Deliverable 3.2: Static building stock analysis

MODERATE

Marketable Open Data Solution for Optimized Building-related Energy Services

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Executive Summary

This report provides a summary of the data collection process for the project MODERATE, an open-source database that contains data for the 27 nations of the European Union. The database has been gathered at national level for two sectors, namely residential (comprising single-family homes, multi-family homes, and apartment blocks), and service (encompassing offices, trade, education, health, hotels and restaurants, and other non-residential buildings).

The completeness, accuracy, and reliability of data regarding space heating, space cooling, and domestic hot water has significant differences. While there is significant research on space heating and domestic hot water, the space cooling market in the European Union is not extensively explored in scientific literature, and several data gaps exist.

Addressing the data gaps involved more than just extrapolating and compiling data from prominent sources like the EU Building Stock Observatory, BPIE, Tabula and Invert/EE-Lab, since it also entailed meticulous research from scientific literature, including journal papers, project deliverables and conference proceedings. It is through this in-depth approach that data deficiencies have been addressed.

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1. Introduction

The scope of this study is to provide insights on the data collection and generation process of the Horizon Europe (HEU) project MODERATE. The initial phase of the MODERATE project focuses on analysing, calculating, and standardizing building stock related information for EU member states (MS) at national level (Nomenclature of Units for Territorial Statistics – NUTS0).

The purpose of this deliverable is to outline the methods employed for data collection and analysis across various sectors, including service and residential domains. This deliverable outlines the approaches used for data collection and analysis in different sectors: residential and service.

To facilitate access to relevant data and information, metadata is also provided. All data produced during this stage of the project can be downloaded from the MODERATE GitLab repository (https://gitlab.inf.unibz.it/moderate/building-stock-analysis).

Accessing building stock data at NUTS0 level involves utilizing extensive data tools as well as individual literature sources such as journal papers, conference papers, and project deliverables. The collected data encompass all EU27 countries and predominantly comprise measured data, supplemented by estimated data to fill any existing gaps. However, it is worth noting that data availability varies between the residential and service sectors, particularly concerning historic building stock data. Prior to 1945, statistics for the service sector are limited, making it challenging to maintain uniformity.

Detailed investigations and comprehensive documentation of space heating (SH) data can be found in scientific literature, encompassing various spatial levels, including specific cases of individual buildings. The identified data extensively covers all EU27 countries. In terms of total useful energy demand (UED) for the service and residential sectors for space heating plus domestic hot water (DHW) and space cooling (SC) in the entire European Union 27, space heating and domestic hot water show the highest useful energy demand at approximately 2,620 TWh/y, followed by space cooling with 170 TWh/y.

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2. Building Stock Analysis

2.1. Methodology

Data collection has been conducted on a country-by-country basis, meticulously organized within both the residential and service sectors. This systematic approach ensures that specific types of buildings and distinct time periods are thoroughly addressed and accounted for.

The residential sector has been further categorized into distinct building typologies, which include:

- Single family houses (including terraced houses) (SFHs);
- Multifamily houses (MFHs);
- Apartment blocks (ABs – high-rise buildings that contain several dwellings and have more than four storeys (1).

The service sector encompasses the following categories:

- Offices: this category includes both private and public offices, as well as office complexes.
- Trade: it comprises various types of establishments such as individual shops, department stores, shopping centers, grocery stores, car dealerships and garages, bakeries, hair salons, service stations, laundries, conference and exhibition buildings, and other wholesale and retail infrastructures.
- Education: this category includes primary, secondary, and high schools, as well as universities, facilities for professional training, school dormitories, and research centers/laboratories.
- Health: it encompasses private and public hospitals, nursing homes, and medical care centers.
- Hotels and restaurants: this category covers hotels, hostels, cafes, pubs, restaurants, canteens, and catering services for businesses.
- Other non-residential buildings: this category includes warehouses, transportation and garage buildings, military barracks, agricultural buildings such as farms and greenhouses, as well as sports facilities like sports halls, swimming pools, and gyms) (2).

In order to provide a comprehensive overview of the building stock among member states and describe time-related specifications, the following construction periods have been defined:

- Before 1945: buildings constructed before 1945 are typically categorized as historic buildings. The historic building stock is diverse, making it challenging to apply standardized assessments. However, certain characteristics can be generalized, such as the use of solid construction methods for residential buildings;
- 1945-1969: buildings erected after World War II and before 1969 often lack of insulation and have inefficient energy systems. This is due to the use of inexpensive construction materials and short construction timelines. Consequently, these buildings exhibit higher specific energy demands;
- 1970-1979: buildings constructed between 1970 and 1979 saw the implementation of initial insulation applications, influenced by the global energy crises of the 1970s;
- 1980-1989 and 1990-1999: buildings built during these two periods reflect the introduction of the first national thermal efficiency regulations, which emerged around 1990;

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- 2000-2010: buildings within this period are influenced by the EU Energy Performance of Buildings Directive – EPBD (2002/91/EC and subsequent revisions), and their analysis helps understand its impact;
- 2011-2020: recently constructed buildings are analyzed to evaluate the effects of the economic crisis on the construction sector in Europe.

