation on the inside of the roof	0.10
Wall		Breeze block wall with clay tiles and 7-8 cm of insulation on the inside of the wall	0.42-0.47		Add 11-12 cm of insulation on the inside of the façade	0.24-0.26		Add 16 cm of insulation on the inside of the façade	0.19
		Concrete wall with 8 cm of insulation on the outside	0.36		Add 12 cm of insulation on the outside of the façade	0.26		Add 16 cm of insulation on the outside of the façade	0.19
		Shuttered concrete wall with 4 cm of insulation on the inside of the façade	0.78		Add 12 cm of insulation on the outside of the façade	0.26		Add 16 cm of insulation on the outside of the façade	0.19
Floor		Concrete floor with 5-8 cm of sub-slab insulation	0.42-0.54		Add 12 cm of sub-slab insulation	0.27		Add 16 cm of sub-slab insulation	0.21
		Concrete floor with 2 cm of sub-screed insulation	1.25		Add 7 cm of sub-screed insulation	0.32		Add 10 cm of sub-screed insulation	0.23
Windows		**(1)** Wood frame, double glazed 4/6/4, air, **(2)** wood or PVC frame, double glazed, 4/12/4, air	**(1)** 2.80 **(2)** 2.60		Wood or PVC frame, double glazed, with reinforced thermal insulation for glazing (Ug = 1.1)	1.40		Wood or PVC frame, triple glazed, with reinforced thermal insulation for glazing (Ug = 0.8)	1.00
FACILITIES									
Heating system		Wood stoves (>2001) and electric convectors			Wood-fired boiler, individual insulated network			Wood-fired boiler, individual insulated network	
Domestic hot water system		Electric heater, individual distribution, without looping			Instantaneous DHW by individual boiler			Thermal solar system contribution to the improved boiler	

COLEOPTER www.coleopter.eu - contact@rurener.eu
Project funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF)

1990-1999	Existing state			Usual refurbishment			Advanced refurbishment		
Element	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**
CONSTRUCTION ELEMENTS									
Roof		Concrete flat roof with 8-6 cm of insulation	0.43		Add 10 cm of insulation on the outside of the roof	0.23		Add 20 cm of insulation on the outside of the roof	0.14
		Insulation between wood joist	**(1)** 0.19 **(2)** 0.24		Add the equivalent of 6 cm of insulation on the outside or inside of the roof	0.25		Add the equivalent of 10 cm of insulation at the outside or inside of the roof	0.18
		Wooden roof with 14 cm of insulation	0.23	-	-	-		Add 30 cm of insulation on the outside of the roof	0.10
Wall		**(1)** Concrete wall with 8 cm of insulation on the outside of the façade, **(2)** concrete wall	**(1)** 0.36 **(2)** 3.00		Add 12 cm of insulation on the outside of the façade	0.26		Add 16 cm of insulation on the outside of the façade	0.19
		Concrete wall with 10 cm of insulation on the inside of the façade	0.33		Add 12 cm of insulation on the outside of the wall	0.26		Add 16 cm of insulation on the outside of the wall	0.19
Floor		Concrete slab with **(1)** 7 cm or **(2)** 10 cm of sub-screed insulation	**(1)** 0.42 **(2)** 0.36		Add 12 cm of sub-slab insulation	0.27		Add 16 cm of sub-slab insulation	0.21
		Concrete slab with 10 cm of sub-slab insulation	0.34	-	-	-		Add 16 cm of sub-slab insulation	0.21
Windows		**(1)** Wood or PVC frame, double glazed, 4/12/4, air, **(2)** wood or PVC frame, double glazed, 4/12/4, air, and low emissivity layer, **(3)** metal frame, double glazed, 4/12/4, air	**(1)** 2.60 **(2)** 1.80 **(3)** 3.30		Wood or PVC frame, double glazed, with reinforced thermal insulation for glazing (Ug = 1.1)	1.40		Wood or PVC frame, triple glazed, with reinforced thermal insulation for glazing (Ug = 0.8)	1.00
FACILITIES									
Heating system		Standard oil boiler			Gas condensing boiler, individual system		-	-	
Domestic hot water system		Electric heater, individual distribution without looping			Instantaneous DHW by individual boiler			Thermal solar system contribution to the improved boiler	

2000-2005	Existing state			Usual refurbishment			Advanced refurbishment		
Element	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**
CONSTRUCTION ELEMENTS									
Roof		Concrete flat roof with 10 cm of insulation	**(1)** 0.28 **(2)** 0.19		Add 10 cm of insulation on the outside of the roof	0.23		Add 20 cm of insulation on the outside of the roof	0.14
		**(1)** Wooden roof with 20 cm of insulation, **(2)** insulation between wood joist	**(1)** 0.19 **(2)** 0.24		Add the equivalent of 4-6 cm of insulation on the outside or inside of the roof	0.17-0.18		Add the equivalent of 8-10 cm of insulation at the outside or inside of the roof	0.13-0.14
Wall		Hollow cinder block wall or concrete wall with 10 cm of insulation on the inside of the façade	0.30-0.33		Add 12 cm of insulation on the outside of the wall	0.26		Add 16 cm of insulation on the outside of the wall	0.19
Floor		Concrete slab with **(1)** 7 cm or **(2)** 10 cm of sub-screed insulation	**(1)** 0.42 **(2)** 0.36		Add 12 cm of sub-slab insulation	0.27		Add 16 cm of sub-slab insulation	0.21
		Concrete slab with 10 cm of sub-slab insulation	0.34	-	-	-		Add 16 cm of sub-slab insulation	0.21
Windows		**(1)** Wood or PVC frame, double glazed, 4/12/4, air, and low emissivity layer, **(2)** frame, double glazed, 4/12/4, reinforced thermal insulation for glazing	**(1)** 1.80 **(2)** 1.60		Wood or PVC frame, double glazed, with reinforced thermal insulation for glazing (Ug = 1.1)	1.40		Wood or PVC frame, triple glazed, with reinforced thermal insulation for glazing (Ug = 0.8)	1.00
FACILITIES									
Heating system		Standard oil boiler			Gas condensing boiler, individual system		-	-	
Domestic hot water system		Electric heater, individual distribution without looping			Instantaneous DHW by individual boiler			Thermal solar system contribution to the improved boiler	

