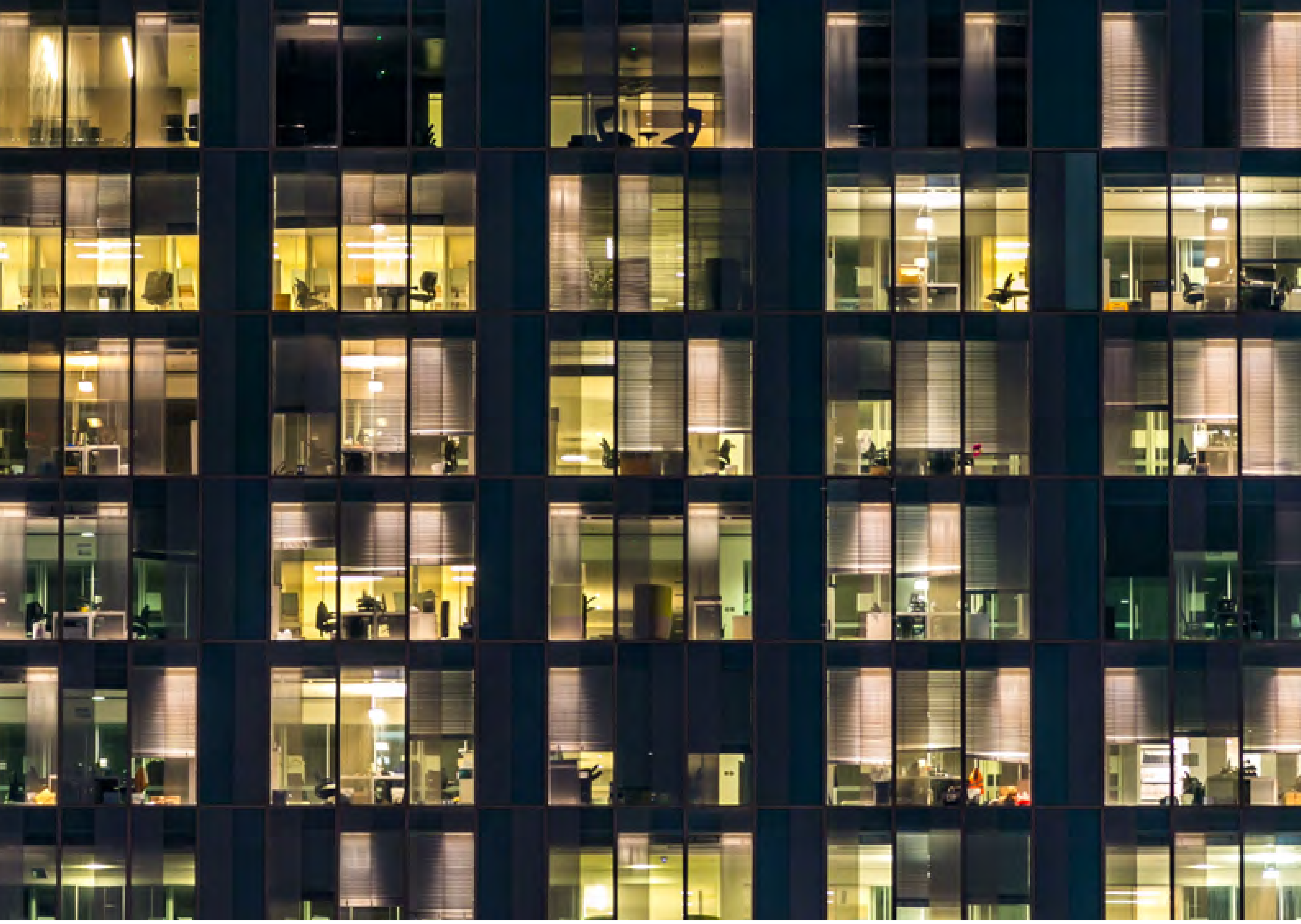

European Building Stock Analysis

A country by country descriptive and comparative analysis of the energy performance of buildings

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U. Filippi Oberegger, R. Lollini (Eurac),
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Executive summary

This work analyzes data for the entire European building stock (EU27+UK) and describes its characteristics by country and energy consumption patterns. The data related to covered floor area, number and type of buildings, final energy consumption, construction materials, and construction methodology were utilized. Data has been assembled within the Horizon 2020 HotMaps project – the open-source mapping and planning tool for heating and cooling — regarding two different sectors: residential (single-family houses, multi-family houses, and apartment blocks), and service (offices, trade, education, health, hotels and restaurants, and other non-residential buildings). The information presented in the dataset varies in time; the analysis and the discussion were addressed from the historical periods before 1945 to post 2010. The complete repository of the data can be found by following this link https://gitlab.com/hotmaps/building-stock/-/tree/master/data.

The work presented in this book is divided by the following chapters:
1. Introduction
2. Methodology
3. Main results (by countries)
4. Summary results
5. Final discussion
6. Conclusion

The Introduction section addresses the goal to reduce greenhouse gas (GHG) emissions in Europe by 80–95%, relative to 1990 levels, by 2050. Presently, the European building stock accounts for around 720 Mtoe/y, which is approximately 40% of the entire EU primary energy demand. To reduce energy consumption and, thus, GHG emissions, a proper investigation for building typologies, existing floor area, and energy consumption of space heating (SH), space cooling (SC), and domestic hot water (DHW) must first be implemented. Finally, our research shows that to increase building energy efficiency, establishing new energy-efficient materials, equipment, and operational strategies rather than focus on one single isolated technology is essential to reach the European Union (EU) 2030 and 2050 climate and energy goals.
The Methodology section describes procedures for data collection, organization, and analysis. The data collection process implied that extrapolating and assembling data was from extensive data tools available online and through researching data from scientific literature such as journal papers, conference proceedings, and project deliverables. The organization process stated that data were categorized according to buildings' categories and time of construction. Data were analyzed by using the qualitative method. For more detailed information, please refer to chapter 2 – Methodology.

The main results per country – each member state (MS) of the EU plus United Kingdom (UK) – was analyzed and described. The data was divided as follows:
— Constructed floor area, number, and type of buildings
— Space heating, space cooling, and domestic hot water use
— Construction methodology
— Spase heating (SH), space cooling (SC), and domestic hot water (DHW) technologies

Information about the covered floor area (Mm^2), number of buildings, and their types are described and presented in percentages. This information allows us to see the data in proportions to the considered historical periods.
The SH, SC, and DHW technologies section displays the information about heating and cooling (H&C) equipment types used in the European building stock. The data collection represents the status quo in 2016. Different types of fuel use were also discussed to address their impact on greenhouse gas (GHG) emissions.
The Summary of results section synthesizes the information presented in the previous chapters – the main results for the entire EU27+UK – to provide a clear understanding of the entire European building stock development. The chapter addresses the patterns and the most critical information for the European market we need to consider to be familiar with and know the future scenario needs to be implemented for energy effieciency (EE) and GHG emissions reduction.
The final chapter entails a discussion and improvement proposal to predict and decrease the final energy consumption for the European energy building stock to reduce GHG emissions.
Regarding the main findings, from the data, it is clear to identify final energy consumption for SH, DHW and SC where the highest position is held by SH and DHW with approximately 3280 and 890 TWh/y, respectively, in comparison to SC, which has a significantly lower final energy consumption of about 107 TWh/y.
The analysis by sectors reviled that the residential sector demonstrates for about 2307 and 545 TWh/y FEC for SH and DHW respectively. The noticably smaller values held by the service sector with about 973 and 345 TWh/y accordingly. However, FEC for SC has an opposite trend. The measured energy consumed by the service sector than by the residential one (80 TWh/y versus 27 TWh/y).

The analysis of different data sources show significant deviations. Despite our rigorous analysis, considerable uncertainties remain, being also reflected in a lack of official and consistently collected data across the EU Member States. Thus, we consider the task of a building stock analysis as a continuous activity, not being completed with this publication. Rather, further work on the improvement of data consistency and better understanding of the deviation of different data sources is needed. In that sense, despite of the richness of the dataset, we understand the published data set as a starting point for further work, both within our own ongoing and future research and by other research groups. We are confident that the sharing of the information as open data sets contributes to this process of gradual improvement of data reliability in order to provide decision makers with a solid basis for decarbonising the sector.

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Abbreviations

AB	Apartment block
BPIE	Building Performance Institute Europe
EU	European Union
EUR	Euro
e.g.	Example given
el	Electric
FEC	Final energy consumption
GHG	Greenhouse gas
h	Hour
i.e.	Id est
K	Kelvin
km	Kilometer
km^2	Square kilometer
kW	Kilowatt
LTRS	Long-term renovation strategies
MFH	Multi-family house
Mil.	Million
MS	Member state
MSs	Member states
Mm^2	Million square meter
m	Meter
m^2	Square meter
NR	Non residential
Nr	Number
PVC	Polyvinyl chloride
RE	Renewable energy
RES	Renewable energy sources
SC	Space cooling
SFH	Single-family house
SH	Space heating
s	Second
URL	Uniform resource locator
WWII	World War 2
y	Year

1. Introduction

1. Introduction

The EU aimed to decrease greenhouse gas (GHG) emissions by 20% by 2020 compared to 1990 levels. In parallel, renewable energy sources (RES) production was expected to increase by 20%, along with a 20% overall efficiency upgrade (1). By 2030, an integrated policy framework will compel EU Member States (MSs) to direct a coordinated approach and provide investors with applicable regulatory guidelines. By that year, the EU intends to decrease domestic emissions of GHG by 40% relative to 1990 levels. National policies are designed to permanently improve energy efficiency (EE) and increase the energy produced with RES to 27% (2). In order to achieve the 2050 targets, the EU must pursue further efforts. The EU MSs have declared a goal of decreasing GHG emissions in Europe by 80–95% relative to 1990 levels by 2050 (3). Primary energy demand in the EU amounted to about 1800 Mtoe/y in 2010, principally attributed to different heating and cooling (H&C) applications (almost 900 Mtoe/y, accounting also for industrial heat). The entire building sector accounts for around 720 Mtoe/y (40% of the entire EU primary energy demand). The most significant shares of energy demand within the European building stock are assigned, in decreasing order, to space heating (SH), domestic hot water (DHW), and space cooling (SC) with around 3200, 890, and 107 TWh/y, respectively (4). Recently, the EU and all of its MSs conducted a thorough investigation to classify their building stocks based on building typologies and existing floor area, without specifying energy demand values for SH, SC, and DHW according to the various construction periods.

The results presented in this book correlated with the contribution towards energy efficiency and sustainable green design features into new/existing buildings. Buildings have become a top priority in recent years for building owners, designers, contractors, engineers, and facility managers. This book intends to address a deliberate and, for the first time, established data analysis of the whole European building stock—revealing a current trend of building final energy consumption and efficiency. The results concern different sectors and types of buildings. The whole picture of the European building stock analysis has established that building energy efficiency is not just the result of applying one or more isolated technologies but rather a complex process of establishing new energy-efficient materials, equipment, and operational strategies.

2.

Methodology

2. Methodology

Data have been collected per country and organized within the residential and service sectors, addressing specific types of buildings and time periods.

The residential sector has been subdivided based on the following building typologies:

— Single-family houses (SFHs);

— Multi-family houses (MFHs);

— Apartment blocks (ABs – high-rise buildings that contain several dwellings and have more than four storeys) (5).

The service sector includes the following categories:

— Offices: composed of private and public offices; this section also includes office blocks;

— Trade: individual shops, department stores, shopping centres, grocery shops, car sales and garages, bakeries, hairdresser, service stations, laundries, congress and fair buildings, and other wholesale and retail infrastructures;

— Education: primary, secondary and high schools. Furthermore, universities, infrastructure for professional training activities, school dormitories, and research centres/laboratories are part of this sector;

— Health: private and public hospitals, nursing homes, medical care centres;

— Hotels and restaurants: hotels, hostels, cafés, pubs, restaurants, canteens, and catering in business;

— Other non-residential buildings: warehouses, transportation and garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sport facilities (e.g. sport halls, swimming pools, and gyms) (5).

In order to present a complete picture of the building stock and to describe time-related specifications, the following construction periods have been defined:

— Before 1945: buildings constructed before 1945 are generally classified as historic buildings. The historic building stock is highly inhomogeneous, making it difficult to apply a standardized assessment. Nevertheless, certain characteristics may still be generalized, such as the use of massive construction methodologies for residential buildings;

— 1945-1969: buildings erected after World War II and before 1969 are generally characterized by nearly missing insulation and inefficient energy systems, caused by the choice of cheap construction materials and by short construction times. These results in higher final energy consumption.

- 1970-1979: buildings built between 1970 and 1979 present the first insulation applications (as a consequence to the world energy crises of the 1970´s);
- 1980-1989 and 1990-1999: buildings constructed during these two periods reflect the introduction of the first national thermal efficiency ordinances (around 1990);
- 2000-2010: buildings considered to be influenced by the impact of the EU Energy Performance of Buildings Directive (2002/91/EC and following recasts);
- After 2010: recently constructed buildings are analysed to understand the impact of the economic crisis on Europe´s construction branch. The present analysis contains data updated until the year 2016.

With regard to the building typologies and construction periods previously described, the following features have been analysed:

Constructed, heated, and cooled floor areas	[%]
Number of dwellings/units, and of buildings	[%]

FEC

SH + DHW	[kWh/m² y], [TWh/y]
SC	[kWh/m² y], [TWh/y]

Construction materials and methodologies

Walls:		
Construction material	– bricks, concrete, wood	[%]
Construction methodology	– solid wall, cavity wall – honeycomb bricks/hollow blocks wall – insulation or not	[level of presence] [level of presence] [level of presence]

Windows:		
Construction material	– wood, synthetic/pvc, aluminium	[%]
Construction methodology	– single glazing, double/triple glazing – low-emittance or not	[level of presence] [level of presence]

Roof:		
Construction material	– concrete, concrete+bricks, wood	[%]
Construction metodology	– tilted, flat – insulation or not	[level of presence]

Floor:		
Construction material	– concrete, concrete+bricks, wood	[%]
Construction methodology	– concrete slab, wooden floor – insulation or not [level of presence]	[level of presence]

Thermal transmittance	– *U*-values – building's components.	[W/m2 K]

Technologies for SH, SC, and DHW

Technologies used for SH:	
Individual, central, or district heating	[level of presence]
Boiler (condensing or not), combined, stove, electric heating,	[level of presence]
Solar Collectors, Heat pumps	[level of presence]
Fossil fuels (solid, liquid, gas), electricity, biomass	[level of presence]

Technologies used for SC:	
SC or not	[level of presence]

Technologies used for DHW preparation:	
Individual, central, or district heating	[level of presence]
Boiler (condensing or not), combined, stove, electric heating,	[level of presence]
Solar Collectors, Heat pumps	[level of presence]
Fossil fuels (solid, liquid, gas), electricity, biomass	[level of presence]

It is essential to distinguish the value for final energy consumption (FEC) concerning the collected information. The FEC represents the amount of energy consumed throughout a considered period, the value related to SH, DHW and SC consumption. FEC is the empirically measured energy input into the supply system required to satisfy end users. The quantity differs by considering the efficiency of supply technology and the distribution losses but may also differ due to user behavior. In the form of electricity (in heat pumps and air-conditioners), FEC can be compared to fuel consumption (e.g., gas in a gas boiler) only by performing an adequate conversion into primary energy.

Data quality, completeness, accuracy, and reliability are essential aspects of generating the default datasets of the Horizon 2020 (H2020) HotMaps project. Hence, the following features have been taken into consideration in this process:

- Data inventory
- Data reliability
- Data definition and comparability

Data inventory

One of the significant challenges in developing an inventory of FEC data for SH, SC, and DHW in different sectors is to provide an almost complete list of existing information. The advantage of using data coming from EU information providers and EU projects is that these are available for large territories (e.g., BPIE) (6). However, the data provided are rarely fully complete. Therefore, national statistics have been used as data sources to increase data coverage.

The data collection process implied not only extrapolating and assembling data from data tools available online (e.g., TABULA) (7), but also researching data source-by-source from single scientific literature such as journal papers, conference proceedings, and project deliverables (8). The already mentioned lack of data per energy type (SH, SC, and DHW) could be filled only through an in-depth approach.

A critical 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).

Data reliability

All sources taken into consideration have been analyzed to assess the reliability of the gathered data. In particular, the methodology applied to generate data of the utilized fonts has been taken to a closer look. Furthermore, the information gaps have been completed by in-depth investigations on scientific literature.

Data definition and comparability

The data have been collected per country, concerning the most recent year; most data refer to the year 2016. Despite the majority of the data providers utilizing standardized data formats and units, this does not necessarily mean that data are fully comparable. Adjusting differences and inconsistencies among different data characteristics (e.g., time references) to improve data comparability is one of the essential aspects of data elaboration.

Apart from the use within HotMaps and other existing tools, the developed dataset is expected to improve data quality for users in the energy sector and provide data that is valuable to monitor progress towards achieving the goals defined in EU energy-related Directives.

In the following paragraphs, the main sources and the methodology of data elaboration are described for all the main features in the dataset. The data regarding covered area have been retrieved for each construction sector, building type, and period from Invert/EE-Lab database. (9). The total values for the residential and service sectors have been obtained by summing the data of all the building typologies for each time period. With regard to the heated and cooled floor area, the data for the residential sector have been obtained from the EU Building Stock Observatory (10), while the data for the service sector was obtained from several sources for each MS.

The section Construction materials and constraction methodologies contains the U-values of the main building elements (i.e. walls, windows, roof, and floor). The data have been obtained for each building typology from TABULA Web-tool (11) for the residential sector, and from the EU building database (10) and the results of the project iNSPiRe (12) for the service sector. The total values of thermal transmittance for each sector have been calculated by weighting the U-values of the single subsector with the respective constructed floor area.

— The main source for the construction methodologies and technologies for SH, SC and DHW for the residential sector is the TABULA Web-tool (11). The descriptions of the construction features have been collected for each building typology (SFHs, MFHs, and ABs) and construction period. Data has been organized in sub-sections for walls, windows, roof, and floor. The percentages presented in the dataset resulted from weighting the data for the total floor area of each building typology.

— The data concerning SH, SC, and DHW have been mainly collected using the TABULA Web-tool (11). However, the web site indicates for each building typology and construction period only the most widespread technology. For this reason, the dataset section technologies for SH, SC, and DHW does not contain the data in percentage, but indicates only the diffusion of each technology and fuel. The data has been calculated for the total residential sector, weighted on the total floor area of each building typology, and has been grouped based on the percentage of diffusion as follows:

— > 75%: most widespread technology/fuel;

— 25% to 75%: widespread technology/fuel;

— < 25%: less widespread technology/fuel.

Concerning the service sector, the TABULA Web-tool (7) does not contain any data. Furthermore, the scientific sources detailing typical construction features and technologies for SH, SC, and DHW are scarce. Hence, expert questioning has been carried out. A questionnaire containing all features already included

in the dataset for the residential sector has been sent to two experts per country. The collected data has been analyzed, and the results have been clustered in geographical areas.

The clusters, based on the geographical proximity of the countries, are the following:

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

The results have been counterchecked with the few sources available on the topic.

The main source for the specific FEC of space heating, space cooling, and DHW per country is Invert/EE-Lab database (9). Based on these values, the final energy consumption per year for each country has been calculated by the following equations:

- Space heating + domestic hot water [TWh/year]:
  Mm^2 heated floor area × SH consumption+Mm^2 total floor area × DHW consumption
- Space cooling [TWh/year]:
  Mm^2 cooled floor area × SC consumption

The following section describes the main results by country with respect to each analyzed period. The description is primarily based on the figures explaining the analyzed dataset (8). According to each country: the first figure describes million square meters (Mm^2) of covered floor area in percentages. The second figure describes the number and type of buildings are erected regarding residential and service sectors—the number of buildings is given in millions (Mil.) and is represented in percentages. The third and fourth figures describe a trend of Specific Final Energy Consumption (FEC) for Space Heating (SH), Domestic Hot Water (DHW), and Space Cooling (SC). The fifth figure provides information about the used construction materials related to only the residential sector. The value is indicated as a percentage for each specific material. The percentage represents the share of that material in use. Each following description of a country consists of the same types of figures as mentioned above. Information about construction methodology and technology for SH, DHW, and SC are presented only in a written form due to the complexity of the mined data, while due to a lack of data it is not possible to display complete figues on the utilization of construction materials.

3.

Main results

3. Main results

3.1. AUSTRIA

This section represents a selection of the main results that were obtained from the building stock analysis dataset regarding Austria (8).

In Figure 1, the Mm² of covered floor area in Austria's residential and service sectors is presented in percentages regarding historical periods.

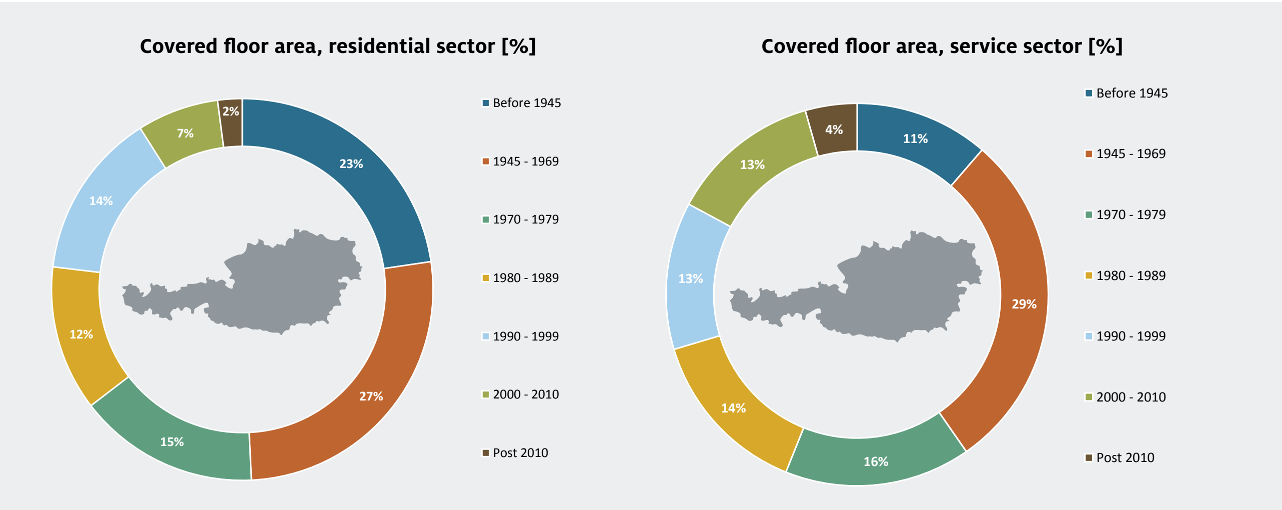

Figure 1. Split of the residential and service building stock raised per construction periods [%] (Austria)

The historic buildings of the residential sector (i.e., construction period Before 1945) show high percentages of covered floor area, around 23%. The result appeared because the period before 1945 covers the entire historic building stock. The period between 1945-1969 refers to the beginning of the post-World War 2 era, with the highest 27%. Interestingly, the two earliest periods occupied half of the entire residential building stock. On the other hand, the minor portion demonstrates the last two periods, 2000-2010 and post 2010, with just 7 and 2 percent, respectively.
The relative equality of the results in covered floor area among both sectors can be noticed from 1945 to the late 1990s. However, before 1945 the service sector showed a lower percentage of covered floor area than the residential one, about 11% compared to 23%. Between 1945-1969, both sectors also demonstrate similarities, being the sectors with the highest percentage in terms of

covered floor area: 27% versus 29%. The explanation is that this construction period consists of 24 years, while the subsequent periods (i.e., from 1970) include only ten years. Moving further, we can observe that after the 1970s, the percentages of occupied floor area constantly decrease until recent years.

Figure 2 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 2 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

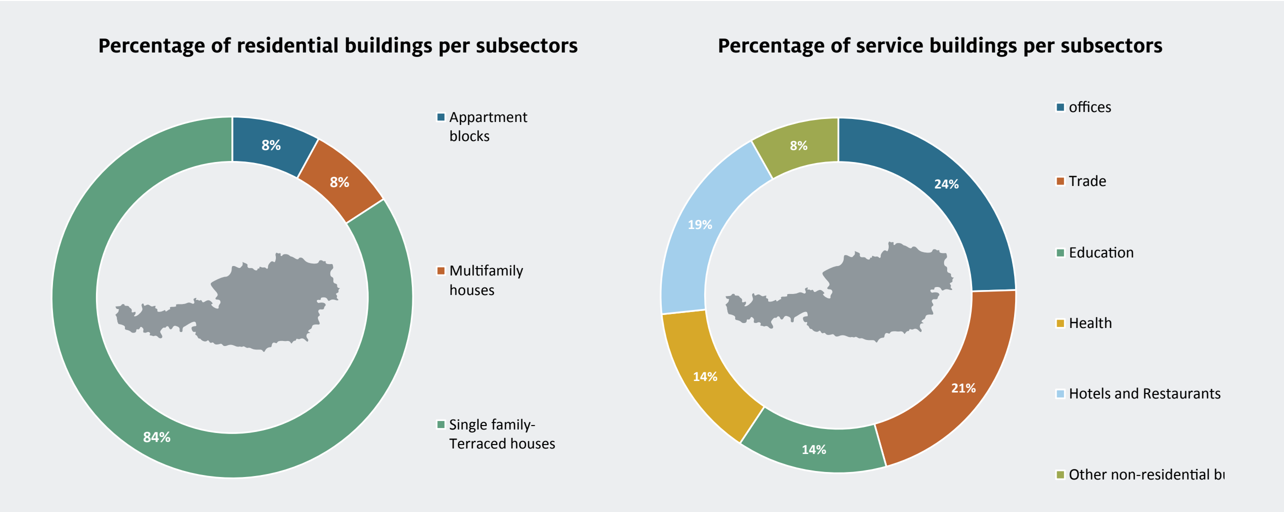

Figure 2. Split of residential and service buildings per different subsectors [%] (Austria).

The residential sector is dominated by SFHs with 84%, followed by MFHs and ABs with approximately 8% for each sector.

The service sector is predominantly occupied by offices and trade buildings with 24 and 21% respectively. Hotels and restaurants follow with 19%. Education and Health buildings come next with 14% each. Other non residential buildings are last positioned with 8%.

Figure 3 shows the development of the specific FEC (kWh/m²y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

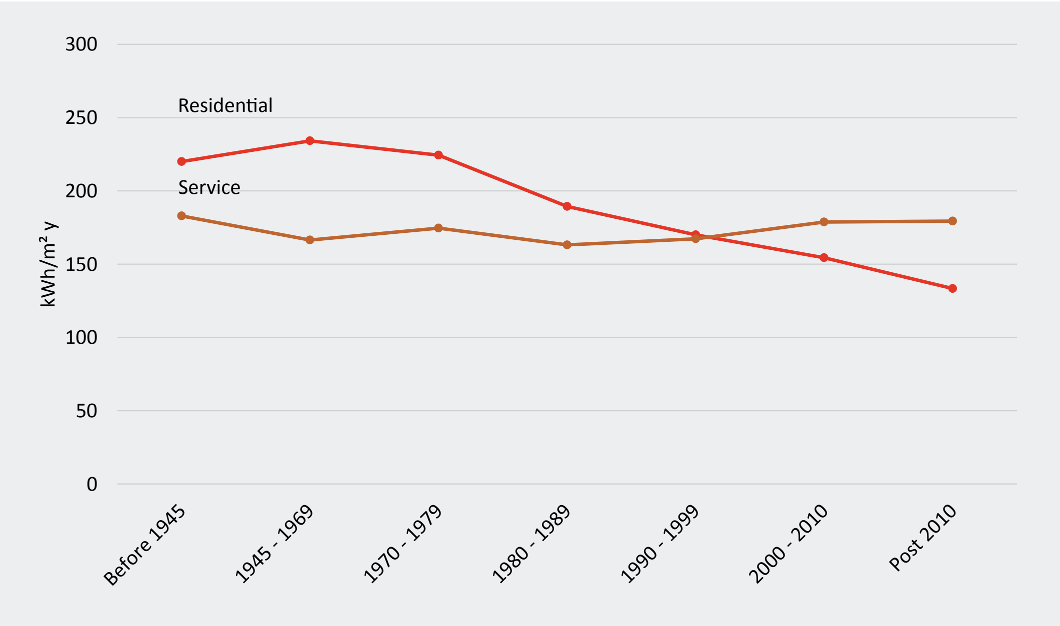

Figure 3. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Austria).

The trend of the specific FEC for residential buildings varies, as presented in Figure 3. Noticeably, from the construction periods before 1945 to post-World War 2 (1945-1969), the specific FEC was increased from approximately 220 kWh/m²y to 235 kWh/m²y. This trend could be explained by using cheap construction materials without insulation and outdated construction methodology relative to the current perspective. The limitation in the quality was necessary for the post-war period to provide civilians with new housing quickly (7). After this time frame, the specific FEC decreases. The decrease becomes more visible for buildings erected after the 1970s when energy-efficient insulation materials were present for the first time to respond to the world energy crisis. Finally, the specific FEC ends up with a value of around 133 kWh/m²y in the post-2010 construction period. The reason was that the quality of construction materials and construction methodology was increased. This increase resulted from the first national thermal efficiency ordinances in the 1990s and the impact of the EU Energy Performance of Buildings Directive (13).

The specific FEC for the service sector shows an opposite trend in comparison to the residential one. The value was declined from 183 to 166 kWh/m²y concerning buildings erected during the same considered periods (before 1945 and 1945-1969). Thus, the specific FEC for SH and DHW is about 68 kWh/m²y higher for households than for services between 1945-1969. However, the tendency of decreasing the specific FEC for the service sector does not remain the same. Instead, the specific FEC shows fluctuations regarding different construction periods and finally ends with the value of 179 kWh/m²y in buildings erected during the post-2010.

Noticeably, this value is close to 183 kWh/m²y in the earliest construction period, before 1945. The result could be explained by a DHW consumption proportional to the number of employees, while specific FEC for SH is inversely proportional. New energy-efficient materials and technologies for SH and DHW help to neutralize this dependency but not avoid it. Also, the sector is characterized by a high diversity of different types of buildings and their occupancy variations, which often do not follow a similar trend in specific FEC.

Figure 4 shows the development of the specific FEC (kWh/m²y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

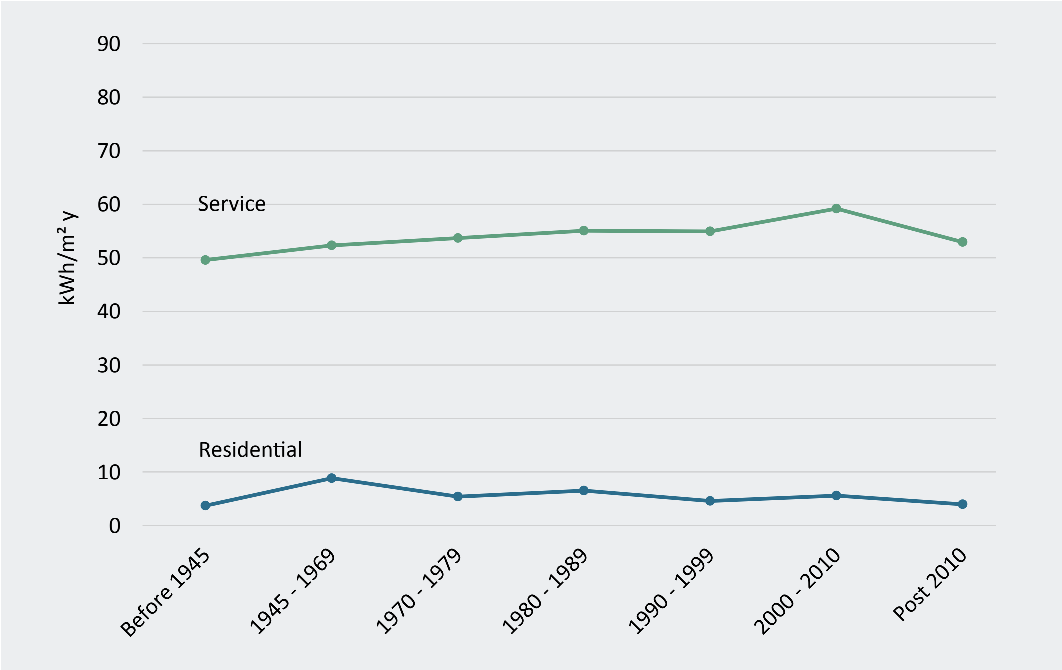

Figure 4. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Austria).

As evident from the figure displayed above, specific FEC for SC in the residential sector develops relatively constantly in buildings erected between 1970-2010. The only noticeable construction period is 1945-1969, where the specific FEC was increased from approximately 4 kWh/m²y to about 9 kWh/m²y. A reasonable explanation would be those low-quality materials and outdated construction methodology, caused by the same reason, as mentioned in the previous figure (specific FEC for SH and DHW).

Compared to the peak of specific FEC related to the residential buildings erected during 1945-1969, the service sector shows a gradual increase that eventually peaked in the 2000-2010 construction period with a value of about 59 kWh/m²y. The difference in specific FEC from 1945 to its peak is about 9 kWh/m²y. Interestingly, the peak of the specific FEC for SC appeared rapidly from 1990-1999, with a value of about 54 kWh/m²y. Finally, the value dropped back to 53 kWh/m²y in the post-2010 period.

Observation for buildings constructed during all analyzed periods shows that the FEC for SC nearly stays the same in both sectors. Several possible reasons may have led to relatively the same SC FEC. Firstly, the European population increased comfort standards. Secondly, the Austrian alpine climate often does not require SC applications. And thirdly, modern building architecture with larger glazing areas. The third possible reason has a relatively low impact, while the other two might have more significant influences.

Regarding the construction methodology presented in the data set provided by the H2020 Hot-Maps repository (8), the main construction topology for walls, concerning all historical periods, is honeycomb bricks and hollow blocks walls; solid walls are present only in historical buildings. The construction methodology for windows is mainly double and single glazing windows. Single glazing windows are not presented in the buildings constructed during the two last periods (the 2000s and post-2010). The low emittance glass is only in buildings constructed after 1980s. We can observe that the flat roof is the most popular decision regarding all construction periods except the 1970s, followed by the tilted roof. The tilted roof is presented in buildings erected from 1945 to the 1970s, with insulation only in 1970s —the flat roof with insulation is in buildings constructed after the 1980s. Concrete slabs (insulation presents from 1970s) were primarily used in Austrian houses throughout all historical periods.