Table 1 provides a comprehensive analysis of the key characteristics pertaining to the building typologies and construction periods mentioned earlier.

Table 1. Summary of the most important analysed features about building components.

Construction materials and methodologies	**Unit of measurement**
Constructed, heated and cooled floor areas	[Mm^2]
Number of dwellings/units and buildings	[Mil.]
Owner occupied, private rented, social housing dwellings/units	[Mil.]
Occupied, vacant and secondary dwellings units and others[1]	[Mil.]
Volume / Surface ratio	[m]
Windows surface	[m^2]
Thermal transmittance – U-values: walls, windows, roof and floor	[W/m^{2}K]

Walls:

– brick, concrete, wood, others	[%]
– solid wall, cavity wall, honeycomb bricks/hollow	[%]
– blocks wall, others[3]	[%]
– brick, concrete, wood, others[2]	[%]
– insulation or not	[%]

Windows:

Construction material: wood, synthetic/PVC, aluminium, low-emittance or not	[%]
Construction methodology: single glazing, double glazing, triple glazing low-emittance or not	[%]

Roof:

Construction material: wood, concrete, concrete + bricks	[%]
Construction technology: tilted, flat-insulation or not	[%]

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Floor:

Construction material: wood, concrete, concrete + bricks, and others[4]	[%]
Construction methodology: concrete slab, wooden floor, others[5]-insulation or not	[%]

Technologies used for space heating:

Individual, central, or district heating	[Less widespread/Widespread/Most widespread]
Boiler (condensing or not), combined, stove, electric heating	[Less widespread/Widespread/Most widespread]
Solar Collectors, Heat pumps	[Less widespread/Widespread/Most widespread]
Fossil fuels (solid, liquid, gas), electricity, biomass	[Less widespread/Widespread/Most widespread]

Technologies used for space cooling:

Space cooling or not	[Less widespread/Widespread/Most widespread]

Technologies used for domestic hot water:

Individual, central, or district heating	[Less widespread/Widespread/Most widespread]
Boiler (condensing or not), combined, stove, electric heating, Solar Collectors, Heat pumps	[Less widespread/Widespread/Most widespread]
Solar Collectors, Heat pumps	[Less widespread/Widespread/Most widespread]
Fossil fuels (solid, liquid, gas), electricity, biomass	[Less widespread/Widespread/Most widespread]

NOTES

1 Unregistered dwellings, which are neither occupied, vacant, nor secondary homes

2 Construction materials that are less commonly utilized, such as stone or a combination of stone/brick and stone/concrete structures

3 Implementation of prefabricated panels and lightweight exterior walls

4 Predominantly constructed with stone floors

5 Less prevalent use of unconventional construction techniques for floors, such as vaulted or coffered ceilings

Table 2, on the other hand, presents the key findings related to energy indicators. It is important to differentiate between two measures: useful energy demand (UED) and final energy consumption (FEC). The useful energy demand represents the net energy required to satisfy space heating, space cooling, and domestic hot water needs. On the contrary, the final energy consumption is the actual measured energy input into the supply system, needed to meet the aforementioned demand. These two quantities differ due to various conversion factors (2), which account for the efficiency of each supply technology and distribution losses. User behaviour can also contribute to the disparity. For instance, if a boiler is used for space heating and domestic hot water, the final energy consumption will exceed the useful energy demand, as the efficiency of this technology is less than 1 (around 0.8-0.9 for current European installations). Conversely, in the case of electrically driven technologies like heat pumps, which have an energy efficiency ratio greater than one (EER > 1, approximately 2-3 for current EU installations), the final energy consumption for space cooling is lower than the useful energy demand. It is important to note that comparing the useful energy demand for space heating, space cooling, and domestic hot water is appropriate, but comparing final energy consumption in the form of electricity (used in heat pumps and air-conditioners) to fuel consumption (such as gas in a gas boiler) requires a proper conversion to primary energy. This conversion is necessary because electricity and fuel have different levels of embedded energy. Primary energy, typically measured in kWh or toe, takes into account the use of resources (both fossil and non-fossil) and enables accurate comparisons across different energy carriers (3).

Table 2. Summary of the most important analysed features about energy indicators.