Project funded by the Interreg Sudoe Programme through the European Regional Development Fund (ERDF)

2006-2012	Existing state			Usual refurbishment			Advanced refurbishment		
Element	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**	**Construction detail**	**Description**	**U (W/m²K)**
CONSTRUCTION ELEMENTS									
Roof		Concrete flat roof with **(1)** 8 cm, or **(2)** 12 cm of insulation	**(1)** 0.28 **(2)** 0.19		Add **(2)** 10 cm of insulation	**(2)** 0.23		Add **(1)** 20 cm of insulation	**(1-2)** 0.12
		**(1)** Wooden roof with 20 cm of insulation, **(2)** insulation between wood joist	**(1)** 0.19 **(2)** 0.24		Add the equivalent of 4 cm of insulation on the outside or inside of the roof	0.17		Add the equivalent of 8 cm of insulation on the outside or inside of the roof	0.14
Wall	 1 2	**(1)** Concrete wall with 12 cm of insulation on the outside of the façade, **(2)** cellular concrete blocks wall	0.29		Add the equivalent of 5 cm of insulation on the outside of the façade	0.20-0.22		Add the equivalent of 10 cm of insulation on the outside of the façade	0.15-16
		Concrete wall with 10 cm of thermal insulation on the inside of the façade	0.30		Add 12 cm of insulation on the outside of the wall	0.26		Add 16 cm of insulation on the outside of the wall	0.19
Floor		Insulating vaults on crawl space with sub-screed insulation	0.18		Add **(1)** 7 cm - **(2)** 10 cm of insulation underneath	**(1)** 0.32 **(2)** 0.28		Add **(1)** 10 cm - **(2)** 14 cm of insulation underneath	**(1)** 0.23 **(2)** 0.19
		Concrete slab with **(1)** 12 cm or **(2)** 16 cm of sub-screed insulation	**(1)** 0.27 **(2)** 0.20	-	-	-		Add 16 cm of sub-slab insulation	0.21
Windows		Frame, double glazed, 4/12/4, reinforced thermal insulation for glazing	1.60		Wood or PVC frame, double glazed, 4/16/4 with reinforced thermal insulation for glazing (Ug = 1.1)	1.40		Wood or PVC frame, triple glazed, with reinforced thermal insulation for glazing (Ug = 0.8)	1.00
FACILITIES									
Heating system		Standard oil boiler			Gas condensing boiler, individual system		-	-	
Domestic hot water system		Electric heater, individual distribution without looping			Instantaneous DHW by individual boiler			Thermal solar system contribution to the improved boiler	

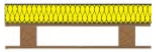
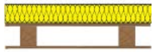
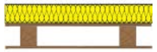
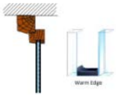
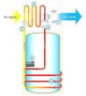
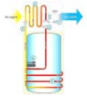
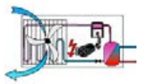
After 2012	Thermal regulation 2012			Label "*effinergie +*"			Passive level		
Element	**Construction detail**	**Description**	**U *(W/m²K)***	**Construction detail**	**Description**	**U *(W/m²K)***	**Construction detail**	**Description**	**U *(W/m²K)***
CONSTRUCTION ELEMENTS									
Roof		Concrete flat roof with **(1)** 8 cm, **(2)** 16 cm, or **(3)** 20 cm of insulation	**(1)** 0.28 **(2)** 0.15 **(3)** 0.12		Concrete flat roof with **(1)** 12 cm, or **(2)** 20 cm of insulation	**(1)** 0.19 **(2)** 0.12 **(3)** -		Concrete flat roof with **(1)** 20 cm, or **(2-3)** 24 cm of insulation	**(1)** 0.12 **(2)** 0.10 **(3)** 0.10
		Wooden roof with 22 cm of insulation above	0.17		Wooden roof with 30 cm of insulation above	0.13		Wooden roof with 30 cm of insulation above	0.13
Wall		Insulating brick wall with 10 cm of insulation inside the wall	0.21		Insulating brick wall with 12 cm of thermal insulation inside the wall	0.18		Concrete wall with 26 cm of thermal insulation outside the wall	0.12
		Concrete wall with 12 cm of insulation outside the wall	0.25		Concrete wall with 16 cm of thermal insulation outside the wall	0.19			
		Timber frame wall with 14 cm of insulation and interior lining with 4 cm of insulation	0.24		Timber frame wall with 20 cm of insulation and interior lining with 4 cm of insulation	0.18		Timber frame wall with 22 cm of insulation and interior lining with 10 cm of insulation	0.11
Floor		Insulating vaults on crawl space	0.21		Insulating vaults on crawl space with 8 cm of insulation	0.12		Insulating vaults on crawl space with 8 cm of insulation	0.12
		Concrete floor with 12 cm of insulation under slab	0.27		Concrete floor with 16 cm of insulation under the floor	0.19-0.21		Concrete floor with **(1)** 20 cm or **(2)** 26 cm of insulation under the floor	**(1)** 0.17 **(2)** 0.12
Windows		Frame, double glazed, 4/12/4, reinforced thermal insulation for glazing	1.60		Wood or PVC frame, double glazed, with reinforced thermal insulation for glazing (Ug = 1.1)	1.40		Passive carpentry, triple glazed, 4/16/4/16/4, with reinforced thermal insulation for glazing	0.80
FACILITIES									
Heating system		**(1)** Air-to-water electric heat pump		-	-			Multi-integrated system with exhaust air heat pump	
Domestic hot water system		Heat pump + storage tank, individual distribution without looping			Heat pump + storage tank, individual distribution, improved insulation, without looping			Multi-integrated system + storage tank, individual distribution, improved insulation, without looping	

