Bottom-up characterization of the Spanish building stock for energy assessment and model validation

Georgina Medina Benejam*, Érika Mata*, Angela Sasic Kalagasidis, Filip Johnsson***
*Department of Energy and Environment, Chalmers University of Technology
**Department of Civil and Environmental Engineering
Chalmers University of Technology

SE-412 96 Göteborg, Sweden

Email: georgina.med@gmail.com, mata@chalmers.se, Angela.Sasic@chalmers.se, filip.johnsson@chalmers.se

Abstract:

In developed economies such as in the European member states, the largest potential for energy efficiency improvements in the building sector lies in retrofitting existing buildings. Therefore a methodology is being developed which can represent the European building stock by means of reference buildings with the aim to assess the effects of energy saving measures by applying a building energy simulation model developed by the authors: the *Energy Assessment of Building Stocks* (EABS). In this contex, the present work: 1) presents a characterization of the Spanish building stock by means of archetype (reference) buildings used to simulate its energy demand, 2) serves as a test on the accuracy of applying the EABS model on Spain (i.e. a south European country), including the non-residential sector. The Spanish building stock is represented by 120 archetype buildings corresponding to 6 building types, 5 climate zones and 4 periods of construction. Applying these archetype buildings in the EABS model gives a total energy demand for the residential sector of 181 TWh for the year 2005, which is considered satisfactory since it only differs with 3% (higher) from what is available in the international databases GAINS and Eurostat. Corresponding modeling of the non-residential sector yields an annual total energy demand of 91TWh, which is about 7% lower than the GAINS/Eurostat figure. Possible reasons for this difference are discussed in the paper.

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

1 Introduction

As a response to the international concern of climate change, the European Union is working to improve the energy efficiency in all end-use sectors in order to decrease carbon dioxide (CO_2) emissions. Taking effective measures in the building sector can represent a significant contribution to reach this target, since this sector accounts for 37% (year 2007 data) of the total final energy use in the European Union (EC, 2010).

Because turnover in the European building stock is low, the largest potential for energy efficiency improvements lies in retrofitting existing buildings (Balaras *et al.*, 2005). The work presented in this paper is part of an ongoing work to develop a methodology to assess potential energy saving measures to be applied to the European building stock. The methodology involves both a description of the building stock and development of modelling tools which can assess the effects of such energy efficiency measures. Thus, a methodology to represent a building stock in an aggregated form has been proposed and the model *Energy Assessment for Building Stocks* (EABS) has been developed and validated for the Swedish residential sector, which was represented by sample buildings, (i.e., actual sample building data were used as input for the model (Mata & Sasic-Kalagasidis, 2009). The work reported in this paper continues the development of the methodology using the Spanish building stock as test case, representing the stock by means of defining a number of archetype (reference) buildings. As opposed to sample buildings, archetype buildings are defined theoretically by collecting data on the overall characteristics of the building stock (e.g., period of construction, materials used, floor area) and information related to the specific building sector of the region studied (e.g., fuel shares, efficiencies, climate). The work is part of the project Pathways to Sustainable European Energy Systems (Johnsson, 2011). Spain is used in this work since it is considered important to also verify the methodology for the building characteristics of a south European country with climate conditions being significantly different from those in Sweden. In addition, this work also includes the non-residential sector.

In general, there are only few examples of work available which provide a characterization of entire residential building stocks through reference buildings with the aim of quantifying the energy savings obtained by applying energy conservation measures: Hens *et al.*, (2001) on the Belgium stock; Balaras *et al.*, (2005) about permanent dwellings in Greece; Clinch *et al.*, (2000) on the Irish stock; Clarke *et al.*, (2004) on the Scottish stock; Martinlagardette (2009) on the French stock. A study including reference buildings representative of both the EU15 residential and non-residential sector was performed by Petersdorff *et al.*, (2006). With respect to Spain, studies which characterize the entire Spanish building stock are lacking. The Plan for Energy Improvement in Barcelona defines and characterizes archetype buildings similar to this work, but only covers the region of Catalonia (Barcelona Regional, 2002). However, to the authors knowledge, there are no studies which describe the entire Spanish building stock. Thus, the aim of this work is to develop a bottom-up characterization of the Spanish building stock, including both the residential and non-residential buildings, by means of archetype buildings and to use these buildings to validate the EABS model.