Useful energy demand (UED):

Space heating (SH)	[kWh/m²y], [TWh/y]
Space cooling (SC)	[kWh/m²y], [TWh/y]
Domestic hot water (DHW)	[kWh/m²y], [TWh/y]

Final energy consumption (FEC):

Space heating (SH)	[kWh/m²y], [TWh/y]
Space cooling (SC)	[kWh/m²y], [TWh/y]
Domestic hot water (DHW)	[kWh/m²y], [TWh/y]

In the process of creating the default datasets for the MODERATE project, ensuring data quality, completeness, accuracy, and reliability are crucial. Therefore, the following aspects have been carefully considered during this process:

- Data inventory;
- Data reliability;
- Data definition and comparability.

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2.1.1. Data inventory

Developing a comprehensive inventory of data and information for the EU building stock presents a significant challenge, particularly when aiming to provide an almost exhaustive list of available information. While utilizing data from EU information providers and projects offers advantages due to their coverage of large territories (e.g., BPIE (4)), but it should be noted that these datasets are often incomplete. As a result, national statistics have been incorporated as data sources to enhance the coverage of data.

The data collection process involved not only gathering and consolidating data from online data tools (e.g., TABULA (5)), but also conducting extensive research across various scientific literature sources, including journal papers (e.g., the study by Pezzutto et al. (4)), conference proceedings (e.g., the study by Mahlknecht et al. (6)) and project deliverables (e.g., the iNSPiRe project (7)). This meticulous approach was necessary to address the existing data gaps concerning different energy types (e.g., space heating, space cooling, and domestic hot water) and individual nations. During the analysis, specific emphasis was placed on the sources detailed in *Table 3*, which are highlighted for their relevance and importance.

Table 3. Sources used for the compilation of the MODERATE database.

Author/s	Title	URL
Diefenbach N. et al.	Energy Performance Indicator Tracking Schemes for the Continuous Optimisation of Refurbishment Processes in European Housing Stocks	https://episcope.eu/fileadmin/episcope/public/docs/pilot_actions/DE_EPISCOPE_NationalCase_Study_IWU.pdf
Droste, C., and Knorr-Siedow, T.	Social Housing in Germany	https://doi.org/10.1002/9781118412367.ch11
Ahmed, K., et al.	A New Method for Contrasting Energy Performance and Near-Zero Energy Building Requirements in Different Climates and Countries	https://doi.org/10.3390/en11061334
H2020 AmBIENCe	D4.1: Database of grey-box model parameter values	https://ambience-project.eu/a-database-that-aims-to-improve-the-field-of-building-energy-performance/
Elsinga, M., and Wassenberg, F.	Social Housing in the Netherlands	https://doi.org/10.1002/9781118412367.ch2
H2020 ZEBRA	Energy efficiency trends in buildings Data Tool	https://zebra-monitoring.enerdata.net/overall-building-activities/share-of-new-dwellings-in-residential-stock.html#wall-u-values-building-codes.html
Baralides, A.	Social Housing in Spain	https://doi.org/10.1002/9781118412367.ch13

Civel, E. and Elbeze, J.	Energy efficiency in French homes: how much does it cost?	http://www.chaireeconomieduclimat.org/RePEc/cec/wpaper/16-05-Cahier-R-2016-03-Civel-Elbeze.pdf
Brown, N.W.O. et al.	Sustainability assessment of renovation packages for increased energy efficiency for multi-family buildings in Sweden	https://doi.org/10.1016/j.buildenv.2012.11.019
Cardoso, J.P.H.	Vacant housing stock: Analysis and action proposal	https://fenix.tecnico.ulisboa.pt/downloadFile/1689244997256146/Extended%20Abstract.pdf
Balaras, C.A. et al.	European residential buildings and empirical assessment of the Hellenic building stock, energy consumption, emissions and potential energy savings	https://www.sciencedirect.com/science/article/pii/S0360132305004671
Lévy-Vroelant, C. et al.	Social Housing in France	https://onlinelibrary.wiley.com/doi/epdf/10.1002/9781118412367.ch8
National statistics of Sweden	Number of dwellings by region, type of building and period of construction	https://www.statistikdatabasen.scb.se/pxweb/en/ssd/START__BO__BO0104__BO0104D/BO0104T02/table/tableViewLayout1/
FEANTSA	Finland National Report: Housing Solutions for People who are homeless	https://www.feantsa.org/download/finland_housing_homelessness_2008387891179536436699.pdf
Lux, M.	Social Housing in the Czech Republic	https://doi.org/10.1002/9781118412367.ch10
Instituto Nacional de Estatística	Inquérito ao Consumo de Energia no Sector Doméstico - 2020	https://www.ine.pt/xportal/xmain?xpid=INE&xpgid=ine_publicacoes&PUBLICACOESpub_boui=527966882&PUBLICACOESmodo=2
Mayer, Z. et al.	Analysis of financial benefits for energy retrofits of owner-occupied single-family houses in Germany	https://doi.org/10.1016/j.buildenv.2021.108722
Instituto Nacional de Instituto Nacional de Estatística	Population and Housing Censuses 2011 Detailed data	https://www.ine.es/en/prensa/np824_en.pdf
Statistics Denmark	BOL101: Dwellings by region, type of resident, use, tenure, ownership and year of construction	https://www.statbank.dk/BOL101
The National Institute of Statistics and Economic	Statistics and studies	https://www.insee.fr/en/statistiques/3733168 https://www.insee.fr/en/statistiques/5887128
National statistics of Sweden	Number of dwellings by region, type of building and tenure	https://www.statistikdatabasen.scb.se/pxweb/en/ssd/START__BO__BO0104__