Table 4. French building typologies and water-energy efficiency strategies. Source: Rochard, Shanthirablan, & Brejon (2015)

3. LOCAL AVAILABILITY OF RENOVATION AND CONSTRUCTION MATERIALS

The aim of this section is to compile the raw materials, local processing of the materials and local production in COLEOPTER territories to be used in renovation and/or construction works. All this information has been compiled and complemented with a set of properties to consider in water-energy renovation and construction in the Sudoe area. This information is included in Section 3.2. Section 3.1 describes the main material properties and characteristics included in the analysis.

3.1 MATERIAL PROPERTIES GUIDE

CES EduPack Database for Architecture [7] (Ashby, Fernandez, & Gray, 2008) was used to collect the properties of the materials included in this report. This database contains more than 120 materials commonly used in architectural applications, including engineered woods, steels, concretes, bricks and cements. A comprehensive set of mechanical, thermal, electrical, hygrothermal, acoustic and eco-properties are provided by the CES Edupack Database, along with durability information.

This report only includes properties with a high impact in terms of water-energy renovation and construction. The description below is based on Ashby, Fernandez, & Gray (2008). Additionally, the materials compiled in Section 3.2 are identified by building subsystem, in other words, by where in a building they can be used.

3.1.1 Building subsystem

The **superstructure (S)** is the collection of elements, including columns, beams, slabs and other components, that transfer static and dynamic loads from the building down to the foundation (or the substructure). Most building superstructures are hidden from view, covered by interior and exterior finishing materials. Other superstructures are an integral aspect of a building's architecture. Examples are the Eiffel Tower or the Centre Pompidou, both in Paris.

The **enclosure (E)** includes all the components that contribute to a durable, reliable weather barrier between the ever-changing exterior climate and the need for a stable interior environment. Windows, doors, vapour and air barriers, brick masonry, wood siding, copper flashing and many other components are assembled to control the flux resulting from air pressure, water vapour and thermal gradients between the inside and the outside. In addition, the enclosure is the "face" of a building and thus plays an important symbolic role.

The **interior (I)** building system includes all the non-structural components that spatially define the habitable space of buildings such as floor assemblies and surfaces, ceilings and wall materials, partitions, interior glazing, doors and other space-defining elements.

The building **services (Sv)** are a set of elements that provide a constant stream of air, heating and cooling, electricity, water and data delivered from central utility plants in the building to all spaces within the interior volume. This diverse group of components includes metal ducts to deliver heated or cooled air, copper and PVC plumbing to transport water, insulated copper wiring, glass optical fibre cables and many kinds of devices that serve these delivery systems including, chillers, boilers, pumps and valves. These systems are material intensive, as they require not only all kinds of metals and

[7] GRANTA EduPack software, Granta Design Limited, Cambridge, UK, 2020 (www.grantadesign.com)

ceramics to store and deliver water and air, but also a great variety of polymers and composites for seals, adhesives, gaskets and other joint conditions.

While **water facilities (W)** are part of the services subsystem, the present report identifies them in an individual category to emphasize their relevance in renovation and construction works.

3.1.2 General properties

Source identifies when a material comes directly from nature.

The **price** (in €/kg) of materials depends on many factors, including the influence of supply and demand, the amount someone wishes to purchase and the relationship with the supplier. The prices of commodity materials given in the CES Edupack Database are derived from current London Metal Exchange, Bullion Market and Commodity Market values. Where this is not possible, prices are derived from a price model.

Density (in kg/m^3) is the mass per unit volume.

3.1.3 Thermal and combustion properties

The **conductivity** of a material represents its ability to conduct heat. Some materials conduct heat well, others offer resistance to conduction. In this document, the thermal conductivity is ranked on a 4-point scale: good insulator, poor insulator, poor conductor and good conductor.

Thermal resistivity (in m·ºC/W) is the rate at which heat is conducted through a solid at steady state.[8] It is governed by thermal conductivity λ. The thermal resistivity is the reciprocal of the thermal conductivity. Figure 7 shows a CES Edupack Database representation of the thermal resistivity of various materials.

