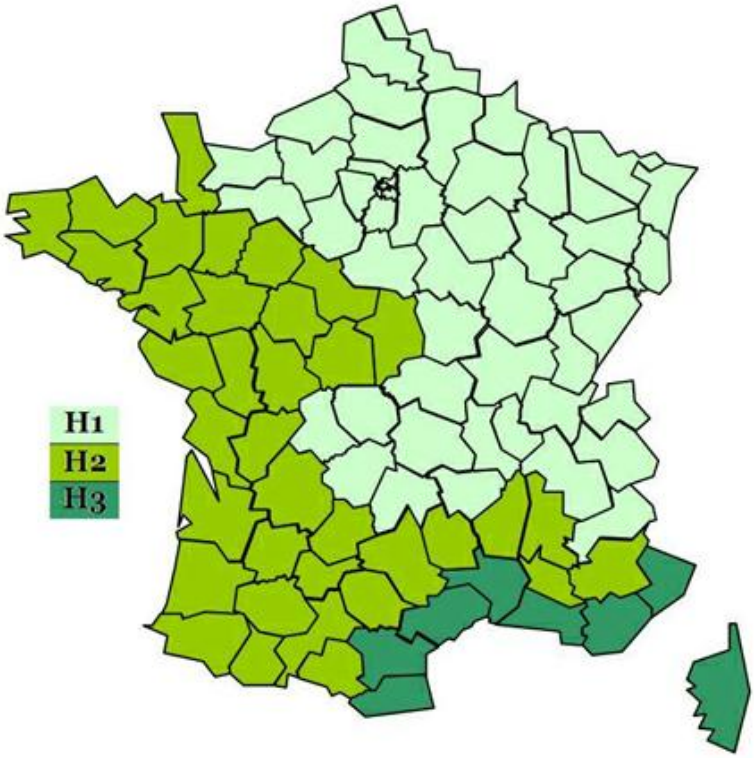

The three climate zones of metropolitan France, as defined by the thermal regulations of 2005.

Bottom-up description of the French building stock, including archetype buildings and energy demand

Master's Degree Thesis for the Sustainable Energy Systems Programme

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Department of Energy and Environment
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Cover: The three climate zones in metropolitan France, as defined by the thermal regulations of 2005 (Cegibat, 2012).

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Abstract

The work of this thesis was undertake to address an urgent need to describe the European building stock, so as to allow future assessments of the effects of different energy-saving measures. The available information on building stocks in Europe is very limited. In this respect, this work contributes to the compilation of a European building stock database.

The French building stock is described in this thesis by means of archetype buildings, following a methodology that was developed earlier within the Pathways Project . A bottom-up approach is used for this description, starting with segmentation of the building stock into archetype buildings, followed by characterization of these buildings and quantification of all the buildings represented by the archetype buildings. These archetype buildings are used as inputs for the *Energy, Carbon and Cost Assessment for Building Stocks* (ECCABS) simulation tool, to calculate the energy demand (for heating, hot water, and electricity) of the stock. The resulting energy demand is thereafter compared to the values for energy consumption in France, obtained from statistical databases, to validate the method.

In this thesis, we estimate that 54 residential buildings and 45 non-residential archetype buildings would be needed to describe the entire French building stock. The calculated final energy demand (disregarding the energy used for cooking) is 435.7 TWh/year for the residential sector and non-residential 179.4 TWh/year for the non-residential sector. These values are slightly lower (between 1.1% and 7.4% lower) than those in the official statistics.

It is concluded that the French building stock can be described using the data available in the literature and the applied methodology. In addition, it is demonstrated that the

ECCABS model is suitable for application to a temperate climate country, such as France.

Keywords: French building stock, reference buildings, bottom-up description, sustainable energy systems, energy demand, ECCABS, modeling, residential, non-residential

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1 Introduction

1.1 Background

Over the past two decades, there has been growing concern globally regarding the high-level usage of energy in developed countries, and the associated effects in terms of climate change, scarcity of resources etc.

Among the possible strategies to reduce energy usage, and concomitantly the levels of CO_2 emissions, improvements in energy efficiency within the building sector is under investigation, as this sector is among the highest energy consumers and CO_2 emitters. In fact, in the EU-27 countries in 2009, the building sector accounted for 39% of the final energy consumption (Eurostat, 2009). Specifically, the building sector in France accounted for 44% of the final energy consumption (Figure 1.1) and 23% of the national CO_2 emissions in 2009 (ADEME, 2011). Since more than half of the French buildings are considered to be old (i.e., built before 1975) and therefore of low efficiency (ADEME, 2011), there is strong potential for energy efficiency improvements that would lead to a decrease in an important proportion of the total energy consumption in Europe. The building stock in France accounted for 17% of the energy consumed in this sector in 2009 in the EU-15 countries (Eurostat, 2009), representing the second largest consumer after Germany.

Energy savings can be substantial when appropriate energy saving measures are applied. Efforts have been undertaken to reduce energy consumption in buildings in France. The first thermal regulations of 1975 in France had the stated objective of decreasing energy consumption. As a result, consumption was reduced from 325 kWh/m^2 in 1973 to 181 kWh/m^2 in 1998, thanks to the refurbishment of all buildings and the introduction of strict technical regulations for new buildings (Balaras, 2004).

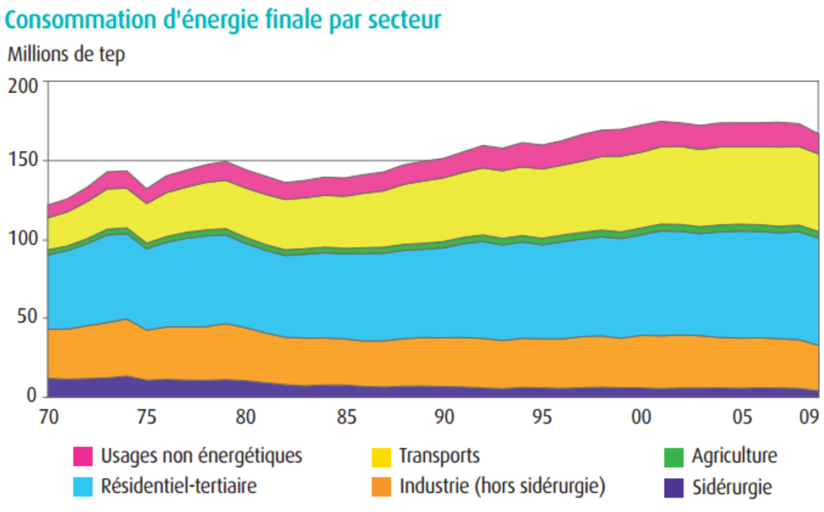


Figure 1.1: Final energy consumption in France by sector. Values shown are tonne of oil equivalents (tonne-equivalent petrol, tep) (ADEME, Les chiffres clés du bâtiment, 2011). Key to color coding: non-energy purposes, pink; transportation, yellow; agriculture, green; residential and non-residential, clear blue; industry with exception of iron metallurgy, orange; and iron metallurgy, dark blue.

This type of assessment of energy saving measures is complex, as it requires a description of the building stock, which becomes more difficult to obtain the larger the building stock and due to the lack of adequate data. Various studies have reported descriptions of the residential stock using reference buildings for: the Belgian stock (Hens, 2001); permanent occupied dwellings in Greece (Balaras, 2005); the Irish stock (Clinch; 2000); the Scottish stock (Clarke, 2004); and the French residential building stock (Martinlagardette, 2009). Regarding the descriptions of both residential and non-residential building stocks, there are only two examples: Petersdorff (2006), which deals with the entire EU-15 building stock; and the more recent study conducted by Medina (2011) on the Spanish stock. Therefore, the entire French building stock is still not completely described.

1.2 Context of this thesis

The present Master's Degree thesis work is part of the Pathways to Sustainable European Energy Systems project (the 'Pathways Project'), which aims to evaluate and propose robust pathways or bridging systems towards a sustainable energy system in Europe.

Within the Pathways Project, in the so-called "Households and services package", guidelines to assess potential energy saving measures (hereinafter referred to as ESM) in the European building stock have been developed.

The first step is to represent the European building stock in an aggregated form. The possibility of gathering all the data needed to analyze energy use in buildings across Europe has been studied by Ó Broin (2007), who concluded that not all the countries of Europe can be described adequately under the current circumstances. The availability of data for the French stock has also been examined (Martinlagardette, 2009; Gravalon, 2007), and it was concluded that all the required data could be collected, at least in the case of the residential sector. Further details of the above-mentioned investigations and associated studies are provided in Section 3.2.

The second step is to create a modeling tool that can be used to study the effects of these ESM being applied to the building stock. For this purpose, the Energy Carbon and Costs Assessment for Building Stocks (ECCABS) model was created and tested, initially with the Swedish residential sector being represented by sample buildings, and showed promising results (Mata, 2011). Subsequently, this model was applied to the Spanish building stock (Medina, 2011), including the residential and non-residential sectors, and the feasibility of the model was demonstrated.

In addition to France, five other EU countries (Spain, Germany, Italy, Poland, and the UK), which have the largest building stocks and account for more than 70% of the energy used in buildings in Europe (Balaras et al., 2005), are included in the Pathways Project.

1.3 Aim

The aim of this thesis is to advance the development of a methodology to represent a building stock in an aggregated form by describing a number of archetype buildings, which are representative of the building stock, using French buildings[1] as a case study.

Thus the main objectives are to:

a) describe the French building stock using archetype buildings, so as to: (i) contribute to the evaluation of the bottom-up methodology used to describe the EU building stock, including the residential and non-residential sectors, by means of archetype buildings; and (ii) contribute to the construction of a database of EU buildings, to encompass the information on archetype buildings.

b) test the applicability of the ECCABS model to the specific features of France as a EU country with a temperate climate.

The results presented in this thesis should be useful for future studies on ESM that could be applied to the French building stock.

1.4 Structure of the report

This Master's Degree thesis includes five chapters in which the conducted work and the results are described.

The data sources are described in Chapter 2, which also lists and discusses the main policies and regulations relevant to this study.

Chapter 3 explains the ECCABS model used for the simulation and describes the methodology for segmentation of the building stock into archetype buildings, as well as the characterization and quantification of these buildings.

In Chapter 4, the results of the segmentation process are presented, as well as the results of the energy consumption obtained from the ECCABS model simulation using the archetype residential and non-residential buildings for the years 2005 and 2009, respectively.

In Chapter 5, possible explanations for the observed discrepancies between the values calculated for energy consumption and those derived from national and international statistics are discussed.

Finally, in Chapter 6, the conclusions are summarized.

[1]Note that the scope of the present study is limited to metropolitan France (i.e., European continental France, including the island of Corsica) due to several reasons, such as differences in climate and population needs (see Section 3.4).

2 Data sources

This master thesis has a strong focus on collecting information and data collection and therefore a thorough investigation by means of national or international databases and other sources are needed. The sources used in this thesis are briefly reviewed in this chapter. The sources can be categorized into three groups: international sources; national sources; and implemented regulations. The international sources are the first presented, these are used mainly to compare the results of the simulation. Regarding the national sources, these are supposed to give information about how to characterize (that is to say to determine the characteristics) the building stock. Finally, some of the regulations established since 1975 until now have been necessary to get some parameters to characterize the building stock and therefore will be commented as well.

2.1 International data bases

The international data bases consulted in this master thesis have information at European level. These sources have been used to compare the consumption provided by the model with the existing on statistics. The international sources are presented alphabetically.

- **Eurostat**

Eurostat is the official statistical office and statistics database for the European Union. Its mission is to provide the European Union with high quality statistics to make possible comparisons between countries or regions within the European Union. Information about final energy consumption has been extracted from this source (Eurostat, 2009).

- **Intelligent Energy Europe (IEE)**

The Intelligent Energy Europe's (IEE) task is to boost clean and sustainable solutions. It supports their use and diffusion and the exchange of related knowledge and know-how. The ENPER-EXIST project published by IEE gives information about the availability of data of some of the European countries building stock (IEE, 2007).

- **Odyssee Energy efficiency indicators in Europe**

Odyssee is a database of energy and energy efficiency monitoring for Europe (27 European countries plus Norway and Croatia). This database includes a very detailed set of data and indicators by sector in order to assess energy efficiency performance and trends. Energy consumption data has been taken from this source (Odyssee, 2005).

2.2 National sources

Information taken from the below presented national sources has been applied in order to specify the technical and thermal characteristics of the French building stock as well as the quantity of buildings in it. The national sources are presented alphabetically.

- **ADEME "Agence de l'Environnement et de la Maîtrise de l'Energie" (Environment and Energy Management Agency)**

ADEME is a public institution under the supervision of the Ministries of Ecology, Sustainable Development, Transport and Housing, Higher Education and Research, and the Economy, Finance and Industry. Its mission is to implement public policies within the areas of environment, energy and sustainable development. The agency can also provide expertise and advices to public authorities, local governments, companies or public in general. At the same time it can also provide financial aid.

The 3-CL method created by ADEME has been used to calculate the surfaces of the buildings and the publication "chiffres clés" for other purposes in this master thesis (ADEME, 2006a).

- **AICVF "Association des ingénieurs en climatique, ventilation et froid" (Association of Engineers in climatisation, ventilation and cooling)**

AICVF is a nonprofit association aiming to contribute to the scientific, technique and technologic development of the heating, ventilation and air conditioning (HVAC) systems towards a sustainable development and increase of the energy performance of the buildings. Moreover AICVF provides information, formation and knowledge to its members and other actors within the sector.

From one of the guides of the AICVF (*Calcul previsionnel des consommations d'energie – bâtiments non residentiels, 2000*) the indoor temperatures and the hot water consumption of the non-residential sector have been extracted.

- **ANAH "Agence Nationale de l'Habitat" (National Agence for Housing)**

ANAH is a public institution with the objective to enhance the quality of the existing dwellings within the residential stock by means of investigation and publication of studies and thereby promote the increase in life quality in the dwellings. ANAH has carried out the study called "*Modélisation des Performances énergétiques du parc de logements - État énergétique du parc en 2008"* which has been used for the segmentation and quantification of the residential French dwelling stock (ANAH, 2008).

- **ARENE Île de France "Agence Régionale de l'Environnement et des nouvelles Énergies" (Regional Agency of the Environment and NewEnergies)**

ARENE has as an objective to collaborate on the path towards the sustainable development in "Île de France" (Paris and its suburbs) by means of promoting and diffusing the practices needed for the ecological and social transformation towards a sustainable development, especially regarding energy consumption and climate change. After diffusing the knowledge achieved ARENE works for the appropriate implementation of the practices concerning this field.

One of the publications of ARENE Ile de France (*Les consommations d'énergie dans les bureaux*, 2009) has been used to find the percentages of the energy sources used by office buildings located in climate H1.

- **CEREN "Centre d'Etudes et de recherches economiques sur l'energie" (Center for the Studies and Economic Research on Energy**

CEREN is an institution whose aim is to calculate the energy consumption with accuracy by means of public statistics and own inquiries. CEREN has provided data regarding the consumption of the non-residential sector as used in this master thesis.

- **CLIP "Club d'Ingénierie Prospective Energie et Environnement" (Prospective Energy and Environment Engineering Club)**

CLIP, managed by IDDRI (IDDRI will be presented afterwards), is a structure gathering partner institutions, research institutes, technical centers, industrial enterprises. It provides decision makers with the models of future scenarios. To meet this objective CLIP carries out different studies concerning the potential of new energy systems, the penetration of new technologies within the different social and geographic contexts with their consequences on the environment especially about the carbon dioxide emissions. The studies are published in the journal "Les cahiers du CLIP".

For this master thesis a study conducted by the CLIP (*Répartition de la taille des logements selon leur période de construction*) has provided the average heated floor area for the residential sector.

- **CNRS - "Centre national de la recherche scientifique " (National Centre for Scientific Research)**

CNRS is a government-funded public organisation of scientific and technologic research under the charge of the Ministry of Higher Education and Research. Its mission is to gain and transfer scientific knowledge to the society. With more than 34,000 people employed CNRS covers all the fields of knowledge and it is the largest fundamental research organization in Europe

One of the projects conducted by CNRS is "ETHEL" (Energy Transport Housing condition Environment Location) where it has been analyzed the variables influencing the energy consumption in France within these sectors and has been used in this master thesis in different sections, for instance to know the shares of the different energy sources used for heating purposes (Raux, 2009).

- **CSTB "Centre Scientifique et Technique du Bâtiment" (Scientific and Technical Center for Buildings)**

CSTB is a public institution of an industrial and commercial nature under the supervision of the Ministries of Housing, Sustainable Development, Transports and Ecology. It was created to be an independent actor working close to the technicians and professionals of the construction sector promoting the innovation within the building sector. Its four main areas of work are: research, expertise, evaluation and diffusion of knowledge always working towards the achievement of a sustainable development of the: products for construction, the buildings themselves and their implementation in the urban sites. At the same time, CSTB is promoting the security and the quality of the sustainable way of constructing thanks to its 850 collaborators and other international partners.

CSTB has contributed to the ENPER-EXIST project from IEE by providing information about the French building stock.

- **DGUHC "Direction générale de l'urbanisme, de l'habitat et de la construction" (General Directorate of Urban Development, Housing Condition and Construction)**

DGUHC is a directorate of the Ministry of the Equipment also under the charge of the Ministry of Dwellings. DUHC is in charge of urban legislation and therefore has enacted thermal regulations in France that have been consulted in this master thesis to get the parameters of insulation and will be explained in the next chapter.

- **IDDRI "Institut du Développement Durable et des Relations Internationales" (Insitute of Sustainable Development and International relations)**

IDDRI is a foundation created to study sustainable development issues which needing international coordination such as climate change and depletion of natural resources. The research performed within IDDRI focuses on global governance, North-South relations and international negotiations.

IDDRI has three main objectives: informing policy decisions; identifying emerging issues; and creating a platform for dialogue between stakeholders (research organizations, public and private economic actors, unions and NGOs). IDDRI defines the challenges, gathers stakeholders and identifies new issues. IDDRI promotes scientific research conducted in France and elsewhere.

- **INSEE "Institut nationale de la statistique et des études économiques". (National Institute of Statistics and Economical Studies)**

INSEE is a public administration where information and statistics can be found about different topics such as: agriculture, commerce, finances, society, economy, education, enterprises, industry, population, salary, health, transport and tourism, territory and employment. Concretely for this master thesis statistics related to commerce, education, population, health, life conditions and society and energy has been very useful to characterize the non-residential sector.

- **Legifrance**

Legifrance is a public service with the purpose to make the law more easily available to the people interested in publications related to this field. A large number of law articles from recent years or even past ones can be found on an electronic format. Some decrees have been consulted from this source to, for example, extract the minimum isolation properties of the buildings (Legifrance, 2012).

- **Ministère du Developpement Durable (Ministry of Sustainable Development)**

The aim of the Ministry of sustainable development (Ministry of Ecology, Sustainable Development, Transports and Housing) is to drive the change of the society in a way that would be possible to face the scarcity of natural resources and the climate change. It has been useful during the quantification process to consult its database (Sita@del2) to obtain the surface of non-residential buildings constructed each year in France during the period 1985-2009 (Ministry of Sustainable Development, 2011a).

- **Ministère Éducation (Ministry of Education):**

The Ministry of education of the French government gives a broad information and detailed data about the number of institutions, buildings, about the number of teachers, professors and students within all the public and private education systems. Thanks to it the characterization of the education sector has been possible.

- **Ministère de la Santé (Ministry of Health)**

Regarding the health sector, the website of the Ministry of health has provided some statistics and especially useful reports to quantify this sector like the *"Données statistiques"* from the Ministry of Health (2010).

- **Négawatt**

The aim of the Négawatt association is to make proposals and undertake actions in order to change the current energy politic into a more efficient one and at the same time more keen to progress towards the renewal energies.

Négawatt is formed by experts and professionals involved in the project by their own will and independently.

In this source (Négawatt, 2011) the energy sources used in single family dwellings and multifamily ones have been found.

- **ROSE Île de France "Réseau d'Observation Statistique de l'Énergie" (Statistic Observation Network of the Energy)**

Rose is the statistical observatory of ARENE. It gathers an extensive database about the energy sector in the region Île de France such as energy consumption for each sector, energy production or others. Information has been used to determine the percentages of each energy source used in the climate zone represented by Paris (situated in Île de France) for the rest of the non-residential categories in this master thesis (Rose, 2011).

- **USH "Union Social pour l'Habitat" (Social Union for Housing)**

The USH organization represents a large number of HLM (*Habitation à loyer modéré,* low rent housing) agencies. The HLM are nonprofit public or private organisms who rent dwellings for low-income tenants. USH shares the same nonprofit nature of the HLMs and it works as a representative and research institution.

Regarding the use of USH as a source it has provided the number of social dwellings in 2007.

2.3 Policies and regulations

The relevant policies and the thermal regulations established in France for the building sector are presented chronologically in this section. Policies are here seen as principles to guide decisions while the regulations are administrative legislation. In addition to the sources from French Institutions, the thermal regulations have given most of the values of the thermal characteristics of the building stock, while the policies provide an overview of the situation in France regarding CO_2 emissions targets for the building sector.

- **Regulations:**

- ***"Code du travail" (Labor Law):*** The first official law regarding labor conditions in France appeared in 1922 and since then it has been revised and improved many times. The "code du travail" gathers regulations about labor law. For the purpose of this thesis the sanitary ventilation rates of the non-residential buildings have been consulted in this source.

- ***RT 1975 (Thermal regulation from 1975):*** During the period of reconstruction after the world wars (1945-1975) many buildings were constructed but little focus was put on the energy efficiency of the building. The first thermal regulation was published in 1974 and became effective in 1975 after the oil crises of 1973. This meant that the residential building sector for the first time in France was set under regulation.

  The RT 1975 was extended in 1976 to include the non-residential buildings by setting a minimum allowed performance for the isolation of the building envelope. The RT1975 has provided the U-values needed to characterize the buildings built after its implementation.

- ***RT 1989 (Thermal regulation from 1989):*** RT 1989 is a reinforcement of the RT 1975 for both residential and non-residential sectors. Some of the minimum U-values from the RT 1975 are decreased and therefore they have been used to characterize the buildings constructed after 1989.

- ***RT 2000 (Thermal regulation from 2000):*** RT 2000 is established in 2001 after the agreement of Rio and Kyoto in which France participated (RT 2000, 2003). It is valid for all new buildings (residential as well as non-residential) that have a temperature of use above 12 °C. It reinforces the thermal performances and divides France into 7 zones (3 in winter and 4 in summer) depending on their climate to apply the regulation in a smaller and more efficient scale. RT 2000 has been used for the characterization of the buildings built after 2000.

- ***Plan Climate 2004:*** The Plan Climate is an update of the old National Plan for combating Climate Change (PNLCC) published in 2000. Pan Climate 2004 was enacted that same year with the objective to reach the factor four, that is to say to divide by four the level of greenhouse gas emissions existing in France in 1990 by 2050. It means that for the residential sector the energy consumption for space heating will have to be around 50-80 kWh/m^2.

  In order to promote this change Plan Climate will allow tax breaks for clean energy appliances, such as boilers, solar water heaters and high-insulation windows. Plan Climate has been used to be aware of the context of the residential building sector in France around the reference year under study (2005).

- ***"Diagnostique de Performance Energétique" (DPE) (Diagnostic of Energy Performance) – 2006****:* The DPE label shows the energy consumption of a building classified in different energy performance indicators, being A the most efficient and G the less efficient one. DPE appears after the demand from the European community in 2002 to update their thermal regulations for new buildings, create new regulations for the renovation works, inspect boilers and cooling systems, and establish a certificate of energy performance when selling, renting or constructing a dwelling. The objective of the DPE label is to standardize the dwelling stock and enable the identification of their primary energy consumption (see example Figure 2).

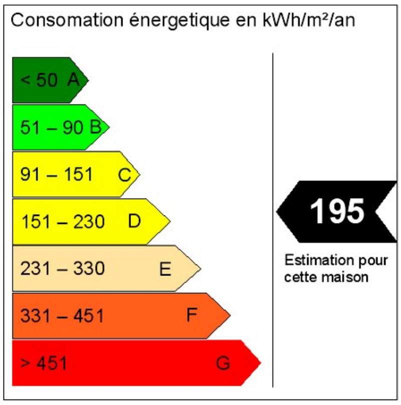


Figure 2.1: Example of a Diagnostic of Energy Performance label (Mon projet immobilier, 2011)

RT 2012 is the current thermal regulation and it is focused in a new dwelling accounting less consumption (level A of the energy labeling): less or equal to 50kWh/year and m^2 for the heating consumptions, hot water, cooling, ventilation lighting and appliances. Since the year 2012 is out of the scope of this master thesis, this source has not been used for the characterization of the stock, but it is presented here to show the current legislation.

- **Policies:**

- ***Grenelle de l'environnement (2007):*** The Ministry of Environment launched at the end of 2007 the so called "Grenelle de l'environnement" consisting of several political meetings to take decisions regarding the sustainable development of France and the environment in general. It joined the Ministry of sustainable development, local authorities and NGOs focusing on "building and urban planning", "transport and travelling" and "energy and carbon sequestration".
  Regarding the building and urban planning area, the Grenelle agreed on putting target values for the energy consumption for space heating among other measures to reach the goal fixed during the Kyoto protocol known as "Factor four". In other words, divide by four the level of CO_2 emissions by 2050 respect the values from 1990.

3 Methodology

In this master thesis work a methodology has been applied where an entire building stock is described through a number of archetype buildings, see Figure 3.1. An archetype building is a representative building corresponding to a number of buildings having the same characteristics. It is thus a "theoretical" building as opposed to a sample building where applied values are based on measurements of unique, existing buildings (Mata, 2011).

The methodology to specify the buildings stock using archetype buildings can shortly be summarized in three steps. The first step is the segmentation of the building stock, i.e. to decide the required number of archetype buildings to represent the entire stock. The second step is the characterization of these buildings (by defining and computing their technical characteristics) and the third step is the quantification of the archetype buildings, i.e. how many buildings represented by each archetype building exist in the stock. In other words, calculate the weighting coefficients. These three steps performed for the French building stock are further described in Chapter 4.

After the building stock is described by the archetype buildings, an energy simulation using the ECCABS model (see next section) is conducted, which provides a net and final energy demand for the entire sector under investigation. To validate the performed categorization and energy simulation, the final energy demand for the buildings stock resulting from the model is compared to the corresponding values of energy consumption found in national and international statistics. Finally, a sensitivity analysis is carried out to determine the most relevant variables affecting the building's energy consumption.

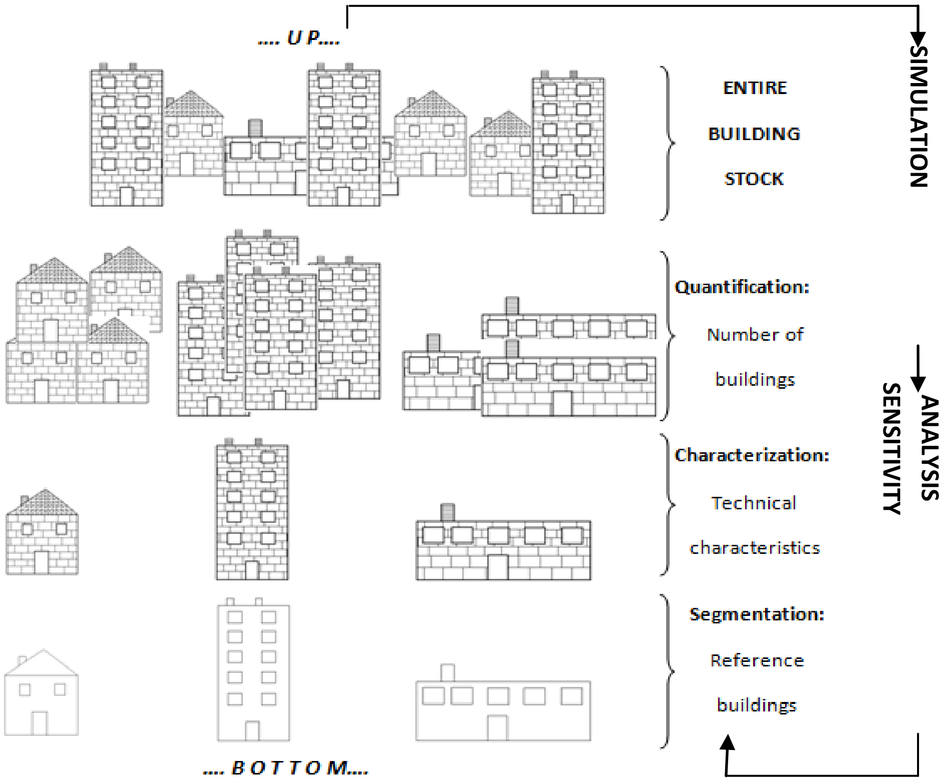


Figure 3.1: Methodology based on a bottom-up approach to describe the building stock through archetype buildings, used in this master thesis.

