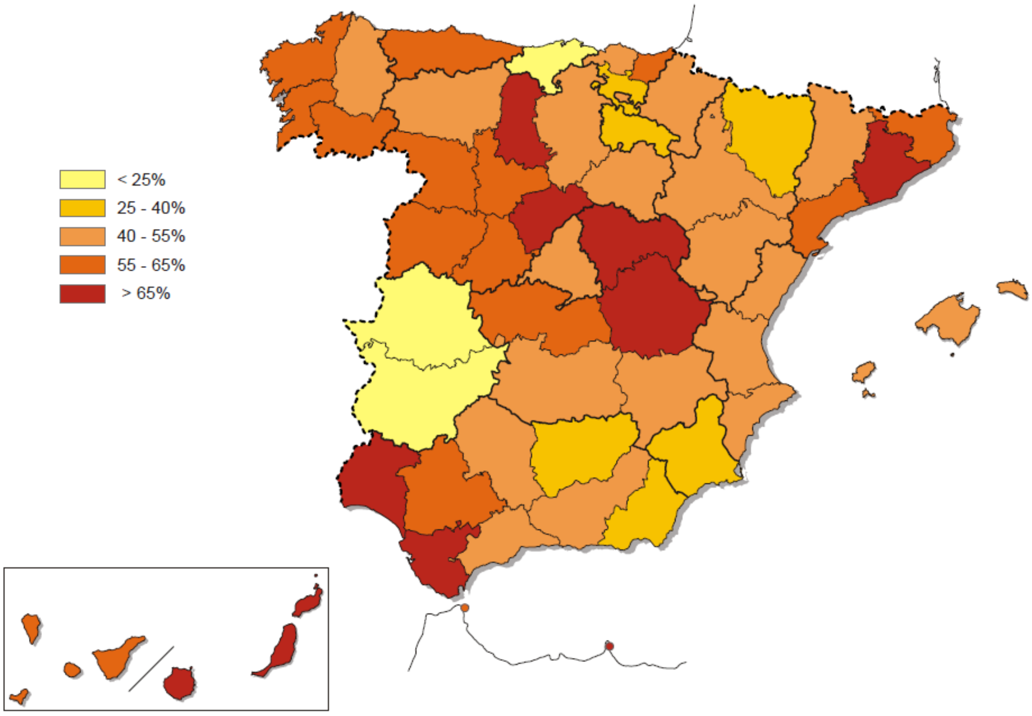

Distribution of new buildings in 2008 with respect to fraction of buildings with installed solar energy systems

Bottom-up characterisation of the Spanish building stock – Archetype buildings and energy demand

Master Thesis for the degree of Mechanical Engineering

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Cover: Distribution of new buildings in 2008 with respect to fraction of buildings with installed solar energy systems (Ministerio de Fomento, 2009)

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Abstract

In developed economies, such as the European Union's member states, the largest potential for energy efficiency improvements lies in retrofitting existing buildings. Yet, there is both a lack of information about the building stock and associated modelling tools that can be used to assess such measures as basis for develop energy efficiency strategies and design policies to be applied to the European building sector. Therefore, a methodology has been developed that represents the European building stock as reference buildings with the aim to assess the effects of energy saving measures. The model used for the building energy simulation is the *Energy Assessment for Buildings Stocks* (EABS), which gives the net energy demand in an aggregated form for the building stock considered.

This master thesis focuses on the Spanish building stock and continues the development of the methodology that has earlier been tested using the Swedish residential stock as base. In this master thesis, archetype (reference) buildings are defined to characterise the building stock and are used as inputs to the EABS model. The work also serves to test the adequacy of applying a bottom-up methodology on a south European country where also the non-residential sector is included. The results, which present data of the buildings' net energy demand for space heating, cooling, electricity and hot water, are compared to statistical data available in national and international sources expressed in terms of final energy. Modifications and adjustments are made in the building description process in order to match the results obtained with the reference statistical databases.

The Spanish building stock is represented by 120 archetype buildings corresponding to six building typologies, five climate zones and four periods of construction. The results of the simulation give a total energy demand for the residential sector of 181 TWh for the year 2005, which is considered satisfactory since it only differs with 3% compared to the statistics provided by the international databases GAINS and Eurostat. Regarding the non-residential sector 91 TWh of total energy demand were obtained from the energy simulation for the year 2005, which is about 7% lower than the energy demand given in GAINS and Eurostat. Corresponding simulation for the year 2008 yields an annual energy demand of 218 TWh and 101 TWh for the residential and non-residential sector respectively. Such figures are around 19% higher and 10% lower than the corresponding energy demands given in the international databases Eurostat, IEA and the national institution IDAE. Possible reasons for these differences are discussed in this master thesis.

Keywords: archetype buildings, Spanish building stock, energy demand, bottom-up modelling, energy simulation

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1. Introduction

1.1. Background

New options and solutions are still needed in the path of mitigation of climate change. The Kyoto Protocol was one of the first claims in response to this concern, recognising institutionally the need of taking immediate measures to decrease the amount of carbon dioxide (CO_2) emitted. As well known, a major cause of this greenhouse gas is the combustion of fossil fuel. In this context, efficiency in the building sector emerges as an important topic to work on taking into account that this sector represents 40% of the total EU´s final energy consumption (Directive 2002/91/EC, 2002), and mainly covered by fossil fuels (Hens et al., 2001). There are significant opportunities to enhance energy efficiency in this sector, both for residential and non-residential buildings and especially by the retrofitting of existing buildings (Metz et al., 2007).

Regarding the residential building sector, the number of dwellings in the European Union is about 196 million and about 11% of them are located in Spain (Balaras et al., 2005). Therefore, taking effective measures in the Spanish building stock can lead to significant energy savings also in a European context.

To assess the effect of energy conservation measures applied to a certain building stock, this building stock must be characterised. The larger the size of the building stock is (e.g., regional, national, European), the more difficult is the characterisation process since less accurate data is available and buildings also need to be aggregated. Currently, there are only a few examples of available studies that provide a characterisation of the residential building stock using reference buildings: Hens (2001) on the Belgium stock; Balaras (2005) about permanent dwellings in Greece, which represent 68% of the Greek national residential stock; Clinch (2000) about the Irish building stock; Clarke (2004) on the Scottish building stock; and Martinlagardette (2009) on the French building stock. A study including reference buildings that represents both the residential and non-residential sector was performed by Petersdorff (2006) for the entire EU-15 building stock. With respect to Spain, the Plan for Energy Improvement in Barcelona defines and characterises archetype buildings in a similar way to what is done in this thesis work, but this plan only covers the region of Catalonia (Barcelona Regional, 2002). Thus, there is a lack of studies describing the entire Spanish building stock.

1.2. Context of the Thesis

This thesis is part of the project *Pathways to Sustainable European Energy Systems* (herein referred as the "Pathways Project") (Johnsson, 2011) which aims to illustrate pathways towards a more sustainable European energy systems focusing on meeting targets for example regarding energy efficiency, reductions in CO_2 emissions, and increased use of renewable energy. Within the Pathways Project, a methodology has been developed for assessing potential energy saving measures in the European building stock, which involves both a description of the existing building stock and a development of modelling tools to assess the effects of such energy efficiency measures. This methodology proposes to represent a building stock in an aggregated form and the model *Energy Assessment for Building Stocks* (EABS) was developed and validated for the Swedish residential sector, where the building stock was represented by sample buildings.[1] (Mata, 2011).

[1] Sample buildings are buildings considered representative of the stock and described using measured data of the actual building stock under study (Mata, 2011).

The six EU countries with the biggest building stocks representing over 70% of the buildings' energy use in Europe (Balaras et al., 2005), Spain among them, are being studied in the Pathways Project. The availability of the relevant building data required to analyse energy use in buildings across Europe has been studied by Ó Broin (2007) and several studies on the French building stock have been performed (Martinlagardette, 2009; Gravalon, 2007).

1.3. Aim of this Thesis

The aim of this master thesis is to continue the development of a methodology to represent a building stock in an aggregated form through the description of a number of reference buildings that are representative of the stock, using Spain as a test case. Thus, this thesis work: 1) contributes to the evaluation of the methodology of characterising a building stock by means of archetype buildings; 2) serves as a test on the suitability of applying the EABS model to Spain, and also including the non-residential sector. Spain is selected as it is considered important to verify the methodology for a south European country with the building characteristics as well as the climate being significantly different from Sweden.

The characterisation of the Spanish building stock could, in a later step, be used to assess the effect of applying different energy efficiency measures. However, this assessment is not within the scope of this thesis work.

1.4. Structure of the report

Data to characterise the building stock and validate the results of the energy simulation have been provided by national institutions, Spanish regulations and international statistical databases. These sources are presented in Section 2.

In Section 3 the model used for the simulation is first introduced. Then, the criteria applied to segment the Spanish building stock and to define the archetype buildings is explained. Finally, the characterisation process of such reference buildings is reported.

Section 4 reports the resulting segmentation of the Spanish building stock into representative buildings. The simulation of the energy demand based on such buildings is also presented for the years 2005 and 2008 using the corresponding archetype buildings as inputs to the EABS model. The results obtained are discussed and compared with available data in national and international databases

The results of the sensitivity analysis are discussed in Section 5.

Possible reasons for the deviation between the results of the energy simulation and the statistics provided by international databases are discussed in Section 6.

Finally, the conclusions drawn from the work carried out in this master thesis and the further work still needed are presented in Section 7.

2. Data sources

This section presents the main sources that have provided the necessary information for describing the Spanish building stock. Data extracted from national data sources are primarily published online. The Spanish building regulations provided many of the data that are used to describe the energy systems of the buildings and to define the indoor climate conditions. Finally, the international databases consulted are presented. These databases provided the statistics used in order to compare the results obtained from the energy demand simulation.

2.1. National institutions

The Spanish institutions consulted are:

- **INE: National Statistics Institute (*Instituto Nacional de Estadística*)**

  The National Statistics Institute is an autonomous administrative institution assigned to the Ministry of Economy and Finances via the Secretary of State for the Economy. INE plays an important role in the public statistic activity, being in charge of the national large scale statistical operations as demographic and economic censuses or economic and social indicators (INE, 2011).

- **Ministry of Buildings (*Ministerio de Fomento*)**

  The Spanish Ministry of Buildings is responsible of many tasks, such as the management of the transport infrastructures and the planning for housing, urbanism and architecture. The "Secretary of State for housing and urban projects" *(Secretaría de Estado de vivienda y actuaciones urbanas)* is a subdivision of the ministry and it is in responsible of the diffusion, promotion and investigation of the architecture and building sector. Data regarding the quantification and the use of the Spanish building stock is provided in the website of the Ministry (Ministerio de Fomento, 2011).

- **IDAE: Institute for the Energy Diversification and Saving (*Instituto para la Diversificación y ahorro de la energía*)**

  IDAE is a public institution attached to the Spanish Ministry of Industry, Tourism and Commerce. This organisation works on promoting a new more efficient and sustainable energy system for Spain through the energy saving and efficiency assessment and the promotion and development of renewable energy systems The IDAE also has an important role to cooperate with other countries within the framework of European and International energy programmes (IDAE, 2011).

  Presented below are the studies published by IDAE that have been used as important data sources in this master thesis:

  - E4. Energy savings and Efficiency Strategy for Spain 2004-2012 (IDAE, 2003) (*Estrategia de Ahorro y Eficiencia Energética en España 2004-2012*): the E4 is an energy plan developed with the aim of achieving a more efficient energy use in Spain. It is designed to contribute to the IDAE target of developing a more sustainable energy model for the country, guaranteeing the supply and the quality of the energy with no damage to the environment.

- Spanish Building Code. Acceptance of alternative procedures; CTE-LIDER, 2009 (CTE-LIDER, 2009): this document describes the requirements to be satisfied by the procedures used to simulate the energy demand of a building. Values that can be assumed to define the operational conditions of the building (e.g., indoor climate conditions, internal heat gains, ventilation levels) are presented in the annexes of the document.

2.2. Policies and regulations

The following regulations on thermal properties of buildings exist in Spain:

- **Decree 1490/1975.** Compulsory for all new buildings constructed after the approval (June of 1975), it was the first regulation stating measures energy savings in the building sector. It set the required heat transfer coefficient of the buildings depending on the climate zone. This decree became out dated when NBE-CT-79 came into force (Decree 1490/1975, 1975).

- **Spanish Building Code from 1979; NBE-CT-79.** Compulsory for all new buildings constructed after the approval (July of 1979). It sets the required indoor thermal conditions and thermal properties for the buildings as, for instance, the maximum heat transfer coefficient of the different building elements. It became out dated when CTE came into force in 2006 (NBE-CT-79, 1979).

- **Spanish building code in force, CTE**. It was approved in May of 2006 and it is divided in six "basic documents": Structural security (DB-SE); Security in case of fire (DB-SI); Security of use and accessibility (DB-SUI); Salubriousness (DB-HS); Protection against noise (DB-HR); and Energy saving (DB-HE) (CTE, 2006). Two of these documents were used as important data sources in this master thesis:

    - **Salubriousness (***Salubridad***); DB-HS.** The document establishes the required procedures to ensure the compliance of the health regulations. Values for different parameters for the performance of the buildings facilities are set, such as required ventilation rate (CTE-HS, 2006).

    - **Energy savings (***Ahorro de energía***); DB-HE.** The document establishes the required procedures and regulations for energy savings in the building sector. It sets, for instance, the required U-values and the hot water demand for the design of the installation (CTE-HE, 2006).

- **Regulation of Building Thermal Facilities, RITE, 1998.** Approved in 1998, this regulation is applied to all non-residential buildings. It became out dated when the new RITE was approved in 2006 (RITE, 1998).

- **Regulation of Building Thermal Facilities; RITE, 2006**. Approved within the "Planning of Energy savings and Efficiency Strategy for Spain 2005-2007" (IDAE, 2003) RITE is applied to all non-residential buildings. This regulation is focused on the specifications for the use of the buildings thermal facilities. Parameters for the design of these facilities are set, such as the required indoor climate conditions and ventilation rates (RITE, 2006).

2.3. International databases

The following international institutions provided the energy demand statistics used in order to evaluate the results from the energy simulation:

- **Eurostat** is the official database of the European Commission and works on processing and publishing comparable statistical information at the European level. The national data of the Member States is collected by the statistical authorities of each country and then sent to Eurostat. The main role of Eurostat is to analyse and verify the information received, using harmonised methods to ensure that the data of the different countries can be compared (Eurostat, 2011).

- **GAINS** (Greenhouse Gas and Air Pollution Interactions and Synergies) is the database of the International Institute for Applied Systems Analysis (IIASA). This database covers the following subsectors: 1) residential; 2) commercial and public services; and 3) other services, including agriculture, forestry, fishing and unspecified sectors. IIASA is an international research organisation that conducts policy-oriented research into problems that are too large or too complex to be solved by a single country or academic discipline, such as climate change, sustainable development or energy security (GAINS, 2005)

- **IEA** (International Energy Agency) works for a sustainable economic development for the member states. The 28 member states have agreed to share energy information, to coordinate their energy policies and to cooperate in the development of rational energy programmes that ensure energy security, encourage economic growth and protect the environment (IEA, 2011).

The required climate data for the energy simulation was extracted from the database **Meteonorm** which is a meteorological database containing climate data for solar engineering applications (Meteotest, 2000). It is important to note that such climate data represents statistically generated test reference years which are based on the climate measurements performed between the years 1961 to1990 (i.e., the climate data presented for each of the locations was measured in a certain year of the period 1961-1990 and this year was considered as a representative year in terms of climate for this location). Thus, updated climate data has not been available.