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		BO0104D/BO0104T04/table/tableViewLayout1/
Federal Institute for Research on Building, Urban Affairs and Spatial Development (BBSR)	Housing and property markets in Germany 2020	https://www.bbsr.bund.de/BBSR/EN/publications/AnalysenKompakt/Issues/ak-08-2021-dl.pdf?__blob=publicationFile&v=2
Redmond, D. and Norris, M.	Social Housing in the Republic of Ireland	https://doi.org/10.1002/9781118412367.ch9
Hegedüs, J.	Social Housing in Hungary	https://doi.org/10.1002/9781118412367.ch12
ENTRANZE Project	Share of owner-occupied dwellings in residential stock	https://entranze.enerdata.net/share-of-owner-occupied-dwellings-in-residential-stock.html
Entranze/ Inspire Project	U-value roofs residential buildings	https://ec.europa.eu/energy/eu-buildings-database_en
Building Stock Obervatory	U-value floors residential buildings	https://ec.europa.eu/energy/eu-buildings-database_en
Landolfo R. et al.	Classification of European building stock in technological and typological classes	https://doi.org/10.1016/j.jobe.2021.103482
Bulgarian Statistical National Institute	National Statistical Institute	www.nsi.bg/
Csoknyai T. et al.	Building stock characteristics and energy performance of residential buildings in Eastern-European countries	https://doi.org/10.1016/j.enbuild.2016.06.062
Reinprecht, C.	Social Housing in Austria.	https://doi.org/10.1002/9781118412367.ch4

As shown in *Table 3*, one important aspect of the data inventory is to ensure the understandability and correct interpretability of information. Together with the data, standardized structured information is provided, including the specification of author/s, titles, time reference, and if available the Universal Resource Locator (URL).

2.1.2. Data reliability

To ensure the quality of the data, we conducted a validation analysis. The following logical test were conducted:

- For the heated area check, the value of the total area must be greater than the heated area.

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- For checking the cooled area, the total area must be greater than the cooled area.
- Occupant's check: first add the values for occupied, free and secondary apartments and then subtract from the number of apartments, the result must be zero, otherwise there will be an error.
- Space heating: the values for useful energy demand must be smaller than the final energy consumption.
- Domestic hot water: the values for the useful energy demand must be smaller than the final energy consumption.
- Space cooling: the values for the useful energy demand must be greater than the final energy consumption.
- Finally, in order to evaluate the U-values for the different sectors, the data were graphically evaluated to assess the trends and patterns per each building element.

2.1.3. Data definition and comparability

Data collection was performed on a country-by-country basis, primarily focusing on the most recent year, which predominantly refers to 2020. While standardized data formats and units were utilized by the majority of data providers, it should be noted that this does not guarantee full comparability of the data. Ensuring data comparability requires addressing discrepancies and inconsistencies among different data characteristics, such as time references, which is a crucial aspect of the data processing stage. In addition to its utilization within MODERATE and existing tools, the developed database is expected to enhance data quality for energy sector users and provide valuable information for monitoring progress towards the goals outlined in EU energy-related directives. The subsequent paragraphs provide a description of the main sources and methodology employed for data processing across various aspects within the database. The Covered area data for each construction sector, building type, and period were retrieved from the Invert/EE-Lab database (8). Total values for the residential and service sectors were calculated by summing the data for all building typologies within each time period. Heated and cooled floor area data were obtained from multiple sources, with the most frequently used sources being (9) – (10). Regarding the Tenure/ownership status, distribution, and Occupancy fields, data for the residential sector were obtained from the EU Building Stock Observatory (11), while multiple sources were utilized for the service sector, varying for each member state.

The Construction features section encompasses U-values of key building elements, including walls, windows, roof, and floor. Data for each building typology in the residential sector were obtained from the TABULA web-tool (5), while data for the service sector were sourced from the EU building database (11) and the results of the project iNSPiRe (12) for the service sector. Total thermal transmittance values for each sector were calculated by weighting the U-values of the respective subsectors with the constructed floor area.

For the Construction materials and methodologies section, as well as the Technologies for space heating, space cooling, and domestic hot water section within the residential sector, the TABULA web-tool (5) served as the primary data source. Descriptions of construction features were collected for each building typology (Single-family houses, Multi-family houses, and Apartment blocks) and construction period, with data organized into sub-sections for walls, windows, roof, and floor. The

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presented percentages in the database were derived by weighting the data with the total floor area of each building typology.

