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ABSTRACT (50 - 150 words)

This paper presents a methodology for systematic description of the EU building stock through archetype buildings with the aim to form a basis for analysing the potential for and cost of energy saving measures. The analysis includes the residential and non-residential sectors. Four countries in different climate regions, accounting for about half of the final energy consumption of EU-27 buildings, have been selected for the study, namely: France, Germany, Spain and UK. The number of archetypes per country has been defined corresponding to different categories of building type, construction year, climate region and main fuel source for heating. The accuracy of the description is validated by simulating energy demand with the building stock model ECCABS, and comparing the modelled final energy demand with corresponding data from statistics. The calculated total final energy demand for each country is within -9% and +3 % deviation from available statistics, which is considered satisfactory.

KEYWORDS (6-8)

archetype buildings, EU building stock, energy demand, ECCABS model, energy simulation

INTRODUCTION

While significant potentials for energy savings and mitigation of greenhouse gas emissions within the building sector have been identified in many countries (see [1] for a summary of potentials worldwide), these potentials are far from fully exploited. The failure to realise the potentials for energy savings is due to: a lack of knowledge about the characteristics of the buildings; a lack of awareness of the best steps to take for each building stock; and the complexity associated with implementing energy-saving measures (ESMs). The lack of knowledge regarding the characteristics of the buildings (i.e., size, structure, and dynamics of change of the building stock) represents a major obstacle to investigations into how energy performance can be improved for the building stock [2-8]. This work assesses the possibility to describe the European (EU) building stock with the aim to form a basis for analysing the effect and costs of applying different energy saving measures to the entire stock. Four countries are selected for the study, namely France, Germany, Spain and UK which together account by about half of the energy consumption of buildings in EU-27.

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A building stock can be described through representative buildings in terms of *sample buildings* or *archetypes* [9]. Sample buildings are herein designated as representing actual buildings (with data obtained from measurements). As the building stock of a country consists of buildings with different characteristics, an extensive sample of the buildings is required in order to derive the thermal characteristics of the building stock. Thus, establishment of the sample requires significant efforts towards measuring and quantifying the parameters of the building sample. On the contrary, archetype buildings are theoretical buildings based on knowledge of the overall building characteristics of the region (e.g., age, size, construction materials, and house type) in combination with national statistics related to the building sector (e.g., energy use, climate). Literature gives descriptions of the building stock for several countries according to certain categories (cf. for France: [10-11]; for Germany: [12-14]; for Spain: [15-16]; and for UK: [17-20]) although these descriptions do not include all relevant parameters for determining the energy demand, for instance only heated floor areas or number of buildings are given. On an EU level, there are examples of a more comprehensive description of a set of buildings; however the number of buildings is not quantified to allow the representation of all residential and non-residential buildings in the stock [17, 21]. Thus there is much work to do to complete a description of the characteristics of EU buildings on which to base the investigation of improvements in energy performance. This paper presents a methodology for systematic description of the EU building stock through archetype buildings, including the residential and non-residential sectors.

BUILDING STOCK DATA REQUIREMENTS AND AVAILABILITY

Building stocks are generally divided into Residential (R) and Non-Residential (NR) buildings, the latter are also known as the tertiary or commercial sector. The data requirements for assessing energy-saving and carbon dioxide (CO_2) mitigation strategies depend on the type of modelling used. On the EU and international levels, three readily accessible databases provide data on the building sector, namely: Eurostat [22], ODYSSEE-MURE [23], and the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) database [24]. They are updated on a regular basis and their main contents are summarised in Table 1.

In addition to the above sources, some European projects (e.g. [17]) and periodical reports have compiled all the information available on the building stock of a given country or set of countries. [25] has mapped the available data, indicators, and models related to the energy demands of European buildings. [7] have reviewed the energy consumption data for buildings worldwide in the last 30 years (not in a continuous way but providing snapshots when the information was available). Although the databases listed in Table 1 provide a valuable overview of the EU building stock, the data cannot be used for an archetype-based modelling of the thermal performance of the stock since there is a lack of physical description of the buildings required for such an analysis.

Table 1. Summary of international data sources for the energy consumption levels and characteristics of the European building sector.