3. Methodology

Figure 3.1 illustrates the steps followed to develop this master thesis. The first three steps (segmentation, characterisation and quantification) enabled the representation of the existing building stock. After these steps, the energy simulation was performed. The evaluation of the suitability of the application of the EABS model to Spain was realised in parallel. The process step "Energy efficiency measures" indicated below the dotted line in Figure 3.1 is beyond the scope of this master thesis and it can be considered as further work. Such step consists of evaluating the energy saving potential of the Spanish building sector by the application of energy efficiency measures to the building stock described.

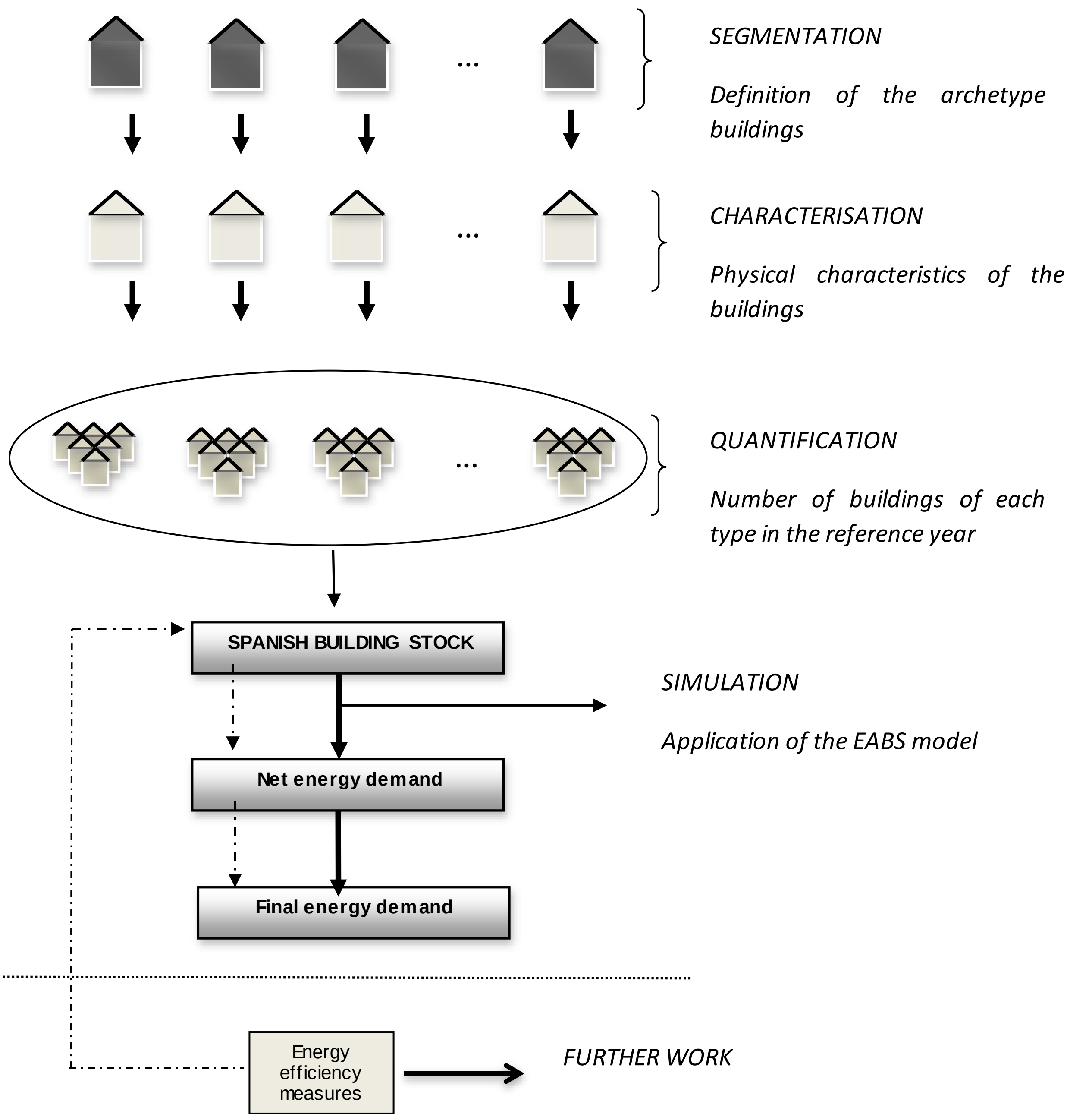


Figure 3.1: Schematic description of the bottom-up methodology applied in this work

3.1. The EABS model

To model net energy demand two main modelling approaches are currently applied: top-down and bottom-up models. Characteristics, advantages and disadvantages of these approaches are carefully reported by Swan and Ugursal (2009).

One aim of the Pathways Project is to estimate the potential energy savings of applying different energy efficiency measures to the existing building stock and thus, the effect on the net energy demand (Johnsson, 2011). In this context, a bottom-up engineering approach was found suitable to apply (Mata and Sasic Kalagasidis, 2009). This implies that the representation of the stock needs to be done in an aggregated way, either by sample buildings or by archetypes. In this master thesis archetype buildings are used. Such buildings are reference buildings considered representative of the whole stock to be characterised. They are described by collecting data about the overall characteristics of the buildings (e.g., period of construction, materials used, floor area) and information related to the specific building sector of the region under study (e.g., fuel shares, efficiencies, climate). As opposed to archetype buildings, sample buildings are reference buildings described using measured data of the building stock under study.

The model used to perform the energy simulation in this thesis is the "Energy Assessment of Building stocks" (EABS), which is a model developed within the Pathways Project (Mata and Sasic Kalagasidis, 2009). This modelling approach is based on the calculation of the energy demand of a group of buildings that are described in detail and selected to be representative of the entire stock. The results are then scaled up to represent the entire region under study considering the number of buildings of the stock that are represented by each reference building. In this master thesis, as indicated above, these reference buildings which are representative of the Spanish building stock are described by using archetype buildings.

The EABS model uses as input data thermal and physical properties of the buildings. The input file consists of a list of parameters which is presented in Section 3.3.

The net energy demand of the buildings is given as the output of the simulation, i.e. the energy provided to the building after considering the losses in the installed energy systems. Such energy demand is calculated through an energy balance for each building modelled as one thermal zone. The results are provided for each of the buildings analysed and they contain data of space heating and cooling use, electricity and hot water production (Mata, 2011).

The results of the energy simulation are compared to statistical data available in international databases expressed in terms of final energy. Thus, the net energy for end-uses is converted into final energy by using assumptions on efficiencies for the different fuel shares (see Section 3.5).

3.2. Methodology for segmentation

The characterisation of the building stock is carried out for a number of buildings considered representative of the entire Spanish building stock: the archetype buildings. The number of such archetype buildings is decided in the segmentation process and they are defined according to categories previously considered as the ones that have the largest impact on the energy consumption of the buildings.

The number of archetype buildings chosen is a compromise between accuracy and feasibility since the more type of buildings, the more precisely the stock is represented, but it also becomes more difficult to work with the data and it increases the simulation time. Table 3.1 presents the segmentations performed in other studies that present a characterisation of the building stock of a country/region in an aggregated way. These studies have been used as a reference to determine the criteria to segment the Spanish building stock.

As it can be seen in Table 3.1, the criteria applied in most of the studies are similar. The category "dwelling typology/ type of building" is included in all the studies, and "climate zone" and "age of construction" are the other categories most often considered.

The sample building representation of the Swedish residential stock, as used as input data in the study by Mata (2011), included a category for ventilation types. However, the data needed to consider such category in the segmentation of the Spanish building stock was lacking. Therefore, following the segmentation proposed by Mata (2011) and included in the Pathways Project (Mata et al., 2011) three categories are considered in this master thesis to segment the Spanish building stock into archetype buildings: building type, climate zone and period of construction.

Table 3.1: Criteria for segmentation followed in other studies which characterise the building stock in an aggregated way. Sources specified in the table.

COUNTRY	*SOURCE*	*CRITERIA FOR SEGMENTATION*
FRANCE	National Centre for Scientific Research (CNRS, Rapport R2: Bilans énergétiques Transport-Habitat et méthodologie BETEL.)	-Dwelling typology - Climate zone - Age of construction - Type of heating system - Energy source for heating
FRANCE	National Agency for improving Housing Conditions (ANAH, 2008)	-Dwelling typology - Climate zone - Age of construction - Energy source for heating
EU-15, EFTA AND TURKEY	Petersdorff et al., (2002)	-Type of building - Construction period
GREECE	Balaras et al., (2005)	-Type of building - Construction period
SCOTLAND	Clarke et al., (2004)	- Type of building - Construction period
CATALUNYA (SPAIN)	Contribution of dwellings in Catalonia to the reduction of emissions Greenhouse Gases (IC, 2006)	- Type of building - Construction period
SPAIN	Energy savings and Efficiency Strategy for Spain 2004-2012. "Building sector" document (IDAE, 2003)	- Type of building - Climate zone

Building type

The inputs for the EABS model that are dependent on the building type are listed in Table 3.2.

Table 3.2: Inputs of the EABS model whose values are dependent on the building type.

Notation	Description	Comments
TC	Effective heat capacity of the building	Differences apply especially between residential and non-residential buildings
$\mathbf{Tr_{min}}$	Minimum desired indoor temperature	Different values set by regulations for residential and non-residential sector
$\mathbf{Tr_{max}}$	Maximum desired indoor temperature	
$\mathbf{O_c}$	Specific heat gain from people	
$\mathbf{L_c}$	Specific heat gain from electric lights	
$\mathbf{A_c}$	Specific heat gain from appliances	
A	Heated floor area	
S	Total exterior area of the building envelope	
$\mathbf{V_c}$	Sanitary ventilation rate	Different values for SFD and MFD*

* SFD, Single-Family Dwelling; MFD, Multi-Family Dwelling

Based on the data available, the author of this thesis has considered two types of reference buildings for the residential sector (SFD, Single-family Dwellings; MFD, Multi-family Dwellings) and four types for the non-residential sector (commercial services, offices, sports and leisure and other services).

The classification of the non-residential buildings corresponds to the classification used by the "Ministry of buildings" (Ministerio de Fomento, 2011) in Spain, but excludes industrial, agricultural and transport buildings, since these categories are not accounted for in the statistics given by the international databases used subsequently to compare the results obtained from the energy demand simulation (see Section 6).

Climate zone

The climate outdoor conditions affect the heating and the cooling demand. Therefore, the energy simulation considers a different weather file for each climate zone. Such weather files are input files required by the EABS model that contain data describing the climate conditions of each climate zone (see Mata and Sasic Kalagasidis (2009) for further details about input files of the EABS model).

In addition, the technical characteristics of the buildings can also show important differences between regions since the building is designed according to fit the climate requirements. Thus, the building codes require different heat transfer coefficients (U) dependent on the climate zone. Moreover, since the constructing elements of the buildings present different materials and properties depending on the region, the heat capacity of the building (TC) also depend on the climate zone.

There are different maps available dividing Spain by climate zones. The CTE-2006 (CTE-HE, 2006) regulation takes into account twelve climate zones, see Figure 3.2. This division is the result of combining the five climate zones of the winter (from A to E) division and the four of the summer division (from 1 to 4).

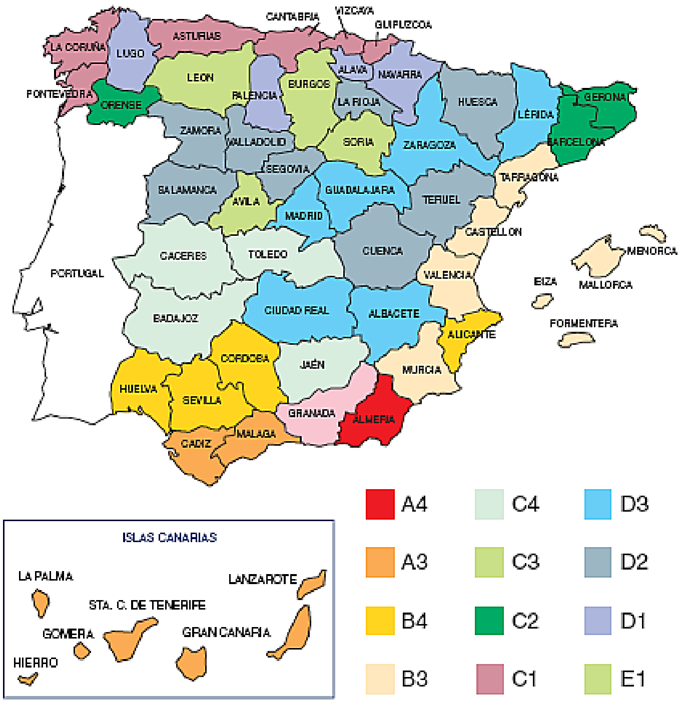


Figure 3.2: Spanish climate zones combining winter and summer divisions. Souce: Costrumatica.com, 2011

Figure 3.3: Spanish climate zones following the winter division used in CTE-2006. Source: building.dow.com, 2011.

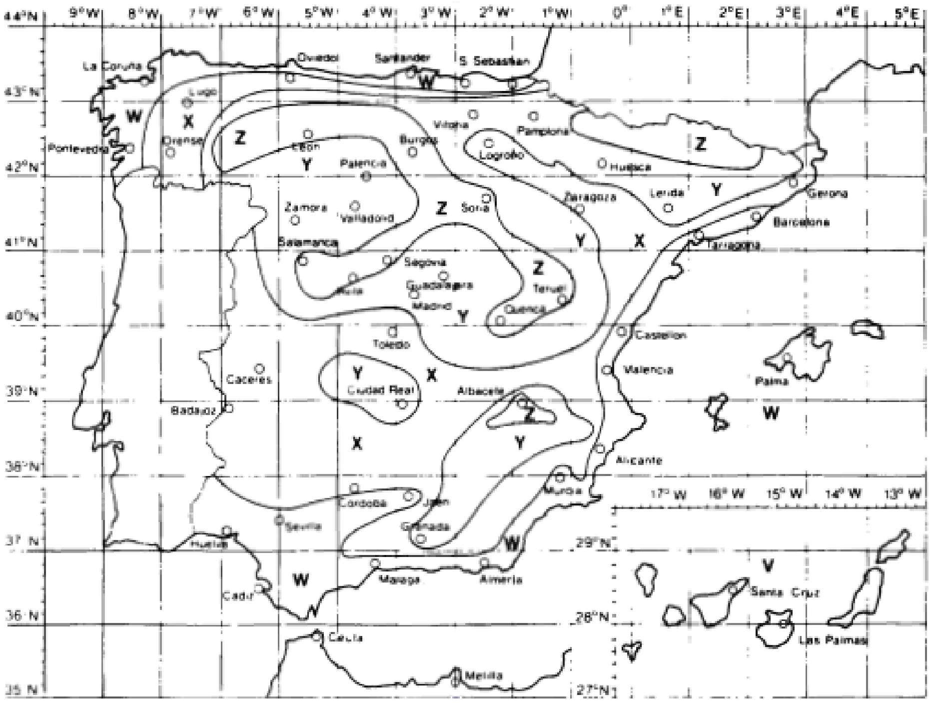


Figure 3.4: Spanish climate zones used in NBE-CT-79 (Decree 1490/1975, 1975)

The heating demand accounts for the largest share of the total Spanish energy demand of the building sector, while the share of energy consumption for cooling is more or less negligible (only 0.9% of the total energy consumption of Spanish households in 2008[2] (IDAE, 2009)). Thus, the climate zones that have the largest impact on the thermal parameters are the ones following the winter division, i.e., the Spanish territory is divided into five different climate zones. This winter zone division is shown in Figure 3.3 and the different zones are notated with letters from A to E.