3.1 The ECCABS model

The model used to obtain the net energy demand of the French building stock in this thesis work is the so-called Energy, Carbon and Cost Assessment for Building Stocks (ECCABS). It is designed to assess the effects of ESM for building stocks (Mata, 2011). The main outputs from the model are: net energy demand by end-uses; delivered energy (to the building); CO2 emissions; and costs associated with the implementation of ESM. In addition, the model aims to:

- facilitate the modeling of any building stock of any entire region or country;
- allow for easy and quick changes to inputs and assumptions in the model;
- provide detailed outputs that can be compared to statistics, as well as in a form such that they can be used as inputs to other (top-down) models;
- be transparent.

To achieve these objectives, the complexity of the model has to be limited so as to avail of inputs from available databases and to facilitate short calculation times. Reducing the amount of input data will support efforts to gather data in regions for which information is lacking. Therefore, the archetype buildings are described in the model with a restricted number of parameters. These parameters required by the model to define the archetype buildings are related to the geometry of the building like the heated floor area, to the user services such as lighting, to the construction materials like the isolation value (U-value) or to other categories. To carry out the simulation a weather file for each climate zone selected in the model containing the temperature for each hour during one year is needed. Besides, since the model can be applied to any country a latitude coefficient is needed as well to represent the particular impact of the latitude of the country (the difference in sun light/heat input).

The outputs from the model are given in an aggregated form for the studied building stock, and the levels of input data required to describe the energy system and the possible scenarios are also limited. The model is a bottom-up engineering model, which means that calculation of the energy demand of a sample of individual buildings is based on the physical properties of the buildings and their energy use (e.g. for lighting, appliances, and water heating), and the results are scaled-up to represent the building stock of the region studied. Thus, the modeling assumes that a number of buildings can be assigned as being representative of the region to be evaluated. The energy demand and associated CO2 emissions of the existing stock can be calculated for a reference (baseline) year and the potential improvements of the ESM application can be given as a comparison to the baseline. The model is written to be generally applicable and, thus, does not have any embedded data (Mata, et al., 2011). In this master thesis the use of the model has been restricted to the energy assessment and further work would be to implement the ESM in the model to study their effect. Then a full assessment of the energy potentials, associated CO2 emissions and costs could be carried out.

3.2 Segmentation of the building stock

Following the bottom-up methodology to describe the French building stock, a segmentation of the stock is needed as a first step. This segmentation step aims to decide the number of such archetype buildings. For this purpose, the criteria selected to classify the buildings of the stock are those having the largest impact in their energy consumption.

Table 3.1 shows the segmentation chosen by other authors within studies aiming to describe the building stock of a country in an aggregated way. This provides certain indications of which segmentation will be suitable to apply in order to distinct archetype buildings from each other.

Country	Source	Criteria for segmentation		Subtypes
France	Martinlagardette, 2009	R	- Dwelling typology - Climate zone - Construction period - Energy source for heating	- SFD, MFD Private/Public - H1, H2, H3 - Before 1975, After 1975 - Electric, Others
France	CNRS, 2008	R	- Dwelling typology - Climate zone - Construction period - Type of heating system - Energy source for heating	- SFD, MFD - H1, H2, H3 - Before 1915, 1915-1948, 1949-1967, 1968-1974, 1975-1981, 1982-1989, 1990-1999, After 2000 - Central collective, all electric, others - Gas, fuel, electric, coal/wood, gas bottle
France	ANAH, 2008	R	- Dwelling typology - Climate zone - Age of construction - Energy source for heating	- SFD, MFD Private/Public - H1, H2, H3 - Before 1975, After 1975 - El., Gas, Fuel, Others
EU	TABULA 2010	R	- Dwelling typology - Construction period	- SFD, MFD - Before 1975, After 1975
EU-15, EFTA & Turkey	Petersdorff et al., 2002	R NR	- Type of building -Climate zone	-R: SFD, Large MFD, Small MFD NR: Large, small -Cold, moderate, warm
Greece	Balaras et al., 2005	R NR	- Type of building - Climate zone - Construction period	-R: Single, Apartment NR: Hospitals, Hotels, Schools,Offices/Commercial -A, B, C, D, E -Before 1919, 1920-1945, 1946-1960, 1961-1970, 1971-1980, 1981-1990, 1991-2001
Scotland	Clarke, J.A., et al., 2004	R	- Type of dwelling - Construction period	-Detached, Semi-detached, Terraced, Tenement, Four-in-a-block, Tower block, Conversion - Pre 1919–1965, 1966-1982, 1983-2002
Spain	Medina, 2011	R NR	- Type of building - Climate zone - Construction period	- R: SFD, MFD NR: Commercial, Office, Sports & Leisure, Other - A, B, C, D, E - Before 1976, 1976-1979, 1980-2005, 2006-2008
Catalunya (Spain)	IC, 2006	R	- Type of building - Climate zone - Construction period	- SFD, MFD - 1, 2, 3, 4 - Before 1940, 1941-1980, 1981-1990, 1991-2001
Spain	IDAE, 2003	R NR	- Type of building	- R: POD, non-POD NR: Office, Health, Commercial, Restaurant, Education
R, residential; NR, non-residential; SFD, Single-Family Dwelling; MFD, Multi-Family Dwelling; POD, Permanently Occupied Dwelling.				

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

The segmentation criteria of most of the studies have some points in common. The category "dwelling typology/ type of building" is included in all the studies, and "climate zone" and "age of construction" are often considered. Most of the categories used in these studies could be applied to the French building stock. However 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 which could not be used for the French case due to the lack of data related to this category. Yet, following the segmentation proposed by Mata (2011) three main categories are considered in this master thesis to segment the French building stock into archetype buildings, namely: **type of building**, **climate zone** and **period of construction**. In addition, an extra category has been added exclusively to the segmentation of the French residential building stock, **the energy source for heating**, as suggested by Martinlagardette (2009). The reason for this decision is that the thermal characteristics depend on the source for heating and actually it is possible to find out the number of dwellings depending on their source of energy as will be shown in Section 3.3.

The four different criteria to segment the French building stock are in detail described below.

- **Segmentation criteria 1:** Type of building

As can be seen in the previous Table 3.1 most of the studies performed have used the building types as a criterion to segment the building stock. The energy use in buildings of different typology is not the same. For instance, a single family dwelling (SFD) has a larger heated floor area than a private or public multifamily dwelling (MFD). The isolation performance is also different depending on the building type (better for SFD than for MFD as will be seen later in this chapter).

The parameters needed by the ECCABS model which depend on the type of building are presented in Table 3.2. When a parameter in the table have no comments means that for each one of the building types the parameter takes different values.

Input	Description	Comment
A	Heated floor area	
Hw	Hot water demand	
Oc, Lc, Ac	Average constant gain due to people, lighting or appliances	Public and Private MFD have the same values
Pfh	Heat losses of the fan	Differences within the non-residential sector
S	Total external surfaces of the building	
SFP	Specific Fan Power	Differences within the non-residential sector
Sw	Total surface of windows of the building	
TC	Effective heat capacity of a heated space (whole building)	
Trmin	Minimum indoor temperature	Differences only within the non-residential sector
Trmax	Maximum indoor temperature	Differences between the residential and non-residential sector
U	Mean U value of the building	
Vc	Sanitary ventilation rate	Diffrences between SFD and MFD Differences within the non-residential sector

Table 3.2 Inputs to ECCABS model dependent on the building type.

The residential sector

The residential sector has been divided into single-family-dwelling (SFD) and two kinds of multifamily-dwellings: the private ones (Private MFD) and the public ones (Public MFD), following studies performed for the French building stock of Martinlagardette (2009) and ANAH (2008). Multifamily-dwellings are split into two categories as the third category, Public MDF also known as "logement sociaux" (social dwellings) - which are, thanks to a private or a public initiative, provided to people with low incomes - tend often to be less energy efficient than Private MDF (Martinlagardette, 2009).

The non-residential sector

The building types (subsectors) within the non-residential sector included in this thesis work are consistent with the classification given by national sources (such as CEREN, Ministère du development durable, ADEME, AICVF).

The total energy consumption for the year 2007 of these different building types in France is presented in Table 3.3. In addition, consumption values for the year 2009 are provided for the different building types, these values are extrapolated values (as further described in Annex M).

Building types	2007	% of the total	2009
Offices	55.14	24.8	60.19
Commercial	51.83	23.3	56.58
Health	26.50	11.9	28.93
Education	26.11	11.7	28.50
Café, hotel, restaurant	23.77	10.7	25.95
SCL	18.17	8.2	19.83
Community housing	12.66	5.7	13.82
Transports	8.55	3.8	9.34
Total non-residential	**222.72**		**243.14**

Table 3.3 Final energy consumption in TWh for the non-residential sector in 2007 and 2009 (Ministry of Sustainable Development, 2007) *and* (Eurostat, 2009).

As Table 3.3 shows, the sectors with the largest consumption are the five first presented on the table. These most consumers are the most interesting to study since more potential energy savings can take place and therefore they have been included in the study except of the sector "bars hotels and restaurants" which has not been taken for the segmentation because of the lack of data. In fact, the surface constructed of buildings from this subsector is not accounted in the Sit@del2 database (Ministry of Sustainable Development, 2011a), the source where the quantification has been based on. It only shows the surface of hotels, and makes it impossible to include in the study. The same decision has been taken by the author of this master thesis for the transports and community housing subsectors since no data is available to characterize them. The Sport&Culture&Leisure subsector (SCL will be used since that moment in the text) has been included in the study since even not having a huge share within the energy consumption of the stock this subsector is well described in literature.

Other buildings, e.g. industry sector, the agriculture sector and the storage/warehouses buildings have not been taken into account since they are not included into the definition of non-residential buildings used in this master thesis. The non-residential sector covers the activities of offices, commerce, transports, health, education, sport-culture-leisure, cafe-hotels-restaurants, community housing and transports. The perimeter of the non-residential sector is defined by complementarity with the agricultural and industrial activities (primary and secondary sectors) (INSEE, 2012a).

For the non-residential sector, five types of buildings have been selected to segment the building stock: Offices, Commercial, Health, Education and Sport&Culture&Leisure. The offices and commercial subsectors are those representing all the offices and commercial locals respectively. Health buildings include these related to health services service providing the possibility to stay overnight or not. The education building subsector includes all buildings related to education and research, for instance schools, institutes, universities. The last subsector, Sport&Culture&Leisure includes buildings hosting activities such as cinemas, museums, sport halls or others.

- **Segmentation criteria 2**: **Climate zone**

The second category of segmentation chosen is the climate zone, since the outdoor climate conditions significantly affect the heating and cooling demand of the building.

The variables of the ECCABS model that depend on the climate zone are the mean U-value (the average isolation coefficient of the building, U) and the effective heat capacity of a heated space (TC) since buildings are constructed according to the climate characteristics. Obviously the weather file and the latitude coefficient depend as well on the climate zone.

In this thesis, France is divided into three main climate zones: the South (H3); the West (H2); and the North/East (H1), see Figure 3.2. They are the representative zones in France for the winter period according to the RT 2005. Since it is during the winter season when most of the annual energy consumption takes place (Martinlagardette, 2009), the five climate zones of summer as defined in RT 2005 have been neglected. This is also the assumption adopted by ANAH (2008) and Martinlagardette (2009) for the French dwelling stock and by Medina (2011) in the study of the neighboring country Spain.

They are needed as many weather files as climate zones selected to represent the country climate, and each one of them represents the weather in the most populated cities within the climate zone. The cities representing the three different climate zones are thus: Paris as a reference for climate H1, Toulouse for climate H2 and Marseille for climate H3. These weather files[2] are input files required by the ECCABS model that contain data describing the climate conditions of each climate zone during one year (Mata & Kalagasidis, 2009). This segmentation criterion has been applied for both residential and non-residential sectors.

[2]The weather files have been taken from Meteonorm (Meteostest, 2000).

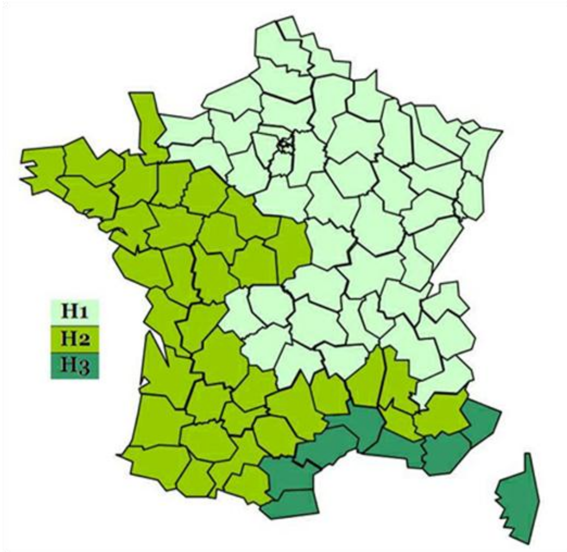


Figure 3.2: The 3 winter climate zones in France (H1, H2, H3) used to segment the building stock regarding the climate conditions (Cegibat, 2012).

- **Segmentation criteria 3: Year of construction**

The age of a building indicate the building's energy efficiency. As shown in Figure 3.3, old buildings are often less energy efficient than more recently built buildings (Energy label A indicate a high energy efficiency, while energy label I indicate a low energy efficiency). This criterion is also applied by most of the other studies presented in Table 3.1 that also are executed in order to describe the building stock in an aggregated way.

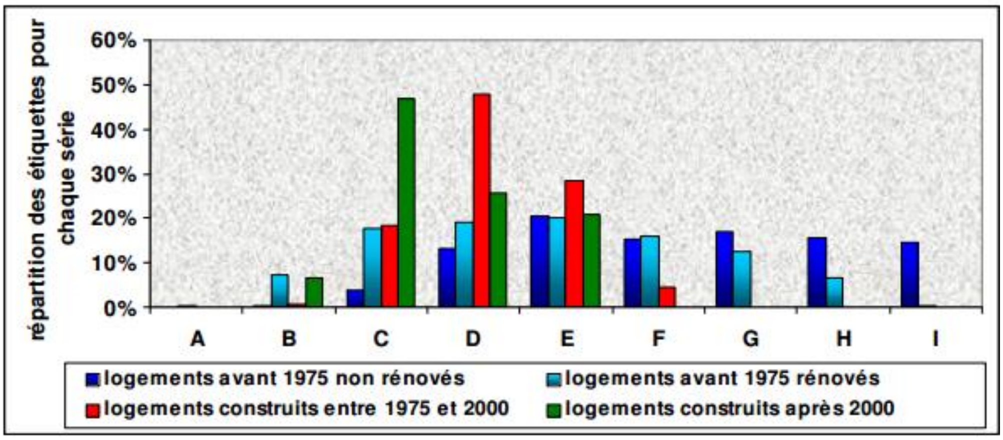


Figure 3.3: Distribution of Energy Performance labels of French dwellings classified by construction period (ANAH, 2008). *Old buildings have lower energy labeling. In dark blue: dwellings built before 1975 not refurbished, clear blue: dwellings built before 1975 refurbished, red: dwellings built during 1975-2000, green: dwellings built after 2000.*

The input parameters for the ECCABC model which depend on the construction period are shown in Table 3.4. A long the time construction materials have changed and therefore the isolation performance as well. Also the introduction of mechanical ventilation in 1975 (as assumed in this master thesis) and the rest of the parameters in Table 3.4 take different value depending on the construction period.

Input	Description	Comment
A	Heated floor area	Only within the residential sector
SFP	Specific Fan Power	Difference between before and after 1975
Sw	Total surface of windows of the building	Only within the non-residential sector
TC	Effective heat capacity of a heated space (whole building)	Building materials and its properties have changed over the time
U	Mean U value of the building	Values set by regulations
Vc	Sanitary ventilation rate	Values set by regulations

Table 3.4: Input variables for the ECCABC model dependent on the construction period.

Residential sector

The dwellings in France are divided in three time-related groups: buildings constructed before 1975, buildings constructed before 1975 but having conducted renovation work, and buildings constructed between 1975 and 2005. As ANAH (2008) does not provide data regarding the number of dwellings after 2005, this is the last year considered within the scope of this thesis. Probably it would have been valuable to define more time periods, for instance before the world wars, after the wars during the reconstruction period where the buildings were constructed in a fast and not so efficient energy wise way, the period starting in 1975 when the first thermal regulation appearedand probably a last period grouping the newest buildings with better energy efficiency (Martinlagardette, 2009). However this segmentation has not been possible to do due to the lack of data, and therefore the applied classification is the same as ANAH (2008) and Martinlagardette (2009).

Non-residential sector

It was in 1976 (IEE, EPA-NR, 2005) when the first thermal regulation was set up for buildings within the non-residential sector. Then the next regulation that set new obligations for this kind of buildings appeared in 2000, the RT2000. Based on these regulations the buildings of this sector have been divided into three different groups: the ones built before 1977, the ones built between 1977 and 2000 and the rest of the buildings built until the end of the year 2009 which is the reference year for the non-residential sector. The segmentation regarding the period of construction is shown in Table 3.5.

Sector	1	2	3
Residential	Before 1975	Before 1975 refurbished	After 1975
Non-residential	Before 1977	Between 1977 and 2000	After 2000

Table 3.5: Segmentation of the building stock by period of construction used in this work. Presenting both residential and non-residential segmentations.

- **Segmentation criteria 4: Source of energy for heating purposes**

The isolation performance (represented by the U-values) of the residential buildings constructed between 1975 and 2000 depend on the energy source used for heating. After the first thermal regulation in 1975 the insulation requirements for houses using electric heating was updated and strengthened as compared to buildings with other heat source (Energie, 2007). This was thereafter applied until the thermal regulation of 2000 (RT 2000) which abolished this difference.

This segmentation criterion is in this thesis work only applied to the residential sector since no other information has been found that the source of energy would influence the thermal requirements on non-residential buildings. The two categories adopted (electricity and others), corresponds to the categories used in the studies of ANAH (2008), Martinlagardette (2009) and CNRS (2008).

As a result of the segmentation criteria process above presented, the residential sector is represented by 54 archetype buildings (3 building types, 3 climate zones, 3 age periods and 2 energy sources for heating) while the non-residential sector is represented by 45 archetype buildings (5 building types, 3 climate zones, 3 age periods).

Once the archetype buildings that will represent the entire building stock are selected, the next step is to characterize them.

3.3 Characterization of the archetype buildings

The characterization of the archetype buildings has been done according to the input variables needed to run the ECCABS model, which are presented in Table 3.6. These variables are showed and commented in this section. Some refer to the building geometry, others to the properties of construction materials, required indoor climate conditions or to the thermal characteristics of the building service systems (Mata & Kalagasidis, 2009). While some of them have been possible to be determined by means of a source, others have had to be estimated and this will be also explained in this section.

Input	Units	Description
A	m^2	Heated floor area
HRec_eff	%	Efficiency of the heat recovery system
Hw	W/m^2	Demand of hot water
HyP	W/m^2	Consumption of the hydro pumps
Oc, Lc, Ac	W/m^2	Average constant gain due to people, lighting or appliances
Pfh	W/m^2	Heat losses of the fan
Ph, Pc	W/K	Response capacity of the heating/cooling system
S	m^2	Total external surfaces of the building
SFP	$kW \cdot s/m^3$	Specific Fan Power
Sh, Sc	W	Maximum heating/cooling power of a heating/cooling system
Sw	m^2	Total surface of windows of the building
TC	J/K	Effective heat capacity of a heated space (whole building)
Trmin	°C	Minimum indoor temperature
Trmax	°C	Maximum indoor temperature
Ts	%	Coefficient of solar transmission of the window
Tv	°C	Tint to start opening windows/nat ventilation
U	$W/m^2 \cdot °C$	Mean U value of the building
Vc	$l/s/m^2$	Sanitary ventilation rate
Vcn	$l/s/m^2$	Natural ventilation rate
Wc	%	Shading coefficient of the window
Wf	%	Frame coefficient of the window

Table 3.6: The necessary input variables for the ECCABS model.

A -Heated floor area (m^2)

The heated floor area of the buildings within the residential sector has been found in CLIP (1992) for the three different categories and the two time periods (before and after 1975), as shown in Table 3.7.

- SFD, MFD's: $A_{SFD,MFD} = \frac{\sum_{before\ 1915}^{2005} \#buildings_{periodi} * Area_{periodi}}{\sum_{before\ 1915}^{2005} \#buildings_{periodi}}$ Equation 3.1

Where:

$\#buildings_{periodi}$ is the number of SFD or MFD buildings constructed in period i.

$Area_{periodi}$ is the area of the SFD or MFD buildings constructed in period i.

Sector	Category		Area (m^2)	Source
Residential	SFD	Before 1975	99.1	CLIP (1992)
		After 1975	110.2	CLIP (1992)
	Private MFD	Before 1975	879.6	CLIP (1992)
		After 1975	881.7	CLIP (1992)
	Public MFD	Before 1975	811.9	CLIP (1992)
		After 1975	811.9	CLIP (1992)
Non-residential	Offices		1000.0	Assumed
	Commercial		232.5	INSEE (2004) + calculation
	Health		4167.1	Calculated
	Education		1489.1	Calculated
	SCL		605.0	Assumed

Table 3.7: Surface of the archetype buildings considered in this work. Sources specified in the table.

Data regarding the heated floor area for the non-residential sector is scarce, therefore some assumptions and calculations were used when necessary, namely:

- Commercial: the average heated floor area in 2004 has been found in (INSEE, 2004). Assuming the same constant yearly growth rate as for the one of the period between 1992 and 2004 (3.16 %) (INSEE, 2004).

$$A_{commercial\ 2009} = \mathrm{A}_{2004} * (1 + \mathrm{growth})^{\mathrm{years}}$$ Equation 3.2

Where:

A_{2004} is the average heated floor area of commercial buildings in the year 2004.

growth is the growth rate in commercial heated floor areas.

years is the number of years until reaching 2009 (the target year).

- Office: The surface of the buildings has been assumed to be 1000 m^2 since most of the office buildings look like MFD but at the same time there are big buildings that make the average floor to be higher than the one for residential MFD.
- SCL: The average value of the heated floor area of the SCL buildings has been assumed to be the same as in Spain (Medina, 2011).
- Health:

Number of buildings providing the possibility to stay overnight: 4,259

(Ministry of Health, 2010).

Surface in 2010: 106,537,472.38 m^2 (Ministry of Sustainable Development, 2011a)
Assumption: 50% of the surface belongs to these buildings above.

Assumption: Average heated floor area of smaller buildings without providing the possibility to stay overnight: 2,500 m² ($Area_{small\_buildings}$).
Number of buildings without providing the possibility to stay overnight:

$$\frac{0{,}5 * \text{total area}_{2010}}{Area_{small\_buildings}} = 21{,}307\ buildings$$

$$A_{health} = \frac{Totalarea_{2010}}{Totalbuildings_{2010}} \qquad \text{Equation 3.3}$$

Where:

$Totalarea_{2010}$ is the total existing area of the health subsector in year 2010.

$Totalbuildings_{2010}$ is the total number of buildings within the health subsector.

- Education:

$$A_{Education} \frac{\sum B_i * A_i}{\sum B_i} \qquad \text{Equation 3.4}$$

Where:

B is the number of buildings

A is the heated floor area of the building

i is higher education, high school, primary, secondary education

Table 3.8 sums up the sources and the values of A_i and B_i to introduce in the Equation 3.4 above.

Education 2009/2010 **182,319,337 m²**	Higher education	Higher education	Higher education	College/ lycée	Écoles		Others
					Maternel.	Element.	
Info	(2009) All France	(2009) France metropolitan	(2007-2008) All France	France metropolitan	France metropolitan		France metropolitan
B Source	4,410 INSEE, 2012b	**4,296** calculation	4,315 INSEE, 2012b	**11,377** Ministry of Educ., 2010	**16,497** Ministry of Education, 2010	**37,783**	**52,697** calculation
A Source	4,287.37 assumed as 2007-08	**4,287.37** assumed as 2007-08	4,287.37 calculation	**3,642.68** calculation	**812.94** calculation		**1,486.51** calculation
Total surface Source	18,907,300 calculated	18,416,088 calculated	18,500,000 Comptes,2007	41,442,750 calculated	44,126,197 calculated		78,334,301 calculated

Table 3.8 Values of heated floor area and number of buildings for the different education buildings. Sources specified in the table.

Further information about how to calculate the heated floor area of the education buildings can be found in Annex A.

The applied values for the different building types of the non-residential sector is presented above in Table 3.7.

HRec_eff – Efficiency of the heat recovery system (%)

In France, the recovery of energy in ventilation systems is not used at all (Martinlagardette, 2009), and therfore the efficiency of the heat recovery system is set to 0%. This applies for the residential as well as the non-residential building sector.

Hw - Hot water demand (W/m^2)

The hot water demand has been calculated after finding the suitable information both the residential and the non-residential building sector. Regarding the residential sector, ANAH (2005), gives how many liters per person that are consumed in one day for the three building types (SFD, Private MFD, Public MFD).

As for the non-residential sector, the values of hot water demand are based on AICVF (2000) which gives the average consumption for offices, education and sport buildings in liters per person. The same source also shows the average hot water consumption of health buildings specified as liters per bed. However the consumption of the commercial sector, due to the lack of data has been estimated using the final energy consumption for water provided by ADEME (2006a) for the year 2001. This consumption has been assumed to be proportional to the surface of the subsector and then the consumption for the year 2009 has been found knowing the surface of the subsector in that year. The values obtained are summarized in Table 3.9 showing the quantity of hot water consumed by sector in W/m^2:

Sector	Category	Hw consumption (l/person or bed)	Hw consumption (clim H1) (W/m^2)
Residential	SFD	55.00	2.52
	Private MFD	50.00	3.81
	Public MFD	50.00	3.83
Non-residential	Offices	7.80	0.99
	Commercial	4.00	1.77
	Health	25.00	4.92
	Education	7.80	1.65
	SCL	34.00	7.54

Table 3.9: Hot water consumption for all the building stock in liter per person or bed and W/m^2 (ANAH, 2005 and AICVF,2000).

To calculate the consumption in (W/m2) the temperature of the water before heating is required. The cold temperatures can be found in Table 3.10 while the temperature after heating the water is assumed to be 60 degrees (AICVF, 2000).

Climate	Temperature (°C)
H1	10.5
H2	12.0
H3	14.5

Table 3.10: Temperature of incoming cold water before heating it for each climate zone (AICVF, 2000).

Then, the total demand of hot water Hw can be calculated in (W/m^2) by using Equation 3.5.

$$Hw = {C_{Hw} * Q_{Hw} * p}/{A} \qquad \text{Equation 3.5}$$

Where:

C_{Hw} is the hot water demand in liters per person as summarized in Table 3.9.

p is the number of people in the building, as calculated in Annex B and summarized in Tables 3.11 and 3.12.

	Before 1975	After 1975		
Residential	**SFD, Private and Public MFD**	**SFD**	**Private MFD**	**Public MFD**
	2.90	2.64	2.60	

Table 3.11: Number of people the residential building types are designed to accommodate.

Non-residential	Offices	Commercial	Health	Education	SCL
	83.3	23.3	315.9	131.4	56.1

Table 3.12: Number of people non-residential buildings are designed to accommodate.

A is the heated floor area of the building.

Q_{Hw} is the heat required to warm the required amount of water in kwh/liter, as obtained from the Equation 3.6

$$Q_{Hw} = \rho * Cp * \Delta T \qquad \text{Equation 3.6}$$

Where:

ρ is the water density, i.e. 1,000 kg/m^3

Cp is the heat capacity of water, i.e. 4.18 kJ/kg/K

ΔT is the temperature increase (K)

- **HyP** - Consumption of the hydro pumps (W/m^2)

The electrical consumption of the hydro pumps for both residential and non-residential sectors has been set to 0.36 W/m^2 (Mata, 2011).

- **Oc, Lc, Ac** - Average constant heat gain from occupancy, lighting and appliances (W/m^2)

The heat gains produced by occupants, Oc, lighting, Lc, and appliances, Ac, need to be specified as an average constant value for all the year. In Figure 3.4 the average values obtained for each subsector are shown.