		Odyssee	**Eurostat**	**GAINS**
Years included	Units used	From 1980	From 1990	2005-30
Buildings' characteristics				
Stock of dwellings	k	Yes		Yes (1, 6)
Stock of dwellings (permanently occupied)	k	Yes(1)		Yes (1, 6)
Stock of dwellings with individual central heating	k	Yes(9)		
Stock of dwellings with room heating	k	Yes(9)		
Floor area of dwellings (total)	m^2			Yes (1, 6)
Floor area of dwellings (average)	m^2	Yes(1)		
Floor area of new dwellings (average)	m^2	Yes(1)		
Stock of refrigerators	k	Yes		
Stock of freezers	k	Yes		
Stock of washing machine	k	Yes		
Stock of dishwashers	k	Yes		
Stock of televisions	k	Yes		
Floor area of tertiary dwellings (total)	1000m2	Yes(5)		
Energy consumption levels				
Total final consumption		Yes	Yes	
Coal consumption, residential sector	Mtoe	Yes(4)		
Oil products consumption , residential sector	Mtoe	Yes(3)		
Gas consumption, residential sector	Mtoe	Yes(3)		
Heat consumption, residential sector	Mtoe	Yes(4)		Yes(6)
Wood consumption, residential sector	Mtoe	Yes(4)		
Electricity consumption, residential sector	Mtoe	Yes(2)	Yes	Yes(2, 7)
Final energy consumption, residential sector	Mtoe	Yes(3)		
Final consumption, residential with climatic corrections	Mtoe	Yes		
Final consumption, tertiary sector	Mtoe	Yes(3)	Yes	Yes
Coal consumption, tertiary sector	Mtoe	Yes		Yes
Oil products consumption, tertiary sector	Mtoe	Yes		Yes
Gas consumption, tertiary sector	Mtoe	Yes		Yes
Heat consumption, tertiary sector	Mtoe	Yes		Yes
Wood consumption, tertiary sector	Mtoe	Yes		Yes
Electricity consumption, tertiary sector	Mtoe	Yes(5)		Yes(2, 8)
Final consumption, tertiary sector	Mtoe	Yes(5)		Yes
Total consumption, tertiary sector (climate corrected)	Mtoe	Yes		
CO_2 emissions				
CO_2 emissions	$MtCO_2$	Yes(10)		Yes
Total CO_2 emissions (with electricity)	$MtCO_2$	Yes(10)		Yes

k= thousand units
Mtoe=Megatons of oil equivalent
(1)Data provided disaggregated into Single-family Dwellings and Multi-family Dwellings.
(2)Data provided disaggregated into Space heating, Hot water, Cooking, Lighting and Appliances.
(3)Data provided disaggregated into Space heating, Hot water and Cooking.
(4)Data provided disaggregated into Space heating and Hot water.
(5)Data provided disaggregated into hotels/ restaurants, health and social actions, education/research, administration, private services, offices and trade (wholesale and retail).
(6)Data provided disaggregated into Existing and New.
(7)Data provided disaggregated into Cooling and Heating.
(8)Data provided disaggregated into Cooling, Heating and Ventilation.
(9)Only permanently occupied dwellings.

METHODOLOGY FOR BUILDING STOCK DESCRIPTION

The description of a building stock through archetype buildings follows three steps: segmentation, characterization and quantification. Data was compiled through several surveys conducted on a country basis, for which there is corresponding reports available [26-29].

Segmentation

In the segmentation process, the number of archetype buildings required to represent the entire stock is decided. Segmentation criteria, given in Table 2, include building type, construction year, heating system and climate zone, chosen since these give a good representation of the energy demand of the buildings as well as they facilitate data compilation (i.e. matching the form of data sources). The meteorological data of the most populated city in the climate zone is considered representative of the climate in the zone, and the meteorological data for each of such cities used in the modeling is generated by Meteonorm [30].

Table 2. Segmentation categories proposed in this work, and relevant building data depending on the category.

Categories	Relevant building data dependent on the category
Building type	Effective heat capacity of the building
	Floor area
	External surface area
	Internal gains
	Minimum desired indoor temperature
	Maximum desired indoor temperature
	Sanitary ventilation rate
Construction year	Average U-value of the building
	Window area
	Ventilation rate
Heating system	Indoor temperatures
	Fuels used
Climate zone	Average U-value of the building
	Outdoor climate data

The segmentation was applied for Residential (R) and non-residential (NR) buildings for France, UK and Spain whereas for Germany so far only the R stock is included. The following archetype buildings were obtained:

France: total of 99 archetype buildings corresponding to:

- Three building types for R buildings: Single-Family Dwellings (SFD) and Private and Public Multi-family Dwellings (PrMFD, PuMFD) [10]; and five building types for NR buildings: Commercial (C), Educational (E), Health (H), Offices (O), and Sports, Culture and Leisure (SLC), which account for 80% of the final energy use of the NR sector [22, 31].
- Three climate zones: North-East (represented by the city of Paris), West (Toulouse), and South (Marseille) as considered for winter period in the building codes [32].
- Three periods of construction in accordance to the changes in the building regulation codes for R buildings [10]: before 1975, before 1975 refurbished, after 1975, and three different periods for the NR buildings [33-34]: before 1977, 1977/2000, after 2000.
- Two sources of energy for heating purposes, only for R buildings: electric heating and other source for heating [10].