Similarly, data related to space heating, space cooling, and domestic hot water within the residential sector were predominantly collected using the TABULA web-tool (5). However, the website only indicates the most prevalent technology for each building typology and construction period. Consequently, the Technologies for space heating, space cooling, and domestic hot water section of the database does not provide percentage data but rather indicates the diffusion of each technology and fuel. Data for the total residential sector were calculated by weighting the total floor area of each building typology, and the information was grouped based on the percentage of diffusion.

The data has been computed for the overall residential sector, taking into account the total floor area of each building typology and then categorized based on the percentage of adoption as outlined below:

- > 75%: most widespread technology/fuel;
- 25% to 75%: widespread technology/fuel;
- < 25%: less widespread technology/fuel.

When it comes to the service sector, the TABULA Web tool (5) does not provide any data. Moreover, there is a scarcity of scientific sources that describe typical construction features and technologies for space heating, space cooling, and domestic hot water within this sector. Therefore, expert consultation was conducted to gather relevant information. A questionnaire, encompassing all the features already included in the residential sector database, was distributed to two experts from each country. The collected data was analysed, and the results were grouped into geographical areas.

The clusters were formed based on the geographical proximity of the countries and are listed below:

- Northern Europe: Denmark, Finland, Sweden, Estonia, Latvia, Lithuania;
- Central Europe: Austria, Belgium, Germany, Netherland, Luxembourg, France and Ireland;
- Eastern Europe: Poland, Czech Republic, Hungary, Slovenia, Slovakia, Croatia, Bulgaria, Romania;
- Southern Europe: Spain, Italy, Greece, Cyprus, Malta, and Portugal.

The obtained results have been cross-referenced with the limited available sources pertaining to the subject matter (13) – (14).

The primary source for the fields related to the useful energy demand for space heating, space cooling, and domestic hot water is Invert/EE-Lab (8). Using these values as a basis, the Final energy consumption has been determined by multiplying the useful energy demand with the corresponding ratio values obtained from the database (15). The *Total useful energy demand* has been derived in the following manner:

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- Space heating + domestic hot water [TWh/year]:

$$\frac{(Mm^2\ heated\ floor\ area \times SH\ demand)+(Mm^2\ total\ floor\ area \times DHW\ demand)}{1000}$$

- Space cooling [TWh/year]:

$$\frac{Mm^2\ cooled\ floor\ area \times SC\ demand}{1000}$$

Finally, the *Total final energy consumption* has been calculated with the following equations:

- Space heating + domestic hot water [TWh/year]:

$$\frac{(Mm^2\ heated\ floor\ area \times SH\ consumption)+(Mm^2\ total\ floor\ area \times DHW\ consumption)}{1000}$$

- Space cooling [TWh/year]:

$$\frac{Mm^2\ cooled\ floor\ area \times SC\ consumption}{1000}$$

Regarding every section within the database, the overall totals for the "*Residential sector_Total*" and for the "*Service sector_Total*" (measured in Mm^2, Mil., TWh/y) have been calculated by aggregating the values of the corresponding subsectors.

In cases where the data was not directly available, missing values were estimated by analyzing the existing information. For more details on these estimations, please refer to Section 3.1 "Limitations of data."

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3. Main Results (EU27)

In this section, we provide a compilation of key findings derived from the analysis of the data contained in the building stock analysis database. To streamline the presentation, only significant sources are referenced in Section 3. For more comprehensive information regarding the data sources, please refer to the following link: https://gitlab.inf.unibz.it/moderate

Figure 1 illustrates a comparison of the EU27 building stock in the residential and service sectors, categorized according to different construction periods.

