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Survery and simulation of energy use in the European building stock.
In:

Survey and simulation of energy use in the European building stock

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Abstract

Buildings account for around 40% of the final energy consumption in Europe and are central in the work towards increased energy efficiency. In order to plan and perform effective energy renovation of the buildings, it is necessary to have adequate information on the current status of the buildings in terms of architectural features and energy needs. Unfortunately, the official statistics do not include all of the needed information for the whole building stock.

This paper aims to fill the gaps in the statistics by gathering data from studies, projects and national energy agencies, and by calibrating TRNSYS models against the existing data to complete missing energy demand data, for countries with similar climate, through simulation. The survey was limited to residential and office buildings in the EU member states (before July 2013). This work was carried out as part of the EU FP7 project iNSPiRe.

The building stock survey revealed over 70% of the residential and office floor area is concentrated in the six most populated countries. The total energy consumption in the residential sector is 14 times that of the office sector. In the residential sector, single family houses represent 60% of the heated floor area, albeit with different share in the different countries, indicating that retrofit solutions cannot be focused only on multi-family houses.

The simulation results indicate that residential buildings in central and southern European countries are not always heated to 20 °C, but are kept at a lower temperature during at least part of the day. Improving the energy performance of these houses through renovation could allow the occupants to increase the room temperature and improve their thermal comfort, even though the potential for energy savings would then be reduced.

Keywords - building stock survey; energy demand; renovation; simulation; TRNSYS

1. Introduction

The current building stock across Europe comprises many energy-inefficient buildings, with different typologies, sizes and construction methods. The majority of these were also built before the introduction of building regulations or energy standards were in place. The performance of the existing building stock across Europe, from both an energy and comfort perspective, needs to be improved. This is particularly important if the targets for reduced energy consumption that have been set by Energy Performance of Buildings Directive are to be achieved. In order to plan and perform effective energy renovation, it is important to have adequate information on the current status of the buildings in terms of architectural features and energy needs to inform the most appropriate methods. Unfortunately, the official statistics do not include all of the needed information for the whole building stock.

The work described in this paper has been conducted as part of an EU FP7 project called iNSPiRe. The objective of this four year EU-funded research project is to tackle the problem of high-energy consumption by producing systemic renovation solutions that can be applied to residential and office buildings. The renovation packages developed as part of the project aim to reduce the primary energy consumption of a building to less than 50 kWh/m²·a. The work is limited to the EU-27 countries.

The first aim of this paper is to present the results from a literature survey on the existing residential and office building stock across EU-27. The extensive building stock survey involved gathering information and data concerning the architectural characteristics and energy use of these buildings. The energy consumption and demand data was further broken down by space heating, domestic hot water, cooling and lighting requirements. A categorisation process using building types and climatic regions was applied to the findings from the building stock survey and a database containing all the statistical data from the literature survey was created. Despite the extensive literature review, there were information gaps.

The second aim was to give complementary information about the average and total heating and cooling demands of residential and office buildings, based on simulations. To fill in the gaps in the energy statistics a set of building models, based on boundary conditions from the statistics, were created and simulated. These models were defined to represent typical single family houses, multi-family houses and office buildings, and used to derive average heating and cooling energy consumption for each building type, climate region and construction period. The models were then calibrated against existing data, and used to derive new data where missing.

2. Survey of building stock

2.1. Method

The data gathering exercise focused on published literature and other sources, with the aim of obtaining information about the current residential and office building stock. The types of information gathered included number and floor area of residential buildings/dwellings and offices buildings; typology; age distribution; construction by type and age; façade and glazing types; average floor area; geometry; number of floors; U-value and thermal characteristic and performance of the buildings, by age; ownership and tenure i.e. number of social housing, owner occupied, private renting etc.; energy consumption and demand in terms of both total and individual end-use including space heating, domestic hot water, cooling, lighting; fuel and heating system types and comfort requirements.

A wide variety of sources were consulted including the Office of Statistics for each country in the EU-27 member states, energy agencies and outputs from censuses and previous European Projects [1], [2], [3], [4], [5], [6], [7], [8].

The availability and detail of information and data about the residential stock varied from country-to-country. For the office stock, it was very limited. To address this issue, building experts across Europe were contacted and semi-structured interviews were conducted to gather additional objective and subjective information. Those individuals interviewed were from universities, research organisations, property agencies, national statistics, architects, building companies etc.