Since each climate zone requires a different weather file, considering more climate zones would mean an increased number of archetype buildings. Therefore, it was considered important to minimise the number of climate zones included, since such number is a significant parameter that increases the computational time.

A different division of the country into climate zones is considered in the decree of 1975 and the regulation NBE-CT-79. In order to have comparable zones between the different regulations, the climate zones considered in the decree of 1975 and NBE-CT-79 (Figure 3.4) were identified with the ones used in CTE-2006 (Figure 3.3) as it is shown in Table 3.3.

As mentioned in Section 2.3, the climate data used in the energy simulation was extracted from Meteonorm (Meteotest, 2000). In this master thesis the five Spanish weather stations, as indicated in Table 3.3, were chosen to represent the five climate zones. They are located in the city with the

[2] One could think that this figure is very low and part of the cooling demand is hidden in the electricity demand. However, IDAE gives in the "report of energy consumption" the total final energy consumption of Spanish households disaggregated in heating, hot water, cooking, lighting, air conditioning and appliances (IDAE, 2009), so the share of energy consumption specifically for cooling is provided.

largest population in each region, as it was assumed that these cities have the largest number of buildings. Thus, the climate data of the weather stations is assumed to be representative of the corresponding climate zone.

Table 3.3: Identification of climate zones considered in CTE-2006 with the ones considered in previous regulations (Decree 1975 and NBE-CT-79) and weather stations of Meteonorm chosen to represent the climate zones in this thesis work.

Weather station	Climate zone CTE-2006	Climate zone Decree 1975 and NBE-CT-79
Málaga	A	W
Sevilla	B	W
Barcelona	C	X
Madrid	D	Y
Burgos	E	Z

Period of construction

The age of the building construction needs to be considered when estimating the energy demand since buildings are constructed following the regulations of the corresponding period. Table 3.4 lists the inputs of the EABS model that depends on the period of construction.

Table 3.5 reports the periods of construction considered in this master thesis which are defined according to the changes in building regulations.

The new regulation CTE was approved in the year 2006. The compliance of this new regulation would require additional efforts and costs that many investors might not be willing to take. Therefore, it is likely that a large number of constructing licenses could have been requested before March, the month of the approval of the new regulation. A research process was carried out by the author of this thesis to find out if there is a peak of constructing licenses in Spain before March of 2006, i.e. if the situation above explained actually happened. However, the source consulted (Ministerio de Fomento, 2011) does not show a different trend in 2006 compared to other years surveyed. Table 3.6 shows the distribution of the constructing licenses over the year.

Table 3.4: Inputs of the EABS model whose values are dependent on the period of construction

Notation	Description	Comments
TC	Effective heat capacity of the building	Building materials and its properties have been evolving over time
$\mathbf{V_c}$	Sanitary ventilation rate	Values set by regulations
U	Heat transfer coefficient of the building	
$\mathbf{Tr_{min}}$	Minimum desired indoor temperature	
$\mathbf{Tr_{max}}$	Maximum desired indoor temperature	

Table 3.5: Periods of construction according to Spanish building regulations

PERIOD OF CONSTRUCTION	REGULATION
Before 1976	No regulation
Between 1976 and 1979	Decree 1490/1975 (*Decreto por el que se establecen medidas a adoptar en las edificaciones con objeto de reducir el consumo de energía*)
Between 1980 and 2005	NBE-CT-79:.Building regulation. Thermal conditions of buildings (*Norma básica de la edificación. Condiciones térmicas de los edificios)*
Between 2006 and 2008	CTE: Technical building code (*Código Técnico de la Edificación*)

Table 3.6: Distribution of construction licenses in 2006 (Ministerio de Fomento, 2011)

Month	Regulation in force	Number of licenses	%
January-March	NBE-CT-79	59436	27%
April-December	CTE	162322	73%

As result of the segmentation process reported in this section, **120 archetype buildings** are considered in this master thesis (**6 building types x 5 climate zones x 4 periods of construction**) as representative of the Spanish building stock. The final distribution of the buildings and existing surface area according to this segmentation is presented in Section 4.1.

3.3. Methodology to characterise the Spanish building stock

The parameters presented in Table 3.7 are the inputs used to characterise the building stock in the EABS model. These parameters are related to the building geometry, properties of the construction materials, required indoor climate conditions and thermal characteristics of the building service systems (Mata and Sasic Kalagasidis, 2009).

Table 3.7: Inputs for the EABS model used to characterise the building stock.

Notation	Description	Units
TC	Effective heat capacity of the building	J/K
W_c	Solar shading coefficient for a window	0-1
W_f	Part of the total window area covered by window frames	0-1
T0	Initial indoor temperature	°C
Tr_{min}	Minimum desired indoor temperature	°C
Tr_{max}	Maximum desired indoor temperature	°C
S_h	Maximum heating power of a heating system	W
S_c	Maximum cooling power of a cooling system	W
P_h	Response capacity of a heating system	W/K
P_c	Response capacity of a cooling system	W/K
HRec_eff	Efficiency of the heat recovery unit	0-1
Pfh	Specific heat gain from ventilation fans	W/m^2
T_v	Set point temperature for natural ventilation	°C
O_c	Specific heat gain from people	W/m^2
A_c	Specific heat gain from appliances	W/m^2
L_c	Specific heat gain form electric lights	W/m^2
V_{cn}	Natural ventilation rate	$l/s/m^2$
V_c	Sanitary ventilation rate	$l/s/m^2$
HyP	Specific electric power demand for operation of hydronic pumps	W
COP	Coefficient of performance of heat pumps	-
Weight	Coefficient to scale up the type to the whole building stock	-
T_s	Window solar transmittance	0-1
A	Heated floor area	m^2
S_w	Total window area	m^2
S	Total exterior area of a building envelope	m^2
SFP	Specific fan power	$W/l/m^2$
H_w	Specific heating power demand for hot water production	W/m^2
U	Heat transfer coefficient of the building	W/m^2K

Two main methods have been used to determine the values set for each parameter: 1) by data collected directly from sources; 2) by using calculations or assumptions. The methods and the subsequent processes are explained below for each parameter.

Effective heat capacity of the building (TC)

The effective heat capacity of the building represents its thermal inertia and it is calculated by summing up the volumetric heat capacities of the layers in direct contact with the internal air, i.e. internal layers of exterior walls and roof, internal walls and middle floors. Thus, the following expression is applied (Mata and Sasic Kalagasidis, 2009):

$$TC = \sum \rho_i \cdot Cp_i \cdot S_i \cdot d_i$$ Equation 1

Where:

$\boldsymbol{\rho_i}$ is the density of the layer (kg/m^3)

Cp_i is the specific heat capacity of the layer (J/kgK)

$\mathbf{S_i}$ is the area of the layer (m^3)

$\mathbf{d_i}$ is the thickness of the layer (m). According to EN ISO 13790, the maximum thickness is 1)10cm or 2) the thickness defined from the external wall to the middle of the building element, whichever comes first.

Data regarding the building materials and their properties are needed to calculate the effective heat capacity of the building (see Appendix E). Due to the lack of such data, the characteristics and materials of the Catalonian buildings, which are presented in the Catalonian study PMEB are applied for all Spanish buildings (Barcelona Regional, 2002). Since only dwellings and office buildings are described in the PMEB study, the material properties of the residential buildings are assumed for the buildings types "sports and leisure", "commercial services" and "other services". Data extracted from the study CTE-LIDER (2009) is also used for buildings constructed after 2006.

<u>Minimum desired indoor temperature (Tr_{min})</u>

The minimum desired indoor temperature has been considered the same than the allowed indoor temperature set by the regulations. Table 3.8 shows the minimum allowed indoor temperature according to NBE-CT-79 depending on the building type.

No requirements concerning indoor temperatures are set in the regulation CTE approved in 2006. Therefore, a minimum indoor temperature of **18°C** is assumed for all residential buildings.

To determine Tr,min for the non-residential sector, the RITE regulation is applied, which sets the allowed range of temperatures depending on summer (23-25 °C) and winter season (21-23 °C). As opposed to the indoor air temperature, this regulation sets the required operative temperature, which is used to measure the thermal comfort. Such temperature is the average of the mean radiant and the ambient air temperatures, weighted by their respective heat transfer coeffici ent (ASHRAE, 2009). However, since no other data regarding required indoor temperature was found, the operative temperature is assumed to be equal to the air temperature in this master thesis.

Therefore, a minimum indoor temperature of **21°C** is considered for all non-residential buildings, since RITE is compulsory for this building sector.

Table 3.8: Minimum allowed indoor temperature according to NBE-CT-79 depending on the building type (NBE-CT-79, 1979)

BUILDING TYPE	Tr_{min} **(°C)**
Dwellings, education, commercial, culture and sedentary work	18
Sports centres, light work	15
Heavy work	12

Maximum desired indoor temperature (Tr_{max})

Specifications concerning maximum indoor temperature were only found in RITE (25 °C and 23 °C for the summer and winter season respectively). Again, the temperature value set refers to the operative temperature. As indicated below, values set by RITE for the operative temperature are assumed for the indoor temperature. Therefore, a value of **25°C** for Tr_{max} is considered for all archetype buildings.

Maximum heating and cooling power of a heating and cooling system (S_c, S_h)

It is assumed that the energy provided by the energy systems of the building should always satisfy the demand. Therefore, the values for S_c and S_h are set high enough to ensure that the systems are capable of providing the energy demanded.

Response capacity of a heating (cooling) system (P_c, P_h)

It is assumed that the response capacity of the energy systems of the building was high. Therefore, the values for P_c and P_h are set high enough to ensure that the systems are capable of responding to any change in the demand (e.g., a drop in the outdoor temperature or an increase in the internal loads).

Efficiency of the heat recovery unit (HRec_eff)

A value of zero is set for this parameter, since it is assumed that the buildings in south European countries, such as Spain, do not usually work with heat recovery units (Boermans and Petersdorff, 2008).

Specific heat gain from occupants, appliances and lighting (O_c, A_c, L_c)

The values set for the specific heat gain from occupants and appliances are extracted from CTE-LIDER (see Section 2.1). In the annexes of this document, values for parameters such as heat gains or ventilation rates that can be assumed to define the operational conditions of the building are presented. A different hourly value is given for each parameter considered depending on the building type, as given in Table 3.12.

Since a constant value all year through is needed in this study, a weighted average of the hourly values for weekdays, Saturdays and Sundays is calculated for each building type. This averaged value for the specific heat gain from occupants is presented in Figure 3.5.

Table 3.9: Example of hourly values for the specific heat gain from occupants for non-residential buildings (W/m^2)(CTE-LIDER,2009).

Ocupación sensible (W/m^2)	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Laboral	0.00	0.00	0.00	0.00	0.00	0.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	0.00
Sábado	0.00	0.00	0.00	0.00	0.00	0.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	6.00	0.00
Festivo	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

An average value for the specific heat gain from lighting in residential buildings is also extracted from CTE-LIDER (2009). Using the same method applied to calculate the heat gain from occupants and appliances, an average value of **1.65 W/m²** is obtained.

Equation 2 is used to calculate the heat gain from lighting for non-residential buildings (CTE-HE, 2006).

$$P = \frac{VEEI \cdot Em}{100} \quad (W/m^2) \qquad \text{Equation 2}$$

Where:

a) **VEEI** (*Valor Energético de la Instalación*) is the value for the energy efficiency of the electric system. The values for the different building types considered are listed in Table 3.11. Such values are chosen based on the data given by DB-HE (2006) (see Section 2.2) and shown in Table 3.10.

b) **Em** is the average illuminance (*Iluminancia media mantenida*). The "Technical guide of efficient lighting" (*Guía técnica de iluminación eficiente*) (IDAE, 2006) gives the level of illuminance for each building type as reported in Table 3.11.

The values for Lc obtained by applying Equation 2 are considered for archetype buildings constructed after 2006. However, for archetype buildings constructed before 2005, it is assumed that the energy demand for lighting is lower (deduction of 10%), since the lighting facilities installed in such buildings might not allow a total instant power for lighting as high as the current lighting facilities do. The values obtained for the archetype buildings build before 2005 (majority of the existing building stock in 2008) are illustrated in Figure 3.5.

Table 3.10: VEEI values for different building types in W/m² (CTE-HE, 2006)

Use	VEEI
Lecture rooms	4
Administrative	6
Hospitals	4.5
Common spaces	4.5
Common spaces in residential buildings	7.5
Sport centres	5
Supermarkets	6
Libraries and museums	6
Malls	8
Shops	10
Hotels	10

Table 3.11: Level of illuminance (Em) in lux for each building type (IDAE, 2006) and the energy efficiency of the electric system (VEII) in W/m² (DB-HE, 2006).

Building type	Em (lux)	VEII (W/m²)
Commercial services	400	9
Offices	400	6
Sports and leisure	300	7
Others	300	7

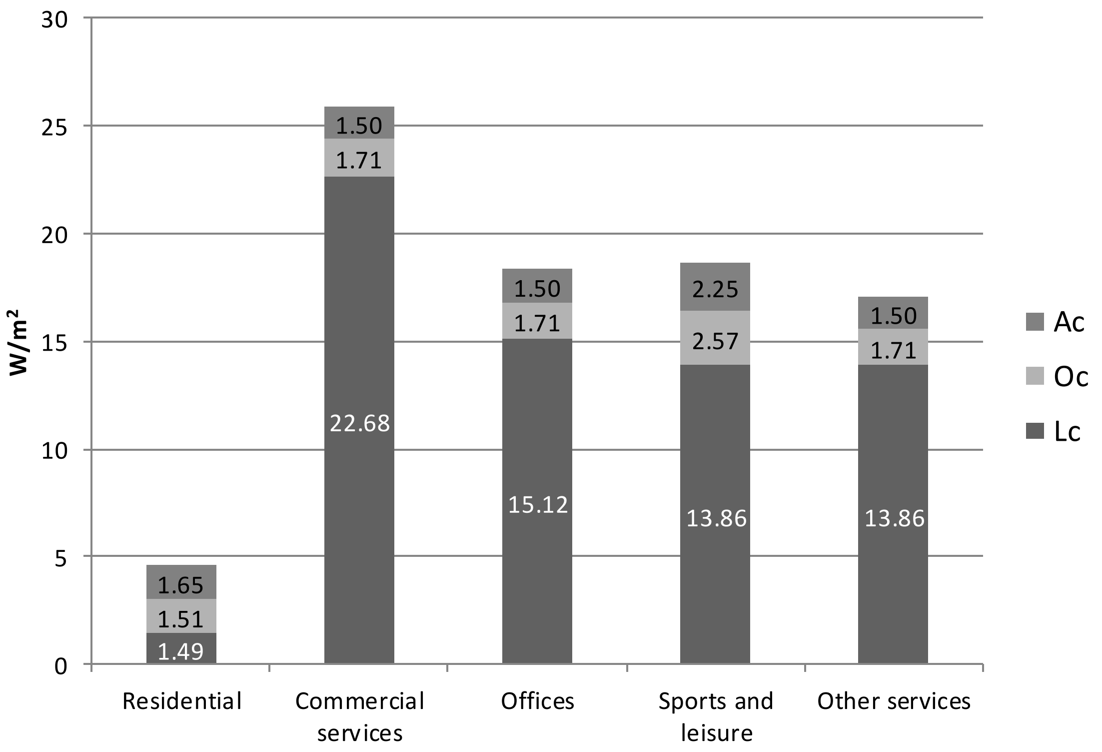


Figure 3.5: Average value for the internal heat gain (from occupants (Oc), appliances(Ac) and lighting (Lc)) for each building type considered in this thesis work (W/m²).