2 Methodology

2.1 Data sources

The data used to derive the archetype buildings was extracted from three groups of sources: (1) National institutions, such as IDAE (Institute for the Energy Diversification and Saving/*Instituto para la Diversificación y Ahorro de la Energía*), the National Statistics Institute (INE, *InstitutoNacional de Estadística*) and the Ministry of Buildings

(*Ministerio de Fomento*); (2) existing regulations related to the building sector in Spain, which are the Decree 1490/1975 approved in 1975, the NBE-CT-79 approved in 1979, the Spanish Building Code in Force CTE approved in 2006, and the RITE (Regulation of Building Thermal Facilities/*Reglamento de InstalacionesTérmicas en los Edificios*) also approved in 2006; (3) International Databases, which are Eurostat, official database of the European Commission, and the GAINS (Greenhouse Gas and Air Pollution Interactions and Synergies) database of the International Institute for Applied Systems Analysis (IIASA).

The required climate data to run the energy simulation was extracted from the database Meteonorm (Meteotest, 2000). It should be mentioned that such climate data represents statistically generated test reference years (one for each of the cities selected as representative of the five Spanish climate zones), which are based on measurements carried out during the period 1961-1990.

2.2 The EABS model

The EABS model used to perform the energy simulation in this work is a bottom-up engineering model, i.e. modelling the energy demand of a group of buildings that are described in detail and selected to be representative for the entire stock of a region and then scaling-up the results to represent the region considered. The model is developed in Matlab and Simulink (Mathworks, 2010) and consists of two parts: a Simulink model, which solves the energy balance for buildings, and a code written in Matlab, which handles the input and output data from the Simulink model. The net energy demand of the reference buildings (output data) is obtained based on the physical and thermal properties of the buildings, a description of the heating and ventilation systems and building and climate conditions (input data). The energy demand is calculated through an energy balance for each building modelled as one thermal zone. The modelling is carried out by using time series of climate data with one hour time step and for one year (Mata, 2011). Each climate zone considered requires a different weather file. Hourly values of the climate parameters taken from the most populated cities of each climate zone are considered representative of the whole climate zone in this work (Meteotest, 2000).

The results of the energy simulation are compared to data available in international databases expressed in terms of final energy. Thus, the modelled net energy for energy end-use in the buildings is converted into final energy, using assumptions on efficiencies for the different fuel shares.

2.3 Representation of the Spanish building stock- archetype buildings

Three steps are followed to represent the Spanish building stock through archetype buildings: segmentation, characterization and quantification.

The number of archetype buildings required to describe the stock is decided in the segmentation process. In this work, 120 archetype buildings were considered, corresponding to:

- 6 building types. Two are for the residential sector, divided in Single-Family Dwellings (SFD) and Multifamily Dwellings (MFD); while the remaining four concern the non-residential buildings, which are Commercial, Sports and leisure, Offices, and Other services.

- 5 climate zones (A, B, C, D, E) according to those considered in the technical building code (CTE-HE, 2006).
- 4 periods of construction, decided in accordance to the changes in the building regulation codes: (1) before 1975; (2) 1975/1979; (3) 1980/2005; (4) 2006/2008[1].

In the characterization step, the period of construction is translated to U-values according to the regulations: Decree 1490/1975 (1975), NBE-CT-79 (1979) and CTE-HE (2006). For buildings constructed before the implementation of the first thermal regulation in 1975, an average U-value is assumed based on the document "Building typologies" from the PMEB (Barcelona regional, 2002) and Boermans&Petersdorff (2008). Ventilation rates are extracted from RITE (2006) for non-residential buildings and from CTE-HS (2006) for the residential sector. It is assumed that buildings constructed before the approval of such regulations do not have mechanical ventilation. For such buildings, the ventilation rate is taken as the infiltration rate provided by CTE-LIDER (2009). Values for heat gains from people, lighting and appliances are extracted from the appendices of CTE-LIDER (2009). Average hot water demands for SFD and MFD are provided by CTE-HE (2006) and corresponding values for the non-residential sector are set based on information available in the PMEB (Barcelona Regional, 2002). A share of residential buildings without any heating system is assumed for each climate zone (A: 55%, B: 13%, C: 14%, D: 8%; E: 8%) (INE, 2007). Fuel shares for heating, hot water and electricity demand are extracted from IDAE (2009). In addition, properties of the construction materials for Catalan buildings provided by Barcelona Regional (2002) are applied for all Spanish buildings. Accurate data regarding the efficiency of the building energy systems at a national level is lacking and, therefore, average values are considered based on information available from IDAE (2010) and Johnsson (2001).