Information about construction materials and construction methodology of the service sector was received by questioning experts. The information concerning Central Europe (Austria, Belgium, Germany, Netherland, Luxembourg, France, UK and Ireland) was eventually summarized. Concerning the Austrian service sector, the information is presented in the table below (Table 1).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, education, health, other nonresidential buildings							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete + insulation	Aluminum and synthetic/PVC, low emittance glass only in few cases.	Concrete +insulatios	Concrete+ insulations	Solid wall	Double glazing	Flat roof	Concrete slab
Trade, hotels and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete bricks + insulation	Aluminum and synthetic/PVC	Concrete and bricks +insulatios	Concrete +insulatios	Solid walls	Double glazing	Flat roof	Concrete slab

Table 1. Construction materials, construction methodology-service sector (Austria).

The details from the table above clearly let us know that the service sector demonstrates similarities in construction materials and methodology regarding different types of buildings. For offices, educational, health, and other non-residential buildings, the use of relatively the same construction materials and methodology stay mainly the same. At the same time, it is also valid for trade, hotels, and restaurants.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). According to all historical periods, Table 2 shows the thermal transmittance value (W/m^2K) regarding residential and service sectors.

Table 2 helps to figure out the impact of building elements on specific FEC. Here we can observe how thermal insulation materials and building elements regarding different periods affect heat flow. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.41	2.01	1.02	1.13
1945 - 1969	1.40	2.64	0.79	1.40
1970 - 1979	1.32	2.48	0.79	0.70
1980 - 1989	0.88	1.96	0.52	0.52
1990 - 1999	0.35	1.29	0.29	0.37
2000 - 2010	0.22	1.35	0.19	0.22
Post 2010	0.34	1.04	0.16	0.37
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	0,70	3,20	1,10	1,20
1945 - 1969	0,64	2,91	0,70	1,50
1970 - 1979	0,66	2,08	0,60	1,00
1980 - 1989	0,57	2,10	0,40	0,60
1990 - 1999	0,48	1,40	0,30	0,50
2000 - 2010	0,32	1,30	0,20	0,45
Post 2010	0,35	1,40	0,10	0,40

Table 2. Thermal transmittance of construction elements (Austria).

The analyzed data related to SH and DHW in the Austrian residential sector is characterized by central space heating systems. In most buildings (erected before 1945 to the late 1980s), the non-condensing boiler is used. Regarding buildings constructed after the 1980s, condensing boilers are mainly utilized.

The liquid fuel is widely used throughout all considered periods, followed by gas being less prevalent in the market. Liquid fuel is mainly used in SFHs, MFHs and in ABs . However, in MFHs constructed before 1945 and between 1945-1969, gas is primarily used. In the ABs, both mentioned fuels are utilized.

The results for SC technology show that in most cases, SC is not represented in the Austrian residential market. This situation can be easily seen in Figure 4, where the residential sector shows a relatively low specific FEC for SC. Low consumption may be due to an alpine climate, characterized by low turbidity that enhances radiative heat losses during clear nights. (15)

These findings demonstrate the lack of renewable energy sources for SH DHW and SC in Austrian residential building stock. Moreover, as was mentioned above, residential sector mostly use liquid fuel, which is characterized by a higher carbon content than gaseous ones.

According to expert questioning: the most common technology in the service sector for SH and DHW is gas condensing boilers. In few cases, heat pumps are applied and electricity. Space cooling is not present in most cases, except health industry, where space cooling is mainly utilized.

3.2. BELGIUM

This section represents a selection of main results that were obtained from the building stock analysis dataset regarding Belgium (8).

In Figure 5, the Mm² of covered floor area in Belgian's residential and service sectors is presented in percentages regarding historical periods.

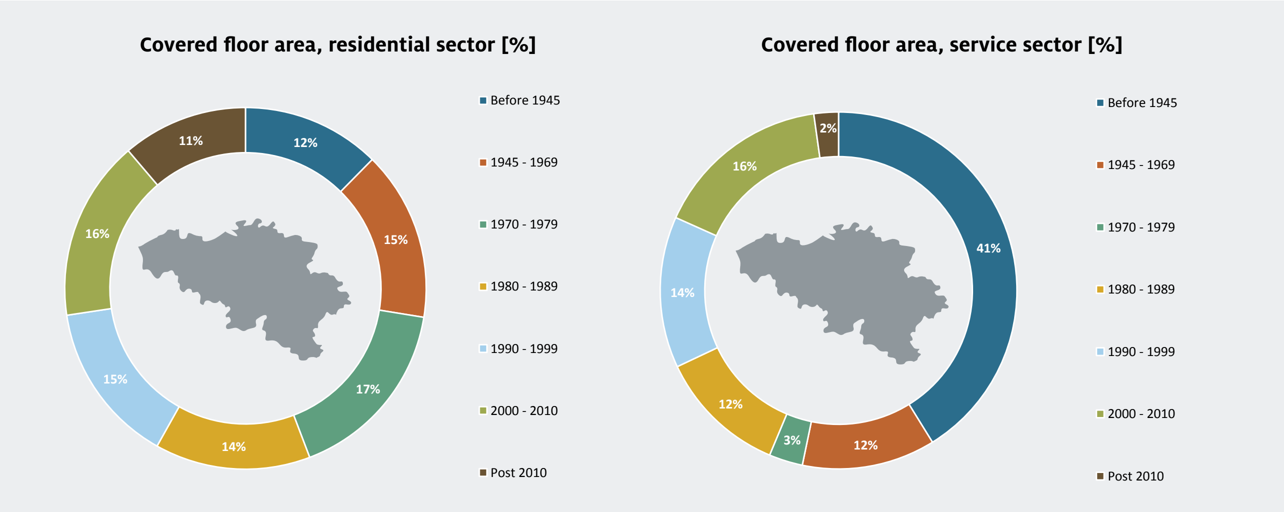

Figure 5. Split of the residential and service building stock raised per construction periods [%] (Belgium).

As visible from the figure above, the residential sector demonstrates close similarities across all historical periods. The data indicate that each consecutive period is characterized by a relatively equal building area. Each subsequent period differs from the previous one by no more than 3%. The slight increase in covered floor area happened in the 1970s, 1990s, and 2000s. Interestingly, the earliest period (before 1945) and the latest one (Post 2010) indicate 12 and 11% respectively.

In contrast, the service sector does not demonstrate equalities in different periods. As shown from the figure above, the historical period «before 1945» displays the highest percentage of covered floor areas, 41%, which means that the significant numbers of service buildings in Belgium are characterized as historical buildings. On the other hand, the minor portion demonstrates the period between 1970-1979 and post 2010 with just 3 and 2%. The matching results in both sectors are in the 1990s and between 2000-2010 with the value around 15% and 16%, respectively. Fewer closer results indicated in the period between 1980-1989 with 14 and 12% respectively.

Figure 6 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 6 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

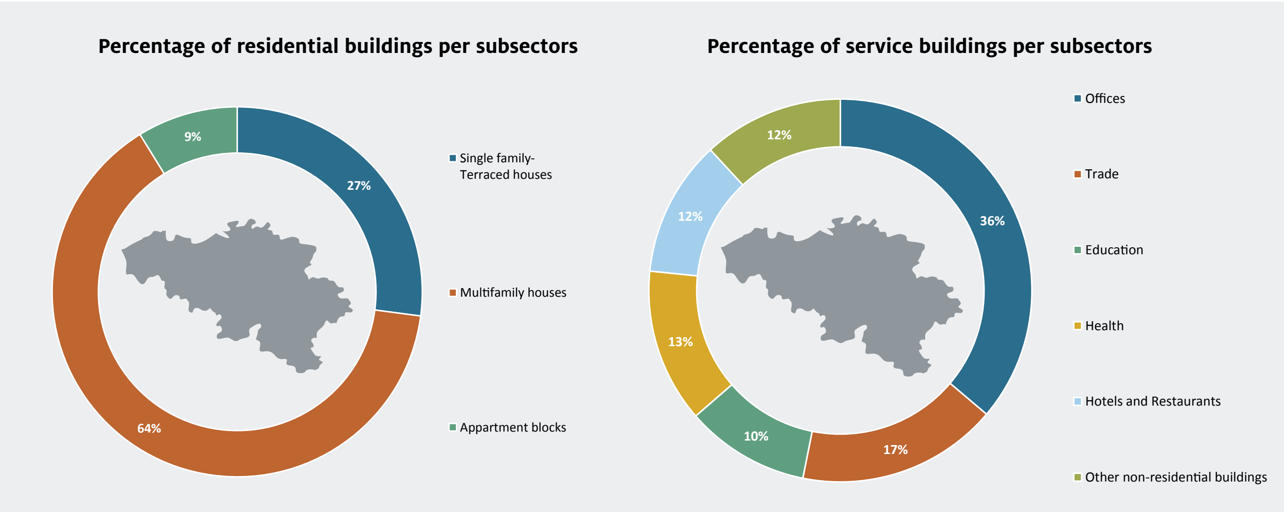

Figure 6. Split of residential and service buildings per different subsectors [%] (Belgium).

The residential sector is dominated by MFHs with 64%, followed by SFHs with approximately 27% of buildings and a significantly smaller number of ABs with 9% only.

The service sector is predominantly occupied by offices - 36%. Trade buildings are the second largest building type with 17%, followed by health with 13%. Other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms), account for 12%. Similar results are shown for hotels and restaurants. Educational buildings indicate a slightly smaller number - 10%. They account for being the least represented building types in the service sector of Belgium.

Figure 7 shows the development of the specific FEC (kWh/m²y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

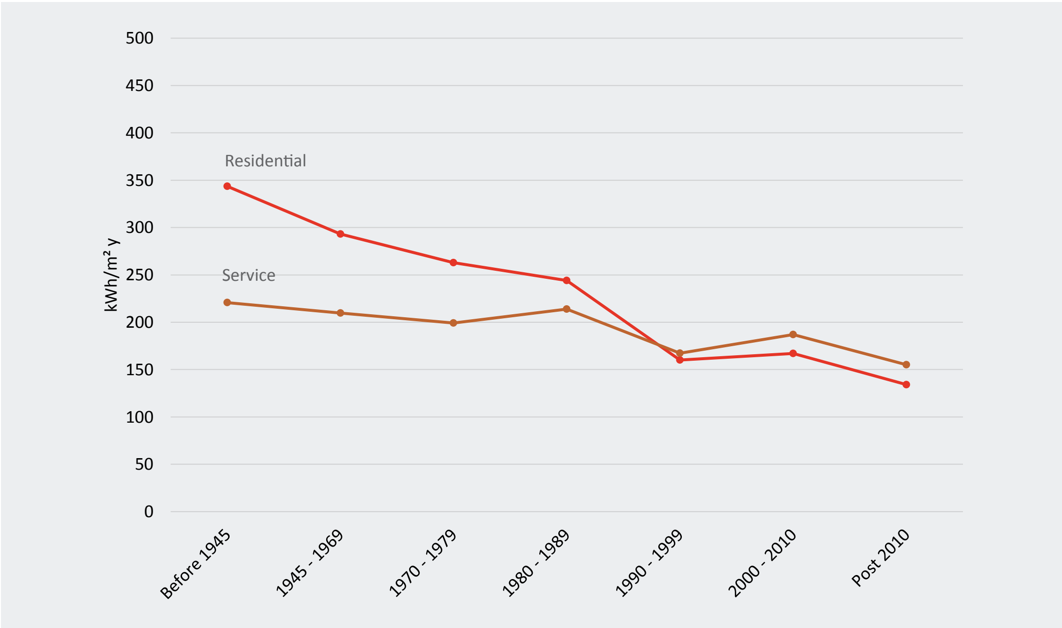

Figure 7. Development of specific final energy consumption for pace heating and domestic hot water, residential and service sectors [kWh/ m² y] (Belgium).

The trend of the specific FEC for residential buildings varies, as presented in Figure 8. Noticeably, the specific FEC gradually decreased from approximately 350 kWh/m²y to 250 kWh/m²y regarding buildings constructed before 1945 and those from the 1980s. After this time frame, a reduction in specific FEC appeared more rapidly and ended with a value of about 160 kWh/m²y in the 1990s.

Compared to the 2000-2010 construction period, the specific FEC slightly increased to the value of about 167 kWh/m²y. The higher the number of occupants, the more the household consumes, but this is not a linear relationship because it is influenced by the number of persons, their consumption pattern, and the quality of insulation materials used (16). Finally, the last post-2010 period shows a substantial reduction to 134 kWh/m²y, thanks to the building's structure with high insulation components and new construction procedures.

A similar trend is detected in the service sector. However, the sector demonstrates lower FEC than the residential one. Buildings erected before 1945 indicate about 220 kWh/m²y of the specific FEC compared to 340 kWh/m²y in the residential one. Moving further, we can observe that the specific FEC for SH and DHW in the service sector is decreasing relatively slower than in the residential one. For buildings erected between 1945-1969, the specific FEC is 210 kWh/m²y, vs. 293 kWh/m²y in the residential sector. Buildings erected in the 1970s demonstrate approximately 260 and 200 kWh/m²y, respectively. As a result, residential buildings erected in the 1990s consume more than the service ones, with about 160 vs. 167 kWh/m²y. This tendency remains the same regarding the two last periods, as shown in Figure 7.

Figure 8 shows the development of the specific FEC (kWh/m²y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

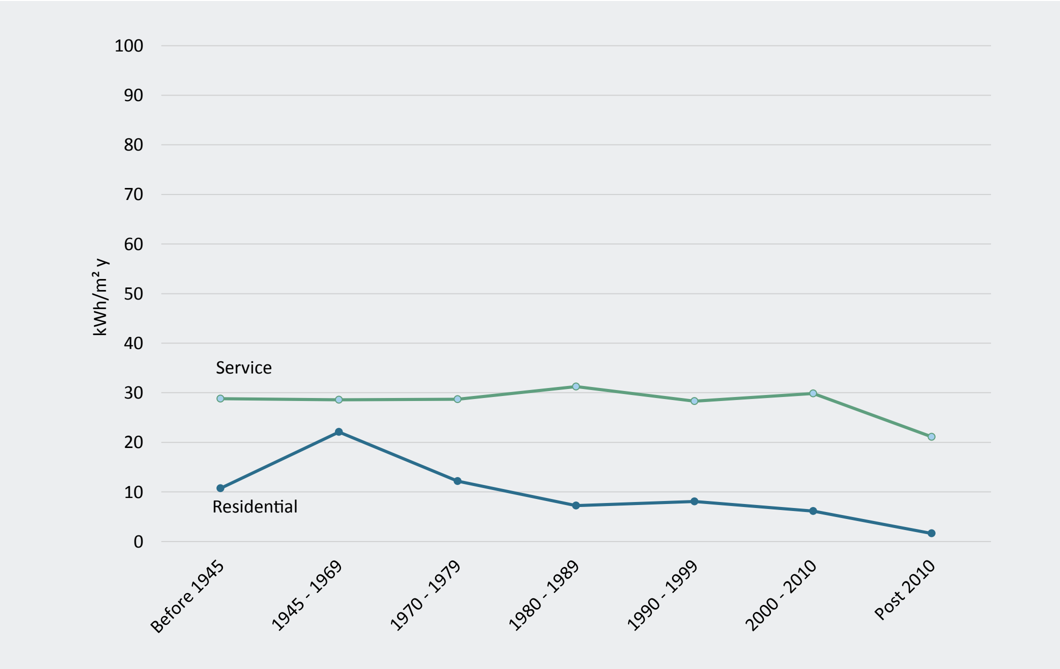

Figure 8. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Belgium).

As seen from Figure 8, specific FEC for SC in the residential sector is raised from the first construction period (before 1945) to the period between 1945-1969. According to the analyzed dataset (8), the given trend has occurred because a higher occupancy density characterizes buildings erected in that period (1945-1969). As a result, the specific FEC for SC was increased from 11 to 22 kWh/m² y. In comparison between historical buildings erected in this time (1945-1969) and those from the late 1980s, the specific FEC was steadily decreased to around 7 kWh/m² y. The trend demonstrates a relatively slight decrease in specific FEC regarding the 2000s with 6 kWh/m² y. Buildings erected after 2010 are characterized by small specific FEC for SC. The resulting value is around 1 kWh/m²y.

The resulted small specific FEC is not always a matter of well-insulated building elements or a number of people in a building, but also a climate impact that, regarding Belgium, does not account to spend a significant portion of FEC for SC. As the figure above shows, the service sector consumes a slightly higher specific FEC for SC. Interestingly, the specific FEC for SC remains almost constant throughout all considered periods in the service sector. It is visible that from the construction periods before 1945 and between 2000-2010, the specific FEC for SC relatively stays the same, around 30 kWh/m² y. The only different period is the last one (Post 2010), where the final value is reduced to 20 kWh/m² y.

The resulting small specific FEC is not always a matter of well-insulated building elements or a number of people in a building, but also a climate impact that, regarding Belgium, does not account for a significant portion of FEC for SC.

Regarding the construction methodology presented in the dataset provided by the H2020 HotMaps project (8), the main construction topology for walls is a cavity wall with insulation only in buildings related to periods from the 1990s to post 2010. Solid wall presents in historical buildings only (constructed before 1945) without the presence of insulation. The construction methodology for windows is mainly double and single glazing windows. Single glazing windows are given only in two first periods (before 1945 and 1945-1969). Low emittance glass is given only in buildings erected in the 2000s and post-2010 periods. We can observe that a flat roof is the most popular decision in buildings regardless of historical periods, followed by the tilted roof. Insulation for roof and floor is only presented in buildings constructed after the 1970s. Concrete slabs are the most widespread technology for floors in Belgian houses throughout all periods.

Information about construction materials and construction methodology of the service sector was received by experts questioning. The information concerning Central Europe (Austria, Belgium, Germany, Netherland, Luxembourg, France, UK and Ireland) was eventually summarized. Concerning the Belgian service sector, the information is presented in the table below (Table 3).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, educational, health, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete + insulation	Aluminum and synthetic/PVC, low emittance glass only in few cases.	Concrete + insulation or Concrete+ bricks +insulatios	Concrete+ insulations	Solid wall	Double glazing	Flat roof	Concrete slab
TRADE, HOTELS AND RESTAURANTS							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete or bricks+ insulation	Aluminum and synthetic/PVC	Concrete and bricks +insulatios	Concrete +insulatios	Solid walls	Double glazing	Flat roof	Concrete slab

Table 3. Construction materials, construction methodology-service sector (Belgium).

The table above shows that the service sector demonstrates similarities in construction materials and methodology regarding different types of buildings. For office, educational, health, and other non-residential buildings, the use of construction materials and methodology stay mainly the same, while it is also true for trade, hotels, and restaurants.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 4 shows the thermal transmittance value ($W/m^2 K$) regarding two considered building sectors (residential and service) for all periods.

Table 4 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and buildings elements regarding different periods affect heat flow and, as a result, specific FEC.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	2.05	5.00	2.96	0.70
1945 - 1969	1.70	4.76	3.39	2.19
1970 - 1979	1.34	4.28	0.85	0.77
1980 - 1989	1.40	3.89	0.92	0.91
1990 - 1999	0.70	3.46	0.46	0.51
2000 - 2010	0.40	2.00	0.30	0.37
Post 2010	0.23	1.70	0.21	0.21
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.90	4.50	2.00	0.80
1945 - 1969	1.80	4.60	2.00	0.90
1970 - 1979	1.75	4.20	2.20	1.00
1980 - 1989	1.70	3.80	1.20	0.90
1990 - 1999	1.30	3.70	0.90	0.80
2000 - 2010	0.80	2.30	0.70	0.70
Post 2010	0.40	2.50	0.30	0.50

Table 4. Thermal transmittance of construction elements (Belgium).

According to the analysis, the individual SH and DHW system is mainly available in buildings constructed during all analyzed periods. However, the central SH system started to be used after the 1980s. This is because building erected before 1945 until the late 1980s use the stove for SH as a most widespread technology. After this period, condensing boilers are utilized for SH and DHW systems. The non-condensing boiler uses in buildings were erected until the 1980s. Building constructed after this period is mainly equipped by condensing one.

Liquid fuel and gas are widely used for SH and DHW in the residential sector. Single-family users and multifamily houses mainly use liquid fuel. Interestingly, SFHs erected before 1945 use electricity as the most widespread technology for DHW.

The results for SC technology show that buildings erected before 1945 to the 1980s do not use SC technology in most cases. However, buildings constructed after this time, in most cases, are equipped with a SC system. This situation can be easily seen in Figure 8, where the residential sector shows a relatively low specific FEC for SC. Low consumption is explained by climatic conditions of the northern part of Europe, which do not require SC often.

These findings demonstrate a lack of renewable energy sources for SH, DHW, and SC in the Belgian residential building stock that mainly utilize liquid and gaseous fuels, characterized by higher carbon content.

According to expert questioning: the most common technology in the service sector for SH and DHW is gas condensing boiler. In few cases, heat pumps are applied and electricity. SC is not presented in most cases, except in the health industry, where SC is mainly used.

3.3. **BULGARIA**

This section represents a selection of main results that were obtained from the building stock analysis dataset regarding Bulgaria (8).

In Figure 9, the Mm^2 of covered floor area in Bulgarian residential and service sectors is presented in percentages regarding historical periods.

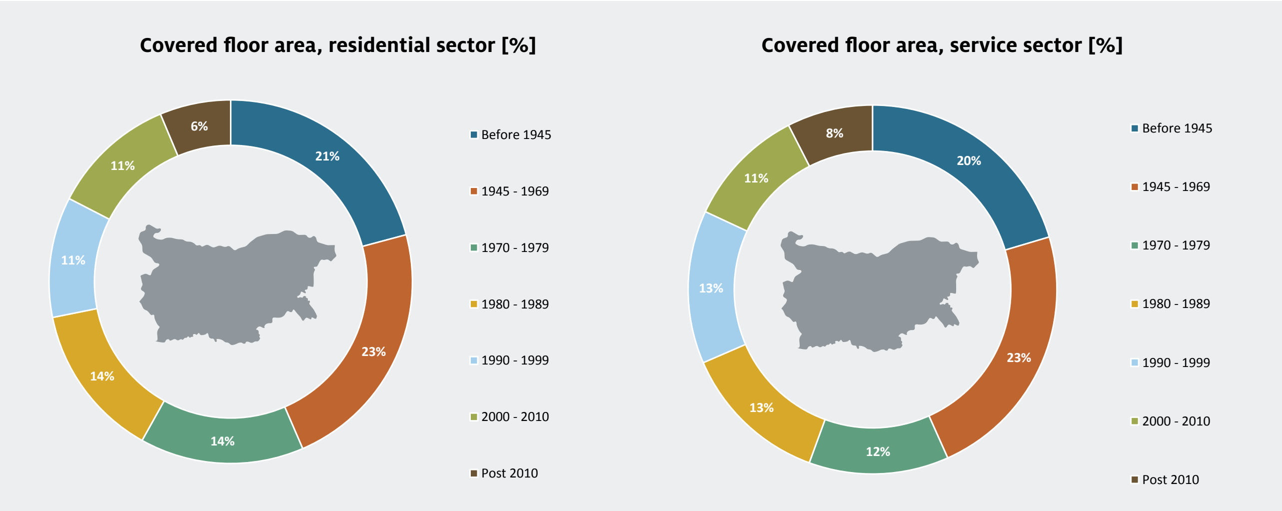

Figure 9. Split of the residential and service building stock raised per construction periods [%] (Bulgaria).

The result demonstrates the relatively high percentage of covered floor area regarding buildings constructed before 1945 - around 21%. The post-WWII period (1945-1969) accounts for a slightly higher percentage of covered floor area, with 23%. Interestingly, the two earliest periods occupied a significant portion of Bulgaria's entire residential building stock – 44%. On the other hand, the minor portion indicates the last two periods, 2000-2010 and post 2010, characterized with just 11 and 6%, respectively. Periods of the 1970s and 1980s are covered equally by approximately 14%. The same pattern demonstrates that the 1980s and 1990s are characterized by a value of about 11%, respectively.

The relative equality of the results in covered floor area among both sectors can be noticed regarding all historical periods. Moreover, as seen from the graph, the period between 1945-1969 shows 23% of the total covered floor area. The same is also true for the 2000s, where both sectors account for 11% respectively. The earliest historical period (before 1945) related to both analyzed sectors distinguish only 1% of differences in between. Thus, covered floor area in residential and service sectors (before 1945 and between 1945-1969) demonstrate relatively the same percentage with about 44% and 43% respectively.

The analysis shows that the fractional distribution of Mm^2 as a percentage of covered floor area is relatively similar in both sectors.

Figure 10 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 10 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

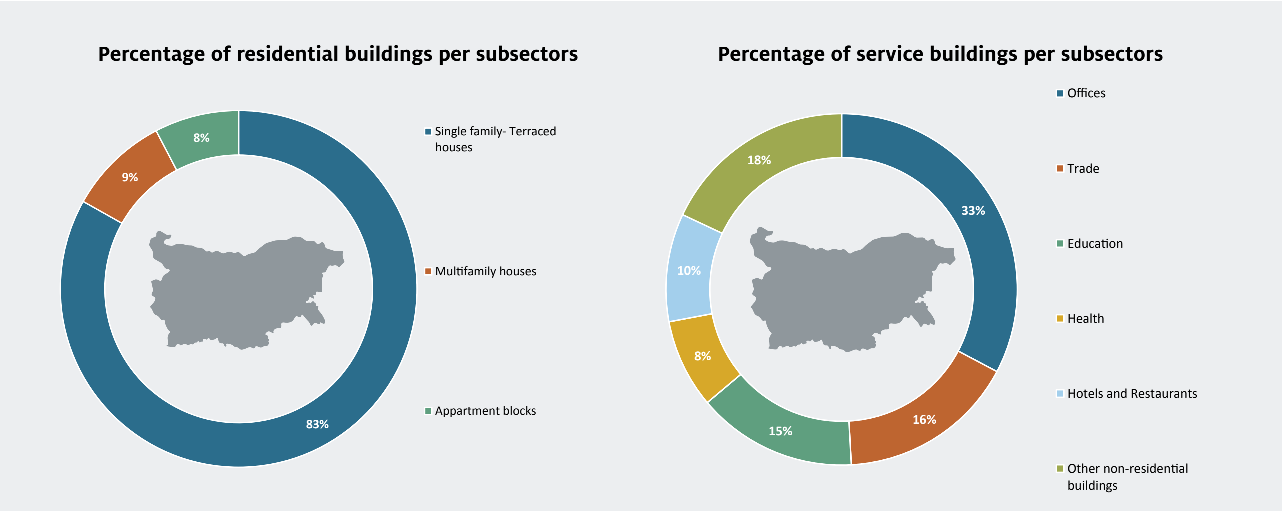

Figure 10. Split of residential and service buildings per different subsectors [%] (Bulgaria).

The residential sector in Bulgaria is characterized mainly by SFHs with 83%, followed by significantly less than 9% of MFHs and solely 8% of ABs.

The service sector is primarily occupied by office buildings - 33%. The second-largest category is "Other non-residential buildings," including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms) with about 18%. Trade buildings are the third-largest building type with 16%, followed by educational buildings with 15%. The two minor portions of the service sector are divided by the hotel and restaurants category with 10% and health with only 8% accordingly.

Figure 11 shows the development of the specific FEC (kWh/m²y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

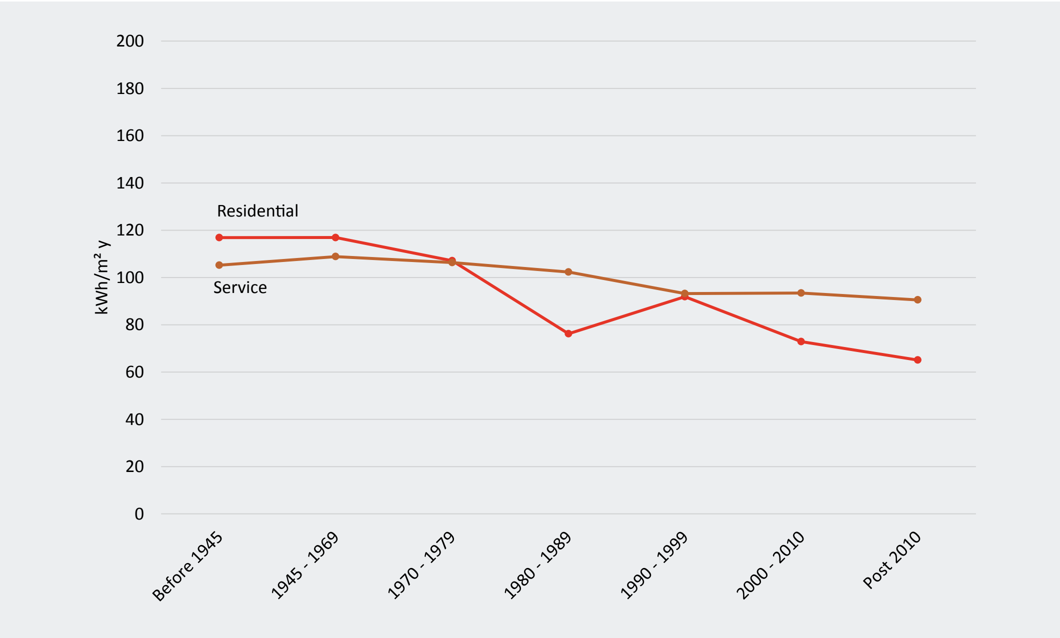

Figure 11. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Bulgaria).

The figure above illustrates that both sectors (residential and service) follow the same pattern in specific FEC for SH and DHW. The pattern demonstrates a gradual reduction in specific FEC concerning buildings erected during periods that are under consideration.

The residential sector (red line) demonstrates around 117 kWh/m²y of the specific FEC for historical buildings erected during the first period (before 1945). Interestingly, buildings erected between 1945-1969 displays no deviation in the specific FEC compared to the historical one. The only noticeable period where the specific FEC starts to reduce is the construction period of the 1970s, where the value was lowered to about 106 kWh/m²y. Compared to buildings erected in the 1970s, buildings erected between 1980-1989 are characterized by a substantial reduction in specific FEC, where the value was reduced to about 76 kWh/m²y. Surprisingly would be to see that buildings constructed in the 1990s have not continued that trend. They are characterized by a higher specific final energy consumption, around 93 kWh/m²y, in comparison to buildings of the 1980s. In contrast, buildings constructed in the 2000s and post-2010 period illustrate a noticeable reduction in specific FEC, with the value of approximately 73 and 65 kWh/m²y accordingly.

The service sector (orange line) shows that historical buildings erected before 1945 consume about 105 kWh/m²y compared to the residential buildings (117 kWh/m²y) at the same time. service buildings erected during the following period (1945-1969) demonstrate a slightly higher specific FEC for approximately 109 (kWh/m²y). Buildings erected between 1970-1979, characterized by a negligible reduction of specific FEC, resulted in the same value as mentioned for the residential sector of that time (106 kWh/m²y). The construction period of the 1980s shows a slight decrease of specific FEC to about 102 kWh/m²y. Interestingly, the service budlings related to the 1990s consume the same 93 kWh/m²y as the residential ones. Budlings erected in the last two periods also account for the same 93 and 90 kWh/m²y respectively.

Figure 12 shows the development of the specific final energy consumption FEC (kWh/m²y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

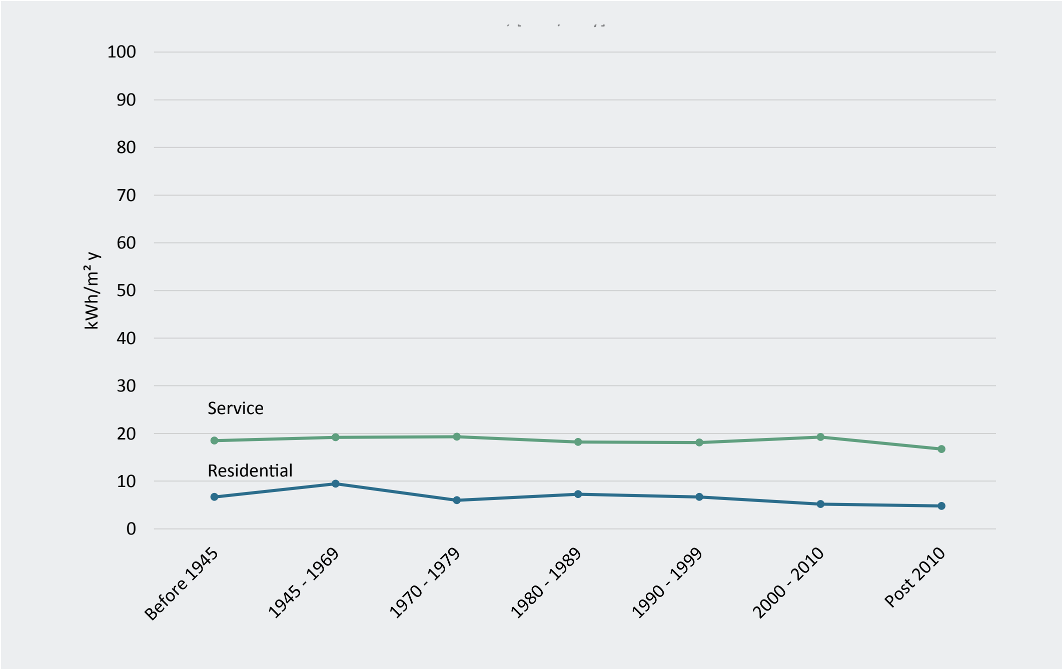

Figure 12. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Bulgaria).

Figure 12 illustrates that specific FEC of the residential sector demonstrates a slight rise from the first construction period (before 1945) to the period between 1945-1969, from 6 to 10 kWh/m²y. Concerning building erected in the 1970s, we can see the impact of the first established thermal insulation, which caused a decrease of specific FEC back to 6 kWh/m²y. Interestingly, buildings erected in the following periods do not account for any noticeable increase or decrease in specific FEC. The specific FEC in the following construction periods accounts for a slight decrease from 7 to 5 kWh/m²y for buildings erected from 1980 to post 2010.

In contrary to the residential sector, the service one consumes for about 10 kWh/m^2y more specific FEC. As can be seen from the figure above, the specific FEC for service buildings erected in different periods demonstrates relatively the same value for specific FEC. Across the whole Bulgarian service building stock, the specific FEC accounts for about 19 and 18 kWh/m^2y. The only noticeable declination in the specific FEC demonstrates buildings erected after 2010. They account for about less than 16 kWh/m^2y.

Regarding the construction methodology presented in the dataset provided by the H2020 Hot-Maps project (8), the main construction topology for walls is a solid wall without insulation. Honeycomb bricks / hollow blocks wall presents in a small number of residential buildings erected during the 2000s and post-2010 periods with insulation. The construction methodology for windows is mainly double-glazing, presented in buildings erected from the 1970s to the 2000s. Low emittance glass only in buildings of the 2000s. Single glazing windows are given only in two first periods (before 1945 and 1945-1969), while the triple one with low emittance glass referred to the post-2010 period. We can observe that a flat roof is the most popular decision in buildings regardless of historical periods except "2000-2010", followed by the tilted roof. The tilted roof is presented in buildings erected before 1945, between 1945-1969, and during the last two periods (2000-2010, post-2010). Insulation for a flat roof is presented in buildings erected in the 1970s and after, while for tilted ones, in the 2000s and post-2010 periods. Concrete slabs are the most widespread technology for floors in Bulgarian houses throughout all periods, with insulation only in buildings erected during the 2000s and after 2010. Wooden floor (rafters + boards) referred to historical buildings constructed before 1945 and between 1945-1969.