Natural ventilation rate (V_{cn})

Natural ventilation is assumed to be used whenever the indoor temperature exceeds a certain value called the *set point temperature for natural ventilation*. This value is notated in the EABS model as "$\mathbf{T_v}$" and it is set to **24°C** in this master thesis. Therefore, it is assumed that when indoor temperature exceeds 24°C the building occupants will open the windows.

The value of natural ventilation rate is the airflow rate generated when natural ventilation is being used (i.e., with windows opened). A value of this parameter of **4 CPH** (changes per hour) is assumed for all type of buildings. It is extracted from annexes of CTE-LIDER (2009) where it is considered as the existing airflow rate when the windows are opened. Considering a ceiling height of 2.5 m per floor, this is equivalent to **2.78 l/s/m²**.

Sanitary ventilation rate (V_c)

The sanitary ventilation rate represents the necessary airflow rate for ventilation to comply the required indoor air quality and is set by the regulations. RITE sets the value for the sanitary ventilation rate for non-residential buildings depending on the level of air quality (from level 1, the highest, to level 4, the lowest) required by each building.

A level 2 is considered for office buildings (V_c=**0.83 l/s/m²**) and a level 3 for the building uses commercial, sports and leisure and other services (V_c=**0.55 l/s/m²**) (RITE, 2006). Since RITE was approved in the year 2006, the ventilation rates of 0.83 $l/s/m^2$ and 0.55 $l/s/m^2$ are assumed for the non-residential buildings constructed after this year.

For the residential sector the values indicated in Table 3.12 extracted from DB-HS (2006) are used to obtain the sanitary ventilation rate for buildings constructed after 2006.

Table 3.12: Required sanitary ventilation rate in each local of residential buildings (l/s) (CTE-HS, 2006).

LOCAL	Per person	Per m^2	Per local
Bedrooms	5		
Living rooms	3		
Bathrooms			15
Kitchens		2	

To calculate an average V_c for a residential building it is assumed that the total floor area of the building is divided into the different rooms as follows: 15% bathroom, 20% kitchen, 30% living room and 35% bedrooms, according to the drawings presented in the PMEB (Barcelona Regional, 2002). Moreover, an average value of **2.86** people per dwelling is assumed, based on data extracted from INE (2011). According to this, the values of V_c for the residential building types SFD and MFD obtained are **0.51 $l/s/m^2$** and **0.42 $l/s/m^2$.**

For archetype buildings constructed before 2006, it is assumed that both residential and non-residential buildings had no mechanical ventilation. Therefore, an air infiltration rate is considered as the sanitary ventilation rate for such buildings. The air infiltration rates used are presented in Table 3.17. Values in CTE-LIDER are given in CPH (Changes per Hour). This was recalculated to l/s/m2, as used in this thesis, by considering a ceiling height of 2.5 metres.

Table 3.13: Air infiltration rate for SFD (Single-Family Dwellings), MFD (Multi-Family Dwelling) and other uses (CTE-LIDER, 2009).

	SFD	MFD	Other uses
Air infiltration ($l/s/m^2$)	0.21	0.17	0.07

Total window area (S_w)

The window area of the building is calculated as a percentage of the total area of the facade. Percentages of window area referenced to the total opaque facade (Sw/Swalls) considered in this master thesis are based on drawings found in the PMEB study (Barcelona Regional, 2002). Such percentages are shown in Table 3.14.

Table 3.14: Window area referenced to facade area (Barcelona Regional, 2002)

Sw/Swalls	Residential (%)	Non-residential (%)
Before 1979	17.5	17.5
After 1979	32.5	39.0

Total exterior area of a building envelope (S)

The expressions used in this section to calculate the total exterior area of the building envelope are extracted from Martinlagardette (2009), a previous master thesis work which was also carried out within the Pathways Project.

The total exterior area of a building is calculated by adding up the areas of the floor, the roof, the walls and the windows:

$$S = Swalls + Sroof + Sfloor + Sw \qquad \text{Equation 4}$$

According to the 3-CL method[3] used by the "French Environment and Energy Management Agency" (ADEME), the total areas of the walls, the floor and the roof are obtained following the expression below (Martinlagardette, 2009):

$$Sroof = Sfloor = \frac{A}{Levels} \qquad \text{Equation 5}$$

$$Swalls = ATTxFormx\sqrt{\frac{A}{Levels}}xLevelsxHR - Sw \qquad \text{Equation 6}$$

Where:

ATT is the attached character of the dwelling

Form is a parameter which indicates the configuration of the building

LS is the living space or heated floor area (see annex A)

Levels is the number of floors of the building

HR is the height under the roof (2.5 m)

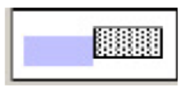
Sw is the window area

Attached character of the dwelling (ATT)

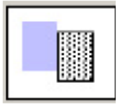
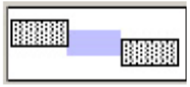
The attached character of the dwelling (ATT) can take the following values according to the 3-CL method:

ATT=1 : Detached house

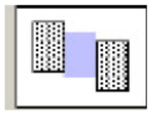
ATT=0.8: Attached on one side



[3] For calculating end-use energy consumption in dwellings, ADEME refers to algorithms from the 3-CL method, which is based on the DEL2 method. The latter is a rapid calculation tool that uses a statistic model providing default values, such as U-values, and equations for calculating surface areas, etc.

ATT=0.7: Attached on one big side or two small sides  or 

ATT=0.7: Attached on one big side and one small side 

ATT= 0.35: Attached on two big sides 

In this thesis a general assumption is made according to the building type:

- All the single-family buildings are considered as detached (i.e., ATT=1).
- All the multifamily buildings are assumed to be attached on two small sides or one big side and one small side (i.e., ATT=0.7).
- An average value is considered for all non-residential buildings (i.e., ATT= 0.675), assuming that there will be buildings of all the attachment characters.

Form

This parameter takes different values depending on the configuration of the building. They are described in the 3-CL method according to Table 3.15:

Table 3.15: Form values depending on the configuration of the building (Martinlagardette, 2009)

CONFIGURATION		**VALUE**
Compact		4.12
Elongated		4.81
Developed		5.71

Depending on the building type, the following assumption is made:

- Single-family buildings are assumed to be compact (i.e., Form=4.12)
- An elongated configuration is considered for multifamily buildings (i.e., Form=4.81)
- An average value is assumed for all non-residential buildings (i.e., Form=4.92)

Levels

The values considered for the number of floors of each archetype buildings are based on data extracted from INE (2011), which gives the number of residential buildings with a certain number of floors. The location of each building, the period of construction and the building type (only for residential buildings) are also specified by INE. Thus, an average number of floors could be calculated for each archetype building. These average numbers are presented in Table 3.16.

No data was found regarding the number of floors in residential buildings constructed after 2001. Due to this, the values corresponding to the buildings constructed between 1980 and 2001 are considered for later periods.

INE does not provide disaggregated data by building use regarding non-residential buildings. In addition, no data for buildings constructed after 2001 was found. Therefore, the values presented in Table 3.16 are assumed for all the archetypes of non-residential buildings.

Table 3.16: Number of floors for residential buildings constructed before 2001. Based on data extracted from INE (2011).

PERIOD OF CONSTRUCTION	CLIMATE ZONE									
	Zone A		**Zone B**		**Zone C**		**Zone D**		**Zone E**	
RESIDENTIAL	*SFD*	*MFD*	*SFD*	*MFD*	*SFD*	*MFD*	*SFD*	*MFD*	*SFD*	*MFD*
Before 1980	1.46	4.01	1.54	4.56	1.60	4.92	1.60	4.90	1.72	4.41
1980-2001	1.72	3.57	1.71	4.07	1.82	4.28	1.92	4.44	1.89	4.39
NON-RESIDENTIAL	**Zone A**		**Zone B**		**Zone C**		**Zone D**		**Zone E**	
Before 2001	1.42		1.36		1.48		1.43		1.41	
After 2001	1.88		2.10		2.06		2.05		1.47	

<u>Specific heating power demand for hot water production (H_w)</u>

Hot water demands of **30** and **22 litres/day/person** are considered for SFD and MFD buildings respectively (CTE-HE, 2006).

To transform the hot water demand given in litres to power demand the following expression is used:

$$\mathbf{Q = m \cdot Cp \cdot \Delta T = v \cdot \rho \cdot Cp \cdot \Delta T} \qquad \text{Equation 7}$$

Where:

v: demand of hot water in m^3/day (an average 2.86 occupants per dwelling was assumed (INE, 2011)).

ρ: water density (i.e., 1000 kg/m^3)

Cp: heat capacity of the water (i.e., 4.18kJ/kg/K)

ΔT: temperature difference. It was assumed that the water is heated from ambient temperature (~25°C) to the 60°C set by the regulation CTE-HE (2006).

The average power demand of hot water for non-residential buildings is based on data extracted from the Annex 1 of the "Plan for energy improvement in Barcelona (PMEB)" and it is reported in Table 3.17. The PMEB is a study carried out by Barcelona Regional, a limited company whose shareholders represent different public bodies. It is focused in the building sector of Barcelona, which lies in climate zone C. However, since no other data was found regarding hot water demand in non-residential buildings, the values extracted from PMEB are considered for all the climate zones in Spain.

Table 3.17: Annual average power demand of hot water for non-residential buildings considered in this thesis work. Based on data extracted from Barcelona Regional (2002).

Building use	Annual power demand (W/m^2)
Commercial	0.13
Offices	0.17
Sports and leisure	2.33
Other services	1.00

Specific fan power (SFP)

The "Regulation of Building Thermal Facilities" (RITE, 2006) sets the specific fan power depending on the complexity of the installed system (from 1 to 5). The complexity of the installed systems in residential buildings is assumed to be 2 for residential buildings, 3 for offices and 4 for the remaining building types (commercial, sports and leisure and other services).

Therefore, the specific fan power, SFP, assumed for the buildings constructed after 2006 is presented in Figure 3.6. Since buildings constructed before 2006 are assumed to have no other ventilation system than natural ventilation (an air infiltration rate was considered as the sanitary ventilation rate), the value for SFP is set to zero for these archetype buildings.

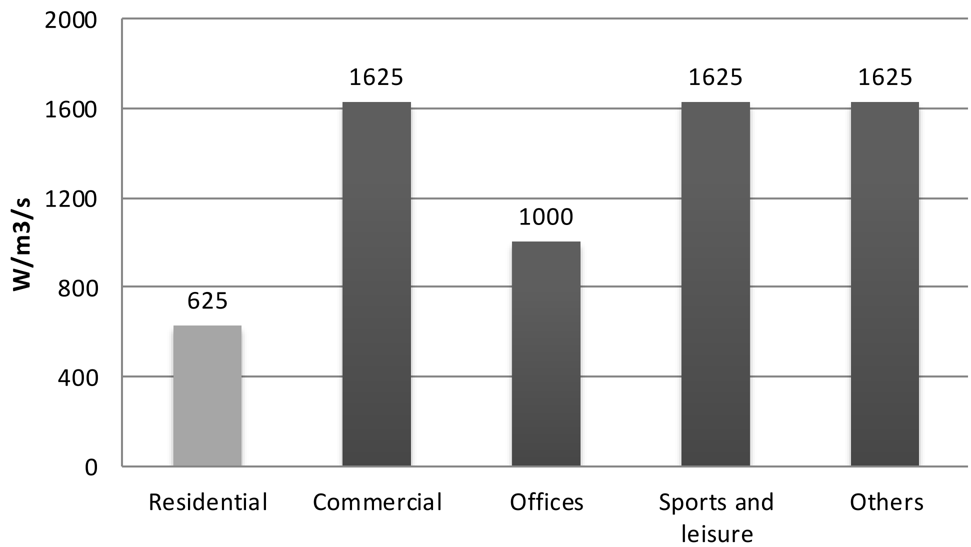


Figure 3.6: Specific fan power considered in this thesis work for archetype buildings constructed after 2006 (RITE, 2006).

Heat transfer coefficient of the building (U)

The requirements regarding the heat transfer coefficient of the buildings, U, are determined by the Decree 1490/1975 and the regulations NBE-CT-79 (1979) and CTE-HE (2006). These documents provide the required U-values of the different elements of the building (i.e., facade, walls, floor and roof) for each climate zone. Table 3.20 reports the U-values for each building element (i.e., roof, floor, façade, windows) assumed for the archetype buildings constructed after 1979. An average U-value for the whole building is calculated using the values from Table 3.20 (U_i) and the total area of each element (S_i):

$$U = \frac{\sum_i U_i * S_i}{\sum_i S_i} \qquad \text{Equation 8}$$

The U-values considered for the buildings constructed between 1975 and 1979 are based on the values shown in Table 3.19, which are set according to the value of the parameter "f". According to the Decree 1490/1975 (1975), the shape factor ("f", *factor de forma*) is "the ratio between the sum of the areas of the separation building elements and the volume enclosed by them". This parameter represents how much heat can be transferred by the building surfaces, but it is not specified by the regulation whether the surfaces not in contact with the outside must be taken into account or not. Thus, it is not clear how such parameter should be calculated. However, it seems reasonable to take only into account the surfaces in contact with the outside. Since the surface of the building envelope (S) as calculated in this work only considers such surfaces, the following expression was used in this master thesis:

$$f = \frac{S}{A * h} \qquad \text{Equation 9}$$

Where:

S is the total surface of the building envelope (see Equation 4)

A is the total heated floor area of the building

h is the ceiling height (2.5m in this thesis work)

The U-values of each element of the archetype buildings constructed before 1975 considered in this master thesis are shown in Table 3.18. Since there are no regulations corresponding to this period, such values are determined as an average of those found for this period in the literature (Barcelona Regional, 2002; Boermans and Petersdorff, 2008). The heat transfer coefficient for the whole building is calculated by applying Equation 8.

Table 3.18: U-values considered in this work for buildings constructed before 1975 (Barcelona Regional, 2002; Boermans and Petersdorff, 2008).

Element	U-value (W/m^2C)
Facade	1.70
Ground slab	2.25
Roof	2.25
Window	5.80

Table 3.19: Required U-values according to the Decree 1490/1975 (W/m²)[4]*. Parameter "f" is the ratio between the sum of the areas of the separation building elements and the volume enclosed by them. (Decree 1490/1975, 1975)*

f	Zone W	Zone X	Zone Y	Zone Z
0.20	2.33	1.98	1.80	1.69
0.25	2.09	1.69	1.57	1.40
0.30	1.86	1.51	1.40	1.28
0.35	1.69	1.40	1.28	1.16
0.40	1.57	1.28	1.16	1.11
0.50	1.40	1.16	1.05	1.05
0.60	1.28	1.05	0.99	0.91
0.80	1.16	0.95	0.87	0.81
1.00	1.11	0.91	0.84	0.78
1.20	1.05	0.88	0.81	0.76

Table 3.20: U-values considered for the archetype buildings constructed after 1979 (NBE-CTE-79, 1979; CTE-HE, 2006).

Climate zone	Period of construction	Roof	Floor	Facade	Windows
Zone A	1980/2005	1.40	1.4	1.20	5.80
	2006/20008	0.65	0.69	1.20	5.80
Zone B	1980/2005	1.40	1.40	1.20	5.80
	2006/20008	0.59	0.68	1.07	5.80
Zone C	1980/2005	1.20	1.40	1.20	5.80
	2006/20008	0.53	0.65	0.95	5.80
Zone D	1980/2005	0.90	1.20	1.20	5.80
	2006/20008	0.49	0.64	0.86	5.80
Zone E	1980/2005	0.70	1.20	1.20	5.80
	2006/20008	0.46	0.62	0.74	5.80

3.4. Methodology for quantification

Quantification of the number of buildings

Each of the archetype buildings defined in the model is assigned a coefficient indicating at the number of buildings in the country represented by that archetype building. This coefficient is called "the weighting coefficient" and it enables to extrapolate the results obtained for each archetype building to represent the entire Spanish building stock.