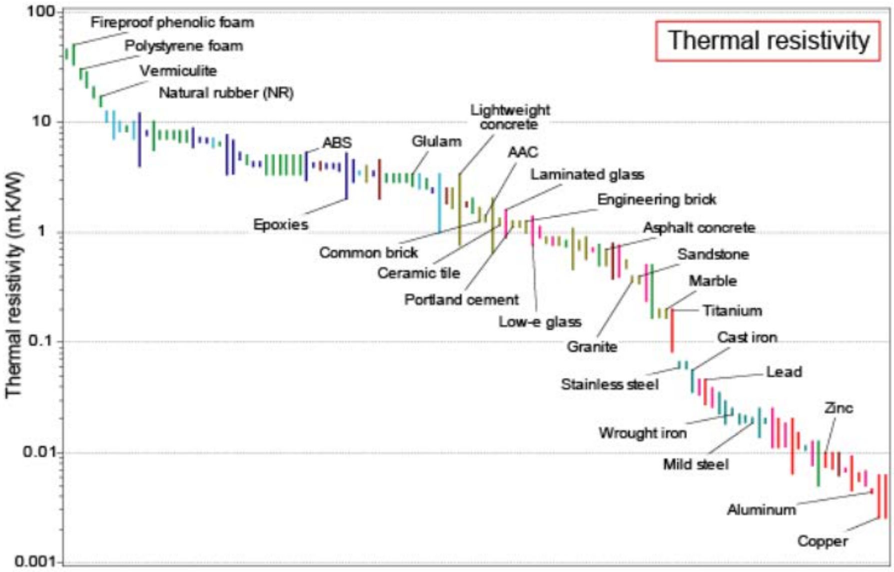


Figure 7. Bar chart of thermal resistivity of various materials. Source: Ashby et al. (2008)

[8] Meaning that the temperature profile does not change over time.

Specific heat capacity at constant pressure (in J/kg·ºC) specifies the amount of heat required to raise the temperature of 1 kg of material by 1°C (K). It is measured by recording the heat flux (W/m^2) flowing from the surface at temperature T_1 to one at T_2 in the material, separated by distance.

Emissivity is a measure of the heat radiation emitted by a material. An ideal black body is assigned an emissivity of 1. The emissivity is highly dependent on the surface condition of the material, whether it is polished, painted or coated. The information in this report refers to the emissivity of the material in its natural state.

3.1.4 Hygrothermal properties

Water absorption (in %) is defined as the increase in mass as a result of moisture absorption when a major surface of a specimen is placed in contact with liquid water.

Water vapour permeability (in kg·m/s·m^2·Pa) is defined as the mass of water vapour transmitted in unit time, under unit pressure difference, through a unit area of material of unit thickness. The CES Edupack database uses values quoted for relative humidity of 50% and room temperature.

Frost resistance. Resistance to water absorption is the most important aspect of resisting damage due to freeze-thaw cycles. Brittle and porous materials, such as lime mortars, brick and concrete, may be critically damaged by absorbing liquid water that then freezes and expands within the solid. In this document, frost resistance is ranked on a 5-point scale ranging from very good to very poor.

3.1.5 Eco-properties

Eco-properties are grouped into three categories (primary material production, material processing and material recycling) as detailed below. All categories include **embodied energy** and the **CO_2 footprint**. Additionally, primary material production includes **water usage** and material recycling includes the **recycle fraction**.

Primary material production

- The **embodied energy** (in MJ/kg) is the energy required to make 1 kg of the material from its ores or feedstocks. The data are approximate but are still useful to rank materials by the energy they have required. Figure 8 presents the embodied energies and thermal conductivities of various construction materials.

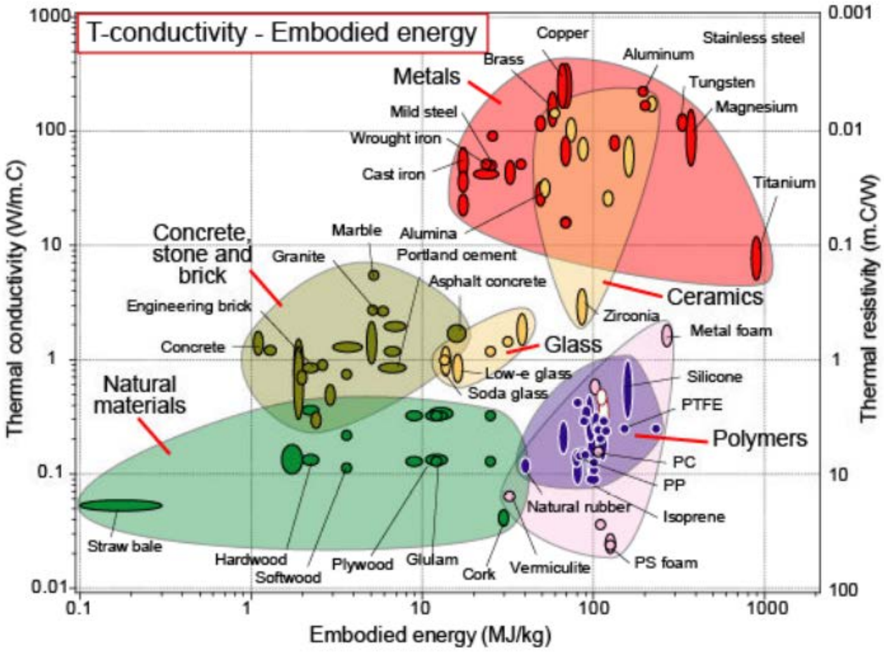


Figure 8. Embodied energy and thermal resistivity of construction materials. Source: Ashby et al. (2008)

- The **CO_2 footprint** (in $kgCO_2/kg$) is the mass of equivalent CO_2 produced and released into the atmosphere, as a consequence of the production of one kg of the material.
- **Water usage** data (in l/kg) are largely compiled by direct measurements of factory inputs and outputs. The range for engineering materials extends from 10 l/kg to over 1000 l/kg. Water usage data includes extraction of minerals, material conditioning, pollution control, cooling material or equipment, etc. The water consumption for natural materials includes water used for cultivation, on top of that utilised during manufacturing. It should be noted that water usage is very dependent on location. The scarcity or abundance of water will affect manufacturing practice. These values give a global world average and do not reflect local variations in water supply.