To streamline the analysis and results, the EU-27 countries were grouped into seven climatic regions (see Table 1). These regions were selected based on the degree-days and countries were grouped accordingly [9]. Seven representative locations, one from each region, were selected for the simulation purposes.

The information collected during the literature review has been presented in a database and report specifically created for the project [10],[11].

Table 1. Locations for simulation and related climatic zones

Climatic zone	**Countries within climatic zone**	**Location**
Southern Dry	Portugal, *Spain*	Madrid
Mediterranean	Cyprus, Greece, *Italy*, Malta	Rome
Southern Continental	Bulgaria, *France*, Slovenia	Lyon
Oceanic	Belgium, Ireland, Netherlands, *UK*	London
Continental	Austria, Czech Republic, *Germany*, Hungary, Luxembourg, Romania, Slovakia	Stuttgart
Northern Continental	Denmark, Lithuania, *Poland*	Gdansk
Nordic	Estonia, Finland, Latvia, *Sweden*	Stockholm

2.2. Results - Survey of residential building stock

The building stock survey revealed that the residential building stock varies across the EU-27 countries in a number of distinct ways: scale (linked to the population and household profile of each country); age (linked to history and public/private support for development); type (single family house (SFH) or multi-family house (MFH)) and construction; energy used for space heating/cooling, hot water, appliances/cooking (linked to climate, each country’s history and regulatory regime); fuel used (linked to natural resources, industrialisation and geography).

The concentration of residential floor area is in the six most populated countries of France, Germany, Italy, Poland, Spain and United Kingdom. Across the EU-27, single family houses represent the majority of the heated floor area at 60%. The remaining 40% is multi-family houses.

The majority of the residential stock within the EU-27 countries dates from before 1971. This reflects the developed nature of the EU economies and also the post-war reconstruction of the 1950s and 1960s. After 1945 there was an urgent need to rebuild quickly and cost effectively and this resulted in construction of energy inefficient homes. Standardised building methods were introduced in the 1950s. Industrially prefabricated constructions and composite construction methods were used during the 1950s and 1960s to reduce construction costs. The EU-wide picture shows that generally construction has slowed over successive decades with construction after 2000 being significantly lower than preceding decades, although there are exceptions within particular countries. Figure 1 shows the breakdown of SFH and MFHs by age.

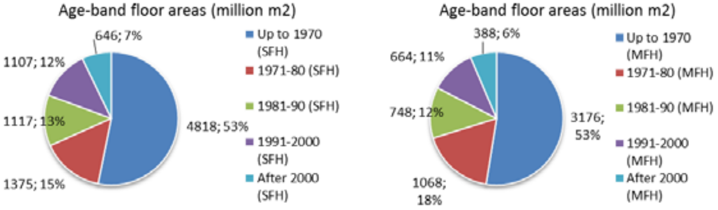

Fig. 1 Area covered by SFH and MFH, by age band

The survey revealed that the size of dwelling also varies across Europe. For example, a single family house built between 1945 and 2000 has an average floor area of 102 m^2. In contrast a multi-family dwelling has only 65 m^2 floor area.

Likewise, construction types differ and include brick, block or stone masonry, reinforced concrete, timber or others such as system built. Single family homes are generally dominated by masonry construction with either solid wall or cavity wall construction. Multi-family homes are often masonry and concrete for low rise dwellings and pre-1960s buildings. From 1960 onwards more skeleton frames, reinforced concrete and some steel framed constructions were seen.

Overall, the level of owner-occupation across the EU-27 is high. In some countries (Bulgaria, Lithuania, Romania) it can be greater than 90% and in most countries it is higher than 70%. The high levels of owner occupation revealed can be helpful for retrofit projects, as one of the key barriers to retrofit measures that reduce energy consumption is where the costs are borne by the landlord but the benefits are seen by the tenant. This is a situation that occurs in rented properties. However, there are other challenges with retrofitting owner occupied properties that are easier to overcome in social housing, such as financing and economies of scale in multi-family houses.

Thermal performance of building elements has improved in all EU-27 countries since 1945. Countries in the coldest climates have always had good thermal insulation and countries in the hottest climates used to have poor thermal insulation. In terms of targeting fabric retrofit measures, older dwellings give more potential for improvement.

This is good because over half the residential stock in the EU-27 countries was built before 1970.