Germany: Limited to R stock, represented by 122 archetypes corresponding to:

- Five building types [35], namely: SFD including Two-family dwelling also prefabricated houses (TFD), Row houses (RH), MFD with maximal four floors and eight to ten apartments, apartment blocks with maximum ten floors (AP), High-rise buildings consisting of more than ten floors (HH), mostly from the 1960s and 1970s.
- Three climate zones represented by the cities of Essen, Stuttgart, and Munich, adjusting the four recommended zones [36] for calculating the heating load after the DIN EN 12831 to the political division of the territory in sixteen states.
- Ten periods of construction, decided in accordance to historical events, changes in construction technologies and building regulation codes [35]: before 1918 except framework buildings, framework buildings before 1918, 1919/48, 1949/57, 1958/68, 1969/79, 1980/83, 1984/94, 1995/2002, 2003/09.

Spain: A total of 120 archetypes corresponding to:

- Two building types for R buildings (SFD and MFD); and four building types for NR buildings, i.e. C, SLC, O, and other services (X).
- Five climate zones represented by the city of Málaga, Sevilla, Barcelona, Madrid, and Burgos, as considered in the technical building code [37].
- Four periods of construction, according to the building regulation codes: before 1975; 1975/1979; 1980/2005; 2006/2008[1].

UK: A total of 252 archetype buildings, including:

- Six building types for R buildings [38]: detached (D), semidetached (SD), terraced (T), MFD, bungalow (B), and others (X), and three building types for NR buildings [39]: O, warehouses (W) and retails (R). These NR building types are known as the Valuation Office's bulk classes and cover about 70% of the all ratable[2] NR buildings, but exclude for instance hospitals, schools, churches, etc.
- Four climate zones [40] represented by the cities of London, Birmingham, Newcastle and Glasgow.
- Seven construction periods according to the updates of the regulation Part L [41-44]: before 1985, 1986-1991, 1992/95, 1996-2002, 2003/06, 2007/10, and after 2010.
- Two types of heating systems, central and non-central (assumed that premises which currently have non-central heating system are all built before 1985). The average internal temperature for centrally heated dwellings is given to be 17.5 °C while it is 14°C for non-centrally heated premises [38].

Characterization

In the characterization step, each archetype is described by defining and computing their technical characteristics based on the parameters from the segregation given in Table 2.. Reports from official entities responsible for dwellings (e.g., Ministry of Dwellings/Energy/Environment in the four countries) provide information about the buildings' physical characteristics. However, it is difficult to find corresponding data for non-residential buildings. Regulatory codes are useful for determining the indoor conditions and thermal properties of the building envelope. For instance, for **French buildings** the period of

[1] The modelled energy demand presented in this paper for the year 2005 does of course not consider period 2006/2008, and thus was obtained considering only 90 archetype buildings.

[2] Ratable value represents the open market annual rental value of a business/ NR property. Factory buildings are also included, but in this paper they have been excluded due to lack of data on energy use of this kind of buildings to compare the results obtained from the energy demand simulation.

construction is translated to U-values according to the building regulations for the R sector [45-47] and for the NR sector [48]. There is no data regarding the U-values of the oldest R and NR buildings per climate zone, and the U-values of the climate H3 is assumed to be 15% higher than those of the other two zones [49]. Ventilation rates for R buildings are extracted from [48], and for NR buildings from [27, 50, 94]. Natural ventilation rates for R buildings are calculated according to the DEL.6-Method [11] and for the NR buildings, from [27] since no data has been found for the French case. Heat gains from occupants are calculated considering that metabolic gains [51] are low, except for the SCL where occupants are more active. Heat gains from lighting, equal to their electricity consumption, for R buildings are calculated by adding 3W/m^2 to each 100 lux of installed illuminance [47], and the illuminance of 300lux required in households. For NR buildings range from 3.1 to 11.5 W/m2 and are calculated from the lighting consumption [52] assuming schedules for operation and occupancy [26]. Heat gains from appliances in R buildings 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 [11]. For NR buildings gains from appliances range from 1.1 to 4.7 W/m2 [27, 50]. Building materials are taken from [63].