[4] The required U-values are provided by the Decree 1490/1975 in terms of kCal/h°C and they are transformed to W/m². See section 3.5 for identification of climate zones W-Z with A-E.

Several sources are used to obtain the number of existing buildings in each period, i.e. the weighting coefficient of each archetype building. The sources consulted and their given values for the number of buildings are presented in Appendix A. From this database the values reported in Appendix B are selected. To get the final number of existing buildings, a demolition rate is applied to this data. This rate is calculated based on data extracted from the Ministry of buildings (Ministerio de Fomento, 2009) given as a percentage of demolished buildings related to the total existing buildings. Since this information is only available for the years 1998 to 2008, see Table 3.21, an average demolition rate for these years is calculated and assumed as the annual demolition rate for all periods analysed.

Considering the average demolition rate presented in Table 3.21, the final values of the number of existing buildings are calculated according to the following expression:

$$\mathrm{C} = \mathrm{B} \times (1 - \mathrm{r})^{\mathrm{n}} \qquad \text{Equation 10}$$

Where:

C is the number of existing buildings obtained after considering the demolition rate (values presented in appendix C)

B is the number of existing buildings before considering the demolition rate (values presented in appendix B)

r is the annual demolition rate

n is the number of years of the period considered

The number of constructed buildings per year is only available in the Ministry of Buildings for the last twelve years (Ministerio de Fomento, 2011). For buildings constructed before 1998, only an aggregated value per decade was found (INE, 2011). Thus, the number of constructed buildings between 1976 and 1979 is based on those constructed between 1971 and 1980 using a compound annual growth rate. Table C.2 in appendix C reports the values finally considered for the number of buildings constructed before 1976 and between 1976 and 1979 after applying the obtained **3%** annual growth rate (CARG) [5] (INE, 2011). Table C.1 in the same appendix reports the corresponding number of buildings for the remaining archetype buildings (constructed from 1980 to 2008) that are directly extracted from INE (2011) and the Ministry of Buildings (Ministerio de Fomento, 2011).

Table 3.21: Calculation of the demolition rate considered in this thesis work (Ministerio de Fomento, 2009).

TOTAL NATIONAL	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Thousands of existing buildings	11453	11603	11755	11925	12104	12326	12554	12795	13017	13162	13236
Demolished buildings	9543	10794	11838	11799	12718	14420	18165	20997	28480	26141	14573
DEMOLITION RATE	**0.08%**	**0.09%**	**0.10%**	**0.10%**	**0.11%**	**0.12%**	**0.14%**	**0.16%**	**0.22%**	**0.20%**	**0.11%**
AVERAGE						**0.13%**					

5 $CAGR = \left(\frac{Ending\ value}{Beginning\ value}\right)^{\frac{1}{\#years}} - 1$ (Equation 11), where $Ending\ value$ is the number of existing buildings in 1980, $Beginning\ value$ is the number of existing buildings in 1971 and $\#years$ is equal to 10.

Quantification of the existing surface

Several sources are consulted to obtain the existing surface values of the Spanish building stock. The sources consulted and the values of constructed surface extracted from each one are presented in Appendix A. The final values chosen from all the data gathered are shown in Appendix B. To get the final existing surface that is used in the energy simulation, a demolition rate is applied to the values shown in Appendix B. An average demolition rate for years from 2002 to 2008 of 0.24% is obtained following the same method explained above for the quantification of the number of buildings. To disaggregate the values of the surface of existing residential buildings by zone, several sources are consulted for the periods of construction "before 1979" and "1980-2005". As it can be seen in appendix A, the data found did not match. As an example, the bars in Figure 3.7 illustrate the range of values of the existing surface that is obtained for climate zone A, taking into account all the data gathered. The final value chosen applied in this thesis work for this parameter is also indicated with a dot. Corresponding figures for the other climate zones are presented in Appendix E.

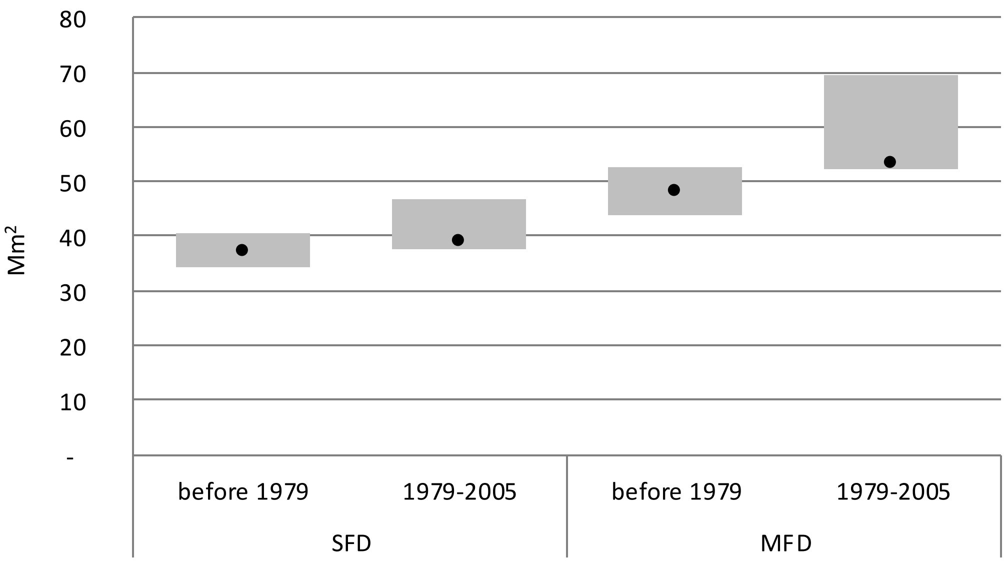


Figure 3.7: Range of values for the surface of residential buildings of climate zone A constructed before 2005 belonging to the existing stock in 2008 (Ministerio de Fomento, 2011; INE, 2011).

The values eventually considered as the existing surface for each period are:

- Before 1979: average value of the range provided by INE (see Appendix A and Figures D.1 to D.5 in Appendix D)
- Data belonging to the period "1979-2005". Sum of:
  - 1980-2001: average value of the range provided by INE (see Appendix A)
  - 2002-2005: extracted from the Ministry of Buildings.

The figures presented in Appendix D are just related to the residential sector, since INE does not provide disaggregated data for the non-residential sector. To get such data, assumptions are made (see Appendix A).

Values of constructed surface per year are only available in INE for the last twelve years. For buildings constructed before, only an aggregated value per decade was found. Thus, the constructed surface between 1976 and 1979 has to be obtained based on those constructed between 1971 and 1980. To do so, a compound annual growth rate is calculated to 4.3% using Equation 11.

Table C.4 in Appendix C reports the values finally used in the energy simulation for the number of buildings constructed before 1976 and between 1976 and 1979 after applying the assumed annual growth rate. Table C.3 in the same appendix reports the corresponding values for the surface of the remaining archetype buildings (constructed from 1980 to 2008) that are directly extracted from INE (2011) and the Ministry of Buildings (Ministerio de Fomento, 2011).

3.5. Final energy consumption of the Spanish building sector

As explained in Section 3.1, the EABS model calculates the total energy demand as net energy. Nevertheless, the corresponding statistics from Eurostat and GAINS that are used to calibrate the model are expressed in terms of final energy. To be able to compare the results from the energy simulation with these statistics, the net energy demand obtained is transformed to final energy demand using Equation 11 the fuel shares presented in Figures 3.8 and 3.9 and efficiencies reported in Table 3.22.

$$\text{Final energy} = \text{Useful energy} * \sum \frac{\text{Share}_i}{\text{Efficiency}_i} \qquad \text{Equation 12}$$

Where "i" is the corresponding fuel (i.e., oil, gas, electricity, solar, biomass)

Data regarding the efficiency of the energy systems installed in the Spanish buildings were lacking. Efficiencies for oil and gas for the residential sector are set as average values of data extracted from IDAE (2010). Such data is reported in Table 3.23.

The solar energy sources used for hot water production are mainly solar collectors its efficiency is influenced by many parameters (CECU. 2011; Energía Solar, 2011). A value of 0.3 for such efficiency is assumed in this thesis work, as shown in Table 3.22.

Table 3.22: Fuel efficiencies in the residential and non-residential sector. Sources: [1] Johnsson(2011); [2]IDAE (2010); [3]assumption based on CECU (2011) and Energía Solar (2011) ; [4] own assumptions

FUEL	RESIDENTIAL	NON-RESIDENTIAL
Oil	0.87 [2]	0.76 [1]
Coal	0.70 [1]	0.8 [1]
Gas	0.87 [2]	0.76 [1]
Renewables (solar)	0.3 [3]	0.3 [3]
Renewables (biomass)	0.61 [1]	0.61 [1]
Direct electricity	1 [4]	1 [4]
Electricity provided by heat pumps	2 [4]	2 [4]

Table 3.23: Expression for the efficiency of gas boilers (IDAE, 2010)

Type of boiler	Power range, P (kW)	Efficiency (%)
Standard	4 to 400	≥ 84+2logP
Low temperature	4 to 400	≥ 87.5+1.5logP
Condensation	4 to 400	≥ 91+logP

For the residential sector, the fuel shares considered in this master thesis for the energy uses hot water heating and space heating are presented in Figure 3.8. Corresponding fuel shares are also provided for different building types (uses) in the non-residential building sector, see Figure 3.9 (A-F). Since disaggregated data by energy end-use is not available for the non-residential sector, the shares presented in Figures 3.9 (A-F) are considered for the end-uses heating and hot water.

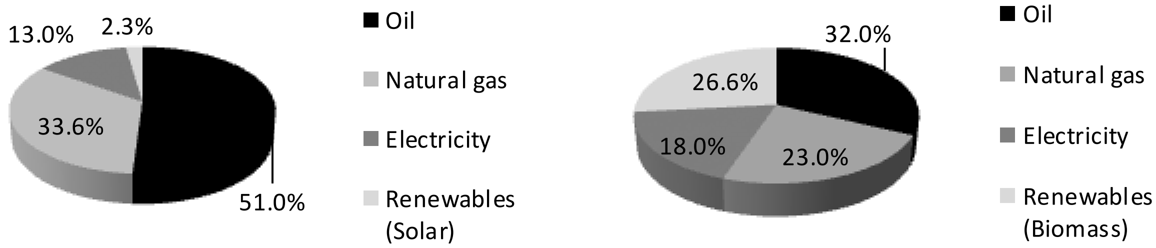
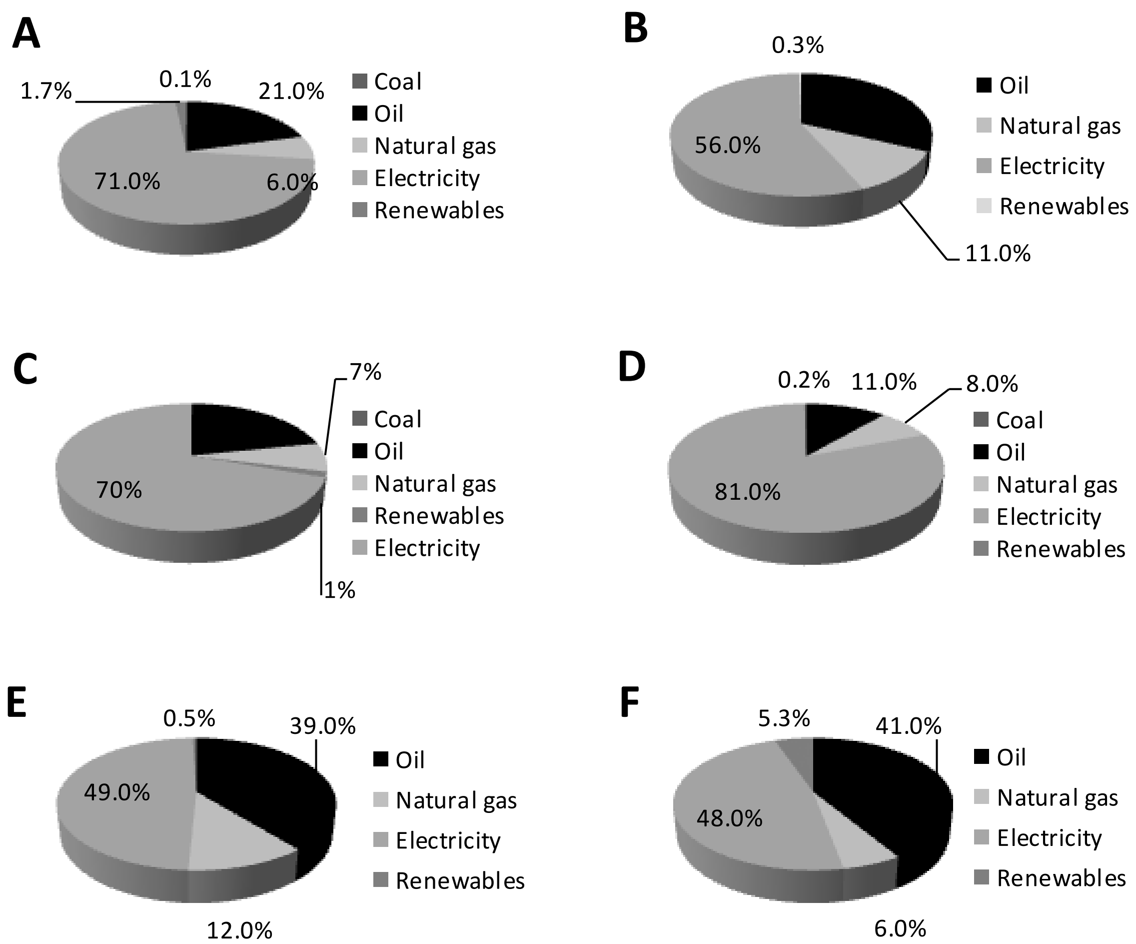


Figure 3.8: Fuel shares for hot water heating (left) and space heating (right) of residential buildings. Source: (IDAE, 2009)



Figures 3.9 (A-F): Fuel shares for energy demand in the non-residential building uses (A) Offices, (B) Education, (C) Services, (D) Commercial, (E) Hospitals, (F) Restaurants. Source: (IDAE, 2009)

4. Results

4.1. ***Characterisation of the Spanish building stock through archetype buildings.***