Material processing

- The **embodied energy** (in MJ/kg) in material processing includes the energy used to convert the material to one kilogram of the product.
- The **CO_2 footprint** (in $kgCO_2/kg$) in material processing represents the emitted CO_2 associated with the conversion of the material to one kilogram of the product.

Material recycling

- The **recycle fraction** (in %) is the fraction of current supply that is derived from recycling.
- The **embodied energy** (in MJ/kg) in material recycling includes the energy used to recycle one kilogram of the product.
- **CO_2 footprint** (in $kgCO_2/kg$) in material recycling represents the emitted CO_2 to recycle one kilogram of the product.

3.2 RAW MATERIALS, LOCAL PROCESSING AND LOCAL PRODUCTION IN EACH TERRITORY

Table 5 shows the raw materials and products available in the three territories for building renovation and construction work. Additionally, it gives their main properties to facilitate the selection of more appropriate materials to maximize the local impact of water-energy efficiency projects.

All raw materials and products are identified by their availability in the Sudoe territories with the collaboration of COLEOPTER partners and associates in each country. Raw materials are identified by local [9] availability (**L**) and the existence of local processing (**LP**) of the material. Products are identified if they are produced at local scale (**LPD**).

[9] Local refers to CIM do Ave in Póvoa do Lanhoso, Murcia in Tallante and Creuse in Chambon-sur-Voueize and Chénérailles.