For **German R buildings**, U-values are set according to the regulations [35]. In Germany natural ventilation is a prevailing way for supplying fresh air to the buildings. The share of buildings with a mechanical ventilation system is less than 1.5 % and only around half of them are coming with heat recovery (the latter are disregarded). Additionally, 10 % of the newly constructed buildings are equipped with a ventilation system [53]. Sanitary (natural) ventilation rates between 0.60 and 0.85h^{-1}, depending on construction year, were calculated from [54]. Values for heat gains from appliances and occupancy range, respectively, between 1.78 W/m2 and 2.66 W/m2 and between 1.11 W/m2 and 2.00 W/m2, for the different building types according to [55]. Heat gain from lighting is 0.27W/m2 for all buildings, calculated from the energy consumption for lightning per person and per year [56], the average amount of person per household [57] and the average floor area of a German dwelling [52]. Hot water demand is between 1.16 W/m2 and 3.38 W/m2 for the different building types according to [58].

For **Spanish buildings** the period of construction was translated to U-values according to the regulations [37, 59-60]. Ventilation rates for R buildings are taken from [37]; for NR buildings from [62]. For buildings constructed before the implementation of the first thermal regulation in 1975, an average U-value is based on [21, 63]; and ventilation rates for R buildings are taken as the infiltration rate provided by [61] and for NR were based on the level of air quality required for the building [62]. Heat gains from occupants, lighting and appliances were extracted from the appendices of [61]. Average hot water demands for R buildings are provided by [37] and corresponding values for NR buildings are based on [63]. Building materials are as those of Catalan buildings [63].

The U-values of the **buildings in the UK** are based on the requirements of building legislation Part L during each time period. Values for the buildings constructed before 1985 are taken from [18-20]. Sanitary ventilation rate for R buildings is 0.3 l/s per m2 [64-65]. Rates for NR buildings range from 0.9 to 1.2 l/s per m2 and are based on the average rate per person [64] and the required air changes per hour [66]. NR buildings built after 1985 are assumed to have a mechanical ventilation system, and after 1990 also a heat recovery system. Natural ventilation rates for R buildings built after 1996 accomplish legislation requirements [42-44], and for older buildings ventilation rates are taken from [20]; and for NR buildings infiltration rates vary from 0.5 to 1.0 h^{-1} [67]. Average heat gains from lighting for R buildings is 0.9 w/m^2 as calculated from [18] and in accordance to [82]; and for NR buildings heat gains from lighting vary from 4.3 to 10.8 W/m2 [68]. Average heat gains from apliances for R buildings vary from 2.4 to 5.5 W/m2 as calculated from [18]; and for NR buildings is for warehouses 3.0 W/m2 (calculated from [39]), for offices 4.3 W/m2 [69] and for retail 7.3 W/m2 [67]. Average heat gains from occupants for R buildings vary from 0.52 to 1.6 W/m2 as calculated from the number of persons per household [38] and the metabolic heat gain from occupants; for NR buildings vary from 1.39 to 3.31 W/m2 as calculated from the occupancy of warehouses [70], offices [69, 71] and retails [67]. Average hot water demand for R buildings is 103 liters per household per day for all dwelling types [20]; for NR buildings varies from 0.9 to 1.6 W/m2 [68].

Quantification

The quantification step determines how many buildings represented by each archetype building exist in the stock. National statistics are generally sufficient to quantify the number of buildings and their areas. The number of buildings in France is taken from [17, 71]. The number of social dwellings existing in 1975 is given in [74] (2007) and the existing public MFD in 2007 are given in [74]. A refurbishment rate of 45,000 renovations per year has been assumed for the period 1977-2005 [75]. Heated floor areas for R buildings are given in [46]; for NR buildings data is scarce, therefore areas for NR-C and NR-E are calculated from the average heated floor area in 2004 found in [76]; for NR-H are calculated using the number of buildings providing the possibility to stay overnight [77] and the surface in 2010 [78]; and for NR-SCL from [27].

The number of R buildings in Germany and their heated floor areas are given for all archetype buildings by [35, 79]. Adjustments required to quantify separately High Towers and Apartment blocks (which [79] considers as one type) are presented in [28]. The number of Spanish buildings and their heated floor areas are taken from [80-81]. Demolition rates given in number of buildings and per floor areas are, respectively, 0.13% and 0.24% are calculated from [82]. Finally, the total number of buildings in UK per each region and time period is derived from the BRE's domestic and non-domestic fact files [38, 82].

Calculated final energy demand for a reference year

After the building stock is described by the archetype buildings, an energy simulation using the Energy, Carbon and Cost Assessment of Building Stocks (ECCABS) model 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 with the corresponding values of energy consumption found in national and international statistics.

