# Comparative Analysis of Residential Energy Consumption in Different European Countries

Mestrado em Engenharia da Energia e do Ambiente

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Leiria, Setembro de 2019

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Dissertação realizada sob a orientação do Professor Doutor Luís Miguel Pires Neves e do Professor Doutor Sotirios Karellas

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# Originalidade e Direitos de Autor

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# Resumo


A humanidade consome mais recursos naturais do que a capacidade que a Terra tem para regenerá-los. Diante desse problema, os olhos do mundo estão virados para a sustentabilidade. Várias ações para diminuir e consumir recursos naturais de maneira eficiente estão a realizar-se em todo o mundo. A União Europeia desenvolveu várias estratégias para o uso eficiente de recursos, incluindo a energia. Existe um alto potencial para economizar a energia no setor dos edifícios, principalmente na área de edifícios residenciais.

Este estudo focou-se nas residências unifamiliares para conhecer os fatores que afetam o consumo de energia por meio de uma análise comparativa da energia utilizada em residências de diferentes países do Mediterrâneo europeu. Os países escolhidos para esta análise foram a Grécia, Portugal e Espanha, países que compartilham condições meteorológicas, geográficas e políticas semelhantes. Para esta análise, apenas foi levada em consideração a energia utilizada para aquecimento e arrefecimento de ambientes e para aquecimento de água.

Dados estatísticos e regulamentações nacionais foram utilizadas para escolher duas regiões de cada país e representar uma casa típica de cada região. Os valores anuais de consumo da energia foram obtidos através de simulação dinâmica, testando a variação de parâmetros tais como temperatura interna, horário de operação dos sistemas e comportamento dos ocupantes com vista à análise do seu impacto.

Como resultado das simulações, obteve-se que o aquecimento de espaços é a atividade que mais consome entre as selecionadas, possuindo um grande potencial de economia de energia. O uso eficiente da energia mantém o conforto térmico dos ocupantes e reduz o consumo de energia. O estudo mostrou que vários fatores afetam o uso da energia, mas o principal é o comportamento humano, sendo por isso importante o papel das políticas reguladoras de consumo que alteram comportamento das pessoas.

A evolução das políticas na Europa tem sido notável nos últimos anos, mas é necessária a criação de políticas mais rígidas que ajam com rapidez suficiente. Os ocupantes devem equilibrar o consumo entre conforto e a consciência energética, procurando mudar algumas das múltiplas pequenas decisões que tomamos todos os dias para criar um futuro mais sustentável no nosso planeta.

**Palavras chave:** Comportamento humano, Consumo de energia no Mediterrâneo, Simulação dinâmica do comportamento energético de edifícios residenciais.

# Abstract

Humanity consumes more natural resources than the Earth has the ability to regenerate them. Given this problem, world eyes are over sustainability. Several actions for reducing and consume natural resources efficiently are being carried out worldwide. The European Union has developed several strategies for the efficient use of resources, including energy. There is a high potential for energy savings in the building stock sector, mainly in the residential buildings area.

This study focused on the single-family houses to know the factors that affect the energy consumption through a comparative analysis of the energy used in dwellings of different European Mediterranean countries. The countries chosen for this analysis were Greece, Portugal, and Spain, countries that share similar geographical, political and meteorological conditions. For this analysis, only was taken into account the energy used for space heating and cooling and water heating.

Using statistical data and national regulations, two regions of each country were chosen, and a typical house from each region was represented to obtain annual energy consumption results through simulation. Variable parameters such as internal temperatures, system operation hours and occupant behavior were tested on the models to see their impacts on energy consumption.

As a result of simulations, it was concluded that space heating is the activity that consumes the most among the selected ones, therefore, having a great potential for energy savings. The efficient use of energy keeps the thermal comfort of the occupants reducing the energy consumption. The study showed that several factors affect energy consumption, but the main one is human behavior. The role of energy policies are important over the consumption through people´s behavior.

The evolution of the policies in Europe has been remarkable in recent years, but they are not enough. Tighter policies that act fast enough are necessary. Occupants must balance the consumption between comfort and energy awareness, aiming to shift some of the

multiples small decisions and actions taken every day, in order to create a more sustainable future on our planet.

**Keywords:** Human behavior and energy consumption, Mediterranean energy consumption, Dynamic simulation of energy consumption in residences.

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# Acronyms

| | |
|---|---|
| ASHRAE | American Society of Heating, Refrigerating and Air-Conditioning Engineers |
| $CO_2$ | Carbon Dioxide |
| CTE | Technical Building Code |
| DB – HE | Basic Document for Energy Saving |
| DL | Law Decree |
| DHW | Domestic Hot Water |
| EC | European Commission |
| EE | Energy Efficiency |
| EED | Energy Efficiency Directive |
| EPBD | Energy Performance of Building Directive |
| ES / SP | Spain |
| EU | European Union |
| GDP | Gross Domestic Product |
| GHG | Greenhouse Gases |
| GR / EE | Greece |
| HVAC | Heating, Ventilation and Air Conditioning |
| KENAK | Greek Regulation for the Energy Efficiency of Buildings |
| LOE | Building Planning Law |
| IEA | International Energy Agency |
| IWEC | International Weather for Energy Calculations |

| | |
|---|---|
| NBE CT | Basic Building Standard for the Thermal Conditions in Buildings |
| NUTS | Nomenclature of Territorial Units for Statistics |
| NZEB | Nearly Zero Energy Building |
| PT | Portugal |
| RCCTE | Regulation of Characteristics of Thermal Behavior of Buildings |
| RD | Royal Decree |
| REH | Energy Performance Regulation of Housing Buildings |
| RITE | Regulation of Thermal Installations in Buildings |
| SCE | System of Energy Certification of Buildings |
| SFH | Single Family House |
| TEE | Technical Chamber of Greece |
| TOTEE | Technical Codes of the Technical Chamber of Greece |
| UN | United Nations |
| WHO | World Health Organization |

# 1. Introduction

Each year, humanity's demand for natural resources exceeds the Earth's own ability to regenerate them and the natural capacity to process and absorb greenhouse gases (GHG) and waste. Humanity consumes on average the equivalent of 1,7 planets in resources to meet its consumption rhythm. Understanding and accepting that we live in a world with limited resources and knowing the ecological limits for decision making will allow us to live in harmony with the planet. (Global Footprint Network, 2019)

In the world, the building and construction sector consumes 36% of final energy and generate up to 35% of energy-related GHG emissions (UNEP, 2017; IEA, 2019a). The residential subsector is the largest energy consumer of the entire building sector. (IEA, 2019a)

Moreover, if no action beyond current commitments is taken to improve the uptake of energy efficiency (EE) measures in the buildings sector, energy demand could increase. To avoid the increase of the energy demand and reduce it or at least stabilize it, multiple actions are required as policies, strategies, behavioral changes, new technology, infrastructure, financial planning and a great effort from all the involved areas. (IEA, 2017)

In 1983, Van Raaij & Verhallen, posed a question for their study. Why consumers do not have a conscious behavior related to the use of energy? In the end, several interesting answers were found; some of them even today can be applied to residential consumers. Consumers do not always know the costs of many household behaviors. The feedback information do not come on time, making people do not be aware of energy-wasting types of behavior. Energy consumers see energy conservation as a government or someone else problem. Many consumers are not willing to give up comfort, mainly related to room temperatures. The lack of effort and concern in the area by energy users. (Van Raaij & Verhallen, 1983)

One publication written by (UNEP, 2017a) shows how the creation of policies can be positively affected and have better results thanks to the understanding of the people´s behavior, also identifies behavioral barriers for sustainable development: 1. Many "choices" in consumption are often habitual behaviors. 2. Consequences of consumption are often hard to see; 3. Sustainable consumption may seem irrelevant to consumers; 4. Behavior is influenced by the social environment; 5. For many consumers, maintaining sustainable behavior can be difficult. Policies must be created and designed in order to destroy the previous barriers, remembering that if it works in one place, for a specific population, may not always work in another.

Thus, the objective of this investigation is to perform a comparative analysis of the energy consumption used for space heating and cooling and water heating in single-family houses (SFH) in European countries, through the simulation of a representative and typical house of each country in order to determine the factors that influence on the energy consumption. To achieve the main objective is also required:

• Delimit and focus the study on specific regions of each country.

• Represent a SFH model with the typical and most representative characteristics of each region.

• Analyze national and community energy policies.

• Simulate the hose models created for the climates of each region.

• Know the occupant´s residential energy consumption behaviors in each country.

The analysis is focused on the comparison of the energy consumption of the residential area, specifically over SFH, represented by the most typical house, in two regions of three European Mediterranean countries, through the energy consumption simulation during one year, only taking into account the energy consumed by the space heating, cooling and water heating systems. The analysis also reflects some aspects of EE policies and different occupant behaviors. The main sources for the investigation were the Eurostat statistical database and the national statistical institutes of each country.

Therefore, the present investigation is structured in 7 chapters detailed below.

Chapter 1 is the introduction chapter; it defines the problem, establish the main and the specific objectives, the scope and the limits of the analysis and also describes, in general, the contents of this document.

Chapter 2 is about the theoretical framework; it gives a general international and local contextualization of the problem with the revision of some related literature; also reviews some contributions made by previous studies related to the purpose of the analysis.

Chapter 3 describes in detail the methodology that will be used to meet the stated objective and the process that will be carried out during document development.

Chapter 4 define the case, describe some characteristics of the analysis and the reasons why the countries were chosen; it gives a brief overview of each of them and describe some characteristics that are considered important for the present analysis. The chapter also analyzes and briefly compare the local energy policies with some other important international documents, directives, agreements and other relevant factors such as climate and demography, selecting the regions where the analysis will be focus on each country.

Chapter 5 defines the parameters that will be used in the simulations. It details how each parameter was selected or defined. It divides the simulation parameters into constant and variable; the variable parameters somehow try to represent the behavior of the occupants of the SFHs.

Chapter 6 shows the simulations results carried out with the parameters defined in Chapter 5; the results are interpreted, compared and a brief discussion of them is made.

Chapter 7 finally shows the conclusions that were obtained from the analysis of energy consumption; some recommendations, and suggestions to deepen the analysis or for future research are presented.

# 2. Literature Review

This chapter is about the theoretical framework and the literature review. Here the established problem is analyzed in an international and regional context, together with the analysis of policies and directives for the efficient use of energy, a briefly reviewed of topics such as occupants energy behavior, the role of buildings in energy consumption and previous work related to the purpose of this investigation.

## 2.1. International Context

In the last few decades, the eyes of the world are over the sustainability that is why the United Nations (UN) using the framework of the Millennium Development Goals, in 2015 announced the 2030 Agenda for Sustainable Development. The agenda has 17 goals and 169 associated targets in areas of critical importance for humanity and the planet. Nowadays all the countries must implement methods in order to aim the objectives and generate positive changes in our present world. Many of the announced targets are related to reducing our environmental footprint, sustainable consumption and production, sustainably managing the natural resources and taking urgent action on climate change. (United Nation, 2015)

Several of these goals as the number 7, 11, 12, 13 and 15 are related with the promotion of the sustainable consumption of resources and energy, in diverse areas and with the protection of the planet. Specifically, the goal number 7 was created in order to change the current form of production and consumption of energy towards a more sustainable, clean and accessible for all. To reach it is necessary the implementation and generation of new solutions as fast as possible. The target 7.3 is particularly focused on by 2030 double the global rate of improvement in EE, the main indicator of compliance of this target is the energy intensity, measured in terms of primary energy and the Gross Domestic Product (GDP). (United Nations, 2019)

In the world panorama is also important to talk about the Paris agreement, written within the framework of the United Nations Framework Convention on Climate Change and adopted in 2015 by 195 countries to combat climate change and adapt to its effects in the context of sustainable development and environmental integrity. The agreement entered into force on November 4 of 2016 and every 5 years there will be an evaluation of the progress towards achieving the purpose of the Agreement, requiring the best efforts of all parties through "nationally determined contributions".(UNFCCC, 2015)

At the European level, the European Commission (EC) establish as a priority the energy union and climate. The EE constitutes one of the five dimensions of the European Energy Union Strategy, designed to enhance energy security, sustainability, and competitiveness. The European Union (EU) set itself a target of 20% of energy-saving by 2020, focus the actions on sectors with the greatest energy-saving potential such as buildings. However, the EC objectives go further and even more challenging goals have already been set for 2030 and 2050. To achieve the objectives, several actions have been carried out, such as the establishment of directives, some financial plans and the creation and implementation of regional and national policies. (European Commission, 2019a)

According to Eurostat in 2016 in the EU, the energy consumption in the residential sector represented 25,4% of the total energy consumed by end-users in all the areas, excluding the energy used in the energy sector for delivery and transformation; residential consumption represents the second-largest consuming sector after transportation. The energy in the residential area is used for various purposes mainly space and water heating, space cooling, cooking, lighting, electrical appliances, and other end-uses. A little more than a third of all the energy used is covered by natural gas followed by electricity and then renewables; products derived from crude oil, derived heat and coal products are used in a small proportion. Most of the residential energy demand (79,2%) is used for space and water heating so here is where considerable saving could be attained. (Eurostat, 2019)

A non-homogeneous situation characterizes countries in Europe, different buildings type, available renewable technologies, climate, culture, and several variables to be considered (EPBD-CA, 2019). Based on each country characteristics, there are some differences; for instance, in the total amount of energy used by each state to the space heating, being Malta and Portugal, those uses less energy with 16% and 21,1% respectively. The most significant users are Luxemburg with 79,9% and Hungary with 74%. (Eurostat, 2019)

At this point, it is essential to define the term Energy Efficiency. According to the US Energy Information Administration, the terms “Energy Efficiency” and “Energy Conservation” are related, but have some differences. Energy Efficiency is the use of technology that requires less energy use to perform the same function, and Energy Conservation is any behavior that results in less energy consumption. (U.S. EIA, 2019)

On the other hand, the EC defines Energy Efficiency as using less energy input for an equivalent level of economic activity or service. Therefore, the improvement of EE means an increase in energy efficiency as a result of technological, behavioral, and/or economic changes. (European Commission, 2019a)

One publication by (IEA, 2010), refers that the EE in final consumption plays an even more critical role in reducing energy consumption and emissions compared to the reduction provided by the production of energy from renewable sources. Energy saving is the most cost-effective way to increase security of supply and reduce import dependency. (European Parliament and Council of the European Union, 2009)

The efficient use of energy has benefits that go beyond savings in the price of the unused energy, it includes a lot of others benefits and co-benefits, like the reduction of local and global emissions, the decrease in health problems associated with air quality and another social and economic impacts. In general, these benefits can be classified in three groups, environmental, social and economic. (Reuter, et al., 2018)

The three main groups of benefits of efficient energy use were sub-classified into eight co-benefits. Inside the environmental main group are the global & local pollutants and energy and resource management; in the main social group are the life comfort and the energy poverty, and the economic main group contains the security and delivery of energy, macro & micro economic benefits and innovation and competitiveness. The author presents one or more indicator for each subgroup that allow the comparative analysis of the benefits of the applications of energetic measures and policies in every EU country over the time. (Reuter, et al., 2018)

There are two ways to save energy in a building, one of them is the implementation of saving technology as purchase LED illumination or improve de insulation of the building. It is evident that this measure involves some capital investment but offer an immediate long-term result and easily quantifiable. On the other hand the other way of achievement savings is related with the behavior of the occupants of the buildings. The implementation of behavioral changes implies low-cost or no-cost and does not need high-tech knowledge, but represent a high level of difficulty because it depends a lot of people´s owns factors and at the same time may only has transitory effects, without consider that the results can be challenging to quantify. (Mills & Schleich, 2012)

However, in most cases, the potential for energy savings due to behavioral changes may be higher than the application of technological solutions. The results of the changes in energy behavior can be seen in all types of buildings, regardless of the conditions or their age because the behavioral changes are applied in people. The results can be perpetuated if the occupants develop an energy conservation culture being able to positively affect other occupants and other sectors like industrial or commercial ( Masoso & Grobler, 2010). With the application of strategies for modifying the behavior of people, it is possible to reduce individual energy consumption from 5 to 20% (EEA, 2013).

## 2.2. Energy Policies

For the generation of appropriate specific policies for each country, it is essential to take into account the specific differences between them in terms of energy-saving technology adoption and energy conservation practices. (Mills & Schleich, 2012)

The combination of fiscal instruments with policies can present better results. They can modify the consumer behavior and to reach the EE objectives. The two categories of financial instruments act oppositely; they are taxes and subsidies. Taxes influence the consumer by increasing the costs of specific goods and services, in contrast, subsidies incentive and influence the consumer to choose goods or services; in this case with favorable properties for the environment. (European Union, 2009)

The application of subsidies cost money to the government; for this reason, the government must try to avoid future expenses or to generate economic or other benefits. At the same time, subsidies can be target to a specific costumers group. On the other hand, most of the countries applied taxes to the transportation and use of energy; in some cases, it can have a regressive impact on low-income householder lead them to energy poverty.(European Union, 2009)

Depending on the product and market conditions, subsidies have more impact than taxes to promote EE. However, the application of fiscal instruments can also induce to adversely behaviors if they are not carefully designed and applied correctly or in some cases can generate a rebound effect (European Union, 2009). It means that the application of policies does not always have the expected result, for instance, raise the price of energy does not always result in lower consumption. The understanding of human behavior is also crucial for the creation and application of policies with the use of this tool; better results are guaranteed. (UNEP, 2017a)

A quick and precise feedback by the energy suppliers can be useful for the customers to know the real cost of each activity that associates the consumption of some type of energy. A short time interval between energy use and payment, will be a more effective feedback mechanism; estimates bills most of the time confuse the householders and its worse when they have a poor knowledge of the real price of energy. In some countries sometimes, the energy price changes depending on the amount of use and the time of day. (Van Raaij & Verhallen, 1983)

The implementation of energy awareness campaigns with a small investment can somehow be considered as a small-scale policy. The campaigns can be of various types such as awareness campaigns, incentives, punitive measures, technology, etc. Another way to save energy is by just remembering the most straightforward and cheapest lesson with the most significant savings, the golden rule " If you do not need it, do not use it! " ( Masoso & Grobler, 2010). All this leads us to conclude that policies alone are not enough; behavioral changes are necessary to the transformation towards low carbon economy (European Union, 2015).

The applications of some EE policies start in most of the countries after the second oil crisis in the seventies and in the nineties of the last century at the European level. At the beginning of the EU, the policies were not intended for the regulation of buildings since the buildings did not affect the initial objectives of the free market and free mobility. That changed when energy union and climate change became subjects of EU in the 1990's. Then the EU started works to reduce the use of fossil fuels, and since buildings in the EU are responsible for around 40% of the energy consumption, they began to be part of regulations. The regulation of buildings was further promoted with the conclusions of the European Climate Change Program in 2000. (European Commission, 2019a)

Since then the EU members have adopted several low, medium or high impact energy policies, and these policies can be of different types as legislative/normative, legislative/informative, financial, fiscal, information/education, cooperative and taxes that involve end-users and main actors of the energy consumption in all the areas. (European Commission, 2015)

The use of these policies has given positive results like the regular decrease of household energy consumption around 1,5% per year in the EU members since 2000. Some of these policies are related with diffusion of compact fluorescent lamps and light-emitting diode technology for lighting, the labeling and eco-design regulations for electrical appliance, new efficient buildings and the renovation of existing dwellings to reduce the energy use in space heating. (IEEP, 2015)

At the European level, there are several policies related to increasing the EE; the design, implementation, and monitoring of these policies and programs by the EC had technical and scientific advice. With the application of these policies in all the EU members, multiple benefits are expected in the future. They include the reduction of energy dependence by the region, among other significant social, economic, and environmental benefits. The policies include actions over buildings, household appliances, implementation of action plans, the rollout of smart meters for gas and electricity, and some other activities that involve producers and consumers. These measures are established in European legislation under the following directives: Energy Efficiency Directive, Energy Performance of Buildings Directive, Energy Labelling Directive, Ecodesign Directive. (European Commission, 2019c)

### 2.2.1. Energy Efficiency Directive 2012/27/EU

In 2007, the European Council adopted ambitious targets for 2020, which include, among others, by 2020 reaching 20% EE. Energy Efficiency Directive (EED) 2012/27/UE was approved in October 2012 and entered into force in December 2012 to help to aim the objective, based on the big potential of energy saving in areas such as energy performance of buildings, on energy services and cogeneration; it covers all sectors except transportation. The EED for the first time clearly defines and quantifies the EU EE targets. (European Commission, 2019a)

All the country members must incorporate the majority of the EED provisions into national law and prepare every three years a National Energy Efficiency Action Plan (NEEAP) with an annual report of achievements; the countries also will have an active monitoring by the European Commission.

The EED seeks to employ actions in several axes such as buildings, public purchased, energy audits and energy management systems, metering and billing information, promotion of use of high-efficiency cogeneration, heating and cooling, energy transformation, transmission and distribution. (European Parliament and Council of the European Union, 2013)

In 2016, driven in part by the Paris Agreement, the commission proposed a new target of 30% of EE by 2030. This is how the directive is continuously improving and updating the objectives, and the plans and strategies to reach them. To be aligned with the new targets in 2018, the directive was amended by the Directive 2018/2002/EU and by the Directive 2018/844/EU published in June of 2018, which contains plains for short, medium and long-term objectives facing to 2050. (European Parliament and Council of the European Union, 2018)

### 2.2.2. Energy Labeling Directive 2010/30/EU

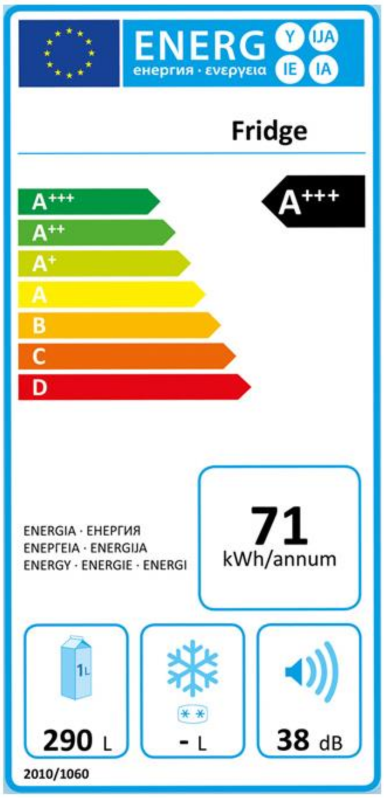
The energy labeling began to be implemented in 1995 thought the first version of the Directive 92/74/EEC. Although only in some big household appliances like refrigerators, freezers, washing machines, and dishwashers, over the years, they have been expanding to other ones. In 2010, the previous directive was updated by the Directive 2010/30/EU, extending the scope to energy-related products that have a significant direct or indirect impact on energy consumption during use. Currently, the labels are mandatory and are applied in the majority of appliances, even in windows. (European Commission, 2019a)

Years later, the European Commission identified the need to update the Directive 2010/30/EU, which is not in force since 2017 it was replaced by the Regulation 2017/1369, which maintains substantially the same scope, but clarify and update the contents.

The energy labeling indicates in a clearly and simply way the EE of each household appliance and some other relevant information of use like energy consumption, energy range, level of noise, among others. The more efficient, the lower consumption and therefore, the more savings in the electricity bill. Energy labeling enables customers to make informed choices based on the energy consumption of energy-related products.

The format of the label has been changing over time. Initially, the scale went from A to G. However, new higher categories were created, since fortunately the appliances were increasingly efficient. To follow the advance of the efficiency technology, “+” symbols were added to the highest categories and the lowers categories (F and G) disappeared. That action confused the users who were used to see category A as the best. Currently, in the market, the scale goes from A+++ to D, as shown in figure 1. In 2020, the current range will be adjusted and replaced by the original one (A-G). (European Commission, 2019a)

**Figure 1. Energy label actually used - (European Commission, 2019a)**




### 2.2.3. Energy Performance of Building Directive (EPBD) 2018/844/EU

The Energy Performance of Buildings Directive (EPBD) is a European legal instrument that works together with the EED to improve the energy performance of Europe's building stock. The directive was based in Kyoto agreement and in the directive 93/76/EEC of 13 September 1993 to limit carbon dioxide emissions by improving energy efficiency an informative but not mandatory directive.

The Member Countries uptake of energy performance requirements aims to gradually reduce energy demand and increase supply from renewable sources in the European building stock. The EPBD requires Member Countries to implement and to increase EE requirements in buildings, leading to achieve the European 2050 long-term energy strategy. However, the rate of building renovation in Europe is around 0,8% per year. (European Commission, 2019a)

The first version of the directive 2002/91/EC entered into force in January 2003 and obliges the Member States, in a period not exceeding three years, the transposition of the directive in their national legislation. In some countries, the EPBD transposition brought significant results mainly to those who did not have any regulation for EE over the construction sector before (García-Hooghuis & Neila, 2013). However, it did not mandate any specific level of requirements. (EuroACE, 2018). There are four keys aspects implemented by the first version of the EPBD.

1. All member states must establish a calculation methodology of the energy performance of buildings, taking into consideration the different factors related to energy consumption

2. Each country must implement regulations that minimize the energy performance requirements; the new regulation must be applied to all new buildings and large existing buildings when they are refurbished.

3. To build, sell, or rent a building, it must have an Energy Performance Certificate.

4. Regular boiler and heating system inspection and maintain of air conditioning systems.

In order to strengthen the energy performance requirements, to clarify and streamline some provisions of the 2002/91/EC, in 2008 started the recast of the directive and it concluded in 2010 with the Directive 2010/31/EC, implementing a transposition deadline July 2012. (European Parliament and Council of the European Union, 2010). The recast requires Member Countries to strengthen the minimum requirements compared to the previous version, also imposed minimum standards for individual building elements. Some previous measures were reinforced like:

- The extension to all buildings of the minimum requirements of energy performance levels when a major renovation takes place
- Energy certifications for all properties constructed, sold or rented out are mandatory
- The improvement of heating and cooling systems inspections and the generation of requirements reports.
- The Member States are required to establish penalties for non-compliance.