	Availability in the Sudoe territories									Building system					General properties		Thermal and combustion properties			Hygrothermal properties		Material production			Material processing		Material recycling		
	CIM do Ave			Murcia			Creuse			S	E	I	W	Sv	Source	Density	Resistivity	Specific heat capacity	Emissivity	Water absorption	Water vapour permeability	Embodied energy	CO_2 footprint	Water usage	Embodied energy	CO_2	Recycle fraction	Embodied energy	CO_2 footprint
	L	LP	LPD	L	LP	LPD	L	LP	LPD							kg/m^3	m.°C/W	J/kg.°C	%	%	Kg.m/s.m^2.Pa	MJ/kg	kg/kg	l/kg	MJ/kg	kg/kg	%	MJ/kg	kg/kg
PETROUS MATERIALS																													
Brick and tile																													
Ceramic tile			✓			✓					✓	✓	✓		Natural	2.05e^3-2,.4e^3	1.18-1.33	750-850	0.5	0.05-0.3	1.02e^{-13}-7e^{-13}	11.4-12.6	1.59-1.76	12-13.2	3.18-3.52	0.239-0.264	0.1	-	-
Common brick			✓			✓				✓	✓	✓			Natural	1.69e^3-1.95e^3	1.25-1.67	750-850	0.75-0.93	2-7	4.38e^{-12}-4.67e^{-12}	2.2-5	0.206-0.227	5.27-5.38	9.7-10.7	0.727-5.83	15-20	-	-
Engineering brick			✓			✓				✓	✓	✓			Natural	2.1e^3-2.5e^3	1-1.25	750-850	0.75-0.93	0.5-2	4.38e^{-12}-4.67e^{-12}	26.5-29.3	3.71-4.1	5.27-5.83	7.29-8.05	0.547-0.604	0.1	-	-
Facing brick			✓			✓				✓	✓	✓			Natural	2.05e^3-2.3e^3	1.11-1.25	750-850	0.75-0.93	2-7	2.5e^{-12}-2e^{-11}	20.5-22.6	2.86-3.16	5.27-5.83	3.24-3.58	0.243-0.269	0.1	-	-
Refractory brick			✓			✓				✓	✓	✓	✓		Natural	600-900	2.86-4	750-800	0.75-0.93	0.2-0.3	-	2.4	0.181-0.2	21.8-24.1	1.63-1.8	0.122-0.135	0.1	-	-
Ceramics (other than tiles)													✓		Natural	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cement																													
Cement (ordinary Portland)						✓				✓	✓	✓	✓		Natural	1.79e^3-2.21e^3	1.11-1.25	815-865	0.54	9.76e^{-12}-2.6e^{-11}	-	5.4-6	0.906-1	35.1-38.8	2.35-2.6	0.177-0.195	1.1-1.3	-	-
Concrete																													
Asphalt concrete						✓				✓	✓	✓	✓		Natural	2.2e^3-2.8e^3	0.5-0.7	850-920	0.9	0	0	1-1.3	0.0903-0.0998	3.23-3.57	0.537-0.593	0.0403-0.0445	0.758-0.838	0.0631-0.0698	13-14.4
Autoclaved aerated concrete						✓				✓	✓				Natural	400-900	1.25-1.43	860-1.1e3	0.63-0.97	-	6.01e^{-12}-2.8e^{-11}	1-1.3	0.0903-0.0998	14.3-15.8	0.949-1.05	0.0712-0.0787	0.758-0.838	0.0631-0.0698	13-14.4
Concrete (structural lightweight)						✓				✓	✓				Natural	1.4e^3-2e^3	0.769-3.33	860-1.1e3	0.63-0.97	-	2e^{-12}-6.01e^{-12}	1-1.3	0.0903-0.0998	14.3-15.8	2.49-2.76	0.187-0.207	0.758-0.838	0.0631-0.0698	13-14.4
Dense concrete						✓			✓	✓	✓		✓		Natural	2e^3-2.4e^3	0.571-0.909	835-1.05e3	0.63-0.97	-	2e^{-12}-6.01e^{-12}	1-1.3	0.0903-0.0998	3.23-3.57	2.06-2.28	0.155-0.171	0.758-0.838	0.063-0.07	12.5-15
High performance concrete						✓				✓	✓				Natural	2.5e^3-2.7e^3	0.77-0.9	900-1e3	0.63-0.97	-	2e^{-12}-6.01e^{-12}	1-1.3	0.0903-0.0998	3.23-3.57	6.08-6.72	0.456-0.504	0.758-0.838	0.0631-0.0698	13-14.4
High volume fly ash concrete						✓				✓	✓		✓		Natural	1.83e^3-2.2e^3	0.8-0.9	813-867	0.63-0.97	-	2e^{-12}-6.01e^{-12}	1-1.3	0.0903-0.0998	3.23-3.57	5.31-5.87	0.398-0.44	13-14	-	-
Reactive powder concrete						✓				✓	✓				Natural	0.146-2.75e^3	0.7-0.83	900-1e3	0.63-0.97	1.5-1.6	2e^{-12}-6.01e^{-12}	1-1.3	0.0903-0.0998	3.23-3.57	25.6-28.3	1.92-2.12	13-14.4	-	-
Plaster																													
Plaster						✓					✓	✓			Natural	1.18e^3-1.7e^3	1.67-2.5	600-1e^3	0.9	-	-	2.09-2.31	0.186-0.206	9.79-10.8	2.72-3.01	0.204-0.225	0.1	-	-
Bitumen																													
Bitumen						✓				✓	✓				Natural	997-1.05e^3	0.17-0.2	1.68e^3-1.8e^3	0.93-0.95	0	0	101-111	0.2-0.3	-	-	-	0.1	-	-
Stone																													
Granite	✓	✓		✓	✓		✓	✓		✓	✓	✓	✓	✓	Natural	2.63e^3-2.8e^3	0.358-0.398	775-840	0.44	0.1-0.5	-	5.5-6.4	0.303-0.335	3.23-3.57	11.4-12.6	0.858-0.949	1-2	-	-
Limestone				✓	✓					✓	✓	✓	✓	✓	Natural	2.55e^3-2.6e^3	0.465-1.09	807-924	0.95	2.5-11	-	0.24-0.35	0.0147-0.0163	13-14.4	6.19-6.84	0.464-0.513	1.3-1.5	-	-
Marble				✓	✓		✓	✓		✓	✓	✓	✓	✓	Natural	2.73e^3-2.84e^3	0.167-0.2	853-887	0.75-0.95	0.1-0.5	4.73e^{-13}-6.51e^{-12}	1.8-2.2	0.118-0.13	3.23-3.57	5.66-6.26	0.425-0.469	1.3-1.5	-	-
Sandstone				✓	✓					✓	✓	✓	✓	✓	Natural	2.24e^3-2.66e^3	0.345-0.398	837-923	0.6-0.83	2-8.5	-	0.4-0.6	0.0269-0.0297	3.23-2.57	7.34-8.11	0.551-0.608	1.3-1.5	-	-
Slate				✓	✓					✓	✓	✓	✓	✓	Natural	2.6e^3-2.9e^3	0.476-0.556	-	0.9	0.01-0.1	-	1.16-1.29	0.0698-0.0772	3.23-3.57	10.5-11.6	0.788-0.871	5-10	-	-