U-value data for the wall, floor, window and roof elements were collected for each country and further broken down by age. These are presented in the iNSPiRe database and report [10],[11]. Fig. 2 shows the average wall U-values weighted according to the floor areas in each country per climatic region.

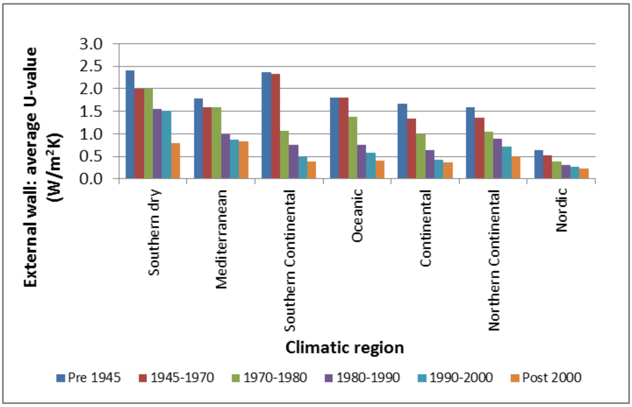

Fig. 2 External wall u-values in residential buildings by construction year. Caulclauted from sources [3], [4], [6] and review of historic building regulations

The average and total energy consumption by end-use for the residential buildings in the EU-27, by country and region is shown in Table 2. These figures have been derived from statistical data collected from the literature survey. The averages are weighted based on the country's area. Statistical uncertainties exist due to the lack of data for some countries. The heated and cooled areas in a few cases had to be estimated, creating some uncertainties over the averages and total figures reported.

The Southern Dry region has lowest average specific heating consumption and Southern Continental has the highest (at 180 kWh/m²·a). The statistics report Latvia has the highest average specific space heating energy consumption, at 215 kWh/m²·a and Malta has the lowest. This is directly related to the climatic conditions and also the state of the building stock in Latvia. Germany, because of its size and large population, has the largest total space heating consumption. With regards to average energy consumption for domestic hot water consumption, Bulgaria has the lowest at 8 kWh/m²·a and although this was reported in a number of sources, seems rather low when compared to other countries. Estonia has the highest average consumption at 61kWh/m²·a, however this was extrapolated using the figure for an average dwelling.

Spain has the greatest average specific cooling energy consumption at 54 kWh/m²·a, followed by Cyprus and Malta at 53 kWh/m²·a. The lowest specific residential cooling consumption is reported in Ireland. Average lighting energy consumption was more uniform ranging between 4 kWh/m²·a to 11 kWh/m²·a.

Table 2. Statistical data summary - average specific and total energy consumption in residential buildings by end use, country and climate region