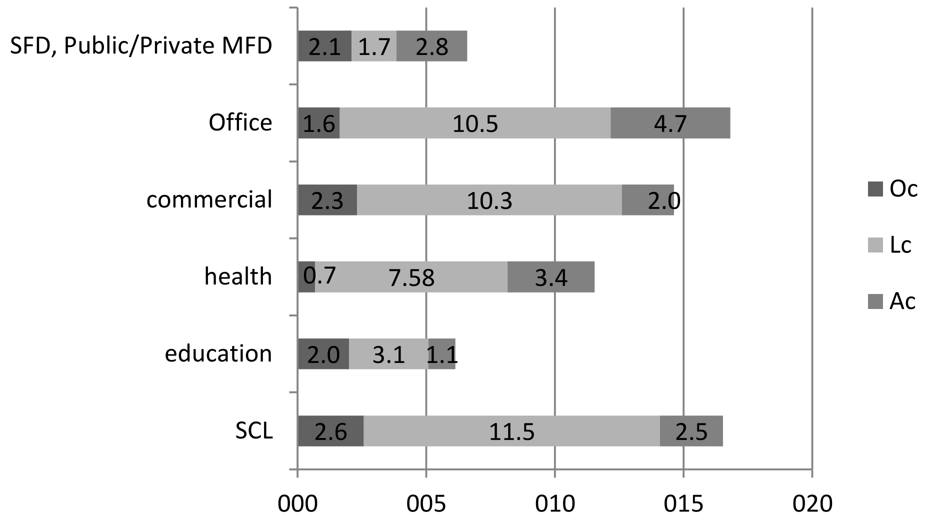


Figure 3.4: Average constant heat gains for all the building stock (Oc: heat gains from occupation, Lc: heat gains from lighting, Ac: heat gains from appliances).

The heat gains from the occupants, Oc, have been calculated considering a low activity of the people (72W produced by the body) (AICVF, 2000) for all the subsectors, except for the SCL subsector where an average value of 90W per person has been used.

The heat gains from lighting, Lc, are assumed to be equal to the lighting consumption. According to the RT 2000 the lighting consumption within the residential sector is 3W/m^2 each 100 lux of illuminance. Knowing that, an average value of 300lux has been assumed to be the right one to develop the domestic activities in the households as (Rixen, 2012) suggests. Therefore the reference value becomes 9W/m^2.

For the non-residential sector the reference values of the light consumption have been obtained directly from the annex of the RT 2008 (RT-bâtiment, 2008) and an average constant heat gain value has been calculated assuming the number of days during the year when the buildings remain open and the number of hours per week or per day needing artificial light. The result can be observed in Table 3.13:

Non-residential	Reference (W/m^2)	Average (W/m^2)
Offices	32.0	10.0
Commercial	32.0	10.3
Health	27.0	7.5
Education	30.0	3.1
SCL	34.0	11.5

Table 3.13: Reference value and value used as the internal heat gain due to lighting (Lc) (RT-bâtiment, 2008).

The heat gains of the appliances Ac**,** in the residential sector are 2.1 W/m^2 for a SFD of 103.8 m^2 and 3.4 for a MFD of 66.0 m^2 (Martinlagardette, 2009) the same value as their electricity consumption. At this point, knowing the surface of each reference building of the residential sector a proportional consumption can be calculated for each one of them.

Regarding the non-residential sector, office buildings' appliances consumption is 7.5 W/m^2 for the ground floor and 15.0 W/m2 for the rest of the floors of the building (Filfli, 2006). Health sector consumes around 3.2 W/m^2 (Filfli, 2006). Commercial buildings' electricity consumption has been calculated as having the same proportion in the sum of the three heat gains Lc, Oc and Ac as it is for Spanish commercial buildings (Medina, 2011) since there is no information available in literature regarding this topic in France. For the education subsector it has been assumed to worth around 1.5 W/m^2. The value for SCL is the same as the one for Spain too (Medina, 2011) since no data is available regarding this characteristic of this subsector in France. These values are expressed in Figure 3.5 above.

To calculate the yearly average heat gains information about the opening days per year, the hours per day opened, and the occupation are needed. This data is summarized in Table 3.14 and 3.15 for the occupation and the lighting in the residential sector and 3.16 for the occupation, lighting and appliances use within the non-residential one including the sources where the information has been taken from. Directly after the tables the equations used to calculate the average yearly constant heat gains (Oc, Lc) are presented:

Residential (SFD and MFD)		Occupation	Source
days/year		365	Assumed
hours/day awake	weekdays	6	Assumed
	weekend	12	Assumed
hours/day sleep	weekdays	8	Assumed
	weekend	8	Assumed

Table 3.14: Data to calculate the heat gains from occupation in residential buildings

Residential (SFD and MFD)		Lighting		Source
Season		winter	summer	
days/year		182.5	182.5	Assumed
hours/day climate H1	weekdays	6.0	3.0	Assumed
	weekend	7.0	3.5	Assumed
hours/day climate H2	weekdays	6.0	2.5	Assumed
	weekend	6.8	3.5	Assumed
hours/day climate H3	weekdays	5.5	3.0	Assumed
	weekend	6.0	4.0	Assumed

Table 3.15: Data to calculate the heat gains from lighting (Lc) in residential buildings

Non-residential	days/year	source	hours/day	source
Offices	227	CPC	12.0	assumed
Commercial	-	-	7.7	Les-horaries, 2012
Health	350	CPC	-	-
Education	180	CPC	10.0	assumed
SCL	350	CPC	-	-

Table 3.16: Days per year of use for the non-residential buildings. Source specified in the table.

$$Oc = \frac{W^{3}}{person} * people * \frac{days\ of\ use}{365\ days} * \frac{hours\ of\ use}{24\ hours} * \frac{1}{surface} = W/m^2$$ Equation 3.7

$$Lc = \frac{Wref}{m^2} * \frac{days\ of\ use}{365\ days} * \frac{hours\ of\ use}{24\ hours} * \frac{1}{surface} = W/m^2$$ Equation 3.8

Where:

$\frac{W}{person}$ is the heat generated by the body of a person.

$people$ is the number of occupants in the building.

$days\ of\ use$ is the days the building is open within a year.

$hours\ of\ use$ is the number of hours per day the building is open.

$surface$ is the heated floor area of the building.

- **Pc, Ph** - Response capacity of the heating system

It is assumed that all the buildings have enough response capacity of the heating and the cooling system to afford any change in the demand.

- **S** - Total external surface of the building (m^2)

The total surface of the envelope of the building can be found (Martinlagardette, 2009) using the equation 3.9:

$$S = Swalls + Sroof + Sfloor + Sw + Sdoor$$ Equation 3.9

Where:

$Swalls$ is the surface of the external walls of the building.

$Sroof$ is the surface of the roof of the building.

$Sfloor$ is the surface of the floor of the building.

[3]The heat generated by a person depends on the level of activity. Sedentary activities account for 72W while average activities 119W.

Sw is the surface of the external windows of the building.

Sdoor is the surface of the door of the building, which is considered to be 2 m^2 for the residential buildings (ADEME, 2006). For the non-residential sector this value has been assumed to be the double (4 m^2).

The calculation of Sroof, Sfloor and Swalls has been done following the indications of the 3-CL method from ADEME (2006b):

$$Sroof = Sfloor = \frac{A}{Levels} \quad \text{Equation 3.10}$$

$$Swalls = ATT * Form * \sqrt{\frac{A}{Levels}} * (Levels * HR) - Sw - Sdoor \quad \text{Equation 3.11}$$

Where:

ATT is the attached character of the dwelling.

Form is a parameter which indicates the configuration of the building.

A is the heated floor area.

Levels is the number of floors of the building.

HR is the height under the roof.

Sw is the surface of external windows of the building.

Sdoor is the surface of the door of the building.

The 3-CL method defines the value of ATT as can be seen in Table 3.17:

ATT =	1	0,8	0,7	0,7	0,35
Configuration	Detached house	Attached on one side	Attached on one large side or two small sides	Attached on one large side and one small side	Attached on two big sides

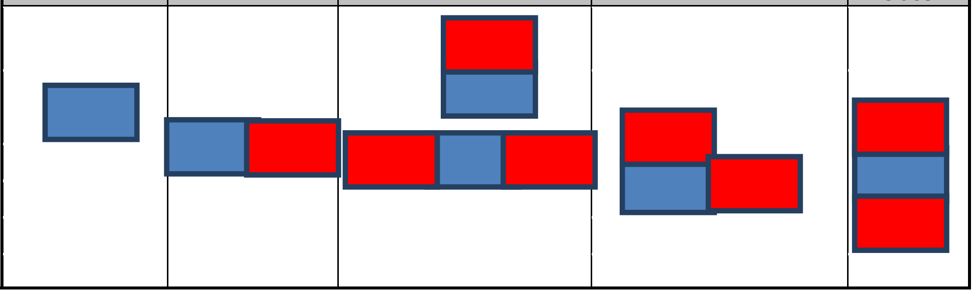


Table 3.17: Different configurations for the buildings (ATT)(ADEME, 2006b).

The residential sector has an ATT value of 1 for all the buildings constructed after 1975 (Martinlagardette, 2009). As for the buildings older than 1968 can be assumed (Martinlagardette, 2009) to have an ATT of 0,7 (attached on two small sides) which leads to an

ATT of 0.75 for SFD, 0.78 for private MFD and 0.89 for public MFD built before 1975 since the number of buildings built before and after 1968 is known.

For buildings within the non-residential sector ATT has been set to 0.68 which is an average value to show the variety in configurations for this sector as assumed in Medina (2011).

The parameter "Form" can take different values (see Table 3.18) depending on the configuration of the building (ADEME, 2006b).

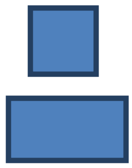
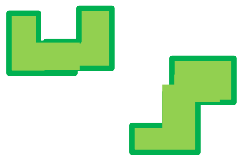
Form =	4.12	4.81	5.71
	Compact	Elongated	Developed
Configuration			

Table 3.18: Different configurations of the buildings (Form) (ADEME, 2006b).

For the residential buildings, compact configurations are assumed for all SFD (4.12) while elongated ones for MFD (4.81) (Martinlagardette, 2009). Regarding the non-residential buildings it has been assumed a developed configuration for all of them (5.71) as (Medina, 2011) assumed in the description of the Spanish building stock within the Pathways Project.

The values considered for the number of floors of the buildings of each subsector have been taken from the study of Martinlagardette (2009) in the case of the residential buildings. For the non-residential sector their values have been had to be assumed (similar to the values in Medina, 2011) since no information was available. However, for offices and health buildings the PhD thesis from Filfli (2006) has provided the number of floors (see Table 3.19).

Sector	Category	Dwellings (per building)	Storeys (per dwelling)	Levels (per building)
Residential	SFD	1.0	2.0	2.0
	Private MFD	13.3*	1.2	8.0
	Public MFD	12.3*	1.3	8.0
Non-residential	Offices	-	-	9.0
	Commercial	-	-	1.4
	Health	-	-	3.0
	Education	-	-	1.4
	Sports&culture&leisure	-	-	1.2

* Assumed 2 dwellingsper level.

Table 3.19: Number of levels, storey and dwellings for the whole building stock (Martinlagardette, 2009; Filfli, 2006).

Finally, the parameter HR from the formula refers to the ceiling height and can be found in Table 3.20. As it can be noticed some of the values have been assumed due to the lack of data, the rest are presented with their source.

	Residential	Offices	Commercial	Health	Education	SCL
HR (m)	2.5	3.0	3.0	3.0	3.0	5.0
Source	Martinlagardette , 2009	Filfli, 2006	assumed	Filfli, 2006	assumed	assumed

Table 3.20: Ceiling height for the whole buildings stock. Sources specified in the table.

- **SFP**, **Pfh** - Specific Fan Power (kW·s/m^3) and heat losses of the fan (W/m^2)

In the residential sector only the buildings constructed after 1975 are provided with mechanical ventilation (Martinlagardette, 2009). For the non-residential sector it is assumed the same. The reference value for the specific power of the fans in the residential sector is given in RT 2000 (2000) and summarized in Figure 3.5.

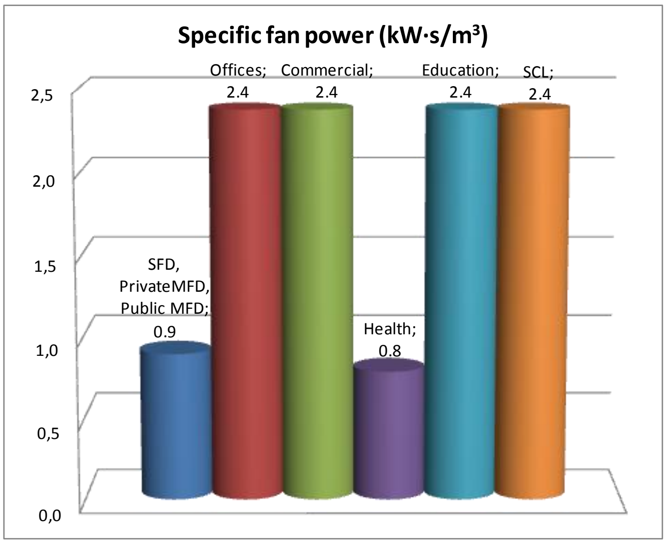


Figure 3.5: Specific Fan Power for all the building stock (RT 2000, 2004; RT 2000, 2000).

The non-residential specific fan power values have been found following the RT 2000 (2004) indications applying the equation:

$$SFP = \frac{Pressure\ drop}{3600 * Effref} \qquad \text{Equation 3.12}$$

Where:

$Pressure\ drop$ is the pressure drop through the fan found in RT 2000 (2004) (see Table 3.21).

$Effref$ is the reference efficiency of the fan (see Table 3.22).

SFP	Vc (m³/(h·pers))	People	Flow (m3/h)	Pressure drop	SFP (W·h/m³)	SFP (kW·s/m³)	Power (kW)
Offices	32*	83.33	2.667	475 Pa	0.66	**2.376**	1.759
Commercial	30	23.25	698	475 Pa	0.66	**2.376**	0.460
Health	70	315.89	22.112	475 Pa	0.22	**0.792**	4.863
Education	15	131.36	1.970	475 Pa	0.66	**2.376**	1.300
SCL	27	56.95	1.538	475 Pa	0.66	**2.376**	1.014

* The value includes the higher sanitary ventilation for meeting rooms and toilets

Table 3.21: Values needed to calculate the SFP and results presentation: Explicit SFP calculation

Extraction	> 15,000 m3/	From 3,000 to 15,000 m3/h	< 3,000 m3/h
Effref	0.6	linear	0.2

Table 3.22: Efficiency of the fan depending on the air flow RT 2000 (2004).

The heat losses have been calculated using the following equation:

$$Losses = \frac{Power * (1 - Effref)}{A} \qquad Equation\ 3.13$$

Where:

$Power$ is the power of the fan found in Table 3.21.

$Effref$ is the efficiency of the fan found in Table 3.22.

A is the heated floor area found in Table 3.7.

And the results are shown in Table 3.23:

Losses	Power (W)	A (m²)	Efficincy fan	Losses (W/m²)
SFD, Public MFD, Privat MFD	81	86	0.2	**0.75**
Offices	1374	1000	0.2	**1.10**
Commercial	851	233	0.2	**2.93**
Health	4863	4167	0.6	**0.47**
Education	757	1489	0.2	**0.41**
SCL	297	605	0.2	**0.39**

Table 3.23: Heat losses from the fan and efficiency used (RT2000, 2004).

- **Sh, Sc** - Maximum hourly capacity of the heating and the cooling system (W)

It is assumed that the heating and cooling systems are completely capable to afford the heating and cooling demand.

- **Sw** - Total surface of windows of the building (m^2)

The windows' surface on the external walls of the residential buildings is equal to the 15.0% of the heated floor area (Martinlagardette, 2009).

Since there is no information available regarding the surface of windows of the non-residential buildings, the same values than in Spain have been used (Medina, 2011) i.e. the surface covered by windows represents 17.5% of the facade for buildings constructed before 1977 and 39.0% of the facade for the ones built after 1977. However, for office buildings the surface of windows of buildings constructed before 1975 has been assumed to be 30.0%. Table 3.24 sums up the percentages of window surface used in this work.

Residential*	**Before 1975**	**After 1975**
SFD	15.0%	15.0%
Private MFD	15.0%	15.0%
Public MFD	15.0%	15.0%
Non-residential**	**Before 1977**	**After 1977**
Offices	30.0%	39.0%
Commercial	17.5%	39.0%
Health	17.5%	39.0%
Education	17.5%	39.0%
SCL	17.5%	39.0%

*Table 3.24: Percentages of surface of windows (*Percentage of heated floor area, **Percentage of the facade) (Martinlagardette, 2009; Medina, 2011).*

- **Trmin, Trmax, Tv**- Minimum and Maximum indoor temperature, and indoor temperature to start opening windows (natural ventilation) (°C)

In the residential sector, minimum acceptable temperature is 19 °C while the maximum allowed is 24 °C (CSTB, 2006).

Regarding the non-residential sector the maximum temperature to enable an efficient work environment is 25 °C for all the different categories whereas the minimum one varies depending on the nature of each category (AICVF, 2000). The minimum temperature for each category can be found in Table 3.25 as well as the maximum one, the initial and the one where the windows are supposed to be opened. Since the category SCL gathers activities with different use inside, the resulting minimum temperature is an average of the temperatures required for sports and culture and leisure (the one for sport is lower since there is a higher caloric activity).

Regarding Tv, the value used in (Mata, 2011) has been taken as a reference for all the buildings. The values are shown in Table 3.25.

Sector	Category	Trmin (°C)	Trmax (°C)	Tv (°C)
Residential	SFD, and both MFD	19.0	24.0	24.0
Non-residential	Offices	21.0	25.0	24.0
	Commercial	19.0	25.0	24.0
	Health	20.0	25.0	24.0
	Education	19.0	25.0	24.0
	SCL	18.5	25.0	24.0

Table 3.25: Minimum and maximum indoor temperatures and temperature when to start natural ventilation. (CSTB, 2006; AICVF, 2000; Mata, 2011).

- **TC** - Effective heat capacity of a heated space (whole building) (J/K)

The TC variable represents the thermal inertia of the building (Mata & Kalagasidis, 2009) and is found by summing the volumetric heat capacities for the different layers in direct contact with the internal air (internal walls, middle floors…) by means of the following equation:

$$TC = \sum \rho_i \cdot Cp_i \cdot S_i \cdot d_i \quad \text{Equation 3.14}$$

Where:

ρ_i is the density of the layer (kg/m3).
Cp_i is the specific heat capacity of the layer (J/kg K).
S_i is the area of the layer (m3).
d_i: is the thickness of the layer (m).

The TC values for the French building stock have been taken thanks to the report of Barcelona regional (2002). It has been assumed the same materials of construction for both residential and non-residential sector and these have been differenced by period of construction. The data used is shown in Annex C, and the resulting TC values used to characterize the residential and non-residential sectors are shown in Tables 3.26 and 3.27 below:

	SFD	Private MFD	Public MFD
<1975 not ref	75,870,453	291,499,981	278,317,487
<1975 ref	75,870,453	291,499,981	278,317,487
After 1975	124,879,717	320,268,006	297,357,202

Table 3.26: TC values for the residential sector used in this work.

		H1	H2	H3
Offices	before 1977	192,758,404	192,758,404	192,758,404
	1977-2000	202,903,850	202,903,850	202,903,850
	after 2000	202,903,850	202,903,850	202,903,850
Commercial	before 1977	298,875,094	298,875,094	298,875,094
	1977-2000	527,405,715	527,405,715	527,405,715
	after 2000	527,405,715	527,405,715	527,405,715
Education	before 1977	1,096,144,612	1,096,144,612	1,096,144,612
	1977-2000	1,803,616,502	1,803,616,502	1,803,616,502
	after 2000	1,803,616,502	1,803,616,502	1,803,616,502
Health	before 1977	1,543,803,602	1,543,803,602	1,543,803,602
	1977-2000	2,272,318,858	2,272,318,858	2,272,318,858
	after 2000	2,272,318,858	2,272,318,858	2,272,318,858
SCL	before 1977	1,380,344,209	1,380,344,209	1,380,344,209
	1977-2000	2,615,488,658	2,615,488,658	2,615,488,658
	after 2000	2,615,488,658	2,615,488,658	2,615,488,658

Table 3.27: TC values for the non-residential sector used in this work.

- **Ts** - Coefficient of solar transmission of the window (%)

The coefficient of solar transmission of the window, in other words the percentage of heat provided by the sun transmitted through the windows is set to 70% for both residential and non-residential sectors (Mata, 2011).

- **U** - Mean U value of the building (W/m^2·°C)

The mean U-value of each archetype building has been calculated using the U-values of each component of the building and their surface as Equation 3.15 shows:

$$U_{building} = \frac{U_{wall}*S_{wall}+U_w*S_w+U_{roof}*S_{roof}+U_{floor}*S_{floor}+U_{door}*S_{door}}{S} \qquad \textit{Equation 3.15}$$

Where:

$U_{walls,}U_{w,}U_{roof,}U_{floor,}U_{door}$ *are the heat transfer coefficients (in other words, the U-values) of the walls, the windows, the roof, the floor and the door of the building respectively.*

S_{wall}, S_w, $S_{roof,}$ $S_{floor,}S_{door}$ *are the surfaces of the walls, the windows, the roof, the floor and the door of the building respectively.*

Most of the U-values in Equation 3.15 for the residential sector have been found in the official literature (RT's) as Pathways methodology suggests, and the rest from ADEME and CLIP. The U-values are shown in Tables 3.28, and 3.29.

			Facade			Window		
			SFD	MFD Priv	MFD Pub	SFD	MFD Priv	MFD Pub
<1975 not ref		H1	1.75	1.75	3.00	4.60	5.00	5,30
		H2	1.75	1.75	3.00	4.60	5.00	5,30
		H3	1.75	1.75	3.00	4.60	5.00	5,30
<1975 ref		H1	1.08			2.45		
		H2	1.08			2.45		
		H3	1.08			2.45		
After 1975	El	H1	0.59	0.60		3.11	3.11	
		H2	0.61	0.61		3.11	3.11	
		H3	0.66	0.67		3.15	3.15	
	Other	H1	0.64	0.65		3.18	3.18	
		H2	0.67	0.68		3.18	3.18	
		H3	0.74	0.73		3.22	3.22	

Table 3.28: U-values for facade and windows, residential sector (ADEME, CLIP, RT 2000).

			Ground			Roof			Door		
			SFD	MFD Priv	MFD Pub	SFD	MFD Priv	MFD Pub	SFD	MFD Priv	MFD Pub
<1975 not ref		H1	1.80	1.50	2.80	1.50	1.00	1.50	3.50		
		H2	1.80	1.50	2.80	1.50	1.00	1.50	3.50		
		H3	1.80	1.50	2.80	1.50	1.00	1.50	3.50		
<1975 ref		H1	0.95			0.30			3.50		
		H2	0.95			0.30			3.50		
		H3	0.95			0.30			3.50		
After 1975	El	H1	0.50	0.47		0.33	0.27		2.72	2.46	
		H2	0.54	0.51		0.41	0.34		2.72	2.46	
		H3	0.61	0.59		0.44	0.37		2.72	2.46	
	Other	H1	0.56	0.52		0.37	0.31		3.21	2.95	
		H2	0.61	0.56		0.59	0.36		3.21	2.95	
		H3	0.69	0.66		0.62	0.43		3.21	2.95	

Table 3.29: U-values for ground, floor and doors, residential sector (ADEME, CLIP, RT2000).

As it can be observed in the previous tables there is no distinction for the U-values of the old buildings (built before 1975, refurbished or not) regarding climate zones. Therefore the author of this master thesis has assumed that the U-values of the climate H3 should be increased 15% regarding the other two climates since usually the values in the warmest climate are slightly higher as ECOFYS (2007) shows.

Therefore the U-values used in this master thesis after the changes applied are presented in Tables 3.30 and 3.31.

			Facade			Window		
			SFD	MFD Priv	MFD Pub	SFD	MFD Priv	MFD Pub
<1975 not ref		H1	1.75	1.75	3.00	4.60	5.00	5.30
		H2	1.75	1.75	3.00	4.60	5.00	5.30
		H3	2.01	2.01	3.45	5.29	5.75	6.10
<1975 ref		H1	1.08		1.08	2.45	2.45	2.45
		H2	1.08		1.08	2.45	2.45	2.45
		H3	1.24		1.24	2.82	2.82	2.82
After 1975	El	H1	0.60	0.61	0.60	3.11	3.11	3.11
		H2	0.63	0.63	0.61	3.11	3.11	3.11
		H3	0.70	0.67	0.68	3.15	3.15	3.15
	Other	H1	0.66	0.66	0.65	3.18	3.18	3.18
		H2	0.70	0.68	0.68	3.18	3.18	3.18
		H3	0.76	0.73	0.73	3.22	3.22	3.22

Table 3.30: U-values for facade and windows after changes applied to the residential sector.

			Ground			Roof			Door		
			SFD	MFD Priv	MFD Pub	SFD	MFD Priv	MFD Pub	SFD	MFD Priv	MFD Pub
<1975 not ref		H1	1.80	1.50	2.80	1.50	1.00	1.50	3.50		
		H2	1.80	1.50	2.80	1.50	1.00	1.50	3.50		
		H3	2.07	1.73	3.22	1.73	1.15	1.73	3.50		
<1975 ref		H1	0.95	0.95	0.95	0.50	0.50	0.5	3.50		
		H2	0.95	0.95	0.95	0.50	0.50	0.5	3.50		
		H3	1.09	1.09	1.09	0.58	0.58	0.58	3.50		
After 1975	El	H1	0.50	0.47	0.47	0.33	0.27	0.27	2.72	2.46	
		H2	0.54	0.51	0.51	0.41	0.34	0.34	2.72	2.46	
		H3	0.61	0.59	0.59	0.44	0.37	0.37	2.72	2.46	
	Other	H1	0.56	0.52	0.52	0.37	0.31	0.31	3.21	2.95	
		H2	0.61	0.56	0.56	0.59	0.36	0.36	3.21	2.95	
		H3	0.69	0.66	0.66	0.62	0.43	0.43	3.21	2.95	

Table 3.31: U-values for ground, floor and doors after changes applied to the non-residential sector.

Therefore, the mean U-value of the building is calculated (Table 3.32):

		SFD			MFD Priv			MFD Pub		
		H1	H2	H3	H1	H2	H3	H1	H2	H3
Before 1975 not refurished		1.92	1.92	2.21	2.06	2.06	2.37	3.10	3.10	3.26
Before 1975 refurbished		1.03	1.03	1.18	1.18	1.18	1.36	1.17	1.17	1.34
After 1975	El	0.70	0.73	0.79	0.84	0.86	0.91	0.82	0.84	0.89
	Other	0.76	0.83	0.89	0.88	0.91	0.97	0.87	0.90	0.95

Table 3.32: Mean U-values for each archetype building within the residential sector.

Information about the U-values of the different components of the non-residential buildings in France built after 1977 (Legifrance, 1976) and after 2000 (Legifrance, 2000) has been found in the thermal regulations for these years. However for buildings constructed before 1977, the values have been assumed to be equal to the ones of the private MFD built before 1975. For office subsector, since it has been assumed to be similar to residential MFD in construction terms, 15% increase in H3 climate values have been assumed (for buildings constructed before 1976).

U-values considered for the non-residential sector (Tables 3.33 and 3.34):

		Facade			Window		
		H1	H2	H3	H1	H2	H3
Offices	before 1977	1.75	1.75	2.01	5.00	5.00	5.75
	1977-2000	1.15	1.35	1.55	3.10	3.90	4.70
	after 2000	0.40	0.40	0.47	2.00	2.40	2.50
Commercial	before 1977	1.75	1.75	1.75	5.00	5.00	5.00
	1977-2000	1.15	1.35	1.55	3.10	3.90	4.70
	after 2000	0.40	0.40	0.47	2.00	2.40	2.50
Education	before 1977	1.75	1.75	1.75	5.00	5.00	5.00
	1977-2000	1.15	1.35	1.55	3.10	3.90	4.70
	after 2000	0.40	0.40	0.47	2.00	2.40	2.50
Health	before 1977	1.75	1.75	1.75	5.00	5.00	5.00
	1977-2000	1.05	1.15	1.35	1.60	2.30	3.00
	after 2000	0.40	0.40	0.47	2.00	2.40	2.50
SCL	before 1977	1.75	1.75	1.75	5.00	5.00	5.00
	1977-2000	1.15	1.35	1.55	3.10	3.90	4.70
	after 2000	0.40	0.40	0.47	2.00	2.40	2.50

Table 3.33: U-values for façade and windows, non-residential sector (Legifrance, 1976; Legifrance, 2000).