	Availability in the Sudoe territories									Building system					General properties		Thermal and combustion properties			Hygrothermal properties		Material production			Material processing		Material recycling		
	CIM do Ave			Murcia			Creuse			S	E	I	W	Sv	Source	Density	Resistivity	Specific heat capacity	Emissivity	Water absorption	Water vapour permeability	Embodied energy	CO_2 footprint	Water usage	Embodied energy	CO_2	Recycle fraction	Embodied energy	CO_2 footprint
	L	LP	LPD	L	LP	LPD	L	LP	LPD							kg/m³	m.ºC/W	J/kg.ºC	%	%	Kg.m/s.m².Pa	MJ/kg	kg/kg	l/kg	MJ/kg	kg/kg	%	MJ/kg	kg/kg
GLASS																													
Laminated glass			✓			✓			✓	✓	✓	✓	✓	✓	Natural	$2.35e^3$-$2.45e^3$	0.9-1.6	850-950	-	0	0	27.7-30.6	1.67-1.84	28.7-31.8	37.48-41.43	2.844-3.146	0.1	21.4-23.7	0.649-0.718
Low-e glass			✓			✓				✓	✓	✓		✓	Natural	$2.44e^3$-$2.49e^3$	0.77-1.4	850-950	0.1-0.4	0	0	17.1-18.9	1.1-1.21	376-416	38.6-42.77	2.936-3.246	0.1	13.2-14.6	0.324-0.359
Soda-lime glass			✓			✓				✓	✓	✓	✓	✓	Natural	$2.44e^3$-$2.49e^3$	0.909-1.11	848-953	0.86-0.95	0	0	10.1-11.1	0.72-0.796	13.6-15.1	33.42-37.76	2.545-2.877	23-25	8.25-9.1	0.504-0.555
METALLIC MATERIALS																													
Ferrous alloys																													
Cast iron						✓			✓	✓	✓	✓	✓	✓	Natural	$6.94e^3$-$7.23e^3$	0.0139-0.025	460-508	350-450	0	0	30.8-34	2.26-2.49	44-48	11063.5-12183.5	829.4-914.9	60-80	7.65-8.45	0.291-0.321
Galvanised steel						✓			✓	✓	✓	✓	✓	✓	Natural	$7.8e^3$-$7.9e^3$	0.0185-0.02	460-505	150-180	0	0	26-28.7	1.78-1.97	56.3-62.2	17310.1-19132.2	1295.8-1437.5	52.3-57.8	7.14-7.89	-
Terne coated steel						✓			✓	✓	✓	✓	✓	✓	Natural	$7.85e^3$-$7.9e^3$	0.0108-0.0112	481	90-150	0	0	32.6-36	2.18-2.41	299-330	17310.1-19132.1	1295.8-1427.4	52.3-57.8	8.49-9.38	-
Stainless steel						✓			✓	✓	✓	✓	✓	✓	Natural	$7.61e^3$-$7.87e^3$	0.0588-0.0667	450-510	640-747	0	0	69.1-76.2	5.18-5.71	130-140	11582.9-12802.1	870.88-960.31	35-40	16.8-18.5	1.36-1.5
Wrought iron						✓			✓	✓	✓	✓	✓	✓	Natural	$7.4e^3$-$7.8e^3$	0.022-0.025	460-470	340-400	0	0	25.1-27.7	1.72-1.9	42.3-46.7	18510.5-20432.5	1385.83-1537.57	52.3-57.8	6.96-7.69	0.0376-0.0415
Non-ferrous alloys																													
Aluminium						✓				✓	✓	✓	✓	✓	Natural	$2.7e^3$-$2.73e^3$	0.0055-0.0065	934-972	77-180	0	0	198-219	12.2-13.5	$1.13e^3$-$1.25e^3$	15679-17297.17	1173.4195-1294.8098	40.5-44.7	33.4-37	0.958-1.21
POLYMERS AND ELASTOMERS																													
Elastomers																													
Ethylene propylene terpolymer						✓					✓	✓	✓		Man-made	860-870	5.88-7.14	$2e^3$-$2.2e^3$	0.86-0.87	0.01	-	90-99.4	4.28-4.73	-	17.483-19.29	2.303-2.54	0.1	-	-
Polychloroprene						✓					✓	✓	✓		Man-made	$1.23e^3$-$1.3e^3$	8.33-10	$2.11e^3$-$2.19e^3$	0.9	0.1-0.2	-	61.2-67.6	67.6	126-378	20.73-22.81	4.9-5.42	1.3-1.5	-	-
Polymers																													
Polycarbonate						✓					✓	✓	✓		Man-made	$1.19e^3$-$1.21e^3$	4.59-5.29	$1.15e^3$-$1.25e^3$	0.88	0.135-0.2	$2.2e^{-12}$-$2.5e^{-12}$	103-114	5.74-6.35	165-182	43.75-48.36	3.2804-3.626	0.67-0.74	35.1-38.6	2.32-2.56
Epoxies						✓					✓	✓	✓		Man-made	$1.11e^3$-$1.4e^3$	2-5.56	$1.17e^3$-$1.25e^3$	-	0.05-0.8	$8.99e^{-13}$-$9.05e^{-13}$	127-140	6.83-7.55	26.6-29.4	53.89-59.35	4.148-4.573	0.67-0.74	-	-
DUCK CANVAS AND FIBERS																													
Foams																													
Fireproof phenolic foam						✓			✓		✓	✓		✓	Man-made	35-70	33.3-50	$1.85e^3$-$1.91e^3$	-	6-7	$3.79e^{-11}$-$3.8e^{-11}$	97.9-108	4.48-4.95	148-163	39.036-43.162	3.1133-3.43	0.1	-	-
Polystyrene			✓			✓			✓		✓	✓	✓	✓	Man-made	47-53	25-30.3	$1.2e^3$-$1.22e^3$	0.6	1-3	$1.46e^{-12}$-$4.38e^{-12}$	106-117	4.04-4.46	433-479	34.325-37.933	2.7104-2.9975	0.95-1.05	45.1-49.8	1.43-1.59
Vermiculite						✓			✓		✓	✓		✓	Man-made	64-160	14.2-17.2	840-$1.08e^3$	0.95-0.98	20-50	-	24.3-26.7	1.3-1.44	14.7-16.3	-	-	0.1	-	-
Man-made fibres																													
Carbon fibre						✓			✓		✓	✓	✓	✓	Man-made	$1.8e^3$-$1.85e^3$	0.005-0.0125	705-715	0.53	-	-	380-420	23.9-26.4	7.03-7.77	-	-	4.73-5.22	-	-
Glass fibre			✓			✓			✓		✓	✓	✓	✓	Man-made	$2.55e^3$-$2.6e^3$	0.741-0.833	800-805	0.75	0	$5.84e^{-11}$-$1.61e^{-10}$	62.2-68.8	3.34-3.69	89.8-99.2	-	-	0.1	-	-