The recast also introduce new concepts like:

1. Nearly Zero Energy Building (NZEB), buildings with a very low, or zero energy consumption. The EPBD establishes that all public buildings constructed from 2018 must be NZEB and all buildings public and private from 2020. Member States must implement financials plans for the transition.

2. Cost optimal levels, and it defined it as “the energy performance level, which leads to the lowest cost during the estimated economic lifecycle” - from financial and macroeconomic perspectives.

In June 2018, The Official Journal of the EU published the Directive 2018/844/EU of the European Parliament and Council, amending the Directive 2010/31/EU on energy performance of buildings and the Directive 2012/27/EU on energy efficiency. EU countries have until 10 March 2020 to write the new and revised provisions into national law (European Parliament and Council of the European Union, 2018). The key features of the actual directive are:

- Long-term renovation strategies must be applied by Member States to transform their present building stock to a highly EE and decarbonized one by 2050, with measurable progress indicators in 2030 and 2040. The reinforce of article 4 of EED.
- Member Countries have the option to implement the Building Renovation Passports. The Building Renovation Passports is a document that shows a long-term renovation roadmap of one specific building; it is a powerful tool that provides more reliable, personalized, and independent information about the energy-saving potential in a building.
- The introduction of the Smart Readiness Indicator will provide real information about the building systems, and it will help the building´s occupant to control the interior conditions and prepare the building to act as an integrated part of the global energy system.
- A strengthening of the financing plans by the member states that contribute to the financing of energy renovation projects to improve the energy performance of buildings.

- The heating, cooling, and ventilation systems inspections provisions have been extensively changed; keep the possibility of using alternative approaches.
- Mandatory individual room temperature room control.
- Mandatory installation of Building Automation & Control Systems by 2025 in large non-residential buildings. The interactions of the Building Automation & Control Systems with the building envelope and its operation have a significant effect on the energy use, on the well-being, on occupants comfort, and on the achievement of long-term carbonization objectives. (European Parliament and Council of the European Union, 2018)

#### 2.2.4. Eco-design Directive 2009/125/EC

In 2005, Directive 2005/32/EC established a framework for the setting of community ecological design requirements for products that use energy. In order to clarify the contents, the directive was reformulated, and in 2009 Directive 2009/125/EC was approved. (European Parliament and Council of the European Union, 2009)

The Ecodesign Directive is a framework directive, which means that it does not directly establish minimum ecological requirements. The directive seeks to regulate the industry and the EU market, excluding products that increase energy consumption and it promotes the production of more efficient products to reduce energy and resource consumption. (European Commission, 2019a)

Many products are regulated across the EU such as household appliances, information and communication technologies or engineering. The ecological design directive works together with the Energy Labeling Directive standards, and they are complemented by other European standards to work in harmony.

#### 2.2.5. EU Strategy on Heating and Cooling.

Heating and cooling are the activities that consume most of the final energy in all areas, including the residential. In Europe, fossil fuels are used to generate more than 80% of heating and cooling, while only less than 20% is generated from renewable energy. In order to explore the issues, challenges and solve this problem in February 2016 Europe launched its first heating and cooling strategy

Customers are the main actors in this strategy that promote the reduction of the demand, the use of modern technology and new solutions in order to change to a sustainable smart heating and cooling system, improving the individual well-being. This strategy also focuses on the modernization of buildings helping to reduce the energy leakage, renovation in the heating and cooling systems, the continuous use of renewable sources, thermal storage, and use of waste heat. (European Commission, 2019a)

## 2.3. Occupant Energy Behavior

Human activities are ruled by natural and social process. According to some authors, the people's energy behavior includes several areas such as socio-demographic factors, family lifestyle, energy prices, cost-benefit tradeoffs, effectiveness and responsibility, feedback information, and home characteristics. Four types of factors can influence the behavior as physiological, individual, environmental, and spatial adjustments; is a complex issue that should be studied under multiple disciplinary perspectives. (Van Raaij & Verhallen, 1983; Ectors, et al., 2017)

Human behavior is unpredictable; to change it is a challenge, even with favorable conditions are in place. Some facts as the lack of standard decisions, programmed mental shortcuts, and the wrong idea that people always make rational and conscientious decisions based on the cost-benefit of the options available to them, are some of the characteristics that make behavioral science a complex science. It needs other social sciences to be deeply understood. (UNEP, 2017a)

Individual behavior plays an essential role in resources consumption. From daily actions to habits and lifestyles, in this sense, it is critical to understand the people's behavior in order to change it. (UNEP, 2017a)

An exciting concept that can help to understand better human behavior is the intention-action gap. It is defined as the disconnection between intention and actions. It means that good intentions are not enough if there are not reflected in real actions. People, in general, are concerned about the environment but taking default decisions or the influence of the decisions of the people around them, especially in times of uncertainty, leads them to undesirable unsustainable behavior. (UNEP, 2017a)

Another phenomenon that acts on human behavior achieving unwanted results is called "annoying factor." They are small tasks that are or seem complicated and therefore, are not made by consumers despite the intention to perform it. Among them are the programming of a heating device or the calculation of the electricity bill, even with the details in the invoice this task becomes somewhat difficult if the consumer has no idea what a kWh is. The simplicity of these tasks can represent significant effects on the energetic consumption. (Behavioural Insights, 2015) (UNEP, 2017a)

In 1983 (Van Raaij & Verhallen, 1983) decided to divide the energy-related behavior in three parts: purchase, usage, and maintenance related behavior. The purchase behavior is related to consumer decisions at the time of buying or acquiring a device that directly or indirectly affects the energy consumption. The energy efficiency labels have a significant impact on this behavior. They allow buyers to be more informed before making their choice in terms of energy consumption and efficiency. A highly efficient technology device can reduce its payback time significantly. (IEA, 2010). This could not mean a solution if the decisions of the people are based on a great interest to the immediate costs and benefits (UNEP, 2017a).

The usage-energy behavior has a high saving potential but at the same time is one of the most difficult to be change because it is related to the habits lifestyle and comfort of the consumers. Objectively means time, frequency, periodicity, and intensity of appliances use, lights, and another's energy-consuming devices. The maintenance-related behavior is associated with small repairs of electronic devices, some house improvements principally in the insulation system, the proper maintenance of applies, and regular inspections of the energy distribution system. (Van Raaij & Verhallen, 1983)

In order to predict specific actions and quantify the amount of energy that will be saved in the future, it is necessary to create behavioral models. The models are complex, and many variables are presented in order to increase the accuracy of the results. Good quality results can be useful for the proper design, operation and optimization of the buildings, the understanding and possible change of behaviors and the creation of specific energy policies. (Yan, *et al*., 2017)

Behavioral models feed on user data to determine behaviors. That is why data collection is fundamental. A quality database can create models that allow the understanding of the people's behaviors inside the buildings. It is necessary to analyze the presence, moving, and the occupant-building interaction. (Yan, *et al*., 2017)

Already exist two ways of collect data, survey and the use of sensors to monitoring. Surveys do not need a significant investment and present results of a large number of people in a short time, but sometimes the interviewees do not respond according to reality. Sensing requires a significant investment, maintenance, and a long period to get good results. A person's behavior can change only with the simple fact of knowing that he or she is being monitored. (Yan, *et al*., 2017)

A study made by (Faitão Balvedi, *et al*., 2018), concludes that it is possible to reduce the uncertainness presented by all the monitoring methods using a mix mode approach. Moreover, the results will be more realistic. Most of the behavior models used a binary state, it means open-close, on-off, for windows and blind control. In these cases, it is not possible to know all the new information that a partially open state can give in terms of energy saving. The influence that exists on building energy consumption was shown by the application of occupant behavior models.

## 2.4. **Buildings**

Many different aspects such as economic, engineering, behavioral and health play a key role in the building sector making a challenging sector but at the same time, the most crucial sector concerning EE policies due to its high potential in terms of energy reduction and efficiency. (European Commission, 2019a)

Given the long useful lifetime of buildings (50 to more than 100 years) and the high number of the existing buildings, it is clear that the most significant potential for improving the energy performance of buildings in the short and medium-term is over the existing building stock (Balaras, *et al*., 2005)

Home characteristics can represent positive and negative effects on energy conservation. In Europe in 2012, around three-quarters of a total of 25 billons $m^2$ were residential buildings area, and most of these are SFH (Eurostat, 2019). Besides, in Europe, around 35% of all buildings are over 50 years old, and 75% of them are considering energy inefficient with a deficient energy performance (category D and E). The renovation of buildings represents significant contributions to the efficient use of energy. Buildings with a high performance can improve the life quality of the occupants, increasing the comfort level and an adequate indoor climate. (European Commission, 2019a)

Warmer countries generally have lower space heating intensities, so less energy is required on average to keep the temperature inside residential building at a comfort level (IEA, 2019b)

However, SFH consume more energy on average than multi-family houses. It can be explained, in part, by the lower exposure to outside temperature, as well as by the fact that they are surrounded by other buildings and have fewer windows. (Gangolells, *et al*., 2016)

The age of the buildings is an important factor that governs energy consumption. Old buildings consumes more energy due to energy losses (Instituto Nacional de Estatística, I.P, 2011; Gangolells, *et al.*, 2016; Pezzutto, *et al*., 2018). In Europe buildings constructed before the 1970s are in average 60% less energy efficient than new buildings (Eurostat, 2019).

Two-thirds of the EU's buildings were built when EE requirements were limited or non-existent; most of these will still be standing in 2050. Around 70% of the EU population lives in privately-owned residential buildings. Owners often do not undertake cost-efficient renovations because they lack awareness of the benefits, lack advice on the technical possibilities, and have financing constraints. (European Commission, 2019a).

The International Energy Agency (IEA, 2019b) has indicated that 76% of the funds to achieve the objectives of the Paris Agreement must be allocated to energy efficiency. On the other hand, the (Buildings Performance Institute Europe, 2019) has found that just 3% of buildings in the EU were assessed as highly energy efficient in 2017, leaving the other 97% in need of energy renovation before 2050.

## 2.5. **Related Works**

In the last years, several studies have been carried out on energy consumption and efficiency in buildings. Some of them have focus on a specific building sector or use the comparison as an analysis tool.

The countries or regions with the highest energy building consumption in the world were compared in a study carried out in 2014 by Xia *et al*. In that study, the annual electricity consumption data of four office buildings with different characteristics was analyzed on annual, monthly, weekly, and daily. Two of those buildings located in the United States of America and two remaining in China. The electrical energy data had to be first normalized to be able to analyze them on the same scale and system. The study highlights the impact that improving the building energy monitoring would have on the quality of the building data that would contribute to research and building EE policy-making. (Xia, *et al*., 2014)

Another study in 2015 compared the building energy consumption in a world scale level using information of international reports and research from the United States of America, the European Union, Brazil, Russia, India and China. The mentioned countries represent the leading global energy consumers. The study concludes that countries where the building stock is growing need to apply energy consumption regulation measures mainly in new buildings. While the measures adopted in the rest of the countries will not be sufficient to guarantee significant reductions in energy consumption. (Berardi, 2015)

Other studies of the same type have also been carried out at European level taking into account the similarities and differences at the political, climatic, energy level that the region presents.

A study carried out in 2005 analyzes the energy for space and water heating consumed by residential buildings in five European countries (Denmark, France, Greece, Poland, and Switzerland). The information on consumption was taken from energy audits; the analysis takes into account the building thermal insulation, the characteristic of the Heating, Ventilation and Air Conditioning (HVAC) system, and the local regulations of each country. As the methodology of the analysis, the buildings were divided by periods and the energy data were standardized, several heating systems were also analyzed. There were apparent differences in consumption related to the type of climate in the chosen countries and comparison with the average European consumption. One of the most important conclusions is that district heating and central space heating with sanitary hot water production are more energy-efficient systems for satisfying the heating demand of buildings. On the other hand, individual heating systems are more energy consuming. (Balaras, *et al*., 2005)

Another study carried out at European level is based on a contemporary office building. Through simulations, it seeks to find how the variation of parameters such as window to wall ratio, thermal mass and internal loads affect energy performance in order to find the optimal office design for each case. The simulation was carried out in four European cities

(London, Munich, Nicosia and Thessaloniki) with specific climatic characteristic, having as advantage common regulations for all countries in the study given by the EC. It was easy to know the minimum required thermal insulation characteristics in each country. (Leonidaki, 2012)

In conclusion, each parameter affects the consumption differently, depending on the climate. However, for all the cases, a low window-wall ratio reduces the consumption and changes of internal loads do not represent significant variations in energy consumption. It is interesting to note that by applying improvements for space heating in the cities located in the north, more energy savings are obtained than in the south cities. Space heating energy represents almost all the final energy consumption in cold cities, while space heating and cooling energy in southern cities is representative. (Leonidaki, 2012)

Energy comparisons have also been carried out between two countries. One study shows an economical and energy comparison analysis of how borehole heat exchangers are used, considering heating and cooling working modes, in a SFH of two cities (Cracow and Thessaloniki). The difference in the average temperatures of the selected cities is evident, which made cooling and mainly heating loads different as well. In Cracow heating during the winter months is important, but in Thessaloniki, heating and cooling are both necessary. (Śliwa & Sakellariou, 2010)

Another study compares the energy demand for cooling and water and space heating in the building stock between Austria and Italy. For a better comparison, the total building stock was divided by periods and sectors, and the energy was compared in terms of primary energy. (Pezzutto, *et al*., 2018)

An analysis conducted in a detached SHF in the center of Italy compares three different calculation methods to obtaining the building energy performance and understanding the typical Mediterranean weather, the similarities in the architectural typology of this region and the limitation of it in terms of energy efficiency. The thermal transmittance and HVAC of building has been estimated with analogy with other similar buildings of the same period and the region “standard”. (Tronchin & Fabbri, 2008)

The first method analyzed was the comparison with the electricity bills, the second method consisted in a simulation using a software, and the third one using the in force Italian method of calculation. At the end, it is showed that the use of the different methods has variations in the results; nations must produce a unique method of calculation. (Tronchin & Fabbri, 2008)

Several other studies have focused on the characteristics of construction and energy consumption in a local context within a country. Some of them have used real data to compare it with national averages, and others have relied on averages and statistics to obtain real characteristics. In some cases, assumptions are the only way due to the lack of information. As in the case of a study conducted on the energy performance of the Greek residential buildings. (Balaras, et al., 2007)

The work described in this dissertation was based partially on the studies mentioned above, with a different and particular focus to fulfill the objectives established in section 1. The differences and specifications are explained in detail in the next section.

# 3. Methodological Proposal

In order to meet the stated objective, a comparison of the energy consumption of SFH in different locations will be carried out. An attempt will be made to represent the most common characteristics of both buildings and occupants, looking for the most typical and representative ones.

There will also be an analysis of the policies and the occupant's behaviors that influence the energy consumption to understand how they affect the final energy consumption. Data and statistical information provided by census, surveys and from the Eurostat platform will be used as a base for the analysis.

A simulation software will be used as a tool to simulate a representative SFH from each region. Simulation software allows the prediction of the effect of technical, physical, and behavioral changes in the building and its systems on the final energy consumption. Models will be designed and simulated to represent them. Information from the in force national regulations will be used.

The energy use by the systems to maintain the temperature of a building and to provide hot water depends on factors such as the variation in climate conditions, the thermal comfort of the occupants, the efficiency of the systems, and their use. (Gangolells, et al., 2016)

In the European residential sector, the most significant energy consumption comes from the heating, ventilation and air conditioning activities of the inhabited spaces and water heating for domestic use. Therefore, the analysis and comparison of the energy consumed by an SFH will be carried out for heating and cooling of spaces, as well as the water heating. These three fields because they are considered the most representative and important for the housing habitability.

Results will be obtained with the application of different conditions that will be analyzed and compared, looking for differences and similarities between energy consumption of different places with particular characteristics. The average data of consumptions available for each region also will be compared with the results obtained.

## 3.1. Use of Building simulation software

Besides of the average consumption information that can be obtained from the statistical databases, a simulation of an SFH model will be carried out with the own and representative characteristics of different locations to obtain an energetic consumption that allows comparison with the statistical information and between them. In the buildings models will be applied different profiles of energy consumption; it will represent the people behavior. Some other characteristics will keep fixed for the entire simulations model during the entire analysis.

### 3.1.1. Software

The software used for the simulation is DesignBuilder Software Ltd., the software allows an easy-to-use advanced simulation that helps evaluate the energy and environmental performance of new and existing buildings.

DesignBuilder Software has nine attached analysis modules, each of which offers a specific type of task or analysis, which includes energy and comfort, HVAC, natural lighting, cost, design optimization and reports that meet various national construction standards and certification, providing a complete integration performance analysis, ideal to meet the particular requirements of this study. (DesignBuilder Software Ltd, 2019)

DesignBuilder Software use EnergyPlus as the main energy and environmental analysis in buildings tool and calculation mechanism. EnergyPlus is a simulator software that provides the power and thermal simulation capability necessary to maintain the thermal control set points, the conditions throughout the HVAC system, the coil loads, and the energy consumption of the plant's primary equipment. EnergyPlus simulated the energy of buildings used in heating, cooling, ventilation, lighting and plug and process loads and the use of water in buildings. (EnergyPlus, 2019)

### 3.1.2. Weather Data

Climate information for simulations was obtained from the EnergyPlus climate database. The EnergyPlus database contains the weather information for the selected locations; the weather data is fully compatible with the selected software and is hourly weather format.

The sources of the weather data for Spain is the Spanish Weather for Energy Calculations, for some places in Portugal is provided by the National Institute of Engineering, Technology and Innovation, for the rest of the locations the source is the International Weather for Energy Calculations (IWEC). (EnergyPlus, 2019)

The bases of the IWEC files provide the information obtained from monitoring up to 18 years for most stations. The meteorological data also have the estimated solar radiation information every hour from the earth-sun geometry and hourly meteorological elements, in particular the amount of clouds. (EnergyPlus, 2019) The typical climate year used is the IWEC form, the result of the American Society of Heating, Refrigerating and Air Conditioned (ASHRAE) Research Project.

## 3.2. Objectives for the selected countries

Each country has its own political, cultural social and geographical characteristics. Some characteristics vary even within the country such as the weather.

The objectives for the selected countries will be compare them, to know and analyze the typical characteristics of the buildings, as well as area, construction period, characteristics of the envelopment and others that influence energy consumption. It is important to analyze the local policies and regulations about the constructions and the use of energy. The characteristics of the HVAC systems and the house occupant energy behavior are also important and influential factors on the energy consumption.

# 4. Case Study Definition

In this chapter, the problem will be defined. To begin with the analysis, countries will be chosen and the criteria by which nations will be selected for analysis and comparison will be established. Then a brief introduction of some relevant aspects of each that will be important throughout the analysis will be presented. A brief historical review and a comparison of the energy policies in each country will be carried out. The analysis will be focus on specific regions of each country based on a demographic analysis.

Climatic information of each country was shown, as well as the national classifications of the territory due to the weather characteristics. The typical average energy consumption by the residential area will serve to get an idea of the expected results when performing the simulations. Then the prices of the different types of energy in each country that will be used in future chapters to obtain consumption costs were shown.

As said before, most of the statistical information used for this analysis was taken from the statistical office of the European Union, Eurostat. The information provided by Eurostat is given by a hierarchical system that divides socio-economically the European territory, thus achieving harmony in the statistics of the region; the system uses the Nomenclature of Territorial Units for Statistics (NUTS) to subdivide each Member State in three levels:

NUTS 1: major socio-economic regions

NUTS 2: basic regions for the application of regional policies

NUTS 3: small regions for specific diagnoses

The system ascribes to each territorial unit a specific code and name. (European Parliament and Council of the European Union, 2003)

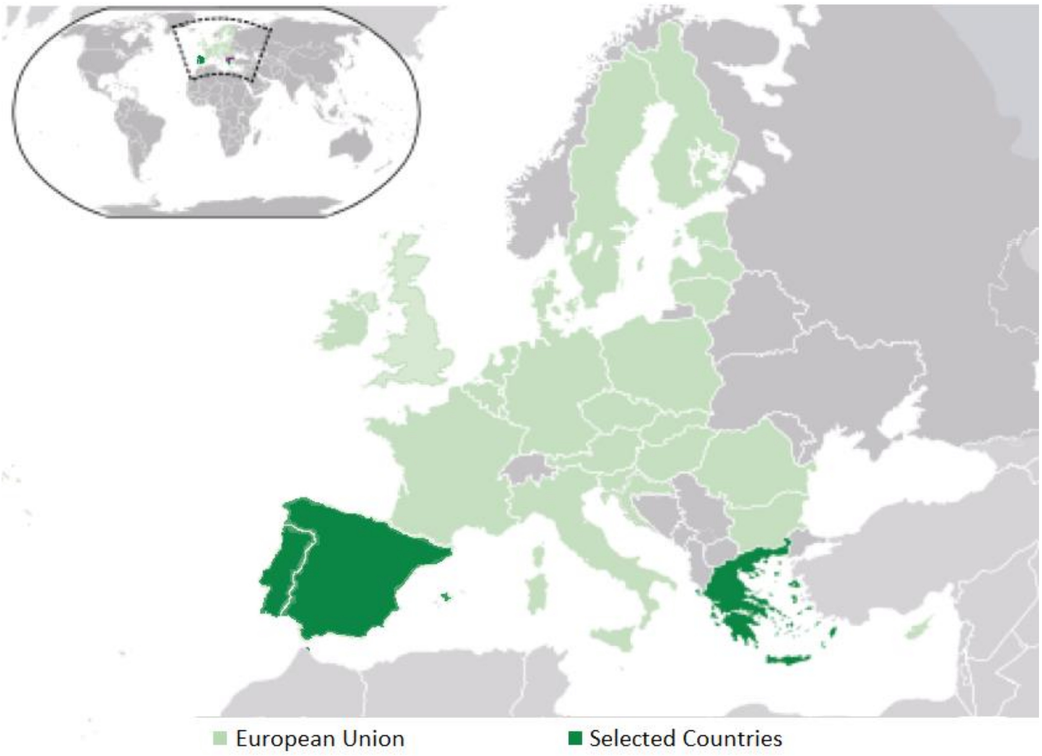
## 4.1. Country Selection

This section will analyze the characteristics of the countries selected for the comparison and the reason for their selection. Three countries belonging to the same region have been chosen to ensure that the temperature difference between European regions does not strongly influence energy consumption.

Greece (GR), Portugal (PT) and Spain (ES) belong to the Mediterranean biogeographical region, located in the Southern Europe region, as shown in figure 2. The countries share specific characteristics of the area such as winter and summer climates, and geographic accidents mainly formed by the total or partial presence of the Mediterranean Sea, particular forests and some other characteristics that make this area unique. (European Commission, 2019b)

The selected countries are part of the 28 member countries of the EU, which means that they follow the same guidelines and have the same objectives in multiple areas including the energy and environment. The countries are also part of the 19 countries that have the euro as their official currency. (European Union, 2019)

**Figure 2. Location of the selected countries in Europe and in the EU**



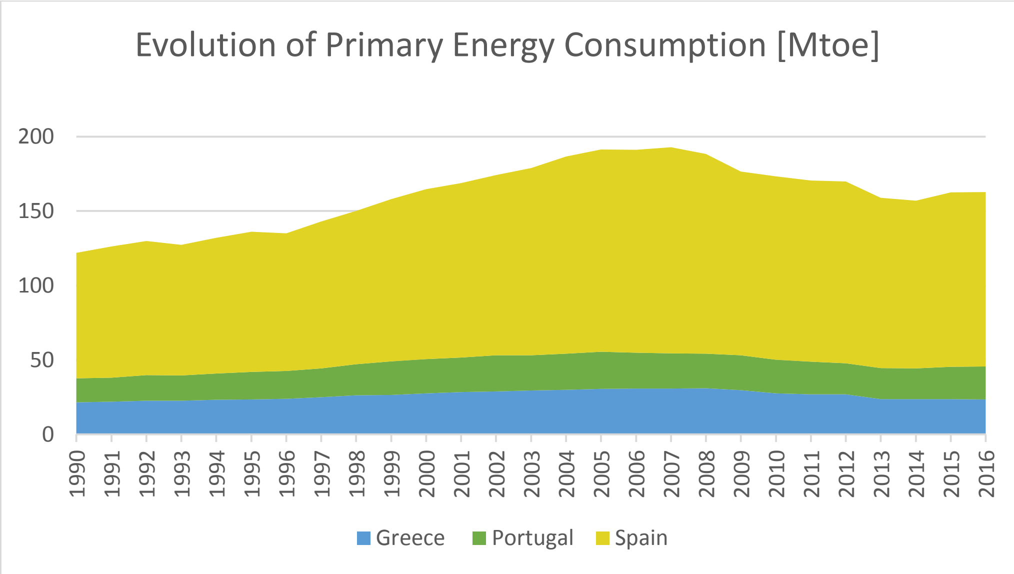

Greece and Portugal have similar characteristics in terms of population, area, GDP, and energy consumption, as shown in table 1. On the other hand, the data for Spain are somewhat higher. However, it will be possible to make a comparison between the three nations.

**Table 1. Countries General Information (Eurostats; World Bank)**

| Countries General Information | | | | |
|---|---|---|---|---|
| | **Country size (km²)** | **Population (2018) millions est.** | **GDP (2017) USD** | **Energy consumption per capita (2014) ktoe** |
| Greece | 132 049 | 10,7 | 200,3 MM | 2182 |
| Portugal | 92 227 | 10,2 | 217,6 MM | 2131 |
| Spain | 505 983 | 46,9 | 1 311 MM | 2571 |

In figure 3 is possible to observe the evolution of the total primary energy consumption of each country in the last years.

**Figure 3. Primary energy consumption GR, PT, ES - (Eurostat, 2019)**




To meet the energy demand each country uses different energy sources. Table 2 shows the share of different fuels in the final energy consumption of the residential sector, specifically.