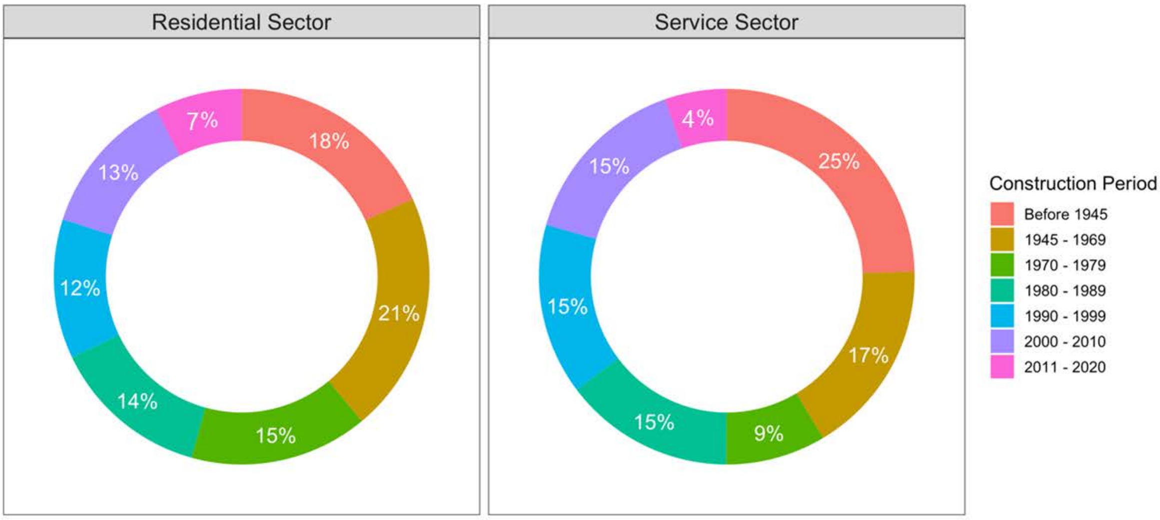

Figure 1. Distribution of residential and service building stocks across various construction periods is depicted as a percentage breakdown for the European Union 27.

The buildings between 1945-1969 show the highest percentages in the residential sector (21%), while the most ancient buildings, constructed before 1945 are the main component of the service sector building stock (25%).

However, data shows that buildings constructed before 1969 cover the majority of the building stock; this is also due to the fact that the period before 1969 includes more years than the other analysed time periods.

It emerges that buildings erected between 1945-1969 are present in a nearly equal percentage in the residential sector and in the service sector, being 21% and 17% respectively, and for the rest, the percentage varies between 1-7% between residential and service sectors.

By excluding buildings constructed prior to 1945, we observe that both the residential and service sectors experienced a peak in construction activity during the 1945-1969 period. It is worth noting that this period spans 14 years, whereas the subsequent periods (starting from 1970) encompass only 10 years each. From the 1970s onwards, the percentages gradually decline, reaching approximately 15% to 5% for both residential and service sectors in more recent years. Several recent studies provide further evidence of this trend across the entire building stock of the European Union (2), (16), (17). The period from 1945 to 1969 saw a surge in building construction due to post-war reconstruction and economic growth, aided by the Marshall Plan. However, construction activities gradually declined afterwards. This confirms the outdated state of Europe's building stock, emphasizing the need for renovation.

Figure 2 illustrates the distribution of various subsectors representing different building types within the residential and service sectors of the EU27. Typically, single-family houses (including terraced houses) are characterized by 2-3 floors, while multi-family houses tend to have 4-8 floors. Apartment blocks, on the other hand, generally consist of more than 4 floors (1), (16), (18), (19).

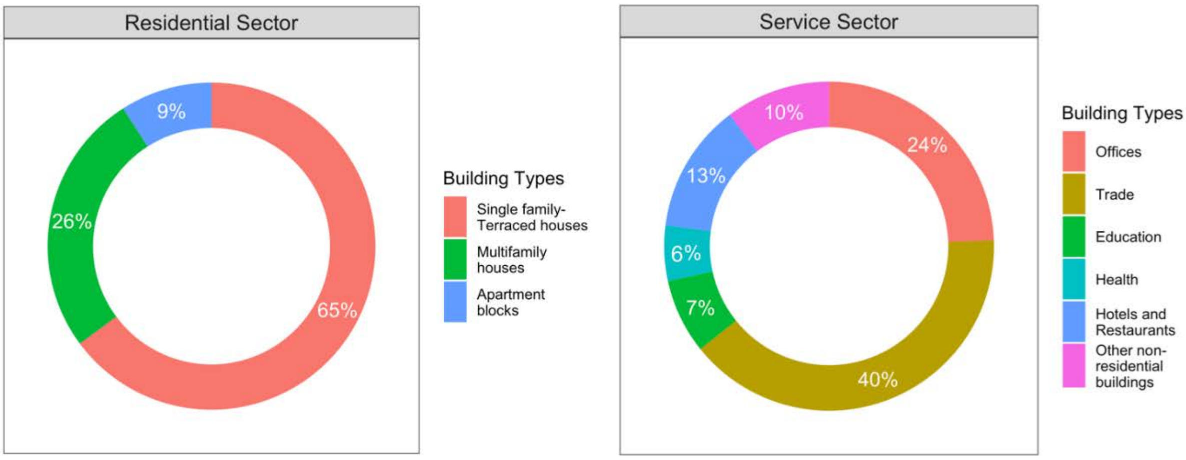

Figure 2. Distribution of residential and service buildings across various subsectors (%, European Union 27).

The residential sector is dominated by single family and terraced houses with almost 65%, followed by multi-family houses and apartment blocks with approximately 26% and 9% respectively. Within the service sector, the absolute majority of building usage is covered by trade buildings with almost 40%. It is followed by offices (about 24%), hotels and restaurants (13%) as well as other non-residential buildings (10%), education (7%), and health (6%).