	Availability in the Sudoe territories									Building system					General properties		Thermal and combustion properties			Hygrothermal properties		Material production			Material processing		Material recycling		
	CIM do Ave			Murcia			Creuse			S	E	I	W	Sv	Source	Density	Resistivity	Specific heat capacity	Emissivity	Water absorption	Water vapour permeability	Embodied energy	CO_2 footprint	Water usage	Embodied energy	CO_2	Recycle fraction	Embodied energy	CO_2 footprint
	L	LP	LPD	L	LP	LPD	L	LP	LPD							kg/m³	m.°C/W	J/kg.°C	%	%	Kg.m/s.m².Pa	MJ/kg	kg/kg	l/kg	MJ/kg	kg/kg	%	MJ/kg	kg/kg
DUCK, CANVAS AND FIBERS																													
Foam																													
Cotton		✓									✓	✓		✓	Natural	$1.52e^{3}$-$1.56e^{3}$	3.33-5	$1.2e^{3}$-$1.22e^{3}$	0.77	-	-	43.5-48.1	2.45-2.71	$7.38e^{3}$-$8.16e^{3}$	-	-	0.1	-	-
Flax		✓									✓	✓		✓	Natural	$1.47e^{3}$-$1.5e^{3}$	3.33-5	$1.2e^{3}$-$1.22e^{3}$	0.87-0.95	-	-	10.5-11.6	0.368-0.407	$2.98e^{3}$-$3.29e^{3}$	-	-	0.1	-	-
Wool		✓									✓	✓		✓	Natural	$1.25e^{3}$-$1.34e^{3}$	3.33-5	$1.32e^{3}$-$1.38e^{3}$	0.87-0.95	-	-	46.1-50.8	1.09-1.2	$1.62e^{5}$-$1.79e^{5}$	-	-	0.1	-	-
WOOD																													
Wood																													
Cork										✓	✓	✓			Natural	177-218	20.8-28.6	$1.9e^{3}$-$2.1e^{3}$	118-142	-	-	3.8-4.2	0.181-0.2	665-735	2.968-3.29	0.18694-0.2757	0.1	-	-
Glulam							✓	✓		✓	✓	✓			Natural	500-650	2.63-3.33	$1.66e^{3}$-$1.71e^{3}$	120-140	12-25	-	11.2-12.4	0.831-0.919	665-735	6.364-7.021	0.4766-0.5266	1.34-1.48	-	-
Hardboard										✓	✓	✓			Natural	800-$1.05e^{3}$	2.86-3.33	$1.66e^{3}$-$1.71e^{3}$	117-137	12-25	$9.12e^{-13}$-$2.01e^{-12}$	35.5-39.3	1.78-1.97	665-735	15.055-16.6	1.1286-1.2478	1.34-1.48	-	-
Hardwood																													
Oak							✓			✓	✓	✓			Natural	851-$1.03e^{3}$	2.5-3.03	$1.67e^{3}$-$1.7e^{3}$	118-142	12-30	-	9.82-10.9	0.841-0.93	665-735	24.58-27.24	1.8487-2.04	8.6-9.4	-	-
Softwood																													
Pine	✓						✓			✓	✓	✓			Natural	380-420	8.33-9.09	$1.66e^{3}$-$1.71e^{3}$	117-137	12-30	$5.84e^{-13}$-$7.8e^{-12}$	8.77-9.7	0.358-0.396	665-735	4.453-4.913	0.3339-0.3685	8-10	-	-

Table 5. Raw materials and products available in the three territories for building renovation and construction work

REFERENCES

Adene. (2020). *Sport centre buildings energy certification in CIM do Ave and most common water-energy efficiency strategies. Personal communication*.

Ashby, M. F., Fernandez, J., & Gray, A. (2008). *The CES EduPack Database for Architecture and the Built Environment*. 12.

Bienvenido-Huertas, D., Oliveira, M., Rubio-Bellido, C., & Marín, D. (2019). A comparative analysis of the international regulation of thermal properties in building envelope. *Sustainability (Switzerland)*, *11*(20). https://doi.org/10.3390/su11205574

Furtado, A., Costa, C., Arêde, A., & Rodrigues, H. (2016). Geometric characterisation of Portuguese RC buildings with masonry infill walls. *European Journal of Environmental and Civil Engineering*, *20*(4), 396–411. https://doi.org/10.1080/19648189.2015.1039660

IVE. (2015). *Potencial de ahorro energético y reducción de emisiones de CO2 en la Comunitat Valenciana*. Retrieved from http://episcope.eu/fileadmin/episcope/public/docs/pilot_actions/ES_EPISCOPE_RegionalCaseStudy_IVE.pdf

IVE. (2016). *Catálogo de tipología edificatoria residencial. Ámbito: España*. Valencia.

Monteiro, C. S., Pina, A., Cerezo, C., Reinhart, C., & Ferrão, P. (2017). The Use of Multi-Detail Building Archetypes in Urban Energy Modelling. *Energy Procedia*, *111* (September 2016), 817–825. https://doi.org/10.1016/j.egypro.2017.03.244

NESDE. (2005). Evoluçao das tipologias construtivas em Portugal. Retrieved March 10, 2020, from http://www-ext.lnec.pt/LNEC/DE/NESDE/divulgacao/evol_tipol.html

PACTE. (2017). *Analyse détaillée du parc résidentiel existant*.

Rochard, U., Shanthirablan, S., & Brejon, C. (2015). *Bâtiments résidentiels. Typologie du parc existant et solutions exemplaires pour le rénovation énergétique en France*. Paris.