The model has been developed in the Matlab and Simulink environments (www.mathworks.com), by the authors. The model 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 individual buildings is calculated based on the physical and thermal properties of the buildings, a description of the heating and ventilation systems, and usage and climate conditions. The energy balance is calculated every hour and the results are summed to give the annual values. The model can be used with both sample and archetype buildings. Each building is treated as one thermal zone. A full description of the building-stock model is given in [90].

Accurate data regarding the efficiency of the building energy systems at a national level was lacking for France and Spain and, therefore, average values were considered based on [84, 85]. A share of Spanish R buildings without any heating system [80] is assumed for each climate zone (A: 55%, B: 13%, C: 14%, D: 8%; E: 8%). Fuel shares for heating, hot water and electricity demand were extracted from [86]. For Germany, the distribution of the several heat and hot water generators/producers was acquired from [53]. The efficiencies of the systems were extracted from [55, 87]. For the UK, different fuel shares have been assigned to R buildings central or non-central heated [38], and to NR buildings [88]. Efficiency of the boilers (2006 to 2010) is taken from [19, 37, 88, 93].

Tables 3 to 6 summarize the final energy demand obtained from using the archetype buildings of Table 2 as input buildings in the ECCABS model for the four countries, presented per building type and end-use.

Table 3. Final energy demands of the French residential sector in 2005, and for the French non-residential building (data for 2009) in TWh according to end-use and building subtypes.

End-uses	*R*	SFD	Private MFD	Public MFD	*NR*	NR-O	NR-C	NR-H	NR-E	NR-SCL
Heating	263.2	183.9	39.7	39.6	*85.4*	23.3	25.9	12.8	18.2	5.2
Hot water	69.7	37.7	20.6	11.4	*16.8*	1.9	3.2	4.5	2.7	4.6
Electricity*	104.2	61.3	27.5	15.4	*84.1*	30.2	25.3	11.3	7.9	9.3
TOTAL	437.2	282.9	87.8	66.4	186.3	55.2	54.4	28.6	28.9	19.1
Heated floor Area(Mm2)	*2269.6*	*1472.4*	*512.0*	*285.1*	*758.3*	*199.7*	*202.7*	*182.3*	*106.5*	*67.0*

Table 4. Existing heated floor areas and annual final energy demand (in TWh) by end-use and building type in the German residential sector (in year 2009), as obtained in this work.

End-uses	*R*	SFD	RH	MFD	AP	HH
Heating	*566.7*	205.65	45.82	235.6	68.5	5.0
Hot water	*49.1*	13.35	5.83	19.4	8.6	0.5
Electricity*	*77.5*	30.21	11.48	24.8	9.0	0.5
TOTAL	*49.1*	13.35	5.83	19.4	8.6	0.5
Heated floor Area (Mm2)	*3269.8*	*1403.2*	*533.5*	*958.8*	*306.4*	*16.7*

Table 5. Existing heated floor areas and annual final energy demand (in TWh) by end-use in the Spanish residential sector (in year 2005) and in the non-residential sector (in year 2009).

End-uses	*R*	R-SFD	R-MFD	*NR*	NR-C	NR-O	NR-L	NR-X
Heating	*101.9*	68.1	33.8	*30.4*	15.3	4.2	4.6	6.4
Hot water	*25.6*	9.5	16.1	*1.7*	0.2	0.1	1.0	0.5
Electricity*	*35.0*	14.8	20.2	*59.0*	37.3	6.4	7.4	7.9
TOTAL	*178.4*	*103.1*	*75.2*	*91.1*	*52.8*	*10.6*	*13.0*	*14.8*
Heated floor Area(Mm2)	*1294.1*	547.2	746.9	*314.9*	168.9	41.8	49.2	54.9

*Electricity=Electricity for electrical appliances, lighting, hydro pumps, fans and air conditioning; R, Residential; NR, Non-Residential; SFD, single-family dwelling; MFD, multi-family dwelling; C, commercial; O, office; L, leisure; X, other.

Table 6. Existing heated floor areas and annual final energy demand (in TWh) by end-use in the UK building sector.

End-uses	*R*	R-D	R-SD	R-T	R-B	R-X	*NR*	NR-O	NR-L	NR-X
Heating	*279.8*	84.1	62.1	2.2	103.8	26.9	*29.3*	13.6	4.1	11.6
Hot water	*95.9*	25.5	26.4	17.7	16.7	9.3	*5.4*	2.1	1.5	1.8
Electricity*	*101.8*	27.1	27.9	18.7	17.9	9.8	*46.7*	22.7	10.7	13.3
TOTAL	*472.9*	135.5	115.3	37.8	137.1	45.3	*81.4*	38.4	16.2	26.8
Heated floor Area(Mm2)	*2360.7*	625.4	574.0	288.7	681.6	184.3	*432.1*	135.8	114.5	181.7

*Electricity=Electricity for electrical appliances, lighting, hydro pumps, fans and air conditioning; R, Residential; NR, Non-Residential; SFD, single-family dwelling; MFD, multi-family dwelling; C, commercial; O, office; L, leisure; X, other.