**Table 2. Share of fuels in the final energy consumption in the residential sector, 2016 - (Eurostat, 2019)**

| Percentage of end Use of Fuels in the Residential Sector | | | | | | |
|---|---|---|---|---|---|---|
| **Country** | **Electricity** | **Derived heat** | **Gas** | **Solid fuels** | **Oil petroleum products** | **Renewables and wastes** |
| Greece | **40,1** | 1,2 | 7,7 | 0 | 29,5 | 21,4 |
| Portugal | **42,9** | 0 | 9,6 | 0 | 16,3 | 31,1 |
| Spain | **39,8** | 0 | 23,1 | 0,5 | 18,3 | 18,4 |
| EU-28 | 24,4 | 7,8 | **36,9** | 3,3 | 11,6 | 15,9 |

Electric energy is clearly the most used in the houses of the selected countries, unlike the average of the European countries in which the most used fuel is natural gas. Given the versatility of electric energy it can be used in multiple activities. In the EU-28 in the residential sector it is almost entirety used in space cooling, lighting and appliances also in others end-uses; a considerable part of it is used for cooking and in less quantity to water and space heating. (Eurostat, 2019)

In general, buildings between World War II and 1960 were built with cheap construction materials and in short times. It means that they have a poor insulation and low efficiency energy systems, being characterized by high-energy demands. Although the chosen countries did not suffer major damages on the buildings stock by the war when compared to other European countries, they went through stages of dictatorships, political instability and civil wars that ended in the 70s. The percentage of residential building area in each country in 2013 was 84,2% for Greece, 80,7% for Portugal and 82,7% for Spain. (European Commission, 2019a)

The following sections show general information and a brief analysis of the critical factors for energy consumption in each of the three countries.

## 4.2. **Greece**

**Table 3. Greece general information- (Eurostat, 2019)(World Bank)**

| Greece General Information | |
|---|---|
| Area | 132.049 $km^2$ |
| Region | Southeastern Europe- Balkan Peninsula |
| Population 2018 (millions) | 10.727 |
| Local Name | Elláda |
| Capital | Athens |
| GDP 2018 (billions) | 184,7 USD |
| Urban Areas | 18.519 $km^2$ (14% of the total country area) |

Greece is a mostly mountainous country situated in the south Balkan Peninsula, it has more than 1.500 islands most of them uninhabited islands over the Aegean Sea. The country is mostly surrounded by water, to the east by the Aegean Sea, to the west by the Ionian Sea and to the south by the Mediterranean Sea. The population in Greece is concentrated in two major urban areas; they are Athens, its capital city, and Thessaloniki.

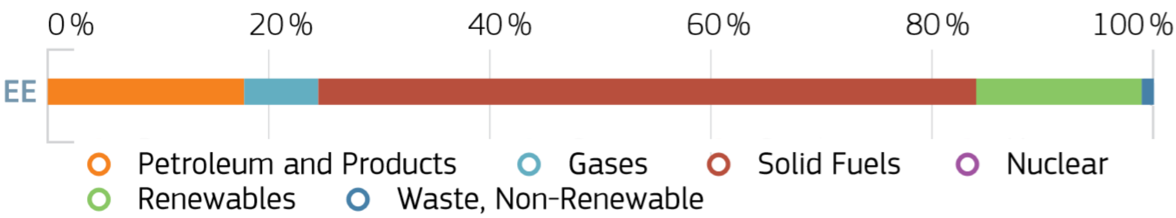
According to the climate, the country can be divided into three main geographic areas. These are the Aegean islands and Attica, the mainland and the highlands. In the mountain region of the north of Greece the winter can be cold with the presence of ice and snow. On the other hand, the southern coastal areas and the islands have a mild winters and a very hot and dry summer. (Greek National Tourism Organisation, 2018; Balkan Heritage Foundation, 2019)

The Greek political system is a democratic parliamentary republic with the Prime Minister as head of the Government, who has the greatest political power and the President as head of state whose duties are essentially protocol. The country is politically divided into 13 administrative regions. (European Union, 2019)

### 4.2.1. Energy Overview GR

In the lasts years, Greece had a significant increase in energy generation through renewables sources, but the country is still mostly dependent of fossil fuels, that have to be imported, to meet the total energy demand and another sources in smaller quantity as can be seen in the figure number 4. (IEA, 2019b)

**Figure 4 . Greece gross inland energy consumption 2016 - (Eurostat, 2019)**




Almost 61% of Greece's primary energy needs are fulfilled through imports, and the remaining 39% is covered mainly by lignite, which is locally extracted and renewable energy sources. (European Association for Coal and Lignite aisbl, 2017)

The non-interconnected Greek islands represent a great expense for the country; most of them use inefficient and expensive diesel generators to obtain electricity. A competitive energy market is the nation's goal. It will bring environmental and sustainable results that improve the quality of life of its inhabitants. The implementation of energy reforms will help achieve this goal. (IEA, 2019b; Ministry of Enviroment and Energy, 2016)

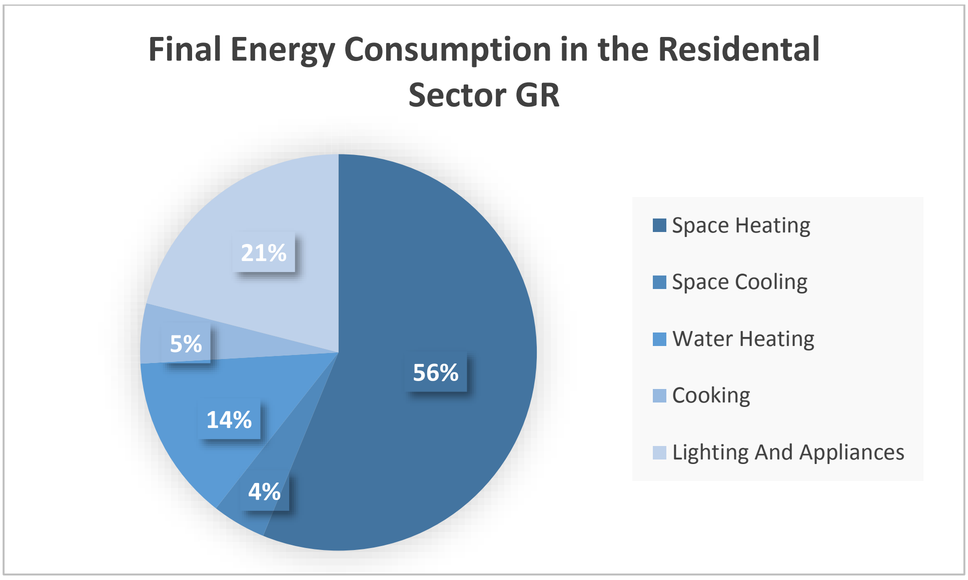
In 2016 the gross energy consumption was 24,14 Mtoe**,** the final energy consumption for the same year was 16,7 Mtoe, and the residential area consumed 4,2 Mtoe, it mean a 25,15% in 2016. (Eurostat, 2019)

#### 4.2.1. Buildings Overview GR

According to the (Helenic Statistical Authority, 2014), the results of the Population-housing census in 2011 shows that 79% of all buildings in the country are domestic buildings with 64,7% of them being permanent residences. The census also shows that two thirds of the residential constructions were built before 1990 with a poor or no insulation.

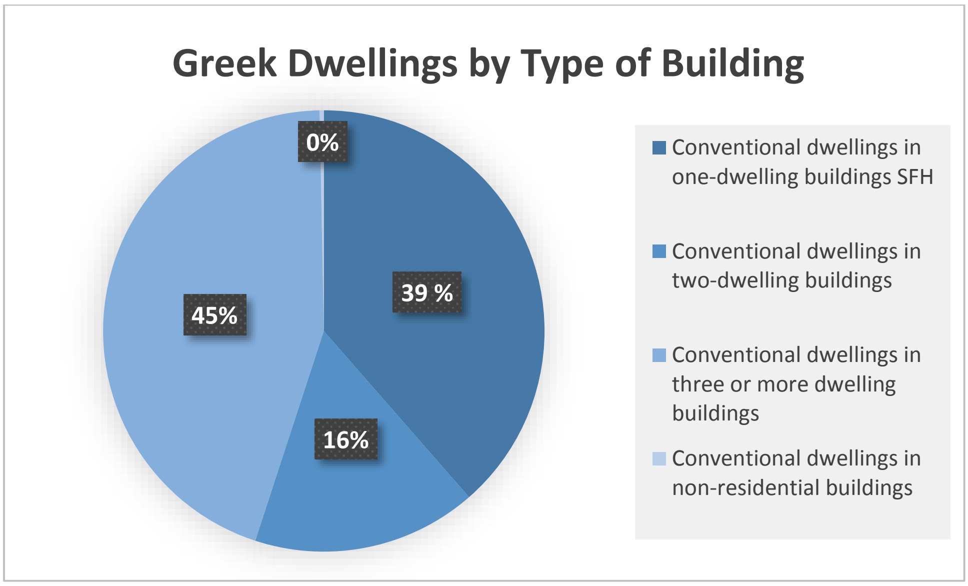
The low insulation level represents a high-energy consumption for heating and cooling. However, the Greek energy consumption by final use is aligned with the European consumption distribution. (Eurostat, 2019)

**Figure 5. Residential energy consumption by final use GR - (Eurostat, 2019)**




More than half of the energy consumed in the residential sector in Greece is used for space heating and another large percentage for lighting and appliances, as shown in figure 5. Different types of buildings divide the residential sector; the percentage of each type is shown in the figure 6. (Eurostat, 2019)

**Figure 6. Dwellings by type of building GR- (Eurostat, 2019)**




A big part of the residential sector in Greece are conventional dwellings in three or more dwelling building than conventional dwelling in one-dwelling building that represent almost 40% of the total. (Eurostat, 2019)

## 4.3. **Portugal**

**Table 4. Portugal general information - (Eurostat, 2019)**

| **Portugal General Information** | |
|---|---|
| Area | 92.227 $km^2$ |
| Region | Southwestern Europe- Iberian Peninsula |
| Population 2018 (millions) | 10.278 |
| Local Name | Portugal |
| Capital | Lisbon |
| GDP2017 (billions) | 217,6 USD |
| Urban Areas | 12.765 $km^2$ (14% of the total country area) |

Portugal is conformed mainly by a continental area situated in the extreme southwest of Europe and by Madeira and Azores archipelagos, both situated in the Atlantic Ocean. Portugal shares 1215km of borders with Spain, the only directly neighboring country of Portugal and another 832km of Atlantic Coast. In the Portuguese mainland, the influences of some natural characteristics like the relief, latitude and proximity to the coast make that the climate varies for one region to another. However, in general terms, the country is characterized by a Mediterranean climate. It means hot and dry summers and mild rainy winters compared with the rest of Europe.

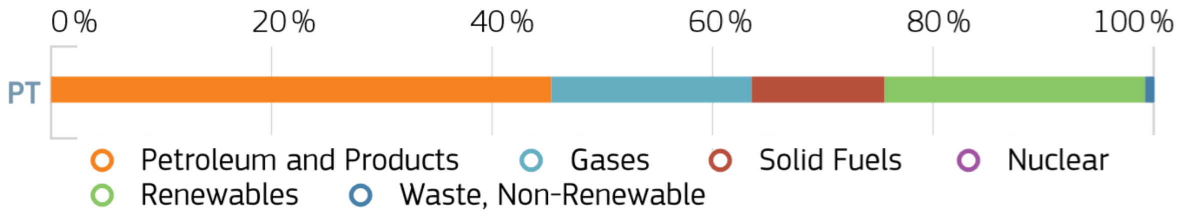
The most densely populated areas are the capital city Lisbon and its suburbs, with about 1.9 million people living there as well as the city of Porto in the north. Most people live in regions near the coast than in inland areas. (Turismo de Portugal, 2013)

The political system in Portugal is framed in a unitary semi-presidential democratic republic with the prime minister as a government head and the president as a head of the state, who has the power to appoint the prime minister and other members of the government. Administratively, the country is divided into 18 continental districts and 2 autonomous regions. (European Union, 2019)

### 4.3.1. Energy Overview PT

The energy in Portugal comes from different sources, as shown on figure 7. In 2016, the gross inland consumption was 23,26 Mtoe, most of this energy comes from petroleum and fossil fuels. On the other hand, Portugal has a high participation of renewable energies. (Eurostat, 2019; Direção-Geral de Energia e Geologia, 2018)

**Figure 7. Portugal gross inland energy consumption 2016 - (Eurostat, 2019)**




The country final energy consumption for the same year was 16,11 Mtoe and the residential area consumed 2,6 Mtoe. It means a 16,14% in 2016. In terms of trade, the country is a total net importer of fossil fuels (Eurostat, 2019). The main source of energy for the residential area is the electricity. (Instituto Nacional de Estatística, I.P, 2011)

Portugal and Spain are part of the Integrated Market for Electricity and Gas (European Union, 2019). It means that the country is directly connected with Spain and indirectly with France. The Energy Service Regulatory Authority is the national legal public entity with administrative and financial autonomy that is responsible for the regularization of the energy in all the sectors. It work on the framework of the law and within the government principles of energy policy. (ERSE, 2017)

Residential energy consumers in the country have an energy market with electric tariff options. Most of the residential user has contracted the Low Tension Normal and they are free to choose between three tariffs. (ERSE, 2017)

When a real measurement of energy consumption can not be made, the consumer will receive a bill with an estimated value based on historical consumption. The periodic of the bills for gas and electricity are monthly or bi-monthly. Are forbidden by law the charges for minimum consumption. (ERSE, 2017)

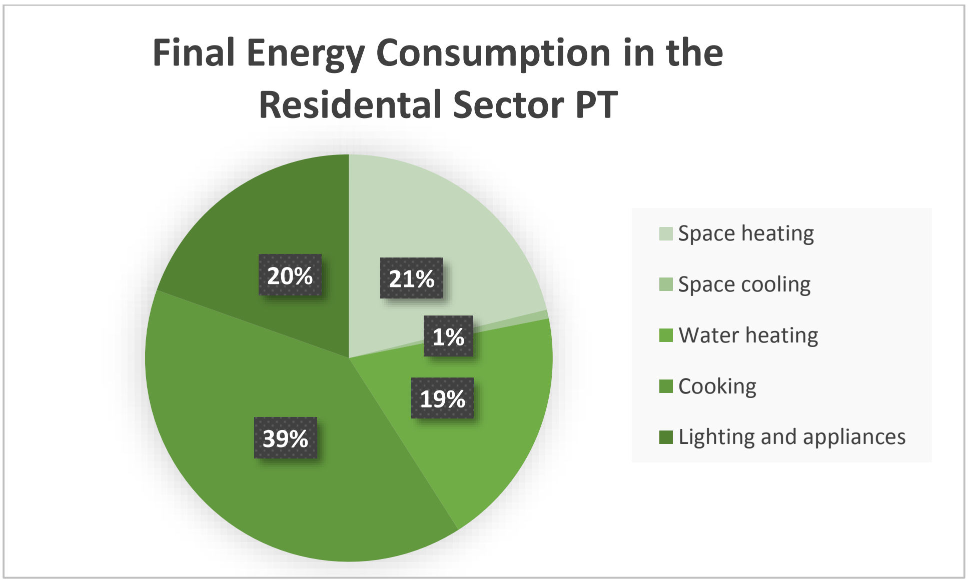
Most of the bill in Portugal contain the value of the carbon dioxide ($CO_2$) emissions this value is calculated based on the $CO_2$ emission factor of Portugal / Europe and is used by all marketers. The addition of this specific information seeks to sensitize the consumer about the environmental effects of the consumption of electric energy. (ERSE, 2017)

### 4.3.1. Buildings Overview PT

Portugal presents a residential building stock built mostly between the 1970s and 1990s inserted in predominantly urban areas. Only a small percentage have some thermal insulation on roof walls and windows. (Instituto Nacional de Estatística, I.P, 2011)

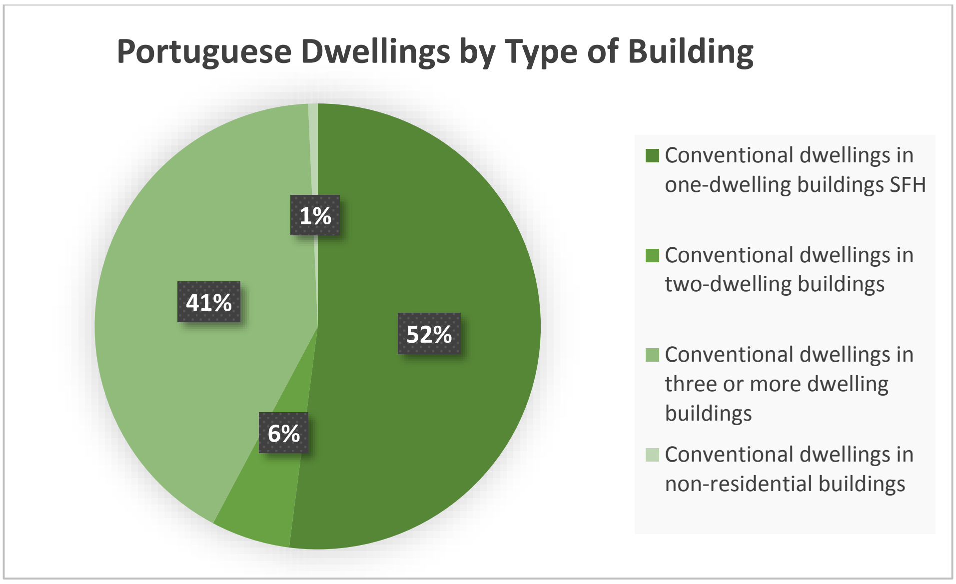
In Portugal, the residential sector ranks third among the sectors with the highest energy consumption after the transport and industrial sectors. The residential sector consumes around 16% of the total final energy. (Eurostat, 2019)

**Figure 8. Residential energy consumption by final use PT - (Eurostat, 2019)**



Unlike the other European countries, in Portugal, the highest amount of final energy in residential buildings is used for cooking, followed by space heating and lighting and appliances, as shown in figure 8. (Eurostat, 2019)

**Figure 9. Dwellings by type of building PT- (Eurostat, 2019)**




More than half of the Portuguese residential sector is made up of conventional dwelling in one dwelling building, conventional dwellings in three or more dwelling buildings represent the other half, and the amounts of buildings of other types of buildings are negligible, as shown in figure 9. (Eurostat, 2019)

## 4.4. Spain

**Table 5. Spain general information - (Eurostat, 2019)**

| Spain General Information | |
|---|---|
| Area | 505.983 km$^2$ |
| Region | Southwestern Europe- Iberian Peninsula |
| Population 2018 (millions) | 46.933 |
| Local Name | España |
| Capital | Madrid |
| GDP 2017 (billions) | 1.311,2 USD |
| Urban Areas | 69.795 km$^2$ (14% of the total country area) |

Spain is located in the Iberian Peninsula and occupies around 80% of it, the territory of the country also includes the Balearic Islands, (Mallorca, Menorca, and Ibiza), in the Mediterranean Sea, the Canary Islands in the Atlantic Ocean and the cities of Ceuta and

Melilla in the north of Africa. Five mountain rages cross continental Spain, and almost half of its territory is composed of plateaus. (Instituto Geográfico Nacional, 2019)

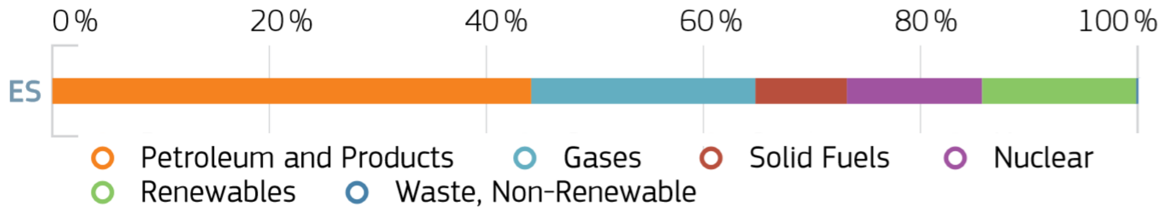
Diverse geographical factors define the climates of the country such as latitude, the width of the peninsula, little rugged coasts, and mountainous reliefs parallel to the coast. These factors also make a big difference between the climates of the periphery and the interior. Most of Spain has a coastal and continental Mediterranean climate zone, except in the north with a mostly oceanic climate. ( Agencia Estatal de Meteorología, 2018)

The Spanish political system is formed by a parliamentary democracy and a constitutional monarchy with the President as head of government and the Monarch as head of state. The President of the Government also chairs the Council of Ministers that constitutes the executive branch. The Spanish unitary state is composed of 17 autonomous communities and 2 autonomous cities with different degrees of autonomy. (European Union, 2019)

### 4.4.1. Energy Overview ES

Spain has a strong dependence on petroleum products and gases to supply its energy needs and is the only country of those chosen that has a nuclear power generation source, as shown in figure 10. In 2016 the gross inland consumption of energy in Spain was 122,17 Mtoe, the final energy consumption for the same year was 82,5 Mtoe, and the residential area consumed 15,06 Mtoe. It mean an 18,25% in 2016, the third after the transport and industry sector. (Eurostat, 2019)

**Figure 10. Spain gross inland energy consumption 2016 - (Eurostat, 2019)**




The country depends entirely on oil imports that are mostly destined for the transport sector. (Instituto para la Diversificación y Ahorro de la Energía, 2019)

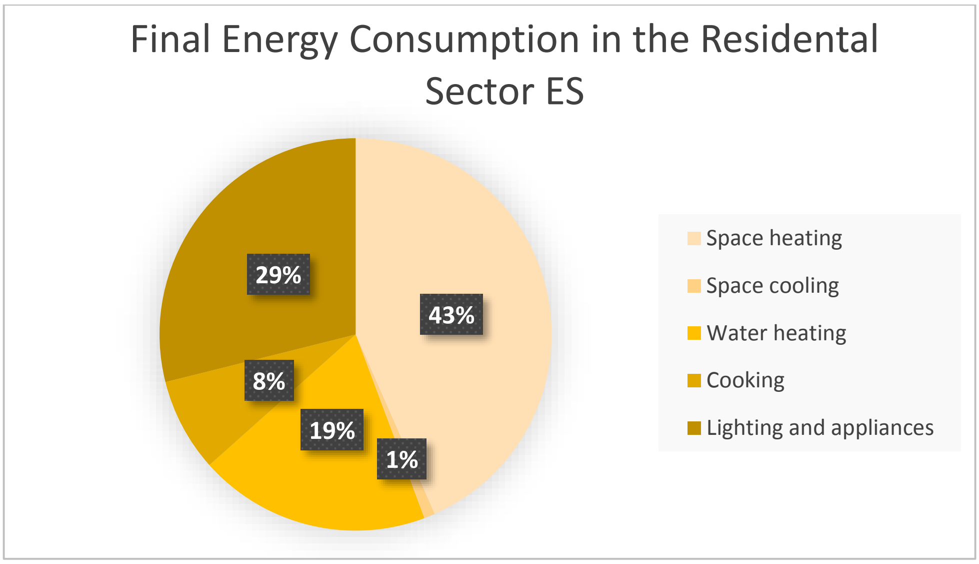
For residential users in Spain the electricity and gas can be acquired through the free market and the regulated market; consumers are free to choose between both markets according to their preferences; each energy market has advantages and disadvantages. (Red Eléctrica de España, 2019)

### 4.4.1. Buildings Overview ES

The countries of southern Europe for tourist reasons are characterized by having a large number of secondary or unoccupied dwellings, Spain is one of the countries with the highest number of homes per inhabitant, (Banco de España, 2003). A little more than half of the residential park in Spain was built before 1980, when there were still no regulations related to energy efficiency. (Eurostat, 2019)

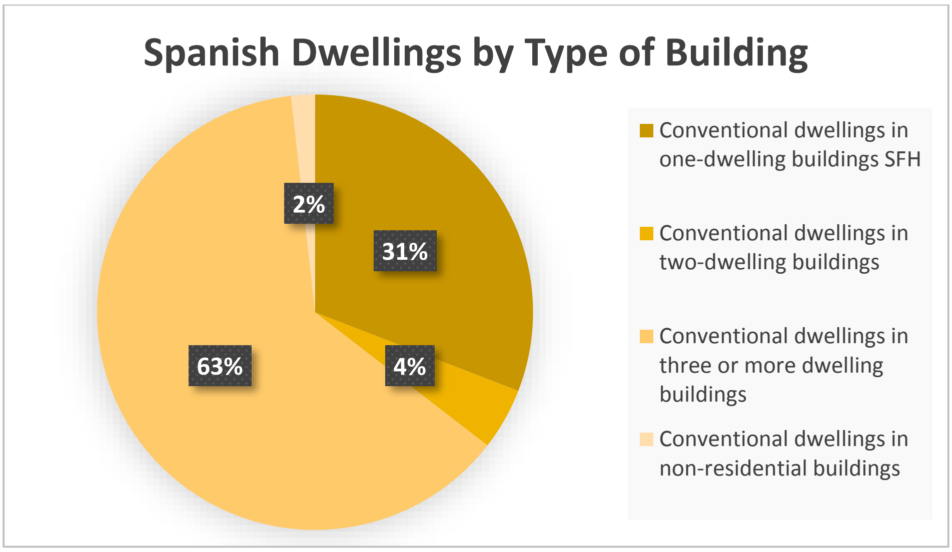
The energy in the residential sector is mainly used for space heating, lighting and appliances, and water heating. It is perfectly aligned with the European consumption model. (Eurostat, 2019)

**Figure 11. Residential energy consumption by final use ES - (Eurostat, 2019)**




Conventional dwellings in one-dwelling building are a third of the Spanish residential stock, the second largest type of buildings far below the conventional dwellings in three or more dwelling buildings, as shown in figure 12 (Eurostat, 2019). According to (Instituto para la Diversificación y Ahorro de la Energía, 2019) in Spain, a SFH in average consumes twice the energy of a multifamily house.