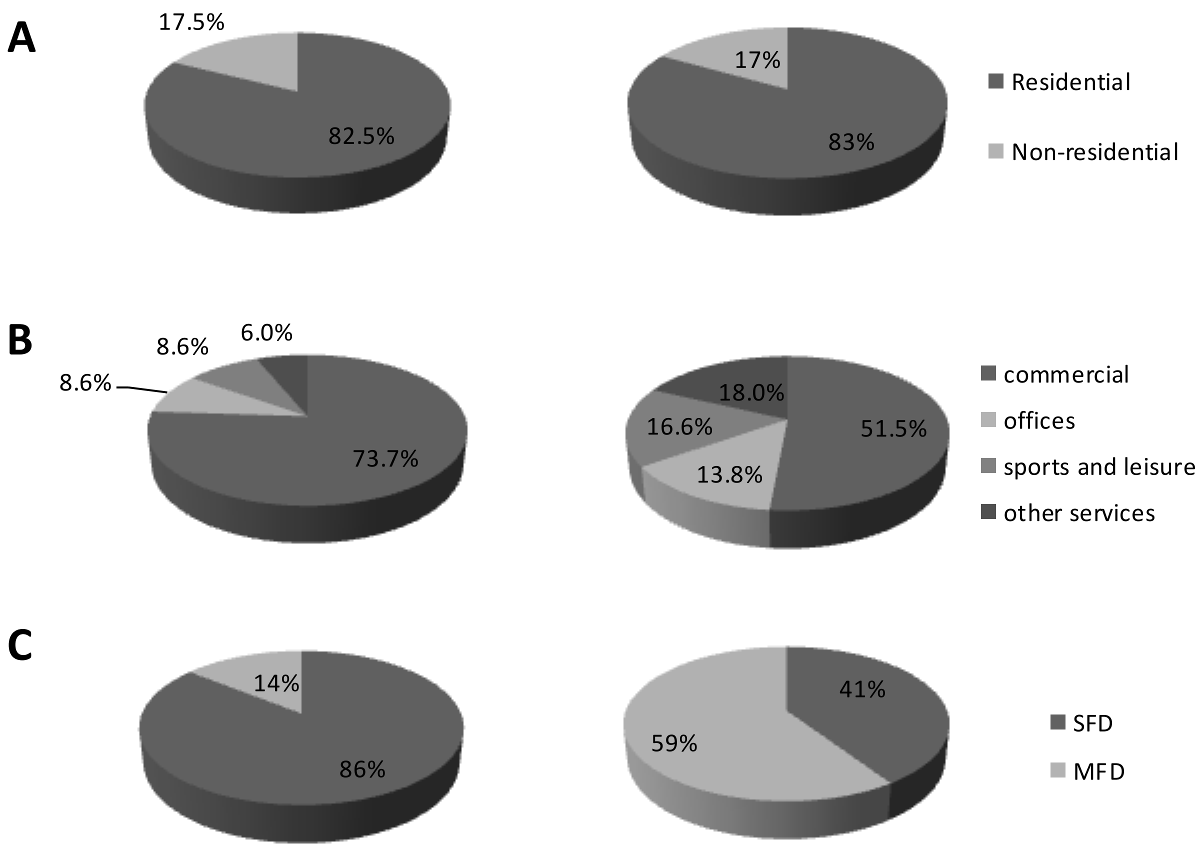
This section presents the characterisation of the Spanish building stock that results from applying the methodology explained in Section 3. These results are reported for each of the steps followed: segmentation, characterisation and quantification.

4.1.1. Segmentation

In this section the distribution of the Spanish building stock is illustrated for each category that is applied in the segmentation that are: building type, climate zone and period of construction.

<u>Building type</u>

Figures 4.1 (A-C) show the distribution of the existing stock in year 2008 by building typology, both in m^2 of surface and number of buildings.



Figures 4.1 (A-C): Distribution of the number of existing buildings in 2008 (left) and surface (right) by building type as obtained in this thesis work. (A) Total, (B) Non-residential, (C) Residential

<u>Climate zone</u>

Figure 4.2 shows the distribution of the existing stock in 2008 by climate zone both in m^2 of surface and number of buildings.

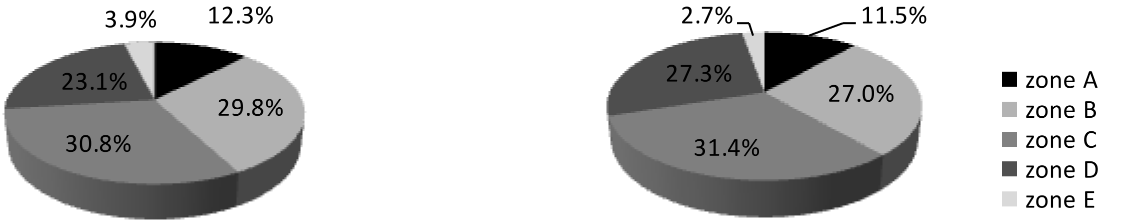
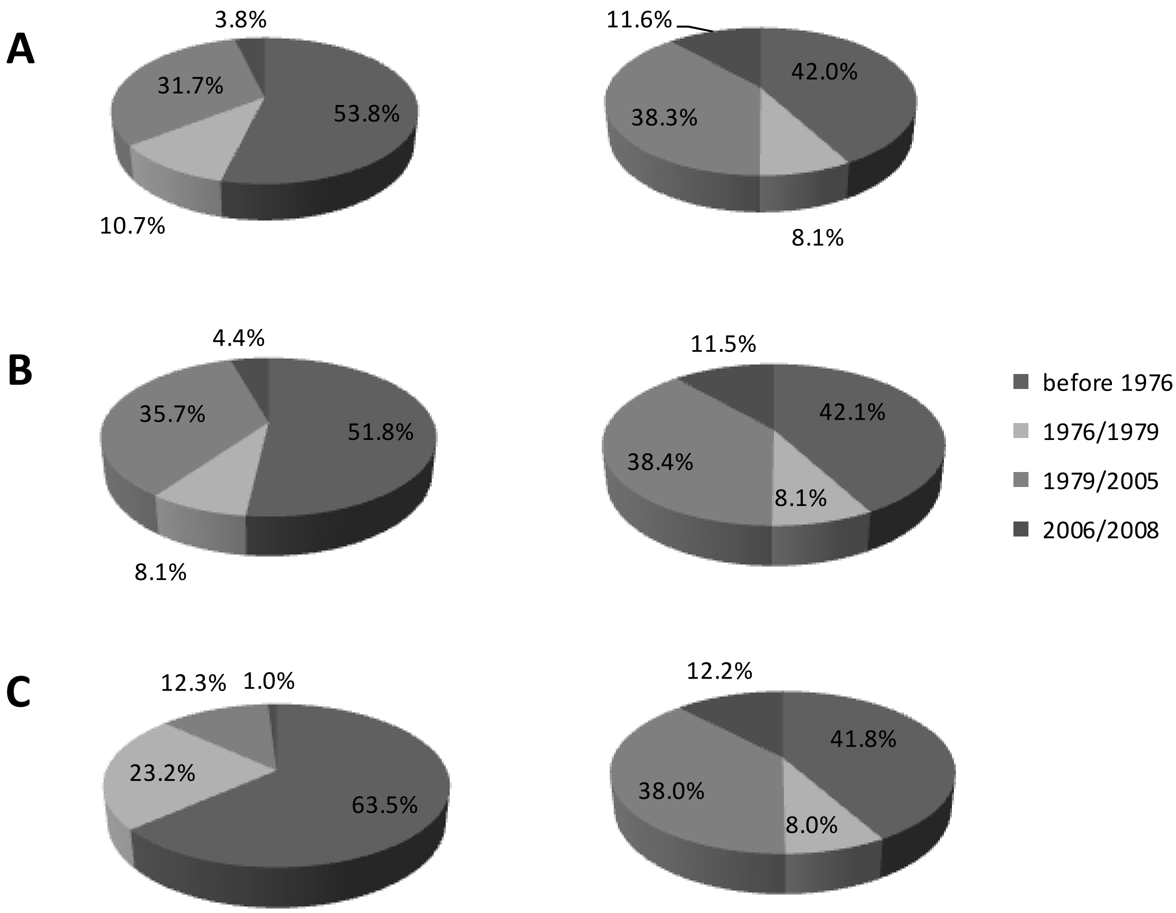


Figure 4.2: Distribution of the number of existing buildings (left) and surface (right) in 2008 by climate zone obtained in this thesis work

<u>Period of construction</u>

Figures 4.3 (A-C) show the distribution of this existing stock in 2008 by period of construction both in m^2 of surface and number of buildings.



Figures 4.3 (A-C): Distribution of the number of existing buildings in 2008 (left) and surface (right) by period of construction as obtained in this thesis work. (A) Total building stock, (B) Residential buildings, (C) Non-residential buildings.

4.1.2. Characterisation.

The physical and technical characteristics of a Spanish average building for each building type are reported in this section. The values shown are presented, for each building type, as a weighted average of those corresponding to the 120 archetype buildings considered in this work, which were determined as explained in Section 3.3.

Residential building

An average residential building contains **2.61** dwellings of **75 m^2** of surface. Its total heated floor area is **176 m^2** and the total exterior area of the building envelope is **304 m^2**.

The average values for sanitary ventilation rate are **0.18 l/s/m^2** and **0.51 l/s/m^2** for residential buildings constructed before and after 2006 respectively. The natural ventilation rate is **2.78 l/s/m^2**.

A value for the heat transfer coefficient of **1.98 W/m^{2}K** was obtained as an average for residential buildings.

Single-family dwelling

An average single-family dwelling (SFD) in Spain has a heated floor area of **77 m^2**. Taking into account that there are **1.08** SFD per building of this type as an average, the total floor area of a single-family building is **83 m^2**. The total exterior area of the building envelope is **220 m^2**.

Regarding technical properties for ventilation, a sanitary ventilation rate of **0.21 l/s/m^2** is considered for all single-family dwellings constructed before 2006. For the ones constructed after this year the value increases to **0.52 l/s/m^2**. The natural ventilation rate is **2.78 l/s/m^2**.

An average heat transfer coefficient of **2.00 W/m^{2}K** was obtained for this building use.

Multifamily dwelling

In Spain, an average multifamily building has **11.8** dwellings of **62 m^2** of surface**.** Therefore, a building of this type has a total heated floor area of **733 m^2**. Its total area of the building envelope is **809 m^2**.

The values for ventilation rates for multifamily dwellings (MFD) constructed before 2006 are **0.17 l/s/m^2** and **2.78 l/s/m^2** for sanitary and natural respectively. The sanitary ventilation rate for buildings constructed after 2006 is **0.42 l/s/m^2.**

Finally, the average heat transfer coefficient for an average MFD is **1.89 W/m^{2}K.**

Non-residential building

An average non-residential building presents **1.47** locals of **121 m^2** of surface. Its total heated floor area is **176 m^2** and the total exterior area of the building envelope is **362 m^2**.

The average values for sanitary ventilation rate are **0.07 l/s/m^2** and **0.56 l/s/m^2** for non-residential buildings constructed before and after 2006 respectively. The natural ventilation rate is **2.78 l/s/m^2**.

A value for the heat transfer coefficient of **1.87 W/m^{2}K** was obtained as an average for non-residential buildings.

Commercial

An average of **1.47** locals per commercial building is considered in this study. Each commercial local has a heated floor area of **83 m^2** and a commercial building presents a total heated floor area of **122 m^2**. The total exterior area of the building envelope is **269 m^2**.

Concerning the sanitary ventilation, values of **0.07 $l/s/m^2$** and **0.55 $l/s/m^2$** are considered as the rate for buildings constructed before and after 2006 respectively. The natural ventilation is set at **2.78 $l/s/m^2$** for all non-residential buildings, as well as for the residential sector.

The average heat transfer coefficient for a commercial building in Spain is **1.87 W/m^2K.**

Offices

A Spanish office building presents a total heated floor area of **377 m^2** with **1.48** offices of **261 m^2** per building. The total exterior area of the building envelope is about **693 m^2**.

The values for the sanitary ventilation rate are **0.07 $l/s/m^2$** for office buildings constructed before 2006, and **0.83 $l/s/m^2$** for the ones constructed after this year.

The average heat transfer coefficient for an office building in Spain is **1.85 W/m^2K.**

Sports and leisure

An average of **1.46** locals per building is considered in this study for the end use of sports and leisure. Each local has a heated floor area of **312 m^2** and the building presents a total heated floor area of **462 m^2**. The total exterior area of the building envelope is about **845 m^2**.

Concerning the sanitary ventilation, values of **0.07 $l/s/m^2$** and **0.55 $l/s/m^2$** are considered as the rate for buildings constructed before and after 2006 respectively.

The average heat transfer coefficient for this building use in Spain is **1.83 W/m^2K.**

Other services

All the non-residential building uses not considered separately are included in this category, as for instance buildings used for education, religious or sanitary purposes. An average of **1.47** locals per building is considered, with a heated floor area of **183 m^2**. The total average heated floor area for a building included in this category is about **265 m^2** and its total exterior area is **520 m^2**.

Concerning the sanitary ventilation, values of **0.07 $l/s/m^2$** and **0.55 $l/s/m^2$** are considered as the rate for buildings constructed before and after 2006 respectively.

The average heat transfer coefficient for this building use in Spain is **1.86 W/m^2K.**

4.1.3. Quantification.

Figures 4.4 (A-C) illustrate the changes in the existing number of buildings and constructed surface in Spain over time. The Spanish building stock have been growing from around 8 million building and 1000 Mm^2 of constructed surface in 1980 to 13 million and 2700 Mm^2. (see Figure 4.4-A). Figures 4.4-B and 4.4-C illustrate corresponding growths of the building stock for the building types of the residential and non-residential sector respectively. Details regarding the number of buildings and surface considered for each archetype building are given in Tables C.1 and C.2 of Appendix C. Appendix A and B report how such values were obtained (i.e., data sources and assumptions made when data was missing).

4.2. *Results and validation of the energy simulation*

The energy demand was calculated using archetype buildings as input data derived for the years 2005 and 2008. Two validation years were selected because values on energy demand given in literature (reference databases) for 2008 are restricted to total energy demand, while energy demand reference values for 2005 are available disaggregated by end use. Data on energy demand disaggregated by end-use is required to verify the EABS modelling since EABS gives the energy demand disaggregated in “heating”, “hot water” and “electricity”. Yet, as the number of buildings has increased by 4% from 2005 to 2008, also the total final energy demand in 2008 is applied here as verification of the modelling. In addition, the archetype buildings for year 2008 are differently described because of the new building regulations that appeared in 2006 requiring new values for parameters such as ventilation rates and U-values.