	Countries	Total floor space in EU (Mm^2)	Heated floor area (Mm^2)	Cooled floor area (Mm^2)	Average specific space heating consumption ($kWh/m^2.a$)	Total space heating consumption (TWh/a)	Average DHW consumption ($kWh/m^2.a$)	Total DHW consumption (TWh/a)	Average space cooling consumption ($kWh/m^2.a$)	Total cooling consumption (TWh/a)	Average lighting consumption (kWh/m2.a)	Total lighting consumption (TWh/a)
Southern Dry	Portugal	410.1	240.3	24.6	128	31	17	7	14	0.3	5	2
	Spain	1568.0	1263.4	940.8	80	100	31	49	14	13.2	5	9
Average/ Total		**1978**	**1504**	**965**	**87**	**131**	**38**	**56**	**14**	**13.5**	**5**	**10**
Mediterranean	Cyprus	38.9	23.3	29.2	55	1	19	1	12	0.3	7	0
	Greece	322.6	310.6	274.2	129	40	11	4	27	7.3	9	3
	Italy	2576.9	1638.4	109.2	138	225	12	32	14	1.6	4	10
	Malta	13.5	8.1	10.1	19	0	12	0	23	0.2	6	0
Average/ Total		**2952**	**1980**	**423**	**135**	**267**	**18**	**36**	**22**	**9.4**	**4**	**13**
Southern Continental	Bulgaria	197.2	195.3	43.4	91	18	8	2	7	0.3	5	1
	France	2479.5	1615.8	124.0	193	311	20	49	18	2.3	4	11
	Slovenia	60.8	60.2	10.3	142	9	41	3	10	0.1	5	0
Average/ Total		**2738**	**1871**	**178**	**180**	**338**	**29**	**54**	**15**	**2.7**	**4**	**12**
Oceanic	Belgium	379.3	375.5	1.9	194	73	32	12	10	0.0	7	3
	Ireland	184.6	182.8	0.9	131	24	30	6	3	0.0	7	1
	UK	1924.5	1828.3	9.6	153	280	38	73	4	0.0	7	13
Average/ Total		**2488**	**2387**	**12**	**158**	**377**	**39**	**90**	**5**	**0.1**	**7**	**17**
Continental	Austria	341.4	338.0	3.4	169	57	27	9	6	0.0	7	2
	Czech R.	309.6	306.5	3.1	168	52	32	10	5	0.0	5	2
	Germany	3229.7	3197.4	48.4	165	527	28	91	7	0.3	4	14
	Hungary	303.3	300.3	9.1	149	45	41	12	10	0.1	11	3
	Luxemb.	16.3	16.2	0.2	221	4	27	0	10	0.0	7	0
	Netherl.	630.8	624.5	9.5	117	73	26	17	8	0.1	6	4
Average/ Total		**4831**	**4783**	**74**	**158**	**758**	**29**	**140**	**7**	**0.5**	**5**	**25**
Northern Continental	Denmark	297.6	294.6	2.1	148	44	28	8	5	0.0	7	2
	Lithuania	104.0	103.0	0.7	126	13	18	2	2	0.0	7	1
	Poland	942.1	932.7	6.6	175	163	37	35	4	0.0	7	7
	Romania	456.4	451.9	3.2	170	77	25	12	5	0.0	7	3
	Slovakia	132.7	131.3	0.9	124	16	36	5	7	0.0	4	1
Average/ Total		**1933**	**1914**	**14**	**164**	**313**	**33**	**61**	**4**	**0.1**	**7**	**13**
Nordic	Estonia	37.4	37.0	0.2	192	7	61	2	12	0.0	7	0
	Finland	199.9	197.9	1.0	205	41	36	7	10	0.0	9	2
	Latvia	61.1	60.5	0.3	215	13	57	3	12	0.0	7	0
	Sweden	386.5	382.6	1.9	143	55	22	9	8	0.0	10	4
Average/ Total		**685**	**678**	**3**	**170**	**115**	**32**	**22**	**9**	**0.0**	**9**	**6**

2.3. *Results - Survey of office building stock*

Similar to the residential, typologies seen in the office stock vary across the EU-27 countries in a number of distinct ways. The literature review revealed that very little is known about the age of the current office stock, particularly those built pre-1980. However, what was evident was that although a large proportion of the office stock within the EU-27 countries dates from before 1980, the office stock is generally younger than the residential stock.

The average and total energy consumption by end-use for the offices buildings in the EU-27, by country and region is shown in Table 3. These figures have been derived from statistical data alone.

Average specific space heating consumption is highest in the Southern Continental region (at 238 kWh/m^2·a) and lowest in Southern Dry at 54 kWh/m^2·a. The EU-27 weighted average for specific space heating consumption is 161 kWh/m^2·a and for 10 kWh/m^2·a for DHW. Average specific space cooling consumption is highest in Southern Dry region (at 42 kWh/m^2·a) and lowest in the Oceanic region at (11 kWh/m^2·a). The EU-27 weighted average for space cooling consumption is 22 kWh/m^2·a. Average lighting energy consumption ranges between 25-71 kWh/m^2·a, however, the average for Spain (71 kWh/m^2·a) does seem high. The EU-27 weighted average for lighting consumption is 39 kWh/m^2·a.

Due to the lack of information found during the literature review, there are some uncertainties over the reliability of the data reported for some of the regions and gaps exist, as shown in the Table 3 and within the U-value section of the iNSPiRe database. Specifically, the literature review revealed limited data about the Northern Continental region and for some countries within Southern Dry, Nordic and Continental regions. The availability of data about domestic hot water energy use in office buildings was limited in most countries.