		Ground			Roof			Door
		H1	H2	H3	H1	H2	H3	H1 H2 H3
Offices	before 1977	1.50	1.50	1.50	1.00	1.00	1.50	3.50
	1977-2000	0.95	0.95	0.95	0.60	0.80	1.00	3.50
	after 2000	0.30	0.30	0.43	0.23	0.23	0.30	2.71
Commercial	before 1977	1.50	1.50	1.50	1.00	1.00	1.50	3.50
	1977-2000	0.95	0.95	0.95	0.60	0.80	1.00	3.50
	after 2000	0.30	0.30	0.43	0.23	0.23	0.30	2.71
Education	before 1977	1.50	1.50	1.50	1.00	1.00	1.00	3.50
	1977-2000	0.95	0.95	0.95	0.60	0.80	1.00	3.50
	after 2000	0.30	0.30	0.43	0.23	0.23	0.30	2.71
Health	before 1977	1.50	1.50	1.50	1.00	1.00	1.00	3.50
	1977-2000	0.95	0.95	0.95	0.50	0.60	0.80	3.50
	after 2000	0.30	0.30	0.43	0.23	0.23	0.30	2.71
SCL	before 1977	1.50	1.50	1.50	1.00	1.00	1.00	3.50
	1977-2000	0.95	0.95	0.95	0.60	0.80	1.00	3.50
	after 2000	0.30	0.30	0.43	0.23	0.23	0.30	2.71

Table 3.34: U-values for ground and floor for the non-residential sector (Legifrance, 1976; Legifrance, 2000).

Then the mean U-values of the buildings have been calculated (Table 3.35):

Mean U-values	before 1977	1977-2000	2001-2009
Office	2.14	1.84	0.82
Commercial	1.67	1.29	0.52
Health	1.56	0.99	0.48
Education	1.44	1.08	0.41
SCL	1.63	1.24	0.50

Table 3.35: Mean U-values for the non-residential sector used in this work.

- **Vc** - Sanitary ventilation rate (l/s/m^2)

The sanitary ventilation rate is the ventilation rate required to assure a healthy indoor air.

For the residential buildings, this rate is shown in (Legifrance, 1982) depending on the number of rooms of the dwelling. The sanitary ventilation in the units needed as an input value for ECCABS are found in Table 3.36.

	Before 1975		After 1975			
Vc	Flow (CPH)	Vc (l/s)/m2	# Rooms	Flow(m^3/h)	A (m^2)	Vc (l/s)/m2
SFD	0.74	**0.51**	4	90	110.16	**0.23**
Private MFD	0.74	**0.51**	4	90	66.13	**0.50**
Public MFD	0.74	**0.51**	4	90	66.13	**0.50**
Source	Martinlagardette, 2009		ANAH, 2005	Legifrance, 1982		

Table 3.36: Sanitary ventilation rates for the residential sector. Sources specified in the table.

In the case of the non-residential sector, for Offices, Commercial and Education buildings the sanitary ventilation is found in Code du travail (2012) and can be translated into the appropriate units (see Table 3.37) by taking the area from Table 3.7 and the number of occupants from Annex B. The health subsector has taken into account two different kind of buildings (providing the possibility to stay overnight or not) and the values of Vc rate different for each one of them. The calculations needed to find out the sanitary ventilation rate for the health subsector can be found in Annex D.

Non-residential	# Person	A (m^2)	Flow (m3/h)/person	Source (for the flow)	Vc (l/s)/m2
Offices	83.33	1000.00	32	Code du travail (2012)	**0.74**
Comercial	23.25	232.49	30	Code du travail, 2012	**0.83**
Health	315.89	4167.07	70	Filfli, 2006 + calculation	**1.47**
Education	131.36	1489.12	15	Code du travail, 2012	**0.37**
SCL	56.05	605.00	27	Medina, 2011	**0.69**

Table 3.37: Sanitary ventilation rates for the non-residential sector. Sources specified in the table.

- **Vcn** - Natural ventilation rate ($l/s/m^2$)

The natural ventilation refers to the flow of air created when opening the windows.

For the residential buildings, this value is 0.60 vol/h or, what is the same, 0.40 l/s/m2 according to the DEL.6-Method (Martinlagardette, 2009).

Regarding non-residential buildings, the values have been extracted from the study of Medina (2011) since no data has been found for the French case. The value is 2.78 $l/s/m^2$.

- **Wc, Wf** - Shading coefficient of the window and frame coefficient of the window (%)

The shading coefficient of the window Wc is the ratio of the solar irradiation that succeeds to reach the window since there can be different factors of shadow (other buildings, nature…). It is set to 55% (Mata, 2011) while the frame coefficient i.e. the part of the total window surface covered by window frames is set to 70% (Mata, 2011) for both residential and non-residential sectors.

3.4 Quantification of the French building stock

In order to aggregate the results obtained for each archetype building and thus to represent the entire French building stock, a parameter called "weighting coefficient" is assigned to each archetype building. This parameter indicates the number of buildings in the country represented by each archetype building.

It is important to mention that for both studied building sectors the number of buildings refer to the existing buildings in the so called "France métropole" (metropolitan France) which includes the continental France plus Corse island, i.e. excluding the buildings located in the "Département d'Outre Mer" (D.O.M.)[4] due to the large differences in climate, the energy consumption per capita and more generally the difference in some social aspects. Therefore a particular study for these regions would be needed. However including this study in this master thesis would increase a lot the time load while the benefits would be small since the energy consumption in these areas is very low (4.4 TWh as the calculation in Annex E shows) in comparison to the one in the metropolitan France. The quantification then only includes metropolitan France.

Regarding the quantification of the residential sector, the most detailed source is Martinlagardette (2009) where dwellings are sorted by the four criteria of segmentation

[4]D.O.M stands for Departement d'Outre Mer. These departments are Guadeloupe, Martinique, Mayotte and Réunion islands and French Guyanne in South America. All of them together account for less than 1% of the total consumption of final energy for space heating, ventilation, lighting, hot water consumption and electric appliances in France.

followed in this master thesis (as described earlier in Section 4.1). The number of dwellings will enable the calculation of the number of buildings using the information about the number of dwellings per building (see Table 3.19). However, some clarifications are needed:

- the number of dwellings presented in Martinlagardette (2009) work is lower than it is reported in other sources. As can be seen in Table 3.38 other studies have found a larger number of dwellings and therefore an average number of the most representative sources, in this case Grenelle environnement, 2007 and TABULA, 2010, was applied. It was thereby concluded that the total number of dwellings is 26,160,000 (see Annex F where dwellings are presented sorted by the four segmentation criteria).

- the public MFD showed are the ones existing in 2007 and they are only classified by climate and energy source for heating. Therefore it has been needed to subtract the dwellings built between 2005 and 2007 which account for 104,000 dwellings (MDD, 2010). Then a first assumption considering the number of dwellings built before 1975 has been made based on Batifoulier (2007) stating that in 1975 there were 3 million of social dwelling apartments. These are the buildings constructed before 1975 and assumed to still exist in 2005. Applying an assumption that 40% of these buildings have been refurbished results with a number of 1.8 million dwellings built before 1975 not refurbished and 1.2 million dwellings refurbished. This assumption is based on the fact that a project was created in 2008 by the Ministry of Sustainable development aiming to refurbish 65,000 social dwellings per year (Van de Maele, 2008). Yet, assuming a lower refurbishment rate (around 45,000 renovations per year) for every year of the period 1977-2005 the value 40% was obtained.

Source	Total dwellings		
ANAH, 2008 and changes by Martinlagardette, 2009	24,607,555	SFD	12,531,798
		MFD	12,075,757
ADEME, 2006	25,812,000	SFD	14,500,000
		MFD	11,312,000
Grenelle environnement,2007	26,510,000	SFD	15,000,000
		MFD	11,510,000
TABULA,2010	25,811,000	SFD	-
		MFD	-
INSEE,2006	25,600,000	SFD	-
		MFD	-

Table 3.38: Total number of dwellings accounted in metropolitan France in the year 2005 depending on the study conducted divided into SFD or MFD. Sources specified in the table.

As a result of applying the assumptions above presented, the total number of dwellings is 24,697,555 which means that 1,552,445 dwellings must be added to reach the total number of dwellings assumed recently (26,160,000). Since the number of MFD in the study conducted by ANAH (2008) is sufficiently high while the number of SFD is lower compared to the other studies as can be noticed on Table 3.38, these extra buildings have been considered to be SFD and have been distributed proportional to the existing values of SFD dwellings of each criterion of segmentation.

Table G.1 in Annex G reports the total number of buildings for each archetype building in the residential sector as obtained as a result of the above calculations. These values have been used as inputs to the energy simulations by the ECCABS model performed within this master thesis work.

The non-residential sector in France is much less documented than the residential sector, as reported in IEE (2007), see Figure 3.6.

Characterisation of existing building stock		at	be	de	dk	fr	gr	It	nl	uk
# buildings	*Total, Res*	☺	☺	☺	☺	☺	☺	☺	☺	☺
	Total, non Res	☺	☺	☺	☺		☺		☺	☺
area / type	*Total, Res*		☺	☺	☺	☺	☺	☺	☺	
	Total, non Res	☺		☺	☺	☺	☺		☺	☺
typical construction period	*Total, Res*	☺	☺		☺	☺	☺	☺	☺	☺
	Total, non Res	☺			☺		☺		☺	
statistical	*Total, Res*	☺	☺	☺	☺	☺	☺	☺	☺	☺
	Total, non Res	☺	☺	☺	☺	☺	☺		☺	☺
estimate	*Total, Res*						☺			
	Total, non Res						☺			

Figure 3.6: Data available about the building stock in for different European countries: Austria, Belgium, Germany, Denmark, France, Greece, Italy, Nederland and United Kingdom (IEE, 2007).

Unfortunately, no sources have been found specifying the quantity of buildings for each category. Therefore the number of buildings has been obtained dividing the existing surface of each archetype building by the average heated floor area of each one of these archetype buildings. The proceeding five steps in order to obtain the weighting coefficients (the number of buildings represented by each archetype building) are presented below:

1. ***To find the value of the overall existing surface of each non-residential subsector.***
   IEE (2005) reports the total surface of each subsector of the non-residential sector in 2001, as presented in Table 3.39.

Non-residential subsector	Total surface in 2001 (m2)
Offices	172,786,000
Commercial	188,303,000
Health	93,920,000
Education	166,391,000
SCL	61,073,000
Total	**682,473,000**

Table 3.39: Surface of the non-residential sector in 2001(IEE, 2005).

2. ***To find the surface constructed every year in each climate zone.***
   Through the official website of the ”Ministere du developpement durable” by means of the Sit@del2 database (Ministry of Sustainable Development, 2011a) it has been

possible to obtain the surface of non-residential buildings constructed[5] in each department, every year in France, since 1985 until 2009. In order to gather the surface for each climate zone it has been needed to sum the surfaces from all the departments forming each climate zone for each year. This data can be found in Annex H.

3. ***To complete the data sheet by means of assumptions or deductions.***
The surface constructed between 1977 and 1985, which was missing in the above mentioned sources, was obtained by assuming that the average annual growing rate of construction of the period 1977-1985 was the same than the average annual growing rate of construction for the period 1980-1987 showed in Table 3.40 (Girault, 2001).

Past and future evolution of the building stock 1980 - 1997 - 2020					
Subsector	1980-1987	1987-1992	1992-1997	1997-2010	2010-2020
	Annual average growth rate				
Commercial	0,4%	1,5%	0,6%	0,8%	0,9%
Education	1,2%	1,6%	1,6%	1,4%	1,4%
Offices	1,7%	3,5%	1,6%	2,4%	2,4%
Cafe-hotel-restaurant	1,1%	1,9%	1,4%	1,5%	1,5%
Health	0,5%	1,0%	1,1%	0,8%	1,0%
Culture	5,0%	5,3%	3,5%	4,6%	1,7%
Transport + parking	2,2%	2,8%	1,9%	2,2%	2,2%
Total	1,1%	2,1%	1,4%	1,7%	1,6%

Table 3.40: Evolution past and future of the non-residential building stock (Girault, 2001).

Furthermore it has been assumed that the surface constructed in each climate zone is proportional to the surface constructed in 1980.

Methodology to calculate the constructions made each year of the period 1977-1984 for each climate zone:

$$Construction\ 1984_{H1} = totalsurf_{1985} * \left(1 - \frac{1}{1+\%growth}\right) * \left(\frac{H1}{H1+H2+H3}\right) \quad \text{Equation 3.16}$$

$$Construction\ 1983_{H2} = totalsurf_{1984} * \left(1 - \frac{1}{1+\%growth}\right) * \left(\frac{H2}{H1+H2+H3}\right) \quad \text{Equation 3.17}$$

Where:

$Construction\ i_k$ is the surface constructed of the subsector in year i in the climate zone k in m^2.
$totalsurf_i$ is the existing surface of the subsector in year i in m^2.
$\%growth$ is the percentage of growth of the subsector.
Hx is the existing surface of the subsector in climate zone x.

[5] Sit@del2 offers two different data about the surface of buildings. The surface having been started to be constructed and the surface of buildings authorized to start the construction. In this thesis it has been used surface started to construct, since the authorized ones it is not possible to know when were they going to start to build them and therefore would be very difficult to allocate within the years.

By means of these assumptions the surface for the period 1977-2000 has been deducted for each climate zone. Then, since the period 2000-2009 doesn't show any difficulty it only lacks to define the surface for the period before 1977. Since it has been found in point number one the existing surface for the year 2001 it is possible to calculate the surface before 1977 from the subtraction of the total surface in 2001 minus the constructed surface from 1977 until 2000.

4. Include demolition rates

While using this methodology to calculate the surface of the non-residential sector before 2001 a hidden assumption has been carried out. Since the values from 2001 account for existing surface whereas the surface of the period 1977-2001 account for surface constructed, the demolition of that last period has not been taken into account. But by the moment it is subtracted from the total real surface of 2001 it is assumed automatically that the demolitions of the period 1977-2001 took place in buildings built before 1977.

Regarding the period 2002-2009, the demolition rates are assumed to be the same as these reported by (Girault, 2001) for the period between 1986 until 1997 (i.e. 0.7% in offices, 1.3% in commerce, 0.0% in health and 1.9 in SCL). Nothing is said about education buildings but it has been assumed as 0.0% as it is for the health subsector. The methodology for the calculation is as follows:

$$Demolition_{2002} = Total\ surface_{2001} * (\%demolition) \qquad \text{Equation 3.18}$$

$$Demolition_{2003} = (Total.surface_{2002} - demolition_{2002}) * (\%demolition) \qquad \text{Equation 3.19}$$

Where:

$Demolition_i$ is the surface demolished of the subsector in the year i in m^2.

$Total\ surface_i$ is the existing surface of the subsector the year 2001 in m^2.

$\%demolition$ is the percentage of surface demolished per year within this subsector, found on Girault (2001).

Knowing that the surface of buildings constructed before 1980 (Girault, 2001) in 1998 was:

Surfaces du parc tertiaire	**1998**	dont parc	
		d'avant 1980	1981 & après
	millions de m2	%	
Transport	22	62%	38%
Café-hôtel-restaurant	96	78%	22%
Commerce	175	69%	31%
Bureaux-Administration	156	60%	40%
Sports-Loisirs-Culture	40	32%	68%
Enseignement-Recherche	159	79%	21%
Santé-Action sociale	88	80%	20%
Total du tertiaire	735	70%	30%

Source : estimation du parc par âge/étude SES-Enerdata

Figure 3.7: Surface constructed before 1980 ("d'avant 1980") in 1998.

Then, the comparison with the values of this master thesis is:

Surface (m2)	Before 1980 % (estimation)	Surface before 1980 (estimated)	Estimated in this master thesis
Commercial	69	123,510,000	125,452,383
Offices	60	96,000,000	100,068,757
Education	79	126,400,000	126,311,549
Health	80	71,200,000	74,002,556
SCL	32	12,800,000	22,045,921

Table 3.41: comparison of the surface built before 1980 in m^2.

As indicated in Table 3.41, the surfaces of the non-residential subsectors estimated by Girault (2001) are a bit lower than the ones considered in this thesis. Nonetheless, the surface values used in Girault (2001) are underestimated since they are a bit smaller than the ones found in CEREN (the source used to find the surface before 1980 in Girault (2001)). Therefore it can be assumed that the values are correct up to 1998.

A second comparison was conducted, this time between the surface values of each subsector considered in this master thesis and the ones accounted by CEREN (ADEME, 2011). The differences are presented in Table 3.42.

Surface 2009	ADEME,2011 (CEREN)	Calculated in this master thesis	Difference (%)
Offices	200.989.000	193.778.193	-3.59
Commercial	203.626.000	202.703.573	-0.45
Health	105.780.000	109.740.623	3.74
Education	181.822.000	182.319.337	0.27
SCL	67.585.000	65.996.316	-2.35

Table 3.42: Differences between statistical surface and the calculated one in the thesis in m^2.

This comparison reveals that the surface of health buildings is overestimated in this thesis while, on the contrary, the offices and SCL sectors buildings are underestimated. This, considering that both sources, the one used in ADEME's report (CEREN) and the one used in this thesis (Girault, 2001; Ministry of Sustainable Development, 2011a) should give similar numbers. The differences in the health category can be explained by the fact that no demolition was assumed between 2001 and 2009. Therefore, as it has been demonstrated, since the total surface should be a bit lower, a cautious demolition rate of 0.4 % will be used. Regarding offices building, the assumption of using the same demolition rate as the period 1986-1998 seem to be overestimated and therefore the annual demolition rate of 0.7% was lowered to 0.3%. The decision has been taken for the SCL sector where the demolition rate has been fixed to 1.6% instead of the previously applied 1,9% (see demolition values Table 3.43). Then, the resulting final values are the ones in Table 3.44 and can be accepted as the appropriate ones.

Demolished surface (m^2)	Commercial	Offices	Health	SCL	Education
demolitions in 2002	2,447,939.00	518,358.00	375,680.00	977,168.00	0.00
demolitions in 2003	2,469,981.18	529,349.49	379,992.90	1,004,041.76	0.00
demolitions in 2004	2,527,149.18	539,778.55	386,784.31	1,036,350.98	0.00
demolitions in 2005	2,583,450.13	550,921.54	393,464.82	1,068,779.12	0.00
demolitions in 2006	2,647,409.36	562,250.65	401,209.44	1,104,150.58	0.00
demolitions in 2007	2,709,541.58	576,081.82	411,930.42	1,143,656.59	0.00
demolitions in 2008	2,778,863.00	591,694.57	422,554.84	1,181,355.78	0.00
demolitions in 2009	2,831,094.50	604,236.35	431,533.90	1,205,527.33	0.00

Table 3.43: Total surface demolished each year for the period 2002-2009 by subsector non-residential sector assuming the demolition rates from Girault (2001).

Surface 2009	ADEME, 2011 (CEREN)	Calcuated in this master thesis	Difference (%)
Offices	200,989,000.00	199,741,754.00	-0.62
Commercial	203,626,000.00	202,703,573.00	-0.45
Health	105,780,000.00	106,537,472.00	0.72
Education	181,822,000.00	182,319,337.00	0.27
SCL	67,585,000.00	67,631,509.00	0.07

Table 3.44: Difference in surface after applying new demolition rates.

5. Calculation of weighting coefficient

Once the total existing surface of each archetype building has been calculated the weighting coefficients are obtained by dividing this surface by the average heated floor area of each archetype building. The final results of this process are presented in Section 4.3.

3.5 Fuels used for heating purposes

Depending on the energy source used for heating purposes the final energy consumption of a building can vary in a larger or smaller way. As mentioned previously in Section 3.2 the ECCABS model provides the total energy demand (i.e. the useful energy consumption) while the energy consumption presented in official statistics accounts for final energy consumption. In order to obtain the final energy consumption from the energy demand it must be added the conversion losses. Therefore it is crucial to know the percentage of energy sources used by each archetype building and the efficiencies of each energy source.

The percentages of the energy sources used within the residential sector have been taken from Raux (2009), where the percentages for each climate zone are specified. Thereafter, these values have been separated into SFD and MFD as they are in Négawatt (2011). That is to say, the total amount of district heating has been assigned only to the MFD (the main district heating consumers) while the amount of wood has been assigned to SFD only (the main wood consumers as shown in Négawatt). Most of the electricity used as a source for heating is direct electricity; therefore no heat pumps are taken into account (Raux, 2009). The resulting percentages of the energy sources used by each archetype building from the residential sector are shown in Table 3.45:

Energy source (%)			Electricity	Gas	District Heat.	Others	Fuel	Wood
H1	SFD	El	100.00	0.00	0.00	0.00	0.00	0.00
	SFD	Other	0.00	39.37	0.00	5.51	31.50	23.62
	MFD Private	El	100.00	0.00	0.00	0.00	0.00	0.00
	MFD Private	Other	0.00	48.23	6.43	6.75	38.59	0.00
	MFD Public	El	100.00	0.00	0.00	0.00	0.00	0.00
	MFD Public	Other	0.00	48.23	6.43	6.75	38.59	0.00
H2	SFD	El	100.00	0.00	0.00	0.00	0.00	0.00
	SFD	Other	0.00	29.41	0.00	4.58	32.68	33.33
	MFD Private	El	100.00	0.00	0.00	0.00	0.00	0.00
	MFD Private	Other	0.00	43.27	1.92	6.73	48.08	0.00
	MFD Public	El	100.00	0.00	0.00	0.00	0.00	0.00
	MFD Public	Other	0.00	43.27	1.92	6.73	48.08	0.00
H3	SFD	El	100.00	0.00	0.00	0.00	0.00	0.00
	SFD	Other	0.00	34.97	0.00	6.29	28.67	30.07
	MFD Private	El	100.00	0.00	0.00	0.00	0.00	0.00
	MFD Private	Other	0.00	49.50	0.99	8.91	40.59	0.00
	MFD Public	El	100.00	0.00	0.00	0.00	0.00	0.00
	MFD Public	Other	0.00	49.50	0.99	8.91	40.59	0.00

Table 3.45: Percentage of energy sources for the residential sector (Raoux, 2009; Négawatt, 2011).

Regarding the non-residential sectors, the percentages for climate zone H1 for offices (ARENE, 2009), commercial buildings (ARENE, 2008) and education (ROSE, 2011) are defined in literature while the remaining archetype buildings (in other subsectors and climate zones) have been assumed to have the same average shares: 47.47% electricity, 28.11% gas, 19.82% fuel, 4.61% others and no district heating (Ministry of sustainable development, 2011b). The share of different heating sources used in the non-residential sector, as applied within this work, is presented in Table 3.46.

Energy source (%)		Electricity	Gas	District Heating	Others	Fuel
Offices	H1	42.00	34.00	21.00	3.00	0.00
	H2	47.47	28.11	0.00	4.61	19.82
	H3	47.47	28.11	0.00	4.61	19.82
Commercial	H1	70.00	13.00	8.00	6.00	3.00
	H2	47.47	28.11	0.00	4.61	19.82
	H3	47.47	28.11	0.00	4.61	19.82
Health	H1	47.47	28.11	0.00	4.61	19.82
	H2	47.47	28.11	0.00	4.61	19.82
	H3	47.47	28.11	0.00	4.61	19.82
Education	H1	9.40	57.00	15.16	0.00	18.42
	H2	47.47	28.11	0.00	4.61	19.82
	H3	47.47	28.11	0.00	4.61	19.82
SCL	H1	47.47	28.11	0.00	4.61	19.82
	H2	47.47	28.11	0.00	4.61	19.82
	H3	47.47	28.11	0.00	4.61	19.82

Table 3.46: Percentages of energy sources used for the non-residential sector (ARENE, 2009; ARENE, 2008; ROSE, 2011; Ministry of sustainable development, 2011).

The efficiencies of each energy source: oil (Raux, 2009), gas (Medina, 2011), wood (Raux, 2009), direct electricity (Mata, 2011), district heating (Shimoda et. al, 2005), direct electricity and others (Mata, 2011) are shown in Table 3.47.

	Efficiencies	
Energy source	**Residential**	**Non-residential**
Oil	0.85	0.85
Gas	0.87	0.76
Wood	0.70	X
Direct Electricity	0.98	0.98
District heating	0.82	0.82
Others	0.60	0.60

Table 3.47: Efficiencies of the conversion from energy source to heat for each of the energy sources used in both sectors (Raoux, 2009; Mata, 2011).

4 Results

4.1 Results of segmentation for archetype buildings

This first part of this chapter will present the results of the segmentation conducted in this thesis according to the process described in Section 4.1, for residential and non-residential buildings. These two sectors show different outcomes owing the fact that the reference years of the studies chosen for the two sectors are different. Therefore, the analysis of the results will be more accurate if performed separately, thereby allowing interpretation of the results in coherence with the context of each reference year.

Residential building sector

The results presented in Figures 4.1-4.4 are for the residential sector, with 2005 as the reference year. Year 2005 was chosen due to the availability of data for that year and the fact that it is the baseline year for the Pathways Project study of Martinlagardette (2009), thus offering the possibility for comparisons.

- **Segmentation criterion 1:** Type of building

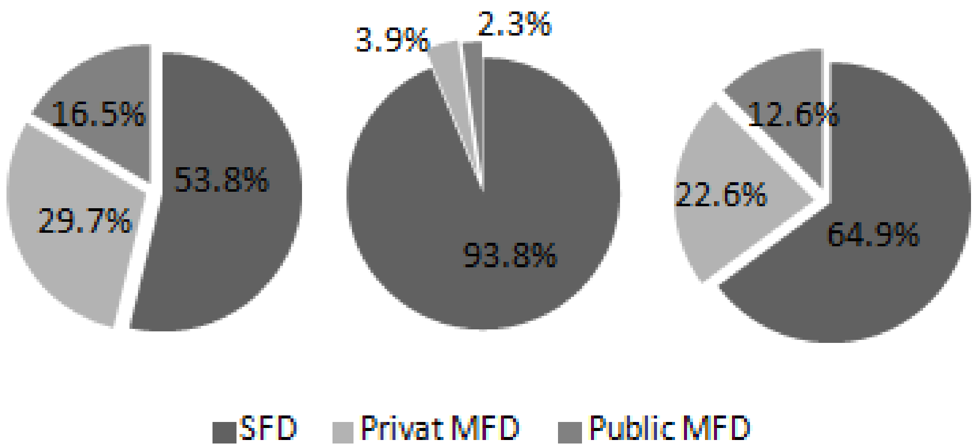


Figure 4.1: Percentages of (from left to right) dwellings, buildings, and total heated floor area in Year 2005, with respect to the types of building within the residential sector. SFD, Single-Family Dwelling; MFD, Multi-Family Dwelling.

- **Segmentation criterion 2:** Climate zone

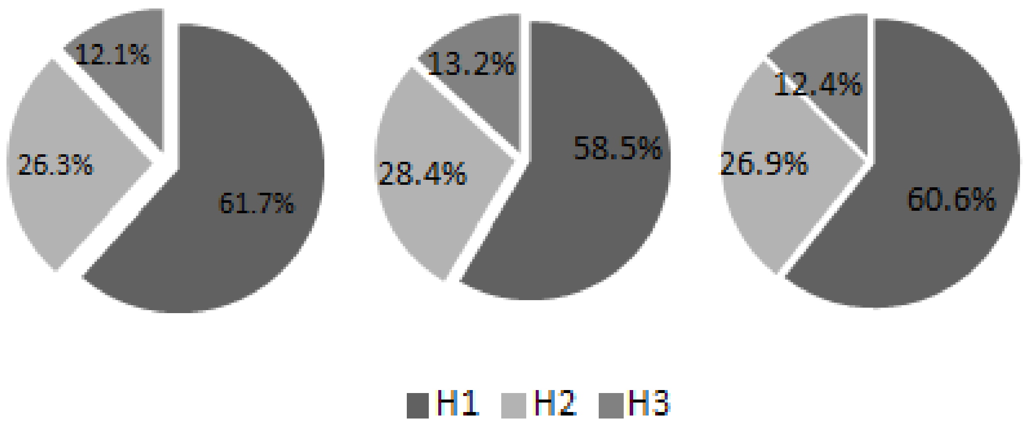


Figure 4.2: Percentages of (from left to right) dwellings, buildings, and total livable surface area in Year 2005, with respect to the climate zones (H1, H2, H3) for the residential sector.