Information about construction materials and construction methodology of the service sector was received by experts questioning. The information concerning Eastern Europe (Poland, Czech Republic, Hungary, Slovenia, Slovakia, Croatia, Bulgaria, Romania) was eventually summarized. Concerning the Bulgarian service sector, the information is presented in the table below (Table 5).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, health, other nonresidential							
Walls	Windows	Roofs	Floors	Wall	Windows	Roofs	Floors
Bricks+ Insulation in few cases	Wood, low emittance glass only in few cases.	Concrete and metallic roof boards + insulation	Concrete+ insulations in few cases	Solid wall	Double glazing	Flat roofs	Concrete slab
Education							
Walls	Windows	Roofs	Floors	Wall	Windows	Roofs	Floors
Bricks+ Insulation in few cases	Synthetic/PVC, low emittance glass only in few cases.	Concrete and tiles + insulation in few cases	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roofs	Concrete slab
Hotels and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roof	Concrete slab

Table 5. Construction materials, construction methodology-service sector (Bulgaria).

The table above (table 5) shows that the service sector demonstrates 100% similar construction methodology and relative similarity with construction materials regarding different types of buildings. For the office, trade, health, and other non-residential buildings, the use of construction materials and methodology stay the same. Education buildings, hotels, and restaurants have similar construction methodology while demonstrating the small difference in construction materials.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 6 shows the thermal transmittance value ($W/m^2 K$) regarding two considered building sectors (residential and service) for all periods.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.37	4.91	1.35	0.76
1945 - 1969	1.44	4.08	1.15	1.35
1970 - 1979	1.10	3.43	0.99	1.50
1980 - 1989	0.83	2.39	0.90	1.20
1990 - 1999	0.65	2.04	0.61	1.09
2000 - 2010	0.42	1.65	0.27	0.90
Post 2010	0.41	0.96	0.22	0.52
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.60	3.10	1.00	1.00
1945 - 1969	1.58	2.92	1.24	1.00
1970 - 1979	1.46	2.83	1.14	0.88
1980 - 1989	1.26	2.76	0.99	0.74
1990 - 1999	1.00	2.68	0.57	0.57
2000 - 2010	0.48	2.51	0.30	0.50
Post 2010	0.35	1.65	0.19	0.39

Table 6. Thermal transmittance of construction elements (Bulgaria).

Table 6 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and buildings elements regarding different periods affect heat flow and thus specific FEC variation.

According to the analysis, individual and district heating systems are the most widespread technology for SH and DHW needs regardless of buildings erected in different periods. In most cases, the non-condensing boiler is used for SH and DHW.

District heating system technology for SH and DHW is mainly equipped with gas boilers (non-condensing). In the case of the individual DHW system, electricity is used as the main energy driver.

Bulgarian residential service is primarily characterized by a lack of space cooling regarding all different building types in the sector.

These findings demonstrate a lack of renewable energy sources for SH, DHW, and SC in the Bulgarian residential building stock that mainly utilize gaseous fuels and electricity from traditional energy sources.

According to expert questioning: the most common technology in the service sector for SH and DHW is non-condensing gas boiler. SC is not presented in most cases, except in the health industry, where SC is mainly used.

3.4. **CROATIA**

This section demonstrates a selection of the main results from our building stock analysis for Croatia.

In Figure 13, the Mm^2 of covered floor area in Croatian's residential and service sectors is presented in percentages regarding historical periods.

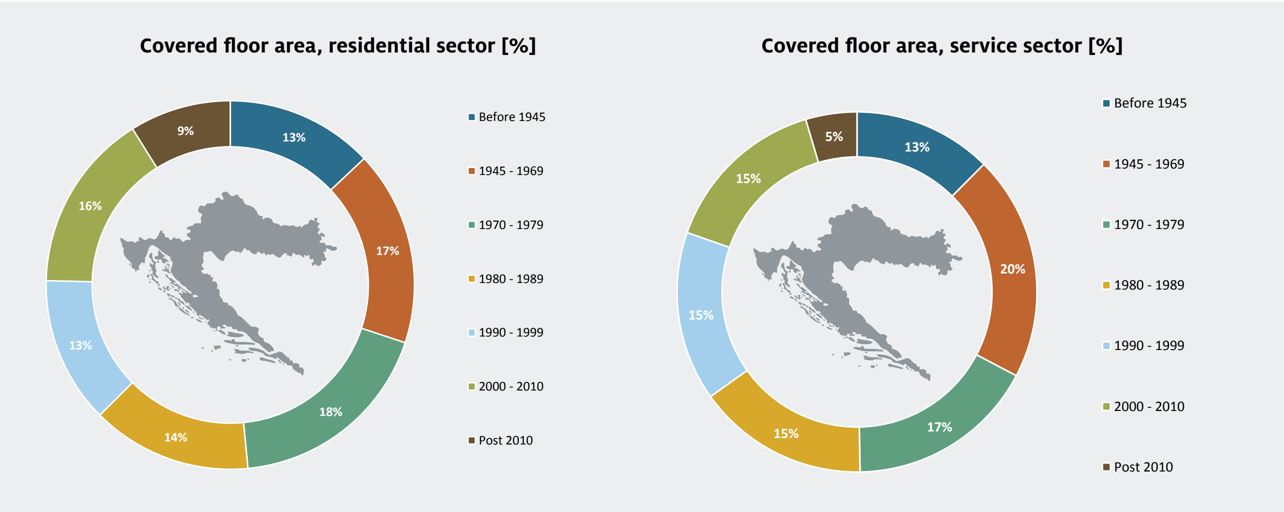

Figure 13. Split of the residential and service building stock raised per construction periods [%] (Croatia).

The residential sector demonstrates that the highest percentage of covered floor area can be found in the 1970s. A total of 18% of these historic buildings have what is considered a high coverage. The second-largest portion belongs to the earlier period, from 1945 - 1969, occupying 17% of the stocks. The third largest one belongs to the 2000s with 16% respectively. These tree construction periods indicate the significant portions of the residential building stock in Croatia. On the other hand, it is interesting to notice that the minor portions of the residential building stock in Croatia belong to the periods before 1945, the 1980s, and 1990s that are claimed for approximately 14% and 13%, respectively. The post-2010 period accounts for the most minor portions of covered floor area compared to the other periods with only 9%.

Regarding the service sector, we can notice that this sector demonstrates similarities with the residential one. The perfect match can be noticed in the period before 1945, where both sectors account for the same 13% respectively. The most significant percentage achieves between 1945-1969, where the service sector covers 20%. After that, the percentages keep decreasing in the later years as from 20% it decreased to 17% in the 1970s and then decreased to 15% in the 1980s. This percentage (15%) remains the same until 2010—the last post-2010 period characterized by the lowest percentage of covered floor area, with only 5%.

Figure 14 visualizes the breakdown of different types of buildings by residential and service sectors. The following percentages in Figure 14 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

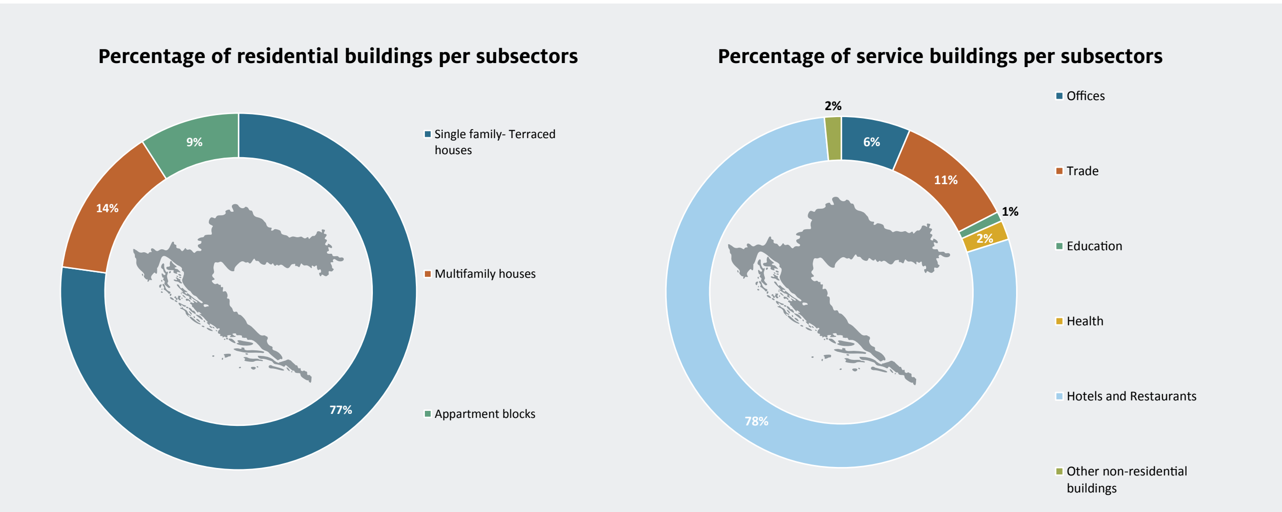

Figure 14. Split of residential and service buildings per different subsectors [%] (Croatia).

Residential buildings are broken up into three types: SFHs, MFHs, and ABs. SFHs make up 77% of the residential sector. MFH's are 14% of the residential sector, followed by ABs with only 9%. So, more than three-fourths of the area is occupied by SFHs, while ABs occupy the least of the sector.

Considering the service sector, we observe that hotels and restaurants are the most widespread building type in Croatia. These types of buildings cover almost 78%. In comparison, trading places come up in the second position with only 11%. Over 6% are designated for offices, and about 1% has been allotted for educational buildings. Only 2% refer to health buildings, and the other 2% for non-residential buildings, which include warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms).

Figure 15 shows the development of the specific FEC (kWh/m²y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

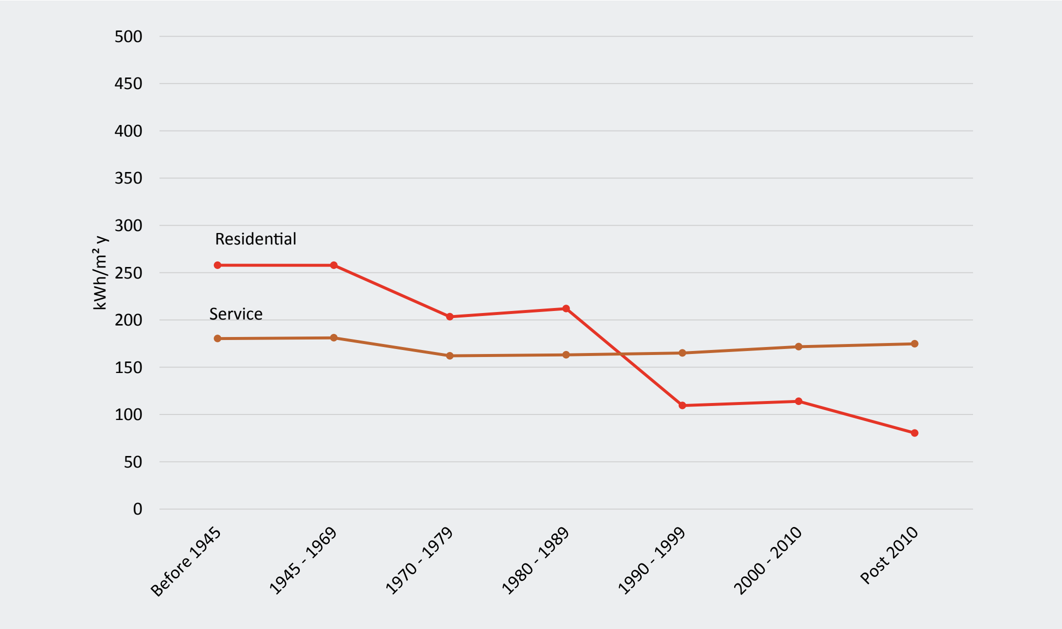

Figure 15. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Croatia).

The trend in Figure 15 shows that specific FEC for SH and DHW has kept varying, but in overall, the trend demonstrates the decrease in specific FEC. Residential buildings erected before 1945 accounts for a higher specific FEC than the service one. The residential sector has approximately 250 kWh/m²y specific FEC, whereas service sectors accounts only for approximately 180 kWh/m²y regarding buildings erected before 1945. Residential buildings erected until 1989 are characterized by a higher specific FEC than the service ones. Then the trend changed, and the specific FEC for residential buildings dropped below 110 kWh/m²y. This is a drastic change that happened with time. It is observed that residential buildings erected after 2010 have a value of the specific FEC lower (approximately 90 kWh/m²y less) than the service buildings of that time. The value of specific FEC for the residential sector declined from 250 kWh/m²y to 50 kWh/m²y over the course of considered periods.

Specific FEC remained almost the same for service sectors across buildings constructed from 1945 till post-2010. It lays between 180 to 160 kWh/m²y, as can be seen from the figure above.

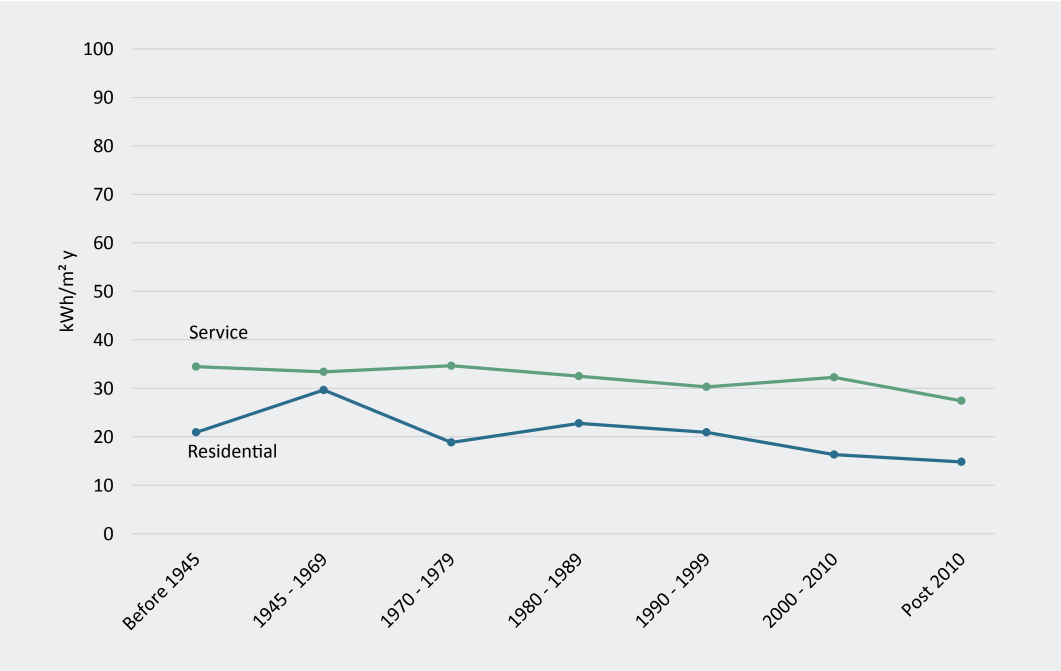

Figure 16. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Croatia).

The Figure 16 shows the trends of service and residential sectors based on the development of specific FEC for SC.

The service sector has remained between 35 kWh/m²y to 28 kWh/m²y since the years 1945 till post-2010 period. The change in this trend is minor. Buildings erected from 1945 till 1979 have almost no change in the trend and remained at about 35 kWh/m²y. The slightly highest node for the service sector is observed in buildings erected before 1945, with around 35 kWh/m²y.

On the other hand, there was a drastic change in residential buildings erected before 1945 and between 1945-1969 as their specific FEC for SC jumped from approximately 20 kWh/m²y to 30 kWh/m²y. Then it falls again to below 20 kWh/m²y for buildings constructed between1970-1979.

Residential buildings erected from 1979 till the 1990s account for relatively the same specific FEC for SC with minimal fluctuation around 20 kWh/m²y, as shown in the figure above. The lowest specific FEC for SC is observed in residential buildings erected after 2010, with the value for approximately 17 kWh/m²y.

Regarding the construction methodology presented in the dataset provided by the H2020 Hot-Maps project (8), the main construction topology for walls is a solid wall without insulation in buildings erected till the 1980s. A cavity wall is mainly present in SFHs erected in the 1980s and

1990s with insulation. Honeycomb bricks/hollow blocks wall are present mainly in SFHs and MFHs erected between 1945-1969 and during the 1970s.

The construction methodology for windows is mainly double-glazing, presented in buildings erected during all considered periods. Single-glazing windows are only in buildings erected before 1945 and between 1945-1968. Low emittance glass is present in buildings erected in the 1980s and afterwards.

We can observe that a tilted roof is present in SFHs regardless of historical periods, with insulation in buildings erected after 1945 and in MFHs erected before 1945. A flat roof is mainly constructed in MFHs erected between 1945-1969 and till post-2010 and in ABs regardless of building's ages. Insulation for roofs in MFHs and ABs is present in buildings erected after 1980. Concrete slabs are the most widespread technology for floors in Croatian houses throughout all periods, with insulation only in buildings erected after 1945.

Information about construction materials and construction methodology of the service sector was received by experts questioning. The information concerning Eastern Europe (Poland, Czech Republic, Hungary, Slovenia, Slovakia, Croatia, Bulgaria, Romania) was eventually summarized. Concerning the Croatian service sector, the information is presented in the table below (Table 7).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, health, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Wood, low emittance glass only in few cases.	Concrete and metallic roof boards + insulation in few cases	Concrete+ insulations in few cases	Solid wall	Double glazing	Flat roof	Concrete slab
Education							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Synthetic/PVC, low emittance glass only in few cases.	Concrete and tiles	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roof	Concrete slab
Hotels and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roof	Concrete slab

Table 7. Construction materials, construction methodology-service sector (Croatia).

The table above (Table 7) shows that the service sector demonstrates 100% similar construction methodology and relative similarity with construction materials regarding different types of buildings. For the office, trade, health, and other non-residential buildings, the use of construction materials and methodology stay the same. Education buildings, hotels, and restaurants show a similar construction methodology while demonstrating a small difference in construction materials.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 8 shows the thermal transmittance value ($W/m^2 K$) regarding two considered building sectors (residential and service) for all periods.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.83	2.35	1.67	1.09
1945 - 1969	1.40	2.74	0.85	1.08
1970 - 1979	0.90	2.55	0.67	0.71
1980 - 1989	0.48	2.00	0.33	0.50
1990 - 1999	0.29	1.34	0.23	0.27
2000 - 2010	0.25	0.95	0.17	0.23
Post 2010	0.19	0.78	0.20	0.29
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.80	4.90	1.90	2.00
1945 - 1969	1.70	4.80	1.80	1.70
1970 - 1979	1.30	4.75	0.90	1.40
1980 - 1989	0.70	4.60	0.50	1.10
1990 - 1999	0.50	2.70	0.30	0.50
2000 - 2010	0.40	1.80	0.20	0.30
Post 2010	1.47	1.54	0.93	0.93

Table 8. Thermal transmittance of construction elements (Croatia).

Table 8 helps to figure out the impact of building elements on specific FEC. As seen from the table below, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and buildings elements regarding different periods affect heat flow and thus specific FEC variation.

The analyzed data related to SH and DHW in the Croatian residential sector is characterized by central space heating systems in buildings erected before 1945 until the 2000s. Buildings constructed in the 2000s and during the post-2010 period are equipped with a district heating (DH) system. In most buildings (erected before 1945 to the late 1990s), the non-condensing boiler is used. Regarding buildings constructed after the 1990s, condensing and combined boilers are mainly utilized.

The liquid fuel and biomass are used for SH and DHW need in buildings erected before 1945 till the late 1990s, followed by gas (all type of buildings erected between 2000-2010 and post-2010) being less prevalent in the market. Liquid fuel and gas are mainly used for MFHs energy needs, while biomass is the main fuel regarding ABs.

The results for SC technology show that in most cases, SC is not represented in this residential market.

The further findings demonstrate the quite noticeable portion of renewable energy sources in the Croatian residential building stock. As can be seen from Figure 14, the major portion of the residential sector is occupied by SFHs (77% of the total) characterized by biomass for SH needs.

According to expert questioning: the most common technology in the service sector for SH and DHW is non-condensing gas boilers. SC is not present in most cases, except in the health industry, where SC is mainly utilized.

3.5. **CYPRUS**

This section represents a selection of main results that were obtained from the building stock analysis dataset regarding Belgium (8).

In Figure 17, the Mm^2 of covered floor area in Cyprus's residential and service sectors is presented in percentages regarding historical periods.

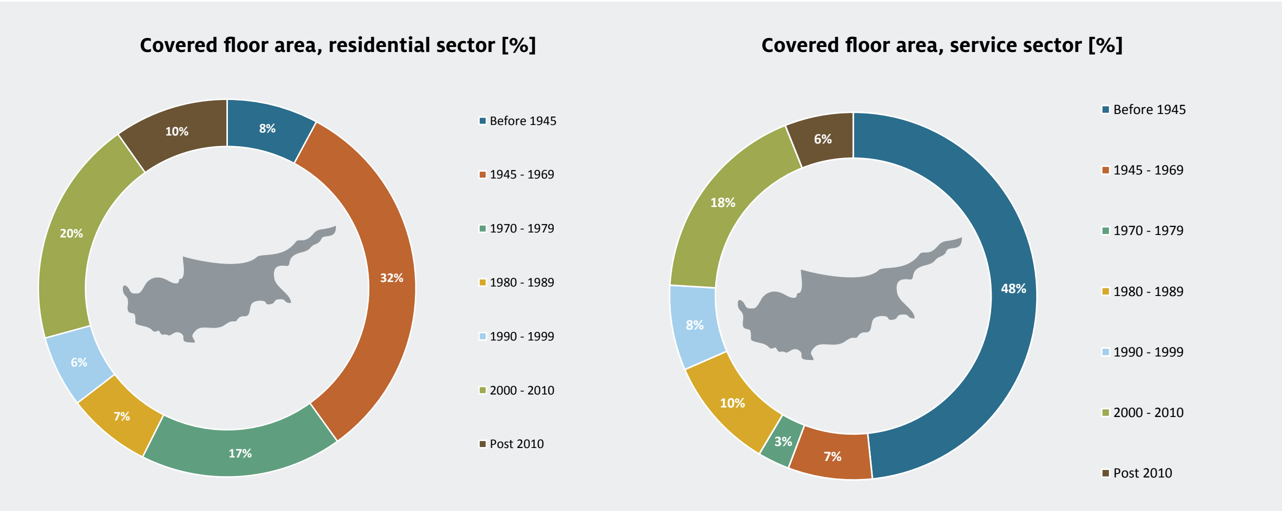

Figure 17. Split of the residential and service building stock raised per construction periods [%] (Cyprus).

The result demonstrates the relatively high percentage of covered floor area regarding residential buildings constructed between the post-WWII period (1945-1969), with 32%. Before 1945, only 8% are occupied. Moving further, we can observe that one of the highest percentages of covered floor area, 17% belonged to buildings constructed in the 1970s. After this, the building construction took a turn and covered floor area resulted in the minor covered areas from 1980 till 1999. Then we can see that the period of 2000s is characterized, by an increase in covered floor area with the value for about 20% during 2000s. This value shows the second-highest percentage of covered floor area after 1945-1969.

Talking about the service sector, we can see that almost half of the floor area regarding buildings constructed before 1945, are characterized by a value of 48%. The value demonstrates that service buildings erected before 1945 cover a significant portion of the service building stock in Cyprus. The 1970s are characterized by the smallest percentage of covered floor area, around 3% in 1970s. The period of 1980s and 1990s demonstrate a slightly higher percentage of covered floor area, around 10%, while between 2000-2010 we can observe an increase with the resulted value of 18%. After 2010, it is found deficient, i.e., 6% only.

Figure 18 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 18 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

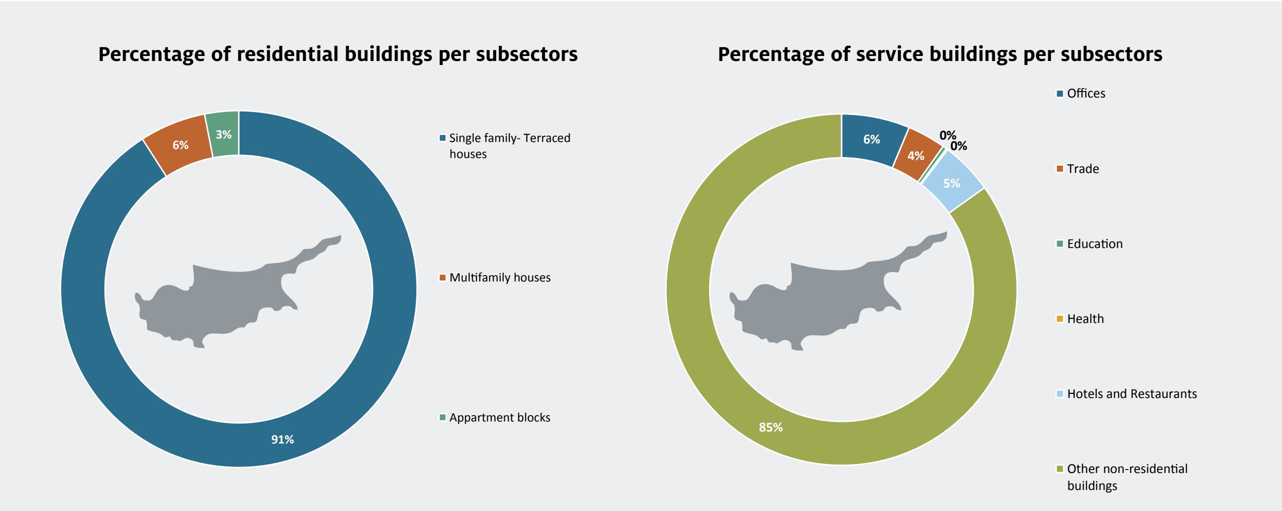

Figure 18. Split of residential and service buildings per different subsectors [%] (Cyprus). (Please note that the trade and education sectors account for 0.4 and 0.1% respectively)

According to this graph, the residential sector in Cyprus is categorized with an excellent ratio of SFHs with 91%. SFHs cover almost all the residential building stock in Cyprus, leaving only 9% for the other building types. MFH's cover 6% of the residential area, whereas ABs cover only 3% overall.

The service sector is highly occupied by non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g. sports halls, swimming pools, and gyms) with a high percentage, i.e., 85%. Only 6% of the area is designated for offices and 5% for hotels & restaurants. Whereas just 4% belong to trade buildings. It is seen that no area is assigned for educational and health building types. These buildings resulted in a value of less than 1%.

Figure 19 shows the development of the specific FEC (kWh/m²y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

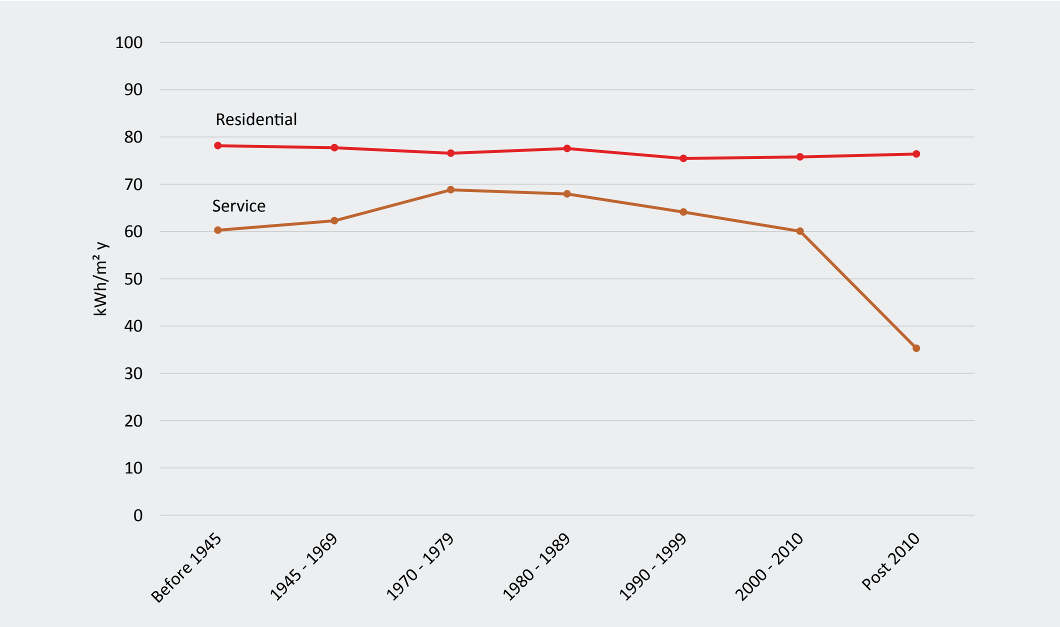

Figure 19. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Cyprus).

The trend of specific FEC for SH and DHW in residential buildings is found to be constant with very little change. It fluctuates between 70 to 80 kWh/m²y regardless of construction periods. A slight change is seen from buildings erected between 1979 – 1980, where the specific FEC increased from 77 to 79 kWh/m²y. A slight decrease in specific FEC characterizes building erected in the 1990s with the value of 77 kWh/m²y. Overall, from all these construction periods, i.e., before 1945 till post-2010, the specific FEC for residential buildings is kept constant with a slight fluctuation of about 3 kWh/m²y.

The specific FEC for SH and DHW shows an opposite trend as compared to the residential sector. Historical buildings related to the period before 1945 and buildings erected between 1945-1969 show about the same specific FEC, with a value of about 60-62 kWh/m²y. Specific FEC then increased regarding buildings erected between 1970-1979. The resulted value is about 70 kWh/m²y. The increase in change is found to be around 10 kWh/m²y. Buildings erected after the 1970s demonstrate the tendency of decreasing the specific FEC (i.e.1980-2010); it gradually dropped back to 60 kWh/m²y. It's worth to underline that the sudden decrease in specific FEC is related to the buildings erected after 2010. They show a value for about 35 kWh/m²y.

Figure 20 shows the development of the specific FEC (kWh/m²y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

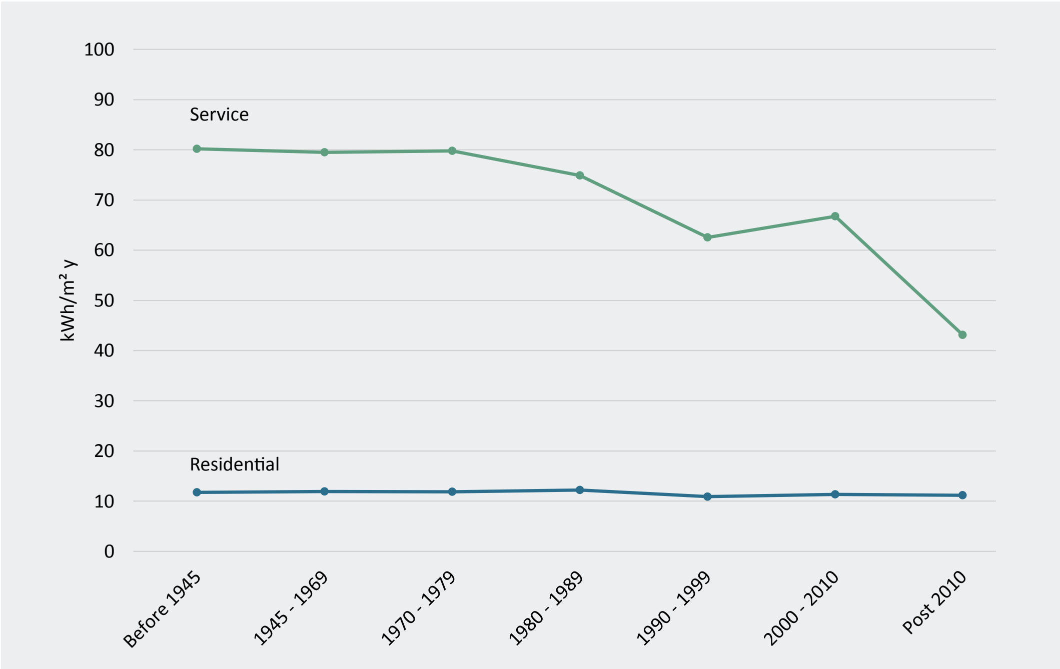

Figure 20. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Cyprus).

The trend of specific FEC for SC in service remains rather constant regarding buildings erected from the period before 1945 till 1979 with the value of approximately 80 kWh/m^{2}y. After this, we can observe that buildings erected from 1980-1989 demonstrate a smaller value of about 73 kWh/m^{2}y. The specific FEC for SC keeps falling until the building erected in 1999 with the value of about 60 kWh/m^{2}y. In contrast, buildings erected during the 2000s are characterized by a relatively higher specific FEC for about 68 kWh/m^{2}y. However, then we see that buildings erected after the post-2010 construction period demonstrates a more significant reduction in specific FEC with the value of almost 40 kWh/m^{2}y.

Talking about the residential sector, the trend of specific FEC remained almost constant regardless of historical periods with a value of approximately 11 kWh/m^{2}y. No noticeable changes are observed in buildings erected before 1945 till post-2010.

Regarding the construction methodology presented in the data set provided by the H2020 Hot-Maps repository (8), the main construction topology for walls, concerning all periods, is solid walls with insulation only in buildings erected after 2010. The construction methodology for windows is mainly single glazing windows. Double and low emittance glazing windows are only presented in the buildings constructed during the last period (post-2010).

We can observe that the flat roof is the most popular decision regarding all construction periods with the presence of insulation in buildings erected in the post 2010 period. The tilted roof is presented only in SFHs erected from 1945 to the 1970s, and in the last post 2010 construction period, without insulation, while the flat one refers to all other types of buildings and construction periods.

Concrete slabs were primarily used in Cyprus's houses throughout all historical periods. Insulation is used only in buildings erected after 2010.

Information about construction materials and construction methodology of the service sector was received by experts questioning. The information concerning Southern Europe (Spain, Italy, Greece, Cyprus, Malta, and Portugal), was eventually summarized. Concerning the Cyprian service sector, the information is presented in the table below (Table 9).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, health, hotels and restaurants, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation only in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete+ insulations in few cases	Honeycomb bricks/hollow block walls	Double and single glazing	Flat roof	Concrete slab
Education							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks and concrete + Insulation only in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulation in few cases	Solid walls	Double glazing	Flat roof	Concrete slab

Table 9. Construction materials, construction methodology-service sector (Cyprus).