**Figure 12. Dwellings by type of building ES - (Eurostat, 2019)**




All the Spanish houses already count with digital smart meters, Spain pushed by the decision of the European Commission, that 80% of the meters must be digital by 2020, decided in a shorter term a more ambitious goal through the order IET/2090/2012, that establish by the end of 2018 100% of the meters must be digital. The digital meters play an essential role in calculating the real price of each kWh, giving the consumer a good and fast feedback of the energy consumption. (Gobierno de España, 2017a)

## 4.5. Energy Policies

All countries have implemented public national policies to restrict energy consumption, either by internal or external factors such as the variation in the price of oil. However, from the implementation of directives at European level, local policies began to have common lines, as shown in figure 13. In this section a brief analysis and a review of the creation, implementation and application of the policies on each country is presented.

### 4.5.1. Policies GR

In Greece, the implementation and definition of the national energy policies, as well as the coordination of the energy sector, is doing by the Ministry of Environment and Energy. (Ministry of Enviroment and Energy, 2016)

Like many other European countries, the implementation of the EPBD represented a start point for some important local regulations about energy consumption and performance in building. However, in Greece, there were relevant regulations before such as the Greek

Thermal Regulation, implemented in 1981. Following along the footsteps of the first German standard, it established thermal transmittance limit values and restricted heat transfer through the building envelope for the different climatic zones. In the first years, it was not totally applied by the new constructions. (Centre for Renewable Energy Sources and Saving, 2014)

In 1986, the Technical Chamber of Greece (TEE) wrote Technical Codes that were established by laws 2421/86 for the installation of boilers for the heating of buildings, 2423/86 for the installation of cooling systems in buildings and 2425/86 for the calculation of cooling loads in buildings. (Centre for Renewable Energy Sources and Saving, 2014)

In 2008 the Directive 2002/91/EC was lately transposed by the Law 3661/2008 of Regulation on the Energy Performance of Buildings (KENAK), providing norms and technical guidelines in order to ensure the EE of new and renovated buildings. In 2010 the Technical Chamber of Greece prepared and included the Technical Codes of the Technical Chamber of Greece (TOTEE) 20701/2010. (The Technical Chamber of Greece, 2019)

The Greek Parliament in 2013 transpose the Directive 2010/31/EU to the national legislation under the law 4122/2013. (Hellenic Republic, 2019)

The TOTEE aim to fill the gap resulting from the lack of valid Greek Technical Specifications in the construction and production sectors and constitute the confirmation of the TEE policy to contribute to the creation of technological infrastructure in our country. (The Technical Chamber of Greece, 2019)

The TOTEE texts give recommendations on the design, selection of materials and components, construction, installation, maintenance and use of a technical project. With these texts, the TEE aims to provide concrete content, and define the rules of art and science at all stages of the life of a technical project (design, study, construction, supervision, delivery, maintenance, use). Currently the mandatory in force regulations in Greece are the KENAK TOTEE updated in 2017. (Hellenic Republic, 2019)

#### 4.5.1. Policies PT

Before 1990, in Portugal, there was not any regulation of the thermal conditions of the buildings. The very first legal regulation of this type was the Regulation of Characteristics of Thermal Behavior of Buildings (RCCTE) published in the Portuguese Republic Diary as

Decree Law (DL) No. 40/90 in February 1990. RCCTE aimed to improve health conditions, hygiene, thermal comfort (heating and cooling) and visual comfort (lighting) in residential buildings and buildings in general, regulating energy consumption. (República Portuguesa, 2019)

Some years later, in 1998 through D.L No.118/98, Building HVAC Regulation was approved. The regulation sought to implement energy rationalization measures, limits on the maximum power of the systems to prevent their oversizing, the practice of certain procedures after installation of the systems and maintenance during normal operation, thus contributing to their EE and avoiding unnecessary investments. (República Portuguesa, 2019)

In 2006 the Community Directive 2002/91/EC (EPBD) was transposed in the local legislation through a set of three legislative decrees. (ADENE – Agência para a Energia, 2016)

The D.L No.78/2006 System of Energy Certification of Buildings (SCE) begins the evaluation of the energy performance in buildings, implements the national energy certification system identifying corrective or performance-enhancing measures applicable to buildings and their energy systems. The SCE was applied for big new buildings in 2007, for small new buildings in 2008 and to all the buildings including existent ones in 2009. (República Portuguesa, 2019)

The D.L No. 79/2006 replaced the previous Building HVAC Regulation that presented a lack of requirements that generated among other problems with indoor air quality; the modification raised the fulfillment of new technical and administrative requirements. (República Portuguesa, 2019)

The D.L No. 80/2006 approves the new version of the RCCTE that defines stringent measures to improve the quality of habitability of buildings reducing their energy consumption; this time the Domestic Hot Water (DHW) systems was also included. (República Portuguesa, 2019)

Directive 2010/31/EU EPBD is transposed in 2013 by D.L No. 118/2013, which aims to ensure and promote the improvement of the energy performance of buildings through the approval of SCE, the Energy Performance Regulation of Housing Buildings (REH) and the Energy Performance Regulation of Commercial Buildings Services. The D.L No.118/2013 was modified several times in the last years having as final version the D.L No.95/2019 of July 2019, currently in force. (República Portuguesa, 2019)

#### 4.5.1. Policies ES

In Spain, since 1957 the construction was regulated by the called MV standards, responsibility of the Housing Ministry. In 1975 the Royal Decree (RD) No.1490/1975, established measures for the first time to be adopted in the new buildings in order to reduce energy consumption as standards for thermal insulation and the country was divided by climate zones. (Gobierno de España, 2019)

The previous standards did not clearly delimit the border between the mandatory and the optional and were difficult for the interpretation, so in 1977 the Basic Building Standards (NBE) were established by the R.D No.1650/1977 of the Ministry of Housing. The NBE are standards in different areas developed from scientific and technological knowledge to be applied in the buildings to establish the minimum necessary conditions to meet individual requirements and protect the economy. (Gobierno de España, 2019)

In that frame in 1979 by the R.D No.2429/79, is approved the Basic Building Standard for the Thermal Conditions in Buildings (NBE CT) - 79, which regulates the thermal conditions of buildings. The regulation is mandatory in all new public and private buildings, aiming to save energy, depending on the weather and shape of the buildings. (Gobierno de España, 2019)

One year later, the Regulation of Heating Air Conditioning and Domestic Hot Water Installations was approved by R.D No.1618/1980, for non-industrial thermal installations in order to rationalize their energy consumption from the point of view of comfort, quality, safety and environment. The regulation implemented some mandatory measures as requirements for minimum boiler efficiency and efficiency of the refrigeration systems, meters for measuring DHW consumption, thermal insulation of pipes and equipment, among others. (Gobierno de España, 2019)

The first and second oil crisis, in 1973 and 1979 were triggers for the creation and implementation of the NBE CT 79 and the Regulation of Heating Air Conditioning and Domestic Hot Water Installations. These regulations governed buildings throughout the country, with the primary objective of saving energy linked to saving money. In the next years, the European Community Directives will influence the regulations.

In 1998, the inspection of thermal installations began to be monitored by the competent bodies of the Autonomous Communities as established by Royal Decree 1751/1998, which approves the Regulation of Thermal Installations in Buildings (RITE). This new regulation incorporates measures of Directive 93/76/EEC, concerning the limitation of carbon dioxide emissions by improving energy efficiency. (Prieto, 2017)

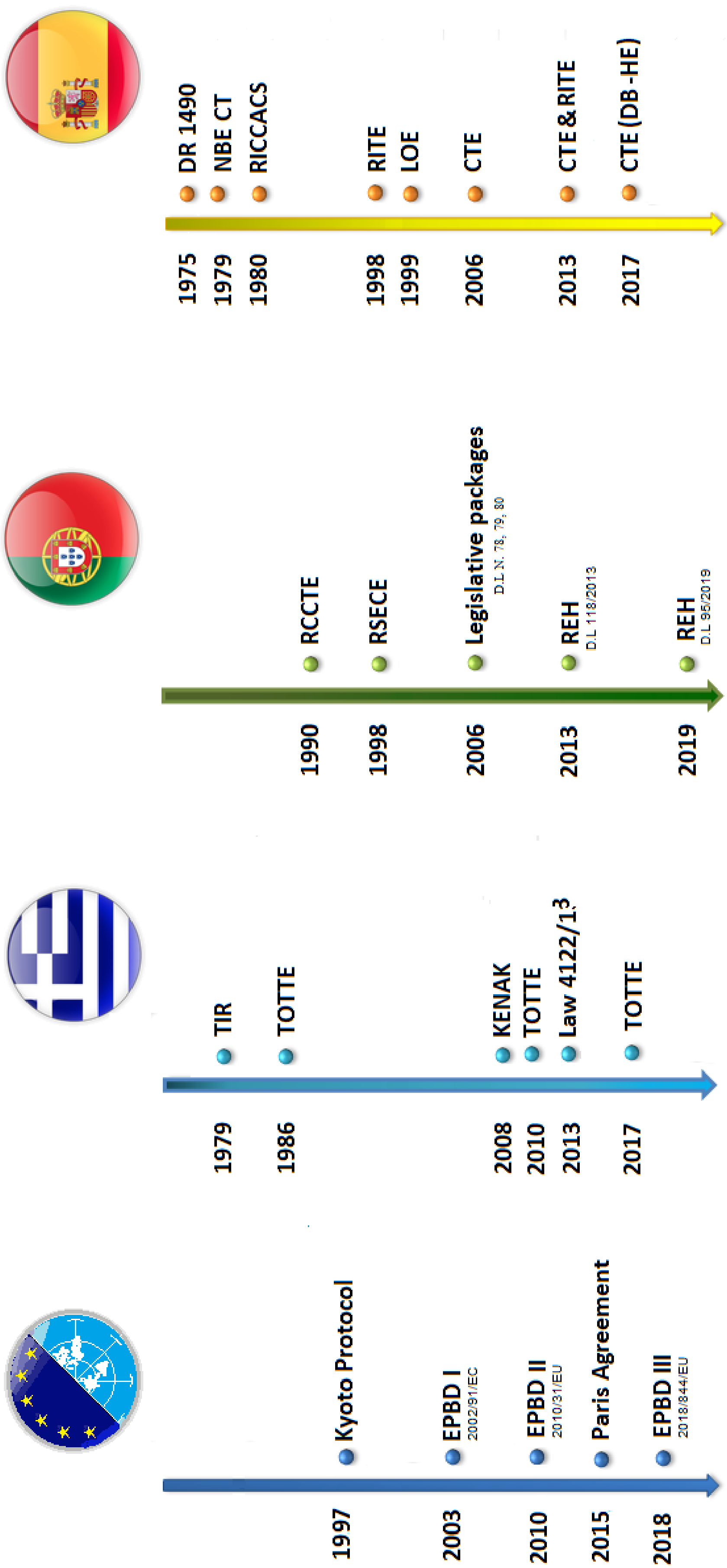
Within the framework of Law 38/1999 on Building Planning, the directive 2002/91/EC EPBD, was transposed to the national legislation by the Technical Building Code (CTE). The CTE was approved in 2006 by R.D No.314/2006 with the aim of improving the safety and quality of the building while seeking to improve user welfare and promote sustainable development. The code is mandatory and is applied to new buildings, as well as existing buildings when carrying out interventions such as extension, modification, reform or change of use, always taking into account the environmental, historical or artistic characteristics of the buildings. (Gobierno de España, 2019)

The CTE is composed of two parts. In the first one, all the safety and habitability requirements of the building are detailed, and the second part is composed of Basic Documents related with structural safety, fire safety, safety of use and accessibility, Energy saving, Protection against noise and Health. Beyond the documents mentioned above, the CTE has complementary non-mandatory technical documents that help to understand better and facilitate its implementation. (Código Técnico de la Edificación, 2015)

Currently, in the nation, the documents that rule the energy consumption of domestic buildings are the latest versions of the RITE and the CTE Basic Document for Energy Saving (DB-HE), with its latest modifications made in 2013 and 2017 respectively, which includes the requirements of the 2010 EPBD and the EED. (Domínguez Martín, 2019)

The Spain government through the Institute for the Diversification and Saving of Energy, assigned to the Ministry for the Ecological Transition through the Secretary of State for Energy, wants to ensure that the country achieve the goals related to energy efficiency, renewable energies and other low-carbon technologies. (Instituto para la Diversificación y Ahorro de la Energía, 2019)

**Figure 13. Timeline of policy implementation at national and international level**



## 4.6. Demographic Analysis

In this section, an analysis of the population of the selected countries is carried out at the NUTS 2 level in order to focus the analysis in the most populated areas since they will also represent areas with the most significant number of residential buildings. The information of the last population censuses carried out was taken from the Eurostat database, to determine the areas with the highest population in each country.

In Greece, the NUTS system divided the country into four main areas, the islands, the Attica Peninsula and central and north Greece. (Eurostat, 2019)

| Greek Population 2011 | | | |
|---|---|---|---|
| **NUTS 1** | **NUTS 2** | **Population** | **%** |
| Vóreia Ellada [North Greece] | Anatoliki Makedonia, Thraki [Eastern Macedonia and Thrace] | 608 182 | 5,6 |
| | Kentrik Makedonía [Central Macedonia] | 1 882 108 | **17,4** |
| | Dytikí Makedonía [Western Macedonia] | 283 689 | 2,6 |
| | Thessalía [Thessaly] | 732 762 | 6,8 |
| Kentrikí Elláda [Central Greece] | Ípeiros [Epirus] | 336 856 | 3,1 |
| | Iónia Nisiá [Ionian Islands] | 207 855 | 1,9 |
| | Dytikí Elláda [Western Greece] | 679 796 | 6,3 |
| | Stereá Elláda [Central Greece] | 547 390 | 5,1 |
| | Pelopónnisos [Peloponnese] | 577 903 | 5,3 |
| Attiki [Attica] | Attiki [Attica] | 3 828 434 | **35,4** |
| Nisia Aigaiou, Kriti [Aegean Islands, Crete] | Vóreio Aigaío [North Aegean] | 199 231 | 1,8 |
| | Nótio Aigaío [South Aegean] | 309 015 | 2,8 |
| | Kriti [Crete] | 623 065 | 5,7 |

**Table 6. Greek population 2011, NUTS2 - (Eurostat, 2019)**

The Attica peninsula and the Central Macedonia region together concentrate more than 50% of all the Greek population, as shown on table 6. Over those regions, the most important and most prominent cities are located. These are Athens in Attica and Thessaloniki in Central Macedonia.

**Figure 14. Most populated regions of Greece (NUTS 2)**

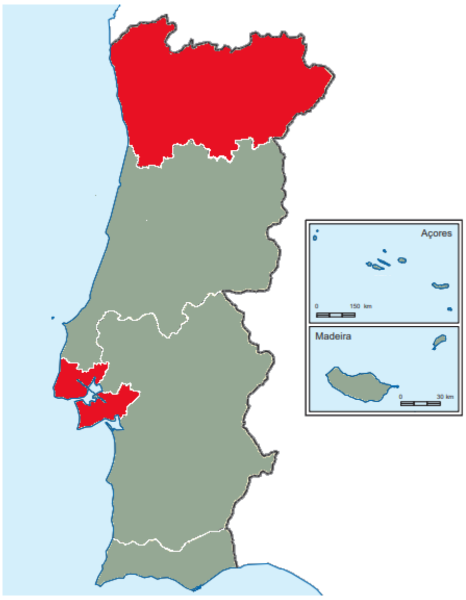
For Portugal´s case the NUTS system, divide the country into three parts, the continental area and two archipelagos. The continental area is subdivided into five parts. Table 7 shows the population for all the NUTS 2 division in the country. (Eurostat, 2019)

| Portugal Population 2011 | | | |
|---|---|---|---|
| **NUTS 1** | **NUTS 2** | **Population** | **%** |
| Continent | North | 3 689 682 | **34,9** |
| | Algarve | 451 006 | 4,3 |
| | Center | 2 327 755 | 22,1 |
| | Lisboa [Lisbon] | 2 821 876 | **26,7** |
| | Alentejo | 757 302 | 7,2 |
| Autonomous Region Açores [Azores] | Autonomous Region Açores [Azores] | 246 772 | 2,3 |
| Autonomous Region Madeira | Autonomous Region Madeira | 267 785 | 2,5 |

**Table 7. Portuguese population 2011, NUTS2 - (Eurostat, 2019)**

The Portuguese continental area is home to 95% of the population of the country. Inside the continent, the North and Lisbon regions concentrate a significant number of habitants; important cities are located within these two regions. Porto in the north and Lisbon in the Lisbon region.

**Figure 15. Mostly populated regions of Portugal (NUTS 2)**




In Spain, the NUTS system, divide the country into seven parts in the first level and the second level divided it into 19 territorial units, as shown in table 8. The most populous regions in the country are along the coastline and in the capital region. (Eurostat, 2019)

| Spain Population 2011 | | | |
|---|---|---|---|
| **NUTS 1** | **NUTS 2** | **Population** | **%** |
| Northwest | Galicia | 2 772 930 | 5,92 |
| | Principado De Asturias | 1 075 185 | 2,30 |
| | Cantabria | 592 540 | 1,27 |
| Northeast | País Vasco | 2 185 395 | 4,67 |
| | Comunidad Foral De Navarra | 640 130 | 1,37 |
| | La Rioja | 321 175 | 0,69 |
| | Aragón | 1 344 510 | 2,87 |
| Madrid Community | Madrid Community | 6 421 875 | **13,72** |
| Center | Castilla y León [Castile and Leon] | 2 540 190 | 5,43 |
| | Castilla [Castile]-La Mancha | 2 106 330 | 4,50 |
| | Extremadura | 1 104 500 | 2,36 |
| East | Cataluña [Catalonia] | 7 519 840 | **16,06** |
| | Valencian Community | 5 009 930 | 10,70 |
| | Illes Balears [Balearic Islands] | 1 100 505 | 2,35 |
| South | Andalucía [Andalusia] | 8 371 270 | **17,88** |
| | Murcia Region | 1 462 130 | 3,12 |
| | Ceuta Autonomous City | 83 515 | 0,18 |
| | Melilla Autonomous City | 81 325 | 0,17 |
| Canarias | Canarias [Canary Islands] | 2 082 655 | 4,45 |

**Table 8. Spanish population 2011, NUTS2 - (Eurostat, 2019)**

An important part of the country´s population is located in Andalusia and Catalonia region (33,94%). However, due to the high population density the study will focus on Catalonia and in the Madrid Community regions. Also in those regions, the largest and most important cities of the country such as Madrid and Barcelona are located.

**Figure 16. Mostly populated regions of Spain (NUTS 2)**


Based on the demographic information, two locations have been chosen of each country with specific climates and characteristics, which have a high concentration of inhabitants and contain the principal's cities in each country. The cities, in a certain way, represent an important economically and politically influence. In table 9 the selected regions and the cities are presented.

| Latitude of the Most Important Cities of the Selected Regions | | | |
|---|---|---|---|
| **Country** | **Region** | **City** | **Latitude** |
| Greece | Attica | Athens | 37,97945 |
| | Central Macedonia | Thessaloniki | 40,64361 |
| Portugal | Lisbon | Lisbon | 38,71667 |
| | North | Porto | 41,14961 |
| Spain | Madrid Community | Madrid | 40,4165 |
| | Catalonia | Barcelona | 41,38879 |

**Table 9. Latitude of the biggest cities in the selected countries**

The selected areas are not only the largest in number of inhabitants but they also have a high amount of SFH in each country. (Eurostat, 2019) The analysis will be focus in the six regions shown in table 9.

## 4.7. **Climate Zones**

Due to the different physical and geographical phenomena, climates may vary from one region to another. That is why each country has decided to divide its surface in climatic zones. This section shows the local climatic divisions and the factors that were considered for each division, focusing finally on the climatic zone to which each chosen region belongs.

The weather data are fundamental when two scenarios are compared because the indoor temperature has a major impact by the external temperature. Moreover, yearly weather data is never the same compared to the previous year. (Laos, 2018)

The degree-day is a unit that relates the outside air temperature and the building energy consumption. It shows the difference of temperature between the outside weather and the indoor comfort average temperature. If the outdoor temperature is, higher than the indoor temperature, it's used the cooling degree-day (CDD) value and if it's lower the heating degree-day (HDD) will be used. The unit can help to know the energy that will be used for cooling or heating the buildings. A high value of the indicators means that more energy will be needed. (U.S. EIA, 2019)

To set the base temperature value for HDD and CDD several factors associated with the building and the surrounding environment were taken into account (Eurostat, 2019). Tables 10 and 11 show the value of the HDD and CDD for the selected regions.

| **Heating Degree Days** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Country | GEO/YEAR | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | Average |
| Greece 1.382 | Central Macedonia | 1.699,8 | 2.064,1 | 1.867,3 | 1.683,7 | 1.550,5 | 1.751,8 | **1.769,5** |
| | Attica | 888,6 | 1.379,3 | 1.204,2 | 990,6 | 935,7 | 1.153,1 | **1.091,9** |
| Portugal 1.304 | North | 1.836,5 | 1.491,3 | 1.809,7 | 1.827,2 | 1.584,7 | 1.548,0 | **1.682,9** |
| | Lisbon | 763,5 | 678,9 | 870,4 | 901,0 | 777,6 | 716,8 | **784,7** |
| Spain 1.799 | Madrid | 2.179,0 | 1.636,5 | 2.016,3 | 2.066,0 | 1.598,3 | 1.678,0 | **1.862,3** |
| | Cataluña | 2.181,1 | 1.715,1 | 1.996,2 | 2.091,7 | 1.704,9 | 1.829,5 | **1.919,7** |

**Table 10. Heating degree-days for the selected locations NUTS 2 (Eurostat, 2019)**

| **Cooling Degree Days** | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Country | GEO/YEAR | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | Average |
| Greece 306 | Central Macedonia | 408,2 | 399,7 | 517,7 | 364,3 | 308,8 | 395,5 | **399,0** |
| | Attica | 561,4 | 518,0 | 696,6 | 561,2 | 492,2 | 511,1 | **556,8** |
| Portugal 233 | North | 140,2 | 61,5 | 71,0 | 136,9 | 39,8 | 93,4 | **90,4** |
| | Lisbon | 267,9 | 119,8 | 159,2 | 223,1 | 60,1 | 114,7 | **157,5** |
| Spain 239 | Madrid | 296,0 | 276,2 | 333,9 | 314,7 | 223,3 | 433,8 | **313** |
| | Cataluña | 158,6 | 141,2 | 202,0 | 112,0 | 119,7 | 217,7 | **158,5** |

**Table 11. Cooling degree-days for the selected locations NUTS 2 (Eurostat, 2019)**

The values are similar because the countries share the same geographical zone. However, the amount of energy needed to keep a building fresh in summer in Greece can be higher than in Portugal. Likewise, the energy needed to heat a building in Spain during cold days could be higher than for the rest of the countries.

According to the type of climate, and some other factors each country has established a particular division system for its territory to quantify and limit heating and cooling requirements.

**Greece**

The KENAK divided Greece in four climatic zones from A to D (warmest to the coldest), based on heating days, altitude and meteorological conditions, as shown in figure 17. (Hellenic Republic, 2010)

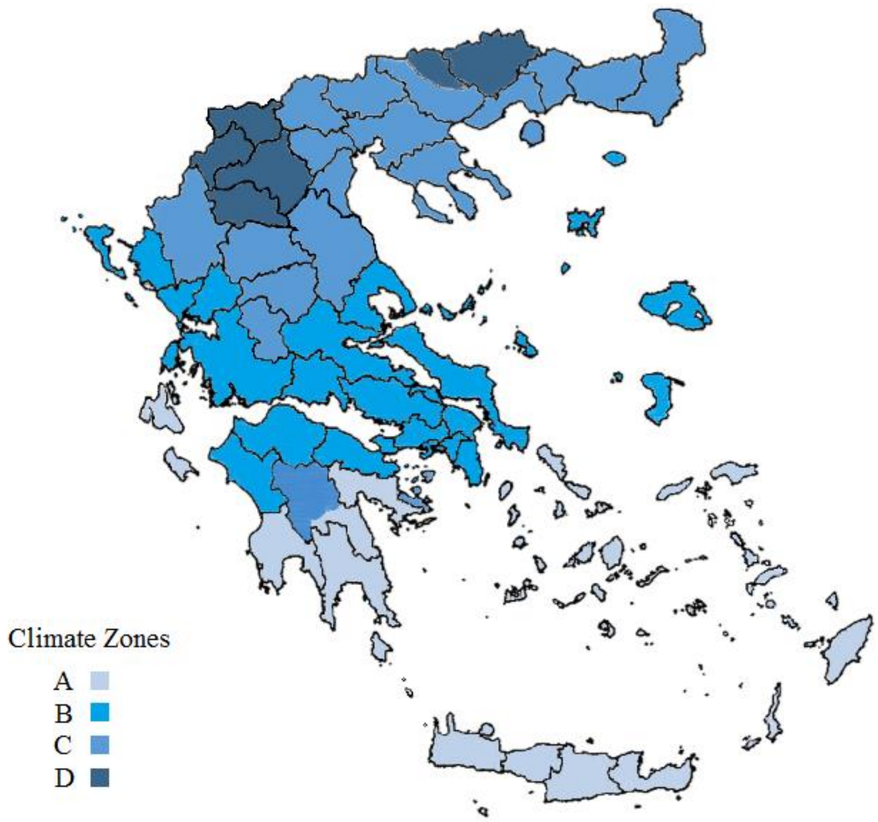
Zone A (South)

Zone B (Central-south)

Zone C (Central-north)

Zone D (North and mountains)

**Figure 17. Greece climate division (TOTEE)**

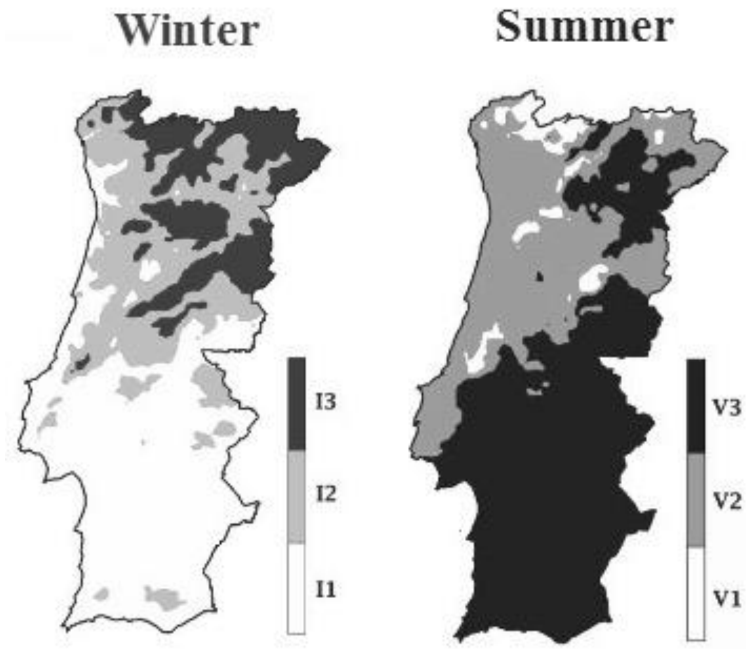


**Portugal**

The DL118/2013 through Dispatch (extract) No. 15793-F / 2013 determines the parameters for climate zoning based on the NUTS 2 nomenclature. It also defines tree climatic zones for summer (V1, V2, and V3) and tree climatic zones for the winter (I1, I2 and I3), as show in figure 18. (República Portuguesa, 2019)

The winter zones are determinate by the number of degree days of a place with a base of 18°C and the summer zones by the average exterior temperature; several parameters are considered as altitude, duration of seasons, average solar energy and outdoor temperatures. (República Portuguesa, 2019)

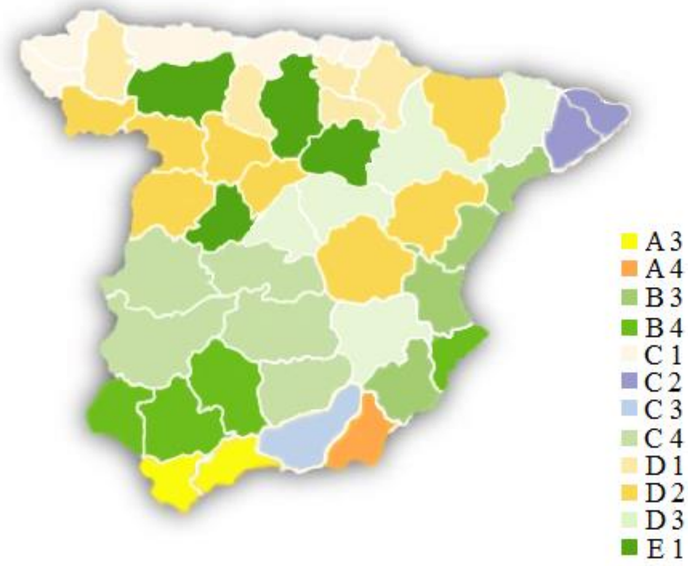
**Figure 18. Portugal climate division (REH)**




**Spain**

In Spain, the CTE through the DB-HE divides the climates of the country. The division system contain a letter that represent the severity of the winter, A for the most pleasant and E for the most extreme and a number represents the severity of the summer from 1 to 4, being number 4 for the hottest climates. In total, there are 13 climate zones, as shown in figure 19. (Gobierno de España, 2017b)

**Figure 19. Spain climate division (CTE)**




Each region selected in the previous subchapter belongs to a different local climate zone, so differences in energy consumption in each one are expected. Table 12 shows all the climatic zones for the selected regions.