- **Segmentation criterion 3:** Period of construction

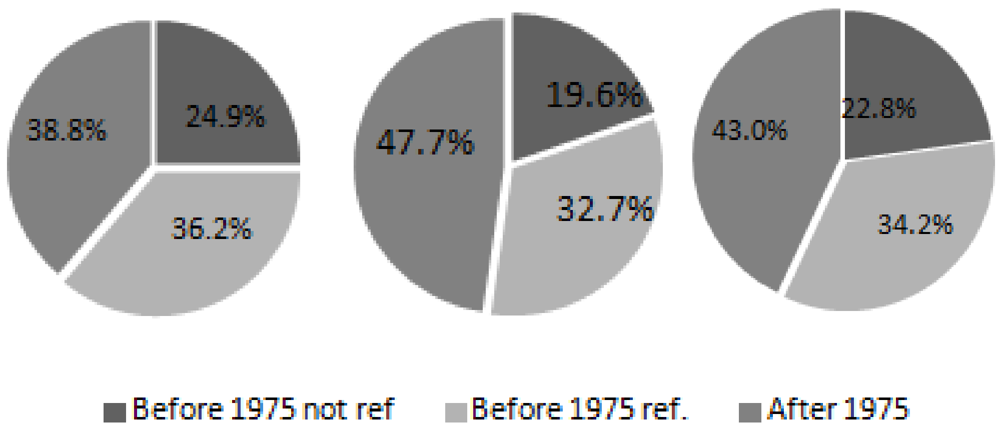


Figure 4.3: Percentages of (from left to right) number of dwellings, number of buildings and total livable surface area in Year 2005, with respect to the period of construction for the residential sector.

- **Segmentation criterion 4:** Source of energy for heating purposes

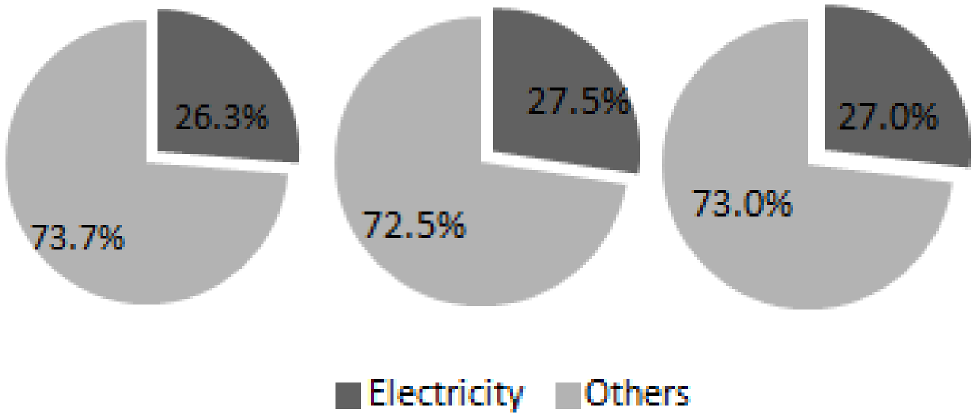


Figure 4.4: Percentages of (from left to the right) number of dwellings, number of buildings and total livable surface area in Year 2005, with respect to the energy source for heating purposes for the residential sector.

Non-residential sector

For the non-residential sector, the results of the segmentation, taking 2009 as the reference year, are presented in Figures 4.5-4.7. The reason for choosing this reference year, which is more recent than that used for the residential sector, is that information is available on the surface of buildings constructed during the period 1985-2009 for this sector (Ministry of Sustainable Development, 2011a). Therefore, it was decided to extend the study to the most recent year for which documentation existed.

- **Segmentation criterion 1:** Building type

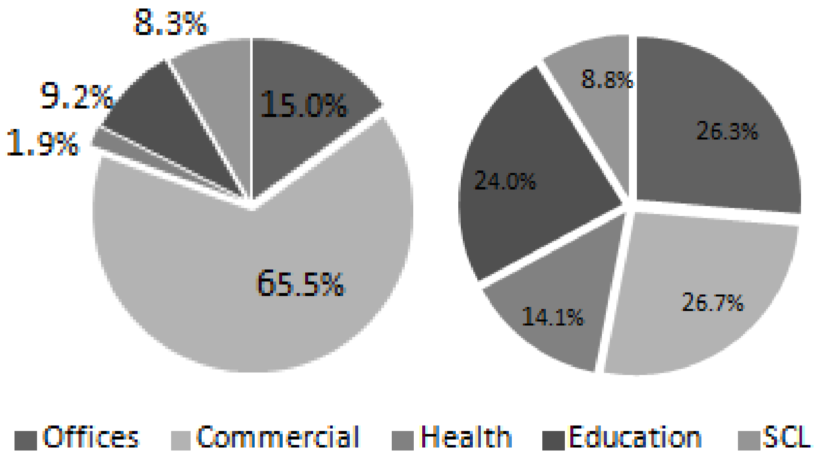


Figure 4.5: Percentages of (from left to right) buildings and total livable surface area in Year 2009, with respect to the type of building within the non-residential sector (SCL: Sport&Culture&Leisure).

- **Segmentation criterion 2:** Climate zone

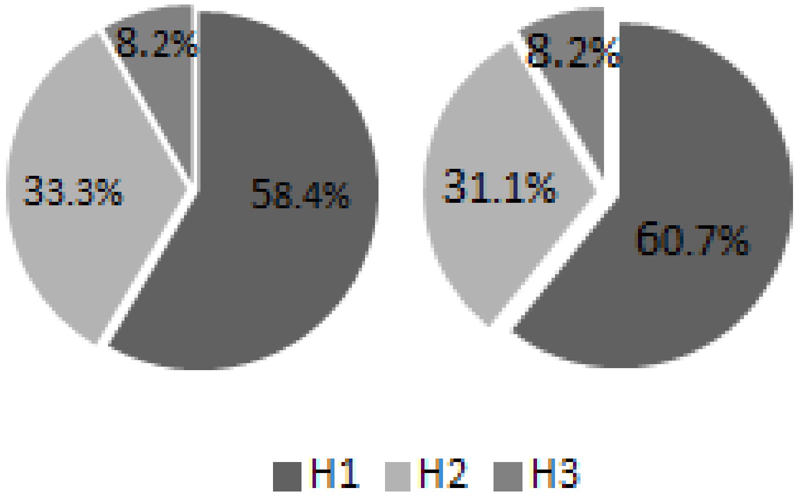


Figure 4.6: Percentages of (from left to right) buildings and total livable surface area in Year 2009, with respect to the climate zone (H1, H2, H3) within the non-residential sector.

- **Segmentation criterion 3:** Period of construction

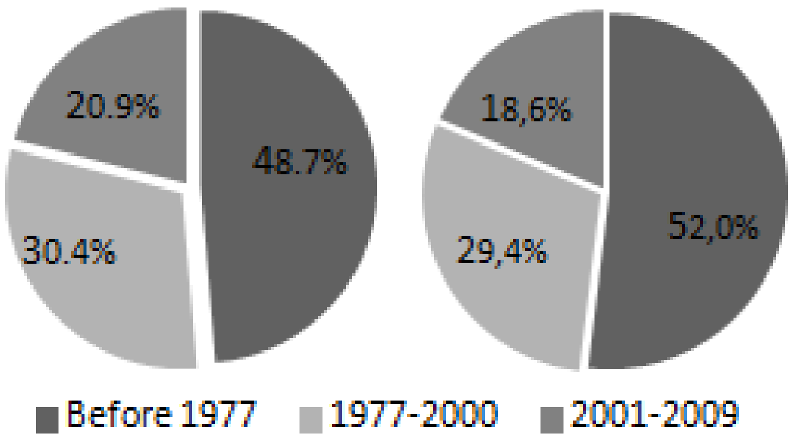


Figure 4.7: Percentages of (from left to right) buildings and total livable surface area in Year 2009, with respect to the period of construction within the non-residential sector.

4.2 Results from characterization of the archetype buildings

This section presents the results of the characterization process, i.e., the specification of the main characteristics of the archetype buildings. The results for all the archetype buildings that describe the residential sector are first presented as a weighted average. Subsequently, the results are shown for all the archetype buildings within each building type. The results for each residential archetype building can be found in Annex I.

The typical residential building, as examined in this thesis, contains on average 1.8 dwellings. Each dwelling has an average heated surface of 85.5 m^2 and is the average occupancy is 2.80 people.

Mechanical ventilation is only available in buildings built after 1975 and no heat exchanger unit within the ventilation system is considered.

The average sanitary ventilation rate is 0.38 $l/s \cdot m^2$. This rate varies according to building type, since the sanitary ventilation rates of new buildings are set by the regulations and the specification of the fan used, whereas for older buildings, they are set depending on the building construction, i.e., the effect of infiltration. The natural ventilation rate for all the residential buildings is 0.41 $l/s \cdot m^2$.

Finally, the mean U-value of the envelope of an average residential building is 1.11$W/m^2 \cdot K$.

The results of the characterization of the residential sector are presented by subsector as follows:

- Single-Family Dwelling (SFD):

A typical SFD has an average heated floor area of 104.5 m^2. Each building has only one dwelling and the average occupancy is 2.77 people.

The sanitary ventilation rate is 0.51 $l/s \cdot m^2$ for buildings built before 1975 and 0.23 $l/s \cdot m^2$ for the remaining buildings.

The average U-value of the building envelope is 1.08 $W/m^2 \cdot K$.

- Private Multi-Family Dwelling (Private MFD)

A typical MFD has an average heated floor area of 66.0 m^2. Each dwelling is occupied on average by 2.83 people. An MFD contains 13.3 dwellings.

The sanitary ventilation rate is 0.51 $l/s \cdot m^2$ for buildings built before 1975 and 0.38 $l/s \cdot m^2$ for the remaining buildings

The mean U-value is 1.36 $W/m^2 \cdot K$.

- Public (Social) Multi-Family Dwelling (Public MFD)

A typical MFD has an average heated floor area of 66.02 m^2. Each dwelling is occupied on average by 2.80 people. A Multi Family building has 12.3 dwellings.

The sanitary ventilation is 0.51 $l/s \cdot m^2$ for buildings built before 1975 and 0.38$l/s \cdot m^2$ for the remaining buildings

The mean U-value is 1.90$W/m^2 \cdot K$.

Non-residential sector

The results of the characterization process for the non-residential sector, which are similar in pattern to those for the residential sector (first showing the whole sector characterization, then for each building type), are presented below (see Annex J for the results for each archetype building within the non-residential sector):

The weighted average non-residential building has an average heated floor area of 569.7 m^2 and has 2.6 levels.

Mechanical ventilation is only available in buildings built before 1976, and no heat exchanger unit within the ventilation system is considered.

The average sanitary ventilation rate is 0.78 $l/s \cdot m^2$, while the natural ventilation rate is 2.78 $l/s \cdot m^2$.

Finally, the mean U-value of the envelope of a typical non-residential building is 1.34 $W/m^2 \cdot K$.

The results from the characterization of the non-residential sector are presented by subsector as follows:

- Offices

An average office building has a total heated floor area of 1000.0 m^2 and has 9.0 levels.

The sanitary ventilation rate is 0.74 $l/s \cdot m^2$ for all the buildings in this subsector.

The mean U-value is 1.79 $W/m^2 \cdot K$.

- Commercial buildings

An average commercial building has a total heated floor area of 232.5m^2 and has 1.4 levels.

The sanitary ventilation rate is 0.83 $l/s \cdot m^2$ for all commercial buildings.

The mean U-value is 1.28 $W/m^2 \cdot K$.

- Health buildings

An average health building has a heated floor area of 4039.0 m^2 and has 3.0 levels.

The sanitary ventilation rate is 1.47 $l/s \cdot m^2$ for all the buildings in this subsector.

The mean U-value is 1.27$W/m^2 \cdot K$.

- Education buildings

An average education building has a heated floor area of 1489.1m^2 and has 1.8 levels.

The sanitary ventilation rate is 0.37 l/s·m^2 for all the education buildings.

The mean U-value is 1.30 W/m^2·K.

- SCL buildings

An average building from the SCL sector has a total heated floor area of 605.0 m^2 and has 1.2 levels.

The sanitary ventilation rate is 0.69 l/s·m^2 for all the buildings in this subsector.

The mean U-value is 1.01 W/m^2·K.

4.3 Results of the quantification

The total number of existing residential buildings in metropolitan France in Year 2005 was 15,016,918 (see Annex G for distributions in relation to each archetype building), including 14,084,243 SFD buildings, 581,762 private MFD, and 350,913 public MFD. This result cannot be compared to the literature or official databases, as such official data (e.g., the number of buildings) are lacking.

Regarding the non-residential sector, the total number of buildings in this sector is 1,330,392 (see Annex K for distributions in relation to each segmentation criterion).

4.4 Results from the ECCABS simulation and validation

The simulation of the French building stock, using the selected archetype buildings, provides the total energy demands within the residential sector and the non-residential sector for Years 2005 and 2009, respectively.

To validate the energy demand, the data must be disaggregated by end-use, since ECCABS provides the energy demand results in a form that is disaggregated for the parameters of "heating", "hot water", and "electricity".

This section presents the modeling results for final energy consumption, and these results are compared to the corresponding values from the literature. The useful energy consumption (the energy demand) is also presented.

In some of the tables in this chapter the values highlighted by gray stripes are these not available elsewhere in the literature, and are therefore a valuable output of this work. In particular, information on useful energy demand is rarely reported in the literature. The final energy demands for the residential and non-residential sectors are derived from ADEME (2006a). However, for neither of the sectors, these values are not available disaggregated per end-use/building type in international databases.

In the present work, the energy required to satisfy specific end-uses in a building is termed the 'net energy'. It comprises heating, cooling, ventilation, hot water, lighting, and appliances. Net energy is not what the consumer pays for, but rather that from which the consumer derives benefits, after losses in the technical systems installed in the building (including on-site renewable energy systems) have been taken into account. Therefore, measurement of the net energy is difficult, and it is a valuable output from the model.

<u>Residential sector</u>

Energy consumption for the French residential building sector for Year 2005 was 437.2 TWh, according to the results of the simulation, as presented in Table 4.1.

For each building type, the simulation gives 282.9 TWh for the SFD, 87.8 TWh for Private MFD, and 66.4 TWh for Public MFD.

The final energy demand for the French residential building stock in Year 2005 obtained in the present work and presented above is 5.0% lower than the 460.0 TWh specified in ADEME (2006a) and 7.4% lower than the 472.1 TWh reported by Eurostat. The energy consumption reported in the literature is presented in detail in Annex L. However, some adjustments were required to subtract the values for the final energy used in the French overseas departments (Departements outre mers) from the primary data (see clarifications in Annex E).

The disaggregated by end-use results from the residential building stock simulation presented in Table 4.1 show that consumption of energy for heating accounts for 264.0 TWh, while the corresponding value for hot water is 68.8 TWh and for electricity is 102.9 TWh. These values from those listed in ADEME (2006a): heating, 323.0 TWh; hot water, 58.6 TWh; and specific electricity, 78.0 TWh. Possible reasons for these discrepancies between the values from statistical sources and the results of the simulation are: inaccuracies during the characterization of the archetype buildings (for instance, the U-values may be inaccurate, the effective heat capacity should be specific French buildings, and some of the other input values are not correct); other assumptions, such as the number of PODs, and the fact that no non-PODs have been taken into account, which means that the energy usage associated with these buildings is not included; and the fact that the weather file data used do not correspond to the year of the simulation and therefore the temperatures used during the simulation don't match with the real ones for the year 2005.

	Final energy demand for:				Useful energy demand for:			
Energy end-use	Heating	Hot water	Electricity	Total	Heating	Hot water	Electricity	Total
SFD	183.9	37.7	61.3	282.9	167.2	34.3	55.7	257.2
Private MFD	39.7	20.6	27.5	87.8	36.1	18.7	25.0	79.8
Public MFD	39.6	11.4	15.4	66.4	36.0	10.4	14.0	60.4
Residential	263.2	69.7	104.2	437.2	239.4	63.4	94.75	397.5

Table 4.1 Final and useful energy demands of the French residential sector in 2005, according to end-use and building subtypes; the results of the simulation in the present work are given in TWh. Values presented on the hatched gray background are those not usually found in the literature.

Expressing the results in Table 4.1 in percentage shares, the distribution of the final energy demand in 2005, categorized by end use for the different buildings types in the residential sector, are presented in Figure 4.8. Heating represents the largest share for all building types, and especially in the case of SFDs, since these buildings have a larger average heated floor area per dwelling. As shown in Figure 4.8, Private MFDs account for the largest shares of both electricity and hot water consumption, while Public MFDs have a similar heating share to SFDs, since the insulation performance of these buildings is poorer, which means that more heating is required to maintain the same indoor temperature.

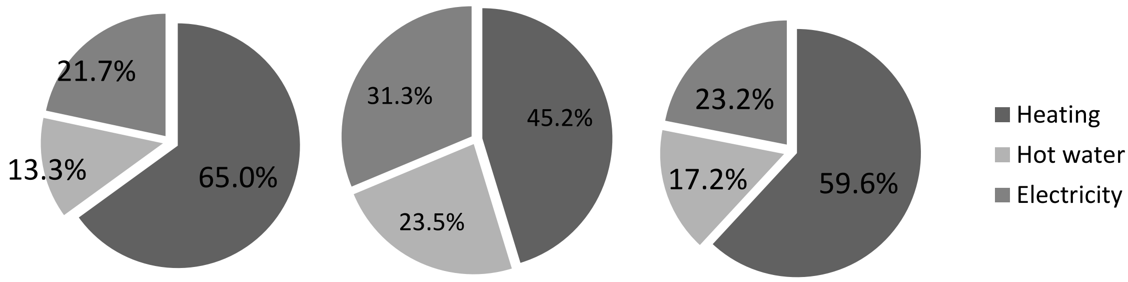


Figure 4.8: Disaggregated results for final energy consumption by end use for (from left to right): SFD, Private MFD, and Public MFD.

The disaggregated distributions of end-use energy consumption for the residential sector are shown in Figure 4.9, in which heating is the predominant end-use, while hot water accounts for only about 16% of end-use energy consumption. This percentage is lower than the corresponding value of 20% reported for Spain (Magrama, 2011) but is higher than, for instance, the corresponding value for German consumption of 9% (Schütz, 2006).

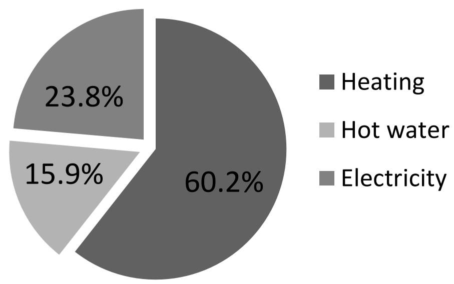


Figure 4.9: Disaggregated results for final energy consumption by end use for the entire residential sector.

Table 4.2 presents the results of the simulation for the residential buildings in terms of specific annual energy demand (kWh/m^2). The average residential building consumes 192.7 kWh/m^2, which is similar to the 211.1 kWh/m^2 reported by ADEME (2006a) if one considers that the latter value does not include the energy used for cooking. Public MFDs consume almost twice as much heating as Private MFDs, as evidenced by the data in Table 4.2.

	Final energy demand for:				Useful energy demand for:			
Energy end-use	Heating	Hot water	Electricity	Total	Heating	Hot water	Electricity	Total
SFD	125.0	25.6	41.6	192.3	113.6	23.3	37.8	174.7
Private MFD	77.6	40.2	53.8	171.6	70.5	36.5	48.9	155.9
Public MFD	139.1	40.1	54.0	247.7	126.4	36.4	49.1	225.1
Residential	116.1	30.7	45.9	192.7	105.5	27.9	41.7	175.1

Table 4.2: Results from the simulation process, presented in kWh/m^2 of final and useful energy consumption, for the residential sector by end-use and building type. The values presented on the hatched gray background are those not usually found in the literature.

<u>Non-residential sector</u>

The final energy demand of the non-residential building sector in France in 2009 is 186.25 TWh, according to the results of the simulation (Table 4.3). Final energy consumption is 55.2 TWh for the office sector, 54.4 TWh for the commercial sector, 28.6 TWh for health, 28.9 TWh for education, and 19.1 TWh for the SCL sector.

Building type	Final Energy demand for:				Useful energy demand for:			
	Heating	Hot water	Electricity	Total	Heating	Hot water	Electricity	Total
Offices	23.3	1.9	30.2	55.2	22.3	1.8	28.9	52.9
Commercial	25.9	3.2	25.3	54.4	24.8	3.1	24.2	52.1
Health	12.8	4.5	11.3	28.6	12.3	4.3	10.8	27.4
Education	18.2	2.7	7.9	28.9	17.4	2.6	7.6	27.7
SCL	5.2	4.6	9.3	19.1	5.0	4.4	8.9	18.3
Total non-residential	85.4	16.8	84.1	186.3	81.8	16.1	80.5	178.4

Table 4.3: Final energy and useful energy demands for the French non-residential building sector disaggregated by subsector and end use, as obtained from this work (data for 2009 in TWh). The values presented on the hatched gray background are those not usually found in the literature.

The total final energy demand obtained in the present work for the non-residential sector is 1.1% lower than the corresponding demand of 188.3 TWh given by CEREN (Ministry of Sustainable Development, 2007) (see Annex M, in which the value for final energy consumed has been subtracted from the CEREN values for Year 2007, as well as Annex N, in which the energy for cooking has been calculated, which is already subtracted in Annex M). The shares of the different subsectors (Office, Commercial, Health, Education, SCL) are only slightly different, i.e., 31.5%, 29.4%, 14.6%, 14.2%, and 10.3%, respectively, (versus 29.7%, 29.2%, 15.4%, 15.5%, and 10.3%, respectively, as obtained in the present work). Therefore, the results obtained in the present study can be judged to be satisfactory. The consumption levels of each non-residential subsector disaggregated by end use are presented in Figure 4.10. That figure shows that electricity use is the predominant end use in the office subsector, mainly due to the heavy use of electric appliances, whereas the educational sector mainly uses energy for heating purposes.

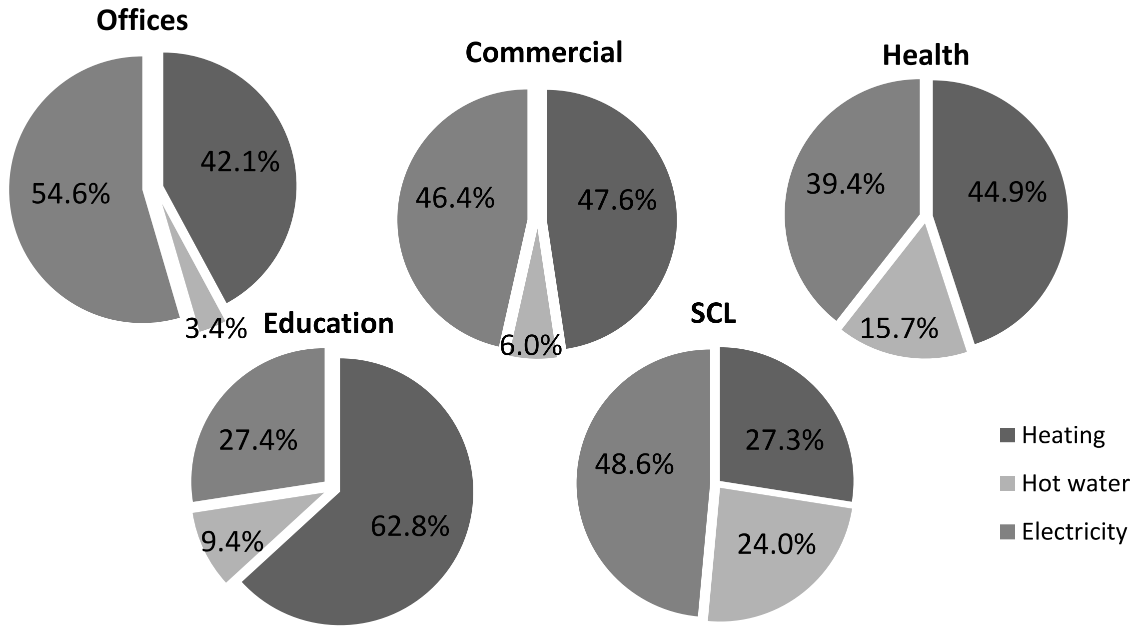


Figure 4.10: Disaggregated results, presented as percentages of final energy consumption, by end use for the Office, Commercial, and Health (upper panels) and Education and SCL (lower panels) subsectors.

The disaggregated by end use results for the entire non-residential sector give a similar value for heating plus hot water consumption (54,9%) to that reported in ADEME (2011), in which the final energy consumption for heating plus hot water accounted for 58% of the total (see Figure 4.11 for the consumption shares).

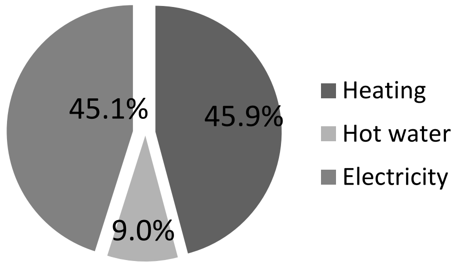


Figure 4.11: Disaggregated results for final energy consumption by end use in the non-residential sector, as obtained in the present study.

Regarding the average specific final energy demand for a typical non-residential building (245.7 kWh/m^2 in total and 134.8 kWh/m^2 for heating and hot water, as presented in Table 4.4), ADEME (2011) presents a total value of 209 kWh/m^2, with 123 kWh/m^2 attributed to heating and hot water. Thus, these values are similar to those produced in the simulation. However, ADEME (2006a) also takes into account the transport sector, community housing, and the bar, restaurant and hotel subsectors in deriving the average value for energy consumption. Moreover, in the study of ADEME (2011), the specific consumption of each subsector is stated as: 268 kWh/m^2 for offices; 233 kWh/m^2 for commercial buildings; 202 kWh/m^2 for health buildings; 122 kWh/m^2 for education; and 193 kWh/m^2 for SCL buildings. These values are in good agreement with the simulation results obtained in this thesis work, with the exceptions of the health and SCL subsectors, for which ADEME reports lower specific consumption levels. These discrepancies may be due to inaccuracies in the characterization of these two subsectors (particularly with respect to the average heated floor area and other parameters, especially for the SCL subsector, which is not described in-depth in the literature). Regarding the education subsector, the observed differences may be due to the non-inclusion of energy for cooking in the calculation of energy consumption.

Energy end use	Heating	Hot water	Electricity	Total
Offices	116.6	9.4	151.1	276.6
Commercial	127.8	16.0	124.7	268.4
Health	120.6	42.2	105.9	268.6
Education	99.7	14.9	43.5	158.7
SCL	77.9	68.6	138.7	285.1
Non-residential	112.6	22.2	110.9	245.7

Table 4.4: Results from the simulation, with values in kWh/m^2, for the non-residential sector by end-use and type of building. The values presented on the hatched gray background are those not usually found in the literature.

5 Sensitivity analysis

This chapter presents and dissects the results of the sensitivity analysis, which was carried out to identify the parameters that have the greatest impacts on the simulation results. The sensitivity analysis has been used to assess the importance of gaps in the data gathering that were already identified during the characterization of the buildings (see Section 3.3).

The analysis is performed separately for the residential and non-residential sectors, although the input parameters under study are the same for both sectors. The selected parameters are those identified during this study as being less well documented, owing to the lack of data, and therefore, those associated with a greater degree of uncertainty. The selected parameters, of which there are 22 in total, are presented in Tables 5.1 and 5.2.

The sensitivity analysis shows the impact on the results of a change of input values, ranging from -10% to +10%. Following the methodology of Firth et al. (2009), the steps of the input variable analysis are 10%, 5%, and 1% of increase and decrease, respectively, in relation to their original applied values. These input parameters have been ordered by categories (Tables 5.1 and 5.2).

The sensitivity analysis aims to show the effect of each input parameter by means of either the sensitivity coefficient or the normalized coefficient. Although both coefficients have been calculated for each parameter and are shown in the tables, the normalized sensitivity coefficient will be used to distinguish the relevant parameters from the non-relevant ones. An input parameter is considered to be relevant when it has a normalized sensitivity coefficient > 0.1 in absolute values.

<u>Residential sector</u>

Table 5.1 shows the results obtained in the sensitivity analysis for the residential sector. Taking as a reference the normalized sensitivity coefficient, it is clear that there are eight major relevant input parameters for a normalized coefficient greater than |0.1|: gas boiler efficiency (Eff gas); oil boiler efficiency (Eff oil); heated floor area (A); total external surfaces of the building (S); mean U-value (Umean); minimum indoor temperature (Tmin); sanitary ventilation rate (Vc); and hot water demand (Hw).