The table above shows that the service sector demonstrates similarities in construction materials and methodology regarding different types of buildings. All kinds of service buildings are erected by using relatively the same kind of material and construction methodology. The only contrast is the wall of educational buildings that are constructed not only out of bricks but also from concrete.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The effect differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 10 shows the thermal transmittance value (W/m^2K) of residential and service sectors according to all historical periods. Table 10 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the periods. Here we can observe how thermal insulation materials and buildings elements regarding different periods affect heat flow.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.39	6.10	3.42	1.88
1945 - 1969	1.06	4.61	2.04	1.37
1970 - 1979	0.89	3.86	1.36	1.11
1980 - 1989	0.81	3.53	1.02	0.99
1990 - 1999	0.77	3.37	0.86	0.91
2000 - 2010	0.75	3.20	0.75	0.89
Post 2010	0.73	3.12	0.67	0.88
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	2.10	6.20	3.20	0.70
1945 - 1969	1.90	6.05	3.30	0.75
1970 - 1979	1.70	5.97	3.40	0.76
1980 - 1989	1.60	5.90	3.50	0.77
1990 - 1999	1.55	2.50	0.50	0.78
2000 - 2010	1.52	1.60	0.70	0.79
Post 2010	1.50	1.10	0.12	0.80

Table 10. Thermal transmittance of construction elements (Cyprus).

The analyzed data related to SH and DHW in the residential sector in Cyprus is characterized by individual and central SH and DHW systems. The most widespread technology for SH is the stove, followed by a non-condensing boiler in buildings erected after 2010. Technology for DHW is characterized using individual non-condensing boilers. A condensing boiler is utilized only in few cases (buildings erected in the 2000s and post-2010). Solar collectors for DHW are presented in SFHs and MFHs constructed in the last period (post-2010) and in ABs (2000-2010, post-2010).

The liquid fuel is widely used throughout all considered periods except the buildings erected after 2010, where gas is mainly utilized. Liquid fuel is used primarily in SFHs and MFHs. ABs, however, use gas regardless of the age of buildings. Electricity is used for DHW needs in the SFHs, except buildings erected in the last 2010 period.

The results for SC technology show that in most cases, SC is not represented in the residential market in Cyprus.

These findings demonstrate the small presents of renewable energy sources for DHW in Cyprian residential building stock.

According to expert questioning: the most common technology in the service sector for SH and DHW is the non-condensing gas boiler. Trade buildings also use electric heating. SC is present in most cases, except educational buildings, and are present in 50% of the cases in other non-residential buildings.

3.6. **CZECH REPUBLIC**

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Czech Republic.

In Figure 21, the Mm² of covered floor area in Czech's residential and service sectors is presented in percentages regarding historical periods.

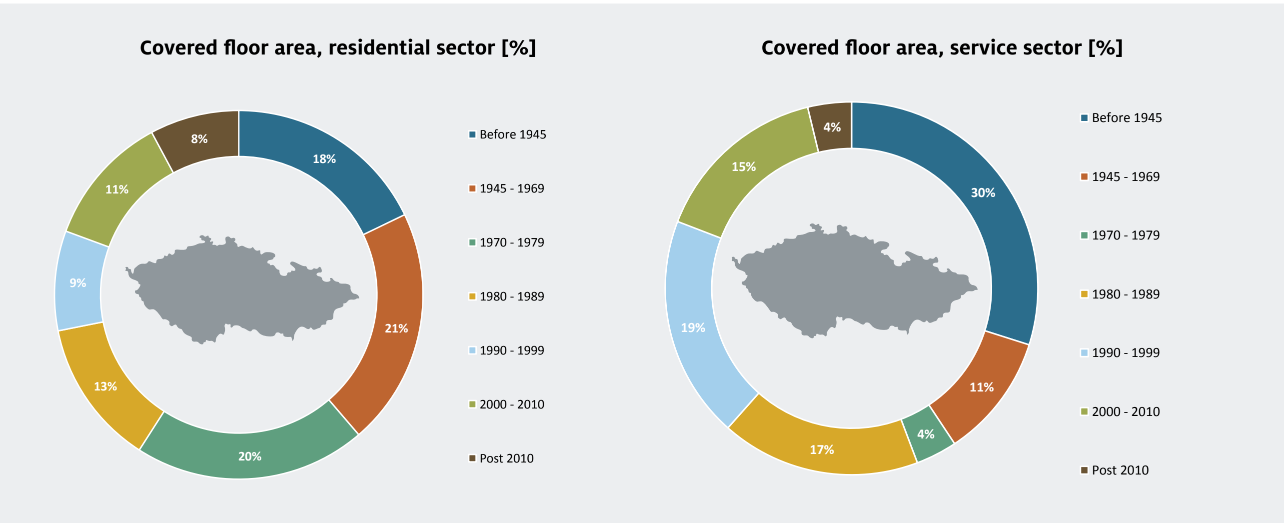

Figure 21. Split of the residential and service building stock raised per construction periods [%] (Czech Republic).

The figure above shows that the highest percentage of covered floor area in the residential sector is related to the post-WWII period (1945-1969), with 21%. The second-highest percentages of covered floor area are 20% in the 1970s. It can be seen that before 1945, the percentage of the covered floor area is, about 18%, which is the third-highest value. From the 1970s to 1980s, the value dropped from 20% to 13% accordingly. Then from 2000 to 2010, the percentage is found to be 11%. The result shows that the lowest percentages of covered floor area are 8% and 9% in post-2010 and 1990-1999 periods respectively.

The results of the service sector indicate that the most significant portion of covered floor area belongs to buildings erected during the historical period (before 1945) with 30%. The second highest percentage is found to be 19% in the 1990s. From 1980 till 1989, the percentage of covered floor area is around 17%. The construction period between 2000-2010 is characterized by a slightly lower percentage of covered floor area, around 15%. Buildings erected during the post-WWII period (1945-1969) cover 11% of the floor area. The smallest value is related to the period between 1970-1979 and the post-2010 with 4% accordingly.

Figure 22 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 22 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

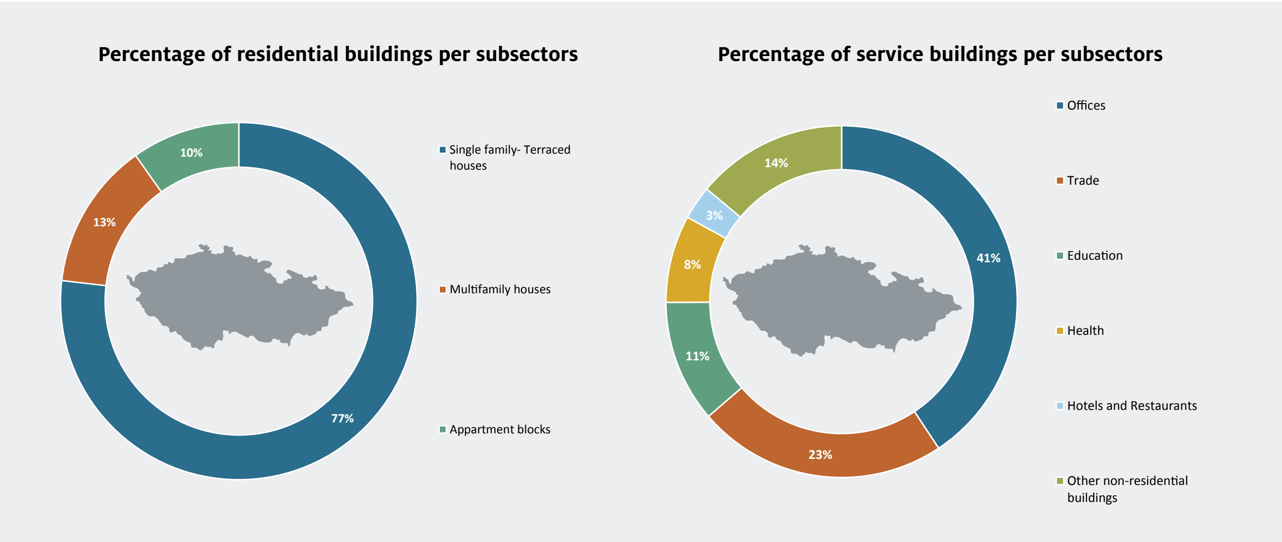

Figure 22. Split of residential and service buildings per different subsectors [%] (Czech Republic).

The residential sector shows that 77% of the sector is categorized as SFHs. This leaves only 23% of the sector behind, including 13% for MFHs, and only 10% for ABs.

Whereas in the service sector, a significant portion of the market is allocated for offices, with a value of 41%. The trade buildings are the second largest subsector in the service sector, with 23% respectively. The third-highest percentage is 14%, covered by non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms). Educational buildings and schools cover about 11% of the sector whereas health care buildings are only 8%. In the Czech Republic, we can see that only 3% of the area is occupied by hotels & restaurants.

Figure 23 shows the development of the specific FEC (kWh/m²y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

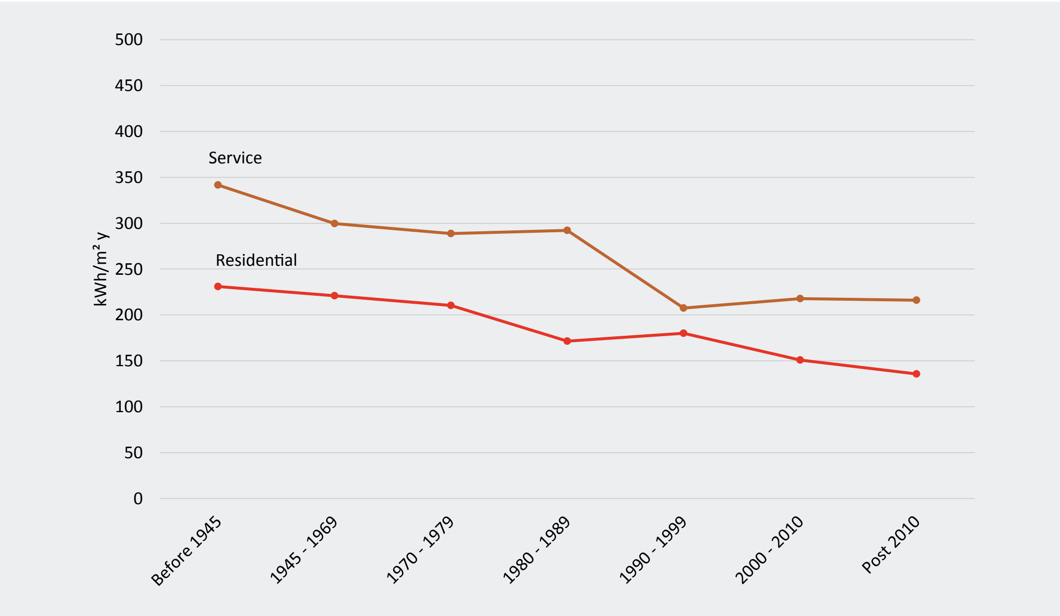

Figure 23. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Czech Republic).

The figure above shows that the specific FEC for SH and DHW in residential buildings is lower than in the service ones. Buildings erected before 1945 consume about 230 kWh/m² y of specific FEC. In comparison, buildings erected between 1945-1969 consume around 10 kWh/m² y less (220 kWh/m² y). The same reduction in specific FEC is noticed with respect to buildings erected in the 1970s. They show the value for about 210 kWh/m² y. The higher reduction in specific FEC is related to buildings of the 1980s with the final value of about 170 kWh/m² y. A slight increase of specific FEC is found in buildings erected in the 1990s with the value of 180 kWh/m² y. The decrease in specific FEC is again observed in buildings of the 2000s and post-2010, with the resulted value of about 135 kWh/m² y.

The trend of specific FEC for SH and DHW regarding service buildings erected before 1945 demonstrates the value of specific FEC of about 350 kWh/m² y. Buildings erected between 1945-1969 result in the rapid reduction of specific FEC; their value is decreased to 300 kWh/m² y. A slight reduction in specific FEC characterizes buildings erected in the 1970s compared to buildings of the previous periods. The value is found to be around 288 kWh/m² y. Buildings erected from 1980 till 1989, having relatively the same specific FEC, i.e. 292 kWh/m² y. Buildings constructed from 1990 till 1999 are characterized by a significant decrease in specific FEC as the value dropped to 200 kWh/m² y. A slight increase in specific FEC is determined regarding buildings of two last periods (2000 till post-2010), with the value of around 215 kWh/m² y respectively.

Figure 24 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

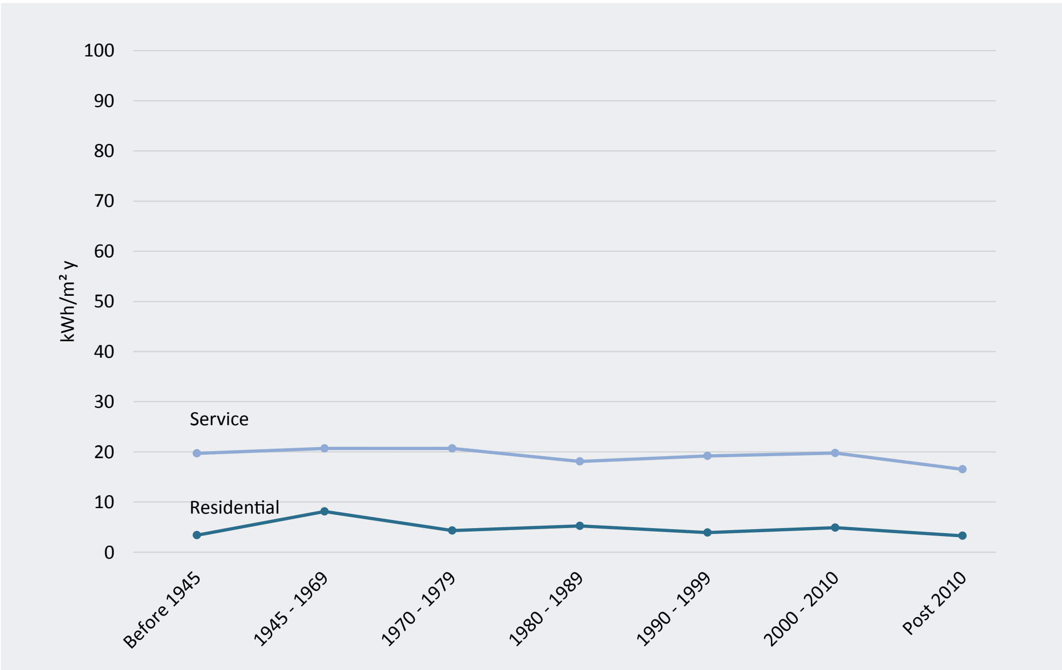

Figure 24. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Czech Republic).

The rate of specific FEC for SC in the residential sector is less than in the service one. Buildings constructed before 1945 consume about 4 kWh/m²y of specific FEC. Regarding buildings erected from 1945 till 1969, the rate increases from 4 kWh/m²y to 9 kWh/m²y. Buildings erected in later years (1970-1979) consume about 5 kWh/m²y of specific FEC. Buildings constructed in further periods (from 1980 till post-2010) consume approximately 5 or 4 kWh/m²y with a minor fluctuation. Relatively small deviations characterize the residential sector in terms of specific FEC regarding buildings erected from 1945 till post-2010.

As can be seen from the figure above (Figure 24), the general trend of specific FEC remains almost the same regardless of construction periods with values for approximately 20-18 kWh/m²y, respectively. A minor change in specific FEC is observed in buildings of the 1980s as the value falls from 20 to 18 kWh/m² y. The value of specific FEC again increases to 20 kWh/m² y regarding buildings erected in the 1990s and 2000s. No noticeable change in specific FEC for SC is found in buildings constructed before 1945 till the 2000s. However, buildings erected after 2010 are characterized by the relatively smaller value of specific FEC, approximately 17 kWh/m² y.

Regarding the construction methodology presented in the dataset provided by the H2020 Hot-Maps project (8), the main construction topology for walls is a solid wall without insulation in buildings erected till the 1970s and a cavity wall that is mainly present in buildings erected from1980s to the last post-2010 period with a presence of insulation starting from 1990s.

The construction methodology for windows is mainly single- and double-glazing windows. Single glazing windows are present in buildings erected during periods, before 1945 to the 1990s. Double-glazing windows are only in buildings erected after the 1980s. Low emittance glass is present in buildings erected in the 2000s and afterward.

We can observe that a tilted roof is present in SFHs, and ABs were erected before 1945 and between 1945-1969 with insulation in buildings erected after 1945. The tilted roof is also present in MFHs erected during the same periods (before 1945, 1945-1969) and in the 1990s and 2000s. A flat roof is mainly constructed in SFHs and ABs, erected between 1970-2010 and in MFHs erected in the 1970s, 1980s, and during the last post-2010 period with insulation, respectively. Concrete slabs are the most widespread technology for floors in the Czech Republic residential building stock throughout all periods, with insulation only in buildings erected after the 1970s.

Information about construction materials and construction methodology of the service sector was received by experts questioning. The information concerning Eastern Europe (Poland, Czech Republic, Hungary, Slovenia, Slovakia, Croatia, Bulgaria, Romania) was eventually summarized. Concerning the service sector in Czech Republic, the information is presented in the table below (Table 11).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, health, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Wood, low emittance glass in few cases.	Concrete and metallic roof boards + insulation in few cases	Concrete+ insulations in few cases	Solid wall	Double glazing	Flat roof	Concrete slab
Education							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Synthetic/PVC, low emittance glass in few cases.	Concrete and tiles	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roof	Concrete slab
Hotels and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Aluminum (50%) and synthetic/ PVC (50%), low emittance glass in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roof	Concrete slab

Table 11. Construction materials, construction methodology-service sector (Czech Republic).

The table above (Table 11) shows that the service sector demonstrates 100% similar construction methodology and relative similarity with construction materials regarding different types of buildings. For the office, trade, health, and other non-residential buildings, the use of construction materials and methodology stay the same. Education buildings, hotels, and restaurants show a similar construction methodology while demonstrating a small difference in construction materials.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 12 shows the thermal transmittance value (W/ m^2 K) regarding two considered building sectors (residential and service) for all periods.

Table 12 helps to figure out the impact of building elements on specific FEC. As seen from the table below, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and buildings elements regarding different periods affect heat flow and thus specific FEC variation.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.31	2.70	1.03	1.79
1945 - 1969	1.41	2.77	0.94	1.06
1970 - 1979	1.31	2.69	0.76	1.00
1980 - 1989	0.93	2.13	0.34	0.88
1990 - 1999	0.38	1.86	0.30	0.51
2000 - 2010	0.34	1.50	0.31	0.41
Post 2010	0.32	1.20	0.20	0.34
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	0.80	2.80	0.80	1.50
1945 - 1969	0.75	2.40	0.60	1.00
1970 - 1979	0.72	2.20	0.50	0.80
1980 - 1989	0.70	2.10	0.42	0.70
1990 - 1999	0.50	1.80	0.35	0.60
2000 - 2010	0.40	1.50	0.20	0.40
Post 2010	0.37	1.49	0.16	0.50

Table 12. Thermal transmittance of construction elements (Czech Republic).

The analyzed data related to SH and DHW in the residential sector is characterized by the use of district heating systems regarding SFHs and MFHs erected before 1945 to the late 1980s, and ABs erected before 1945 to the late 1990s while the Central SH and DHW system are used in buildings of 1990s and afterward, except ABs, where the system is installed only in buildings of the last two periods (2000s, post-2010). Individual DHW system is also present in SFHs erected before 1945 to 1980s. The non-condensing boiler is used in buildings that were erected before 1945 to the late 1980s. Buildings erected afterward were primarily equipped with a combined condensing one.

The most common energy carrier for SH and DHW in the Czech residential building stock is gas and electricity. Gas is the most common fuel regardless of buildings' age. Electricity is mainly consumed in buildings erected before 1945 to the 1980s periods, respectively.

The results for SC technology show that in most cases, SC is not represented in this residential market. The value for specific FEC for SC is around 5 kW/m^2y, according to the information presented in figure 24.

These findings demonstrate a lack of renewable energy sources for SH, DHW, and SC in this residential building stock that mainly utilizes gas and electricity from traditional energy sources.

According to expert questioning: the most common technology in the service sector for SH and DHW is non-condensing gas boilers. SC is not present in most cases, except health industry, where SC is widely used.

3.7. DENMARK

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Denmark.

In Figure 25, the Mm^2 of covered floor area in Denmark's residential and service sectors is presented in percentages regarding historical periods.

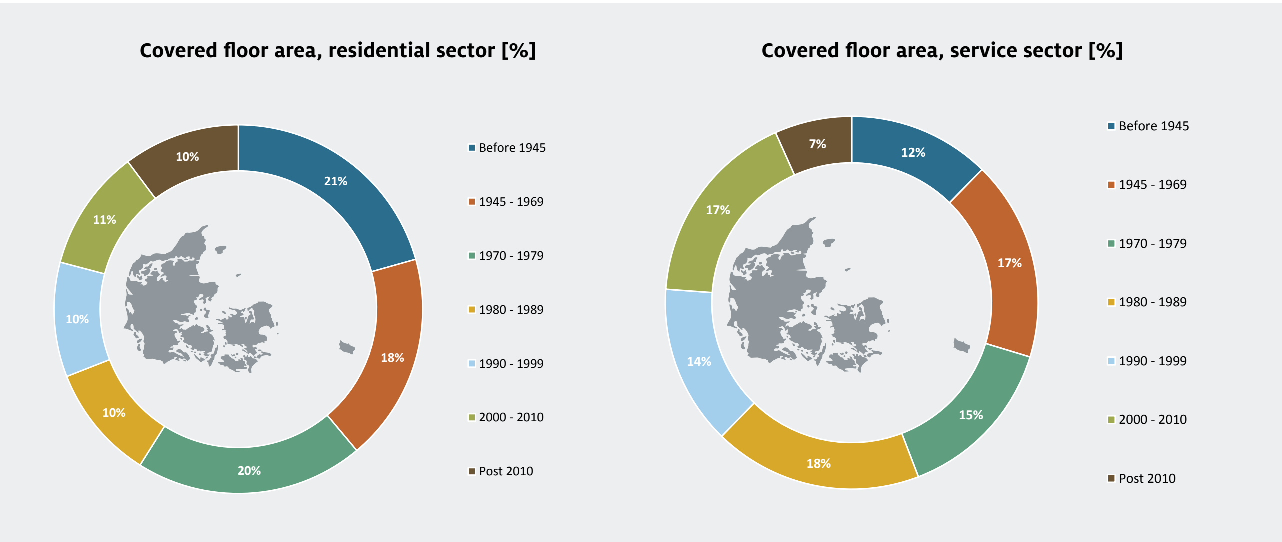

Figure 25. Split of the residential and service building stock raised per construction periods [%] (Denmark).

As we can see from Figure 25, the residential sector indicates close similarities from the year before 1945 till 1979 and from 1980 till post-2010. The highest percent of covered floor area, 21% regarding buildings erected before 1945. Buildings erected in the 1970s cover 20% from the total floor area of the residential building stock. The post-WWII construction period, i.e. 1945-1969, indicates 18% respectively. Before 1945 till 1979, no change of more than 3% is found. 11% of the covered floor area is occupied by buildings erected between 2000-2010. Buildings erected in the

1980s and 1990s are characterized by the same percentage of covered floor area (10%) as well as buildings of the post-2010 period.

In the service sector, the most significant percentage of the covered floor area belongs to buildings erected between 1980-1989 with 18% respectively. The second-highest percentage of covered floor area relates to buildings constructed between 1945-1969, with a value of 17%. The same percentage of covered floor area indicates buildings of the 2000s. Building erected in the 1970s covers 15% of the service sector. Buildings of the 1990s occupy 14% respectively. A relatively smaller percentage of covered floor area demonstrate historical building erected before 1945 with the value of 12%. The smallest value of covered floor area belongs to the last post-2010 construction period, which is 7% accordingly.

Figure 26 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 26 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

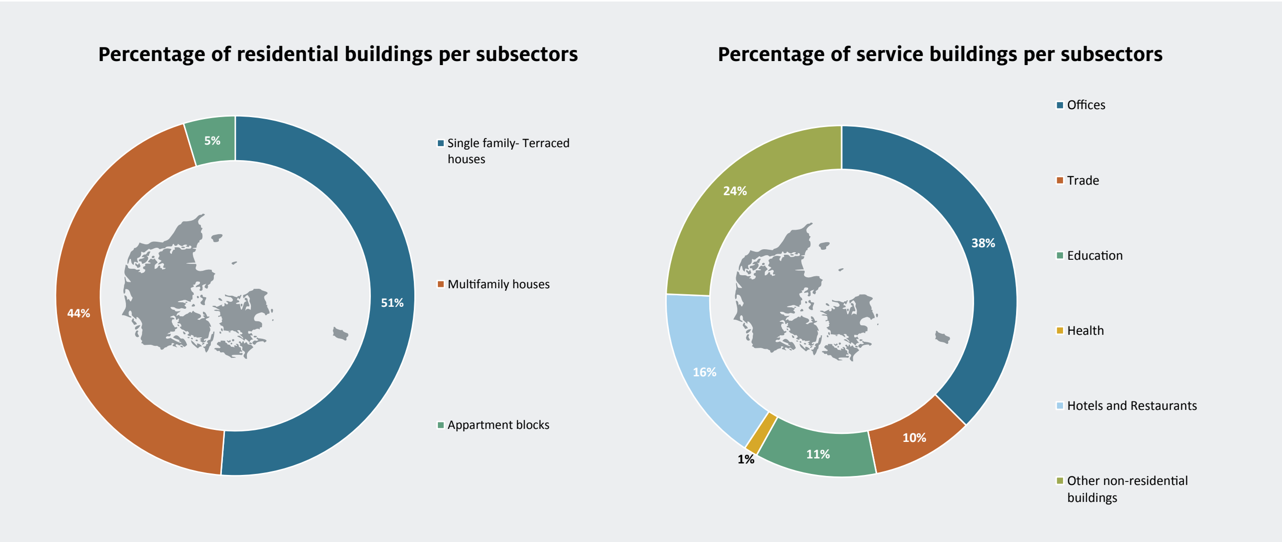

Figure 26. Split of residential and service buildings per different subsectors [%] (Denmark).

Considering this graph, we can see that the residential sector in Denmark is more than half occupied by SFHs, with a ratio of 51%. MFHs are the second-largest subsector of the residential building stock, with a ratio of 44% leaving behind, only 5% of the residential sector is allocated for ABs.

The service sector is mainly characterized by office buildings with 38%. The second-largest percentage ratio is 24% regarding non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms). Moving forward, we see that 16% of the service building stock is allocated for hotels and restaurants, while educational and trade buildings account for 11% and 10% accordingly. Only 1% of the market is allocated for health care buildings and hospitals.

Figure 27 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

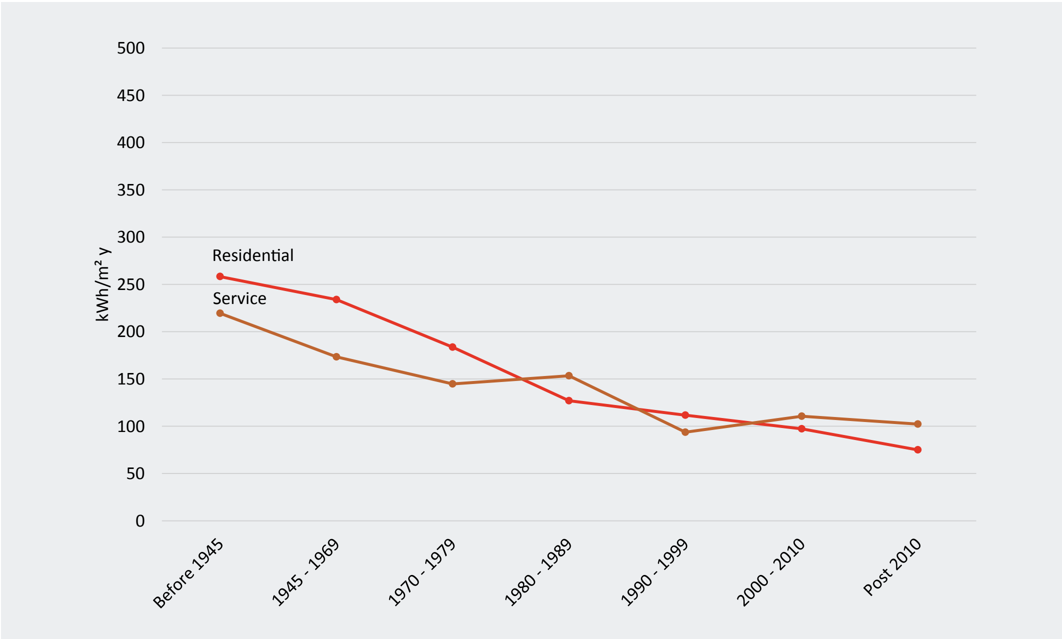

Figure 27. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Denmark).

The trend of specific FEC for SH and DHW in the residential sector decreases with the passing years. The maximum specific FEC is around 260 kWh/m² y, and the least is 75 kWh/m² y. Historical buildings erected before 1945 show the value of specific FEC of about 260 kWh/m² y. Moving forward, we can see that the value of specific FEC is decreasing consecutively. Compared to historical buildings, buildings constructed between 1945-1969 indicate a noticeable reduction to 230 kWh/m² y. Buildings erected in the 1970s show a further reduction in specific FEC to about 183 kWh/m² y. In contrast, we can observe that buildings erected in the 1980s have specific FEC values of about 126 kWh/m² y. It is also quite noticeable that the decline in specific FEC has slowed down regarding buildings of the 1990s, 2000s, and last post-2010 period, respectively. Buildings of these three last periods have specific FEC values of about 112, 97, and 74 kWh/m² y accordingly.

The service sector indicates that historical buildings erected before 1945 show the value of specific FEC for about 220 kWh/m² y, which then stedely decreased to 175 kWh/m² y, regarding buildings erected between 1945-1969. The FEC further decresed, regarding buildings of the 1970s to a value of 145 kWh/m² y. The trend of specific FEC continues to demonstrate fluctuations among buildings of the consecutive periods. Building erected in the 1980s having a slightly higher value of specific FEC of about 153 kWh/m²y, which then dropped below 100, i.e., 90 kWh/m² y, regarding building erected during 1990s. The rate of specific FEC then increases to 110 kWh/m² y in buildings of the 2000s. Buildings erected in the last post-2010 period are characterized by a slight decrease of specific FEC to a value of 100 kWh/m² y, respectively.

Figure 28 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

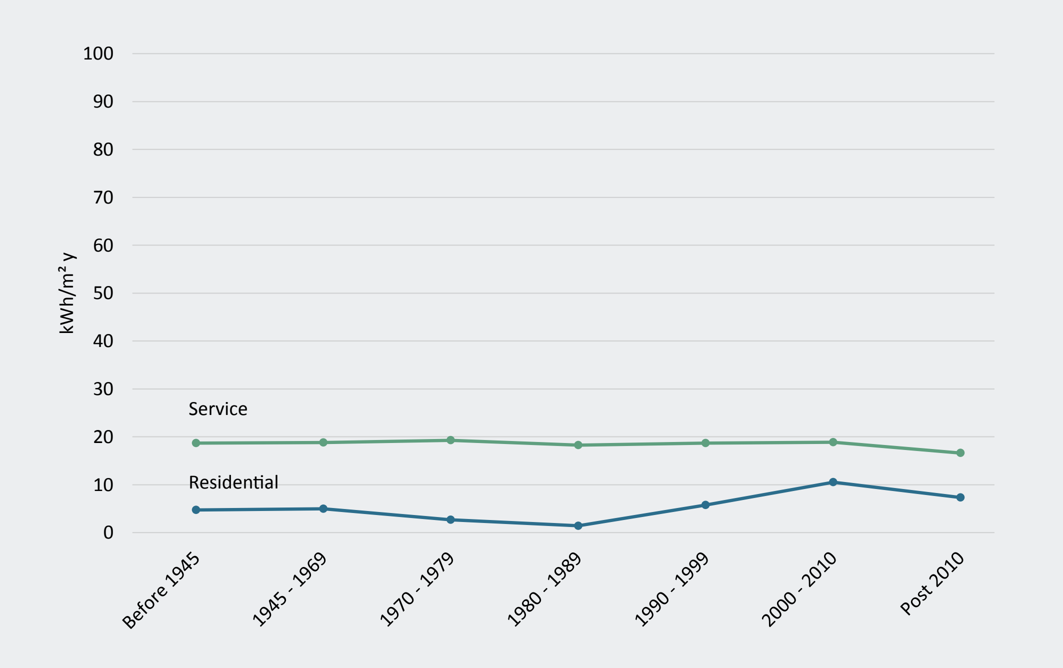

Figure 28. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Denmark).

As this graph shows, the trend of specific FEC for SC in the residential sector has shown some ups and downs. Buildings erected before 1945 until the period between 1945-1969 show a constant value of specific FEC for SC for about 5 kWh/m² y. The rate decreases slightly to 2.6 and less than 2 kWh/m² y, regarding buildings erected in the 1970s and 1980s, respectively. Buildings erected in the 1990s show an increase in specific FEC for SC up to 6 kWh/m² y. It then gradually increases to 10 kWh/m²y regarding buildings erected between 2000-2010. Buildings constructed during the post-2010 period demonstrate a decrease in specific FEC to about 7 kWh/m² y.

The line for the service sector is seen to be almost constant throughout the buildings erected before 1945 till post-2000s, meaning that the specific FEC for SC remains relatively the same with no noticeable change. The constant value is found to be around 19 kWh/m² y. As shown further, the rate drops a bit to 16 kWh/m²y regarding buildings erected during the post-2010 period.

Regarding the construction methodology presented in the dataset provided by the H2020 Hot-Maps project (8), the main construction topology for walls is a solid wall and cavity walls with insulation. Cavity walls are not present in buildings erected in the 1970s and in the 1980s.

The construction methodology for windows is mainly double-glazing, presented in buildings erected after 1945. Single-glazing windows are only in buildings erected before 1945. Low emittance glass is present in buildings erected in the 1980s and afterward. The presents of triple glazing windows are determined regarding ABs erected after 2010.

We can observe that a tilted roof is present in SFHs, and MFHs with insulation in buildings erected before 1945 and after. The tilted roof is also present in ABs erected during the periods before 1945, between 1945-1969, and in the periods of 1990s and 2000s. A flat roof is mainly constructed in ABs, erected in the 1970s and in the post-2010 period. Insulation is present in all mentioned buildings accordingly. A concrete slab is the most widespread technology for floors in the Danish residential building stock, followed by a wooden floor. A concrete slab is present in all buildings erected after 1945, with insulation in SFHs and MFHs erected in the 1980s and afterward. Insulation was presented in ABs erected in the 1970s and afterward. A wooden floor is present in SFHs and MFHs erected before 1945 to the 1970s and in 2000s inclusive, with insulation except historical buildings erected before 1945. The presence of wooden floor is also determined in ABs erected in the first three periods respectively with insulation except ABs erected between 1945-1969.