RESULTS VALIDATION AND DISCUSSION

Table 7 compares the resulting number of archetypes (cf Table 2) for the four countries. The amount of subtypes in the categories of building type and construction year differ the most, since these reflect the historical events, tradition in building styles, changes in construction techniques and building regulation codes. With respect to the building type, the form of data sources generally allows to differentiate clearly data for R and NR buildings As shown in Table 8, the number of subtypes in each sector required to resolve the building stock differ from the simplest division in only SFD and MFD, as in Spain, to the more detailed differentiation of four or five subtypes as required for Germany and UK.. From the information available in the sources, however, it is not possible to clarify to what extent the so-called Row House in Germany is similar to the so-called Semidetached house in UK.

Table 7. Number of archetype buildings depending on the segmentation category, as obtained in this work.

Categories	France		Germany	Spain		UK	
	R	NR	R	R	NR	R	NR
Building type	3	5	5	2	4	6	3
Construction year	3	3	10	4	4	6	6
Climate zone	3	3	3	5	5	4	4
Heating system	2	-	-	-	-	2	2
#Archetypes	54	45	122	40	80	252	84

With respect to the number of climate zones, the division required obviously increases with the variations in altitude, latitude within the country and if there is exposure to seas/oceans. The less such variations in Germany result in only three weather zones, while five weather zones are needed for Spain. Since the archetypes described in this work aim to be representative of EU buildings, it is worth mentioning that literature proposes different number of climatic zones in EU, ranging from three zones [91] to five zones [92]. Both [91, 92] group EU countries in regions, however [92] takes into account both heating and cooling energy needs (i.e. in degree day, DD) of each specific location regardless of the country. An analysis of the number of climate zones required for EU is out of the scope of this work, but it should be noted that the countries selected in this study belong to all regions considered in the above mentioned different proposals for EU. Further work is needed to investigate how the grouping of the four countries studied according to the three to five climate zones in EU would affect the methodology proposed in this paper.

Table 8. Subtypes in the Building-Type category proposed in this work, and the countries in which it is used (F: France, G: Germany, S: Spain, U: UK).

Categories	R	NR
Building type	MFD, Multi-family Dwelling (G, S, U) SFD, Single-family Dwelling (F, G, S) AP, Apartment block<10 floors (G) HH, High-rise buildings>10 floors (G) PrMFD, Private MFD (F) PuMFD, Public MFD (F) RH Row house (G) D, detached (U) SD, semidetached (U) T, Terraced (U) B, Bungalow (U) X, Others (U)	O, Offices (F, S, U) C, Commercial (F, S) SCL, Sports, Culture and Leisure (F, S) E, Educational (F) H, Health (F) R, Retails (U) W, Warehouses (U) X, Other services (S)

As indicated in previous section, the characterization of the buildings is mostly based on building regulation codes and a wide range of national sources. The influence of each model input/building characteristic on the total energy demand as obtained from the modelling has been quantified by normalized sensitivity coefficients, which represent the corresponding percentage change in the output variables given a 1% change in the input parameter [19]. The results of the sensitivity analysis are presented in Table 9, which gives the six input parameters with the greatest effect on the modelled energy demand. For all countries, indoor temperature has the greatest impact on the modelled energy demand. It should be noted that the model used in this work is dynamic, thus the indoor temperature is calculated every hour. Heat demand is defined as the heating power required to maintain the indoor air temperature at a given level. A " on/off" control system is used in the model, which means that the heating system is turned ON if the indoor air temperature is lower than a minimum indoor temperature. Otherwise, the heating is in the OFF position. The relevance of indoor temperature can be interpreted as occupants behaviour and lifestyle preferences having and outstanding role in buildings' energy demand.

Table 9. Summary of R-building parameters most determinant to the final energy demand of the R sector, as resulting from the sensitivity analysis in this work for the different countries studied.