The remaining input parameters listed in Table 5.1 are considered to be non-relevant, which means that a small change in these parameters does not have a strong effect on the energy consumption of the sector. In other words, for these parameters, it is not as crucial as for the relevant parameters to quantify them with a high level of accuracy.

Input parameter[1]	Category[2]	Initial set value for the input parameter (k_j)	Overall change in the input parameter ($2\Delta k_j$)	Overall change in the output parameter (change in y_i)	Sensitivity coefficient (δyi/δkj)	Normalized sensitivity coefficient S_{ij}
Sw	C	55.298	11.060	-4.845	-0.438	-0.060
Ts	C	0.700	0.140	-4.844	-34.600	-0.060
Umean	C	1.132	0.226	56.941	251.551	0.711
Wc	C	0.550	0.110	-4.844	-44.036	-0.060
Wf	C	0.700	0.140	-4.844	-34.600	-0.060
Eff gas	E	0.870	0.174	-22.070	-126.839	-0.2446
Eff oil	E	0.850	0.170	-19.480	-114.588	-0.2174
A	G	368.655	73.731	28.815	0.391	0.360
Ac	G	2.570	0.514	4.135	8.045	0.053
S	G	531.304	106.261	56.944	0.536	0.711
HyP	O	0.360	0.072	1.431	19.875	0.018
Oc	O	1.994	0.399	-4.750	-11.911	-0.059
Tv	O	24.000	4.800	-0.077	-0.016	0.000
Hw	S	3.187	0.637	12.671	19.881	0.158
Lc	S	1.735	0.347	2.737	7.889	0.035
TC	S	168733996.640	33746799.328	-0.677	0.000	-0.008
Tmax	T	24.000	4.800	-0.185	-0.038	-0.001
Tmin	T	19.000	3.800	128.888	33.917	1.621
Pfh	V	0.163	0.033	-0.157	-4.804	-0.001
SFP	V	0.909	0.182	0.245	1.347	0.003
Vc	V	0.405	0.081	12.744	157.411	0.159
Vcn	V	0.410	0.082	0.000	0.000	0.000

[1]Input variables: Sw (surface of windows), Ts (Coefficient of solar transmission of the window), Umean (mean U-value), Wc (shading coefficient of windows), Wf (frame coefficient of the window), Eff gas (efficiency of gas boilers), Eff oil (efficiency of oil boilers, A (heated floor area), Ac (heat gains from appliances), S (Total external surfaces of the building), HyP (Consumption of the hydro pumps), Oc (heat gains from occupation), Tv (Indoor temperature to start opening windows), Hw (hot water demand), Lc (heat gains from lighting), TC (heat capacity of a heated space), Tmax (maximum indoor temperature), Tmin (minimum indoor temperature), Pfh (heat losses of the fan), SFP (Specific Fan Power), Vc (sanitary ventilation rate), Vcn (natural ventilation rate)

[2]Input variable categories: construction (C), efficiency (E), geometry (G), other (O), services (S), temperature (T), ventilation (V)

Table 5.1: Results of the sensitivity analysis for the residential sector.

To give a clearer perspective on the results for the residential sensitivity analysis, the behaviors of the relevant input parameters are plotted in a graph (Figure 5.1). The variability of the energy consumption in percentage is shown for each step of variation (1%, 5%, 10%, -1%, -5%, -10%) in the input parameter, to generate the curves shown in the graph. It is noteworthy that the input parameter that has the strongest effect on energy consumption is the minimum indoor temperature Tmin (1.621 of the normalized sensitivity coefficient). A 10.0% increase in the minimum indoor temperature leads to a 17.1% increase in energy consumption. Therefore, this value should be calculated with the maximum level of accuracy.

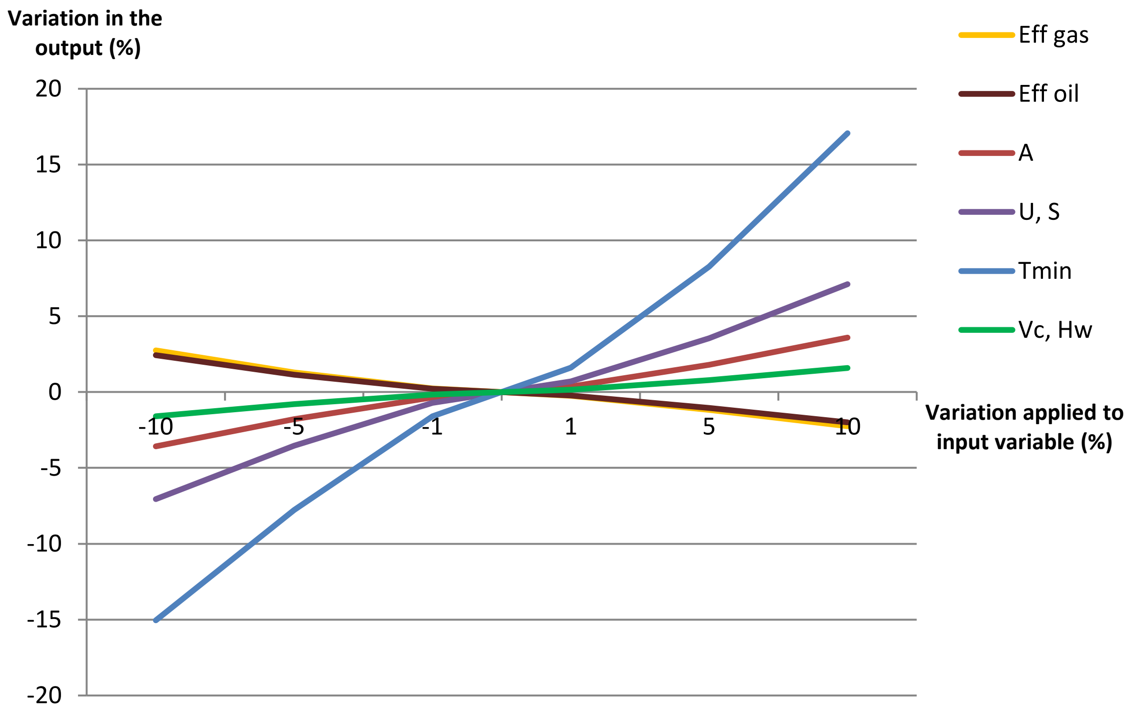


Figure 5.1: Sensitivity analysis for the input parameters of Eff gas, Eff oil, A, U, S, Tmin, Vc and Hw within the residential sector.

Regarding the other relevant input parameters, five of them (A, Umean, S, Vc and Hw) affect the energy consumption in direct proportion to its variation, i.e., an increase in these parameters increases a percentage in the energy consumption. In contrast, the efficiencies of the gas boiler and oil boiler affect in such a way that an increase of them leads to a decrease in the energy consumption. However, these two last input parameter have lower impacts than the other parameters, being only comparable to the sanitary ventilation rate and the hot water demand (Vc and Hw).

<u>Non-residential sector</u>

The results of the sensitivity analysis for the non-residential sector are shown in Table 5.2. There are few differences compared to the sensitivity analysis for the residential sector, and the major relevant parameter is once again the minimum indoor temperature (Tmin), with a normalized sensitivity coefficient of 1.4. As obtained from the simulation, an increase of 10.0% in this parameter leads to an increase in energy consumption of 15.2%.

The other relevant parameters (i.e., having a normalized sensitivity coefficient greater than |0.1|) within the sensitivity analysis for the non-residential sector are: gas boiler efficiency (Eff gas); oil boiler efficiency (Eff oil); heated floor area (A); total external surfaces of the building (S); mean U-value (Umean); sanitary ventilation rate (Vc); hot water demand (Hw), and the heat gains from lighting (Lc).

Input variable	Category	Initial set value for the input parameter (k_j)	Overall change in the input parameter ($2\Delta k_j$)	Overall change in the output parameter (change in y_i)	Sensitivity coefficient (δyi/δkj)	Normalized sensitivity coefficient S_{ij}
Wc	C	0.550	0.110	-1.281	-11.645	-0.027
Sw	C	148.313	29.663	-1.281	-0.043	-0.027
Umean	C	1.256	0.251	19.686	78.393	0.562
Wf	C	0.700	0.140	-1.281	-9.150	-0.027
Ts	C	0.700	0.140	-1.281	-9.150	-0.027
Eff oil	E	0.850	0.170	-3.060	-18.000	-0.081
Eff gas	E	0.760	0.152	-7.950	-52.303	-0.209
A	G	1322.473	264.495	17.651	0.067	0.503
Ac	G	2.710	0.542	1.625	2.998	0.054
S	G	1695.479	339.096	19.686	0.058	0.562
HyP	O	0.36	0.072	0.479	6.653	0.022
Oc	O	1.856	0.371	-1.357	-3.656	-0.029
Tv	O	24.000	4.800	-1.562	-0.325	-0.003
Hw	S	2.418	0.484	3.213	6.645	0.099
Lc	S	8.329	1.666	5.085	3.053	0.151
TC	S	950572696.570	190114539.314	-0.395	0.000	-0.002
Tmax	T	25.000	5.000	-1.119	-0.224	0.025
Tmin	T	19.623	3.925	49.685	12.659	1.399
Pfh	V	1.338	0.268	-0.389	-1.453	-0.002
SFP	V	2.075	0.415	0.583	1.405	0.062
Vc	V	0.775	0.155	8.986	58.012	0.261
Vcn	V	2.778	0.556	0.002	0.004	0.009

[1]Input variables: Sw (surface of windows), Ts (Coefficient of solar transmission of the window), Umean (mean U-value), Wc (shading coefficient of windows), Wf (frame coefficient of the window), Eff gas (efficiency of gas boilers), Eff oil (efficiency of oil boilers, A (heated floor area), Ac (heat gains from appliances), S (Total external surfaces of the building), HyP (Consumption of the hydro pumps), Oc (heat gains from occupation), Tv (Indoor temperature to start opening windows), Hw (hot water demand), Lc (heat gains from lighting), TC (heat capacity of a heated space), Tmax (maximum indoor temperature), Tmin (minimum indoor temperature), Pfh (heat losses of the fan), SFP (Specific Fan Power), Vc (sanitary ventilation rate), Vcn (natural ventilation rate)

[2]Input variable categories: construction (C), efficiency (E), geometry (G), other (O), services (S), temperature (T), ventilation (V)

Table 5.2: Results of the sensitivity analysis for the non-residential sector.

The remaining input parameters listed in Table 5.2 are considered to be non-relevant, which means that a small change in these parameters does not have a strong effect on the energy consumption of the sector. In other words, for these parameters, it is not as crucial as for the relevant parameters to quantify them with a high level of accuracy.

As previously shown for the residential sensitivity analysis, the energy consumption variations obtained during modification of the input parameters are plotted in a graph (see Figure 5.2).

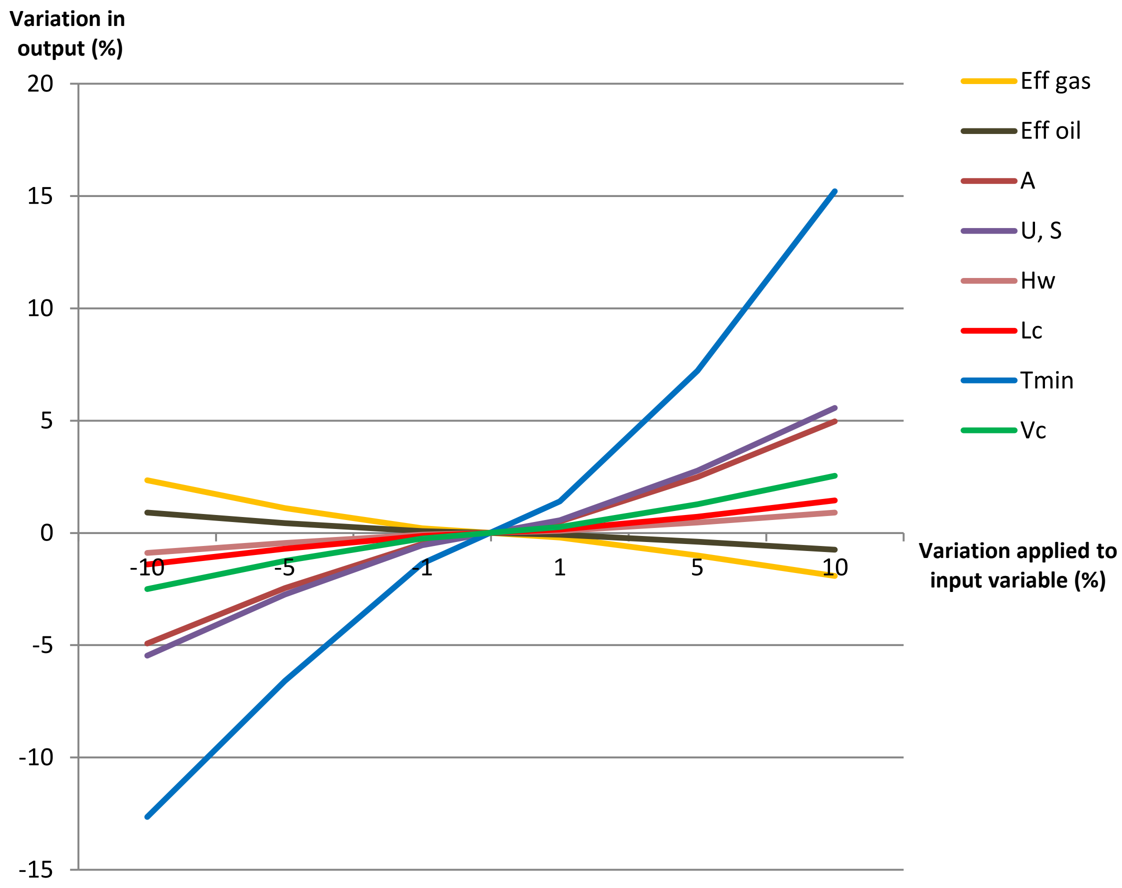


Figure 5.2 Sensitivity analysis for the input parameters of Eff gas, Eff oil, A, U, S, Tmin, Vc and Hw within the non-residential sector.

As shown in Figure 5.2, the minimum indoor temperature has the strongest effect on energy consumption. The remaining input parameters have more modest effects on energy consumption. However, among these parameters, the heated floor area (A), together with the mean U-value (U) and the total external surface of the building (S), have stronger effects than the other parameters.

The oil and gas boiler efficiencies (Eff gas, Eff oil) are (as was the case for the residential sector) the only relevant input parameter that have an indirectly proportional effect on energy consumption. However, applying the same increase to the efficiencies of the oil and gas boilers leads to a larger decrease in energy consumption in the case of the gas boiler. Therefore, gas boiler efficiency has a stronger impact than oil boiler efficiency within the non-residential sector.

6 Discussion

Possible reasons for the discrepancies between the results obtained from the simulation using the ECCABS model and the statistics derived from the reference databases (further presented in Annex L) are discussed in this section. In addition, a comparison of the earlier study conducted with the Spanish building stock (Medina, 2011) with this thesis will be presented. This type of comparison is interesting, since both studies have been developed with the same methodology and within the same context, i.e., the Pathways Project.

One possible source of the discrepancies between the modeled energy demand and the statistical values is the uncertainties associated with some of the assumptions that were made during the characterization process. These assumptions and others are discussed below for the residential sector:

- For the segmentation process of defining the archetype buildings, the classification of PODs into the segmentation criteria proposed by ANAH (2008) has been adapted by:

  a) previously allocating non-POD's (since ANAH includes them) according to climate zone, renovation state, and energy source, as was done for all the residential stock in the study of ANAH (Martinlagardette, 2009). Allocation according to type of building and construction period was possible without the need for any assumption;

  b) assuming all Public MFDs to be permanently occupied;

  c) distributing the Public MFDs into the different construction periods using the same proportion as for the Private MFDs;

  d) assuming a renovated share of 40% for the MFD buildings built before 1975.

  These assumptions could cause the residential building stock that was used in this thesis to not match completely with the real stock, thereby giving a different energy demand.

- Regarding the characterization process, The U-values specified for different archetype buildings differ significantly between the various sources (ECOFYS, ADEME, CLIP), as U-values have not been specified in the French regulations. It has been assumed in the characterization process that the U-values for buildings located in climate zone H3 are 15% higher than those for buildings in climate zones H1 and H2. Nevertheless, the sensitivity analysis shows that this parameter (U-value) strongly affects the resulting energy demand, and thus further work is needed to clarify the above-mentioned issues.

  Finally, the data used in Section 3.3 to characterize the windows surface, Sw, was generally lacking. However, the sensitivity analysis shows that Sw influences the resulting energy demand. Although Sw has been set to 15% of the heated floor area for all the residential buildings (Martinlagardette, 2009), this value might be different depending on the age of the building and the climate zone in which it is located. Recently constructed buildings have larger window surfaces than older ones, and buildings located in warm climate regions also have larger window surfaces. Therefore, this parameter should be studied in greater detail.

- Regarding the quantification process, it turned out to be difficult to specify the total number of permanent occupied dwellings in France, and thereby to obtain the number of buildings in the quantification step. Thus, this value had to be estimated, since the different reports in the literature (Table 3.29) give statistical values that vary significantly depending on the source consulted (variations of more than one million dwellings). In this thesis work, while an average value from the different reports has been used to minimize the inaccuracies, it could still be a source of energy consumption mismatch.

  To define the level of renovation and to know the exact number of dwellings once a renovation has been completed is very difficult, However, it is of great importance to have this information, since the U-value of a refurbished building differs significantly from that of an old building (by up to 80% in some cases), and this obviously has a strong impact on energy consumption. Within the framework of this thesis, it was decided to apply the renovated buildings presented in ANAH (2008), as they have quantified this type of building in France, albeit approximately, and to give them the U-values proposed by ADEME, even if ADEME only takes into account partial renovations of roofs and windows (Martinlagardette, 2009).

Regarding the non-residential sector, some values have been assumed because there is less data available than for the residential sector (IEE, 2007), and this could be a reason for the energy consumption mismatch. These assumptions include:

- Within the segmentation process, the health subsector has been assumed to lack any subsector, even if different buildings providing the possibility to stay overnight or not offering that service have been combined to create the average health building. However, the percentage of buildings providing the possibility to stay overnight or not has been assumed (50%). For a case in which this percentage is lower, the final energy consumption for the health subsector would be higher, since larger health buildings consume more energy.
  Regarding the subsectors of transport, community housing, and hotel, bar and restaurants, characterization has not been possible due to the lack of data, although this should not account for the energy consumption mismatch.
  However, an important point is that the renovation works in buildings in the non-residential sector has not been taken into account. Therefore, the simulation gives a higher value than that predicted if renovation works were included.

- Regarding the characterization of the office subsector, its heated floor area has been assumed to be similar to that of MFDs, although the value is slightly increased (1000 m^2) to take into account the existing large office complexes in France.

  The numbers of levels of commercial, education, and SCL subsectors have been assumed.

  The U-values are not very well detailed in the French thermal regulations. The U-values for non-residential buildings built before 1977 have been assumed to be the same as those for residential buildings, as no thermal regulations existed before this date.

  These assumptions regarding the characterization of the non-residential sector (number of levels per building, heated floor area, and U-value) are the main sources of inaccuracy when calculating the energy demand. The reason for this is that these three parameters strongly affect energy consumption, as shown in the sensitivity analysis. For instance, if the number of levels in the buildings within the office subsector is higher, the energy consumption is higher, as a greater surface of the building is in direct contact with the indoor conditions. Therefore, more detailed and accurate information regarding these three parameters is needed.

- The quantification step takes into account the previous demolition of buildings. However, it has been assumed that the demolition rate for the period 2002-2009 is the same as that for the period 1986-1997. Although the assumed rate obviously cannot be completely accurate, the comparisons described in Section 3.4 shows that this assumption can be accepted.

Regardless of the sector, the values for the effective heat capacity of a heated space (TC) have been assumed to be the same as those obtained for the buildings in Catalonia (Spain) (Barcelona Regional, 2002), due to the lack of data for the French sectors. However, the sensitivity analysis shows that this parameter does not have a strong impact on energy consumption.

The weather files used for the energy simulations contain averaged climatic data for a certain city/weather station, which is assumed to be representative of the whole climate zone. This can represent a source of inaccuracy, since the climate data used are based on measurements conducted between the 1961 and 1990 (Meteotest, 2000). If the energy demand results from the present work were to match the available data, it would be necessary to use the weather files for Year 2005 for the residential buildings and for Year 2009 for the non-residential buildings. Thus, it would be necessary to update the climate data extracted from Meteotest (2000), which was used as input data for the energy simulation.

Since a study of the Spanish building sector within the Pathways Project has been conducted earlier, a comparison of the previous and current studies (Table 6.1) is presented to identify the similarities and differences between these two studies.

Comments regarding:	**Description of Spanish building sector (R+NR). (Medina,2011)**	**Description of French building sector (R+NR) in this thesis.**
Methodology to define archetype buildings		
Segmentation	Possible to define archetype buildings following the Pathways methodology. No category for different ventilation systems.	Possible to define archetype buildings following the Pathways methodology. New category for energy sources used for heating.
Characterization	Main difficulties are linked to the non-residential sector. Lack of data regarding efficiencies of energy systems.	Main difficulties are linked to the non-residential sector. No TC values available for French buildings. Includes mechanical ventilation.
Quantification	No major problems.	Very difficult to obtain quantification of the residential sector due to inconsistencies between the data sources. It is not available the total number of buildings within the non-residential sector, it is only available data on their total constructed surface.
Fuels used	Coal, oil, gas, renewal, electric. Wants to specify for Sh and Hw	Oil, gas, wood, district heating, electric, others
Modeling methodology		
Sensitivity analysis made for:	Entire building sector	Residential and non-residential sectors, separately.
Parameters	U, Hw, TC, Sw, Vc, Vcn, Ac, Lc, Oc, Wc, fuel efficiencies	U, TC, Vc, Lc, Ac, Wc, Hw, Sw
Relevant param.(norm. sensitivity coef. >|0.1|)	U, Hw, TC, Sw, fuel efficiencies	U, Hw, Vc, Sw, Wc (residential). U, Lc, Vc, Hw (non-residential).
Irrelevant param.(norm. sensitivity coef. < |0.1|)	Vc, Vcn, Ac, Lc, Oc	TC, Ac, Lc (residential) TC, Ac, Sw,Wc (non-residential)
Further investigation recommended	TC, Sw, Pfh, Sh, Sc, weather files	Sw investigated. New coefficient related to latitude has been added. Weather files. Weighting coefficients

Table 6.1: Comparison of the French and Spanish building stock description studies.

Both the Spanish and French building stock descriptions were carried out within the framework of the Pathways Project, to allow validation of the use of the ECCABS model, and both studies have succeeded in representing the residential and non-residential sectors by means of archetype buildings.

The French study (the work of this thesis) includes some additional descriptions to those used in the Spanish study, such as:

a) includes an extra segmentation criterion for the residential sector (the energy source for heating);
b) takes into account mechanical ventilation and therefore, specific fan power values and losses;
c) separates the sensitivity analyses of the residential and non-residential sectors. (However, the efficiencies of the fuels used are not investigated);
d) includes the latitude parameter in the simulation model.

The sensitivity analyses of the two studies reveal the importance of the mean U-value, hot water demand, and the surfaces of windows. However, the Spanish analysis found that the effective heat capacity of a heated space was relevant, while the French study did not find this to be relevant.

7 Conclusions and further work

Some conclusions can be made regarding the continuous 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 building stock, using the French buildings as a case study. Specifically, with respect to the suitability of the bottom-up methodology to describe a building stock through archetype buildings:

- It has been possible to segment the French building stock into archetype buildings for both the residential and non-residential sectors. Moreover, an extra category, the energy source for heating, has been added to the segmentation of the French dwelling stock. For the non-residential sector, there is much less available information available.

- Characterization has been possible for the subsectors of Office, Commercial, Health, Education, and SCL, covering 83% of the total surface of this sector and 80% of the final energy consumed. Only the subsectors of hotels, restaurants and bars, as well as those of transport and community housing had to be excluded from the present study due to a lack of relevant data.

- It has been possible to characterize and quantify the archetype buildings used in this thesis. However, some parameters have of necessity been derived by means of assumptions, including some U-values, the surfaces of windows (Sw), the hours of use of appliances, lighting, or occupation, the heated floor area, and the effective heat capacity of a heated space (TC).

- Regarding the contribution to the construction of a database of buildings in the EU, France can be included in a EU database that comprises archetype buildings, since its building sector can be defined using 54 archetype buildings for the residential sector and 45 archetype buildings for the non-residential sector. However, the information regarding the number of permanently occupied dwellings (POD) in France is sometimes ambiguous and varies depending on the data source.

With respect to the suitability of applying the ECCABS model to the peculiarities of France as a EU country with a temperate climate:

- It can be concluded that the ECCABS model gives reliable results when applied to a temperate climate country, such as France, since the energy consumption obtained from the model is similar to that published in official statistics.

- To apply effectively the simulation model, a correction factor for latitude (the latitude coefficient) has been used to adapt the model for the solar irradiation characteristics of France.

- The mean U-value appears to be the input variable the most relevant regarding the effect on energy consumption; the same conclusion was drawn in the study of the Spanish building stock conducted by Medina (2011).

- The effective heat capacity of a heated space (TC) is shown to be a less-relevant parameter in the sensitivity analysis. This is consistent with the fact that the cooler the country is, the further the average outdoor temperature is from the desired internal temperature.

However, the weather files chosen as being representative of each climate zone could be further improved, since the data they contain refer to a year that is different than the reference years used in the present study.

The French building stock is described in this thesis, and further studies, outside the scope of this Master's Degree thesis, should be designed to implement the energy efficiency measures and analyze the consequences for energy demand in the French building sector. This should facilitate assessments of suitable pathways towards sustainable energy systems, particularly within the building sector in Europe.

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Annex A: Heated floor area for education

In order to obtain the calculated values from Table 3.11. in Section 3.3 some information has been gathered. Table A.1 shows the number of buildings of "école elementaire", "école maternelle" and "college and lycee" taken from the Ministry of Education (2010)

From: NATTEF (INSEE) 07114							
Établissements publics et privés du 1er et du 2nd degré							
	1980-81	**1990-91**	**2006-07**	**2007-08**	**2008-09**	**2009-10**	**2010-11**
Écoles maternelles	16.359	19.248	17.410	17.213	16.942	16.497	16.189
Écoles élémentaires	52.327	44.975	38.257	38.116	37.933	37.783	37.609
Total premier degré	**68.686**	**64.223**	**55.667**	**55.329**	**54.875**	**54.280**	**53.798**
Collèges	6.648	6.833	7.011	7.025	7.031	7.017	7.018
Lycées professionnels	2.331	2.171	1.696	1.687	1.672	1.653	1.637
Lycées d'enseignement général et technique	2.328	2.584	2.623	2.626	2.630	2.627	2.640
Établissements régionaux d'enseignement adapté	nd	82	80	80	80	80	80
Total second degré	**11.307**	**11.670**	**11.410**	**11.418**	**11.413**	**11.377**	**11.375**
nd : donnée non disponible.							
Champ : France.							
Source : Depp.							

Table A.1: Number of buildings for "école elementaire", "école maternelle" and "college and lycee" (Ministry of Education, 2010)

Regarding the higher education the number of buildings has been found in the Ministry of Education (2010) and is shown in Table A.2. However these values include the buildings located in D.O.M. and therefore a conversion coefficient has been extracted from the same source as it can be seen in Table A.3. Since the data is divided between metropolitan France and D.O.M. it has been extracted a coefficient which has been used to transform the total surface of education buildings in France into the total surface of education buildings in metropolitan France since this is the scope of the master thesis.