Finally, two main sources are used to quantify the number of buildings and the constructed surface represented by each archetype building: the National Statistics Institute (INE, 2007) and the Ministry of Buildings (Ministerio de Fomento, 2011). Demolition rate is calculated using data available from Ministerio de Fomento (2009) obtaining values for the yearly rate of demolished buildings and demolished surface of 0.13% and 0.24%, respectively.

Additional details regarding the characterization of the 120 archetype buildings for the description of the Spanish stock are given by Medina-Benejam (2011).

2.4 Sensitivity analysis

A sensitivity analysis was performed in order to identify which input data parameters of those used by the EABS model have the greatest impact on the modelled energy

[1] The modelled energy demand presented in this paper for the year 2005 is obtained considering the archetype buildings representative of the existing stock in 2005, i.e. archetype buildings corresponding to periods of construction (1), (2) and (3). Thus, the simulation for the year 2005 is performed with 90 archetype buildings without considering period (4) (2006/2008).

demand. Such an exercise is especially important since this work is based on the use of archetype buildings (based on gathered statistics) as opposed to using sample buildings (based on measured data).

3 Results and Discussion

3.1 Archetype buildings

In 2008 there were 11.95 million building in Spain of which 9.86 million (82%) in the residential sector and 2.09 million (18%) in the non-residential sector. Of the residential buildings, 85.7% are SFD and the remaining 14.3% correspond to MFD. Based on the 2008 statistics the distribution of the number of non-residential buildings by end-use sector is: 73.7% commercial, 8.6% sports and leisure, 8.6% offices and 6.0% other services.

The same 2008 statistics gives that there are 2 124 million m^2 of constructed surface, of which 1 758 (83%) million account for the residential sector and 366 million (17%) for the service[2] sector. 41% of the surface are SFD and 59% MFD. For non-residential buildings the surface is distributed by end-use as: 52% commercial, 16% sports and leisure, 14% offices and 18% other services.

Table 1 summarizes the characteristics of the Spanish building stock as obtained from the archetype concept given in Section 1. The values shown are presented as a weighted average of the of archetype buildings representing the same building type. Thus, for instance, an average residential building in Spain consists of 2.61 dwellings of 75 m^2 of surface each. This gives a total average surface of the building of 176 m^2. The building envelope of an average residential building has 304 m^2 of surface and an U-value of 1.98.

Table 1: Characterization of the Spanish building stock as obtained in this work. The table gives average values of parameters for each building type. Based on 2008 data from INE (2007), Ministry of Buildings (2011) and the regulations mentioned in section 2.1.

BUILDING TYPE	**N. dwellings/ building**	**Surface per dwelling (m^2)**	**Surface per building (m^2)**	**Surface of the building envelope (m^2)**	**U-value (W/m^2 K)**	**Sanitary ventilation rate (l/s/m^2)**	**Natural ventilation rate (l/s/m^2)**
Residential	2.61	75	176	304	1.98	0.18/0.51	2.78
SFD	1.08	77	83	220	2.00	0.21/0.52	2.78
MFD	11.8	62	733	812	1.89	0.17/0.42	2.78
Non-residential	1.48	136	199	405	1.87	0.07/0.56	2.78
Commercial	1.48	94	139	302	1.87	0.07/0.55	2.78
Offices	1.50	291	421	769	1.85	0.07/0.83	2.78
Sports and leisure	1.47	335	496	904	1.83	0.07/0.55	2.78
Other services	1.48	205	298	579	1.86	0.07/0.55	2.78

[2] In this paper, the terms *service sector* and *non-residential sector* are used indistinctly.

Concerning technical properties for ventilation, values for sanitary[3] ventilation rate of 0.21 and 0.51 l/s/m^2 were obtained for residential buildings constructed prior to and after 2006, respectively. Finally, the natural[4] ventilation rate is 2.78 l/s/m^2.

3.2 EABS energy simulations

The energy demand was simulated by the EABS model for the years 2005 and 2008, using as input data the corresponding archetype buildings to represent the existing building stock in each case (90 archetype buildings for 2005, 120 archetype buildings for 2008). This was because figures of final energy demand disaggregated by end use for both residential and non-residential sector were found in the literature only for the year 2005, whereas for 2008 figures are restricted to total demand. Data on energy demand disaggregated by end-use is required to verify the EABS modelling since it gives the energy demand disaggregated in “heating”, “hot water” and “electricity”. Yet, as the number of buildings has increased by 4% from 2005 to 2008, also the total final energy demand in 2008 is applied here as verification of the modelling. Besides, the archetype buildings for year 2008 are differently described because of the new building regulations that appeared in 2006, requiring new values for parameters such as ventilation rates and U-values.