<table>
<tr><th colspan="3">Climatic Zones of Selected Regions</th></tr>
<tr><th>Country</th><th>Region</th><th>Climatic Zone</th></tr>
<tr><td rowspan="2">Greece</td><td>Attica</td><td>B</td></tr>
<tr><td>K. Makedonia</td><td>C</td></tr>
<tr><td rowspan="2">Portugal</td><td>Lisbon</td><td>I1 V2</td></tr>
<tr><td>North</td><td>I1 V2</td></tr>
<tr><td rowspan="2">Spain</td><td>Madrid</td><td>D3</td></tr>
<tr><td>Catalonia</td><td>C2</td></tr>
</table>

**Table 12. Climatic Zones of the selected areas**

## 4.8. Energy Price

In Europe, several factors generate differences in the final price of the energy. Among them are the difference between supply and demand conditions, the geopolitical situation, the national energy mix, import diversification, network costs, environmental protection costs, severe weather conditions, or levels of excise and taxation (Eurostat, 2019). Energy prices change the trend of the consumers. Thus, economic policies have an effect over the prices and the consumers behavior can have an impact on the economy with the variation of energy demand. (Van Raaij & Verhallen, 1983)

Table 13 shows the prices of electricity, natural gas and oil in the selected countries. The values include taxes and correspond to the first half of 2018. (Eurostat, 2019)

| **Energy Price €/kWh** | | | |
|---|---|---|---|
| **Country** | **Electricity** | **Natural Gas** | **Heating Oil** |
| Greece | 0.186 | 0.053 | 0.101 |
| Portugal | 0.224 | 0.075 | X |
| Spain | 0.238 | 0.066 | X |
| EU-28 | 0.205 | 0.059 | X |

**Table 13. Electricity, natural gas and heating oil price 2018 - (Eurostat, 2019)**

Energy taxes for residential use depend on the application of policies in each country. Portugal in 2018 was the country with the highest tax rates applied to electricity in the EU countries, with around 55% of taxes, then Greece with around 39%, and finally Spain with around 22%. However, Portugal has the lowest net energy value without taxes respect to the other compared countries, mainly due to the increase of the use of renewable sources for the energy production. (Eurostat, 2019)

# 5. Definitions of Simulation Parameters

In order to make a good comparison, the analysis focused on specific locations in the selected countries. Buildings in a specific period and a specific type with particular characteristics, trying to represent the reality of each country.

This chapter details how the parameters and other data involved in the simulation of house energy consumption in the six chosen scenarios will be determined. It is necessary to have as much information as possible to ensure a good level of results.

The physical characteristics of the houses that will be simulated in each country should be the most typical and representative of each region to build a model that strongly represents a typical SFH without upgrades in each region and period. Some factors will try to represent natural, political and behavioral influences over energy consumption.

The parameters detailed in this chapter were divided into constants and variable, and were based on statistical information and on energy regulations of each country. At the end, the final model for each region is shown.

## 5.1. Constant Parameters

Once the most representative areas of each country were selected by the demographic analysis, it is important to determine some characteristics of the buildings that directly or indirectly influence on the energy consumption recalling that buildings modifies the external conditions to more pleasant internal conditions.

The parameters determined in this section will be the most representative, will serve as base for the construction of the simulation models and will remain constant for each region.

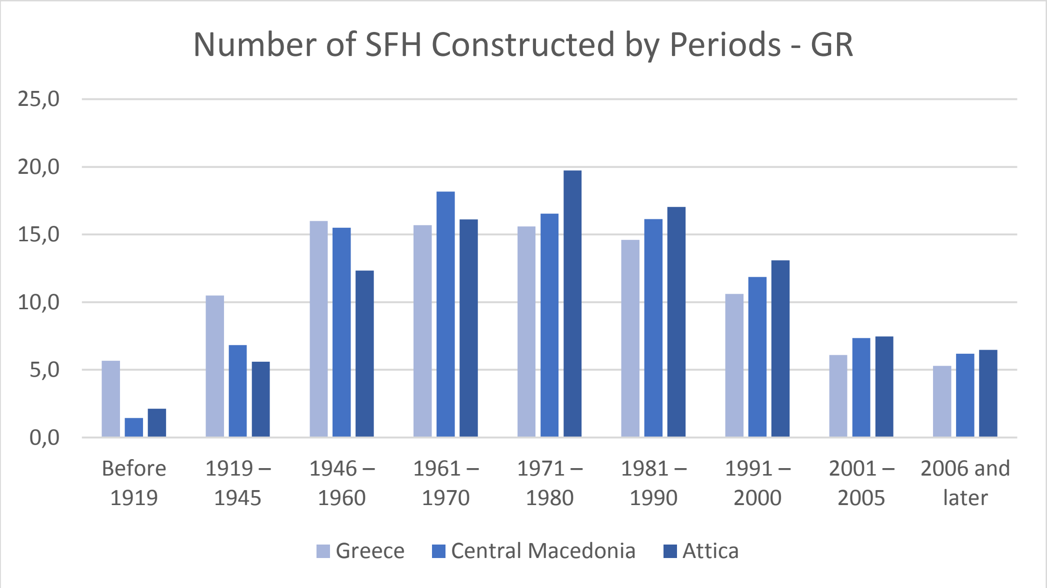
### 5.1.1. Periods of Construction

In this section will be made a limitation of the period of construction of the SFH. From the last census conducted in Europe in 2010, information can be obtained from the number of SFH constructed by periods in the selected areas. The information will be obtained at the level of NUTS 2 statistical regions, as in the demographic analysis.

Taking the census information as a base, a subdivision of periods was carried out according to implementation of policies, changes in legislation that govern the construction sector and to modifications in construction methods of each country in order to have more precise characteristics and specifications of how the buildings were built.

For Greece, the area of Attica has the most significant number of constructed buildings during the years 1971 to 1980. In Central Macedonia most built from 1961 to 1970, while in the whole country 47% of the residential buildings were built between 1946 and 1980, as shown in figure 20. (Eurostat, 2019)

**Figure 20. SFH Constructed by periods GR - (Eurostat, 2019)**




Greek residential buildings can be divided into four sub-periods as shown in table 14. The first period represents historical buildings with particular characteristics. The second period being a period without specific regulations. The third period starts with the implementation of the Greek Thermal Insulation Regulation in 1979, and the last one is made up of houses built with new methods and with the EPBD regulations. The period division is according to (Pallis, et al., 2019).

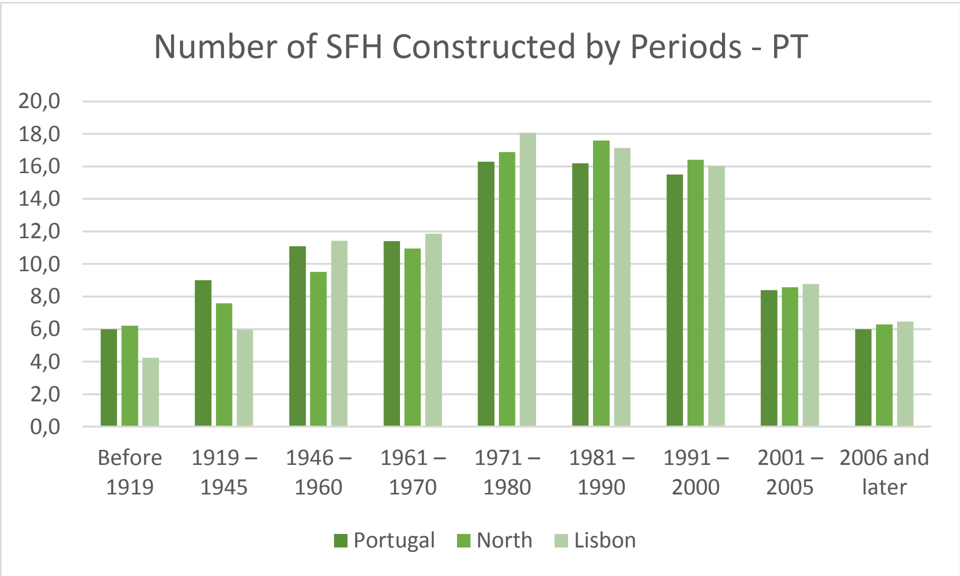
| Percentage of SFH Built by Policies Periods in Greece | | | | |
|---|---|---|---|---|
| **Periods** | | **Greece** | **C. Macedonia** | **Attica** |
| P1 | …1945 | 16,1 | 8,3 | 7,7 |
| **P2** | **1945-1980** | **47,3** | **50,2** | **48,2** |
| P3 | 1980-2000 | 25,2 | 28,0 | 30,1 |
| P4 | 2001-2010 | 11,4 | 13,5 | 13,9 |

**Table 14. SFH policy based construction periods- GR**

The construction period that contains the most significant number of SFH built in Greece is between 1945 and 1980. During this period, most of the buildings were built without any regulation since the first regulation appeared just after, in 1980. This period will be selected for the analysis in the Greek regions.

In Portugal, most of the constructions occurred between the latest 1960s and 2000, with a peak between 1971 and 1980, as shown in figure 21. In the North area, the period with the largest number of constructions was between 1971 and 1990, wherein the area of Lisbon the largest amount of constructions occurred from 1971 to 1980. (Eurostat, 2019)

**Figure 21. SFH Constructed by periods PT - (Eurostat, 2019)**




According to the Portuguese policies regarding construction and energy savings in buildings before 2010, the buildings can be divided in classes respecting to four periods, as shown in table 15. A first sub-period representing what was constructed before the massive increase of the 1960s, a second representing constructions before the implementation of Law 40/90 in 1990, the first regulation on the thermal characteristics in buildings, and the transposition of the Community Directive 2002/91/EC by the country in 2006 marking the beginning of the last period.

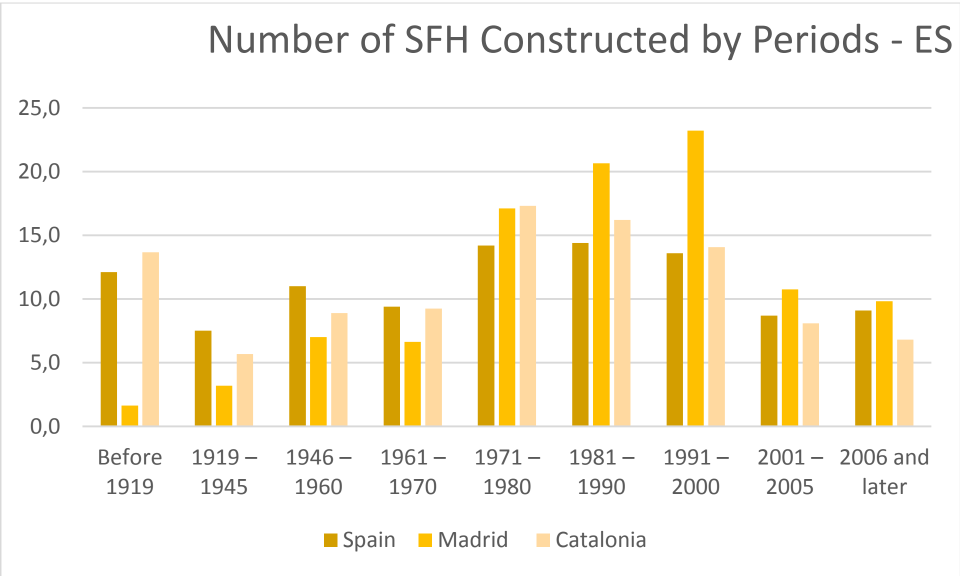
| Percentage of SFH Built by Policies Periods in Portugal | | | | |
|---|---|---|---|---|
| **Periods** | | **Portugal** | **North** | **Lisbon** |
| Period 1 | ...1960 | 26,1 | 23,3 | 21,6 |
| **Period 2** | **1960-1989** | **43,9** | **45,4** | **47,1** |
| D.L No. 40/90 | 1990-2005 | 23,9 | 25,0 | 24,8 |
| RCCTE (Transposition EPBD) | 2006-2010 | 6,0 | 6,3 | 6,5 |

**Table 15. SFH policy based construction periods - PT**

According to the information analyzed, the study will focus on houses built between 1960 and 1989. Most of the SFH in the country and in the selected areas were built before the implementation of any energy regulation.

Spain had an increase in the number of housing constructions that began around the 1970s and remained more or less constant until the year 2000. Within the same period the areas of the Community of Madrid and Catalonia experienced construction peaks, being the 1970s for Catalonia and the 1990s for the Autonomous Community of Madrid, as shown in figure 22. (Eurostat, 2019)

**Figure 22. SFH Constructed by periods ES - (Eurostat, 2019)**




In Spain a groups of norms regulated the construction of buildings, with a focus on the envelope, had an early appeared (Código Técnico de la Edificación, 2015). Although they were not of mandatory application, they marked a difference in the construction area of the country. The first mandatory regulation was implemented in 1979 (NBE CT) followed in 2006 by the transposition of the Community Directive 2002/91/EC through the CTE in the framework of LOE. In function of these norms, the classification of the buildings in Spain was subdivided into five periods, as shown in table 16.

| Percentage of SFH Built by Policies Periods in Spain | | | | |
|---|---|---|---|---|
| **Periods** | | **Spain** | **Madrid** | **Catalonia** |
| P1 | …-1960 | 30,6 | 11,8 | 28,2 |
| P2 - MV | 1960-1980 | 23,6 | 23,7 | 26,6 |
| **P3 - NBE CT-79** | **1980-2000** | **28,0** | **43,9** | **30,3** |
| P4 - LOE | 2001-2006 | 8,7 | 10,7 | 8,1 |
| P5 - CTE | 2006-2010 | 9,1 | 9,8 | 6,8 |

**Table 16. SFH policy based on construction periods- ES**

The majority of residential buildings in the whole country and in the selected areas were built between the year 1980 and 2000. This will be the period to focus the analysis in the Spanish regions.

In Greece as in Portugal, most of the SFH were built before the implementation of any energy regulations on construction. On the other hand, in Spain, the houses were built under the guidelines of the NBE CT-79. The analysis will be focus on the periods of the table 17 in each country.

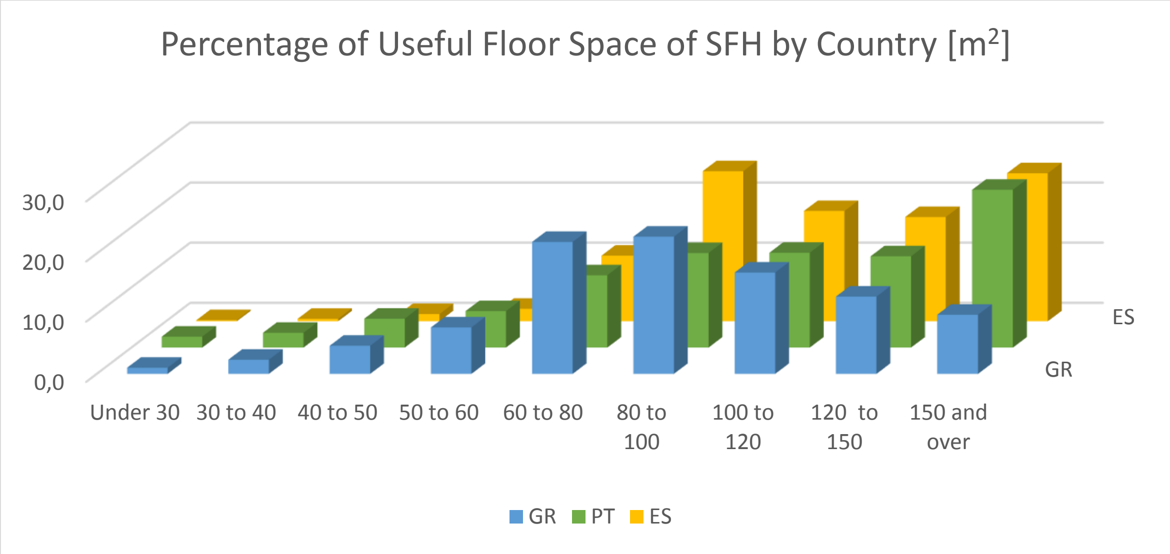
| SFH Selected Periods | | | |
|---|---|---|---|
| **Country** | **Area NUT 2** | **Selected Period** | |
| Greece | Attica | P2 | 1945-1980 |
| | Central Macedonia | | |
| Portugal | Lisbon | P2 | 1960-1989 |
| | North | | |
| Spain | Madrid Community | NBE CT-79 | 1980-2000 |
| | Catalonia | | |

**Table 17. Selected period of the SFH for each region**

### 5.1.2. Useful Space in Building

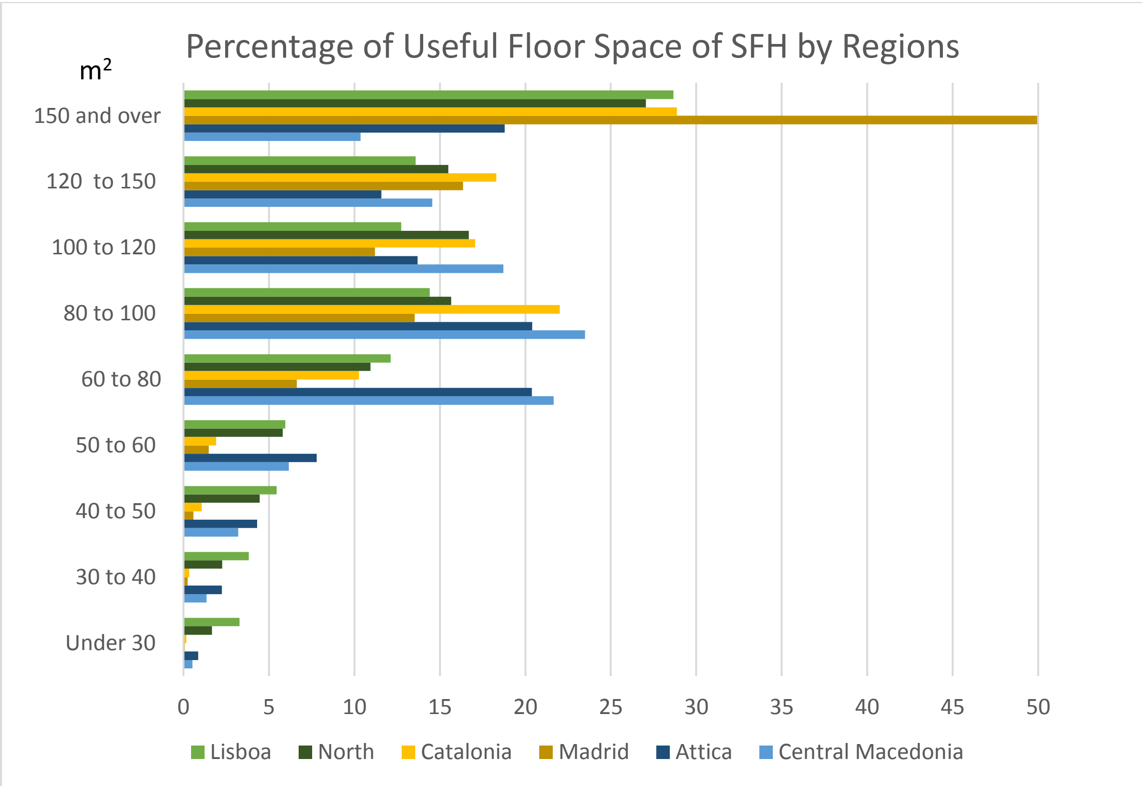
The dwelling area will determine together with the floor ceiling distance the volume of air that will have to be heated or cooled. To determine the area of the houses, the information of the census carried out in Europe in 2010 from the Eurostat database for the selected regions was used again, the information is shown in the figure 23.

**Figure 23. Percentage of Useful Floor Space of SFH by Country - (Eurostat, 2019)**




In an analysis at the country level, it is observed that in Greece, the area of most of the SFH buildings ranges from 60 to 100 $m^2$. In Portugal, the majority is clearly for areas higher than 150 $m^2$, while in Spain the data is divided between areas ranging from 80 to 100 $m^2$ and those that exceed 150 $m^2$. For a more specific analysis, the information of the selected areas is shown in the figure 24. (Eurostat, 2019)

**Figure 24. Percentage of useful floor space of SFH by regions - (Eurostat, 2019)**



For all regions, houses with areas smaller than 60 $m^2$ are negligible. Following national statistics, most of the houses in the Attica region have an area that ranges from 60 to 100 $m^2$. In the region of Central Macedonia there is a slight difference making the area of most of the houses be from 80 to 100 $m^2$.

In the north of Portugal, an important number of houses range from 80 to 150 $m^2$, but constructions with more than 150 $m^2$ are more frequent, very similar to the data obtained from Lisbon.

In the region of Catalonia, a large group of constructions is represented by areas ranging from 80 to 100 $m^2$ and another with areas from 120 to 150 $m^2$ but the vast majority of houses have an area greater than 150 $m^2$. For the Madrid region, it is easily observed that SFH with areas greater than 120 $m^2$ are the most abundant.

It is important to remember that the data obtained on the areas of the houses are grouped by region but not by year of construction. Therefore, the representative area of most of the houses may not always be the same area that represents a house in the periods chosen above.

Thus, for the houses in Greece, many of the characteristics of the SFH were obtained from the 2018 cost optimal report. (Ministry of the Environment and Energy, 2018)

In order to define the area of the houses in the regions of Portugal, data from (Instituto Nacional de Estatística, I.P, 2011) and (Eurostat, 2019) were used. The survey shows, as a result the total number of accommodations and the total habitable area by periods.

In the case of the areas of the houses in Spain, the data provided by the Cost Optimal Report (Ministry of Development of Spain, 2013) was used, which takes as a reference building data of a SFH in Madrid identify as the most typical built. For the Catalonia region, data form (Eurostat, 2019) and the exemplary SFH from the research project (IEE Project TABULA, 2017) were considered.

After the analysis of the available data and with all these considerations, finally the areas of the houses to be conditioned are defined as shown in the table 18.

| **Useful Area of a Typical SFH for the Selected Periods** | | |
|---|---|---|
| **Country** | **Region** | **Area [m$^2$]** |
| Greece | Attica | 80 |
| | C. Macedonia | 80 |
| Portugal | Lisbon | 111 |
| | North | 128 |
| Spain | Madrid | 125 |
| | Catalonia | 171 |

**Table 18. Useful area determined for the SFH in each region.**

The entire area in each one of the six model houses will be considered as a single zone to be conditioned. Gains generated by appliances or any other miscellaneous gain will not be considered in the simulation, except the occupant’s gains.

### 5.1.3. Model of Representative Building

In this section, the shape and form that the houses will have in the simulator will be defined.