France		Germany		Spain		UK	
Parameter	$S_{j,i}$	Parameter	$S_{j,i}$	Parameter	$S_{j,i}$	Parameter	$S_{j,i}$
T_{min}	1.62	T_{min}	1.52	T_{min}	2.05	T_{min}	1.63
U	0.71	S	0.75	V_{cn}	1.82	U	0.88
S	0.71	U	0.75	S	0.84	S	0.87
A	0.30	W_c	0.71	U	0.84	A	0.21
V_c	0.16	A	0.45	A	0.27	H_w	0.20
H_w	0.15	V_c	0.36	S_w	0.11	W_f	0.07

The properties of the building envelope have the second highest impact on the energy demand, such properties include of course the average U-value of the envelope (U), but also the surface of envelope (S) and the windows characteristics (i.e. area, S_w, and percentage of window frame, W_f). Finally hot water demand (H_w) is influential in the R sector since it corresponds to 9-20% of the total final energy demand for the four countries investigated.

However, for the NR sector (not shown in the table), ventilation and lighting are more relevant than hot water demand. For instance, the normalized sensitivity coefficients $S_{i,j}$ for NR obtained for the ventilation rates vary from 0.16 to 0.26; for lighting, from 0.11 to 0.15; and for appliances, from 0.05 to 0.15.

Figure 1 shows the average U-values of the buildings in each country, obtained in this work, for the different subsectors. Generally, the values are lower the colder the climate zone and Spain has the highest U-values for all the building types. According to the annual average degree-days during 1990-2009 reported in Eurostat, Spain and France have very similar climates (respectively 2171 and 2198 DD/yr), then UK 2987 DD/yr and Germany is the coldest country with an average of 3608 DD/yr. However, in spite of being in the coldest climate, U-values of German buildings (i.e. 1.1 W/m^2K for SDF and 1.5 W/m^2K for MFD) are higher than those of the UK buildings (i.e. 1.1 W/m^2K for SDF and 1.2 W/m^2K for MFD). The latter are on average exceptionally low, mostly due to that R buildings constructed before 1985 have an average U-value of around 1.3 W/m^2K, as reported in literature (cf. in [28] a summary of the U-values reported [18-20]). On the contrary, in the other three countries the older buildings have U-values above 2.0 W/m2, with exceptionally high U-values up to 3.5 W/m2 reported in France for the oldest Public MFD which have not been refurbished. Another outstanding result is that Spanish buildings have significantly higher U-values (i.e. around 1.9 W/m^2K for all building types) than French buildings (i.e. 1.1 W/m^2K for SDF, 1.6 W/m^2K for MFD, and and 1.3 W/m^2K for NR), despite of their climates being very similar.

Table 10. Deviation of the resulting final energy demand in the reference year from the corresponding data available in statistics, for the different countries studied. The sources used for the comparison are specified in the table.

Country	Subsector	Deviation from other sources	Other sources
France	R	-5 %	[22]
		-7%	[95]
	NR	-1%	[98]
Germany	R	-9	[95]
		-1%	[96]
		+3%	[21]
Spain	R	+2%	[22, 24]
	NR	-7%	[22, 24]
UK	R	+3%	[88]
	NR	-3%	[88]

The resulting final energy demand for all countries gives general good agreement (from +3% to -9%, as summarized in Table 10) with the international statistics, i.e. Eurostat, Gains and Odyssee. Although international statistics give similar data for each country, national sources report data that slightly differs from the above sources. Data on energy demand disaggregated by end-use, i.e. which can be directly compared with the results from this work, is only available for France and Germany. For France, [95] reports final energy demands that, per end-use, differ significantly from the results of this work (i.e. demand for heating is 22% lower than the result in this work, for hot water 15% higher, and for electricity 24% lower) in spite of the above reported total final energy demand similar to the demand obtained here. [95] does not report of the methodology, and it has therefore not been possible to find reasons for these discrepancies between its values and the results of the simulation.