Subsequently, *Figure 3* and *Figure 4* illustrate the trajectory of the effective energy demand, which is derived by assigning weight to the demand values [kWh/m^{2}y] corresponding to each construction period based on the heated or cooled floor area for space heating and cooling, respectively. The entire floor area has been taken into account for domestic hot water. It should be emphasized that *Figure 3* and *Figure 4* present the actual specific values of useful energy demand (kWh/m^{2}y), categorized according to different construction periods.

In particular, *Figure 3* showcases the progression of specific useful energy demand for space heating and domestic hot water in both residential and service sectors, spanning from the construction period prior to 1945 to 2011-2020.

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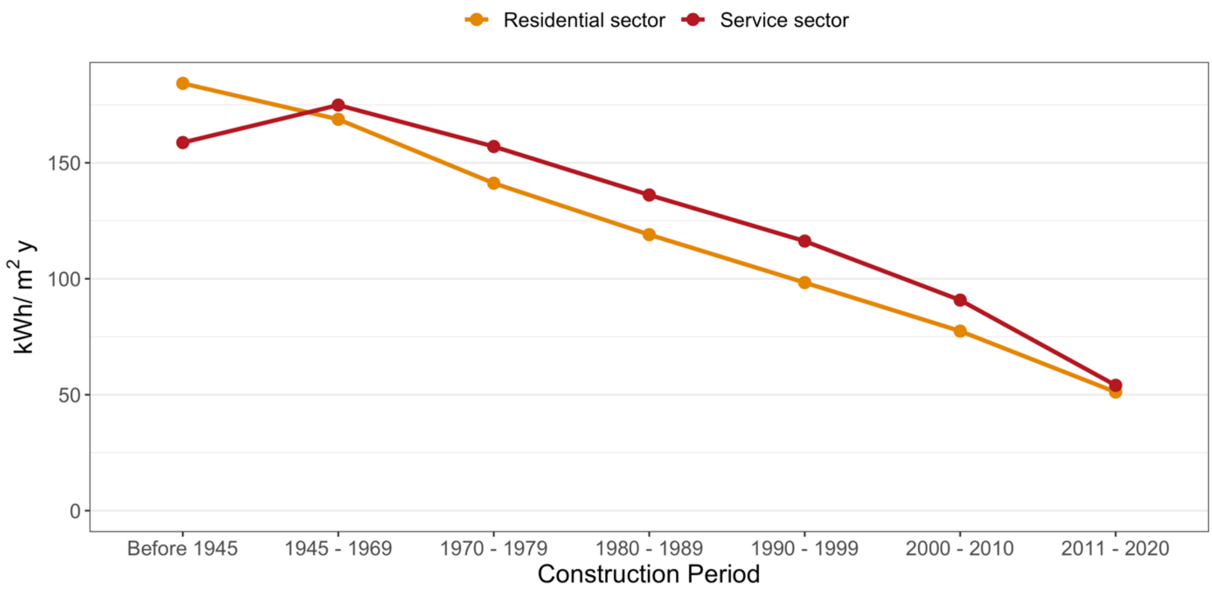

Figure 3. Specific useful energy demand for space heating and domestic hot water in the residential and service sectors has evolved from the construction period preceding 1945 to the timeframe of 2011-2020 (20).

As shown in *Figure 3*, the historic building stock is characterized by the highest specific useful energy demand for space heating and domestic hot water of both sectors. From Before 1945 to the present time, the specific useful energy demand for space heating and domestic hot water decreased from approximately 175 kWh/m^2 to 50 kWh/m^2 y in the residential sector. In the service sector, the specific useful energy demand declined from approximately 150 kWh/m^{2}y to 50 kWh/m^{2}y. Thus, the specific useful energy demand for space heating and domestic hot water is on average about twice as high for households as for services (16).

Figure 3 highlights that the disparity in useful energy demand for space heating and domestic hot water between the residential and service sectors is particularly pronounced during the period before 1945, but diminishes in subsequent years. On the other hand, *Figure 4* depicts the curves of specific useful energy demand for space cooling in both sectors under examination (residential and service).

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Figure 4. Analysed residential and service sectors exhibit a trend in specific useful energy demand for space cooling.

As emerges from *Figure 4*, specific useful energy demand for space cooling had an increase in the residential sector in the first analysed period (1945 to 1969), growing from 22 kWh/m^2 to almost 35 kWh/m^{2}y. Afterwards, the demand decreases and stabilizes at around 30 kWh/m^{2}y.

On the contrary, it decreased until 1979 in the service sector from 60 kWh/m^{2}y to almost 43 kWh/m^{2}y. Afterwards, the values for the service sector continue growing with a peak for the buildings constructed between 2000-2010 with approximately 62 kWh/m^{2}y.