To represent the models of the Greek houses, the data was obtained from the detailed information of the Greek Cost-Optimal Reports that defines typical characteristics of homes in Greece located in the selected areas and in the established periods. (Ministry of the Environment and Energy, 2018)

Some information from the Greek Cost Optimal Report was also used for the SFH models of the regions belonging to Spain and Portugal, namely measures such as the floor-to-ceiling distance (3,3 m) and the window wall ratio (16%).

Due to the lack of precise information on the form of typical houses for the place and the period established in Portugal and Spain, national statistical data was used as well as a few example houses built in the areas to define the basic architectures, as show figures 25, 26 and 27.

The SFH model used by TABULA to represent typical houses for the selected periods in Spain is used as a base to define the model of houses in the regions of Madrid and Catalonia, a house example form TABULA is shown in figure 25. (IEE Project TABULA, 2017)

**Figure 25. SFH in Mediterranean weather in Spain (IEE Project TABULA, 2017)**

According to the Portuguese National Statistics Institute from the census conducted in 2010 at national level, 39% of houses have only one floor and 45% two floors. (Instituto Nacional de Estatística, I.P, 2019)

**Figure 26. Houses in North region - PT**

**Figure 27. Houses in Lisbon region - PT**

The orientation of most of the buildings constructed was determined from statistical information, the orientation are shown in the table 19. Only one door was established per construction, located on the main facade according to the orientation. (Pallis, et al., 2019; Instituto Nacional de Estatística, I.P, 2011; Ministry of Development of Spain, 2013)

| Typical Orientation of the Buildings | |
|---|---|
| **Country** | **Orientation** |
| Greece | South |
| Portugal | East |
| Spain | North |

**Table 19.Typical buildings orientation in the three countries.**

### 5.1.4. Envelope

The indoor temperature is associated with the outdoor temperature. The building envelope being an essential factor to limit the energy needed for space heating and cooling required for thermal comfort. According to current legislation in force in the three countries, the limit for the thermal transmittance values of the envelopes depend on the climate zone of each region. For the selected periods, the houses in Greece and Portugal did not have yet any regulations in force for the characteristics of the thermal envelopes, so most of the houses have a high value of thermal transmittance.

For the Greek typical house the values of the thermal transmittance for the selected period were taken from the Cost Optimal Report, the values are shown in table 20. (Ministry of the Environment and Energy, 2018)

| Building Envelope Characteristics in Greece | | | |
|---|---|---|---|
| **Period (1945- 1980)** | | **Attica** | **C. Macedonia** |
| Thermal transmittance U (W/m$^2$k) | Wall | 2,32 | 2,32 |
| | Roof | 3,33 | 1,95 |
| | Floor | 1,74 | 1,74 |
| | Windows | 4,47 | 4,47 |

**Table 20 Average values of thermal transmittance for a SFH GR - (Ministry of the Environment and Energy, 2018)**

For the Portuguese case, information about the typical materials used in the constructions for the selected period were taken from the system of energy certification of the buildings, (ADENE – Agência para a Energia, 2019a) and from the (Instituto Nacional de Estatística, I.P, 2019), to use the characteristic thermal transmittance values of the material or calculate them according to their properties. As a result, the obtained values are shown in the table 21.

| Building Envelope Characteristics in Portugal | | | |
|---|---|---|---|
| **Period (1960- 1989)** | | **Lisbon** | **North** |
| Thermal transmittance U ($W/m^2$ k) | Wall | 2,12 | 1,58 |
| | Roof | 3,12 | 3,12 |
| | Floor | 2,56 | 2,56 |
| | Windows | 5,7 | 5,7 |

**Table 21. Calculated values of thermal transmittance for a SFH - PT**

During the period selected for Spanish buildings, the NBE CT - 79 was already in force, helping to determine the characteristics of the building envelope, the maximum transmission coefficients and maximum overall heat transmission coefficient for the entire building, the values are shown in table 22. (Gobierno de España, 2019)

| Building Envelope Characteristics in Spain | | | |
|---|---|---|---|
| **Period( 1979- 2000)** | | **Madrid** | **Catalonia** |
| Thermal transmittance U ($W/m^2$k) | Wall | 1,6 | 2 |
| | Roof | 1,2 | 1,4 |
| | Floor | 1,2 | 1,4 |
| | Windows | 5,5 | 5,5 |

**Table 22. Minimum values of thermal transmittance for a SFH ES- (Gobierno de España, 2019)**

For all doors in the models, a thermal transmittance value of 3 $W/m^2$ K was considered. There is just one door for each SFH and it is located in the main wall according to the typical orientation of the buildings table 19.

### 5.1.5. HVAC Systems

In this section, the characteristics of the HVAC systems will be determined. The energy consumption in homes is clearly represented by the consumption the different appliances, being dominated by those that regulate the internal temperature and that heat the water for direct use of consumers, which are part of this analysis. The characteristics of the HVAC systems for the houses in the six locations can be determinate by the statistical data and by the regulations over the HVAC systems.

According to the (Helenic Statistical Authority, 2014), almost all of the conventional dwellings in the country (95,4%) have a space heating system, 66,7% using oil as the main source of energy. The (Hellenic Statistical Authority, 2013) survey on energy consumption in households reveals that 59,5% of the household that participated in the survey has some kind of cooling system and 98,6% have in the dwelling some kind of system to satisfy their needs for hot water, being the most used (74,5%) the electrical thermo siphon system. The

(Ministry of the Environment and Energy, 2018) defines the water and space heating and cooling system for SFH in the selected period and climate zones.

According to (Instituto Nacional de Estatística, I.P, 2011), 78% of all buildings in the residential sector have some device for space heating. The most common heating device is the single electric heater used in the 61,2% of the buildings, then the fireplace is used in the 35,1% of the buildings with some heating system. The percentage of houses with some heating device is similar to houses that have some type of water heater system, being the most used device the electric water heater present in 78,6% of the houses with hot water systems.

Just 22,6% of all the houses in Portugal uses some device for space cooling, being the most common the fan with 69,5% followed by heat pump (air conditioning that heats and cools) with 26% and finally the air conditioning system. Although the fan may not be considered as a space cooling device because it does not affect the temperature or the humidity of the air, the percentage of households with cooling devices must be consider as much less than 22,6%. (Instituto Nacional de Estatística, I.P, 2011). Which led to the assumption that typical house in Portugal does not have an air-cooling device consistent with the reality of the country.

The D.L N 80/2006 in its article 15 defines space and water heating and cooling systems that should be considered in a building and their efficiencies when are not defined. (República Portuguesa, 2019)

According to the (Instituto Nacional de Estadística, 2004), 90% of the houses in the region of Madrid has some type of heating system and 21% some cooling system and 16% for the Catalonia region. At national level, the main fuel used for home heating is the natural gas. This information is useful if we take into account that the period of the houses chosen is those built between the years 1980-2000.

The (Universitat Politècnica de Catalunya, 2017) indicates that the average efficiency of gas heating systems in the country is 80% and the (Código Técnico de la Edificación, 2015) refers a COP of 2 for cooling equipment in private residential buildings when these are not defined.

Table 23 shows the typical energy sources of the HVAC and DHW system in the selected countries.

| Typical Energy Sources of Systems | | | |
|---|---|---|---|
| | **Greece** | **Portugal** | **Spain** |
| **Heating** | Oil | Electricity | Gas |
| **Cooling** | Electricity | Electricity | Electricity |
| **DHW** | Electricity | Electricity | Electricity |

**Table 23. Typical fuel sources for the HVAC system in each region and period – (INE; HEA)**

Although the statistical information shows that in the countries analyzed just a small number of household have some cooling systems, this will be taken into account for the analysis. The final efficiency of the systems will depend on other factors such as the distribution system, the insulation, etc.

To be able to compare the results in terms of total consumption, it is necessary to perform an adequate conversion to primary energy. Taking into account, the different electric power generation mixes in the different countries and other factors as transmission losses. Primary energy provides a base for a clear comparison among various different energy sources. For the selected countries, according to table 23, the energy conversion factors are shown in the table 24. (Gobierno de España, 2013; Technical Chamber of Greece, 2017)

| Energy Conversion Factors | | | |
|---|---|---|---|
| **Energy Source** | **Greece** | **Portugal** | **Spain** |
| Electricity | 2,9 | 2,5 | 2,4 |
| Oil | 1,1 | x | x |
| Natural Gas | x | x | 1,2 |

**Table 24. Conversion factors for different energy sources – (Diario da Republica Despacho n. 17313/2008; TOTEE; RITE)**

### 5.1.6. Occupants

Occupants on a building have an important role on the energy consumption. They define the working time of the HVAC systems, the DHW consumption, and they set and modify the indoor temperature adding heat to the room by irradiation since the normal body temperature is much higher than the room temperature. They also add considerable moisture to the room through exhaled air, which is at 100% relative humidity.

Table 25 shows the average number of inhabitants for a SFH in each country according to the statistics. (Eurostat, 2019)

| Average Number of Persons per Household | |
|---|---|
| Greece | 2,4 |
| Portugal | 2,6 |
| Spain | 2,6 |

**Table 25. Average number of persons per household- (Eurostat, 2019)**

The average number of inhabitants per SFH is very similar between countries, the software will use this number for the different calculations in each of the 6 cases that will be raised.

### 5.1.7. DHW Temperature and Consumption

Regardless of the characteristics of the DWH system, the average demand, the delivery of water temperature, and the main supply temperature, influence the energy used to heat the water. The different normative documents give standard values for the delivered hot water temperature, average tap water temperature and hot water demand. The factors described above are essential for the software to make the necessary calculations and to estimate the amount of energy that will be used in DHW in each case.

Taking the information from TOTEE (Technical Chamber of Greece, 2017), DL No. 118/2013 REH (República Portuguesa, 2019) and RITE (Gobierno de España, 2013) and adapting them to the units required by the simulations software, the values of table 26 are obtained.

| Parameters for Heating Water | | | | |
|---|---|---|---|---|
| **Country** | **Region** | **Average consumption [l/day/person]** | **Annual main supply temperature [ºC]** | **Delivery temperature [ºC]** |
| Greece | Attica | 50 | 17, 6 | 45 |
| | C. Macedonia | | 15,5 | |
| Portugal | Lisbon | 40 | 15,4 | 45 |
| | North | | 13,8 | |
| Spain | Madrid | 28 | 13,3 | 60 |
| | Catalonia | | 14,7 | |

**Table 26. Parameters for DHW- (TOTEE; REH; RITE)**

### 5.1.8. Air Renovation

The air renovation is crucial to keep the air quality; inadequate or insufficient air renewal can adversely affect the health of the building occupants (World Health Organization, 2018). At the same time, depending on the outside air temperature, the air renovation affects the indoor space temperature in the house, modifying the use of HVAC to maintain the required temperature.

The (World Health Organization, 2018) established the maximum concentration of pollutant gases in a house as well as the maximum exposure times of a person to avoid health effects. Likewise, the countries have implemented in their national regulations a minimum rate of air renewal.

The software can use mechanical and natural air renovation. As the mechanical air renewal implies the use of extra energy, natural air renovation was considered for all simulations. The software also requires the number of air renovations per hour which was calculated using the information available in the regulations of each country as TOTEE (Technical Chamber of Greece, 2017), DL No. 118/2013 REH (República Portuguesa, 2019) and RITE (Gobierno de España, 2013).

## 5.2. Variable Parameters

Including the behavior of the occupants in the simulations is a difficult task since these can be very diverse. To represent the different energy occupant's behaviors, a set of parameters were considered variable, as the inside temperature, since it depends on the comfort of the occupant and the systems work schedule. The system work schedule can be linked to the house's occupant schedule. Each family even from the same region can present different schedule of occupancy of the house that depend on some factors such as the age of the occupants, the family size and some others.

### 5.2.1. Heating and Cooling Set Point Temperatures

The heating and cooling temperatures defines the ideal temperatures in an area when heating and cooling is required. The set point temperatures for heating and cooling periods are established for the different type of buildings in the current legal regulations of each country. To set the temperatures is important for simulation software to work properly. The information available from TOTEE (Technical Chamber of Greece, 2017), DL No. 118/2013 REH (República Portuguesa, 2019) and RITE (Gobierno de España, 2013) are shown in the table 27.

| Temperature Level ˚C | | |
|---|---|---|
| **Country** | **Summer** | **Winter** |
| Greece | 26 | 20 |
| Portugal | 25 | 18 |
| Spain | 23-25 | 21-23 |

**Table 27. Set point temperatures for summer and winter in the analyzed countries- (TOTEE, REH, RITE)**

Although the temperatures in table 27 are those recommended by the regulations of each country, the occupants can modify them according to their comfort. The recommended temperatures are taken as a starting point for the representation of the variation of temperatures by the occupants, mainly assuming a deficit in the comfort level. For the temperature variations, maximum and minimum temperature limits must be considered, also recognizing that discomfort depends on the duration of the exposure to the high or low temperatures.

The American National Standards Institute/ASHRAE Standard 55 (American Society of Heating, Refrigerating and Air-Conditioning Engineer, 2017), establishes the ranges of indoor environmental conditions to achieve acceptable thermal comfort for buildings occupants. The standard also defines thermal comfort as “that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation.”

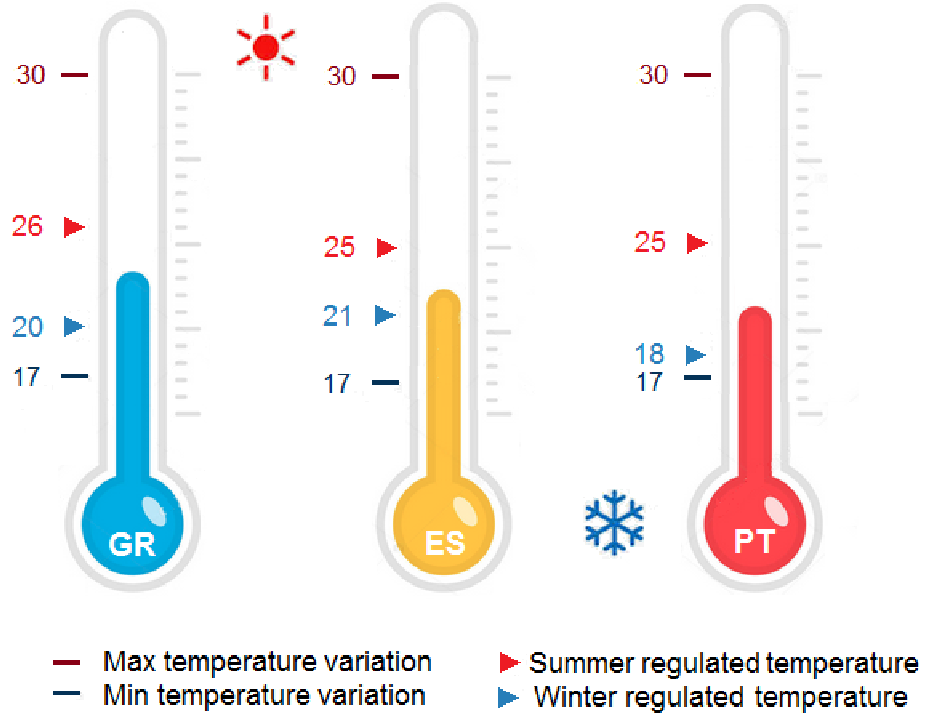
The (American Society of Heating, Refrigerating and Air-Conditioning Engineer, 2017) recommends to keep the thermal comfort house indoor temperature for human occupancy between 19,5 and 27,5 °C with less than 65% of relative humidity to avoid conditions that can lead to microbial growth. Specific temperatures can be determinate by season´s clothing worn, level of activity and other factors.

On the other hand, to avoid hyperthermia and hypothermia, the (World Health Organization, 2018) strongly recommends indoor temperatures not below 18°C due to the implications that low temperatures have on human health causing respiratory and cardiovascular disease, which can even lead to death especially in children and elderlies.

For high temperatures, the (World Health Organization, 2018) has conditional guidelines and does not mention a specific temperature value, but says “there is no demonstrable risk to human health of healthy sedentary people living in air temperature of between 18 and 24 °C”.

The temperature limit values are given by the indoor temperature of a “healthy building” (World Health Organization, 1991). The range establishes a minimum temperature of 17 °C and a maximum of 30 °C. Variances of 0,5 °C will be applied over thermostat up to the maximum and minimum temperatures in order to notice the changes in the energy consumption by the heating and cooling systems in the six scenarios.

**Figure 28. Range of cooling and heating temperature variation for each country (TOTEE; REH; RITE; WHO)**

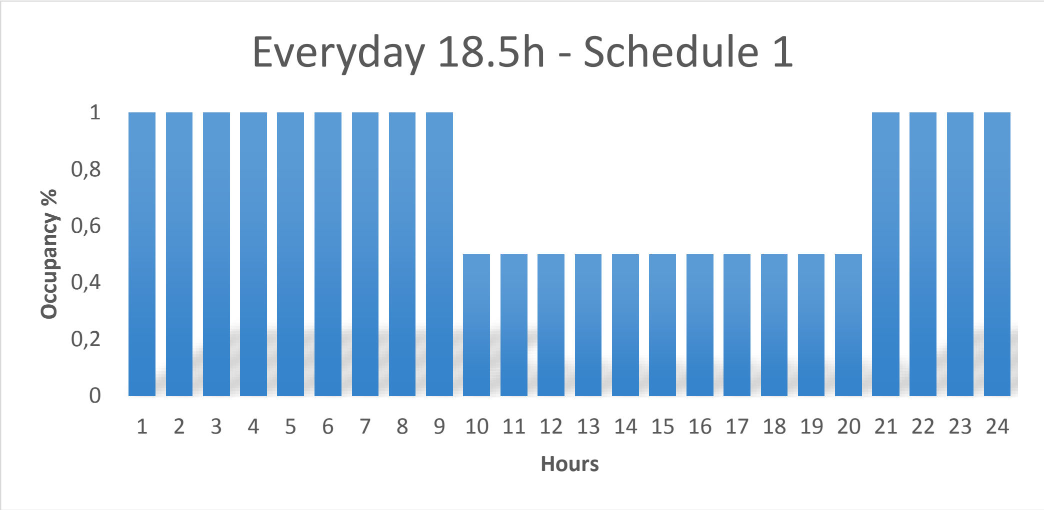



### 5.2.2. HVAC Use Time

The usage time of the HVAC systems is proportional to the energy consumption. The average use time of the HVAC systems is not defined in the regulations of each country; it depends on several factors including the occupant's schedule, the activities that are carried out during the day, and some others specifically related with the people behavior. For these reasons and for the challenge that represents the study of the people´s behavior is tough to establish a representative usage time for each region, but as a way of representing it, three variants were established, in the use time of the systems.

The first HVAC system use time is based on the schedule used by the national official Greek software to determine consumption according to its current legislation, TEE KENAK software (The Technical Chamber of Greece, 2019). In this case, the temperature inside the house must be adjusted to the set values indicated during 18, 5 hours per day, 7 days a week, whenever necessary, according to the figure 29. The total number of work hours is calculated by the hours that the system works at 100% of capacity.

**Figure 29. Schedule 1- (The Technical Chamber of Greece, 2019)**




Maintaining a comfortable internal temperature makes no sense if the building is empty. The second variation of the use time schedule is based on occupancy patterns in residential buildings for weekdays and weekends with 14,4 and 17, 2 working hours respectively. The schedule is based on occupancy patterns in residential buildings and is shown in figures 30 and 31 (Kontar & Rakha, 2018).

**Figure 30. Schedule 2 (Weekdays)- (Kontar & Rakha, 2018)**

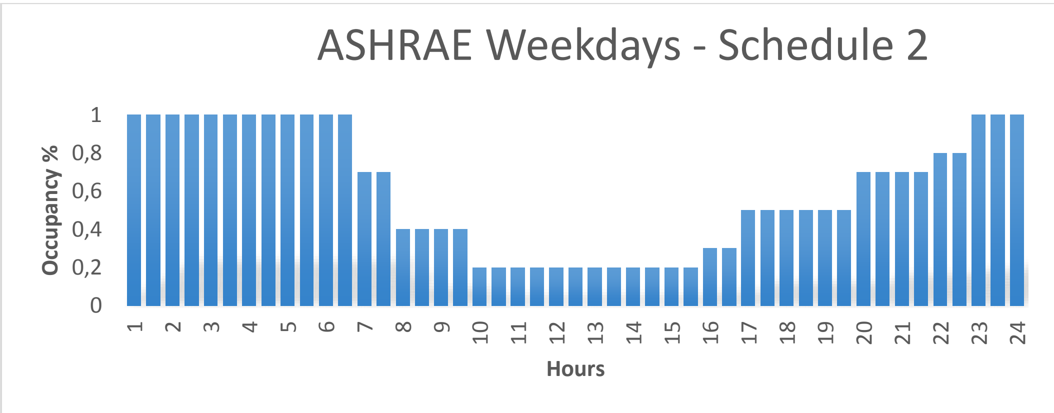
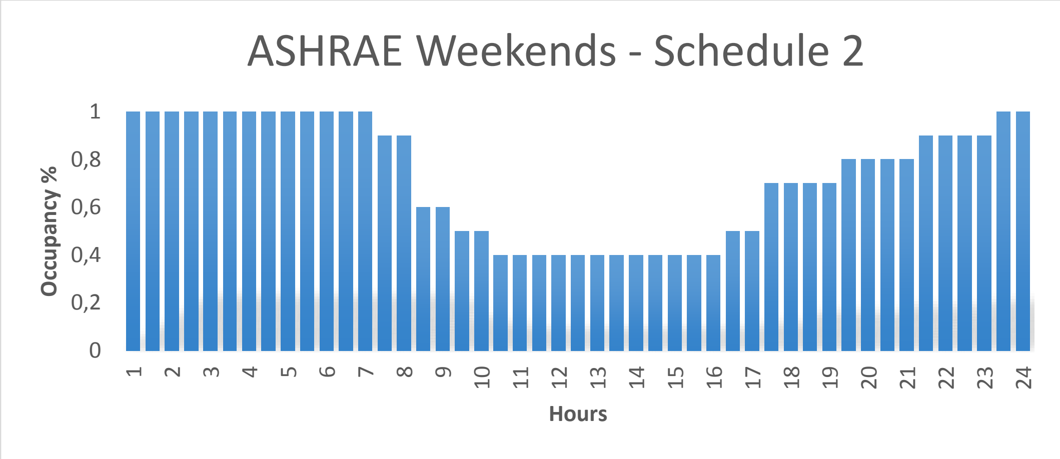
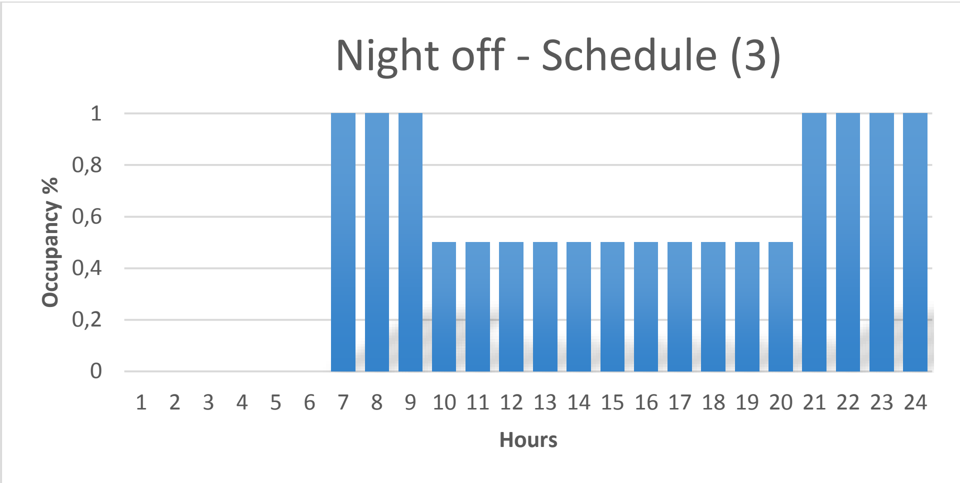


**Figure 31. Shedule 2 (Weekend) - (Kontar & Rakha, 2018)**




The last variation take as base the first 18,5h schedule and limits the operating time of the systems for heating and cooling during the night, while the occupants sleep, a total of 12,5 working hours per day, every day. Schedule 3 is shown in figure 32.

**Figure 32 Schedule 3**




The schedules will be designated by a number for future reference, being:

Schedule 1 – Standard Schedule (18,5h)

Schedule 2 – Occupancy Schedule (14,4 h)

Schedule 3 – Night Schedule (12,5h)

The three variants of schedules were applied to the six models to be simulated for a whole year, assuming for all the cases a holyday of 10 days during the year. In the result section, it is possible to see the effect of the application of the three schedules in the different analyzed cases.

### 5.2.3. DHW

The frequency of taking a shower, duration and intensity of showers; frequency of taking a bath; are some behaviors of the occupants that can significantly influence the use of hot water in residential buildings (Institute for Building Environment and Energy Conservation, 2013). Although one of the most efficient ways to reduce energy consumption in water heating is the implementation of systems that use renewable sources, these do not necessarily reduce water consumption.

Two behavior changes related to energy saving from (Palmer, et al., 2012) were adapted to the six scenarios. The first behavior change consists in replacing bathtubs baths by showers during the week. The report shows that changing at least two bathtubs baths for 7-minute lasting showers it is possible to get an average saving of 160 kWh /year. The second behavior change focuses on the reduction of shower time during the week. Decreasing the shower from 7 to 5 minutes for 4 days during the week, result an average saving of 130 kWh/year.

It would be not right to make a simple sum of the savings obtained with the application of each behavior due to the complex relationships between them.

## 5.3. SFH Models

All the physical characteristics of the buildings determined in section 5.1, previous studies on the residential stock and the observation of houses of some regions were used to model the typical SFH that represent each region. The six final simulated models are shown in the figures 33-38.