Information about construction materials and construction methodology of the service sector was received by questioning experts. The information concerning Northern Europe (Denmark, Finland, Sweden, Estonia, Latvia, and Lithuania) was summarized. Concerning the service sector in Denmark, the information is presented in the table below (Table 13).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, education, health, hotels and restaurants, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Aluminum (50%) and synthetic/ PVC (50%), low emittance glass in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulations in few cases	Honeycomb bricks/hollow block walls	Double and single glazing	Flat roof	Concrete slab

Table 13. Construction materials, construction methodology-service sector (Denmark).

The table above (Table 13) shows that the service sector demonstrates similarities in construction material and construction methodology regarding all types of service buildings.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 14 shows the thermal transmittance value (W/m^2K) regarding two considered building sectors (residential and service) for all periods.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.15	2.69	0.76	0.93
1945 - 1969	0.90	2.67	0.50	0.71
1970 - 1979	0.40	2.49	0.40	0.33
1980 - 1989	0.40	2.38	0.20	0.25
1990 - 1999	0.34	2.03	0.16	0.22
2000 - 2010	0.28	1.68	0.11	0.19
Post 2010	0.19	1.53	0.05	0.07
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.20	2.60	0.50	0.80
1945 - 1969	0.99	2.51	0.57	0.84
1970 - 1979	0.62	2.51	0.28	0.58
1980 - 1989	0.35	2.49	0.23	0.40
1990 - 1999	0.31	2.05	0.20	0.32
2000 - 2010	0.27	1.61	0.17	0.25
Post 2010	0.19	1.47	0.11	0.11

Table 14. Thermal transmittance of construction elements (Denmark).

Table 14 helps to figure out the impact of building elements on specific FEC. As seen from the table below, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and buildings elements regarding different periods affect heat flow and thus specific FEC variation.

The analyzed data related to SH and DHW in the residential sector is characterized by the use of central and district heating systems regarding SFHs and MFHs. ABs use only center SH and DHW systems. The non-condensing boiler and a heat pump are primarily used regarding all types of buildings and construction periods.

The most common energy carrier for SH and DHW in the Danish residential building stock is gas and electricity.

The results for SC technology show that in most cases, SC is not represented in this residential market which is explaining by the mild summer climate that does not often require SC application.

The Danish residential building stock mainly utilizes gas and electricity from traditional and renewable energy sources. Findings demonstrate that technology for SH and DHW, besides utilizing gas, is characterized by heat pump applications.

According to expert questioning: The most common technologies for SH and DHW are district heating systems, central gas condensing boilers, heat pumps, electricity. SC is not present in most cases, except health industry, where SC is often used.

3.8. **ESTONIA**

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Estonia.

In Figure 29, the Mm² of covered floor area in Estonian residential and service sectors is presented in percentages regarding historical periods.

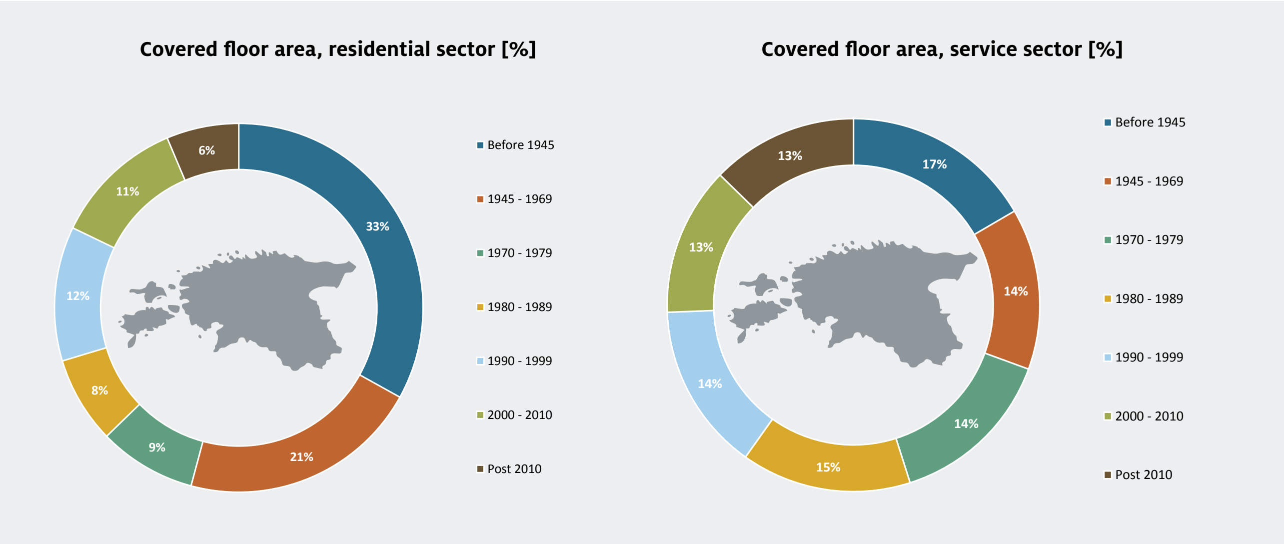

Figure 29. Split of the residential and service building stock raised per construction periods [%] (Estonia).

The result demonstrates the highest percentage of covered floor area regarding residential buildings constructed before 1945 - 33%. The period between 1945-1969 accounts for a lower percentage of covered floor area, with 21%. Buildings erected in the 1970s occupied 9% of the total covered floor area. In residential buildings of the 1980s, the ratio is only 8%. Buildings erected in the 1990s occupied 12% of the covered floor area. Buildings of the 2000s occupy 11% of the floor area, respectively. The minor percentage ratio is found in buildings erected in the post-2010 period, with only 6%.

In contrast, the service sector demonstrates an almost equal ratio in different periods. The figure above shows that the highest percentage of covered floor area refers to buildings constructed before 1945 is 17%. After this, the ratio is 14% from the years 1945 till 1979. A slight increase of 1% is found in 1980 till 1989, i.e. 15%. Then again, the ratio went back to 14% in 1990-1999. Buildings erected in the 2000s and during the last post-2010 period are characterized by the smallest percentage of the covered floor area - 13%.

Figure 30 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 30 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

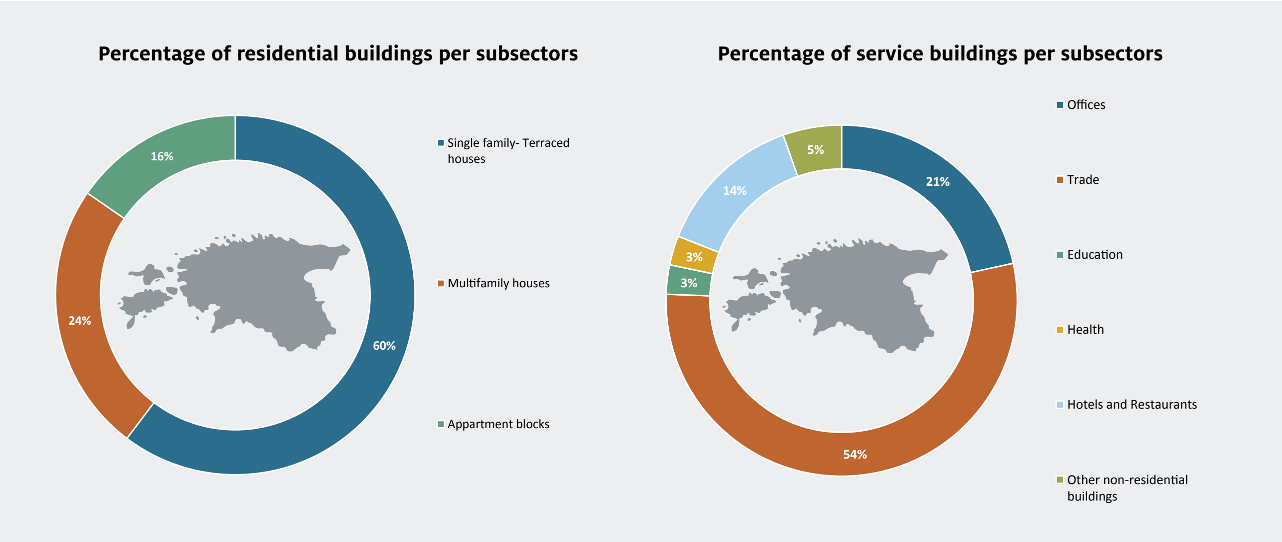

Figure 30. Split of residential and service buildings per different subsectors [%] (Estonia).

This graph clearly shows, that in the residential sector, more than half - i.e. 60% - is occupied by SFHs. Leaving behind, MFHs with 24%. The remaining 16% is occupied by ABs respectively.

Considering the service sector, we observe that trade buildings are the most widespread building type in Estonia. These types of buildings occupied almost 54% of the market. In comparison, the second-highest type of building is offices that occupied 21% accordingly. Over 14% are designated for hotels and restaurant buildings, only 5% is allocated for other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms). Health and education buildings remain the least represented building types, with 3% accordingly.

Figure 31 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

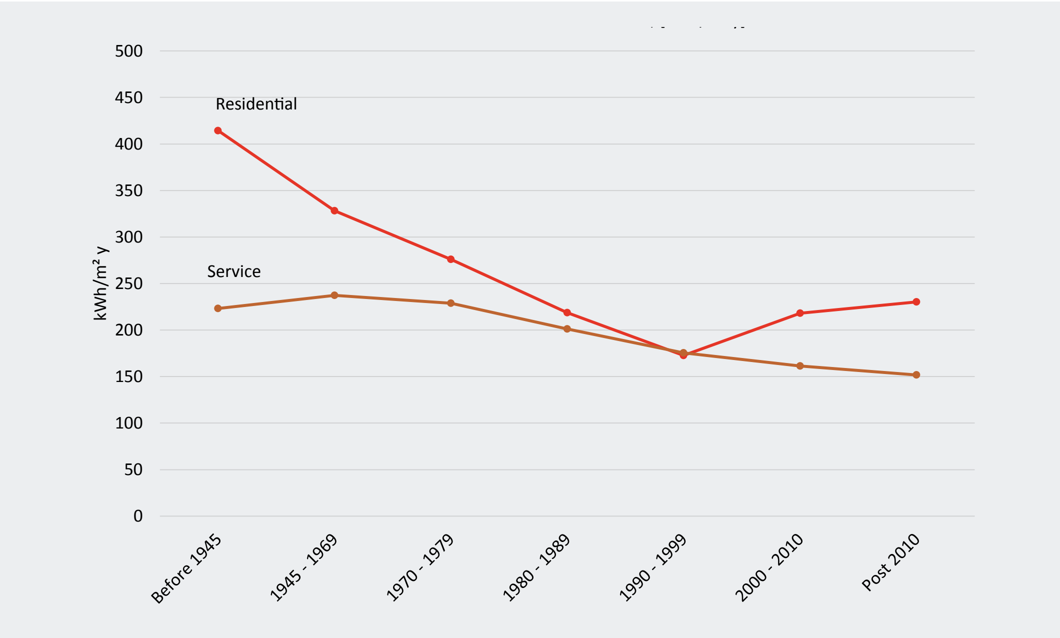

Figure 31. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Estonia).

The trend of specific FEC for SH and DHW in residential buildings decreases almost linearly among buildings erected before 1945 till 1999. The value is dropped from 415 kWh/m² y to 175 kWh/m² y in these years. Buildings erected before 1945 show the highest value of specific FEC for SH and DHW of about 415 kWh/m² y. In comparison, buildings erected between 1945-1969 account for a lower result of 328 kWh/m² y. The trend of specific FEC continues decreasing consecutively. In contrast, buildings erected in the 1970s consume 275 kWh/m² y. A relatively lower result demonstrates buildings erected in the 1980s with the value of 218 kWh/m² y. The lowest specific FEC is found in buildings erected in the 1990s with the value of 175 kWh/m² y. A higher specific FEC characterizes buildings erected after the 1990s. Buildings erected in the 2000s demonstrate 218 kWh/m² y of the specific FEC. After this, the value has increased to 230 kWh/m² y regarding buildings erected during the post-2010 period.

In contrast, the specific FEC of SH and DHW in the service sector does not show vast variations. Buildings erected before 1945 indicate the value of specific FEC of about 223 kWh/m² y. It then slightly increases to about 240 kWh/m² y regarding buildings erected between 1945-1969. Buildings erected from 1970 till 1979 are characterized by a further decrease in specific FEC, with the value of 228 kWh/m² y. Specific FEC for SH and DHW is steadily decreasing regarding buildings constructed from 1980 till the 2000s with values of specific FEC of 201, 175, 161 kWh/m² y, respectively. Service buildings erected during the post-2010 period consume 150 kWh/m² y compared to a residential building (230 kWh/m² y) erected at the same time.

Figure 32 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

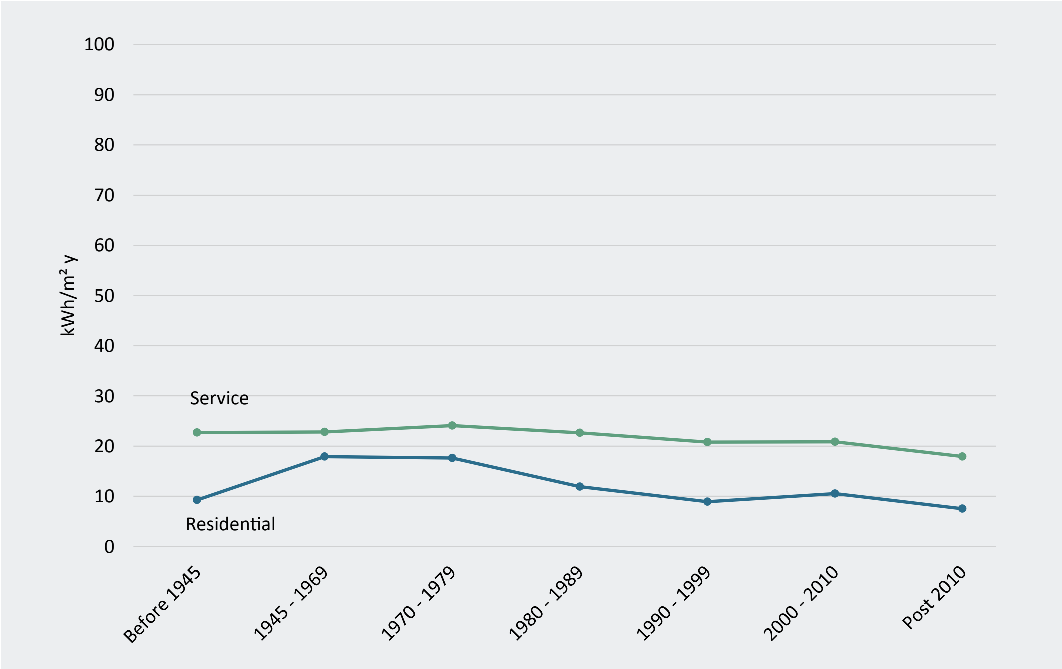

Figure 32. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Estonia).

In the residential sector, the trend of specific FEC of SC indicates that buildings erected before 1945 consume around 9 kWh/m² y. The value then increases to 18 kWh/m² y regarding buildings erected between 1945-1969 and during the 1970s. The specific FEC of SC then decreases to 12 kWh/m² y in buildings of the 1980s. Buildings erected in the 1990s and post 2010 account for a relatively close specific FEC of about 9 and 11 kWh/m² y, respectively. The smallest value of specific FEC belongs to residential buildings erected after 2010 with less than 8 kWh/m² y accordingly.

The analysis of the service sector shows that buildings erected during the 1970s are characterized by the highest value of specific FEC of about 24 kWh/m² y. In contrast, buildings erected in the post-2010 period consume approximately 18 kWh/m²y. The overall trend of specific FEC for SC in the service sector remains almost the same regardless of buildings age, with a value of approximately 21 kWh/m² y.

Regarding the construction methodology presented in the dataset provided by the H2020 Hot-Maps project (8), the main construction topology for walls is a solid wall without insulation. The construction methodology for windows is mainly double-glazing, presented in buildings erected from the 1970s to the 1990s. Single glazing windows are in buildings erected during the first two periods (before 1945, 1945-1969). Triple glazing windows are used in buildings erected in the 2000s and in the last post-2010 period, respectively. Low emittance glass is not present. We can observe that a tilted roof is the most popular decision in buildings regardless of historical periods. Concrete slabs are the most widespread technology for floors in Estonian houses throughout all periods, without insulation.

Information about construction materials and construction methodology of the service sector was received by questioning experts. The information concerning Northern Europe (Denmark, Finland, Sweden, Estonia, Latvia, and Lithuania) was summarized. Concerning the service sector in Estonia, the information is presented in the table below (Table 15).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, education, health, hotels and restaurants, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Aluminum (50%) and synthetic/ PVC (50%), low emittance glass in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulations in few cases	Honeycomb bricks/hollow block walls	Double and single glazing	Flat roof	Concrete slab

Table 15. Construction materials, construction methodology-service sector (Estonia).

The table above (Table 15) shows that the service sector show similarities in construction material and construction methodology regarding all types of service buildings.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 16 shows the thermal transmittance value (W/ m^2 K) regarding two considered building sectors (residential and service) for all periods.

Table 16 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and building elements regarding different periods affect heat flow and thus specific FEC variation.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	0.50	1.70	0.50	0.50
1945 - 1969	0.35	1.40	0.35	0.35
1970 - 1979	0.27	1.25	0.27	0.27
1980 - 1989	0.23	1.17	0.23	0.23
1990 - 1999	0.21	1.13	0.21	0.21
2000 - 2010	0.21	1.11	0.21	0.21
Post 2010	0.20	1.10	0.20	0.20
Service sector				
Historical period	Walls	Windows	Roof	Floor
Before 1945	0.50	1.80	0.40	0.40
1945 - 1969	0.40	1.40	0.30	0.30
1970 - 1979	0.30	1.20	0.25	0.25
1980 - 1989	0.25	1.10	0.23	0.23
1990 - 1999	0.20	1.00	0.20	0.20
2000 - 2010	0.15	0.90	0.17	0.17
Post 2010	0.10	0.81	0.15	0.15

Table 16. Thermal transmittance of construction elements (Estonia).

The analyzed data related to SH and DHW in the residential sector reveals that the leading technology for SH and DHW is a centralized non-condensing boiler for SH and DHW needs regarding all types of buildings and construction periods.

The most common energy carrier for SH and DHW in the Estonian residential building stock is liquid and gas fuels, while electricity is accordingly the third popular energy carrier.

The results for SC technology show that in most cases, SC is not represented in this residential market which is explaining by the short and comparatively warm summer that does not often require SC application.

The residential building stock mainly utilizes liquid fuel and gas. Findings demonstrate that technology for SH and DHW, besides utilizing traditional energy carriers, also uses heat pump applications.

According to expert questioning: The most common technologies for SH and DHW are district heating systems, central gas condensing boilers, heat pumps, electricity. SC is not present in most cases, except health industry, where SC is often used.

3.9. FINLAND

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Finland.

In Figure 33, the Mm² of covered floor area in Finnish residential and service sectors is presented in percentages regarding historical periods.

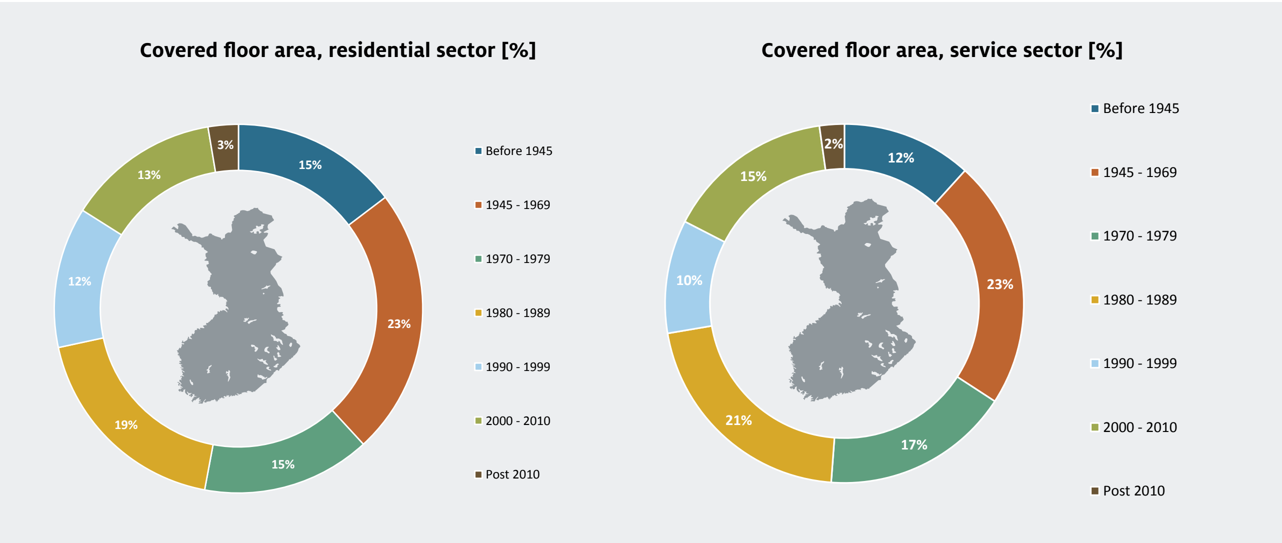

Figure 33. Split of the residential and service building stock raised per construction periods [%] (Finland).

The residential and service sector results show relatively the same percentage ratio of the covered floor area regarding buildings constructed before 1946 till post-2010.

The highest percentage of covered floor area regarding residential buildings has been constructed in the time period of 1945-1969 (23%). Buildings erected in the 1980s occupy 19% of the total covered floor area. Whereas the buildings constructed before 1945 and the buildings constructed in 1970 till 1979, have the same covered floor area i.e., 15%. In residential buildings of the 2000s, the ratio is 13% whereas, in the 1990s, it is 12%. A minor percentage ratio is found in buildings erected in the post-2010 period, with only 3%.

The results in the service sector show close similarities in comparison with the residential sector. Buildings constructed between 1945-1969 cover the highest percentage of covered floor area, i.e., 23%. The second highest percentage indicates service buildings erected during the 1980s. These occupied 21% of the total covered floor area respectively. Buildings constructed in 1970-1979 occupied 17%. Whereas buildings of the 2000s cover 15% of the total floor area accordingly. Buildings erected before 1945 show a lower percentage of covered floor area, i.e., 12%, whereas the period of 1990-1999 indicates only 10%. A minor percentage ratio is observed in buildings erected in the post-2010 period with only 2%.

Figure 34 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 34 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

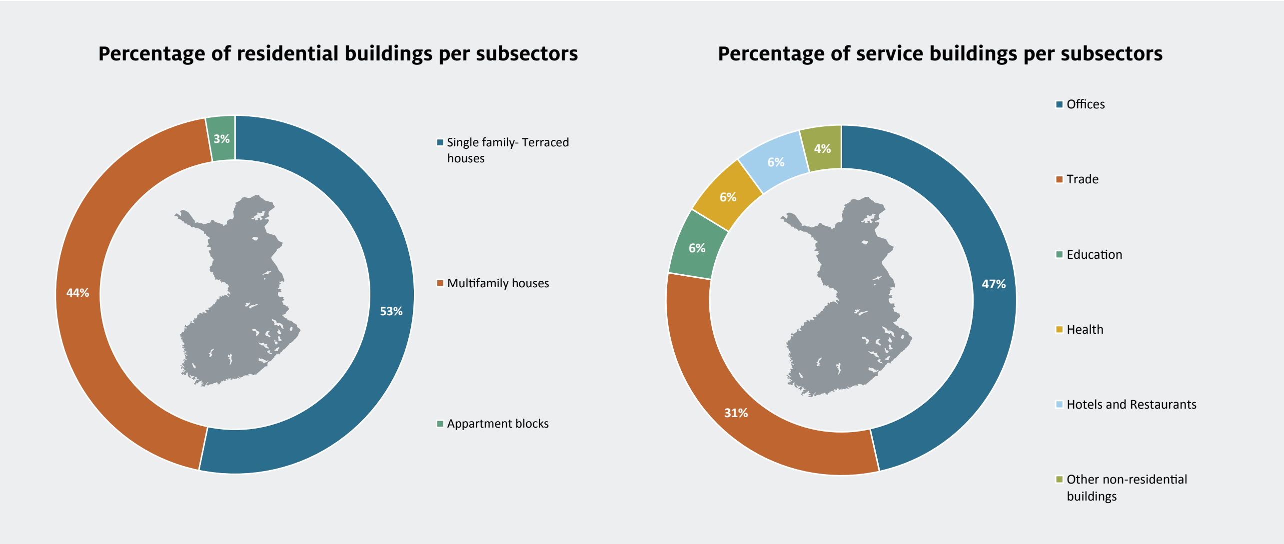

Figure 34. Split of residential and service buildings per different subsectors [%] (Finland).

This data clearly shows that more than half of the residential building stock is covered by SFHs, with 53% in the residential sector. MFHs occupies 44% of the market, leaving behind ABs with only 3% respectively.

In the service sector, almost half of the buildings are characterized as office buildings covering 47%. Trade buildings are also widespread building types that indicate a relatively smaller value of 31% of the whole service building stock. Educational, health, hotels, and restaurants buildings type cover 6% respectively. Only 4% is allocated for non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms).

Figure 35 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

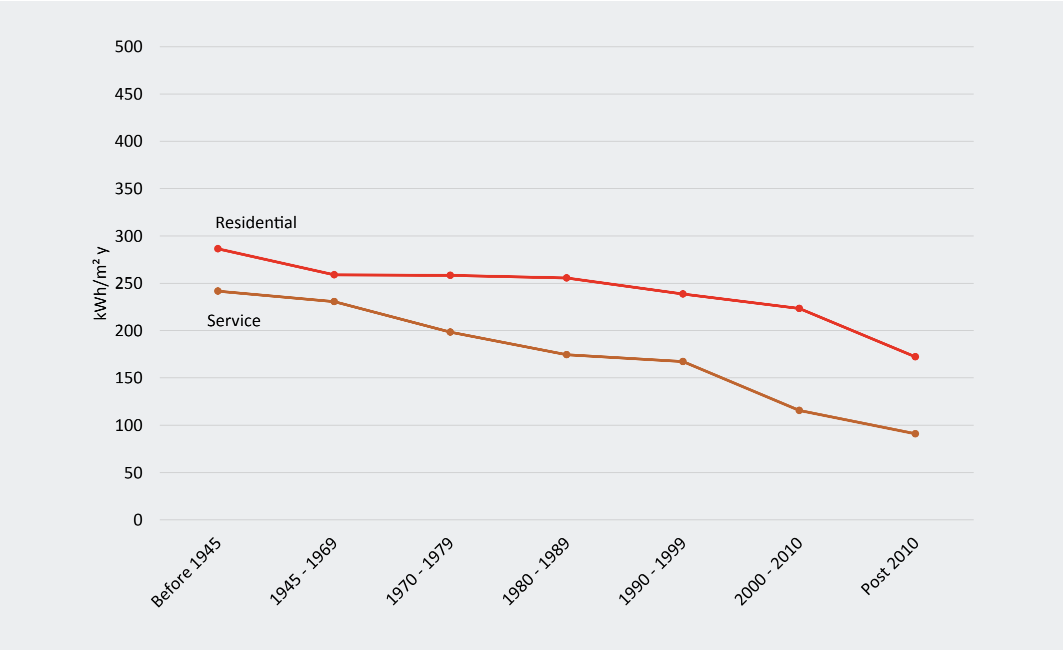

Figure 35. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Finland).

The trend of specific FEC for SH and DHW in the residential sector decreases gradually among buildings erected before 1945 till post-2010. The buildings erected before 1945 consume about 290 kWh/m² y. The consumption rate then drops to 260 kWh/m² y regarding building erected between 1945-1969 and remains the same until 1989. The further decrease in specific FEC for SC is determined in buildings erected in the 1990s with a value of about 240 kWh/m² y and 225 kWh/m² y regarding buildings erected during the 2000s. The lowest specific FEC is found in buildings erected in the post-2010 with 175 kWh/m² y.

The specific FEC for SH and DHW in the service sector shows almost the same trend. Buildings erected before 1945 indicate the value of specific FEC of about 250 kWh/m² y. The value of FEC then decreased to 230 kWh/m² y regarding buildings erected in 1945-1969. Buildings erected from 1970-1979 show a relatively smaller value of specific FEC, i.e., 200 kWh/m² y. The consumption rate continues decreasing to 175 kWh/m² y regarding buildings erected from 1980 until 1989. Buildings constructed in 1990-1999 show the same value of specific FEC for SH and DHW, i.e., 175 kWh/m² y. The value of specific FEC then falls to 110 kWh/m² y in buildings erected from 2000-2010. Service buildings erected during the post-2010 period consume about 90 kWh/m² y compared to residential buildings (175 kWh/m² y) constructed at the same time.

Figure 36 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

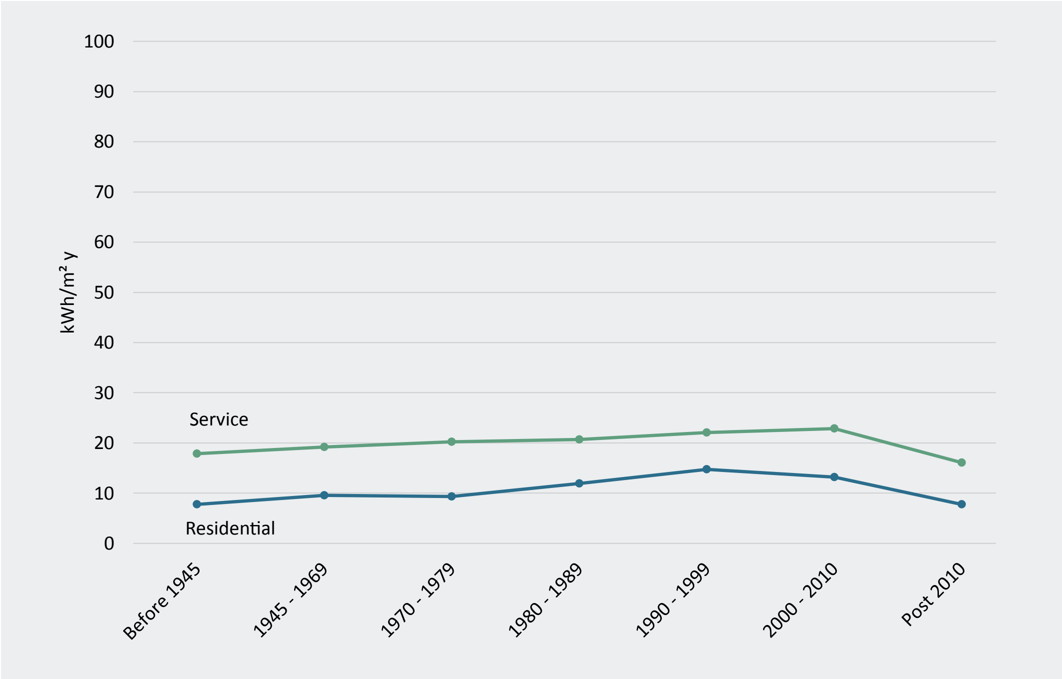

Figure 36. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Finland).

In the residential sector, the trend of specific FEC for SC indicates that buildings erected before 1945 show the value of specific FEC for about 8 kWh/m² y. Buildings erected from 1945-1969 to the late 1970s consume almost the same amount, i.e., 10 kWh/m² y. A slight increase in specific FEC for SC is observed in buildings erected in the 1980s and 1990s, with values of 12 and 15 kWh/m² y, respectively. The specific FEC of SC then decreases to 13 kWh/m² y in buildings of the 2000s. The smallest value of specific FEC belongs to residential buildings erected in the post-2010 period with the value of 8 kWh/m² y.

The service sector results show that buildings erected during the 2000s have the highest value of specific FEC of about 23 kWh/m² y. Buildings erected before 1945 consume about 18 kWh/m² y. The value of specific FEC for SC remains the same in buildings constructed from 1945 till 1989, which is 20 kWh/m² y. The rate of specific FEC then slightly increases to 22 kWh/m² y in buildings constructed in 1990-1999. The consumption rate increases again to 23 kWh/m² y regarding buildings constructed between 2000 and 2010. The reduction in specific FEC is determined in buildings erected in the post-2010 period with the value of about 16 kWh/m² y respectively.

Regarding the construction methodology presented in the data set provided by the H2020 Hot-Maps repository (8), the main construction topology for walls, concerning all periods, is solid walls without insulation. The construction methodology for windows is mainly double-glazing windows presented in buildings erected in the 1970s, 1980s, and 1990s. Single glazing windows are in buildings erected before 1945 and between 1945-1959, respectively. Triple glazing windows are only presented in buildings constructed during the last two periods (the 2000s and post-2010). Windows with low emittance glass are not largely present in the Finnish building stock.

We can observe that the tilted roof is the most popular decision regarding all construction periods and types of buildings without the presence of insulation. Concrete slabs were primarily used in Finnish houses throughout all historical periods. Insulation is also not present regarding all building types.

Information about construction materials and construction methodology of the service sector was received by questioning experts. The information concerning Northern Europe (Denmark, Finland, Sweden, Estonia, Latvia and Lithuania) was summarized. Concerning the service sector in Finland, the information is presented in the table below (Table 17).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, health, hotels and restaurants, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation only in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete+ insulations in few cases	Honeycomb bricks/hollow block walls	Single and double glazing	Flat roof	Concrete slab
Education							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks and concrete + Insulation only in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulation in few cases	Honeycomb bricks/hollow block walls	Double glazing	Flat roof	Concrete slab

Table 17. Construction materials, construction methodology-service sector (Finland).

The table above shows that the service sector demonstrates similarities in construction materials and methodology regarding different types of buildings. All kinds of service buildings are erected by using relatively the same kind of material and construction methodology. The only contrast is the wall of educational buildings that are constructed not only out of bricks but also from concrete.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The effect differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). According to all historical periods, Table 18 shows the thermal transmittance value (W/m2K) of residential and service sectors.