[1] Evolution du nombre d'établissements et structures de l'enseignement supérieur										
(France métropolitaine + DOM)										
Type d'établissem	2001 2002	2002 2003	2003 2004	2004 2005	2005 2006	2006 2007	2007 2008	2008 2009	2009 2010	2010 2011
Universités (1)	80	82	82	81	81	81	81	79	79	79
IUT	112	112	113	114	114	114	114	115	114	114
IUFM universitaires	0	0	0	0	0	0	0	27	27	0
IUFM non universitair	30	30	30	30	30	30	30	3	3	0
Grands établissemer	8	8	8	9	9	9	10	10	11	11
STS (2)	2.068	2.100	2.118	2.116	2.109	2.125	2.133	2.182	2.207	2.258
dont : publiques	1.275	1.293	1.305	1.311	1.312	1.323	1.319	1.335	1.335	1.358
privées	793	807	811	805	797	802	814	847	872	900
CPGE (2)	403	403	405	406	407	406	414	422	429	442
dont : publiques	311	312	314	315	317	318	324	331	337	345
privées	92	91	91	91	90	88	90	91	92	97
Ecoles d'ingénieurs	243	243	244	250	246	247	240	231	232	238
dont : publiques, de	68	69	66	70	69	70	74	59	57	59
publiques, de	19	20	20	21	21	21	11	10	10	10
publiques, de	3	3	3	3	3	3	2	2	2	2
publiques, in	85	83	83	85	84	86	85	92	94	97
privées	68	68	72	71	69	67	68	68	69	70
Ecoles de commerce	234	225	228	227	223	219	210	206	212	213
Etablissements unive	19	15	13	13	13	13	13	13	12	12
Ecoles normales sup	4	4	4	4	4	4	4	5	6	5
Ecoles d'architecture	23	23	23	23	23	23	20	21	22	22
Ecoles supérieures a	229	243	238	237	236	235	242	233	237	235
Ecoles paramédicales	420	409	420	420	418	412	410	409	414	414
Ecoles préparant aux	133	143	147	143	161	180	188	202	202	202
Autres écoles de spe	212	219	221	222	217	212	206	198	203	197
dont : écoles juridi	64	64	61	62	57	58	56	52	52	51
écoles de jo	23	24	25	25	25	24	25	23	27	29
écoles vétéi	4	4	4	4	4	4	4	4	4	4
TOTAL	4.218	4.259	4.294	4.295	4.291	4.310	4.315	4.356	4.410	4.442

Table A.2: Number of buildings of high education(Ministry of Education, 2010).

[2] Nombre d'établissements et de structures de l'enseignement supérieur par académie en 2010-2011

(France métropolitaine + DOM)

	Structures relevant des universités			STS	CPGE	Ecoles d'ingénieurs indépendantes des univ.	Ecoles de commerce, gestion, compta.	Autres établissements	
	Universités (1)	IUT	Ecoles d'ingénieurs dépendantes des univ.						
Aix-Marseille	4	3	3	94	18	5	10	77	
Amiens	1	3		66	8	4	4	31	
Besançon	1	2	1	49	9	2	4	17	
Bordeaux	5	6	2	109	12	9	20	59	
Caen	1	3	2	55	10	4	4	34	
Clermont-Ferrar	2	2	2	47	11	4	3	28	
Corse	1	1		7	2		2	4	
Dijon	1	3	2	61	12	2	5	33	
Grenoble	4	5	3	108	15		5	54	
Lille	6	8	4	125	25	11	8	107	
Limoges	1	1	1	32	4	2	3	20	
Lyon	4	5	2	120	23	11	18	111	
Montpellier	5	4	1	117	13	6	9	70	
Nancy-Metz	3	8	3	79	15	14	1	45	
Nantes	3	6	4	146	25	16	14	75	
Nice	2	2	2	59	13	4	6	34	
Orléans-Tours	2	6	2	80	10	3	3	30	
Poitiers	2	3	1	69	9	3	6	24	
Reims	1	2	1	54	9	2	11	18	
Rennes	4	8	5	137	24	17	6	84	
Rouen	2	3	1	69	13	4	2	27	
Strasbourg	2	5	6	61	13	2	2	42	
Toulouse	4	5	1	107	17	13	12	80	
Total province	**61**	**94**	**49**	**1.851**	**310**	**138**	**158**	**1.104**	
Paris	7	2	2	85	49	14	38	186	
Créteil	4	9	4	116	30	10	3	65	
Versailles	5	7	2	131	39	17	12	85	
Total Île-de-Fr	**16**	**18**	**8**	**332**	**118**	**41**	**53**	**336**	
France métro	**77**	**112**	**57**	**2.183**	**428**	**179**	**211**	**1.440**	4.687
Guadeloupe	1			19	4			8	
Guyane		1		4	2			2	
Martinique				18	4		1	9	
La Réunion	1	1	2	34	4		1	9	
France métro.	**79**	**114**	**59**	**2.258**	**442**	**179**	**213**	**1.468**	4.812
									0,97402328

Table A.3: Number of high education buildings in France and in metropolitan France and calculation of the coefficient metropolitan France/France(Ministry of Education, 2010).

To know the average surface of the elementary, primary and secondary schools some calculations and assumptions have been done taking the necessary information from the Ministry of Education (2010) about the number of classrooms and (1989) about the structure of the buildings ending up with the following results of heated floor area shown in Tables A.4, A.5 and A.6 and providing the Table 3.11 with all the data required.

Nombre de classes	Ecoles maternelle	Élèves (25,7/clas	Classe 60m2/	Accueil	Atélier 20m2 /2	Salle repos (40m2/30enfants)	salle eps/ evolution	burau	salle à manger	Toilette	Surface maternelle
Public											
1	1142	26	51	30	10	34,3	100	12	26	6	269,4
2	2148	51	103	30	20	68,5	100	12	51	12	396,7
3	3769	77	154	30	30	102,8	100	12	77	18	524,1
4	3310	103	206	30	40	137,1	100	12	103	24	651,5
5	2435	129	257	40	50	171,3	110	24	129	30	810,8
6 à 10	2746	206	411	40	80	274,1	110	24	206	42	1186,9
11 à 15	100	308	617	40	120	411,2	110	24	308	72	1702,4
16 et plus											
Total Public	**15.650**										683,4
Privé											
1	26	25,7	51	30	10	34,3	100	12	26	6	269,4
2	27	51,4	103	30	20	68,5	100	12	51	12	396,7
3	29	77,1	154	30	30	102,8	100	12	77	18	524,1
4	17	102,8	206	30	40	137,1	100	12	103	24	651,5
5	10	128,5	257	40	50	171,3	110	12	129	30	798,8
6 à 10	15	205,6	411	40	80	274,1	110	24	206	42	1186,9
11 à 15	0	308,4	617	40	120	411,2	110	24	308	72	0,0
16 et plus	2	411,2	822	40	160	548,3	110	24	411	88	2203,9
Total Privé	**126**										588,8
						Surface moyenne école maternelle					**682,658141**

Table A.4: Calculations for maternelle.

Nombre de classes	Ecoles élémentaire	Élèves (22,7/classe)	Accueil	Classe (50m2/	Atélier	B.C.D. (2m2/place)	bureau	Salle à réunion	Informatique	Salle à manger	Salle repos (40m2/30en	Toilettes	Surface elementair
Public													
1	2800	22,7	70	41,27	10	15	12	10	20	22,7	30,3	10	241,24
2	1750	45,4	70	82,55	10	30	12	10	20	45,4	60,5	16	356,48
3	902	68,1	70	123,82	10	60	12	10	20	68,1	90,8	22	486,72
4	1101	90,8	96,5	165,09	10	60	12	10	40	90,8	121,1	28	633,46
5	1970	113,5	123	206,36	10	60	24	10	40	113,5	151,3	34	772,20
6 à 10	7051	181,6	203	330,18	80	100	24	25	60	181,6	242,1	60	1305,42
11 à 15	2139	272,4	309	495,27	120	100	24	25	60	272,4	363,2	75	1843,37
16 et plus	266	363,2	415	660,36	160	100	24	25	60	363,2	484,3	90	2381,33
Total Public	**17.979**												**986,59**
Privé													
1	53	22,7	70	41,27	10	15	12	10	20	22,7	30,3	10	241,24
2	60	45,4	70	82,55	10	30	12	10	20	45,4	60,5	16	356,48
3	21	68,1	70	123,82	10	60	12	10	20	68,1	90,8	22	486,72
4	11	90,8	96,5	165,09	10	60	12	10	40	90,8	121,1	28	633,46
5	27	113,5	123	206,36	10	60	24	10	40	113,5	151,3	34	772,20
6 à 10	50	181,6	203	330,18	80	100	24	25	60	181,6	242,1	60	1305,42
11 à 15	20	272,4	309	495,27	120	100	24	25	60	272,4	363,2	75	1843,37
16 et plus	9	363,2	415	660,36	160	100	24	25	60	363,2	484,3	90	2381,33
Total Privé	**251**												**780,01**
								Surface moyenne école elementaire					**983,74472**

Table A.5: Calculations for elementaire

Nombre classes	Ecoles primaires	Élèves	Accueil	Atélier	B.C.D. (2m2/place)	bureau	Salle à réunion	Informatique	Toiletes	salle eps/ evolution	Salle à manger	Salle repos (40m2/30enf	Surface primaire	Total
Public														
1	882	23,825	70	10	15	12	10	20	10	100	23,825	31,8	302,6	4.824
2	2508	47,65	70	10	30	12	10	20	16	100	47,65	63,5	379,2	6.406
3	2607	71,475	70	10	60	12	10	20	22	100	71,475	95,3	470,8	7.278
4	2106	95,3	96,5	10	60	12	10	40	28	100	95,3	127,1	578,9	6.517
5	1614	119,13	123	10	60	24	10	40	34	110	119,13	158,8	689,0	6.019
6 à 10	3245	190,6	202,5	80	100	24	25	60	60	110	190,6	254,1	1106,2	13.042
11 à 15	624	285,9	308,5	120	100	24	25	60	75	110	285,9	381,2	1489,6	2.863
16 et +	102	227	414,5	160	100	24	25	60	90	110	227	302,7	1513,2	368
Total Pu	**13.688**												**690**	**47.317**
Privé														0
1	67	23,825	70	10	15	12	10	20	10	100	23,825	31,8	302,6	146
2	444	47,65	70	10	30	12	10	20	16	100	47,65	63,5	379,2	531
3	565	71,475	70	10	60	12	10	20	22	100	71,475	95,3	470,8	615
4	596	95,3	96,5	10	60	12	10	40	28	100	95,3	127,1	578,9	624
5	493	119,13	123	10	60	24	10	40	34	110	119,13	158,8	689,0	530
6 à 10	1729	190,6	202,5	80	100	24	25	60	60	110	190,6	254,1	1106,2	1.794
11 à 15	652	285,9	308,5	120	100	24	25	60	75	110	285,9	381,2	1489,6	672
16 et +	275	381,2	414,5	160	100	24	25	60	90	110	381,2	508,3	1873,0	286
Total Pr	**4.821**												**941**	**5.198**
	TOTAL													52.515
									Surface moyenne école primaire				**755,745**	

Table A.6: Calculations for primaire

Annex B: Number of people in non-residential buildings

- Offices:

The occupation in an office building is 1 person each 12m^2, Filfli (2006). And knowing that the average surface is 1000m^2 the occupation is **83,33** people per building.

- Commercial:

From Arrêté of December 1981 (BATISS, 2010) of 0,2 person/m^2 is found. However, this rate applies only to the "free space", the area where people is moving. Therefore it has been assumed a 50% of free space giving the final result of 0,1 person/m^2. Finally the number of people in an average commercial building is of **23,25**.

- Health:

The number of people in a health building depends on a lot of factors. In order to follow a more or less accurate methodology the values of average occupation in Filfli (2006) has been used. Then, knowing the heated floor area (4.167 m^2) and the number of beds (96) it can be calculated the total number of people (see Table B.1) the building is designed for and therefore the ventilation rate.

	Total	Office	Lab resto pharma	Surgery	Room	Closet	Corridors
Proportion	1	0,12	0,16	0,05	0,22	0,06	0,39
Occupation		0,166pers/bed	1pers/10m2	1pers/5m2	1pers/4m2 (2pers*bed)	0	0
Person	**315,9**	15,91	66,67	41,67	191,64	0	0

Table B.1: Number of people in health buildings (Filfli, 2006).

Information taken from the database of the Ministry of Health (2010) shown in Table B.2 gives:

buildings	beds	beds/building
4259	408.103	**95,82**

Table B.2 Number of beds per building from the health subsector (Ministry of Health, 2010).

- Education:

From the Ministry of Education (2010) it can be found the total number of students in the education system in France, public and private in 2009. (See Table B.3):

Effectifs d'élèves et d'étudiants dans l'enseignement public et privé (en milliers)							
From: NATTEF07148	**1980-1981**	**1990-1991**	**2000-2001**	**2005-2006**	**2007-2008**	**2008-2009 (r)**	**2009-2010**
Premier degré (1)							
Pré-élémentaire	2.456,5	2.644,2	2.540,3	2.612,0	2.551,1	2.535,4	2.532,8
Élémentaire	4.810,0	4.218,0	3.953,0	3.962,0	4.047,3	4.062,3	4.070,5
ASH (2)	129,8	91,2	58,7	50,5	46,8	46,0	43,8
Total du premier degré	**7.396,3**	**6.953,4**	**6.552,0**	**6.624,6**	**6.645,1**	**6.643,6**	**6.647,1**
Second degré							
Premier cycle	3.261,9	3.253,5	3.290,9	3.139,0	3.084,0	3.088,5	3.107,2
Second cycle professionnel	807,9	750,0	705,4	724,0	713,4	703,1	694,3
Second cycle général et technologique	1.124,4	1.607,6	1.501,5	1.512,9	1.470,0	1.446,9	1.431,3
Enseignement adapté (SEGPA)	114,9	114,6	116,6	109,5	104,0	101,3	98,9
Total du second degré (hors agriculture)	**5.309,2**	**5.725,8**	**5.614,4**	**5.485,4**	**5.371,4**	**5.339,7**	**5.331,7**
Second degré agricole	**117,1**	**116,2**	**151,3**	**154,9**	**153,5**	**151,6**	**151,9**
Centres de formation des apprentis	**244,1**	**226,9**	**376,1**	**395,6**	**433,7**	**435,2**	**433,6**
Spécial santé scolarisés	**96,2**	**88,2**	**81,4**	**76,3**	**76,4**	**75,5**	**74,8**
Enseignement du supérieur	**1.184,1**	**1.717,1**	**2.160,3**	**2.283,3**	**2.231,5**	**2.234,2**	**2.316,1**
Total	**14.346,9**	**14.827,5**	**14.935,4**	**15.020,1**	**14.911,6**	**14.879,9**	**14.955,2**
(1) : estimations à partir de 2000.							
(2) : adaptation scolaire et scolarisation des enfants handicapés (ex AIS).							
Champ : France.							
Source : Depp.							

Table B.3: Total number of students in France 2009 (Ministry of Education, 2010).

As for the number of workers from the education system in France in 2009 has been taken from INSEE (2011). See Table B.4:

Personnel de l'Éducation nationale en 2011

Personnel de l'Éducation nationale en 2011

	2007 (1)	2008	2009 (2)	2010	2011
Enseignants (3)	982 678	972 571	940 403	944 497	928 458
public	838 177	829 131	798 742	804 043	789 819
privé	144 501	143 440	141 661	140 454	138 639
Personnel administratif, technique, d'encadrement et de surveillance	227 150	194 403	174 839	183 248	179 759
Total	**1 209 828**	**1 166 974**	**1 115 242**	**1 127 745**	**1 108 217**

(1) : à partir de 2007, les personnes rémunérées sur des comptes d'avance de régularisation et les techniciens et ouvriers à la charge des collectivités territoriales ne sont plus comptabilisés.

(2) : en 2009, les personnels des établissements ayant acquis leur autonomie dans l'enseignement supérieur ne sont pas pris en compte.

(3) : enseignants titulaires, stagiaires et non titulaires des 1er et 2nd degrés, du supérieur et des établissements de formation.

Champ : France.

Source : Depp.

Table B.4: Personnel in education in France (INSEE, Personnel de l'Éducation nationale en 2011, 2011).

Then, the total number of people divided by the total surface of the education buildings gives a rate of 0,088 person/m^2. That means **131,36** people per building in average.

- SCL:

To guess the number of people in an average SCL it has been found through an assumption. It has been assumed that the heat gains from people is the same value as in Spain in Medina (2011): 2,57 W/m^2. Then, since one person releases 72W on average for a sedentary activity and 119W for an average one, it has been taken a value in between (90W). The period of occupation has been set to 270 days a year and 10 hours a day opened.

$$Number_{person} = \frac{2{,}57\ \mathrm{W}}{\mathrm{m2}} * \frac{person}{72W} * \frac{365}{270} * \frac{24}{10} = \mathbf{56{,}05}\ \boldsymbol{people}$$

Annex C: TC values

TC values are calculated thanks to the properties found in the Catalan buildings from Barcelona Regional (2002) and can be found as well in Medina (2011) work. The effective heat capacity of the Spanish buildings has been assumed to be the same as for the French ones. Then, the calculation of the Spanish effective heat capacity is presented (Medina, 2011):

In the following Table C.1 the materials used for construction in Catalonia and the averaged TC/A values for the Spanish buildings are presented (Medina, 2011):

Table C.1: Construction material properties in Catalonia and average values for Spanish buildings.

BEFORE 1979								
RESIDENTIAL								
FACADE	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A	
Tipologies 1 and 2	Late s.XIX till 30's	Pedra calcària	0,1	2000	0,23	828	**165600**	18,6%
Tipologies 3 and 4	1940/1979	Enguixat interior	0,01	800	0,2	720	5760	
		Envà de maó buit	0,04	1200	0,23	828	39744	
		Cambra d'aire	0,05	1,2	0,28	1008	60	
							45564	81,4%
							67891	
PARTICIONES INTERIORES	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A	Average
Tipology 1	Until late s.XIX	Enguixat a cara i cara	0,02	800	0,2	720	11520	
		Envans de maó massís	0,03	1800	0,23	828	38005,2	
		Murs de càrrega de maó massís	0,15	1800	0,23	828	33534	
							415296	**567518**
Tipology 2	Medium s.XIX till 30's	Enguixat a cara i cara	0,02	800	0,2	720	11520	
		Paredons de maó perforat	0,09	1600	0,23	828	53654	
		Murs de càrrega de maó massís	0,14	1800	0,23	828	114761	
							719741	
Tipology 3	1940/1979	Enguixat a cara i cara	0,02	800	0,2	720	11520	
		Envà de maó de quart buit	0,04	1200	0,23	828	39744	
		Pilars de formigó armat	secció 40x4	2400	0,24	864	13271	**761915**
							971913	
Tipology 4	1945/1979	Enguixat a cara i cara	0,02	800	0,2	720	11520	
		Envà de maó de quart buit	0,04	1200	0,23	828	25834	

FORJADOS	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A	Average
		Murs de càrrega de totxo massís o calat	0,14	1800	0,23	828	73030	
							551916	
							725757	
Tipology 1	Until late s.XIX	Bigues de fusta	11x20/ 60cm	800	0,39	1404	41184	
		Revoltons de peces ceràmiques	0,04	2000	0,23	828	66240	
		Replè de runa i morter de cals	0,07	1600	0,23	828	92736	
		Paviment de rajola ceràmica	0,15	1800	0,23	828	223560	
							423720	
Tipology 2	Medium s.XIX till 30's	Cel ras d´escaiola i canyís	0,02	800	0,2	720	11520	**330304**
		Cambra d'aire sobre cel ras	0,2	1,2	0,28	1008	242	
		Biguetes metàl.liques (IPN140)	0,0030 5	7500	0,2	720	16470	
		Revoltons de peces ceràmiques	0,04	2000	0,23	828	66240	
		Replè de runa i morter de cals	0,07	1600	0,23	828	92736	
		Paviment de mosaic	0,03	2000	0,23	828	49680	
							236888	
Tipology 3	1940/1979	Enguixat a la cara inferior	0,01	800	0,2	720	5760	**378915**
		Jàsseres de formigó (cada 3.5m en un sentit)	30x40/ 2,5m	2400	0,24	864	71095	
		Biguetes autoresistents de formigó armat	15x20/ 60cm	2400	0,24	864	103680	
		Revoltons prefabricats de ceràmica	0,18	600	0,23	828	89424	
		Xapa de compressió	0,03	2400	0,23	828	59616	
		Morter	0,02	2000	0,23	828	33120	
		Paviment de terratzo	0,03	2000	0,23	828	49680	
							412375	

Tipology 4	1945/1979	Biguetes autoresistents de formigó armat	15x20/ 60cm	2400	0,24	864	103680	
		Revoltons de ceràmica fets in situ	0,2	600	0,23	828	99360	
		Xapa de compressió	0,03	2400	0,23	828	59616	
		Morter	0,02	2000	0,23	828	33120	
		Paviment de terratzo	0,03	2000	0,23	828	49680	
							345456	
							369874	
CUBIERTA	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A	Average
Tipology 1	Until late s.XIX	Cel ras d´escaiola i canyís	0,02	800	0,2	720	11520	
		Cambra de ventilació	0,08	1,2	0,28	1008	97	
							11617	**28207**
Tipology 2	Medium s.XIX till 30's	Envanets conillers de maó	0,03	1800	0,23	828	44712	
		Cambra de ventilació	0,07	1,2	0,28	1008	85	
							44797	
Tipology 3	1940/1979	Enguixat a la cara inferior	0,01	800	0,2	720	5760	
		Jàsseres de formigó (cada 3.5m en un sentit)	30x40/ 2,5m	2400	0,24	864	71095	
		Biguetes autoresistents de formigó armat	0,05	2400	0,24	864	103680	
							180535	**145707**
Tipology 4	1945/1979	Enguixat a cara i cara	0,02	800	0,2	720	11520	
		Envà de maó de quart buit	0,04	1200	0,23	828	39744	
		Murs de càrrega de totxo massís o calat	0,04	1800	0,23	828	59616	
							110880	
							123852	
SOLERA	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A	

-	Current buildings	Hormigón armado	0,1	2500		1000	**250000**	
BEFORE 1979								
OFFICES								
FACADE	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A	
		Envà interior	0,05	1200	0,23	828	49680	
Tipology 8	Before 1979	Enguixat interior	0,01	800	0,2	720	5760	
							55440	
PARTICIONES INTERIORES	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A	
		Enguixat a cara i cara	0,02	800	0,2	720	11520	
		Envà de totxana	0,09	1200	0,23	828	36664	
Tipology 8	Before 1979	Mur de formigó	0,2	2400	0,24	864	66355	
		Murs de totxo massís	0,14	1800	0,23	828	89722	
							453914	
FORJADOS	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A	
		Cel ras de fibres Armstrong	0,025	240	0,2	720	4320	
		Biguetes metàl.liques(IPN120)	14.2c m2/75 cm	7500	0,2	720	10224	
Tipology 8	Before 1979	Revoltons de ceràmica fets in situ	0,2	600	0,23	828	99360	
		Xapa de compressió	0,03	2400	0,23	828	59616	
		Morter	0,02	2000	0,23	828	33120	
		Paviment de terratzo	0,03	2000	0,23	828	49680	
							256320	
CUBIERTA	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A	
		Cel ras de fibres Armstrong	0,025	240	0,2	720	4320	
Tipology 8	Before 1979	Biguetes metàl.liques(IPN120)	14.2c m2/75	7500	0,2	720	10224	

			cm				
		Revoltons de ceràmica fets in situ	0,2	600	0,23	828	99360
							113904
SOLERA	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
-	Current buildings	Hormigón armado	0,1	2500		1000	**250000**

		1979/2005					
		RESIDENTIAL					
FACADE	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
		Enguixat interior	0,01	800	0,2	720	5760
Tipology 5	After 1979	Envà de maó 1/4 buit	0,04	1200	0,23	828	39744
							45504
PARTICIONES INTERIORES	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
		Totxana	0,07	1200	0,23	828	62597
		Enguixat a cara i cara	0,02	800	0,2	720	11520
Tipology 5	After 1979	Envà de maó de quart buit	0,04	1200	0,23	828	3974
		Pilars de formigó armat	0,0064	2400	0,24	864	13271
							669811
FORJADOS	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
		Enguixat a la cara inferior	0,01	800	0,2	720	5760
Tipology 5	After 1979	Massís de formigó armat	un pilar/5 x5	2400	0,24	864	103680
		Biguetes de formigó armat de 3,5m2	1biga/ 10x22	2400	0,24	864	130340,5 714
		Cassetons prefabricats de ceràmica de 3,5 m2	25cass etons/	600	0,23	828	468411,4 286

			60x22				
		Xapa de compressió	0,03	2400	0,23	828	59616
		Morter	0,01	2000	0,23	828	16560
		Paviment de gres	0,01	1600	0,23	828	13248
							797616
CUBIERTA	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
		Enguixat a la cara inferior	0,01	800	0,2	720	5760
Tipology 5	After 1979	Massís de formigó armat	un pilar/5 x5	2400	0,24	864	37324,8
							43084,8
SOLERA	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
-	Current buildings	Hormigón armado	0,1	2500		1000	**250000**
		2006/2008					
		RESIDENTIAL					
FACADE	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
		Enlucido de yeso	0,015	1100		1000	16500
-	Current buildings	Ladrillo hueco	0,04	920		1000	36800
							53300
PARTICIONES INTERIORES	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
		Enlucido de yeso	0,015	1100		1000	16500
-	Current buildings	Ladrillo hueco	0,04	770		1000	30800
		Enlucido de yeso	0,015	1100		1000	16500
							911429
FORJADOS	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
-	Current buildings	Plaqueta o baldosa cerámica	0,015	2000		800	24000

			Mortero de cemento	0,02	1900		1000	38000
			Forjado cerámico	0,25	1660		1000	415000
								477000
CUBIERTA	Period			d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
-	Current buildings		Forjado cerámico	0,1	1600		1000	**160000**
SOLERA	Period			d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
-	Current buildings		Hormigón armado	0,1	2500		1000	**250000**
			1979/today					
			OFFICES					
FACADE	Period			d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
			Enguixat interior	0,01	800	0,2	720	5760
	Tipology 9	After 1979	Totxana	0,09	1200	0,23	828	89424
								95184
PARTICIONES INTERIORES	Period			d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
			Totxana	0,1	1200	0,23	828	47692,8
	Tipology 9	After 1979	Enguixat a cara i cara	0,02	800	0,2	720	11520
			Paret de maó calat	0,14	1600	0,23	828	96445
								430157
FORJADOS	Period			d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
			Cel ras de fibres Armstrong	0,025	240	0,2	720	4320
			Enguixat a la cara inferior	0,01	800	0,2	720	5760
	Tipology 9	After 1979	Capitells de formigó armat	1pilar/ 5x5	2400	0,24	864	99533
			Biguetes de formigó armat de 3,5m2	1biga/ 10x22	2400	0,24	864	130341
			Cassetons prefabricats de ceràmica de 3,5 m2	25cass etons/	600	0,23	828	468411

			60x22				
		Xapa de compressió	0,05	2400	0,23	828	99360
		Morter	0,01	2000	0,23	828	16560
		Paviment de gres	0,01	1600	0,23	828	13248
							837533
CUBIERTA	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
Tipology 9	After 1979	Forjado cerámico	0,1	1600		1000	**160000**
SOLERA	Period		d	ro	Cp(Wh/kgK)	Cp(J/kgK)	CP/A
-	Current buildings	Hormigón armado	0,1	2500		1000	**250000**

The values of the properties used for both residential and non-residential sectors in this master thesis are presented in Table C.1 being extrapolated from the Spanish building stock. Notice that the values are the same for each climate zone and type of building within each sector due to the lack of data.

Residential	**Cp_walls/S_walls**	**Cp_inner_walls/Sinner_walls***	**Cp_middle_floor/Smiddle_floor**	**Cp_roof/Sroof**	**Cpfloor/Sfloor**
Before 1975	67891	725757	369874	123852	250000
After 1975	45504	669811	797616	43084,8	250000

Non residential	**Cp_walls/S_walls**	**Cp_inner_walls/Sinner_walls***	**Cp_middle_floor/Smiddle_floor**	**Cp_roof/Sroof**	**Cpfloor/Sfloor**
Before 1977	67891	725757	369874	123852	250000
1977-2000	45504	669811	797616	43084,8	250000
2000-2009	45504	669811	797616	43084,8	250000

*Sinner_walls is assumed to be 0,08*A(livable area)

Table C.1: Cp/S values for all buildings of the French stock (Barcelona Regional, 2002; Medina, 2011).

Annex D: Sanitary ventilation rate for health subsector

The health sector has been divided into two different types of buildings, the ones providing the possibility to stay overnight and the ones without this service. The first type is described in (Filfli, 2006) while the second one has had to be assumed. The first assumption done is that each type of building accounts for 50% of the surface within this subsector. Finding the sanitary ventilation rate for each type of building the rate for the whole subsector will be defined.