Table 2 lists the simulation results based on the year 2005 data giving a total final annual energy demand of the Spanish building stock of 272.0TWh. This demand is 1% lower than the reference values provided by GAINS (2005) and Eurostat (2011). The corresponding figure for the residential sector is 180.9TWh which is considered satisfactory since it is only 3% higher than the corresponding GAINS (2005) and Eurostat (2011) values. For the non-residential sector an energy demand of 91.2TWh was obtained which is 7% lower than available data in GAINS (2005) and Eurostat (2011). This somewhat larger difference could be due to the following: (1) there is lack of information regarding the non-residential sector in general. Thus, as indicated above, assumptions had to be made in order to characterize the archetype buildings for this sector, based on the data available (*cf.* Medina-Benejam, 2011); (2) it was difficult to clarify the criteria used by the data sources to measure the energy demand in terms of end use. For instance, in statistics it is not clear if the electricity consumed by an electric heater is filed under “electricity consumption” or “heating consumption”; (3) there is lack of data concerning the efficiencies considered to transform net energy to final energy while these efficiencies strongly affect the resulting energy demand; (4) there are uncertainties regarding some assumptions, all taken from INE (2007): (a) the assumption that 33.5% of households were considered to have cooling system and the assumed corresponding shares of 80% for commercial, offices and sports and leisure and 30% for other services; (b) an assumed 14.8% of the residential buildings considered to be empty residences with no energy demand; (c) the fact that the weather files used for the energy simulations contain statistically averaged climate data, with hourly resolution, applying a certain city/weather station assumed to be representative for the whole climate zone. In addition, as indicated above, climate data are not for 2005/2008 but from a test reference year (Meteotest, 2000).

[3]The sanitary ventilation rate is set by the regulations, since it represents the necessary airflow rate for ventilation to comply the required indoor air quality.

[4]The value of natural ventilation rate is the airflow rate generated when natural ventilation is being used (i.e., with windows opened).

Table 2: Final energy demand for 2005 in TWh obtained from the EABS

FINAL ENERGY DEMAND 2005 (TWh)	RESIDENTIAL	NON-RESIDENTIAL
Heating	105.1	26.2
Hot water	30.0	1.9
Electricity*	45.8	63.1
TOTAL	**180.9**	**91.2**

*Electricity=Electricity for electrical appliances, lighting, hydro pumps, fans and air conditioning

Expressing the figures in Table 2 in percentage shares, the energy demand by end-use in the Spanish residential sector is dominated by space heating (58%), followed by electriciy (25%) and finally water heating (17%). In contrast, the largest share of the annual energy demand for the non-residential sector corresponds to electricity consumption (66%), while space heating and water heating contribute less (32% and 2%, respectively). The resulting distribution of the total energy demand by end use for the residential sector is similar to what is reported by GAINS (2005); 76% for space heating and water heating (58%+17% in this work) and 24% for electricity consumption (25% in this work). The GAINS figures for the non-residential sector show a greater deviation from the present work: 50% for space heating and water heating (32%+2%) and 50% for electricity (66%). However, a distribution of the energy demand by end-use similar to the one obtained in this work is given in IDAE (2005): 29% for space heating, 3% for water heating, 61% for electricity and 7% for other energy end uses. The differences between the distributions reported by IDAE and GAINS could be caused by that different criteria have been followed when disaggregating the energy use, as discussed above.

Tables 3 and 4 report the modelled final energy demand for the year 2005 in terms of kWh/m^2 disaggregated by building type. As can be seen, an average non-residential building presents a more than doubled energy demand per m^2 than an average residential

Table 3: Final energy demand for 2005 for the residential sector in kWh/m^2 obtained from EASB

FINAL ENERGY DEMAND 2005 (kWh/m^2)	SFD	MFD	Weighted average* RESIDENTIAL
Heating	99.7	46.9	69.2
Hot water	17.3	21.6	19.7
Electricity	31.7	29.0	30.1
TOTAL	**148.7**	**97.4**	**119.1**

*Weighted average per existing m^2 of surface of SFD and MFD

Table 4: Final energy demand for 2005 for the non-residential sector in kWh/m^2 obtained from EASB