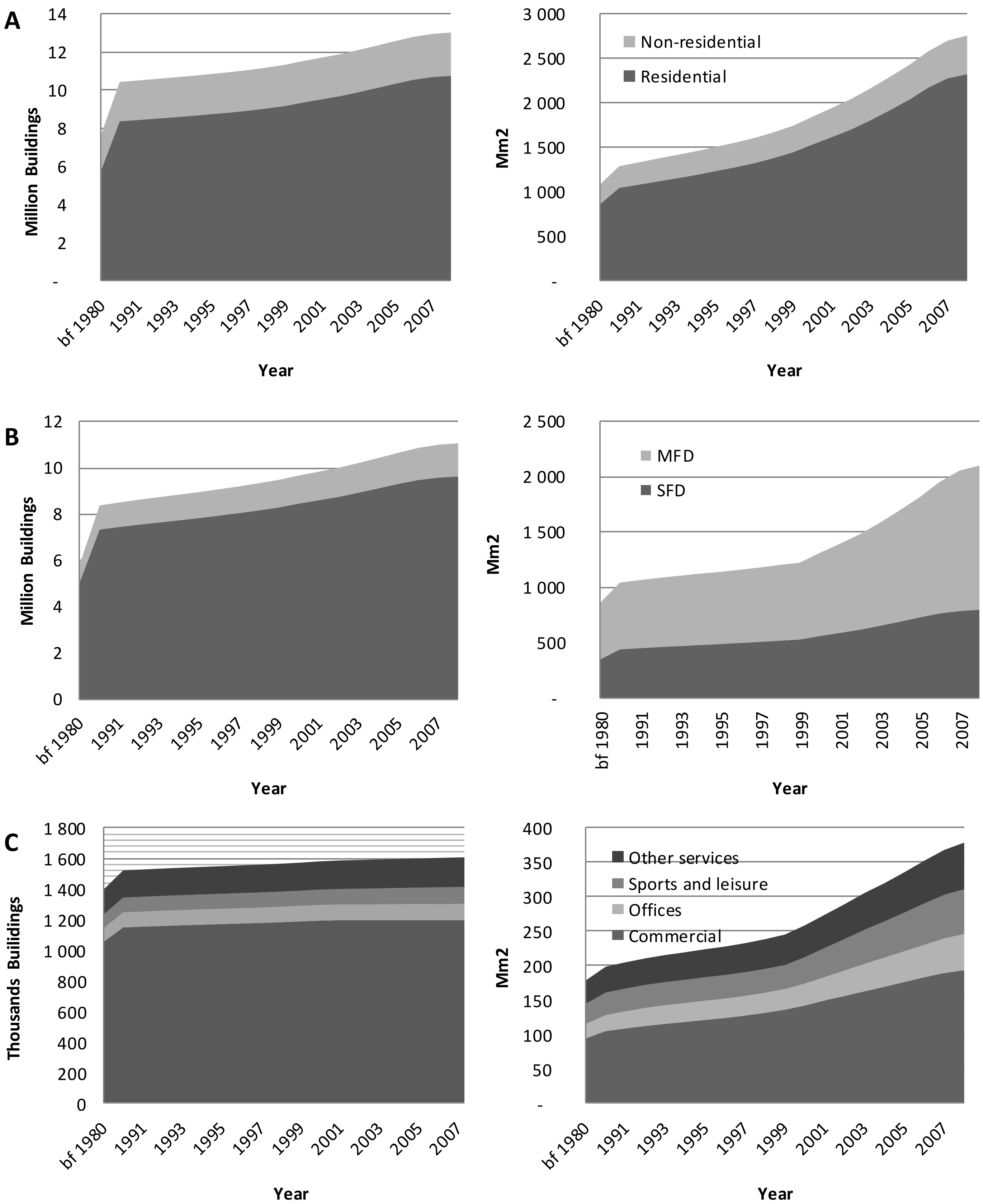
Table 4.1 report the results of the simulation for the year 2005, which was performed with 90 archetype buildings (since the period 2006/2008 is omitted). The methodology applied to calculate final energy from useful energy is reported in Section 3.5.

A total final energy demand of the Spanish building stock in 2005 of 272.1 TWh was obtained in this thesis work when using the EABS model. This annual energy demand is only 1% lower than the corresponding energy demand provided by GAINS and Eurostat, which is reported in Table 4.2. The obtained energy demand for the residential sector (180.9 TWh) is 3% higher than the comparable value of given by GAINS and Eurostat. For the non-residential sector, a total final energy consumption of 91.2TWh was obtained, which is in contrast 7% lower compared to the available statistics presented in Table 4.2. The possible reasons for these differences between the results from the energy simulation and the statistics are further discussed in Section 6.

Table 4.1: National energy demand in TWh for the residential and non-residential sector disaggregated by end use in 2005 as obtained from the energy simulation of this thesis

Energy end-use	RESIDENTIAL SECTOR		NON-RESIDENTIAL SECTOR	
	Final energy	Useful energy	Final energy	Useful energy
Heating	105.1	83.8	26.2	24.5
Hot water	30.0	25.6	1.9	1.7
Electricity[(1)]	45.8	51.9	63.1	69.0
TOTAL	**180.9**	**161.3**	**91.2**	**95.3**

[(1)] Lighting and appliances



Figures 4.4 (A-C): Number of existing buildings (left) and surface (right) in Spain. (A) Total, (B) Residential, (C) Non-residential.

Table 4.2: Data used to compare the results obtained from the energy simulation (Eurostat, 2008; GAINS, 2005; IEA, 2011; IDAE, 2009).

TOTAL ENERGY DEMAND FOR 2005			
Source	*Residential (TWh)*	*Non-residential (TWh)*	*TOTAL (TWh)*
GAINS	176.2	98.55	274.8
Eurostat	175.2	97.7	272.9
TOTAL ENERGY DEMAND FOR 2008			
Source	*Residential (TWh)*	*Non-residential (TWh)*	*TOTAL (TWh)*
IEA	182.6	106.4	289.0
Eurostat	183.7	112.3	296.0
IDAE	191.6	104.5	296.1

Table 4.3: National energy demand in TWh for residential and non-residential sectors disaggregated by end use in 2008 obtained in this thesis work

Energy end-use	**RESIDENTIAL SECTOR**		**NON-RESIDENTIAL SECTOR**	
	Final energy	**Useful energy**	**Final energy**	**Useful energy**
Heating	133.3	106.2	26.7	25.0
Hot water	32.4	27.6	2.2	2.0
Electricity[(1)]	52.1	58.9	72.4	79.1
TOTAL	**217.8**	**192.7**	**101.3**	**106.1**

[(1)]Lighting and appliances

The figures on energy demand presented in Table 4.3 were obtained from the corresponding simulation for the year 2008 (i.e. considering the 120 archetype buildings characterised in this thesis work.

From the energy simulation, a final energy demand of the Spanish building stock in 2008 of 319.1 TWh was obtained. This figure is 10% higher than the total final energy demand provided by IEA, and 8% higher than the one extracted from Eurostat and IDAE. As mentioned before, these databases do not provide data disaggregated by end use. The final energy demand for residential buildings obtained was 217.8 TWh, which is between 14% and 19% higher than the values provided by the reference databases (see Table 4.2). For the non-residential sector, a final energy demand of 101.3 TWh was obtained, which is 3%, 5% and 10% lower than the one provided by Eurostat, IEA and IDAE respectively. The possible reasons for these differences are discussed in Section 6.

As it can be noticed from Figure 4.5 (where the energy demand, as given in Table 4.3, is expressed in percentage share), the electricity is the end use with the largest demand for the non-residential buildings representing a 69% of the total energy demand. In the residential sector, instead, the shares of heating and hot water are bigger (58% and 17% against 29% and 2% for the non-residential sector).

The resulting distribution of the total energy demand by end use for the residential sector is similar to the distribution reported by GAINS (as listed in Table 4.4). The corresponding GAINS distribution for the non-residential sector shows a larger deviation from the division obtained in this thesis work

(Figure 4.5 right). However, a distribution of the energy demand by end use that is similar to the distribution obtained in this work was found in IDAE (2007), i.e. 29% for space heating, 3% for water heating, 61% for electricity and 7% for other energy end uses. The differences between the distributions reported by IDAE and GAINS could be caused by following different criteria when disaggregating the energy consumption, as discussed further in Section 6.

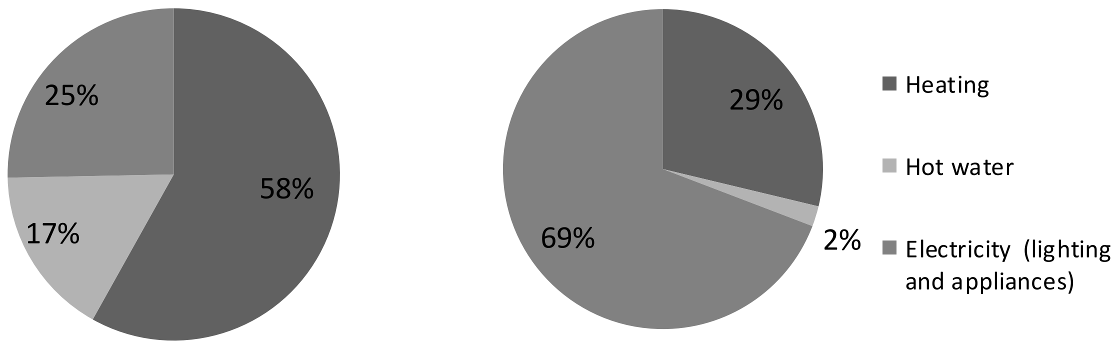


Figure 4.5: Distribution of final energy in 2008 by end use for the residential (left) and non-residential sector (right) obtained in this thesis work.

Table 4.4: Distribution of total final energy demand by end use in year 2005 given by GAINS (GAINS, 2005)

Energy end use	**RESIDENTIAL**	**NON-RESIDENTIAL**
Heating and hot water	76%	50%
Electricity (lighting and appliances)	24%	50%

Table 4.5: Average residential building energy demand in 2005 disaggregated by end use as obtained in this thesis work

Energy end-use	**RESIDENTIAL[(2)]**	**SFD**	**MFD**
Heating	69.2	99.7	46.9
Hot water	19.7	17.3	21.6
Electricity[(1)]	30.1	31.7	29.0
TOTAL	**119.1**	**148.7**	**97.4**

(1) Lighting and appliances
(2) Weighted average per existing m2 of surface of SFD and MFD

Table 4.6: Average non-residential building energy demand in 2005 disaggregated by end use as obtained in this thesis work

Energy end-use	NON-RESIDENTIAL[(2)]	COMMERCIAL	OFFICES	SPORTS AND LEISURE	OTHER SERVICES
Heating	83.3	77.4	84.0	80.1	103.6
Hot water	6.0	1.2	1.6	22.1	9.5
Electricity[(1)]	200.4	241.1	160.8	158.6	143.3
TOTAL	**289.7**	**319.6**	**246.4**	**260.8**	**256.4**

[(1)] Lighting and appliances

[(2)] Weighted average per existing m2 of surface of the building types commercial, offices, sports and leisure and other services

Tables 4.5 and 4.6 report the energy demand in 2005 as obtained in this thesis work disaggregated by end use and building time in terms of kWh/m^2.

The obtained useful energy demand for heating and hot water, as calculated with the EABS model, for an average residential building (119 kWh/m^2) is 13% higher than the corresponding energy demand for the EU that is provided by GAINS (100kWh/m^2). As it can be seen from Tables 4.5 and 4.6, the average non-residential building has more than a doubled energy demand per m^2 of living area compared to the average residential building in Spain. The average SFD consumes 41% more energy per m^2 than the average MFD. The results from the simulation presented in Table 4.5, indicate that the largest share of energy demand for an SFD derives from heating demand, while an MFD generally requires more energy for hot water production and electricity than for heating. Regarding the non-residential sector, commercial buildings account for the largest energy demand per m^2 of heated floor area.

The energy demand per m^2 of floor area obtained for each non-residential building type was compared to the corresponding energy demand extracted from IDEA (2003). For the average commercial building, the modelled energy demand is 19% lower than the energy demand reported by IDAE. The modelled energy demand of 246 kWh/m^2 as obtained for an average office building is far (41% higher) from the 145kWh/m^2 reported by IDAE for the same building type. Regarding the building type of "sports and leisure", the energy demand obtained from the simulation differs 14% (lower) from the corresponding figure extracted from IDAE. It has not been possible to determine the causes of these differences between the modelled energy demand per m^2 for the different building types and the corresponding energy demand given by IDAE. Finally, the energy demand modelled for the building type "other services" is more difficult to compare with available data, since it includes many different building types, as education (43kWh/m^2 according to IDAE), health (251kWh/m^2) or hotels (403kWh/m^2).

5. Sensitivity analysis

In order to analyse which parameters have the highest effect on the energy demand, a sensitivity analysis was carried out. Due to the time constraints of a master thesis, the sensitivity analysis reported in this section was performed only for the year 2005 and the residential sector.

The value of each parameter was modified proportionally (±10%, ±30%, ±50%) to the original value considered (this value is reported in Section 3.3) keeping all other values constant. Figure 5.1 shows the effect on the final energy demand (y axis) of each of these variations (x axis). The effect of the heat transfer coefficient is presented separately in Figure 5.2, since this effect is much larger than effect of the other parameters.

As shown in Figure 5.1, the parameters with the highest influence on the final energy demand, in addition to the U-value, are the hot water demand (H_w), the effect heat capacity of the building (TC) and the window area (S_w).

An increase in H_w increases the total energy demand, e.g.,, increasing the value of H_w by 30% leads to an increase of energy demand of 3.5%. On the other hand, increasing the value of S_w and TC causes a reduction of the total energy demand. A 50% increase of S_w and TC leads to a 3% and 1.3% decrease of the energy demand, respectively. However, these effects are not linear: a decrease of 30% in H_w decreases the energy demand with 2% (instead of 3.5%) and a reduction of 50% in S_w and TC causes a rise of 4% and 2.8% (instead of 3% and 1.3%).

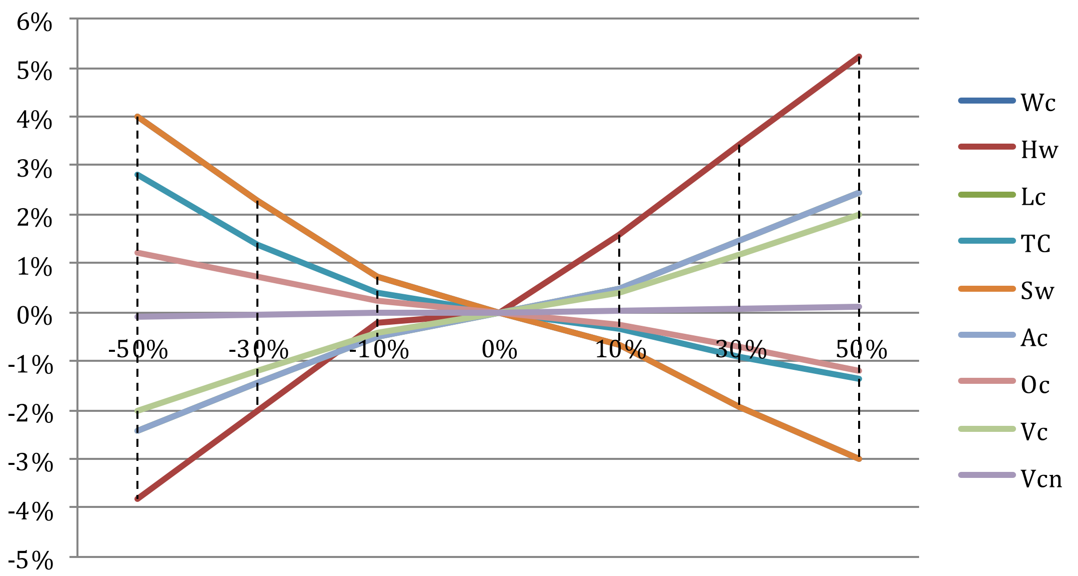


Figure 5.1: Effect of each parameter in relative values obtained from the sensitivity analysis. (Wc: solar shading coefficient of the window; Hw: hot water demand; Lc, Ac, Oc: heat gains from lighting, appliances and occupants respectively; TC: heat capacity of the building; Sw: window surface; Vc: sanitary ventilation rate; Vcn: natural ventilation rate)

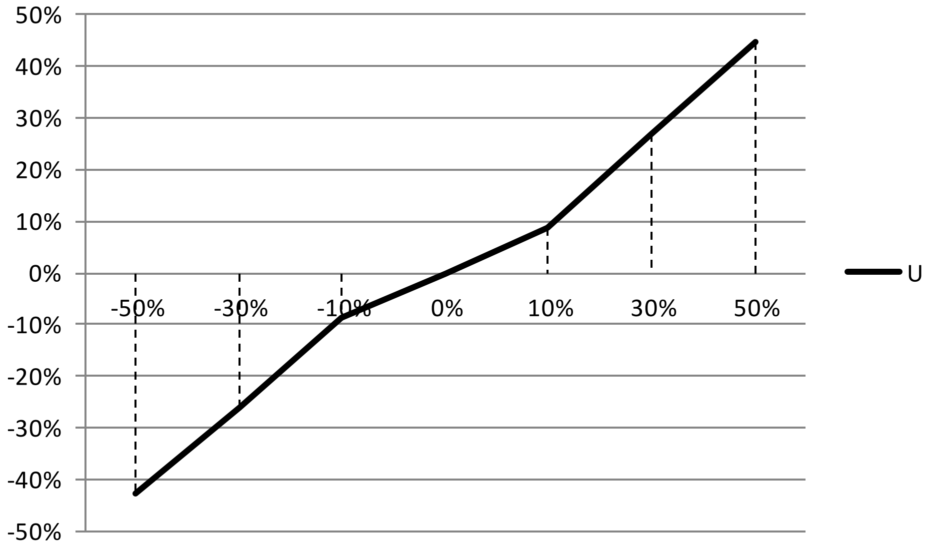


Figure 5.2: Effect of the U-value in relative values obtained from the sensitivity analysis

Figure 5.2 shows the drastic reduction of the energy consumption that could be achieved by decreasing the U-value of the building. Therefore, the sensitivity analysis of the heat capacity of the building can be considered as a first assessment of the energy saving potentials to be achieved through the retrofitting of the envelope (e.g., increasing insulation, replacement of windows with lower U-value). For instance, a 50% decrease of the U-value would cause a reduction of the energy demand of a 42%. Such decrease on the value of the heat capacity of the building can be achieved by adding to the building envelope an insulation layer of 3.5cm (thermal conductivity of the insulation material assumed: λ=0.035 W/m^2K)

Ventilation rates and internal heat gains were shown to have lower influence on the final energy demand compared to the heat capacity of the building or the window area. However, ventilation rates and internal heat gains were found to have a great impact on the energy demand for the Swedish residential stock (Mata, 2011). Two possible reasons for this lower influence of these parameters in the Spanish case were identified: 1) the heat losses through the building envelope are dominant due to the lower insulation of the Spanish buildings compared to the Swedish buildings; 2) higher outdoor temperatures in Spain than in Sweden.