Table 18 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the periods. Here we can observe how thermal insulation materials and different elements of buildings (walls, windows, roof, and floor) affect heat flow.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	0.60	2.20	0.40	0.60
1945 - 1969	0.50	2.05	0.35	0.50
1970 - 1979	0.40	1.90	0.30	0.40
1980 - 1989	0.30	1.70	0.20	0.30
1990 - 1999	0.25	1.60	0.15	0.20
2000 - 2010	0.20	1.50	0.13	0.15
Post 2010	0.13	1.38	0.10	0.10
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	0.80	2.40	0.50	0.60
1945 - 1969	0.60	2.30	0.40	0.50
1970 - 1979	0.50	2.20	0.30	0.40
1980 - 1989	0.30	2.00	0.20	0.30
1990 - 1999	0.20	1.70	0.15	0.20
2000 - 2010	0.15	1.50	0.13	0.15
Post 2010	0.10	1.38	0.10	0.10

Table 18. Thermal transmittance of construction elements (Finland).

The analyzed data related to SH and DHW in the Finnish residential sector reveals that the leading technology for SH and DHW is a centralized boiler for SH and DHW needs regarding all types of buildings and construction periods.

The most common energy carrier for SH and DHW in the Finnish residential building stock is liquid fuels.

The results for SC technology show that in most cases, SC is not represented in this residential market, which is explained by the short and comparatively warm to cool summer depending on the territories (north and south) that in overall do not require SC application.

Findings demonstrate that technology for SH and DHW, besides utilizing traditional energy carriers, also uses heat pump applications. However, as mentioned above, the residential sector mainly uses liquid fuel, characterized by a higher carbon content than gaseous ones.

According to expert questioning: The most common technologies for SH and DHW are district heating systems, central gas condensing boilers, heat pumps, electricity. SC is not present in most cases, except health industry, where SC is often used.

3.10. **FRANCE**

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding France.

In Figure 37, the Mm² of covered floor area in French residential and service sectors is presented in percentages regarding historical periods.

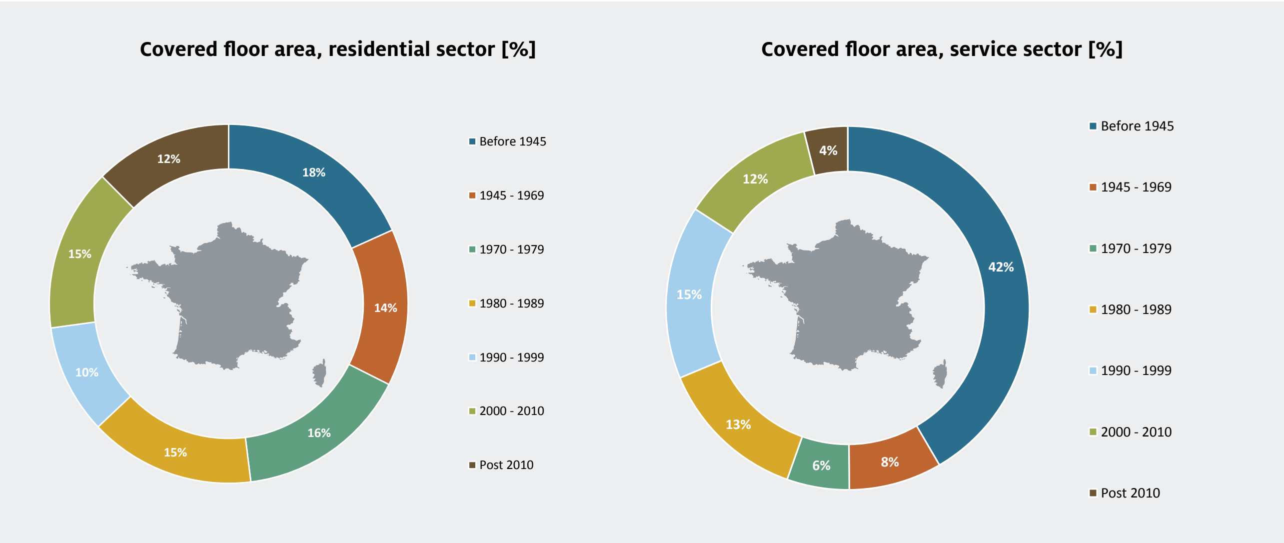

Figure 37. Split of the residential and service building stock raised per construction periods [%] (France).

The data obtained from the residential sector shows that about 18% of the covered floor area are occupied by buildings erected before 1945. Buildings erected between 1945-1969 show a ratio of the covered floor area of about 14%. Buildings erected between 1970 till 1979 cover 16%. Then 15% of the total floor area is occupied by buildings constructed in the 1980s. Whereas the minor area is covered by buildings erected in the 1990s with 10% respectively. Buildings erected between 2000-2010 occupied the same percentage ratio as buildings of the 1980s, i.e., 15%. Buildings that were erected in the post-2010 period occupy 12% of the total floor area accordingly.

Service buildings erected before 1945 occupies most of the floor area, i.e., 42%. In contrast, a significantly lower percentage ratio is found in buildings erected between 1945-1969, with 8%. One of the smallest percentage ratios of covered floor area is found in buildings constructed between 1970-1979, with only 6%. Around 13% of the covered floor area is found in buildings constructed between 1980 till 1989. Buildings erected in the 1990s, i.e., indicate 15%. The period of 2000-2010 holds about 12% of the covered floor area. Whereas the minor percentage ratio indicates buildings constructed in the post-2010 with only 4% accordingly.

Figure 38 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 38 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

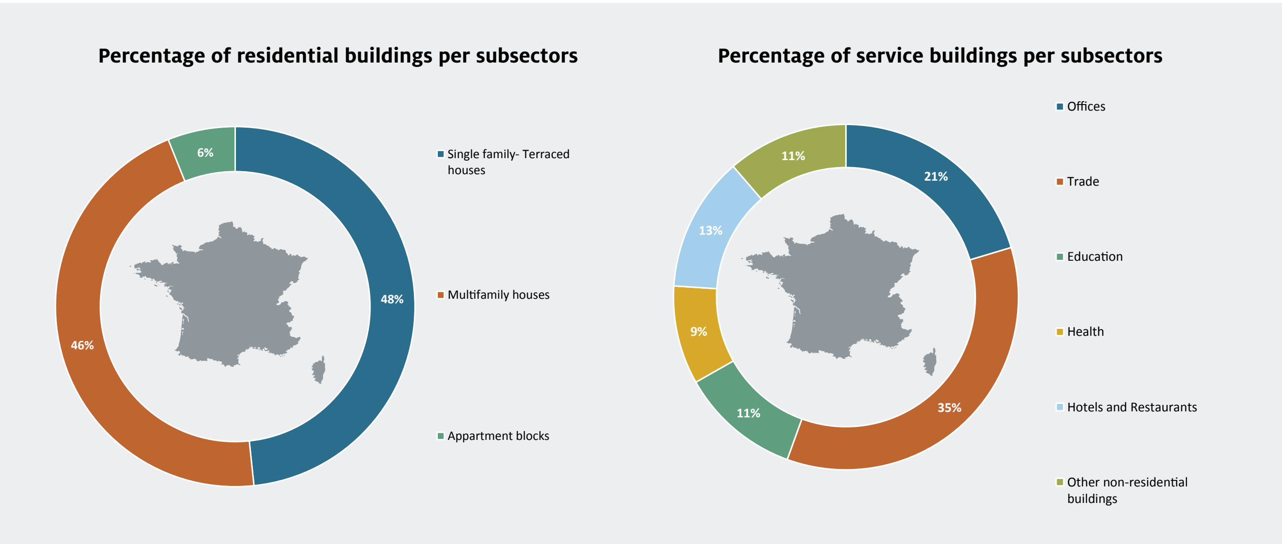

Figure 38. Split of residential and service buildings per different subsectors [%] (France).

Considering this graph, we can observe that the residential sector in France is almost half occupied by SHFs with 48%. MFHs of the residential building stock in France also cover a large portion i.e., 46%, leaving behind the remaining 6% of the residential building stock for ABs.

Trade buildings mainly occupy the service sector of France with 35%. About 21% of the buildings are offices. Hotels and restaurants in the service sector of France occupy 13%. Educational buildings and non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms) cover about 11% of the service building stock, respectively. Only 9% of the market is allocated for health care buildings and hospitals, accordingly.

Figure 39 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

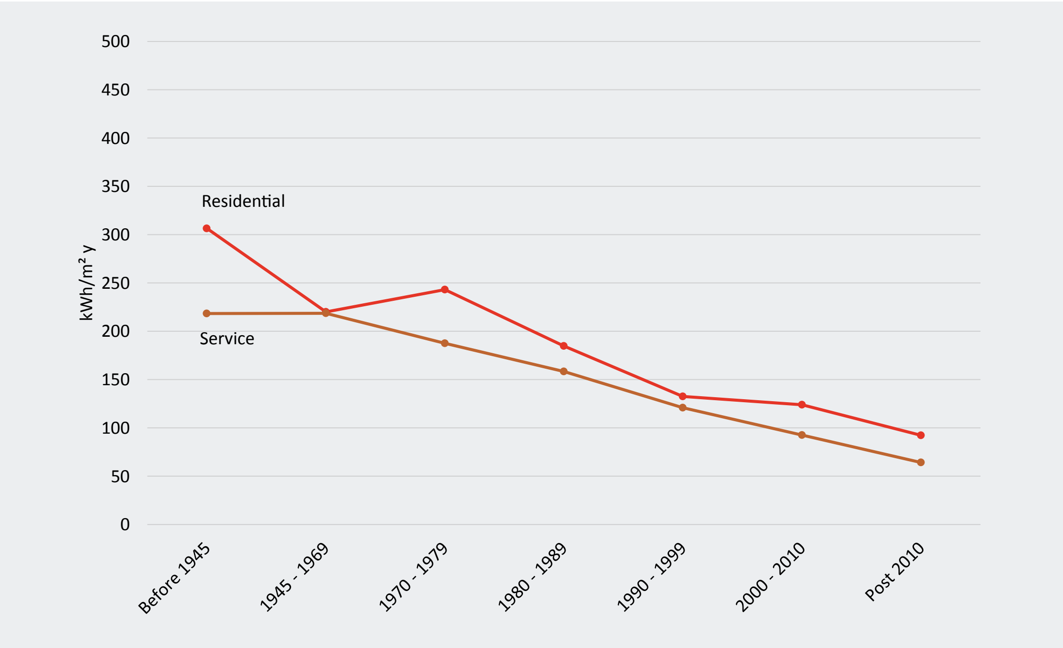

Figure 39. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (France).

The buildings constructed before 1945 consume about 306 kWh/m² y of the specific FEC for SH and DHW. The specific FEC then drops to 218 kWh/m² y in the buildings constructed in 1945-1969. After that, the consumption rate has increased to 243 kWh/m² y regarding buildings erected in the 1970s. The value of the specific FEC for SH and DHW keeps decreasing almost linearly from 243 kWh/m² y to 132 kWh/m² y regarding buildings constructed from the end of the 1970s till the 1990s, respectively. Buildings erected in 2000-2010 show a little lower consumption rate, i.e., 123 kWh/m² y. The lowest value of the specific FEC for SH and DHW was observed in buildings erected in the post-2010 period, with the value of specific FEC of about 92 kWh/m² y.

The trend of specific FEC in the service sector is relatively close to the trend of the residential one. The buildings erected before 1945 till 1969 consume about 218 kWh/m² y. Since then, specific FEC for SH and DHW demonstrates a linear decrease regarding buildings erected from 1969 till post-2010. For instance, buildings constructed in the 1970s indicate the value of specific FEC of 187 kWh/m² y, while buildings erected in the 1980s consume approximately 160 kWh/m² y. Moving forward, we can observe that the value of specific FEC in buildings erected in the 1990s and 2000s are 120 and 92 kWh/m² y, respectively. The most efficient consumption rate is found in buildings erected after 2010 with a value of about 64 kWh/m² y.

Figure 40 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

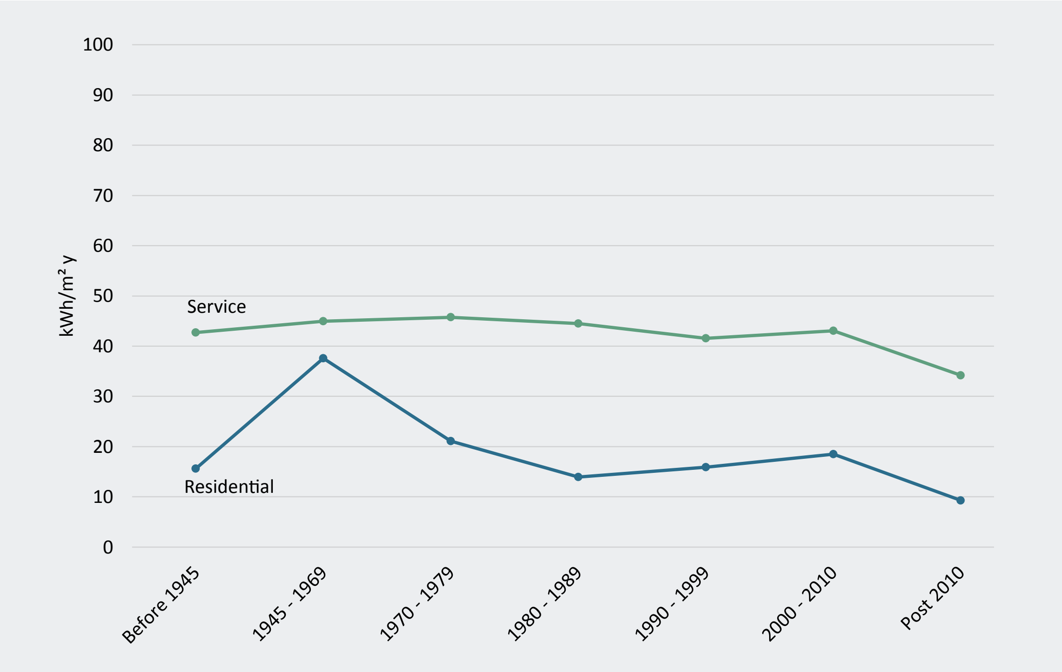

Figure 40. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (France).

The trend of FEC for SC in the residential sector shows that the buildings erected before 1945 consume about 15 kWh/m² y. The rate then increases to 37 kWh/m² y regarding buildings erected between 1945-1969. After this, the consumption rate decreases to 21 kWh/m² y for buildings of the 1970s. Buildings erected in the 1980s indicate about 13 kWh/m² y of specific FEC, respectively. The specific FEC for SC then slightly increases regarding buildings of the 1990s with a value of approximately 16 kWh/m² y. A further increase in specific FEC is observed in buildings of the 2000s with a value of about 18 kWh/m² y. Buildings erected in the period of post-2010 are characterized by the smallest value of specific FEC for SC, i.e., only 9 kWh/m² y.

The trend of specific FEC for SC in the service sector is relatively the same throughout the buildings constructed before 1945 till the 2000s. The buildings erected before 1945 consume about 42 kWh/m² y. The consumption rate then stays relatively the same regarding buildings erected during the consecutive periods, except in the post-2010 period, when the consumption rate drops to 34 kWh/m² y. The highest value of specific FEC is observed in buildings of the 1970s with the value of about 45 kWh/m² y respectively.

Regarding the construction methodology presented in the dataset provided by the H2020 Hot-Maps project (8), the main construction topology for walls is a solid wall. Insulation is present in buildings erected after the 1960s. Honeycomb bricks/hollow blocks walls are present in SFHs erected before 1945 and during the 1970s and 1980s. Insulation is present in buildings erected during the 1980s. The construction methodology for windows is mainly double-glazing, presented in buildings erected from the 1970s to the post 2010 period respectively. Low emittance glass is given only in buildings of the 2000s and post-2010 periods. Single glazing windows are given only in historical buildings (before 1945), and MFHs erected between 1945-1969. We can observe that a tilted roof is the most popular decision regarding SFHs with the presence of insulation (except historical buildings) and MFHs erected before 1945 to the late 1970s and during the period of 1990s. Insulation is presented in all cases. The flat roof is primarily presented in MFHs erected in the 1980s and afterward and in ABs. Insulation for a flat roof is used in buildings erected in the 1980s and afterward. Concrete slabs are the most widespread technology for floors throughout all periods. Insulation is present in buildings erected during the 1980s and afterward, except MFHs where insulation is present regarding buildings erected in the 1970s and afterward.

Information about construction materials and construction methodology of the service sector was received by experts questioning. The information concerning Central Europe (Austria, Belgium, Germany, Netherland, Luxembourg, France, UK, and Ireland) was summarized afterward. Concerning the service sector in France, the information is presented in the table below (Table 19).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, health							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete+ insulation in most cases	Aluminum, low emittance glass only in few cases	Concrete + insulation in most cases	Concrete+ insulations in most cases	Solid wall	Double glazing	Flat roof	Concrete slab
Trade, hotels and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete or bricks+ insulation in most cases	Aluminum and synthetic/PVC, low emittance glass only in few cases.	Concrete and bricks + insu-lation in most cases	Concrete+ insulations in most cases	Solid walls	Double glazing	Flat roof	Concrete slab
Educational, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete+ insulation in most cases	Aluminum and synthetic/PVC, low emittance glass only in few cases.	Concrete and bricks + insu-lation in most cases	Concrete +in-sulations in most cases	Solid walls	Double glazing	Flat roof	Concrete slab

Table 19. Construction materials, construction methodology-service sector (France).

The table above (Table 19) shows that the service sector demonstrates similar construction methodology and relative similarities with construction materials regarding different types of buildings. For instance, trade, hotels, and restaurants show similarities in construction materials and methodology, while it is also valid for office, health, educational and non-residential buildings, respectively.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 20 shows the thermal transmittance value (W/ m^2 K) regarding two considered building sectors (residential and service) for all periods.

Table 20 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and buildings elements regarding different periods affect heat flow and thus specific FEC variation.

RESIDENTIAL SECTOR

Historical period	Walls	Windows	Roof	Floor
Before 1945	1.61	4.05	1.39	1.91
1945 - 1969	2.77	3.82	2.19	1.65
1970 - 1979	1.15	3.49	1.03	1.13
1980 - 1989	0.44	2.83	0.50	0.64
1990 - 1999	0.33	2.64	0.38	0.38
2000 - 2010	0.32	1.60	0.22	0.29
Post 2010	0.19	1.40	0.14	0.20

SERVICE SECTOR

Historical period	Walls	Windows	Roof	Floor
Before 1945	2.10	5.00	1.80	1.80
1945 - 1969	1.65	4.70	1.40	1.40
1970 - 1979	1.42	4.40	1.00	1.20
1980 - 1989	1.20	3.40	0.80	1.00
1990 - 1999	1.00	3.30	0.60	0.80
2000 - 2010	0.40	2.70	0.30	0.40
Post 2010	0.45	2.60	0.37	0.38

Table 20. Thermal transmittance of construction elements (France).

According to the analysis, the individual SH and DHW system is mainly available in buildings constructed during all analyzed periods. The central SH systems are also used in most buildings except buildings erected in the 1970s. The central DHW system is present in buildings erected in the post-2010 period and MFHs erected between 1945 and 1969. The district heating system for SH and DHW is present in buildings erected from the 1970s to the 2000s.

Non-condensing boilers for SH are mainly used in buildings constructed before 1945 to the late 1970s and in buildings erected in the 2000s. Buildings erected in the other periods are mainly equipped with condensing boilers. Non-condensing boilers are predominantly used in all building types for DWH needs. Stoves are mainly present in SFHs (erected before 1945) during the 1980s and 1990s. Electric heaters are mainly used in SFHs erected in the 2000s and MFHs of the 1990s. Heat pump technology for SH and DHW is present in SFHs erected from 1990 to the post-2010 period, and MFHs constructed during the post-2010 period respectively.

The most widespread type of fuel for SH and DHW is gas. Gas is used in buildings erected before 1945, between 1945-1969, and in buildings erected after the 1970s. Liquid fuel is utilized in SFHs erected before 1945 to the late 1970s, as well as in MFHs and ABs erected in the 1970s. Solid fuel is the main energy carrier in buildings of the 1980s and 1990s, respectively. Electricity is the leading energy career for DHW for most building types except historical buildings (erected before 1945).

The results for SC technology show that buildings erected before 1945 to the 1990s do not use SC technology in most cases. However, buildings constructed after this time, in most cases, are equipped with a SC system.

These findings demonstrate a relatively low level of presence of renewable energy sources for SH, DHW, and SC in the residential building stock that mainly utilize gaseous and liquid fuels, characterized by higher carbon content. The presence of renewable energy (heat pump) is determined mainly in SFHs erected from 1990 to the post-2010 period respectively.

According to expert questioning: the most common technology in the service sector for SH and DHW is central gas condensing boiler, heat pumps, and electricity. SC is not presented in most cases, except in the health industry, where SC is mainly used.

3.11. GERMANY

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Germany.

In Figure 41, the Mm^2 of covered floor area in German residential and service sectors is presented in percentages regarding historical periods.

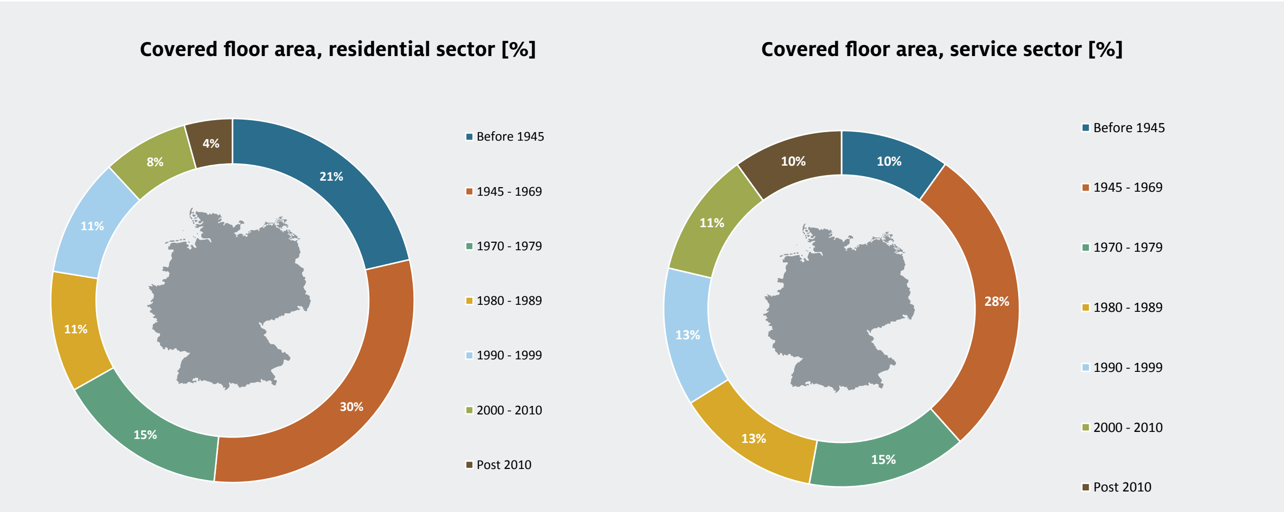

Figure 41. Split of the residential and service building stock raised per construction periods [%] (Germany).

The data analysis shows that buildings built in 1945-1969 occupy the largest part in the residential sector, which is 30%. The period before 1945 shows the second largest percentage of covered floor area, which is 21%. About 15% of the covered floor area is related to buildings erected between 1970-1079. In the residential buildings of the 1980s and 1990s, the ratio is 11% accordingly. The buildings erected in the 2000s cover about 8% of the floor area, whereas buildings constructed in the post-2010 period cover only 4%.

The most significant portion of covered floor area in the service sector is also related to buildings erected between 1945 till 1969, with a percentage ratio of 28%. Buildings constructed between 1970-1979 occupy 15% of the covered floor area. About 13% of the covered floor area is occupied with buildings erected during the two consecutive periods (1980-1989, 1990-1999). The ratio is slightly decreased to 11% regarding buildings erected during the 2000s. The minor percentage ratio is found in buildings erected before 1945 and in the post-2010 period with 10% only.

Figure 42 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 42 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

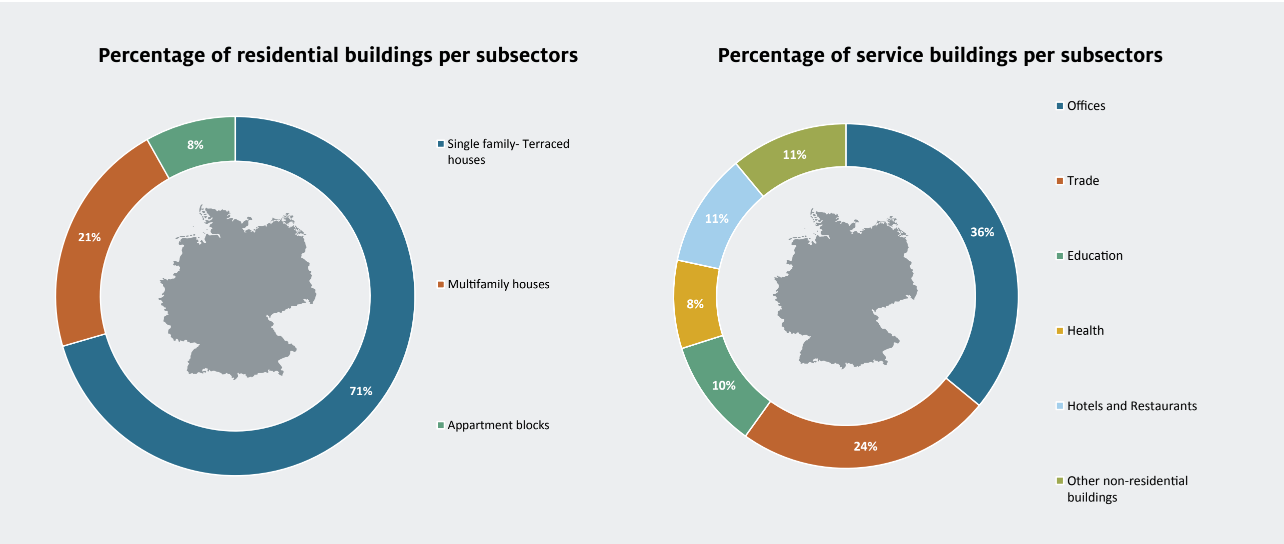

Figure 42. Split of residential and service buildings per different subsectors [%] (Germany).

The graph shows that in the German residential sector, 71% of the buildings are characterized as SFHs. Whereas about 21% of the buildings are MFHs. The remaining 8% is referred to as ABs, respectively.

In the service sector of Germany, most of the service buildings are characterized as office buildings that covered 36% of the market. About 24% of the service sector are trade buildings. Hotels and restaurants occupy over 11% of the service building stock. The same percentage ratio is referred to other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms). Educational buildings cover about 10% of the service sector, whereas the least represented building type is health care buildings which occupy only around 8% of the total service building stock in Germany.

Figure 43 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

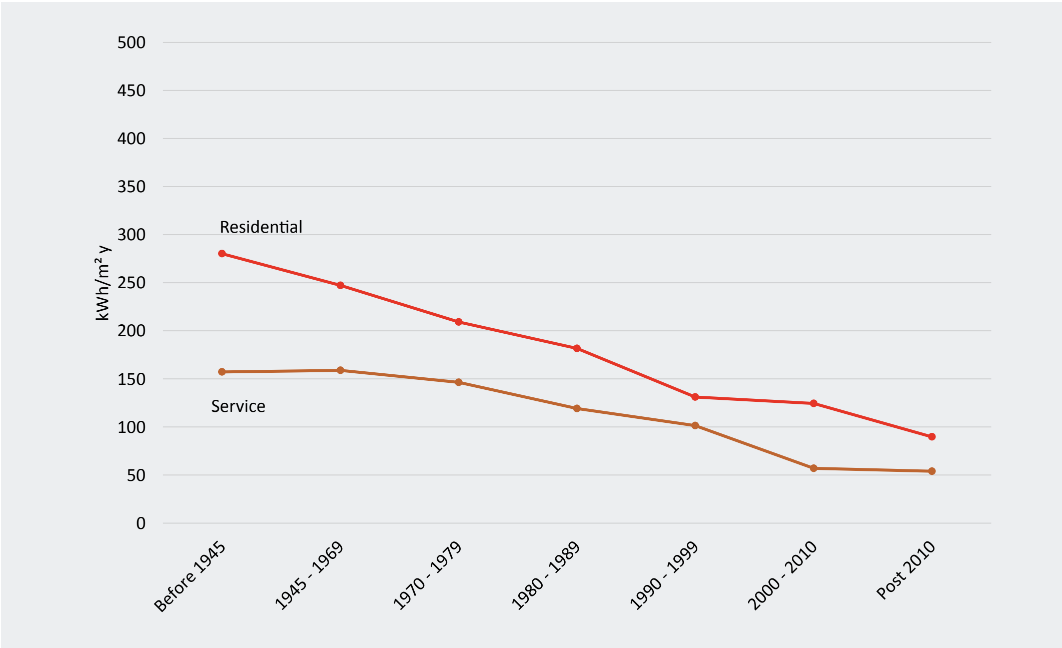

Figure 43. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Germany).

The development trend of specific FEC for SH and DHW is seen to be decreasing regarding buildings erected before 1945 till post-2010. The highest FEC is consumed by the buildings erected before 1945, i.e., 280 kWh/m² y. Buildings erected between 1945-1969 to the late 1990s indicate the stable decrease in specific FEC. The consumption rate decreases from 280 kWh/m² y to 247 kWh/m² y regarding buildings erected between 1945-1969. Buildings erected in the 1970s indicate 209 kWh/m²of specific FEC. The specific FEC of buildings erected in the 1980s and 1990s indicate 181 and 131 kWh/m² accordingly. The trend of specific FEC slightly decreased to 124 kWh/m² y in the buildings of the 2000s. The lowest specific FEC for SH and DHW is consumed by buildings of the post-2010 period with only 89 kWh/m² y, respectively.

In contrast, the trend of specific FEC for SH and DHW in service sector also decreases from early constructed buildings till post-2010 constructed ones. Before 1945, the consumption rate is 157 kWh/m² y. This rate remains almost the same for the years 1945 till 1979 constructed buildings with a slight decrease i.e.,146 kWh/m² y. Buildings erected in 1980s consume about 119 kWh/m² y whereas those erected in 1990s consume 101 kWh/m² y. The consumption rate again drops to 57 kWh/m² y regarding buildings constructed in 2000-2010 period. The lately erected buildings in post 2010 period consume almost the same FEC for SH and DH, which is 54 kWh/m² y.

Figure 44 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

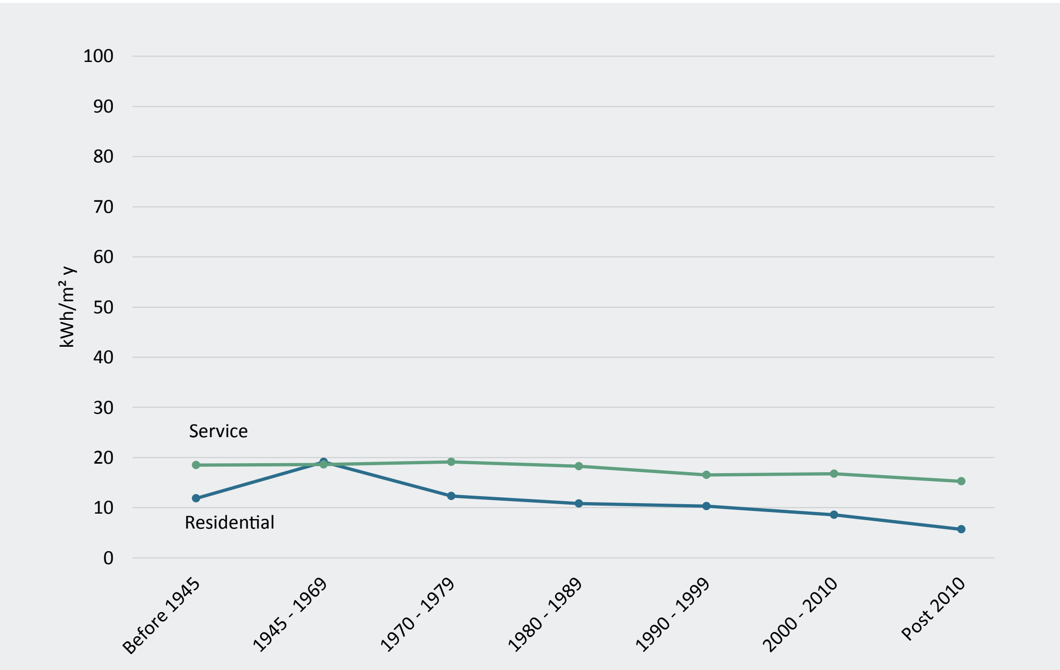

Figure 44. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Germany).

In the residential sector of Germany, the trend of specific FEC for SC shows that the buildings constructed before 1945 consume about 12 kWh/m² y. The consumption rate increases to almost 19 kWh/m² y regarding buildings erected between 1945 and 1969. The trend of specific FEC for SC is then falling back to 12 kWh/m² y regarding buildings constructed in the 1970s. Buildings erected in the 1980s and 1990s indicate relatively the same value of about 10 kWh/m² y. Buildings erected in the 2000s show a slight reduction in specific FEC to the value of 8 kWh/m² y. The lowest specific FEC is observed in buildings erected in the post-2010 period with 5 kWh/m² y

In comparison, the trend of specific FECs for SC in the service sector is almost the same in all periods. Buildings that were built from 1945 to 1989 consume about 19 kWh/m² y. The consumption rate is then slightly reduced to 16 kWh/m² y in buildings erected from 1990 to 2010. The lowest specific FEC for SC is observed in buildings constructed after 2010, with a specific FEC of 15 kWh/ m² y, while in the residential sector, the value for specific FEC is only 5 kWh/m² y.

Regarding the construction methodology presented in the data set provided by the H2020 Hot-Maps repository (8), the main construction topology for walls a solid wall, concerning buildings erected before 1945, during the 1970s and after 1980s respectively with insulation in buildings erected after 1990. Cavity wall is present in SFHs erected between 1945-1969, and during the periods of 1990s and 2000s with insulation. Honeycomb bricks and hollow blocks walls is used in MFHs, and ABs erected between 1945-1969 and 1980s. Honeycomb bricks and hollow blocks walls is also present in SFHs erected during the 1980s. The construction methodology for windows is mainly double-glazing windows. Double glazing windows is used in buildings erected before 1945 to the 2000s. Low emittance glass is in buildings erected during 1990s and 2000s respectively. Low emittance triple glazing windows are presented in buildings constructed in the post-2010 period.

We can observe that the flat roof is the most popular decision regarding MFHs and ABs, erected from 1945 to the post-2010 period with insulation in buildings erected after the 1970s. A flat roof is also present in SFHs erected in the 1970s with the presence of insulation. Tilted roofs are primarily constructed in SFHs, and historical buildings erected before 1945. Concrete slabs (insulation presents from the 1970s) were primarily used in German houses erected after 1945. Historical buildings erected before 1945 is partially constructed with Concrete slabs and wooden floor.