Table 3 - Statistical data summary - average specific and total energy consumption in office buildings by end use, country and climate region

	Countries	Total floor space in EU (Mm^2)	Heated floor area (Mm^2)	Cooled floor area (Mm^2)	Average specific space heating consumption (kWh/m^2.a)	Total space heating consumption (TWh/a)	Average DHW consumption (kWh/m^2.a)	Total DHW consumption (TWh/a)	Average space cooling consumption (kWh/m^2.a)	Total cooling consumption (TWh/a)	Average lighting consumption (kWh/m^2.a)	Total lighting consumption (TWh/a)
Southern Dry	Portugal	21.2	19.1	19.1	-	-	-	-	38	0.7	29	0.6
	Spain	83.6	75.2	75.2	54	4.1	-	-	44	3.3	71	5.9
Average/ Total		**105**	**94**	**94**	**54**	**4.1**	**-**	**-**	**42**	**4.0**	**63**	**6.5**
Mediterranean	Cyprus	1.9	1.7	1.7	-	-	-	-	75	0.1	16	0.0
	Greece	26.2	23.6	23.6	86	2.0	-	-	63	1.5	22	0.6
	Italy	52.4	47.2	47.2	170	8.0	6	0.3	26	1.2	58	3.0
	Malta	1.0	0.9	0.9	-	-	-	-	67	0.1	16	0.0
Average/ Total		**81**	**73**	**73**	**142**	**10.0**	**6**	**0.3**	**39**	**2.9**	**45**	**3.7**

Southern Continental	Bulgaria	28.0	25.2	17.9	103	2.6	10	0.3	18	0.3	9	0.3
	France	198.7	178.8	126.9	257	46.0	16	2.8	15	1.9	37	7.3
	Slovenia	7.3	6.5	4.6	-	-	-	-	18	0.1	-	-
Average/ Total		**234**	**211**	**149**	**238**	**48.5**	**15**	**3.1**	**16**	**2.3**	**33**	**7.5**
Oceanic	Belgium	25.1	22.6	16.0	140	3.2	0	-	15	0.2	38	1.0
	Ireland	10.4	9.4	6.6	157	1.5	11	0.1	6	0.0	32	0.3
	UK	121.7	109.6	77.8	171	18.8	16	1.7	11	0.9	39	4.7
Average/ Total		**157**	**142**	**100**	**165**	**23.4**	**16**	**1.8**	**11**	**1.1**	**38**	**6.0**
Continental	Austria	21.2	19.1	13.5	197	3.8	6	0.1	30	0.4	24	0.5
	Czech R.	35.6	32.0	22.8	265	8.5	-	-	19	0.4	10	0.4
	Germany	359.5	323.6	229.7	140	45.3	6	1.9	16	3.6	38	13.7
	Hungary	5	4.5	3.2	-	-	-	-	34	0.1	-	-
	Luxemb.	1.2	1.0	0.7	-	-	-	-	21	0.0	-	-
	Netherl.	46.9	42.2	30.0	141	5.9	3	0.1	19	0.6	53	2.5
Average/ Total		**469**	**422**	**300**	**152**	**63.5**	**6**	**2.2**	**17**	**5.1**	**37**	**17.0**
Northern Continental	Denmark	44.5	40.1	28.4	120	4.8	-	-	13	0.4	-	-
	Lithuania	8.1	7.3	5.1	-	-	-	-	8	0.0	-	-
	Poland	88.5	79.7	56.6	-	-	-	-	28	1.6	-	-
	Romania	7.6	6.8	4.8	-	-	-	-	16	0.1	-	-
	Slovakia	6.8	6.1	4.3	-	-	-	-	33	0.1	30	0.2
Average/ Total		**155**	**140**	**99**	**120**	**4.8**	**-**	**-**	**22**	**2.2**	**30**	**0.2**
Nordic	Estonia	1.9	1.7	1.2	-	-	-	-	23	0.0	-	-
	Finland	15.9	14.3	10.2	114	1.6	-	-	21	0.2	30	0.5
	Latvia	4.1	3.7	2.6	-	-	-	-	7	0.0	20	0.1
	Sweden	26.8	24.1	17.1	112	2.7	4	0.1	30	0.5	23	0.6
Average/ Total		**49**	**44**	**31**	**113**	**4.3**	**4**	**0.1**	**25**	**0.8**	**25**	**1.2**

3. Simulation of reference buildings

3.1. Method

Following the building stock survey, four types of buildings were identified as representative for the building stock: a single family house (SFH), a small and a large multi-family house (s-MFH and l-MFH) and an office building (OFF). The geometries of the used building models are described in Table 4. Simulations were done in TRNSYS 17 [12] with Type 56 building models (ideal heating and cooling demand calculation). In both MFH models, as well as in the OFF model, three floors were included. To account for the heating and cooling demand of buildings with five or seven floors, results for the middle floor were multiplied in post-processing. A similar approach was used to give results for office buildings with a larger number of office cells per floor, by multiplying results for the middle zones on each floor. Materials and heat transfer properties of building parts were determined from statistics for different building types, construction periods and countries. Seven locations, listed in Table 1, were used to represent regions with similar climate and building construction.