FINAL ENERGY DEMAND 2005 (kWh/m^2)	Commercial	Offices	Sports and leisure	Other services	Weighted average* NON-RESIDENTIAL
Heating	77.4	84.0	80.1	103.6	83.3
Hot water	1.2	1.6	22.1	9.5	6.0
Electricity	241.1	160.8	158.6	143.3	200.4
TOTAL	**319.6**	**246.6**	**260.8**	**256.4**	**289.7**

*Weighted average per existing m^2 of surface of the building types commercial, offices, sports and leisure and other services building. An average SFD consumes around 70% more energy per m^2 than an average MFD. From Table 3 it can also be seen that the largest share of energy demand for an SFD corresponds to heating demand, while an MFD generally requires more energy for hot water production and electricity than for heating. As for the non-residential sector, commercial buildings account for the highest energy demand per m^2 of heated floor area.

The energy simulation run for the year 2008 yields a total final energy demand of the Spanish building stock of 319.1TWh which is 8% higher than the corresponding figures extracted from IDAE (2009) and Eurostat (2011). Although the verification using the 2008 energy demand statistics yields a larger deviation than the 2005 comparison (1% lower than statistics), the 2008 comparison gives similar conclusions as those reported above, as discussed by Medina-Benejam (2011).

3.3 Sensitivity analysis

The sensitivity analysis carried out shows, as expected, that the input data parameters with the most important effect on the resulting energy demand are: (1) the U-value and (2) the hot water demand. For instance, decreasing the U-value by 10% results in a 5% reduction in modelled energy end use. This can be considered as a first assessment of the energy saving potentials to be achieved through the retrofitting of the envelope.

A 50% increase of the hot water demand leads to a 5% increase in energy demand. The values considered in the simulation were 30 l/day per person in SFDs and 20 l/day per person in MFDs. Such values might represent the maximum hot water demand, since they were extracted from the building requirements given in “Calculations and sizing” of the regulation CTE-HE (2006), *i.e.* the average hot water demand in Spanish households may be lower. On the other hand these figures are low compared to corresponding ones in Sweden (42 and 58 l/day per person in SFDs and MFDs, respectively) (Mata, 2011), Estonia (44 l/day per person) (Koiv & Toode, 2006), USA (200 l/day per person) (EM&RS, 1994) and Finland (85 l/day per person) (Koiv & Toode, 2006). A possible reason for this figure being lower in Spain than in the other countries mentioned is the existing concerns about water supply in Spain. The remaining parameters such as the ventilations rates and the internal heat gains were shown to give less influence on the final energy demand: a change of ±50% in the values considered for these parameters causes a difference of ±2-3% on the final energy demand.

In addition, the results are highly sensitive to the conversion efficiency for the different fuels[5] and there is lack of data regarding values for such efficiencies. Thus, there should be a large energy saving potential from improving the efficiency of the building service systems and electrical appliances. For example, an increased efficiency of oil and gas systems from the present average value of 87% to 95% decreases the final energy demand for the residential sector by 4%.

[5] The conversion efficiency for the different fuels is defined as the the efficiencies of the building energy systems (e.g., electric heater, gas boiler, etc.), which were used to transform net energy to delivered (final) energy.

4 Conclusions

It was possible to define archetype buildings to represent the Spanish building stock, and using these as input to the EABS model gives an energy demand similar to that available in official statistics.

A sensitivity analysis confirmed that the heat transfer coefficient of the building (U-value) and the hot water demand strongly influence the final energy demand, while the remaining parameters used to characterize the archetype buildings have less influence on the results.

It can be concluded that the national statistics used and information extracted from the Spanish building regulations were sufficient to characterize and quantify the residential buildings. However, the lack of corresponding data for the non-residential sector is the most likely reason for the larger deviation between the model results and the available statistics for this sector.

There is a lack of data needed to define the values of the efficiencies of the building energy systems. Yet, such values have a large influence on the final energy demand.

5 References

Balaras, C., Athina , G., Georgopoulou, E., Mirasgedis, S., Sarafidis, Y., & Lalas, D. (2005). *European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings.*Building and Environment. Penteli, Greece.

Barcelona Regional. (2002). *Pla de Millora Energètica de Barcelona (PMEB). Document "Sector terciari".* Barcelona. Ajuntament de Barcelona.

Barcelona Regional. (2002). *Pla de Millora Energètica de Barcelona (PMEB). Document "Tipologies d'edificis".* Ajuntament de Barcelona.

Boermans, T., & Petersdorff, C. (2008). *U-values for better energy performance of buildings.* ECOFYS.Cologne.