**Figure 33. SFH final simulation model for Attica region**

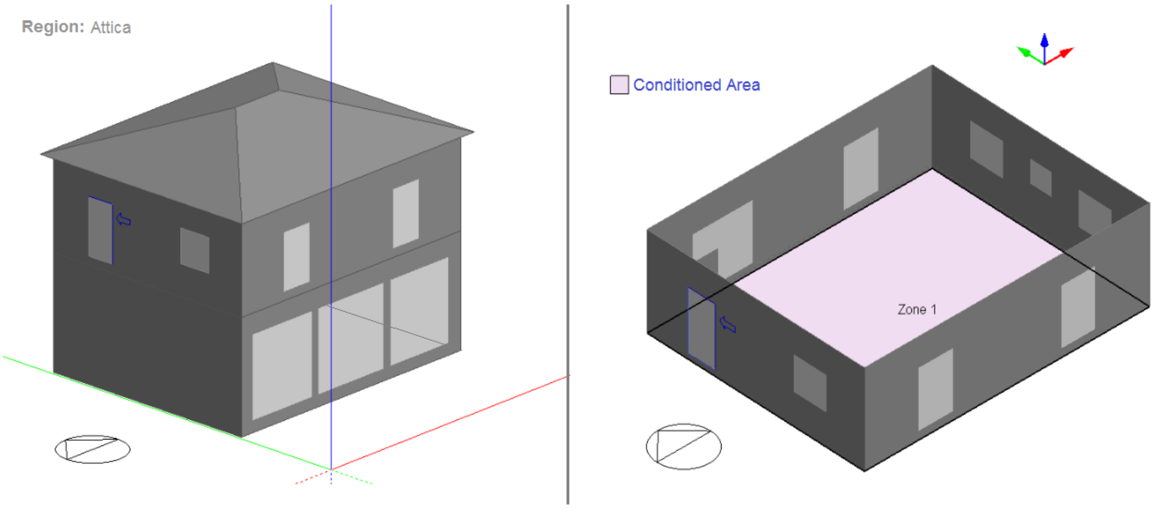



**Figure 34. SFH final simulation model for Central Macedonia region**

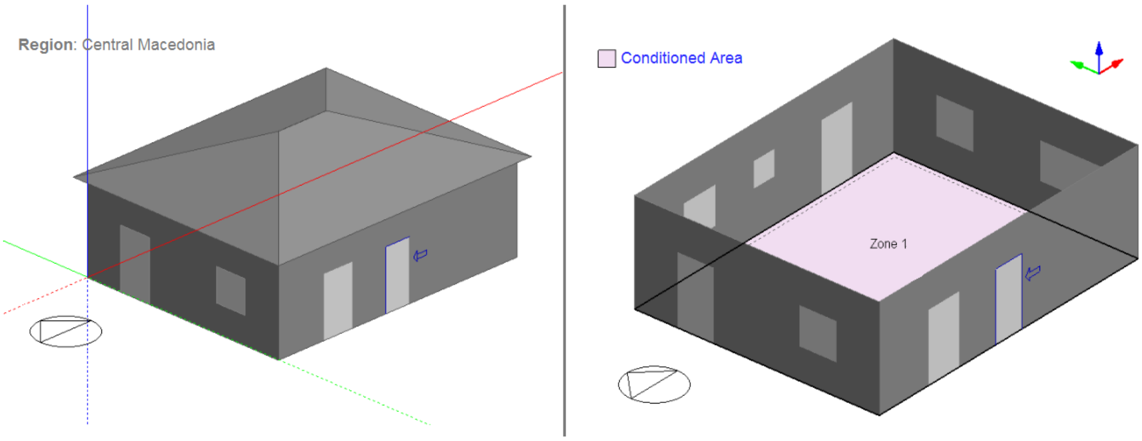



**Figure 35. SFH final simulation model for Lisbon region**

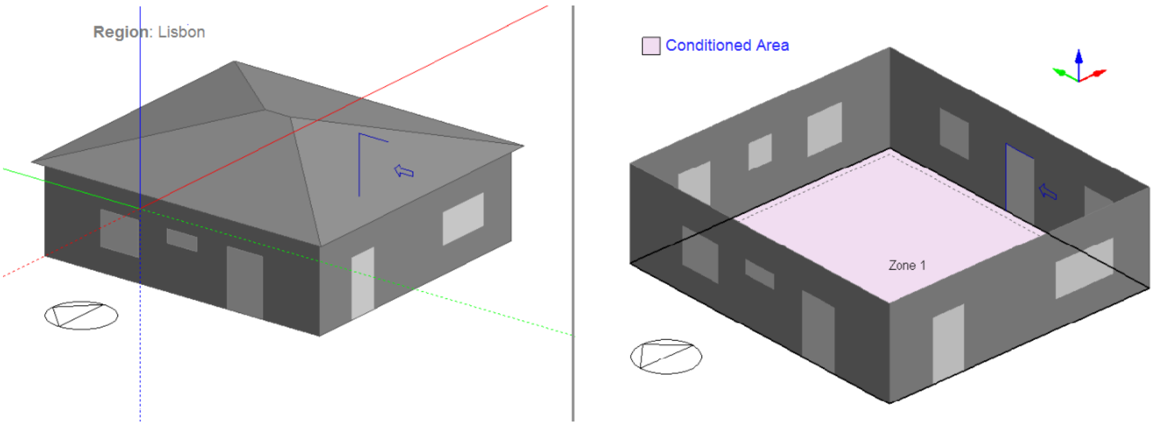


**Figure 36. SFH final simulation model for North region**

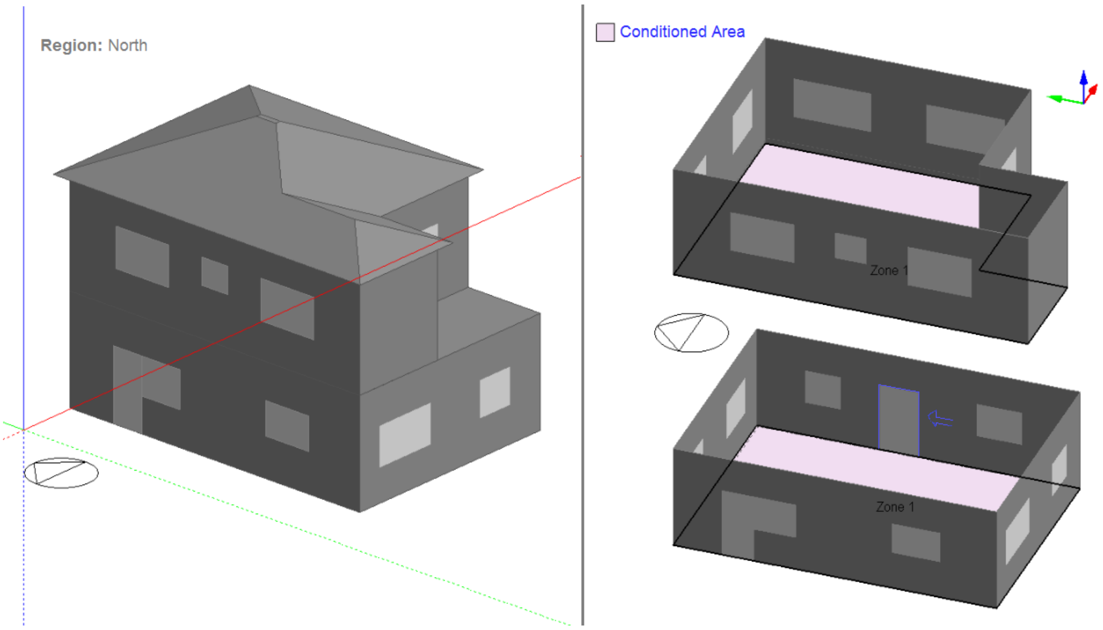



**Figure 37. SFH final simulation model for Madrid region**

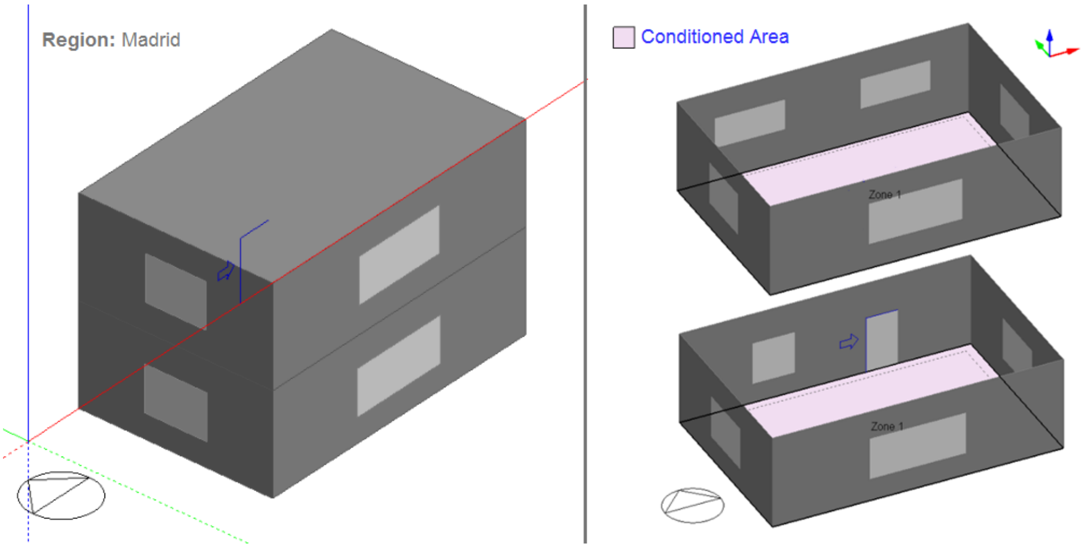
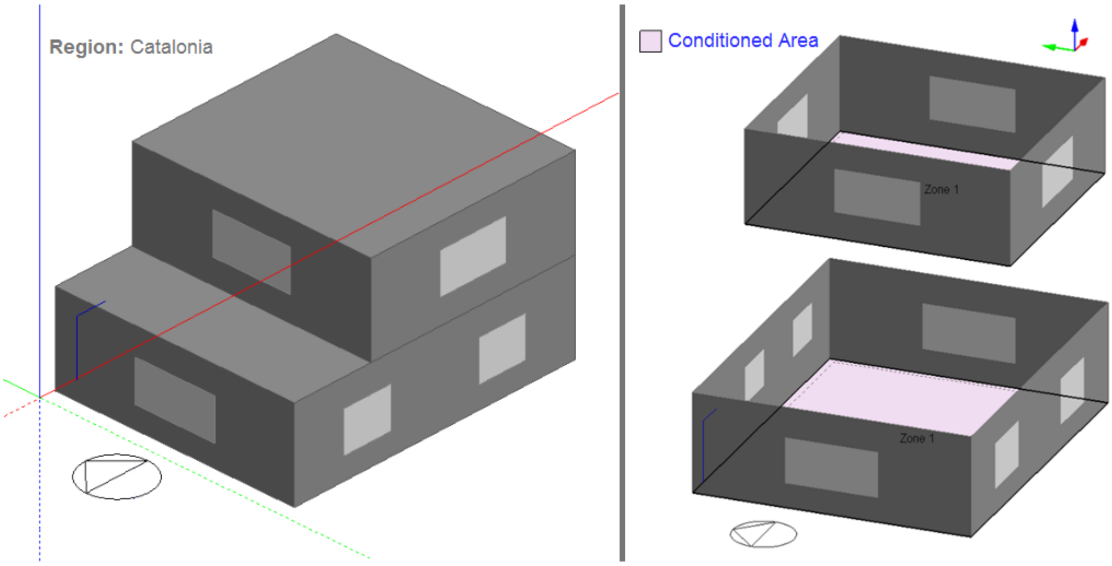


**Figure 38. SFH final simulation model for Catalonia region**




Once applied the physical parameters of useful area, ceiling height, wall window ratio, and characteristics of the thermal envelope the software calculated the area and the volume that will be conditioned, the values are shown in table 28.

| Final Model Area and Volume to be Conditioned | | | | | | |
|---|---|---|---|---|---|---|
| **Conditioned** | **Attica** | **C. Macedonia** | **Lisbon** | **North** | **Madrid** | **Catalonia** |
| Area [$m^2$] | 73,38 | 73,38 | 98,17 | 125,07 | 109,24 | 154 |
| Volume [$m^3$] | 220,7 | 242,1 | 324 | 407 | 355 | 501,4 |

**Table 28. Final model area and volume to be conditioned**

According to the results obtained, the SHF with the highest volume to be conditioned are the models of the regions of Catalonia, North of Portugal and Madrid, and the SHF with smaller volumes are located in Greece. The areas obtained are within the statistical data.

The energy consumption would be expected to be proportional to the volume of the space to be heated or cooled. The resulting areas and volumes will remain constant for all future energy consumption simulations.

## 5.4. Average Energy Consumption

To accurately compare the energy consumption of different systems that use different energy sources in countries with different energy mix, it is correct to use adequate conversion to primary energy, usually expressed in terms of kWh. In this section the average consumption data for heating, cooling and DHW in a house will be shown. The most specific data according to the period, place and type of building for each country was tried to be found in order to be able to make a better comparison between the simulation results and between the countries.

In the Greek case the average primary energy consumption of a SFH building for heating, DHW and cooling were taken from (Pallis, et al., 2019). It has specific information for the selected region and period, the values are shown in table 29.

| Average Primary Energy Consumption SFH built before 1980 [kWh/m²year] | | |
|---|---|---|
| **Climatic Zone** | **B (Attica)** | **C (C. Macedonia)** |
| Heating | 459 | 1021 |
| Cooling | 148 | 58 |
| DHW | 65,8 | 71,05 |
| Total | **672,8** | **1150,05** |

**Table 29. Average primary energy consumption for a SFH - GR - (Pallis, et al., 2019)**

Average primary consumption data for Portugal was taken from the 2014 and 2016 EPBD implementations reports, for residential buildings in all the country for the selected periods without differentiating the climate zones, values are shown in table 30. (ADENE – Agência para a Energia, 2016; 2019b)

| Average Residential Primary Energy Consumption, houses 1980-1995 [kWh/m²year] | | |
|---|---|---|
| | **Lisbon** | **North** |
| Heating | 94 | 94 |
| Cooling | 15 | 15 |
| DHW | 36 | 36 |
| Total | 259 | 259 |

**Table 30. Average primary energy consumption for a SFH – PT - (Calculated use ADENE, 2019)**

According to the (Gangolells, et al., 2016) the average primary energy consumption for SFH in Spain for the climatic zones C2 and D3 in 2014 for residences build in all periods, values are shown in table 31.

| Energy Performance Indicators Primary Energy Consumption SFH [kWh/m²year] | | |
|---|---|---|
| | **D3 (Madrid)** | **C2 (Catalonia)** |
| Heating | 238,3 | 183,2 |
| Cooling | 14,3 | 17,8 |
| DHW | 41,9 | 43,2 |
| Total | 294,5 | 244,2 |

**Table 31. Average primary energy consumption for SFH - ES - (Gangolells, et al., 2016)**

# 6. Results and Discussion

In this chapter, all the constant and variable parameters established in the previous chapter are applied. The results of the energy consumption simulations performed on each model are shown. The constant parameters are the same determined in the chapter 5.1 for all the simulation cases if it is not specify the opposite.

## 6.1. Application of Different Schedules

Space heating and cooling consumption results used the constant parameters defined and the temperatures given by the regulations of each country (table 32). The simulation software used the three different use time schedules of the HVAC systems defined in chapter 5.

The first results shown will be the highest consumption results taking into account the use of schedule 1 (18.5 hours of HVAC system use), and remaining internal set temperatures established by the regulations of each country.

| Annual Final Energy Consumption for Space Heating and Cooling [kWh] | | | | | | |
|---|---|---|---|---|---|---|
| | **Attica** | **C. Macedonia** | **Lisbon** | **North** | **Madrid** | **Catalonia** |
| Heating | 15.134,2 (76%) | 33.313,4 (97%) | 7.291,0 (85%) | 16.410,0 (95%) | 21.868,0 (96%) | 26.283,8 (97%) |
| Cooling | 4.700,1 (23%) | 1.108,2 (3%) | 1.256,0 (15%) | 1.026,0 (5%) | 880,0 (4%) | 858,0 (3%) |

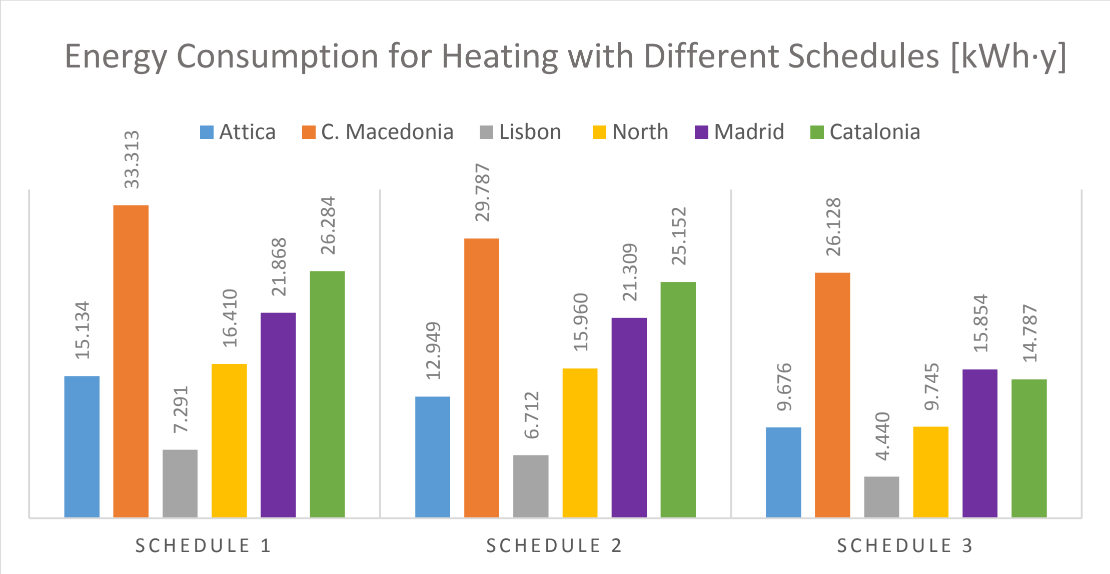
**Table 32. Simulation results: annual final energy consumption for space heating and cooling**

From the table 32, it is easy to observe that the energy used for space heating is much greater than the used for space cooling in all regions. However, the energy used for space cooling is not negligible, and in all regions. Attica is the region with highest percentage of cooling energy consumption in relation with the heating consumption followed by Lisbon.

Buildings located in colder climate zones consumes slightly more energy than those located in hotter climate zones, mainly because of the energy needed for heating (around 70-75% in residential buildings). (Catalan energy Institute, 2016)

Figure 39 shows the application of the 3 schedules on the models for heating.

**Figure 39. Results of energy consumption for heating with different schedules**




According to the volumes of air to be heated, the Greek regions should be the ones that present a lower energy consumption, but this is not the case. It is clear that there is the intervention of many other factors.

As expected, with less usage time of the heating system, the energy consumption for space heating is also lower, being the schedule 3 the one which consumes less energy. The regions with the most important savings with the application of schedule 3 are the North of Portugal and Catalonia, with around 40% of savings compared to the energy use when schedule 1 is applied. On the other hand, the application of schedule 2 decreases energy consumption in regions located in Greece more than in the other regions.

Figure 40 shows the effects produced by the application of the 3 schedules on energy consumption over the six models for space cooling. Due to the high values obtained for the Attica region, the results are shown in figure 41.

**Figure 40. Cooling energy consumption with different schedules**

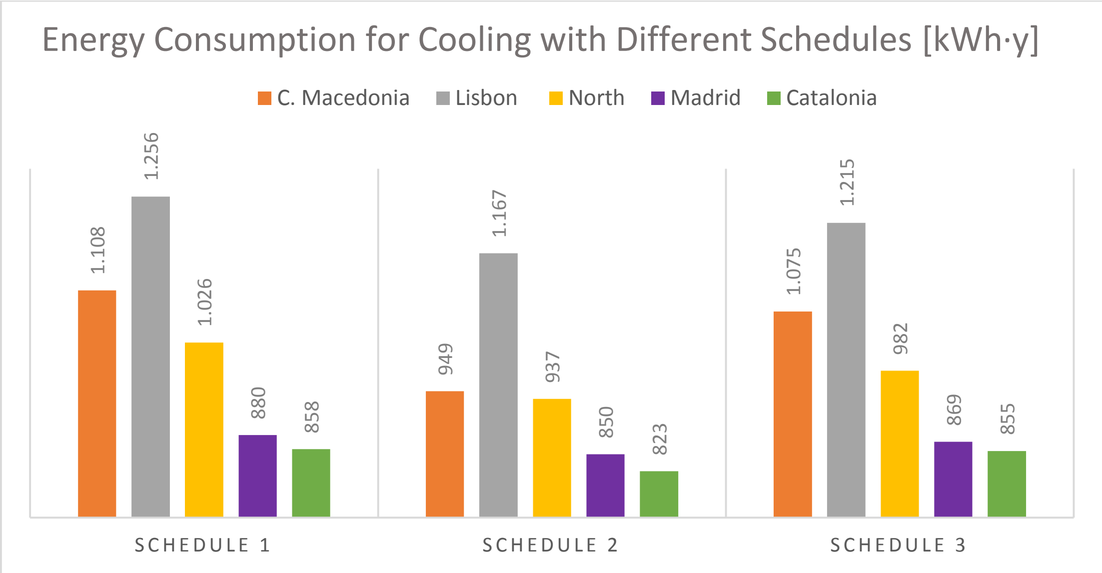
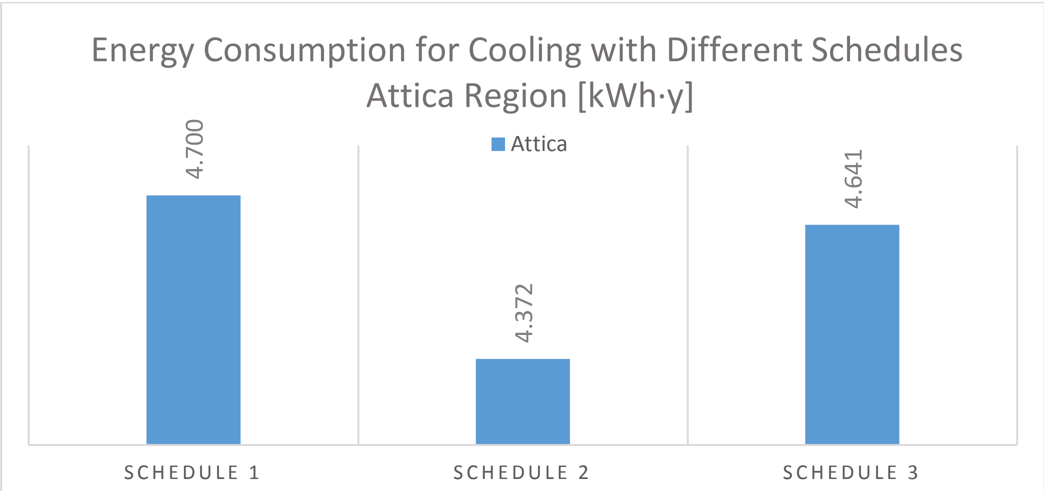



**Figure 41. Cooling energy consumption with different schedules for Attica region**




Differently of what happens for space heating, schedule 2 is the one that generates less consumption for space cooling, but have a low impact over the Spanish regions. The application of schedule 3 only generates savings ranging from 0,5 to 4% with respect to schedule 1.

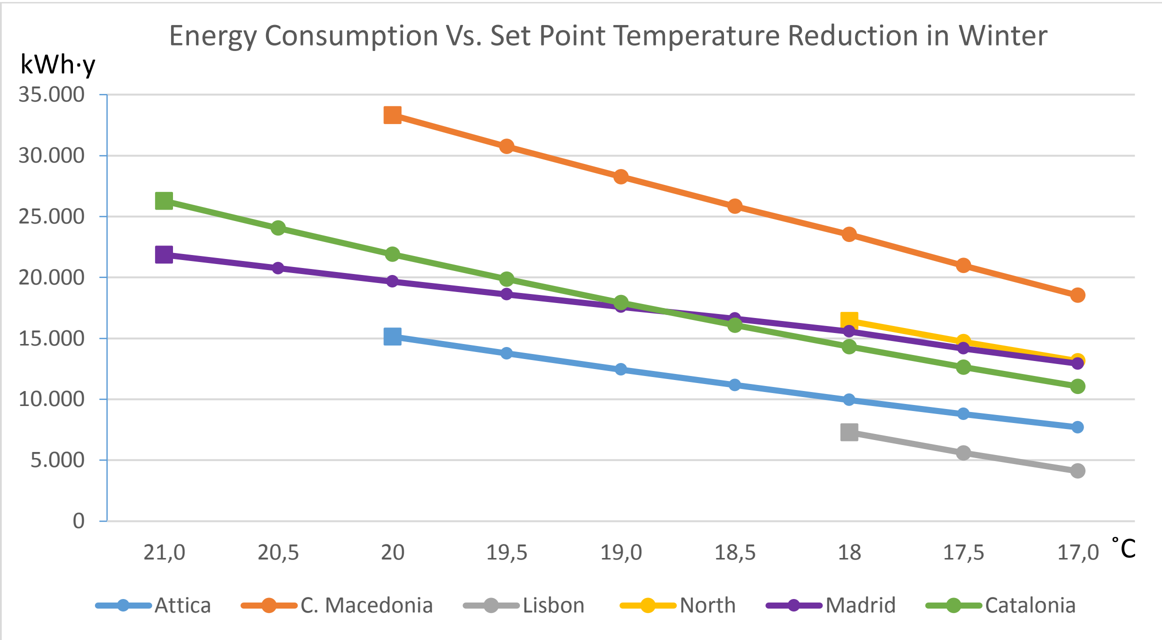
The resulting consumption pattern in the Attica region is in the same line as the consumption pattern in all the other five regions by the fact that the temperature at night is lower and the cooling systems do not have full capacity operation during this period, unlike the nights in the heating period. The decrease in the use of cooling systems during the hottest hours of the day reduces energy consumption.