Table 4. Description of the reference building models used in simulations: a single family house (SFH), a small multi-family house (s-MFH), a large mutli-family house (l-MFH) and an office building (OFF)

	Number of	Dwellings/ offices per	People per dwelling/of	Heated floor area,	S/V ratio	Roof type	Glazing ratio, %

	floors	floor	fice	m²			
SFH	2		4	96	0.90	Saddle roof, 30° tilt	20%
s-MFH	3/5/7	2	2-3	300 – 700	0.61 – 0.46	Flat concrete roof	20%
l-MFH	3/5/7	6	2-3	1170 – 2730	0.42 – 0.26	Flat concrete roof	20%
OFF	3/5/7	6/12	3	486 – 2268	0.58 – 0.36	Flat	30% - 60%

For residential buildings, assumptions on shading and internal gains were mainly based on boundary conditions from Task 44 [13]. Internal gains profiles for multi-family houses were generated for a number of inhabitants of the building using a stochastic model developed by researchers at Uppsala University [14]. The boundary conditions for office buildings were based on data from the Cost Effective project [15] and the technical standard UNI/TS 11300 [16]. Heat transfer to the ground was modelled in accordance with ISO/DIS 13370 [17].

Table 5: Boundary conditions used in the simulation of residential and office buildings

Boundary conditions		**Residential**	**Offices**
Internal gains	People, W/pers	120	120
	Appliances and lights, W/m²	4	28.5
Ventilation rate, 1/h	Controlled	0.30	1.48
	Infiltration	0.15	0.15
Shading		Internal in Stockholm, Gdansk, Stuttgart and London; External in Rome, Lyon and Madrid	External

Set temperatures for heating and cooling were varied in the simulations, in order to calibrate the models against energy statistics. The simulated heating and cooling demands were converted into consumption, using a factor 0.8 for heating and 2.5 for cooling [18], to be comparable to statistics. Results for different building types and construction periods were weighted in accordance with the respective building’s share of the building stock. Having established the heating and cooling set temperatures, these were implemented into the models to derive the heating and cooling demands for all building types, construction periods and climatic regions.

3.2. Results - Simulation of reference buildings

Fig. 3 shows the range of simulated heating demand for residential buildings – minimum, maximum and average – for different set temperatures, including all variations of climate, building typology and age. The rightmost line and the red dot indicate the range and average value from statistics for each climate, which was compared to the simulated averages (yellow squares) to find the set temperature. The comparison between simulations and statistics suggest that the room temperature in many countries can be quite low during the heating season, in some cases (Oceanic and Northern Continental regions) around 18 °C or lower. This can be seen as a sign that the room temperature is not kept at a comfortable level all day, every day, in every room of the house, contrary to what is assumed in the models.

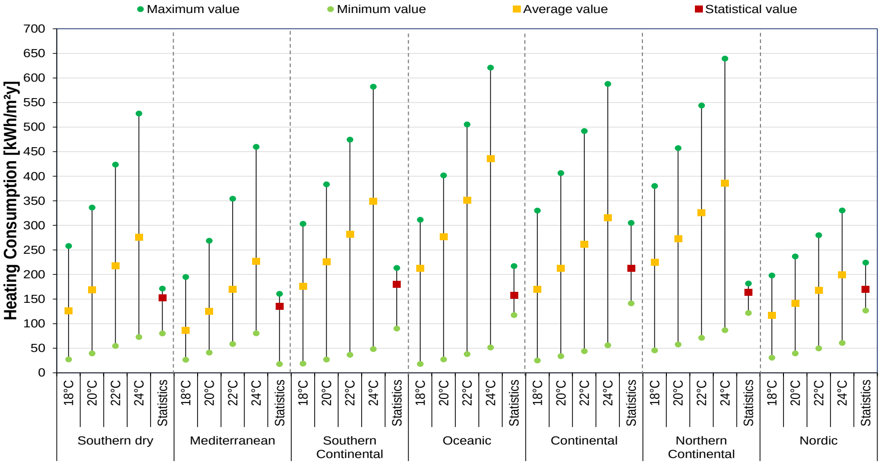

Fig. 3 Yearly heating energy consumption for residential buildings – range of variations for simulation results and statistical values, showing maximum, minimum and average values.