Information about construction materials and construction methodology of the service sector was received by questioning experts. The information concerning Central Europe (Austria, Belgium, Germany, Netherland, Luxembourg, France, UK and Ireland) was summarized afterwards. Concerning the German service sector, the information is presented in the table below (Table 21).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, health							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete+ insulation in most cases	Aluminum, low emittance glass only in few cases	Concrete + insulation in most cases	Concrete+ insulations in most cases	Solid wall	Double glazing	Flat roof	Concrete slab
Trade, hotels and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete or bricks+ insulation in most cases	Aluminum and synthetic/PVC, low emittance glass only in few cases.	Concrete and bricks + insulation in most cases	Concrete+ insulations in most cases	Solid walls	Double glazing	Flat roof	Concrete slab
Educational, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete+ insulation in most cases	Aluminum and synthetic/PVC, low emittance glass in few cases.	Concrete and bricks + insulation in most cases	Concrete +insulations in most cases	Solid walls	Double glazing	Flat roof	Concrete slab

Table 21. Construction materials, construction methodology-service sector (Germany).

The details from the table above clearly let us know that the service sector demonstrates similarities in construction materials and methodology regarding different types of buildings. For offices and health, relatively the same construction materials and methodology are found. At the same time, it is also valid for trade, hotels, and restaurants. Educational and other non-residential buildings demonstrate the same pattern as well.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). According to all historical periods, Table 22 shows the thermal transmittance value (W/m^{2}K) regarding residential and service sectors.

Table 22 helps to figure out the impact of building elements on specific FEC. Here we can observe how thermal insulation materials and building elements regarding different periods affect heat flow. As seen from the table below, the thermal transmittance values demonstrate the reduction throughout the historical periods.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.82	2.80	1.52	1.14
1945 - 1969	1.23	2.89	0.82	1.12
1970 - 1979	1.02	2.64	0.51	0.77
1980 - 1989	0.57	2.36	0.39	0.51
1990 - 1999	0.43	1.80	0.34	0.42
2000 - 2010	0.29	1.36	0.22	0.29
Post 2010	0.25	1.20	0.19	0.28
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.50	2.90	1.00	1.20
1945 - 1969	1.35	2.40	0.90	1.05
1970 - 1979	1.20	2.15	0.80	0.90
1980 - 1989	0.90	1.90	0.50	0.40
1990 - 1999	0.40	1.60	0.30	0.38
2000 - 2010	0.34	1.30	0.20	0.36
Post 2010	0.28	1.15	0.10	0.35

Table 22. Thermal transmittance of construction elements (Germany).

The analyzed data for SH and DHW in the German residential sector is characterized by a central SH and DHW system. In most buildings (erected before 1945 to the late 1980s), the non-condensing boiler is used. Regarding buildings constructed after the 1980s, condensing boilers are mainly utilized. Buildings erected in the last post-2010 period use solar collectors for DHW needs.

The gas is widely used in all considered building types for SH and in ABs for DHW needs. Liquid fuel is mainly used in SFHs, and MFHs for DHW needs, respectively.

The results for SC technology show that in most cases, SC is not represented in German residential building stock, except buildings erected after 2010.

The German residential building stock mainly utilizes gas and liquid fuel from traditional and renewable energy sources. Findings demonstrate that technology for SH and DHW, besides utilizing gas and liquid fuel, is also characterized by using solar collectors for DHW needs.

According to expert questioning: The most common technologies for SH and DHW are central gas condensing boilers, heat pumps, electricity. SC is not present in most cases, except health industry, where SC is often used.

3.12. GREECE

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Greece.

In Figure 45, the Mm² of covered floor area in Greece residential and service sectors, is presented in percentages regarding historical periods.

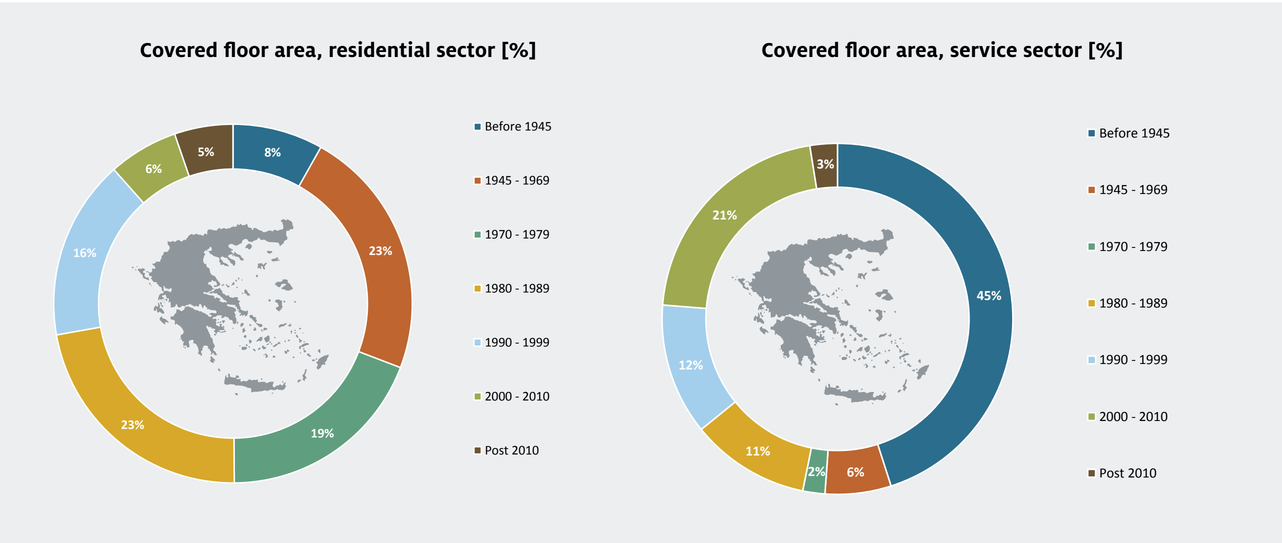

Figure 45. Split of the residential and service building stock raised per construction periods [%] (Greece).

The largest covered floor area is occupied by buildings erected between 1945-1969 and 1980-1989 with 23% each. Buildings erected in the 1970s cover about 19% of the total floor area. In comparison, buildings constructed in the 1990s occupy 16% respectively. Residential buildings constructed before 1945 occupy 8% of the covered floor area. The minor percentages ratio is found in buildings erected in the 2000s and during the post-2010 period with just 6% and 5%, respectively.

Buildings erected from 1990 till 1999 cover about 12% of the floor area in the service sector of Greece. The trend in the service sector is different from the trend in the residential one. Here, the largest covered floor area belongs to buildings erected before 1945 with a percentage ratio of 45%. The second highest percentage indicates service buildings erected during the 2000s, with 21% of the total covered floor area. Furthermore, buildings erected in the 1980s occupy 11% only. Whereas buildings constructed in the 1945-1969 period occupy one of the minor portions of covered floor area, i.e., 6%. The least ratios, i.e., 3% and 2%, are related to buildings erected in the post-2010 and during the 1970s, respectively.

Figure 46 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 46 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

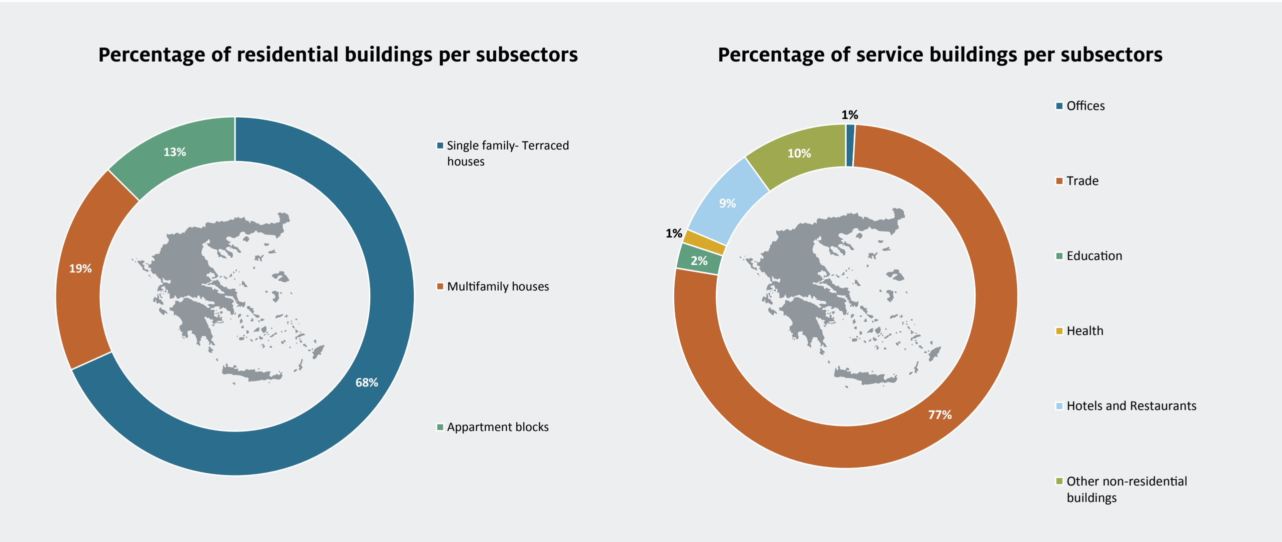

Figure 46. Split of residential and service buildings per different subsectors [%] (Greece).

According to this data, more than two-thirds of Greece's residential building stock is covered by SFHs, with 68% of the total. MFH's occupy 19% of the market, whereas ABs cover the remaining 13% of the residential sector.

Considering the service sector, we notice that trade buildings are the most widespread building type in Greece. These buildings occupy more than three fourth of the market, i.e., 77%. About 10% of the buildings in the service sector are non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms). Hotels and restaurants occupy only 9% of the service building stock. In contrast, educational buildings cover only 2% of the market. Only 1% of the service building stock is allocated for health care hospitals and office buildings in the service sector of Greece.

Figure 47 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

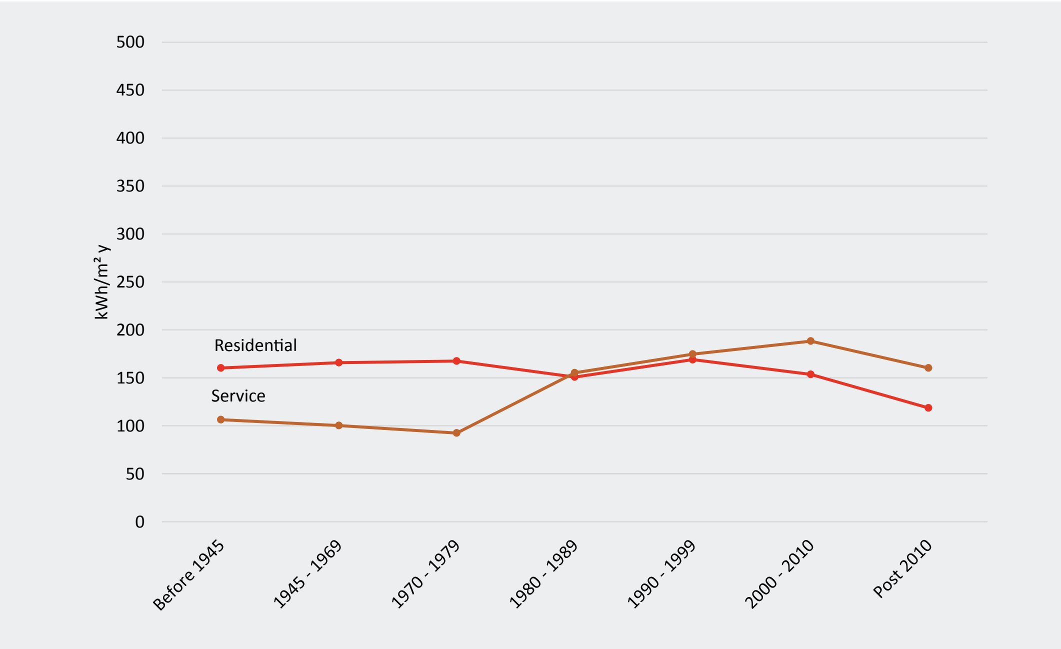

Figure 47. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Greece).

Residential buildings erected before 1945 consume about 160 kWh/m² y of the specific FEC for SH and DHW. The consumption rate is slightly increased regarding building erected from 1945 till 1979 with the value of about 165 kWh/m² y respectively. The rate then slightly drops to around 155 kWh/m² y regarding buildings of the 1980s. Buildings erected in the 1990s indicate an increase in specific FEC up to approximately 174 kWh/m²y. After that, the rate of specific FEC for SH and DHW drops to about 153 kWh/m² y in buildings erected between 2000-2010. The smallest value of specific FEC for SH and DHW is observed in buildings erected in the post-2010 period.

The trend of specific FEC for SH and DHW in the service sector of Greece is increased from around 106 kWh/m² y to 160 kWh/m² y regarding buildings erected before 1945 till post-2010. Buildings erected before 1945 consume about 106 kWh/m² y. Buildings erected from 1945 till 1970 show almost the same consumption rate, i.e., 100 kWh/m² y. In comparison, buildings erected in the 1980s indicate an increase in specific FEC with the value of around 155 kWh/m² y. The consumption rate then keeps increasing. For instance, Buildings constructed in the 1990s indicate the value of specific FEC of approximately 174 kWh/m² y, while those constructed in the 2000s consume about 188 kWh/m² y of specific FEC. Buildings erected in the post-2010 period show the reduction in specific FEC for SH and DHW with the value of around 160 kWh/m² y, respectively.

Figure 48 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

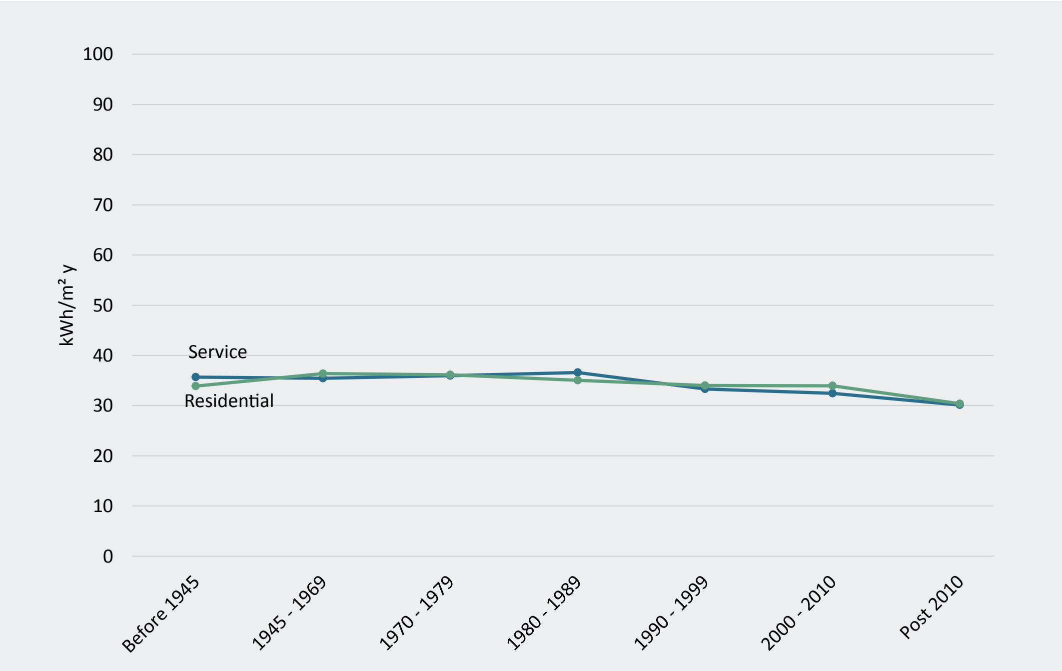

Figure 48. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Greece).

The trend of specific FEC for SC in residential and service sectors is relatively equal regarding buildings erected before 1945 till post-2010.

Specific FEC for SC in the residential buildings erected before 1945 is about 36 kWh/m²y, whereas in the service sector, it is slightly lower, i.e., 34 kWh/m²y. Buildings erected from 1945 till 1969 consume about 36 kWh/m²y in both sectors. The consumption rate remains relatively the same in the residential and service buildings erected in the 1970s. Residential buildings constructed in the 1980s consume about 37 kWh/m²y of specific FEC for SC, whereas approximately 35 kWh/m²y relates to service buildings. The trend then decreases to about 34 kWh/m²y, regarding buildings (residential and service) erected in the 1990s. Residential buildings of the 2000s consume about 33 kWh/m²y, whereas service ones indicate around 34 kWh/m²y of specific FEC for SC. The smallest value of specific FEC is found in buildings erected in the post-2010 period with the value of approximately 30 kWh/m²y, respectively.

Regarding the construction methodology presented in the dataset provided by the H2020 Hot-Maps project (8), the main construction topology for walls is a solid wall and cavity wall. A solid wall is present without insulation — cavity wall with insulation only in buildings erected in the

2000s and post 2010. The construction methodology for windows is mainly double and single glazing windows. Low emittance glass is given only in buildings erected in the post-2010 periods. We can observe that a flat roof is the most popular decision in buildings regardless of historical periods, followed by the tilted roof that is present only in SFHs of the 2000s with insulation. Insulation for a flat roof is determined in buildings erected in the two last analyzed periods (2000-2010, post-2010). Concrete slabs are the most widespread technology for floors in Greece houses throughout all periods with the presence of insulation regarding buildings of the post-2010 period.

Information about construction materials and construction methodology of the service sector was received by experts questioning. The information concerning Southern Europe (Spain, Italy, Greece, Cyprus, Malta, and Portugal) was eventually summarized. Concerning the Greece service sector, the information is presented in the table below (Table 23).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, education, health, hotels and restaurants, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windos	Roofs	Floors
Bricks+ Insulation only in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks, insulation in few cases	Concrete+ insulations in few cases	Honeycomb bricks/hollow block walls	Double and single glazing	Flat roof	Concrete slab

Table 23. Construction materials, construction methodology-service sector (Greece).

The table above (Table 23) shows that the service sector show similarities in construction material and construction methodology regarding all types of service buildings.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 24 shows the thermal transmittance value (W/m^2K) regarding two considered building sectors (residential and service) for all periods.

Table 24 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and building elements regarding different periods affect heat flow and thus specific FEC variation.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	2.38	4.17	2.98	2.49
1945 - 1969	1.76	4.30	2.46	2.45
1970 - 1979	1.41	4.69	1.83	2.39
1980 - 1989	1.00	4.96	1.29	2.30
1990 - 1999	0.83	4.40	0.90	1.77
2000 - 2010	0.70	4.07	0.53	0.98
Post 2010	0.48	2.90	0.44	0.68
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	2.50	5.10	3.20	0.70
1945 - 1969	2.45	5.05	2.95	0.75
1970 - 1979	2.40	5.00	2.70	0.76
1980 - 1989	2.10	5.30	0.70	0.77
1990 - 1999	0.80	3.70	0.50	0.78
2000 - 2010	0.70	3.50	0.30	0.79
Post 2010	0.32	1.60	0.10	0.80

Table 24. Thermal transmittance of construction elements (Greece).

The analyzed data related to SH and DHW in the residential sector reveals that the leading technology for SH and DHW is a centralized non-condensing boiler for SH and DHW needs regarding all types of buildings and construction periods. Individual non-condensing and condensing (post-2010 period) boilers are used in MFHs, and ABs for DHW needs. DHW system is also characterized by using solar collectors regarding buildings erected in the 1970s and afterward. The results for SC technology show that in most cases, SC is not represented in this residential market.

The residential building stock mainly utilizes liquid fuel and electricity. Findings demonstrate that technology for SH and DHW, besides utilizing traditional energy carriers, also uses solar collectors.

According to expert questioning: The most common technologies for SH and DHW are the individual gas condensing boiler, electric heating (trade buildings). SC is present in most cases, except educational buildings.

3.13. HUNGARY

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Hungary.

In Figure 49, the Mm² of covered floor area in Hungarian residential and service sectors, is presented in percentages regarding historical periods.

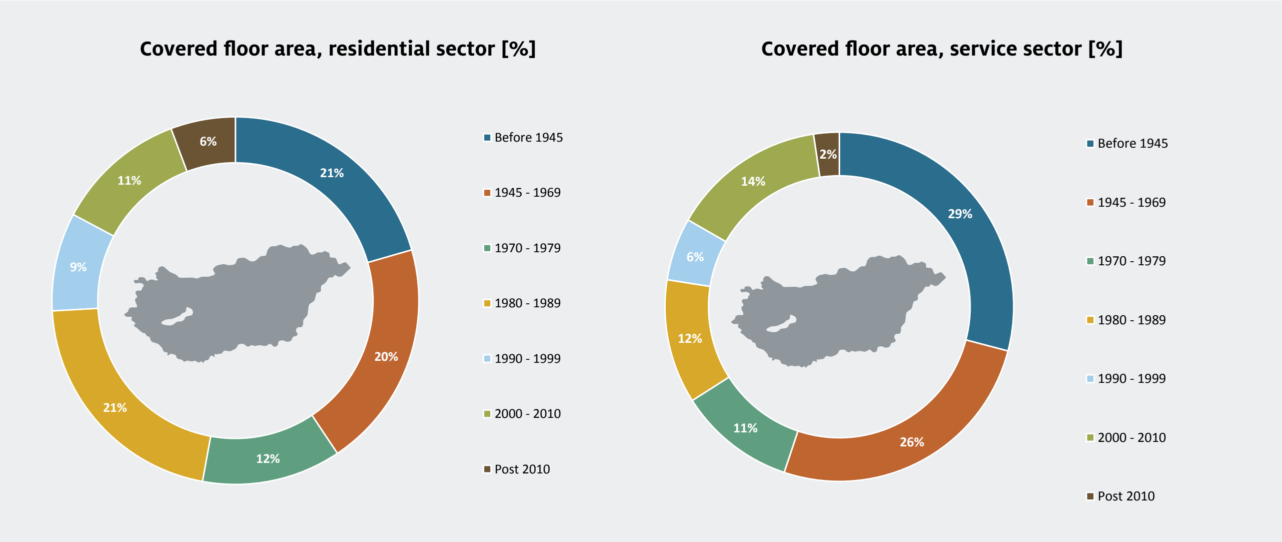

Figure 49. Split of the residential and service building stock raised per construction periods [%] (Hungary).

The data shows that the highest percentage of covered floor area is 21%. This percentage ratio belongs to buildings constructed in two different periods, i.e., buildings constructed before 1945 and those constructed between 1980 till 1989. The buildings erected from 1945 till 1969 cover about 20% of the floor area. Buildings of the 1970s occupy 12% of the floor area. Another 11% of the covered floor area belongs to buildings erected in 2000-2010. Buildings erected from 1990 till 1999 account for a lower percentage of covered floor area, 9%. The least ratio is 6% found in the buildings which are constructed in the post-2010 period.

In the service sector of Hungary, more than half of the covered floor area belongs to buildings constructed before 1945 till 1969. Those constructed before 1945 cover 29% of the ratio, whereas those erected from 1946 till 1969 cover about 26%. The buildings erected in the 2000s occupy 14% of the total covered floor area. About 12% is covered by buildings erected between 1980-1989. Furthermore, buildings erected in the 1970s cover about 11%. Whereas the buildings erected in 1990-1999 period occupy only 6% of the total floor area. The least percentage belong to buildings erected in the post-2010 period with 2% only.

Figure 50 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 50 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

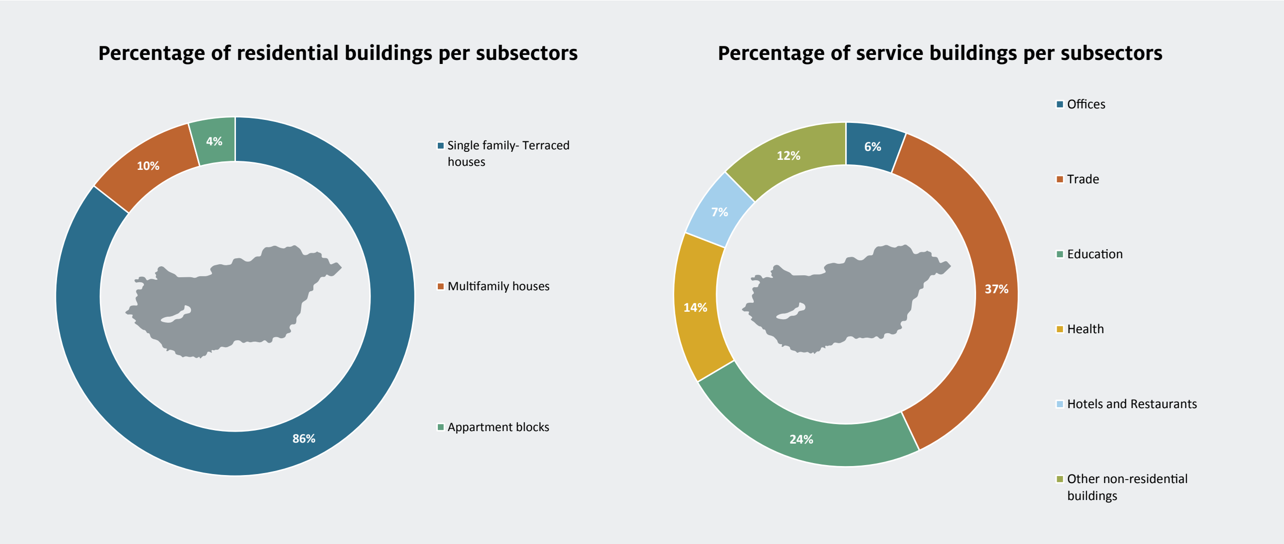

Figure 50. Split of residential and service buildings per different subsectors [%] (Hungary).

In the residential sector of Hungary, SFHs demonstrate the ratio, i.e., 86%. Leaving behind only 14% for MFHs and ABs. About 10% of the market is allocated for MFHs. ABs occupy only 4%.

In the service sector of Hungary, we can see that trade buildings are the most widespread building type, which occupies 37% of the market. Education buildings occupy about 24% of the service building stock. Health facilities cover about 14% of the total service building stock, whereas other non-residential buildings occupy 12% of the market. These buildings include warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms). It is observed that only 7% of the service sector is designated for hotels and restaurants. The remaining 6% of the service sector is allocated for office buildings.

Figure 51 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

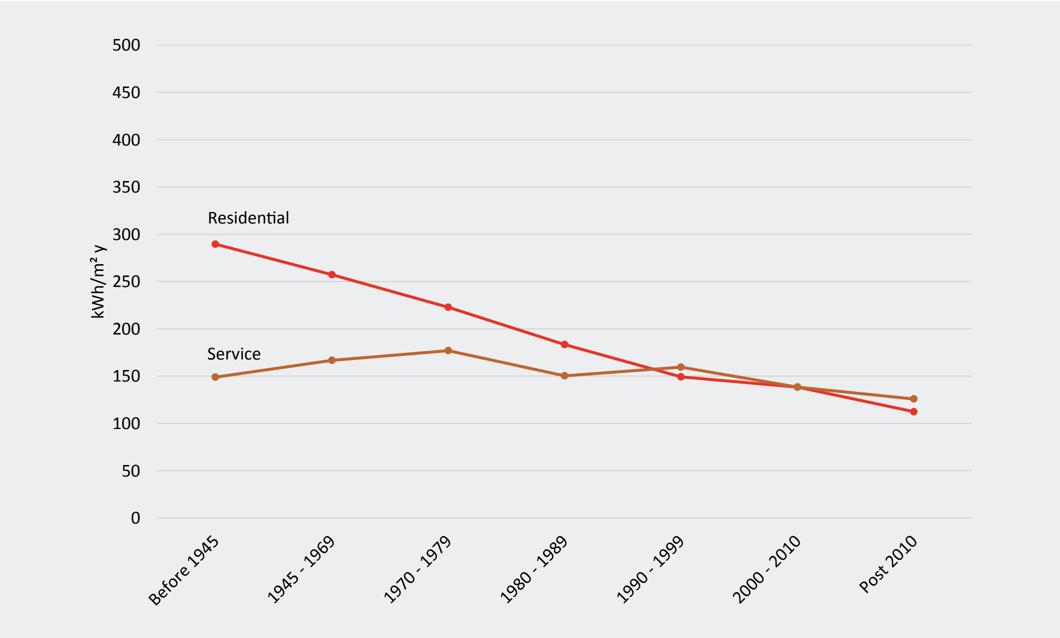

Figure 51. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Hungary).

In the residential sector of Hungary, buildings erected before 1945 consume around 289 kWh/ m² y of specific FEC for SH and DHW. The rate then drops to approximately 257 kWh/m² y in the buildings constructed in 1945-1969. Buildings constructed in the 1970s consume about 222 kWh/ m² y. The consumption rate keeps dropping regarding buildings that have been erected lately. For instance, buildings constructed between 1980-1989 show the value of specific FEC for SH and DHW for about 183 kWh/m² y. The consumption rate then falls to approximately 149 kWh/m² y regarding buildings erected in the 1990s. After that, the consumption rate drops slightly regarding buildings of the 2000s, with the value of about 138 kWh/m² y. Buildings constructed in the post-2010 period show the value of specific FEC for SH and DHW of about 112 kWh/m² y.

The value of specific FEC for SH and DHW in the service sector shows different patterns as the rate demonstrates fluctuation regarding buildings erected during the analyzed periods.

Buildings erected before 1945 show a consumption rate of around 149 kWh/m² y. The rate slightly increases to approximately 166 kWh/m² y regarding buildings erected in 1945-1969. Buildings constructed in the 1970s consume about 177 kWh/m² y. The consumption rate then drops to around 150 kWh/m² y in the buildings of the 1980s. The rate again rises to about 159 kWh/m² y regarding buildings of the 1990s. Service buildings erected between 2000-2010 show similar value for specific FEC with the residential ones, i.e., 138 kWh/m² y. The least specific FEC is consumed by buildings erected in the post-2010 period, with a value of about 125 kWh/m² y.

Figure 52 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

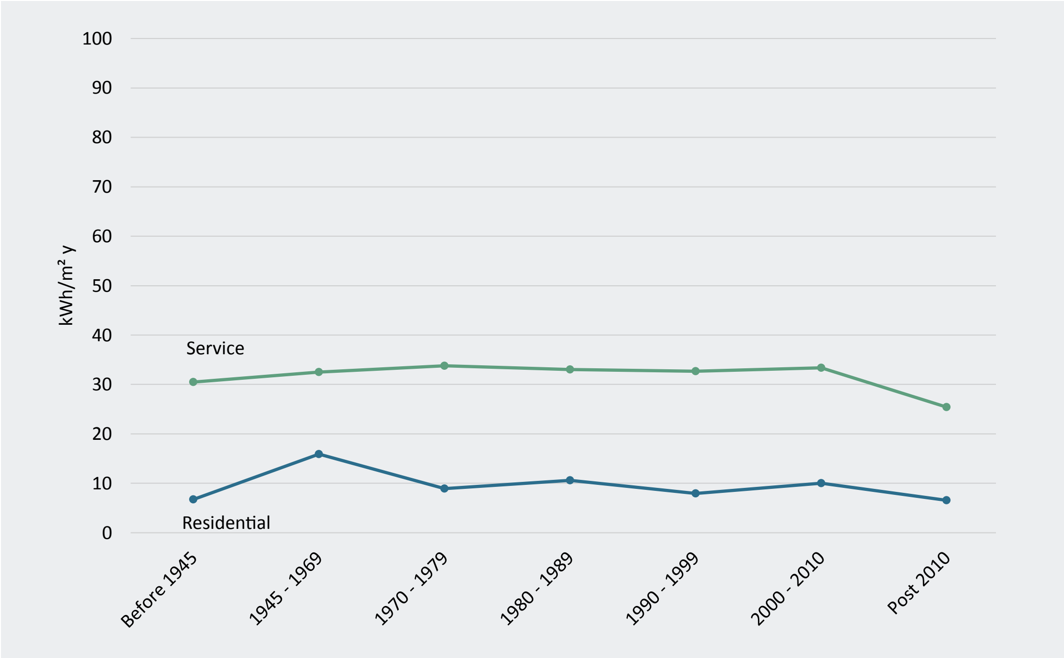

Figure 52. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Hungary).

The trend of specific FEC for SC in the residential sector of Hungary shows different variations as it keeps fluctuating. Buildings erected before 1945 consume about 6 kWh/m² y. This is the lowest specific FEC for SC that is observed in the residential and service sectors. The rate increases to approximately 16 kWh/m² y regarding buildings erected between 1945-1969. the consumption rate drops to about 9 kWh/m² y in buildings constructed in the 1970s. Buildings erected in the 1980s show almost the same rate, which is approximately 10 kWh/m² y. Buildings constructed in the 1990s consume about 7 kWh/m² y, whereas approximately the same, i.e., 10 kWh/m² y of specific FEC, is consumed by buildings erected from 2000 till 2010. Buildings erected in the post-2010 period indicate the smallest value of around 6 kWh/m² y.

The rate of specific FEC for SC in the service sector regarding buildings erected before 1945 is about 30 kWh/m² y. The consumption rate slightly increases to around 32 kWh/m² y in the lately erected buildings, i.e., 1945-1969. The rate keeps increasing slightly to approximately 33 kWh/m² y in the buildings constructed between 1970-1979. The same specific FEC is observed in buildings of the 1980s. About 32 kWh/m² y is consumed by buildings which are erected in the 1990s. Buildings of the 2000s consume a slightly higher specific FEC, almost 33 kWh/m² y. The least specific FEC for SC is observed in the service buildings erected in the post-2010 period, with a value of about 25 kWh/m² y.

Regarding the construction methodology presented in the data set provided by the H2020 HotMaps repository (8), the main construction topology for walls, concerning all periods, is solid walls with insulation, except historical buildings (erected before 1945). The construction methodology for windows is mainly single and double-glazing windows. Single glazing windows are present in buildings erected before 1945 to the late 1970s. Double glazing windows were installed in buildings erected in the 1980s and afterward. Low emittance glazing windows are not presented.

We can observe that the flat roof is the most popular decision regarding MFHs, ABs and SFHs constructed in the 1990s and afterward. Insulation is present in buildings erected in the 1980s and afterward, with insulation in buildings erected in the post-2010 period. The tilted roof is primarily present in SFHs with insulation regarding buildings erected during the three last periods. Concrete slabs are used in houses erected throughout all historical periods. Insulation is present only in buildings erected after 2010.

Information about construction materials and construction methodology of the service sector was received by questioning experts. The information concerning (Eastern Europe: Poland, Czech Republic, Hungary, Slovenia, Slovakia, Croatia, Bulgaria, Romania) was summarized afterwards. Concerning the Hungarian service sector, the information is presented in the table below (Table 25).