Clarke, J., Johnstone, C., Kondratenko, I., Lever, M., McElroy, L., Prazeres, L., et al. (2004). *Using simulation to formulate domestic sector upgrading strategies for Scotland.* Energy and Buildings.

Clinch, J. P., Healy, J. D., & King, C. (2000). *Modelling improvements in domestic energy efficiency.*Dublin: Environmental Modelling&Software.

CTE-HE. (2006). *Documento Básico HE. Ahorro de energía. Código Técnico de la edificación.*

CTE-HS. (2006). *Documento básico HS. Salubridad.*

CTE-LIDER. (2009). *IDAE. Documento de condiciones de aceptación de Programas Informáticos Alternativos a LIDER y CALENER.* Madrid: Ministerio de Industria, Turismo y Comercio.

EC. (2010). *European Union energy and transport in figures.*European Comission. Brussels.

EM&RS. (1994). *Energy use and domestic hot water consumption.* Energy Management & Research Associates (EM&RS)Brooklyn, NY.

Eurostat. (2011). http://epp.eurostat.ec.europa.eu

Hens, H., Verbeeck, G., & Verdonck, B. (2001). *Impact of energy efficiency measures on the CO2 emissions in the residential sector, a large scale analysis.* Leuven, Belgium: Energy and buildings.
IDAE. (2005). *E4: Estrategia de Ahorro y Eficiencia Energética en España. Plan de acción 2008-2012.*
IDAE. (2009). *Informe anual de consumos energéticos.* http://www.idae.es/index.php/mod.documentos/mem.descarga?file=/documentos_Informe_consumos_energeticos_2009._28.03.11_e740946d.pdf.
IDAE. (2010) *Sistema de información sobre eficiencia energética de calderas*. http://www.idae.es/Calderas/.
INE. (2008). *Encuesta de Hogares y Medio Ambiente.* Instituto Nacional de Estadística.
INE. (2007). *Insituto Nacional de Estadística*. http://www.ine.es/inebmenu/mnu_cifraspob.htm.
Johnsson, F. (ed.) *European Pathways - Pathways to Sustainable European Energy Systems*. ISBN 978-91-978585-1-9, Chalmers University of Technology (2011). Can be downloaded at http://www.energy-pathways.org/ .
Koiv, T., & Toode, A. (2006). *Trends in domestic hot water consumption in Estonian apartment buildings.*
Martinlagardette, C. (2009). *Characterisation of the French dwelling stock for application to bottom-up energy modelling.Thesis for the Degree of Master of Science in Industrial Ecology.* Chalmers University of Technology. Göteborg, Sweden
Mata, É. (2011). *Energy Efficiency and Carbon Dioxide Mitigation in Building Stocks. Development of methodology using the Swedish residential stock.* Göteborg, Sweden: Chalmers University of Technology. Accepted for publication.
Mata, É., & Sasic Kalagasidis, A. (2009). *Calculation of energy use in the Swedish housing. Description of the building energy simulation model EABS: Energy Assesment of Building Stocks.* Göteborg, Sweden: Chalmers University of Technology. http://publications.lib.chalmers.se/records/fulltext/122325.pdf
Mathworks. (2010). *MATLAB r2008a.* The MathWorks, Inc. Natick, Massachusetts, USA
Medina Benejam, G. (2011). *Bottom-up characterization of the Spanish building stock. Archetype buildings and energy demand.* Chalmers Universitiy of Technology. Göteborg, Sweden
Meteotest. (2000). *Meteonorm. Global Meteorogical Database for Solar Energy and Applied Climatology. Version 4.0.* Bern. Switzerland.
Ministerio de Fomento. (2009). *Anuario estadístico 2009.*http://www.fomento.gob.es/NR/rdonlyres/9FE92101-E20A-41B7-B355-9BEF8A667611/98025/Anuario2009.pdf.
Ministerio de Fomento. (2011). *Visados de dirección de obra nueva. Boletín estadístico online.*http://www.fomento.es/BE/?nivel=2&orden=09000000.
NBE-CT-79. (1979). *Norma básica NBE-CT-79, sobre condiciones térmicas en los edificios.*
Petersdorff, C., Boermans, T., & Harnisch, J. (2006). *Mitigation of CO2 Emissions from the EU-15 Building Stock. Beyond the EU Directive on the Energy Performance of Buildings.*Ecofys. Cologne, Germany
RITE. (2006). *Reglamento de las instalaciones térmicas en los edificios (RITE) y sus Instrucciones Complementarias (ITE). Real Decreto 1751/1998.*