For cooling, the identified set temperatures lie within 22 – 25 °C for all climates, which is consistent with common comfort criteria [19] as well as energy statistics. As only a small fraction of the residential buildings are actually cooled, this could also be seen as an indication on how much energy would be required to cool the buildings to these temperatures, should cooling become more popular.

The derived heating consumption after calibration is shown in Fig. 4 . Single family houses dominate in terms of floor area in most of northern Europe, thus making the average specific heating demand relatively high. In southern Europe there is a higher share of larger buildings with lower S/V ratio, which reduces the average heating demand.

The average cooling consumption of residential buildings is much lower, with lower variability with respect to building typology and period of construction. In southern climates (Rome, Madrid, Lyon) it ranges from 10 to 25 kWh/m^2·a, while in more northern climates it is below 10 kWh/m^2·a and practically irrelevant, given the scarcity of such systems.

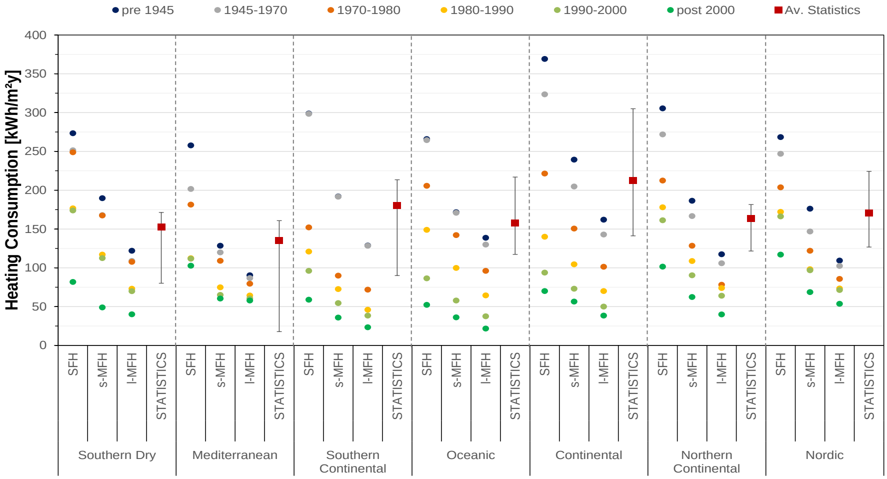

Fig. 4 Simulated yearly heating consumption for residential buildings for three typologies and six periods of construction. Simulated consumption for whole building stock calibrated to value from statistics.

For offices, the identified set temperatures for heating are within the range 19.5 – 24.5 °C for the whole set of variations (building typology and age) in all climates apart from Northern Continental and Southern Dry climate regions, where the temperature appears to be lower than 18 °C. However, the very low temperatures here are consistent with the results for the residential building stock for these regions. The cooling set temperatures were found to be within the range 20 – 26 °C in all regions except “Northern Continental”, where it was lower than 18 °C.

Following the calibration process, heating and cooling consumptions were derived for all variations of the office buildings. Results for heating consumption, for 6 and 12 office cells per floor, are shown in Figure 5. For the Oceanic and Southern Continental regions, the heating consumption based on statistics is higher than all simulated values with exception for the oldest and smallest buildings, showing the large share of these buildings in the two regions. The sometimes very large spread within the same climate and office type is due to the variation of glazing ratio between the construction periods (30% until 1980, thereafter 60%). The variation on the cooling side is much smaller, and well in line with the statistics.

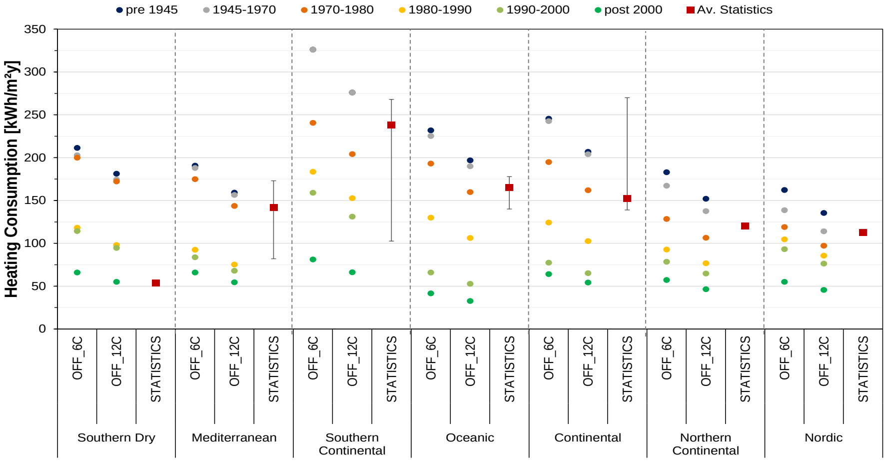

Fig. 5 Simulated yearly heating consumption for offices for two numbers of cells per floor and six periods of construction. Simulated consumption for whole building stock calibrated to value from statistics