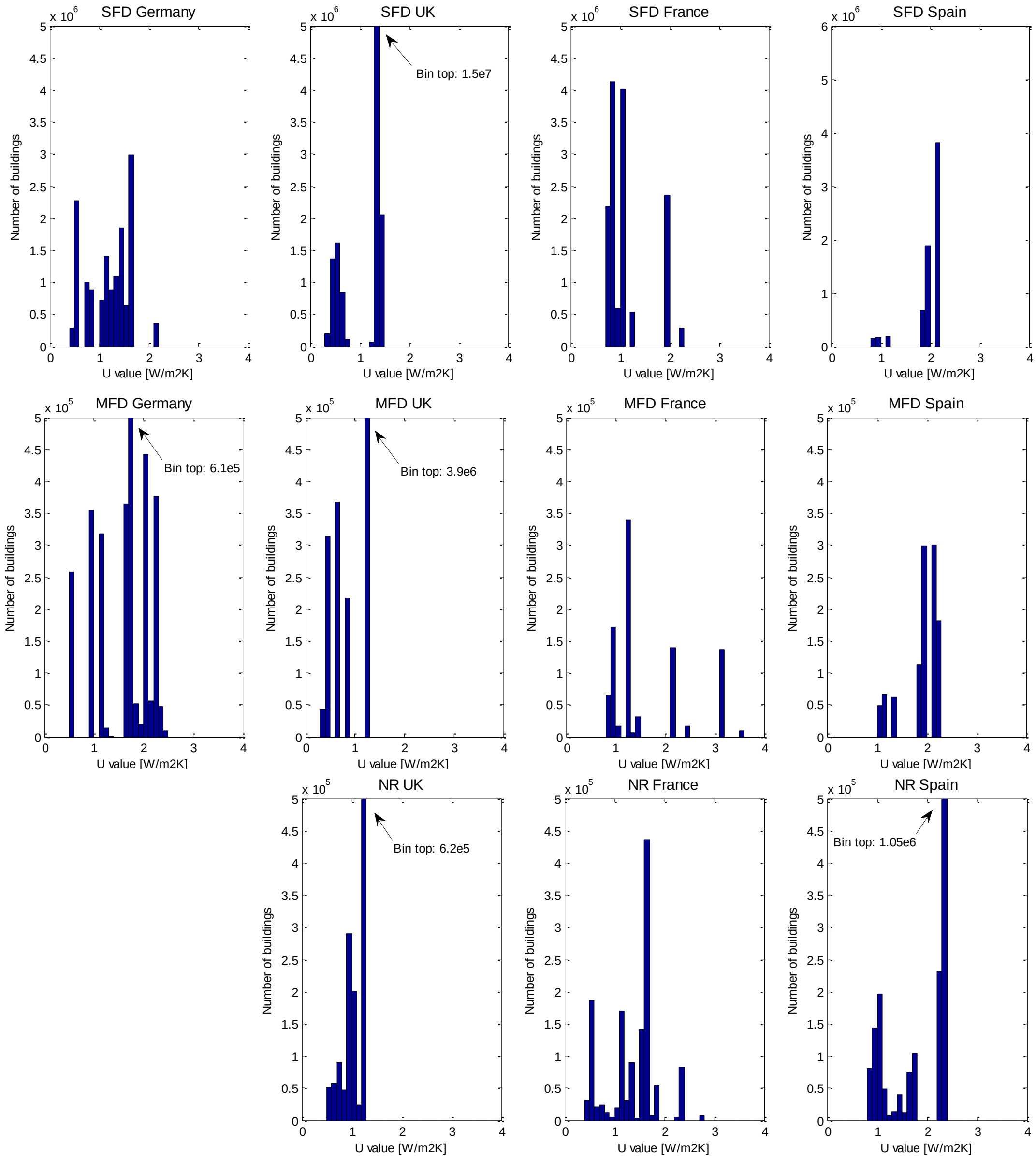

Figure 1. Comparison of the U-values in the existing building types of the different countries investigated.

For Germany, Statistisches Bundesamt [96] gives a total energy demand 3 % higher than our calculations, a hot water demand 27 % lower than our results while space heating demand is 14 % higher. The demand reported for appliances and lightening is similar to our results. Overall, the comparison can be seen as satisfactory.

In addition, using the archetypes of this work as an input to the model gives detailed data on the energy use of each archetype in terms of net and final energy, per end-use and fuel. Thus ECCABS model can be an efficient tool to generate data about the building stock that is generally not available, as the above mentioned.

CONCLUSIONS

The building stocks of four EU-countries, which account for half of the final energy use of EU-27, have been described through archetype buildings, including the residential and non-residential sectors. From the process of defining the archetype buildings, we can conclude that data available on the national level are sufficient to define building parameters relevant for energy demand, provided of course that assumptions can be made when the data are incomplete or insufficient. Namely, data available in national statistics are sufficient to quantify for each of the countries studied the number of buildings and their areas, data reported by official entities responsible for dwellings (e.g., Ministry of Dwellings/Energy/Environment) provide information about the buildings' physical characteristics, and data in regulatory codes can be used to determine the indoor conditions and thermal properties of the building envelope. Noteworthy, the amount of data available as basis for the archetype buildings differ significantly between the four countries investigated and there is generally less data for non-residential buildings. International statistical data are sufficient for the validation of the results obtained at a country level, and using the obtained archetypes as input for ECCABS model, gives a total final energy demand which is between 9% lower and 3% higher than the statistics for the four countries investigated. This is considered satisfactory, and it is concluded that the presented building stock description through archetype buildings give a good estimate of the thermal performance of the building stocks and, thus, can be used as a to investigate the effect of applying different energy saving and CO2 mitigation strategies to national building stocks.

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