Table D.1 shows the values used to calculate the ventilation rate for the buildings offering providing the possibility to stay overnight:

	Total	Office	Lab resto pharma	Surgery	Room	Closet	Corridors
Proportion	1	0,12	0,16	0,05	0,22	0,06	0,39
Vc	-	25 m3/h/pers	6 CPH	15 CPH	18m3/h/pers	-	-
People	-	0,166pers/bed	1pers/10m2	1pers/5m2	1pers/4m2 (2pers*bed)	0	0
	315,9	15,9	66,7	41,7	191,6	0	0
Vc l/(s*m^2)	1,682	0,221	5,0	12,5	1,0	0	0

Table D.1: Data needed to calculate the Vc from buildings offering providing the possibility to stay overnight (Filfli, 2006).

Apart from these values, the already known number of beds (96), heated floor area (4,167m^2) and ceiling height (3m) have been used.

Therefore the final value for the ventilation rate in health subsector buildings is 1.4727 (l/s)/m^2 as Table D.2 shows.

Health buildings	Proportion	Vc (l/s)/(m2)	Health Vc (l/s)/(m2)	Vc m^3/h
with pernoctation	50%	1,6819	1,4727	69,9368
without pernoctation	50%	1,2634		

Table D.2: Final value of sanitary ventilation rate for health buildings.

Annex E: Calculation of energy consumption in D.O.M.

The methodology followed to know the consumption from the residential sector in D.O.M. has been to find out the value of energy consumption in Guyanne (which accounts for 24.000 tep in 2000; found in ADEME, (2000)) and extrapolate it to the rest of the islands directly proportional to their population. Therefore it has been needed to find the population in each one of the other department "d'outre mer" which are:

Guyane 2000: 166.671 inhabitants.

Guyane 2005: 205 954 (INSEE, 2005a)

$$205.954\ inhabit * \frac{24.000 tep}{166.671\ inhabit} = 29656\ tep$$

Guadeloupe (2005): 453.029 (INSEE, 2005b)

$$453.029\ inhabit * \frac{24.000 tep}{166.671\ inhabit} = 65.234\ tep$$

Martinique (2005): 397.820 (INSEE, 2005c)

$$397.820\ inhabit * \frac{24.000 tep}{166.671\ inhabit} = 57.285\ tep$$

Réunion (2005): 774.600 (INSEE, 2005d)

$$774.600\ inhabit * \frac{24.000 tep}{166.671\ inhabit} = 111.540\ tep$$

Mayotte (2005): 193.633 (CIA Fact Book, 2005)

$$193.633\ inhabit * \frac{24.000 tep}{166.671\ inhabit} = 27.882\ tep$$

Then, the total energy consumption in D.O.M. is calculated:

$$291.597\ \mathrm{tep} * \frac{11.630\mathrm{kWh}}{\mathrm{tep}} = \mathbf{3,4\ TWh}$$

It is acceptable to assume that the consumption is directly proportional to the population since between the year 2000 and 2005 the consumption per inhabitant has not change at all. (Ministry of Sustainable Development, 2005)

Regarding the consumption of non-residential buildings in D.O.M. it has been assumed to be proportional to the energy consumed in the residential sector (3.4 TWh out of 476.0 TWh) giving 1 TWh for the non-residential sector.

Annex F: Number of dwellings in the residential sector

The quantification of the dwelling stock in metropolitan France done by (ANAH, 2008) and modified by Martinlagardette (2009) is the following (see Table F.1)

Number of dwellings Sources: Martinlagardette and USH		H1						
		SFD			MFD Priv			MFD Pub
		1975-2000	2000-2005	Total	1975-2000	2000-2005	Total	1975-2000
Before 1975 non refurbished	El	249920		**249920**	260459		**260459**	
	Other	1228252		**1228252**	1051632		**1051632**	
Before 1975 refurbished	El	433709		**433709**	466312		**466312**	
	Other	2071191		**2071191**	1888388		**1888388**	
After 1975	El	1013088	167626	**1180714**	455834	190574	**646408**	479386
	Other	1737213	365017	**2102230**	403009	127049	**530058**	2789174

Number of dwellings Sources: Martinlagardette and USH		H2						
		SFD			MFD Priv			MFD Pub
		1975-2000	2000-2005	Total	1975-2000	2000-2005	Total	1975-2000
Before 1975 non refurbished	El	104861		**104861**	108913		**108913**	
	Other	515348		**515348**	439750		**439750**	
Before 1975 refurbished	El	194829		**194829**	201581		**201581**	
	Other	865565		**865565**	770148		**770148**	
After 1975	El	689040	73146	**762186**	161919	82311	**244230**	195102
	Other	992809	159591	**1152400**	94568	55333	**149901**	767865

Number of dwellings Sources: Martinlagardette and USH		H3						
		SFD			MFD Priv			MFD Pub
		1975-2000	2000-2005	Total	1975-2000	2000-2005	Total	1975-2000
Before 1975 non refurbished	El	42112		**42112**	43668		**43668**	
	Other	206964		**206964**	176315		**176315**	
Before 1975 refurbished	El	85656		**85656**	82199		**82199**	
	Other	388104		**388104**	332619		**332619**	
After 1975	El	378994	40511	**419505**	169450	56866	**226316**	51317
	Other	439865	88387	**528252**	107351	30578	**137929**	244087

Table F.1: Number of dwellings. Distribution ANAH (2008) and Martinlagardette (2011).

The above compilation:

a) lacks a segmentation of the public MFD

b) the total number of dwellings is lower than in the rest of the studies (Table 3.41).

To fix these two issues:

a) regarding the public MFD, these constructed between 2006 and 2007 have been taken away from the values shown in Table F.1. This removal has been done proportionally to the total number of buildings for each segmentation criteria. Concretely 104.000 dwellings (MDD, 2010).

b) it has been assumed an average number of the studies from TABULA (2010) and Grenelle environnement (2007) as explained in Chapter 3, concluding that the total number of dwellings in 2005 was 26,160,000 and then it has been added the number of dwellings missing.

The final result is the following (see Table F.2):

Number of dwellings Sources: Martinlagardette 2009 USH 2007, ANAH 2008		H1		
		SFD	MFD Private	MFD Pub
Before 1975 non refurbished	El	280880	260459	190614
	Other	1380408	1051632	1109033
Before 1975 refurbished	El	487437	466312	127076
	Other	2327771	1888388	739355
After 1975	El	1326981	646408	139670
	Other	2362655	530058	812632

Number of dwellings Sources: Martinlagardette 2009 USH 2007, ANAH 2008		H2		
		SFD	MFD Private	MFD Pub
Before 1975 non refurbished	El	117851	108913	77577
	Other	579190	439750	305319
Before 1975 refurbished	El	218965	201581	51718
	Other	972792	770148	203546
After 1975	El	856606	244230	56843
	Other	1295160	149901	223719

Number of dwellings Sources: Martinlagardette 2009 USH 2007, ANAH 2008		H3		
		SFD	MFD Private	MFD Pub
Before 1975 non refurbished	El	47329	43668	20405
	Other	232603	176315	97054
Before 1975 refurbished	El	96267	82199	13603
	Other	436183	332619	64703
After 1975	El	471473	226316	14951
	Other	593692	137929	71115

Table F.2: Distribution of French dwellings used in this master thesis

Annex G: Number of buildings represented by each archetype building of the residential sector

The weighting coefficients (final number of buildings) for each archetype building belonging to the residential sector can be found in Table G.1:

			SFD	Privat MFD	Public MFD	Total
H1	BNR	EL	280,880	19,534	15,487	315,901
		O	1,380,408	78,872	90,108	1,549,388
	BR	EL	487,437	34,973	10,324	532,734
		O	2,327,771	141,629	60,072	2,529,472
	Af	EL	1,326,981	48,480	11,348	1,386,809
		O	2,362,655	39,754	66,026	2,468,435
H2	BNR	EL	117,851	8,168	6,303	132,322
		O	579,189	32,981	24,807	636,977
	BR	EL	218,964	15,118	4,202	238,284
		O	972,791	57,761	16,538	1,047,090
	Af	EL	856,605	18,317	4,618	879,540
		O	1,295,159	11,242	18,177	1,324,578
H3	BNR	EL	47,328	3,275	1,657	52,260
		O	232,602	13,223	7,885	253,710
	BR	EL	96,267	6,164	1,105	103,536
		O	436,182	24,946	5,257	466,385
	Af	EL	471,473	16,973	1,214	489,660
		O	593,692	10,344	5,778	609,814
Total			14,084,235	581,754	350,906	15,016,895

Table G.1: Weighting coefficient for the residential sector considered in this work.

Annex H: Surface of non-residential buildings constructed, from Sit@del2 database

The values extracted from Sit@del2 are shown as a surface constructed each year for each department. Then it has been the author of this thesis who has gathered all the surfaces into the three climate zones for each year as can be observed in the following Tables H.1 and H.2:

		service public enseignement-recherche	commerce	bureaux	service public santé	service public culture loisirs
2009	H1	838.986	1.645.746	1.528.346	992.735	501.107
	H2	472.004	1.202.087	1.008.767	704.203	400.642
	H3	191.734	295.805	265.197	160.211	105.332
2008	H1	926.871	2.099.747	2.421.649	1.370.059	752.967
	H2	485.853	1.676.827	1.400.810	685.261	575.960
	H3	187.138	310.555	358.132	189.445	181.795
2007	H1	1.303.241	2.819.834	3.117.134	1.415.929	1.281.134
	H2	631.484	2.095.101	1.621.064	824.017	812.628
	H3	207.633	479.614	466.053	416.158	262.437
2006	H1	1.164.042	2.506.996	2.798.402	1.660.041	1.397.000
	H2	660.251	1.840.253	1.366.039	805.398	902.873
	H3	216.019	496.112	445.950	214.806	169.253
2005	H1	1.252.598	2.465.103	2.359.915	1.112.422	1.154.434
	H2	629.526	2.007.405	1.123.221	529.857	802.105
	H3	237.462	503.734	293.233	293.876	254.177
2004	H1	1.353.573	2.394.510	2.311.797	945.527	1.169.683
	H2	650.102	1.627.730	1.082.201	499.974	709.066
	H3	208.920	365.770	320.332	224.626	148.010
2003	H1	1.421.835	2.416.517	2.203.346	955.585	1.147.345
	H2	689.301	1.593.278	960.469	526.030	742.311
	H3	196.211	409.786	312.537	216.238	129.670
2002	H1	1.127.161	2.148.978	2.362.408	605.680	940.786
	H2	617.559	1.575.601	1.003.632	330.796	574.585
	H3	258.833	418.912	297.791	141.749	164.239
2001	H1	1.138.272	2.356.625	3.026.446	702.306	1.090.910
	H2	553.871	1.625.631	1.115.399	482.760	665.670
	H3	250.685	423.282	412.311	122.058	141.949
2000	H1	1.011.090	2.229.339	2.554.686	641.673	1.408.640
	H2	508.805	1.500.823	1.056.294	439.282	886.874
	H3	225.817	264.266	275.367	58.556	286.597

Table H.1: Surface of non-residential buildings per type, year and climate zone (Ministry of Sustainable Development, 2011a).

1999	H1	1.211.496	1.851.272	1.816.762	581.385	1.336.564
	H2	562.692	1.287.172	931.003	385.891	775.485
	H3	145.471	245.199	219.712	53.379	190.865
1998	H1	1.038.969	1.501.219	1.676.560	595.282	914.760
	H2	469.382	1.014.341	796.817	386.552	634.062
	H3	189.914	216.198	164.747	73.017	149.901
1997	H1	1.012.697	1.016.961	1.285.705	440.686	801.967
	H2	544.445	745.274	797.387	446.693	546.689
	H3	174.503	174.434	179.879	93.837	102.907
1996	H1	1.213.404	1.325.472	1.543.144	572.232	702.186
	H2	580.211	928.825	698.977	373.433	509.406
	H3	174.994	196.009	150.962	99.468	103.398
1995	H1	1.230.047	1.442.835	1.690.163	610.224	834.403
	H2	617.997	965.453	757.375	409.926	576.753
	H3	209.359	175.121	166.711	170.723	87.598
1994	H1	1.436.020	1.753.232	2.011.058	787.652	1.106.192
	H2	737.694	1.150.422	696.546	505.597	741.128
	H3	165.321	263.558	182.848	104.438	103.311
1993	H1	1.479.089	1.449.727	2.171.128	686.640	1.060.292
	H2	696.962	1.088.816	811.278	475.001	667.451
	H3	182.649	216.200	254.503	122.237	92.870
1992	H1	1.554.769	2.097.798	2.789.384	658.276	1.255.959
	H2	846.939	1.304.126	1.001.670	406.238	747.004
	H3	167.910	367.697	292.163	84.980	89.513
1991	H1	1.562.688	2.162.381	3.583.045	706.555	1.177.335
	H2	850.782	1.549.686	1.233.134	496.177	764.458
	H3	189.827	378.156	378.930	117.954	100.019
1990	H1	1.373.452	2.612.145	4.266.621	599.880	1.053.098
	H2	694.663	1.792.543	1.401.335	493.214	742.226
	H3	188.588	389.519	378.971	73.106	96.339
1989	H1	1.217.873	2.935.526	4.358.338	653.010	1.072.755
	H2	562.716	1.826.535	1.232.746	396.437	622.823
	H3	133.659	399.734	359.042	134.447	110.795
1988	H1	1.177.263	2.816.784	3.487.005	540.692	1.406.132
	H2	544.441	1.706.087	1.102.412	473.808	852.192
	H3	108.420	414.223	291.912	78.464	136.159
1987	H1	968.664	2.365.311	2.952.012	377.113	1.364.593
	H2	412.513	1.451.481	917.600	266.846	767.255
	H3	105.563	259.290	273.685	38.001	136.734
1986	H1	924.712	1.872.589	2.393.852	324.862	1.231.168
	H2	397.237	1.085.526	817.292	217.042	693.601
	H3	130.138	263.537	220.519	49.947	93.852
1985	H1	948.375	1.637.986	1.856.206	236.753	1.083.571
	H2	382.031	983.942	646.415	165.798	715.360
	H3	113.158	241.086	237.907	38.232	95.150

Table H.2 (Continuation) Surface of non-residential buildings per type, year and climate zone.

Annex I: Results of characterization process for the archetype buildings within the residential sector

Building type	Climate	Construction period	Source of energy	Total heated floor area (A)	Number of occupants	Dwellings (per building)	Sanitary ventilation rate (Vc)	Mean U-value (U)
Sfd	H1	<1975	EL	99.1	2.9	1.00	0.51	1.92
Sfd	H1	<1975	Other	99.1	2.9	1.00	0.51	1.92
Sfd	H1	<1975 ref	EL	99.1	2.9	1.00	0.51	1.03
Sfd	H1	<1975 ref	Other	99.1	2.9	1.00	0.51	1.03
Sfd	H1	> 1975	EL	110.2	2.64	1.00	0.23	0.70
Sfd	H1	> 1975	Other	110.2	2.64	1.00	0.23	0.76
Sfd	H2	<1975	EL	99.1	2.9	1.00	0.51	1.92
Sfd	H2	<1975	Other	99.1	2.9	1.00	0.51	1.92
Sfd	H2	<1975 ref	EL	99.1	2.9	1.00	0.51	1.03
Sfd	H2	<1975 ref	Other	99.1	2.9	1.00	0.51	1.03
Sfd	H2	> 1975	EL	110.2	2.64	1.00	0.23	0.73
Sfd	H2	> 1975	Other	110.2	2.64	1.00	0.23	0.83
Sfd	H3	<1975	EL	99.1	2.9	1.00	0.51	2.21
Sfd	H3	<1975	Other	99.1	2.9	1.00	0.51	2.21
Sfd	H3	<1975 ref	EL	99.1	2.9	1.00	0.51	1.18
Sfd	H3	<1975 ref	Other	99.1	2.9	1.00	0.51	1.18
Sfd	H3	> 1975	EL	110.2	2.64	1.00	0.23	0.79
Sfd	H3	> 1975	Other	110.2	2.64	1.00	0.23	0.89
Priv	H1	<1975	EL	879.6	2.9	13.33	0.51	2.06
Priv	H1	<1975	Other	879.6	2.9	13.33	0.51	2.06
Priv	H1	<1975 ref	EL	879.6	2.9	13.33	0.51	1.18
Priv	H1	<1975 ref	Other	879.6	2.9	13.33	0.51	1.18
Priv	H1	> 1975	EL	881.7	2.6	13.33	0.38	0.84
Priv	H1	> 1975	Other	881.7	2.6	13.33	0.38	0.88
Priv	H2	<1975	EL	879.6	2.9	13.33	0.51	2.06
Priv	H2	<1975	Other	879.6	2.9	13.33	0.51	2.06
Priv	H2	<1975 ref	EL	879.6	2.9	13.33	0.51	1.18
Priv	H2	<1975 ref	Other	879.6	2.9	13.33	0.51	1.18
Priv	H2	> 1975	EL	881.7	2.6	13.33	0.38	0.86
Priv	H2	> 1975	Other	881.7	2.6	13.33	0.38	0.91
Priv	H3	<1975	EL	879.6	2.9	13.33	0.51	2.37
Priv	H3	<1975	Other	879.6	2.9	13.33	0.51	2.37
Priv	H3	<1975 ref	EL	879.6	2.9	13.33	0.51	1.36
Priv	H3	<1975 ref	Other	879.6	2.9	13.33	0.51	1.36
Priv	H3	> 1975	EL	881.7	2.6	13.33	0.38	0.91
Priv	H3	> 1975	Other	881.7	2.6	13.33	0.38	0.97
Pub	H1	<1975	EL	811.9	2.9	12.31	0.51	3.10
Pub	H1	<1975	Other	811.9	2.9	12.31	0.51	3.10
Pub	H1	<1975 ref	EL	811.9	2.9	12.31	0.51	1.17

Pub	H1	<1975 ref	Other	811.9	2.9	12.31	0.51	1.17
Pub	H1	> 1975	EL	813.9	2.6	12.31	0.38	0.82
Pub	H1	> 1975	Other	813.9	2.6	12.31	0.38	0.87
Pub	H2	<1975	EL	811.9	2.9	12.31	0.51	3.10
Pub	H2	<1975	Other	811.9	2.9	12.31	0.51	3.10
Pub	H2	<1975 ref	EL	811.9	2.9	12.31	0.51	1.17
Pub	H2	<1975 ref	Other	811.9	2.9	12.31	0.51	1.17
Pub	H2	> 1975	EL	813.9	2.6	12.31	0.38	0.84
Pub	H2	> 1975	Other	813.9	2.6	12.31	0.38	0.90
Pub	H3	<1975	EL	811.9	2.9	12.31	0.51	3.56
Pub	H3	<1975	Other	811.9	2.9	12.31	0.51	3.56
Pub	H3	<1975 ref	EL	811.9	2.9	12.31	0.51	1.34
Pub	H3	<1975 ref	Other	811.9	2.9	12.31	0.51	1.34
Pub	H3	> 1975	EL	813.9	2.6	12.31	0.38	0.89
Pub	H3	> 1975	Other	813.9	2.6	12.31	0.38	0.95

Annex J: Results of characterization process for the archetype buildings within the non-residential sector

Building type	Climate	Construction period	Total heated floor area (A)	Levels (per building)	Sanitary ventilation rate (Vc)	Mean U-value (U)
Offices	H1	Bef 1976	1000.0	9.0	0.74	2.30
Offices	H1	1976-2000	1000.0	9.0	0.74	1.53
Offices	H1	After 2000	1000.0	9.0	0.74	0.74
Offices	H2	Bef 1976	1000.0	9.0	0.74	2.30
Offices	H2	1976-2000	1000.0	9.0	0.74	1.84
Offices	H2	After 2000	1000.0	9.0	0.74	0.83
Offices	H3	Bef 1976	1000.0	9.0	0.74	2.68
Offices	H3	1976-2000	1000.0	9.0	0.74	2.16
Offices	H3	After 2000	1000.0	9.0	0.74	0.92
Commercial	H1	Bef 1976	232.5	1.4	0.83	1.64
Commercial	H1	1976-2000	232.5	1.4	0.83	1.11
Commercial	H1	After 2000	232.5	1.4	0.83	0.49
Commercial	H2	Bef 1976	232.5	1.4	0.83	1.64
Commercial	H2	1976-2000	232.5	1.4	0.83	1.31
Commercial	H2	After 2000	232.5	1.4	0.83	0.52
Commercial	H3	Bef 1976	232.5	1.4	0.83	1.79
Commercial	H3	1976-2000	232.5	1.4	0.83	1.50
Commercial	H3	After 2000	232.5	1.4	0.83	0.62
Health	H1	Bef 1976	4167.1	3.0	1.48	1.56
Health	H1	1976-2000	4167.1	3.0	1.48	0.86
Health	H1	After 2000	4167.1	3.0	1.48	0.43
Health	H2	Bef 1976	4167.1	3.0	1.48	1.56
Health	H2	1976-2000	4167.1	3.0	1.48	0.98
Health	H2	After 2000	4167.1	3.0	1.48	0.46
Health	H3	Bef 1976	4167.1	3.0	1.48	1.73
Health	H3	1976-2000	4167.1	3.0	1.48	1.14
Health	H3	After 2000	4167.1	3.0	1.48	0.56
Education	H1	Bef 1976	1489.1	1.8	0.37	1.51
Education	H1	1976-2000	1489.1	1.8	0.37	1.00
Education	H1	After 2000	1489.1	1.8	0.37	0.41
Education	H2	Bef 1976	1489.1	1.8	0.37	1.51
Education	H2	1976-2000	1489.1	1.8	0.37	1.16
Education	H2	After 2000	1489.1	1.8	0.37	0.43
Education	H3	Bef 1976	1489.1	1.8	0.37	1.70
Education	H3	1976-2000	1489.1	1.8	0.37	1.32
Education	H3	After 2000	1489.1	1.8	0.37	0.53
SCL	H1	Bef 1976	605.0	1.2	0.70	1.58
SCL	H1	1976-2000	605.0	1.2	0.70	1.06

SCL	H1	After 2000	605.0	1.2	0.70	0.45
SCL	H2	Bef 1976	605.0	1.2	0.70	1.58
SCL	H2	1976-2000	605.0	1.2	0.70	1.24
SCL	H2	After 2000	605.0	1.2	0.70	0.48
SCL	H3	Bef 1976	605.0	1.2	0.70	1.75
SCL	H3	1976-2000	605.0	1.2	0.70	1.42
SCL	H3	After 2000	605.0	1.2	0.70	0.58

Annex K: Number of buildings within the non-residential sector (Ministry of Sustainable Development, 2011a; and calculations)

The number of non-residential buildings has been calculated knowing the average heated floor area of each subsector (see Table 3.10) and the surface constructed every year of each subsector in each climate zone found in Sit@del2 database (Ministry of Sustainable Development, 2011a). Using Equation I.1 the weighting coefficient for each archetype building within the non-residential sector is found:

$$\#buildings_{clim,year} = \frac{surface_{clim,year}}{A} \qquad \text{Equation I.1}$$

Where:

$\#buildings_{clim,year}$ is the number of buildings (weighting coefficient) represented by the archetype building (office, commercial, health, education or SCL) for the climate (clim) and period of construction (year) selected.

$surface_{clim,year}$ is the surface of the subsector for the climate (clim) and period of construction (year) selected.

A is the average heated floor area of the subsector selected.

The result is shown in Table I.1:

Number of buildings Source: Sit@del2 and calculations		Offices	Commercial	Health	Education	SCL	Total
H1	Before 1977	61467	254778	8982	53365	9918	388511
	1977-2000	47184	133951	2391	17666	35710	236902
	2001-2009	24684	99286	2496	7748	17924	152139
H2	Before 1977	21305	150890	6297	21497	5513	205502
	1977-2000	17082	87154	1683	8130	22795	136844
	2001-2009	11738	72023	1398	3961	11690	100811
H3	Before 1977	7890	37199	1447	6367	635	53539
	1977-2000	4945	19522	381	2235	3548	30631
	2001-2009	3447	17066	489	1464	3047	25514
Total		199742	871870	25566	122434	110780	1,330,392

Table I.1 Distribution of non-residential buildings in metropolitan France, in year 2009, as obtained in this work.

Annex L: Final energy consumption investigation for the residential sector.

Table J.1 shows the sources consulted to know the final energy demand of the French residential building stock. As can be seen the value extracted from these sources includes the consumption for cooking and the consumption from dwellings located in D.O.M. (See annex I to know how this consumption has been calculated). Both energy for cooking and energy in D.O.M. are not contemplate in this master thesis and therefore they have been removed and the final value is presented in Table J.1 as “consumption without cooking neither D.O.M.”.

By deep Investigation of the sources (including direct contact with the institutions in the case of ADEME and Eurostat) it has been possible to know which ones included these two fields. However, it has been impossible to know if the value obtained through the source Grenelle (2007) includes the energy consumed for cooking and the energy consumed by buildings in D.O.M.. Anyway, this source has been discarded since it presents less principal dwellings than the ones in this master thesis and it doesn’t specify where its consumption comes from.

Regarding the other sources ADEME (2006a) seems to be the most reliable since it is close to the value given by the European statistics (Eurostat) and it is the report most recent which means it had available the information given in the rest of the sources. This is the reason why this value has been chosen to be compared with the values obtained from the simulation.

Source	Consumption (TWh)	Includes energy from*		Consumption without cooking neither D.O.M. (TWh)
		Cooking**	D.O.M.***	
Eurostat 2005	509.95	YES	YES	472.10
Odyssee, 2005	540.00	YES	YES	500.11
CEREN, 2005	540.00	YES	YES	500.11
ADEME, 2006	497.00	YES	YES	**460.04**
Grenelle, 2007	424.60	?	?	392.56

* This information has been extracted after contacting ADEME and Eurostat, for the rest it has been assumed

** Energy for cooking accounts for the 6.8% of the total energy consumption

*** Energy consummed in D.O.M equals 3.4 TWh (explanation in annex E)

Tabel J.1 Final energy consumption of the residential sector for the year 2005 according to the different sources stated in the table.

Annex M: Calculation of non-residential sector energy consumption

The energy consumption of the French non-residential sector in 2007 was 222,721 TWh according to CEREN and 236,22 TWh according to Eurostat. Since CEREN gives the consumption for each subsector as Table K.1 shows it has been found interesting to use this source. However for the year 2009 there is no consumption given by CEREN, only by Eurostat (257,87) and therefore it has been taken the same proportionally increase in consumption for CEREN as it is in Eurostat giving a value of 243, 14 TWh in 2009.

Energy consumption (TWh)	**2007**	**%**	**2009**
Offices	55,14	24,8	60,19
Commercial	51,83	23,3	56,58
Health	26,50	11,9	28,93
Education	26,11	11,7	28,50
Café, hotel, restaurant	23,77	10,7	25,95
SCL	18,17	8,2	19,83
Community housing*	12,66	5,7	13,82
Transports	8,55	3,8	9,34
Total non residential	**222,72**		**243,14**

Table K.1 Values of final energy consumption of the French non-residential building stock from 2007, sourced by CEREN (Ministry of Sustainable Development, 2007). *For 2009, extrapolation using the shares from CEREN 2007 and values Eurostat 2007 and 2009. (*Community housing: locals opened to all the public managed by the State)*

Annex N: Energy consumption for cooking in non-residential buildings

The consumption for cooking in French non-residential sector is presented in Table N.1 (ADEME, 2001). Assuming energy consumption directly proportional to the surface the values in the last columns of this table, the ones for the year 2009 has been found:

Non residential	Surface 2001 (m2)	Energy 2001 (TWh)	Surface 2009 (m2)	Energy 2009 (TWh)
Offices	172.786.000	0,80	193.778.193	0,90
Commercial	188.303.000	1,10	202.703.573	1,18
Health	93.920.000	1,20	109.740.623	1,40
Education	166.391.000	1,60	182.319.337	1,75
SCL	61.073.000	0,40	65.996.316	0,43
Total	**682.473.000**	**5,10**	**754.538.042**	**5,64**

Table N.1: Energy consumed for cooking in 2001 and extrapolated one to 2009.

Substracting the energy for cooking the resulting values are shown in Table N.2:

Energy consumption (TWh)	2007	%	2009
Offices	55,14	25	59,30
Commercial	51,83	23	55,40
Health	26,50	12	27,53
Education	26,11	12	26,75
Café, hotel, restaurant	23,77	11	25,95
SCL	18,17	8	19,40
Community housing	12,66	6	13,82
Transports	8,55	4	9,34
Total secteur tertiaire	**222,72**		**237,47**

Table N.2: Energy consumption in French for the non-residential sector after having taken away the energy used for cooking (Ministry of Sustainable Development, 2007).