It has to be taken into account that the sensitivity analysis was realised modifying just the value of one parameter in each simulation keeping constant all the others. This means that in reality, the effect on the final results could change, since some parameters are interdependent.

<u>Effect of the fuel efficiencies</u>

Figure 5.3 shows the effect on the energy demand when varying the value of the fuel efficiencies. As indicated in Section 3.5, the conversion efficiency for the different fuels is defined as the efficiencies of the energy systems in the buildings (e.g., electric heater, gas boiler), which were used to transform net (useful) energy to delivered (final) energy.

The results in Figure 5.3 can be considered as a first assessment of the energy savings that could accrue from increasing the efficiency of the building energy systems. The value of 0.87 was considered as an average value for the efficiency of the installed systems in the Spanish households.

Figure 5.3 indicate that if efficiencies are increased to 0.95 for both gas and oil systems the energy demand could decrease by 4%. This could be studied in more depth considering the expected market development for the building's energy systems, which was not realised in this master thesis due to time constraints.

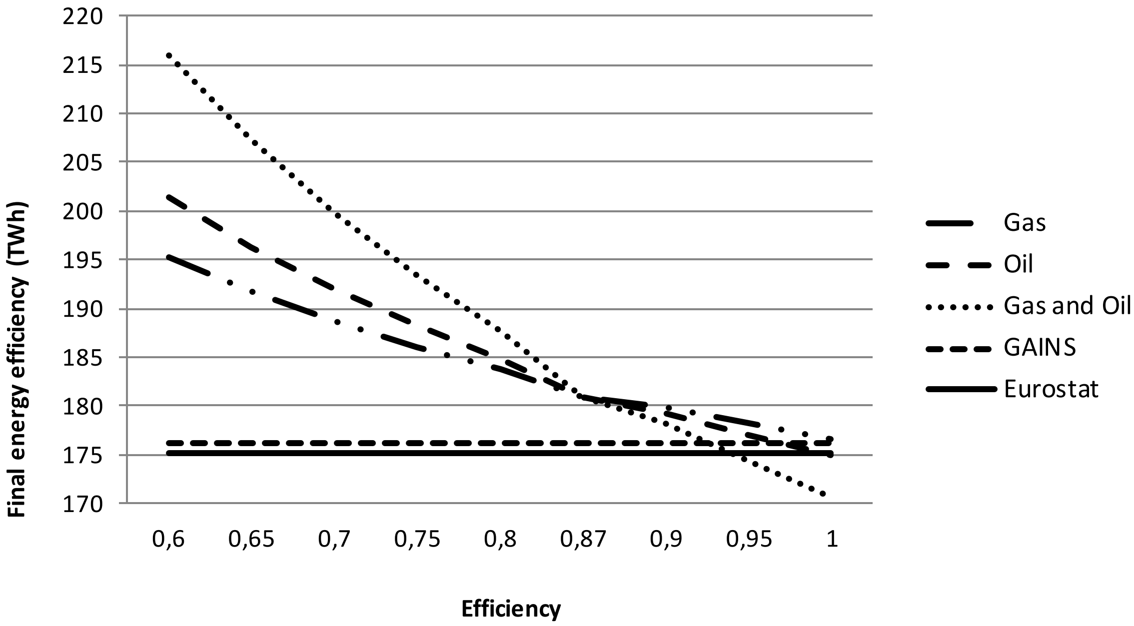


Figure 5.3: Effect of the fuel efficiencies on the energy demand. The dotted line "Gas and oil" illustrates the effect of varying the efficiency of both oil and gas systems at the same time according to the values of the x axis. Line for "Gas" ("Oil") is the result of varying the gas (oil) efficiency according to x axis values while the oil (gas) efficiency is set at 0.87 (original value for the simulation). Straight lines "GAINS" and "Eurostat" indicate the total final energy demand for the residential sector given by such sources.

<u>Possible adjustments of parameters</u>

After analysing the results of the sensitivity analysis, this section discusses some parameters that can be adjusted to refine the modelled final energy demand in order to be closer to the statistics given by GAINS and Eurostat.

- Sanitary ventilation rate (V_c). The value for this parameter for the archetype buildings constructed before 2006 is an infiltration rate (see Table 3.13), since they were considered without mechanical ventilation. Therefore, an adjustment of this parameter could be considered.
- Hot water demand (H_w). The values considered in the simulation were 30 l/d per person in SFDs and 20 l/d per person in MFDs. Such values might represent the maximum hot water demand, since they were extracted from the section "Calculations and sizing" of the regulation (CTE-HE, 2006), indicating that the average hot water demand in Spanish households could be lower. However, this demand is low compared to corresponding hot water demand in: Sweden (42 and 58 l/d per person in SFDs and MFDs respectively) (Mata, 2011); Estonia (44 l/d per person) (Koiv et al., 2006); USA (200 l/d per person) (EM&RS, 1994); or Finland (85 l/d per person) (Koiv et al., 2006). One possible reason for this low hot

water demand could be the existing concerns about security of water supply in Spain. In addition, the share of the total energy demand for water heating (26%) differs significantly from the corresponding share reported by IDAE (26%).

- Window area (S_w). This value was set as a percentage of the total area of the facade, which was set by the author based on the drawings presented in the PMEB (Barcelona Regional, 2002). Therefore, an adjustment for this parameter could therefore be considered.
- Solar shading coefficient (W_c). Values between 0.5 and 0.8 were measured for the Swedish residential buildings and they are considered for the sample buildings used as input data in the study for Swedish building stock (Mata, 2011). No corresponding data for the Spanish building stock for this parameter was found in literature. A value of 0.5 was used in this master thesis, since it was assumed that it must be lower than the corresponding one for the Swedish building stock. This parameter is related to a specific feature of the model, which is considering only one horizontal window. The inaccuracy could be reduced if the model included several facades, for instance, but this could be only applied if there was enough available data for the building stock under study to define such facades, which is not the case of this work.

Adjustments of the parameters discussed right above were tested to evaluate the effect on the energy demand. The modelled final energy demands obtained from such tests are presented in Table 5.1 and compared with the reference databases.

Table 5.1: Adjustments tested and results obtained. "Adjustments" indicate the changes applied to the original value of the corresponding parameter, one parameter modified per test, keeping constant all the others.

	Adjustments				Total final energy demand for the residential sector	Comparison with GAINS and Eurostat
	V_c	H_w	S_w	W_c		
Test 1	0.7				176.03TWh	0%
Test 2		0.7			169.77TWh	-4%
Test 3			1.3		175.00TWh	-1%
Test 4				1.3	175.01TWh	-1%

6. Discussion

Possible reasons for the deviation between the results obtained from the simulation and the statistics given by the reference databases presented in Table 4.2 are discussed in this section.

Uncertainties regarding some of the assumptions that were made during the characterisation process could be a cause for the deviation between the modelled energy demand and the statistics. These assumptions are discussed below:

- In this thesis, it was considered that the heating demand for the residential sector in Spain is not totally covered, since a large number of households have no space heating system according to INE (2011). A certain percentage of residential buildings (the same percentage for both SFD and MFD) without space heating system were assumed for each climate zone, see Table 6.1.

Table 6.1: Percentage of households with no space heating system (INE, 2011)

Climate zone	Percentage
A	55%
B	13%
C	14%
D	8%
E	8%

- In the residential sector, a 33.5% of the buildings were considered to have cooling system in this master thesis (INE, 2008). No data was found regarding the percentage of non-residential buildings with cooling system. In this thesis work, it was assumed that most of the buildings categorised as offices, commercial and sports and leisure have cooling system (80%). A 30% of the buildings classified as "other services" were considered to have cooling system, since this group includes building uses which normally do not have cooling system, e.g. educational or religious buildings.

- The weather files used for the energy simulations contain average climate data for a certain city/weather station (see Table 3.3) which was assumed to be representative of the whole climate zone. This can represent a source of inaccuracy since the locations chosen might not be optimal representative for the weather of the corresponding climate zone, although they were chosen on a population basis. Moreover, it should be noted that the climate data used is based on measurement conducted between the years 1961 to 1990 (Meteotest, 2000). Thus, it might be needed to update the climate data extracted from Meteotest (2000) used as input data for the energy simulation.

- There is lack of available data concerning the conversion fuel efficiencies considered to transform useful energy to final energy (Tables 3.22) and some values had to be assumed for the efficiency of the building energy systems (see section 3.5). At the same time, the results from the sensitivity analysis indicate that this factor seem to strongly affect the resulting final energy demand. Therefore, it might be important to get more accurate and reliable data regarding this factor.

- A 14.8% of the residential buildings (i.e., 14.8% of the weighting coefficient) are empty residences according to INE (2011). It was assumed that such residences consume zero energy. However, some of the residences categorised as empties by INE might consume energy because: a) the residences are occupied during some days over the year; 2) some energy systems in the building keep on working even in empty residences.

The resulting final energy demand for the residential sector in 2005 differs with 3% from the corresponding energy demand given in statistics. The following possible causes for this difference have been identified:

- Each international institution used as a data source in this thesis has its own criteria when counting the energy demand. For instance, it is not clear if the electricity consumed by an electric heater is counted as "electricity" or as "heating". A similar problem exists with air conditioning that is given separately by IDAE while it is not accounted for in GAINS. Further investigation regarding the criteria applied by the data sources is needed to ensure that the figures extracted from the different sources can be compared.

- Retrofitting measures might have been already applied to Spanish existing buildings. However, the energy savings that could accrue from the application of such measures are not accounted for in this master thesis. Considering a rate of building retrofitting would take the effect of these measures into account and this would contribute to decrease the final energy demand obtained in this work.

The final energy demand for the non-residential sector in 2005 is 7% lower than the statistics given by the reference databases. The lack of accurate data for this sector is identified as the most likely cause for this difference. Moreover, a difficulty found during the definition and quantification of the archetype buildings is that the different databases do not use the same classification of buildings. For instance, this sector is classified according to the Ministry of Building in "commercial", "offices", "agriculture", "industry", "transport", "sports and leisure" and "others". However in this master thesis, the buildings types "agriculture", "industry" and "transport" were not taken into account, since they are not accounted for in the "services" sector by the databases Enerdata and GAINS, which are used to compare the final results. Anyway, it is not clear enough if the figures presented for the categories "agriculture", "industry" and "transport" in these databases account for the energy consumption of the buildings, or if they just count the energy consumed to develop the activity itself. Further investigation is needed regarding this issue.

With respect to the results obtained from the energy simulation for 2008, the energy demand for the residential sector is 19% higher while the corresponding one for the non-residential buildings is 10% lower than the figures available in the sources consulted (Eurostat, 2008; IEA, 2011; IDAE, 2009). The possible causes discussed above for the 2005 simulation results can be also assumed for the 2008 simulation. Moreover, since the results for 2005 differ less from the available statistics than the 2008 results, the characterisation of the archetype buildings for the periods after 2005 might be not accurate enough. One possible reason for this is that the values used to describe such archetype buildings are mostly based on the regulations CTE and RITE, therefore: 1) the buildings might not be constructed according to these regulations (although it is specified in the documents that regular inspections should be performed, it is not clear which institution must take this responsibility.

Therefore, it is unlikely that such inspections are actually performed (Carrasco Perera and Gonzalez Carrasco, 2008); 2) this regulation might provide peak-values which do not correspond with the buildings' everyday average performance.

Regarding the application of the EABS model to Spain that has been carried out in this master thesis, the values of some parameters are difficult to set when working with archetype buildings, as opposed to the previous application of the model using sample buildings (Mata, 2011). For instance, the procedure followed to calculate the heating capacity of the building for each period of construction was problematic since all the characteristic building materials and construction layers of the buildings over time should be considered in the calculations. In addition, the only data found regarding building materials and construction layers only concerns to one Spanish region (Catalonia), so it was assumed for the whole country (see appendix E). A possible solution could be, for instance, to include already in the model a procedure to facilitate the characterisation of this parameter, like using average values of the heat capacity of the building for each climate zone.

7. Conclusions and further work

Several conclusions can be drawn from this master thesis both regarding the methodology applied and regarding the use of the EABS model. With respect to the methodology:

- It was possible to define archetype buildings representative of the Spanish building stock following the methodology proposed within the Pathways Project, both for residential and non-residential buildings.

- For the segmentation, it was difficult to identify the criteria used by the reference databases to measure the energy consumption in terms of end use. In addition, the climate data regarding cities/weather stations were assumed to be representative of the climate zones. A methodology could be useful to construct weather files capable of describing the climate of each zone with more accuracy.

- In the characterisation of the building stock, there is lack of data about the efficiencies of the energy systems installed in the buildings when at the same time the modelled energy demand is shown to be highly sensitive to the values set for these efficiencies.

- The sensitivity analysis proved that the input data parameters U (heat transfer coefficient of the building), H_w (hot water demand), TC (heat capacity of the building) and S_w (window surface) strongly affect the final energy demand. On the other hand, ventilation rates and internal heat gains were shown to have less influence on the results.

- The lack of data about non-residential buildings is highlighted and it can represent the major cause of the deviation between the modelling energy demand and the statistics extracted from the reference databases due to a less accurate characterisation.

Finally, regarding the application of the model it is concluded that:

- The application of the EABS model to Spain was found to be generally appropriate, since the energy demand obtained is close to reference values given by statistics.

- Further work is needed to study the effect of some parameters as P_h, P_c (response capacity of heating and cooling system) and S_h, S_c (maximum heating power of a heating or cooling system) and how they can be set to represent more properly the real performance of the building energy systems.

Although it is beyond the scope of this work, energy efficiency measures can be applied to this representation of the Spanish building stock in order to study the possibilities of future energy savings in this sector and in this country. To be able to simulate the application of these measures and estimate their effect, the building stock must first be defined. Thus the already validated, characterisation of the building sector carried out in this thesis is necessary for further simulations assessing the retrofitting of the building stock.

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