4. Discussion and conclusions

4.1. Survey of building stock

The literature survey revealed that residential and office space is concentrated in the six most populated countries of France, Germany, Italy, Poland, Spain and United Kingdom. This means that from an EU-wide perspective it will make most sense to identify building retrofit solutions that suit these countries first and foremost.

These six countries account for 72% of residential and 71% of office floor area in the EU-27. In the residential sector across the EU-27, single family houses represent the majority of the heated floor area at 60%, although this share varies from country to country. This means that to be effective across the whole residential stock, retrofit solutions need to be designed to accommodate both single and multi-family houses. These age distribution figures are significant in that they help to highlight where retrofit programmes may be best targeted, since regulations specifying the thermal performance of new dwellings have generally been getting stricter in recent years.

Through collecting, analysing and validating the data collected a database was created and presented country, regional and European-level data. The total heating energy consumption across residential and office sectors calculated based on the statistics is 2299TWh/year and 159TWh/year respectively, giving a ratio of 14:1. This underlines the importance of the residential sector in energy-reduction retrofit.

The building stock survey undertaken has part of iNSPiRe has consolidated information and data sources (covering previous research projects, energy agencies, census outputs and databases) from across Europe to create an extensive database of

Europe's building stock. The database presents the average energy used and consumed for heating, cooling, domestic hot water and lighting in the selected country or climatic region of Europe for both residential or office buildings. The numbers of literature references used and the standard deviation are also reported for statistical purposes.

The availability of detailed data, particularly for the office building stock was often limited and some assumptions had to be made creating some uncertainties about the accuracy of the data presented. The gaps in the literature have been complemented using the simulation approach described in this paper.

4.2. Simulation of reference buildings

The methodology behind this work is a novel approach with a number of uncertainties, from both a statistical and simulation perspective. The approach itself ensures that the simulation results are consistent with the energy statistics, and it has provided relevant information about the energy consumptions for different building types and construction age at regional and European level. It is a far more detailed and comprehensive approach than has previously been applied, and the derived results are believed to be more reliable than those previously published for the whole of EU. Still, differences between average literature and simulated data (see Figure 3) need to be further investigated in order to find their causes.

It should be noted that part of the building stock has already been renovated to some extent. Improved windows or additional insulation would lead to lower average U-values in practice compared to those when the buildings were constructed and thus lower identified set temperature for heating. However, given that less than 1% of the building stock is renovated every year, it should not influence the results a lot.

Moreover, uncertainties due to boundary conditions used as input to the simulations models can affect the overall results: building typologies and ages distributions, users' behaviours, consistency of reference area and terminology used (i.e. demand/consumption) over the literature references, are the main sources of uncertainty when estimating the energy use of the building stock.

With reference to the users' behaviour, according to the World Health Organisation the optimum indoor temperature from a health perspective is between 18 ºC and 24 ºC [19]. A British study [20], based on long-term measurements of indoor residential temperatures in the UK, showed that the indoor temperature was 17 – 18 ºC in older buildings, while for newer buildings it was 19 – 20 ºC. A report on the European heat market [21] states that the indoor temperatures are 20 ºC in Ireland and 21 – 22 ºC in Sweden. It was also stated here, as well as in a report from the Building Performance Institute Europe [22], that poverty can lead to substantially reduced indoor temperatures, simply because people cannot afford to heat their homes to acceptable temperatures. Generally speaking, set temperatures are not fixed values, but comfort conditions might not always be met for the entire building for 24 hours/day, as a consequence of high energy prices, country economic conditions and severity of the climate. Energy renovation could therefore, in many cases, allow the occupants to improve their thermal comfort, even though the potential for energy savings would then be reduced.

As an overall conclusion, further investigation is needed to understand the actual input parameters, in terms of buildings features and users' behaviour all over Europe.

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