There are a number of possible reasons leading to a rather flat space cooling demand of the residential sector, despite of the current global warming. First, modern building efficiency and retrofit of those erected in the past.

Figure 5 shows a graphical representation of an estimated U-value per each building main element over construction period, both for the residential and service sectors.

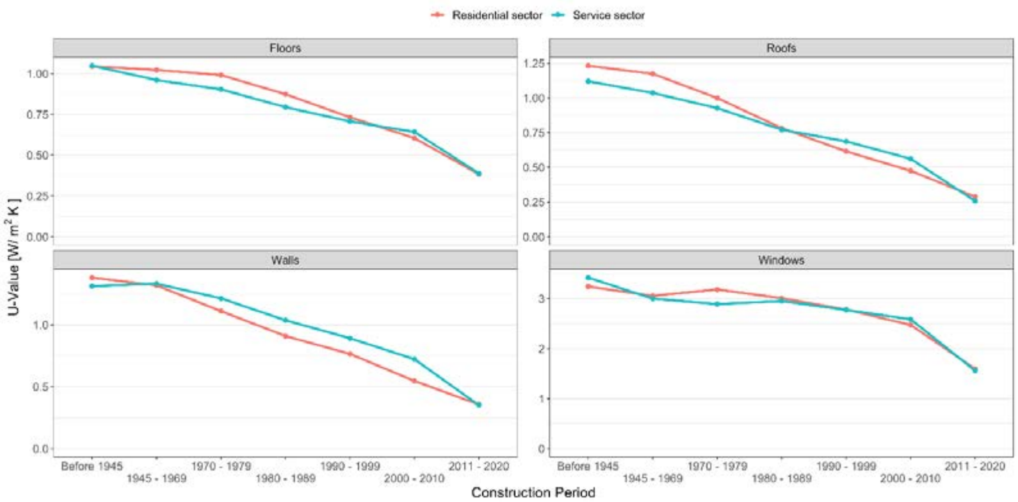

Figure 5. Trend of estimated U-values over construction periods per main building element. Please, note that the U-values axis have different values

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The findings were consistent across all 27 EU countries, indicating a decrease in the U-values of building elements throughout the construction period. This trend serves as a symptom of technological advancements.

3.1. Limitations of data

We adopted different approaches to collect data related to the European building stock analysis. Data has been collected by several sources, like TABULA (5), ZEBRA (21), AMBIENCE (22) Eurostat (23), scientific journal papers, technical reports, and national statistics institutes of different European countries.

In order to get values from different sources and to extend or validate the dataset, we performed lots of searches following the methodology previously presented. Only data from reliable sources that correlated with already collected data was used to extend the dataset. However, if certain data gaps could not be filled, the following assumption and estimations were made:

- Mm^2: if a minimum of three values were available within the same time period (i.e., from Before 1945 to 2020), the values were estimated using linear regression. This estimation method was primarily employed for data related to the period until 2020. In instances where values were missing, interpolation was utilized only if the surrounding values were not estimated. The same approach was adopted for data gaps within the Thermal transmittance (U-values) section of the database, as well as for specific useful energy demand values (kWh/m^2y) for space heating, space cooling, and domestic hot water;
- Mil. – Nr. of buildings: in the health sector (e.g., hospitals) and education sector (e.g., schools), the number of units was considered to be equivalent to the number of buildings;
- Mil. – Social housing: the assumption made is that social housing is not included within the service sector.

Furthermore, in cases where information was unavailable for residential (single-family houses, multi-family houses, apartment blocks) and service (office, trade, education, health, hotels and restaurants, and other non-residential buildings) categories, the data from apartment blocks within the same country were utilized as a substitute (e.g., U-values).

Regarding the specific useful energy demand for domestic hot water, only a few instances presented different values per construction period, measured in kWh/m^2y. In most cases, literature provided only a single value for the entire construction period.

The primary challenges encountered during the analysis were the frequent misuse of terms such as useful energy demand and final energy consumption, as well as the limited availability of data pertaining to space cooling.

To address the first challenge, we ensured a proper distinction between the terms by carefully examining the methodologies associated with the gathered data. Any data lacking supporting documentation was excluded from the database.

For space heating and domestic hot water, the useful energy demand data was converted into final energy consumption by dividing them with values derived from reference (15) for the respective energy types. To establish the conversion factors for each sector (residential, service) and country, a mean value was employed. These conversion factors typically cover around 0.85, reflecting the average efficiency of boilers currently installed across the European Union (24). The same approach was adopted for space cooling, where conversion factors were determined based on the range of 2 to 3. These factors correspond to the average efficiency of space cooling equipment installed in Europe (16).

Concerning the second challenge, it is important to emphasize that a significant portion of data related to the space cooling market in Europe is currently reliant on estimations (9), (25).

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