## 6.2. Set Point Temperature Variations

The following results show the impact that the variation over thermostat set temperature has on energy consumption in both heating and cooling periods. The variation is represented in steps of 0,5 ˚C applied on the simulated models of the six regions. The HVAC system operation time is 18,5h per day as schedule 1 presented in section 5.2.2 for all cases.

For the first case, the thermostat temperatures are decreased during the heating period. The starting temperature is established by local regulations up to the limit temperatures considered in section 5.2.1. Figure 42 shown the energy consuption variation vs. the reduce of the set poin temperature during the winter.

**Figure 42. Energy consumption vs. set point temperature reduction in winter**




A reduction in the thermostat temperature during the winter demonstrates a reduction in energy consumption in all regions. The average energy saving per 0,5 ˚C of reduction is shown in table 33 for each region:

| Average Energy Saved by the Reduction of 0,5 ˚C in the Thermostat During Winter [kWh·y] | | | | | |
|---|---|---|---|---|---|
| **Attica** | **C. Macedonia** | **Lisbon** | **North** | **Madrid** | **Catalonia** |
| 1.240,4 | 2.464,0 | 1.594,5 | 1.634,6 | 1.118,6 | 1.904,1 |

**Table 33. Average energy saved by the reduction of 0,5 ˚C in the thermostat during winter**

The regions with more energy savings are those that are at a higher latitude as is the case of Catalonia, Central Macedonia and North of Portugal regions. The average saving of the 6 regions by the reduction of one centigrade degree is 3.318 kWh per year; it means around 20% of energy savings per each ˚C per year.

In the second case, the thermostat temperatures are altered during the summer period. In other words, an increase in the set temperature is simulated. As in the previous case, the ranges start with the temperatures established in the regulation of each country for summer and the limits are the established in the previous sections.

The changes in the final energy consumption with the increment of the set temperature are presented in figure 43 for five regions. The Attica region is represented in figure 44 with a different scale.

**Figure 43. Energy consumption vs. set point temperature increase in summer**

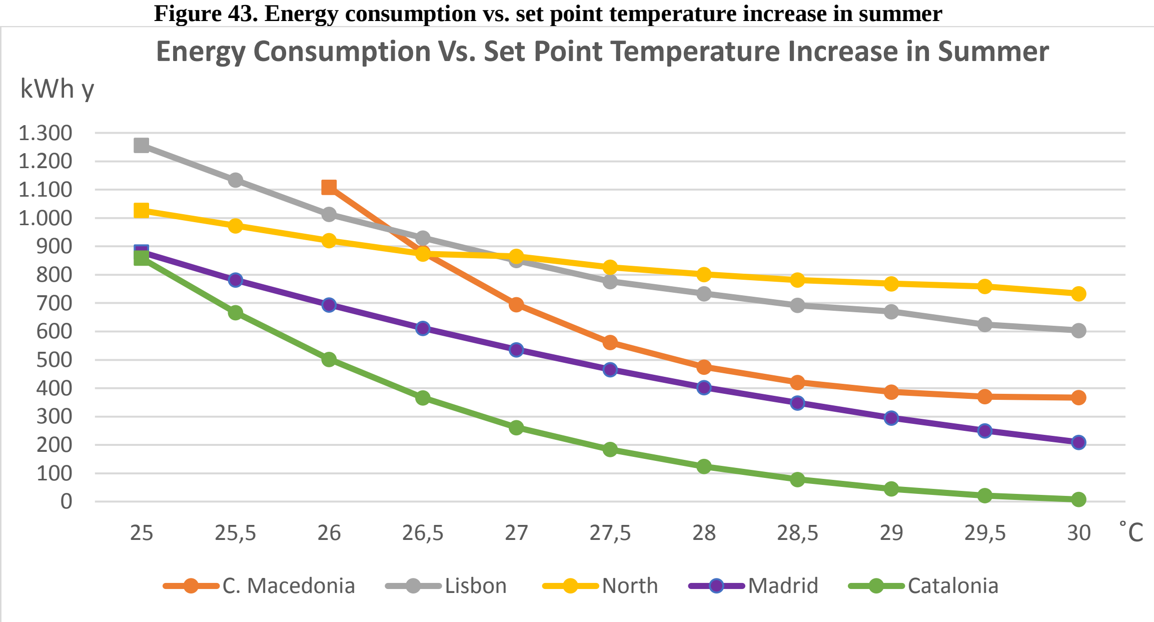
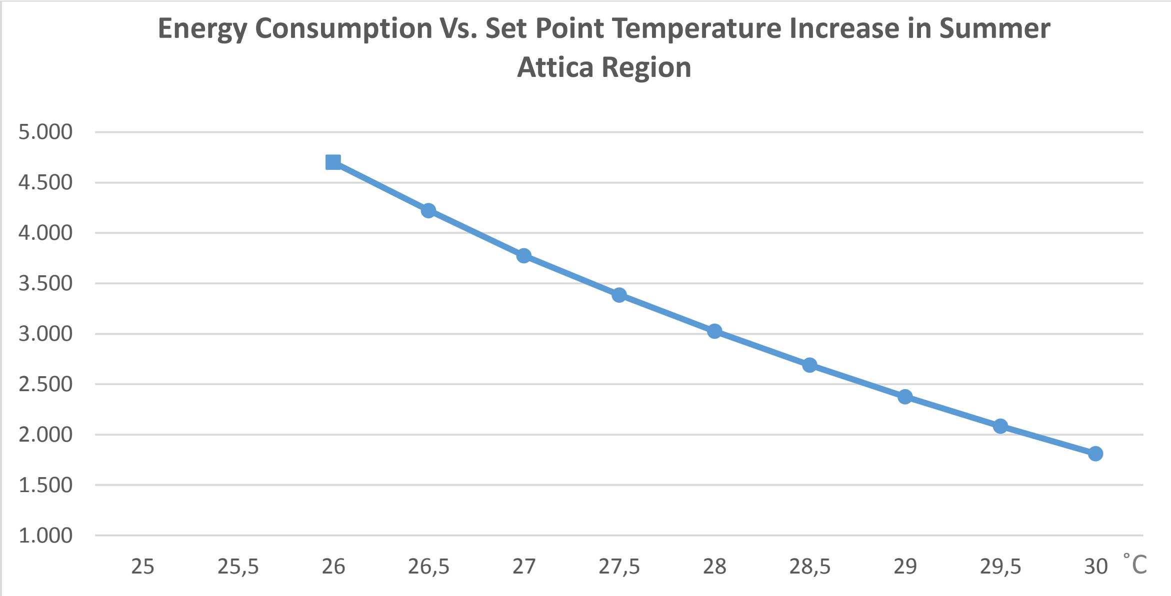


**Figure 44. Energy consumption vs. set point temperature increase in summer Attica**




The increase of the set point temperature of the cooling system thermostat during the summer produces savings in the energy consumption for all regions, but with higher significance in the Greek and Catalonia regions, and lower impact in the North of Portugal, as shown in table 34.

| Average Energy Saved by the Increasing of 0,5 ˚C in the Thermostat During Summer [kWh·year] | | | | | |
|---|---|---|---|---|---|
| **Attica** | **C. Macedonia** | **Lisbon** | **North** | **Madrid** | **Catalonia** |
| 361,1 | 92,7 | 65,3 | 29,2 | 67,1 | 85,0 |

**Table 34. Average energy saved by the increasing of 0,5°C in the thermostat during summer**

The average energy savings due to the increase of one degree Celsius in the set point during the summer, for all the regions is 233 kWh per year.

The values shown in tables 33 and 34 above can be translated into economic terms and it is possible to know the average savings in the energy bill per year.

| Average Savings for the Variation of 0,5 ˚C on the Thermostat [€/year] | | | | | | |
|---|---|---|---|---|---|---|
| | **Attica** | **C. Macedonia** | **Lisbon** | **North** | **Madrid** | **Catalonia** |
| Reduction | 125,28 | 248,86 | 357,17 | 366,15 | 83,90 | 142,81 |
| Increasing | 67,16 | 17,24 | 14,63 | 6,54 | 15,97 | 20,23 |

**Table 35. Average savings for the variations of 0,5°C in the thermostat**

Reducing the set point temperature in winter and increasing it during the summer thus result in a reduction of energy consumption, and therefore economic savings, where the opposite would generate an increase of them. There are greater energy savings by reducing the temperature of the thermostat during the winter than by increasing it during the summer.

## 6.3. DHW Energy Use

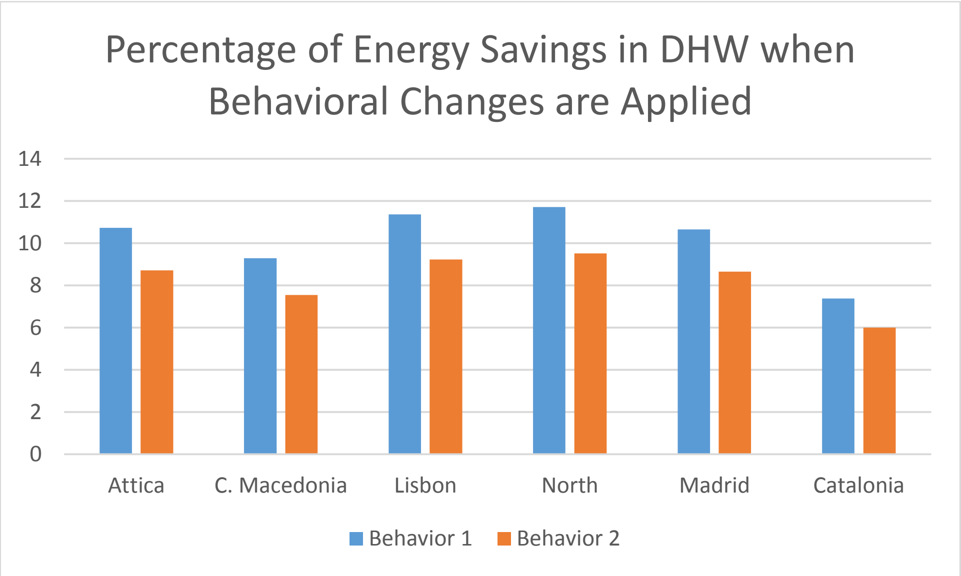
In the case of the energy used for water heating, the behaviors described in section 5.2.3 were specifically adapted for each regions. The values shown in table 36 are the results given by the simulator of the final energy consumed for water heating. These results are obtained based on the costing parameters without the application of any change in behavior.

| Final Energy Consumption for DHW [kWh·y] | | | | | |
|---|---|---|---|---|---|
| **Attica** | **C. Macedonia** | **Lisbon** | **North** | **Madrid** | **Catalonia** |
| 1.554,7 | 1.797,3 | 1.591,0 | 1.543,6 | 1.696,4 | 2.447,7 |

**Table 36. Final energy consumption for DHW**

In figure 45, it is possible to observe the variations in annual energy consumption that result from the application of behavioral changes. The savings obtained are relative to the values of the final energy consumption of DHW shown in table 36.

**Figure 45. Percentage of energy savings in DHW when behavioral changes are applied**




In all cases, the application of behavior change number 1 present a greater energy saving compared to behavior change 2, as stated above. It would not be correct to directly sum the savings of the 2 behaviors. The average savings obtained with the application of behavior change 1 and 2 in the 6 regions are 176 and 146 kWh per year respectively. To express the results of energy savings in monetary terms, table 13 of section 4.8 is used to quantify the monetary savings generated with the application of each behavior, the values are shown in table 37.

| Economic Savings of the Application of the Behaviors on the DHW consumption €/year | | | |
|---|---|---|---|
| | **Greece** | **Portugal** | **Spain** |
| Behavior 1 | 31,1 | 40,5 | 43,0 |
| Behavior 2 | 25,2 | 32,9 | 35,0 |

**Table 37. Economic savings of the application of the behaviors on the DHW consumption**

By applying each change in behavior, savings of around 34 euros per year have been generated. The similarity between the results may be due to the fact that the average number of occupants and water consumption per person are very similar in the three countries.

## 6.4. Comparison with Statistical Data

The results of the simulations without taking into account the variable parameters will be compared with the average consumption of each region obtained in section 5.4. The simulation was carried out using schedule 1 and using the winter and summer temperatures presented in table 27.

To be able to compare the results between them, it is necessary to perform an adequate conversion to primary energy. Simulation results were multiplied by each conversion factor according to their energy source, and divided for the useful area of each model shown in table 28. Result are obtained in terms of primary energy over conditioned area [kWh/m$^2$].

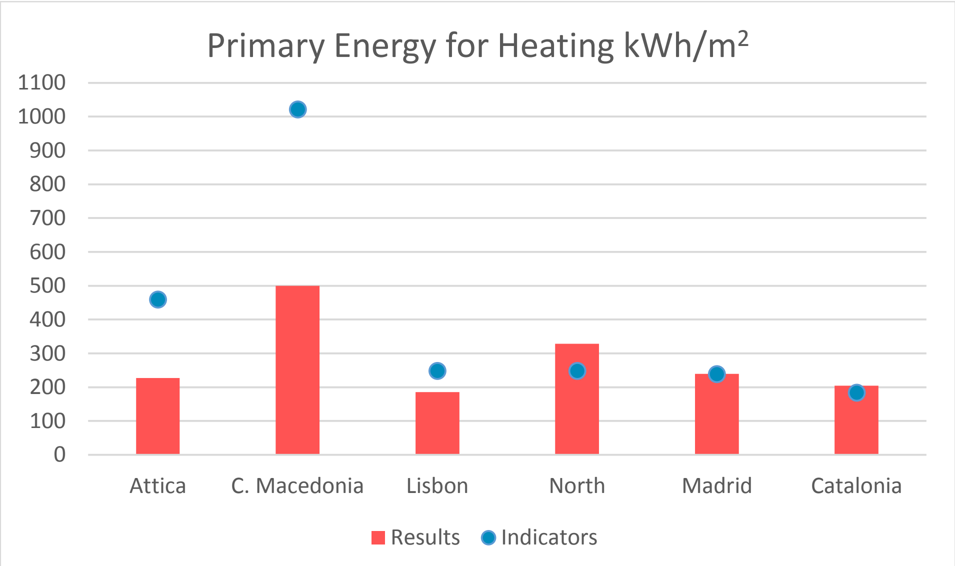
Once the simulation results are represented in terms of primary energy consumptions is possible to compare them.  Primary energy represents a common framework between the chosen countries and a base for a clear comparison among various energy sources.

| Primary Energy Consumption [kWh/m²] | | | | | | |
|---|---|---|---|---|---|---|
| | Attica | C. Macedonia | Lisbon | North | Madrid | Catalonia |
| **Heating** | 226,9 | 499,4 | 185,7 | 328,1 | 239,2 | 203,9 |
| **Cooling** | 185,8 | 43,8 | 32,0 | 20,5 | 19,4 | 13,4 |
| **DHW** | 61,4 | 71,0 | 40,5 | 30,8 | 37,3 | 38,2 |
| **Total** | 474,1 | 614,2 | 258,8 | 379,4 | 295,9 | 255,5 |

**Table 38 Results of simulations in primary energy consumption per m$^2$**

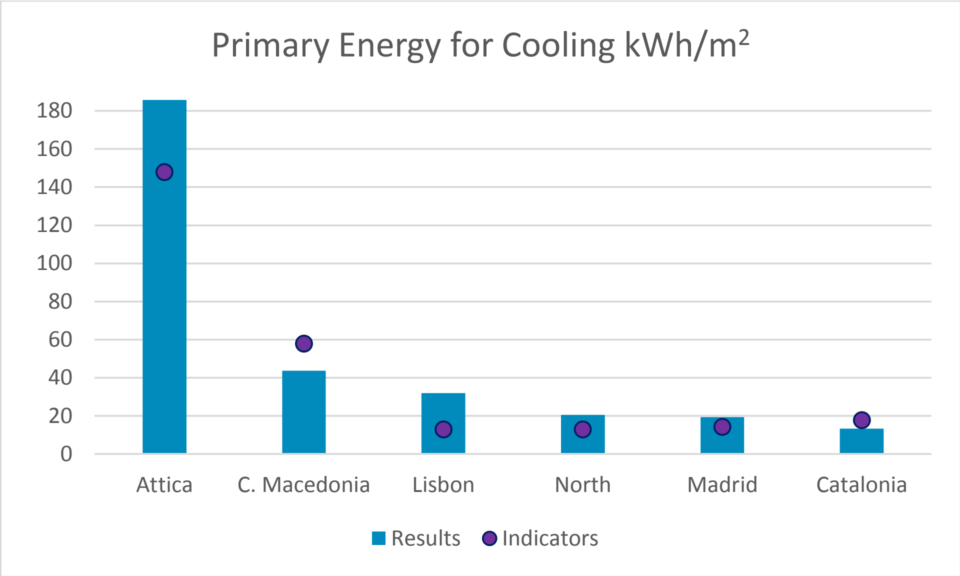
In figures 46 - 49, the values of primary energy consumption resulting from the simulation will be compared with the average primary energy consumption shown in section 5.4.

**Figure 46. Results vs. indicators primary energy consumption for heating**



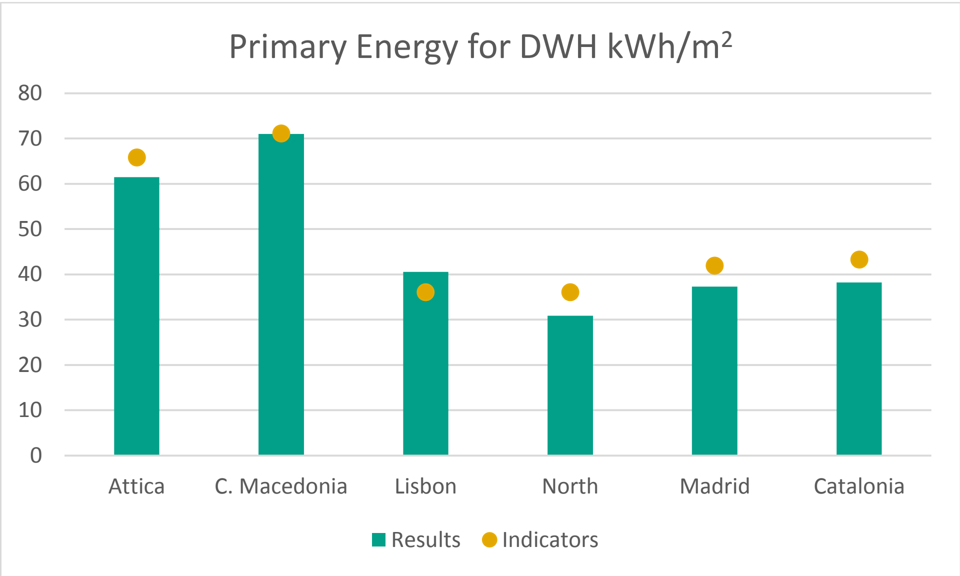

The heating average energy consumption for the Greek areas are very high compared with the obtained results mainly for Central Macedonia. The heating consumption result is slightly lower for the SFH in the Lisbon region and slightly higher for North Portugal, this can be explained because the average consumption obtained was the same for all country. In the Spanish area, the results match better the average values.

**Figure 47. Results vs. indicators primary energy consumption for cooling**




Cooling energy consumption results of Central Macedonia and Catalonia regions are lower than the average. The results for the Portuguese regions are over the average consumption for cooling. This can be explained due to the lack of cooling devices in the country. In the Spanish regions, the results do not show big differences with the average values.

**Figure 48. Results vs. indicators primary energy consumption for heating water**




In energy consumption for heating water the results obtained do not present big differences respect to the average consumption values. The differences are less than 15% for each case.

**Figure 49. Results vs. indicators total primary energy consumption**

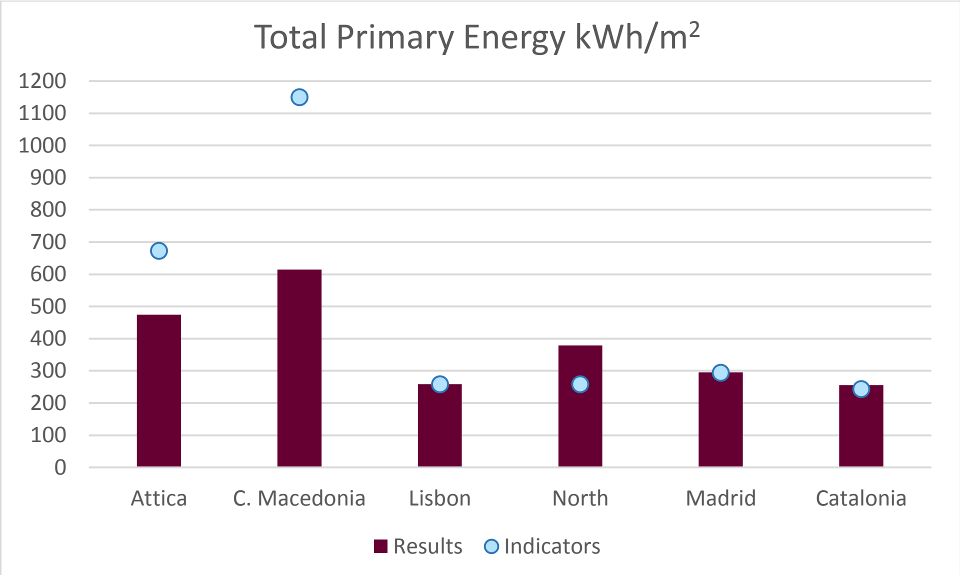



Figure 49 shows the sum of space heating and cooling and heating water primary energy consumption. There are big differences between the results and the average consumption in the regions belonging to Greece and north of Portugal. The results for Spain, like all the previous ones, coincide with the average consumption.

The differences between results and average consumptions can be due different factors as the calculation method.

In the case of Greece, it is known that the average values were obtained through the use of the national official software KENAK that makes calculations using monthly temperatures, unlike DesignBuilder that performs them using hourly temperatures. Another factor may be the technology of the heating or cooling systems that due to the house period sometimes do not have a thermostat, which makes it difficult to maintain a set temperature.

Another explanation may be that the indoor temperature is much higher or lower than recommended, due to the misuse of HVAC systems. Mainly due to the occupant's behavior, this can mean an excess or a lack of comfort depending on the case. Excessive use of energy can be explained by the low thermal insulation of houses. Another explanation can be the lack of gains by electric appliances and other sources consider in the simulations for all the cases.

# 7. Conclusions

The present study demonstrates that several factors affect energy consumption in an SFH in the Mediterranean region. Differences between countries such as climate, level of development, comfort level of the population, houses characteristics, and policies influence the energy use. Even countries with similar characteristics presents differences in consumptions. However, the most important factor turned out to be people's behavior.

The occupants can quickly raise the energy consumption of a house or keep it at acceptable levels; therefore, human behavior strongly affects the energy consumption. The comfort level plays a crucial role in making people's decisions.

Small actions such as the variation of 0.5ºC in the thermostat of the heating or cooling systems dramatically alter the energy consumption.

The combination of the different simulated behaviors will result in lower energy consumption, without taking into account the technical improvements of the systems and the physical properties of the house.

Excessive reduction of the comfort level may involve effects on the occupant’s health. There is a thin line between reducing thermal comfort and maintain an inadequate indoor temperature. However, the exposure time at a certain temperature plays an important and decisive role.

The efficient use of energy is a way to reduce the consumption of buildings without affecting the comfort of the occupants. The behavior of people is also related to the level of environmental awareness. A balance between comfort and energy awareness is necessary

Policies act over energy consumption through changes in people's behavior. Occupants are often forced to perform certain activities to comply with the guidelines.

Current energy policies focused on constructions and buildings are slowly meeting their objectives. The main problem is the age of the buildings and its meager percentage of renovation. Future policies should focus on removing that barrier.

Most houses considered for this analysis, due to the chosen period, were built without thermal isolation minimal requirements. Therefore, dwellings do not have all the requirements that current in force national regulations require to limit energy consumption. Policies achieve a reduction in energy consumption by making the construction sector more efficient by the improvement of thermal insulation in houses. Policies must find a way to force householder to improve the house envelopment.

The lack of clear guidelines of the directives allows each country to be free to choose how to achieve a particular objective. This can be positive because each country had better adaption of the regulations to its population, but on the other hand, it generates a diversity of methodologies. There is no uniformity in the calculation methods, which could generate a problem in the future when it will be necessary to compare the information at an international level using the same scale.

The evolution of the policies in Europe has been remarkable in recent years, but they are not enough since current policies are more focused on new buildings and not in old houses that consume more energy.

The high standard of living can be fought with very useful energy policies focused on other areas, such as ecological design and the energy label directive.

Researchers and policymakers must continue work together to discover and share new and novel methods of applying behavioral science to stop and reduce energy consumption in the building stock. Tighter policies that act fast enough are necessary.

Weather also has an impact over consumption. In the Mediterranean region, unlike other regions in Europe, the space heating and cooling are essential to maintain a pleasant indoor temperature and the thermal comfort of the occupants, which implies the energy consumption by the HVAC systems during most of the year.

It is verified that the activity that consumes more energy is space heating, although in the Mediterranean region temperatures in summer are more extreme than in winter. Thus, space heating represents a high potential for energy savings in an SFH. However, low indoor temperatures have a more harmful effect on health than high temperatures.

Weather impact is inversely proportional to the level of thermal insulation of a house. A dwelling with good thermal insulation is less affected by the outside temperature. Instead, outside temperature apparently has not a strong influence on energy use for heating water.

Without a doubt, the use of devices with more efficient technology will consume less energy, but it cannot be denied that human behavior has a great influence on actions such as the acquisition or improvement of device technologies. Small changes in individual behavior have large-scale results.

Beyond the economic savings that efficient energy use can bring, governments and citizens should think about the environment. We can begin to shift some of the billions of small decisions and actions that we take every day to create a more sustainable future on our planet.

Although the European database has a large amount of statistical information, there is a lack of specific data for buildings of the chosen periods, unlike the new homes that are registered and have an energy performance certification. It is easy to obtain statistical data for future analysis.

Future researches should consider the complexity and heterogeneity of other European regions, as this might lead to significant differences in primary energy consumption.

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