CONSTRUCTION MATERIALS				**CONSTRUCTION METHODOLOGY**			
Office, trade, health, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation in few cases	Wood, low emittance glass only in few cases.	Concrete and metallic roof boards + insulation	Concrete+ insulations in few cases	Solid wall	Double glazing	Flat roof	Concrete slab
Education							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation in few cases	Synthetic/PVC, low emittance glass only in few cases.	Concrete and tiles + insulation in few cases	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roof	Concrete slab
Hotels and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roof	Concrete slab

Table 25. Construction materials, construction methodology-service sector (Hungary).

The table above (Table 25) shows that the service sector demonstrates similarities with construction methodology and relative similarity with construction materials regarding different types of buildings. For the office, trade, health, and other non-residential buildings, the use of construction materials and methodology stay the same. Education buildings, hotels, and restaurants have similar construction methodology while demonstrating the small difference in construction materials.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 26 shows the thermal transmittance value (W/m^2 K) regarding two considered building sectors (residential and service) for all periods.

Table 26 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and buildings elements regarding different periods affect heat flow and thus specific FEC variation.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	0.97	3.50	1.13	0.99
1945 - 1969	1.35	2.70	0.92	0.93
1970 - 1979	1.36	2.34	0.64	0.77
1980 - 1989	1.36	2.16	0.39	0.63
1990 - 1999	0.49	2.00	0.29	0.37
2000 - 2010	0.35	1.75	0.24	0.35
Post 2010	0.22	1.50	0.21	0.31
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.40	3.00	1.40	1.00
1945 - 1969	1.20	2.85	1.20	0.90
1970 - 1979	0.95	2.77	1.00	0.85
1980 - 1989	0.70	2.70	0.70	0.80
1990 - 1999	0.60	2.45	0.50	0.65
2000 - 2010	0.50	2.20	0.30	0.50
Post 2010	0.24	1.23	0.16	0.47

Table 26. Thermal transmittance of construction elements (Hungary).

According to the analysis, the individual non-condensing gas boilers for SH and DHW is used in buildings constructed during all analyzed periods.

The results for SC technology show that in most cases, SC is not represented in this residential market. The value for specific FEC for SC in most cases is around 10 kW/m²y, according to the information presented in Figure 52.

These findings demonstrate a lack of renewable energy sources for SH, DHW, and SC in the Hungarian residential building stock that mainly utilize gas.

According to expert questioning: the most common technology in the service sector for SH and DHW is non-condensing gas boiler. SC is not presented in most cases, except in the health industry, where SC is mainly used.

3.14. IRELAND

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Ireland.

In Figure 53, the Mm² of covered floor area in Irish residential and service sectors, is presented in percentages regarding historical periods.

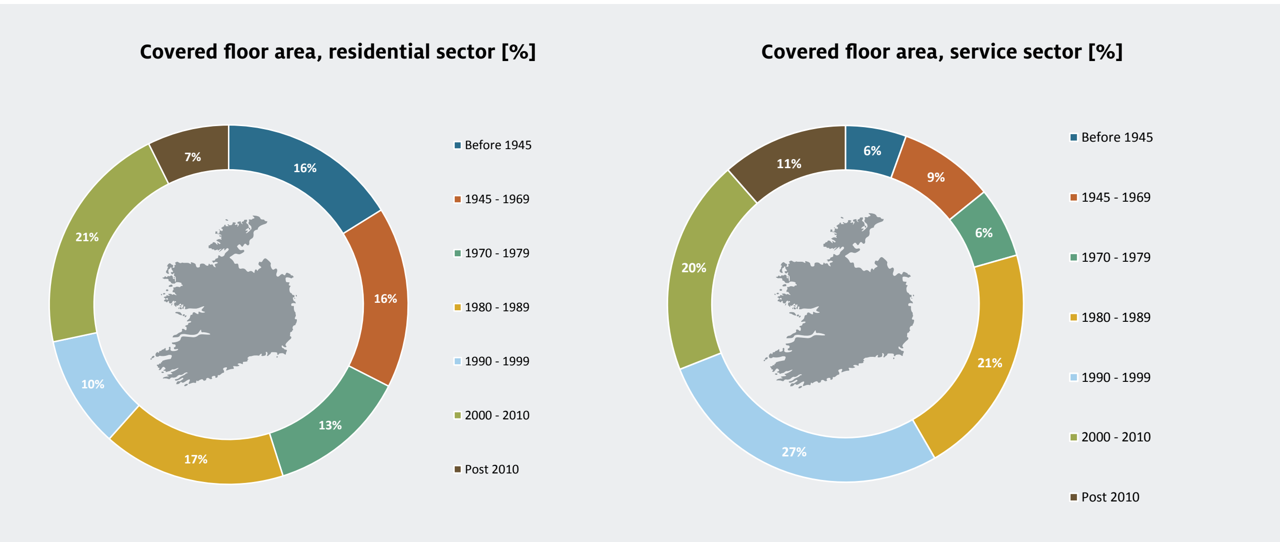

Figure 53. Split of the residential and service building stock raised per construction periods [%] (Ireland).

The result demonstrates the highest percentage of covered floor area regarding residential buildings constructed in the 2000s - 21%. The period between 1980-1989 accounts for a lower percentage of covered floor area, i.e., 17%. Buildings erected before 1945 occupy 16% of the total covered floor area. The equal percentage ratio indicates buildings erected between 1945-1969 respectively, i.e., 16%. In residential buildings of the 1970s, the ratio is 13%. Buildings erected in the 1990s occupied 10% of the covered floor area. The minor percentage ratio is found in buildings erected in the post-2010 period, with only 7%.

Service buildings erected in the 1990s occupy 27% of the total floor area. In contrast, a slightly lower percentage ratio is found in buildings erected in the 1980s, with 21% respectively. The highest percentage ratios of covered floor area are found in buildings constructed between 2000-2010, with 20%. Around 11% of the covered floor area is found in buildings constructed in the post-2010 period. One of the smallest percentage ratios of covered floor area belongs to buildings erected before 1945 with 9%. The minor percentage ratio indicates buildings constructed between 1945-1969 and during the 1970s with only 6% respectively.

Figure 54 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 54 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

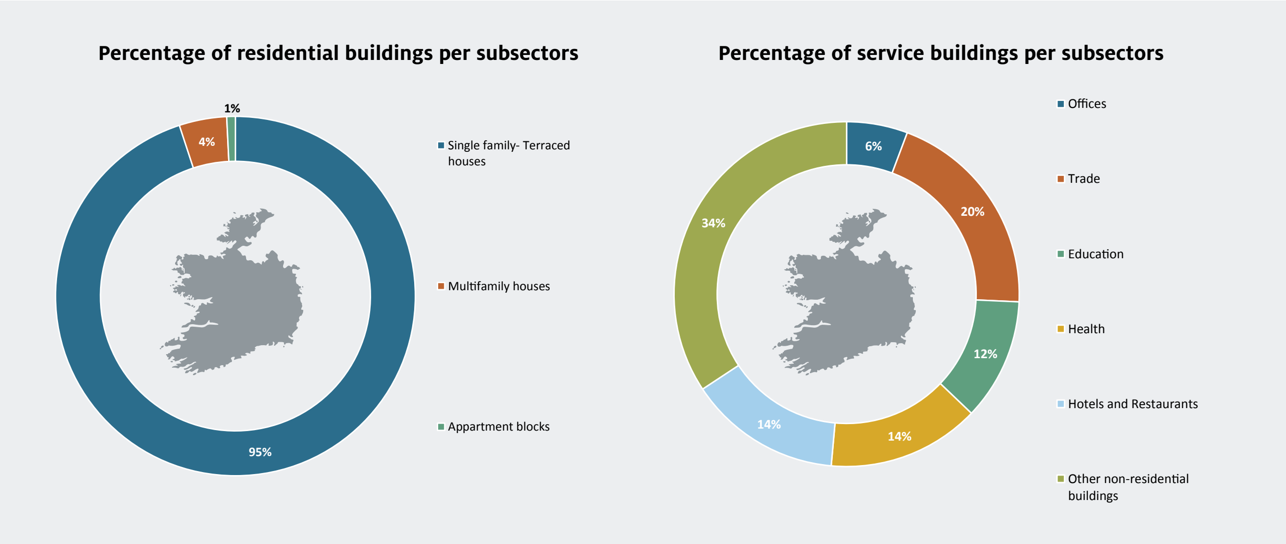

Figure 54. Split of residential and service buildings per different subsectors [%] (Ireland).

The residential sector shows that 95% of the sector is categorized as SFHs. This leaves only 5% of the sector behind, including 4% for MFHs, and only 1% for ABs.

Considering the service sector, we observe that the majority of the service building stock is occupied by other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms) with 34%. Trade buildings are the second largest building type with 20%, followed by health, hotels, and restaurants with 14% respectively. Educational buildings cover about 12% of the service building stock in Ireland. Whereas the minor portion of the market belongs to office building types with 6% accordingly.

Figure 55 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

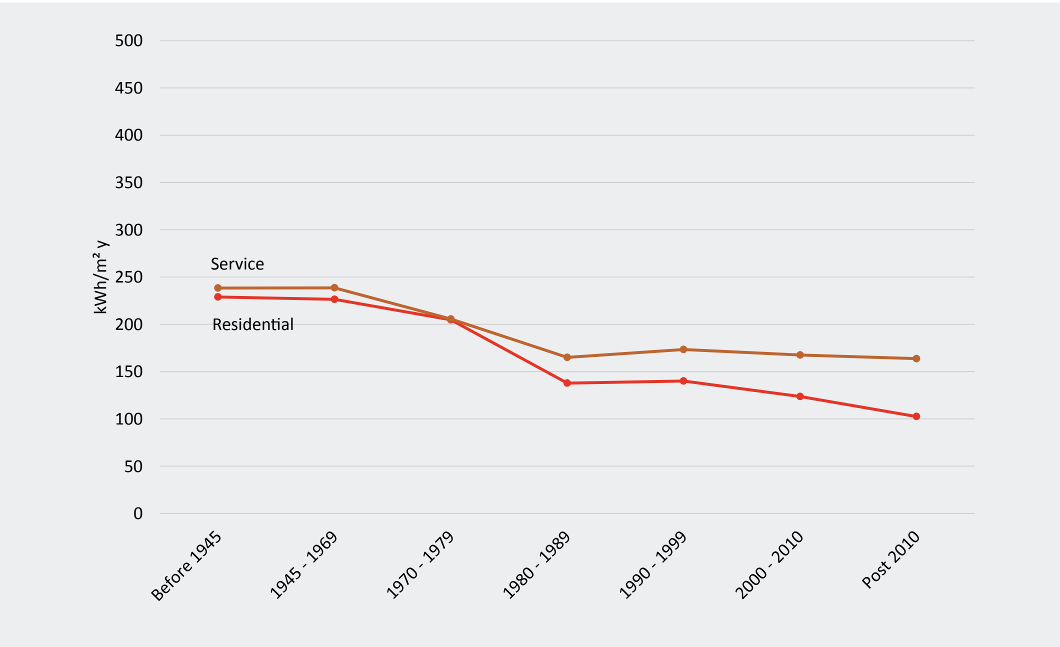

Figure 55. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Ireland).

The development trend of specific FEC for SH and DHW is seen to be decreasing regarding buildings erected before 1945 till post-2010. The highest FEC is consumed by buildings erected before 1945, i.e., 229 kWh/m² y. The consumption rate then slightly decreases from about 229 kWh/m² y to 226 kWh/m² y regarding buildings erected between 1945-1969. Buildings erected in the 1970s indicate approximately 206 kWh/m² y of specific FEC. The specific FEC of buildings erected in the 1980s and 1990s indicate approximately 138 and 140 kWh/m² accordingly. The trend of specific FEC then slightly decreased to about 124 kWh/m² y in the buildings of the 2000s. The lowest specific FEC for SH and DHW is consumed by buildings of the post-2010 period with approximately 102 kWh/m² y, respectively.

The trend of specific FEC for SH and DHW in the service sector demonstrates similarities with the residential one. Before 1945, the consumption rate is approximately 238 kWh/m² y. This rate remains almost the same regarding buildings erected before 1945 till 1969, i.e., 238 kWh/m² y. Service buildings erected in the 1970s indicate the same consumption rate as the residential ones, about 206 kWh/m² y. In comparison, those erected in the 1980s indicate a rapid decrease in specific FEC with the value of around 165 kWh/m² y. The consumption rate then slightly raised to about 174 kWh/m² y regarding buildings constructed in the 1990s. Moving forward, we can observe that the value of specific FEC in buildings erected in the 2000s is relatively less, with a value of about 167 kWh/m² y. The lately erected buildings (post-2010 period) consume relatively the same FEC for SH and DH, which is approximately 164 kWh/m² y.

Figure 56 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

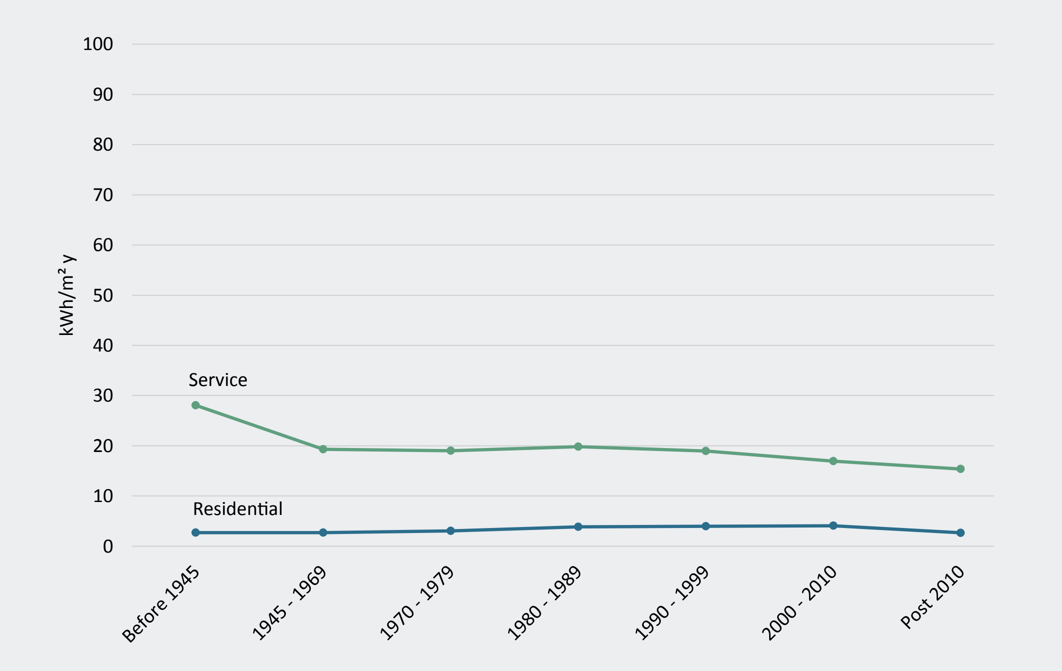

Figure 56. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Ireland).

In the residential sector of Ireland, the trend of specific FEC for SC shows that buildings constructed before 1945 till the 2000s are characterized by an increase in specific FEC for SC. Buildings erected before 1945 consume about 2.7 kWh/m² y. The consumption rate stays almost the same regarding buildings erected between 1945 and 1969. The trend of specific FEC for SC then rises to more than 3 kWh/m² y regarding buildings constructed in the 1970s. Buildings erected in the 1980s and 1990s, and 2000s indicate a relatively equal value of approximately 4 kWh/m² y.

Buildings erected in the post-2010 period indicate the same consumption rate as historical ones (erected before 1945) with the value of about 2.7 kWh/m² y respectively.

In comparison, the overall trend of specific FECs for SC in the service sector decreases. Buildings that were built before 1945 indicate the highest value for specific FEC of about 28 kWh/m² y. The consumption rate then dropped to about 19 kWh/m² y in buildings erected from 1945 to 1969. The rate of specific FEC then stays mainly the same regarding buildings erected from the 1970s to the 1990s, i.e., 19 kWh/m² y. Building erected in the 2000s shows a slight reduction in the specific FEC with the value of about 17 kWh/m². The lowest specific FEC for SC is observed in buildings constructed after 2010, with a specific FEC of approximately 15 kWh/m² y, while in the residential sector, the value is only around 3 kWh/m² y.

Regarding the construction methodology presented in the dataset provided by the H2020 HotMaps project (8), the main construction topology for walls is a cavity wall with insulation only in buildings erected from the 1970s to post 2010. Solid wall presents in historical buildings (SFHs and MFHs) constructed before 1945 without the presence of insulation. A solid wall is also present in ABs erected before 1945, between 1945-1969, and during the period of the 1980s and 2000s. Honeycomb bricks / hollow blocks wall are found in buildings erected between 1945-1969. The construction methodology for windows is mainly double and single glazing windows. Single glazing windows are found in buildings erected before 1945 to the late 1980s. After that, double-glazing windows are mainly installed. We can observe that tilted roof is the most popular decision regarding SFHs and MFHs with insulation. A flat roof is mainly present in ABs. Insulation for a flat roof is in buildings constructed after 1945. Concrete slabs with insulation are the most widespread technology for floors in Irish houses throughout all periods.

Information about construction materials and construction methodology of the service sector was received by experts questioning. The information concerning Central Europe (Austria, Belgium, Germany, Netherland, Luxembourg, France, UK and Ireland) was eventually summarized. Concerning the Irish service sector, the information is presented in the table below (Table 27).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, educational, health, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete +insulation	Aluminum, low emittance glass only in few cases.	Concrete + insulation	Concrete+ insulations	Solid wall	Double glazing	Flat roof	Concrete slab
Trade, hotels and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete or bricks+ insulation	Aluminum and synthetic/PVC, low emittance glass only in few cases.	Concrete and bricks +insulations	Concrete +insulations	Solid walls	Double glazing	Flat roof	Concrete slab

Table 27. Construction materials, construction methodology-service sector (Ireland).

The table above shows that the service sector demonstrates similarities in construction materials and methodology regarding different types of buildings. For Offices, educational, health, and other non-residential buildings, the use of construction materials and methodology stay mainly the same, while it is also true for trade, hotels, and restaurants.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 28 shows the thermal transmittance value (W/m^2 K) regarding two considered building sectors (residential and service) for all periods.

Table 28 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and buildings elements regarding different periods affect heat flow and, as a result, specific FEC.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	2.01	4.75	1.15	1.54
1945 - 1969	2.05	5.67	0.69	1.17
1970 - 1979	1.74	4.91	0.73	1.41
1980 - 1989	0.60	4.12	0.40	1.20
1990 - 1999	0.55	2.81	0.27	0.75
2000 - 2010	0.27	2.36	0.18	0.48
Post 2010	0.21	1.30	0.16	0.31
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.90	4.80	0.80	2.00
1945 - 1969	1.80	4.80	0.90	1.70
1970 - 1979	1.30	4.05	0.80	1.40
1980 - 1989	0.80	3.30	0.40	1.10
1990 - 1999	0.70	2.90	0.30	0.50
2000 - 2010	0.40	2.30	0.20	0.30
Post 2010	0.10	1.84	0.10	0.25

Table 28. Thermal transmittance of construction elements (Ireland).

According to the analysis, a central SH and DHW system is mainly available in buildings constructed during all analyzed periods. Heat pump application is used in buildings erected in the post-2010 period.

Liquid fuel and gas are widely used for SH and DHW in the residential sector. SFHs and MFHs mainly use liquid fuel. Gas is primarily utilized in ABs erected in the 1990s and afterward.

The results for SC technology show that in most cases, SC is not represented in this residential market. The value for specific FEC for SC in most cases is around 3 kW/m^{2}y, according to the information presented in Figure 56.

These findings demonstrate a lack of renewable energy sources for SH, DHW, and SC in the Irish residential building stock that mainly utilize liquid and gaseous fuels.

According to expert questioning: The most common technologies for SH and DHW are central gas condensing boilers, heat pumps, electricity. SC is not present in most cases, except health industry, where SC is often used.

3.15. **ITALY**

This section represents a selection of main results that were obtained from the building stock analysis dataset regarding Italy (8).

In Figure 57, the Mm^2 of covered floor area in the Italian residential and service sectors is presented in percentages regarding historical periods.

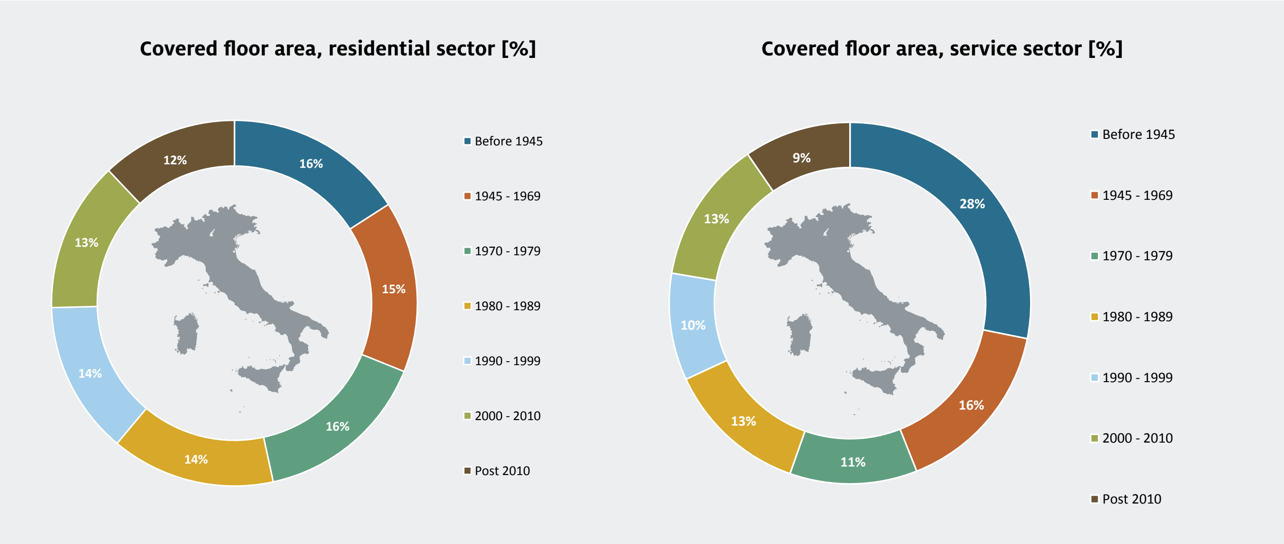

Figure 57. Split of the residential and service building stock raised per construction periods [%] (Italy).

As visible from the figure above, the residential sector demonstrates close similarities across all historical periods. The data indicate that a relatively equal building area characterizes each consecutive period that differs from the previous one by no more than 2%. The higher percentage ratio of covered floor area is determined in the period from before 1945 to the 1970s. The earliest period (before 1945) and the period of the 1970s indicate 16% respectively, while it is also true for periods of the 1980s and 1990s with 14% each. The period between 1945-1969 indicates 15% of covered floor area. The two last periods (the 2000s and post-2010) show 13% and 12% accordingly.

In contrast, the service sector does not demonstrate equalities in different periods. As shown from the figure above, the historical period «before 1945» displays the highest percentage of covered floor areas, 28%, which means that the significant numbers of service buildings in Italy are characterized as historical buildings. The second-largest portion of the covered floor area is found in buildings erected between 1945-1969, with 16%. The period of the 1970s indicates 11% of covered floor area. The matching results were determined in the 1980s and between 2000-2010 with a value of 13%. The minor portion demonstrates the period of the 1990s and the last post-2010 period with 10% and 9% respectively.

Figure 58 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 58 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

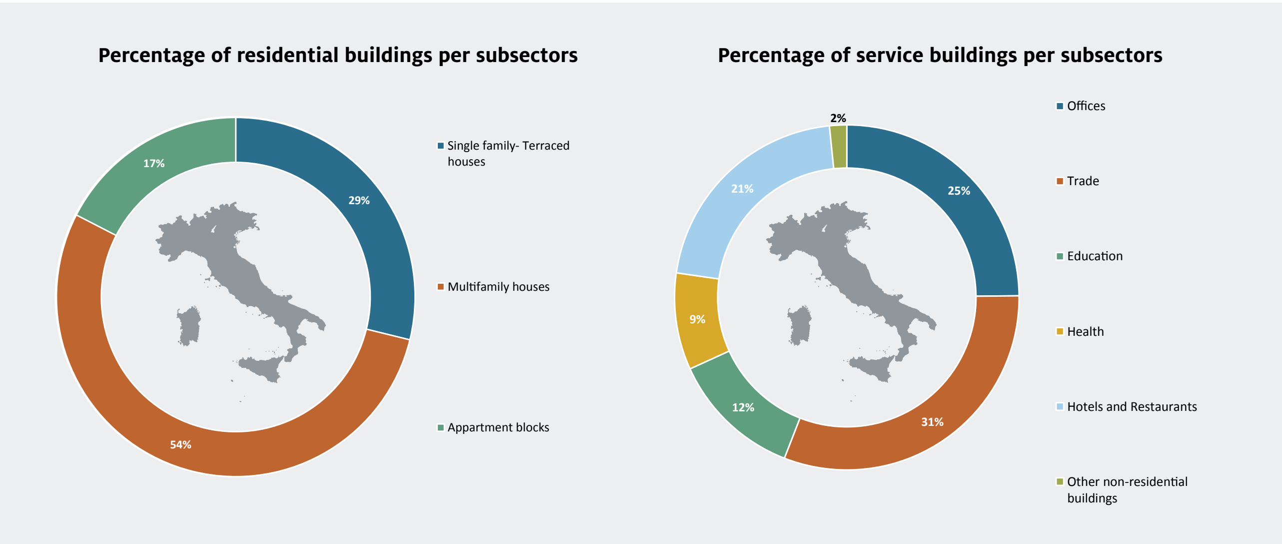

Figure 58. Split of residential and service buildings per different subsectors [%] (Italy).

According to this data, more than half of Italian residential building stock is covered by MFHs, with 54% of the total. SFH's occupy 29% of the market, whereas ABs cover the remaining 17% of the residential sector.

Considering the service sector, we notice that trade buildings are the most widespread building type in Italy (31%). Offices follow with about 25%. Hotels and restaurants come next with 21%. Educational buildings account for 12%. Health sector buildings follow with 9% and Other non-resdiential buildings are last positioned with 2%.

Figure 59 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

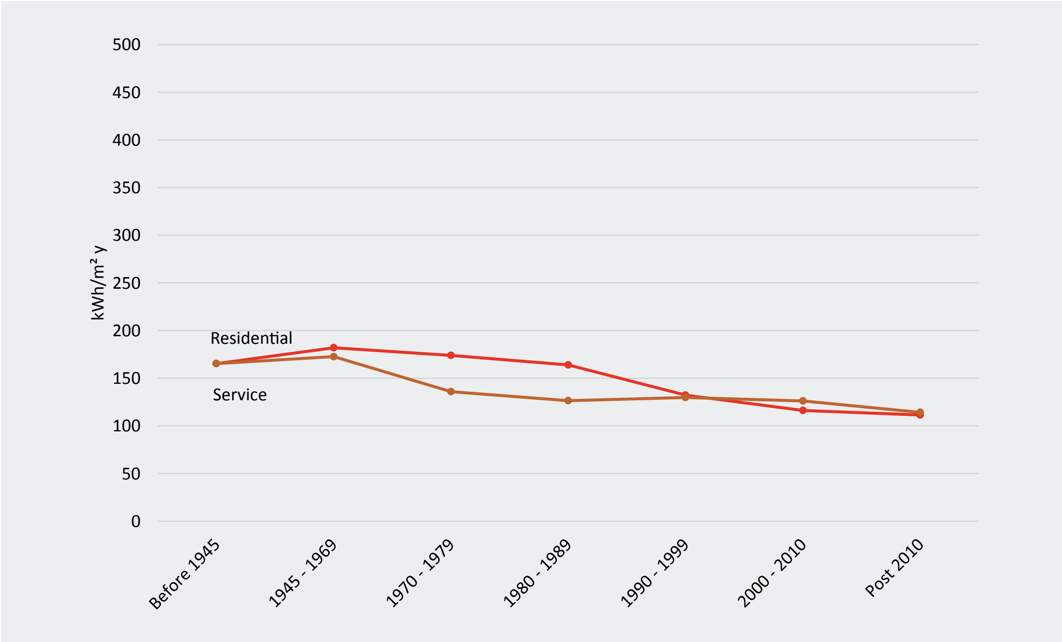

Figure 59. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Italy).

The development trend of specific FEC for SH and DHW is seen to be decreasing regarding buildings erected before 1945 till post-2010. Buildings erected before 1945 indicate the value of specific FEC of about 165 kWh/m² y. The highest FEC is consumed in buildings erected between 1945-1969 with approximately 182 kWh/m² y. Buildings erected in the 1970s indicate the slight reduction in specific FEC to the value of about 174 kWh/m²y. The specific FEC continued decreases in buildings erected in the 1980s with about 164 kWh/m² y. The trend of specific FEC then indicates the drop to approximately 130 kWh/m² y regarding buildings constructed in the 1990s. The reduction in specific FEC then slows down regarding buildings of the 2000s with the value of around 116 kWh/m² y. The lowest specific FEC for SH and DHW is consumed by buildings of the post-2010 period with approximately 114 kWh/m² y.

The trend of specific FEC for SH and DHW in the service sector shows similarities with the residential one regarding buildings erected before 1945, between 1945-1969, and during the last three periods (the 1990s, 2000s, and post-2010). Service buildings erected before 1945 show the same consumption rate as the residential ones, i.e., 165 kWh/m² y. The consumption rate of buildings erected between 1945-1969 indicates a slight increase up to the value of about 172 kWh/m² y. The rate further drops to almost 136 kWh/m² y regarding buildings of the 1970s. Buildings erected in the 1980s consume relatively less, about 126 kWh/m² y, whereas those erected in the 1990s indicate a slightly higher specific FEC of about 130 kWh/m² y, respectively. The consumption rate again drops to about 126 kWh/m² y regarding buildings constructed in the 2000-2010 period. The lately erected service buildings in the post-2010 period consume almost the same FEC for SH and DH as the residential ones, i.e., 114 kWh/m² y.

Figure 60 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

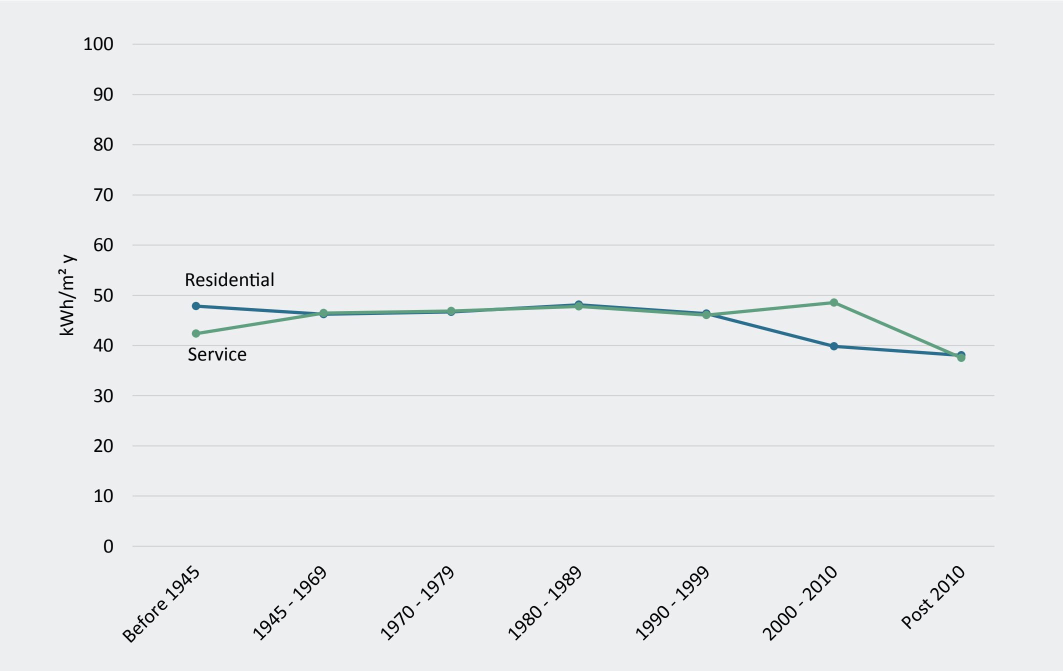

Figure 60. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Italy).

The trend of specific FEC for SC in residential and service sectors is relatively equal regarding buildings erected from 1945 to the late 1990s and during the last post-2010 period.

Specific FEC for SC in the residential buildings erected before 1945 is about 48 kWh/m² y, whereas in the service sector, it is slightly lower, i.e., 42 kWh/m² y. Buildings erected from 1945 till 1969 consume about 46 kWh/m² y in both sectors. The consumption rate remains relatively the same in the residential and service buildings erected in the 1970s, i.e., 47 kWh/m² y. Residential and service buildings constructed in the 1980s consume about 48 kWh/m² y of specific FEC for SC. The trend then decreases to about 46 kWh/m² y, regarding buildings (residential and service) erected in the 1990s. Residential buildings of the 2000s consume relatively less energy of about 40 kWh/m² y, whereas service ones indicate a slight increase to around 48.5 kWh/m² y of specific FEC for SC. The smallest value of specific FEC is found in both residential and service buildings erected in the post-2010 period, with the value of approximately 37.5 kWh/m² y, respectively.

Regarding the construction methodology presented in the data set provided by the H2020 Hot-Maps repository (8), the main construction topology for walls, concerning all historical periods, is honeycomb bricks and hollow blocks walls that are present in SFHs and MFHs erected from the 1970s and afterward. Honeycomb bricks and hollow blocks wall is also determined in ABs regardless construction periods. Insulation was used in buildings erected in the 1980s and afterward. A solid wall is mainly present in historical buildings erected before 1945 and SFHs and MFHs erected between 1945-1969.

The construction methodology for windows is mainly double and single glazing windows. Single glazing windows are presented in buildings that were erected before 1945 and between 1945-1969. Buildings erected after are mainly characterized by using double-glazing windows. Low emittance glazing is present in buildings erected in the 1990s and afterward.

We can observe that a tilted roof is the most popular decision regarding SFHs and MFHs, respectively. A flat roof is presented in ABs regardless of historical periods. Insulation is determined in buildings erected from the 1980s and afterward. Concrete slabs (insulation presented from the 1980s) were primarily used in Italian residential buildings throughout analyzed periods.

Information about construction materials and construction methodology of the service sector was received by experts questioning. The information concerning Southern Europe (Spain, Italy, Greece, Cyprus, Malta, and Portugal) was eventually summarized. Concerning the Italian service sector, the information is presented in the table below (Table 29).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, health, hotels and restaurants, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Flo
Bricks+ Insulation only in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete+ insulations in few cases	Honeycomb bricks/hollow block walls	Single and double glazing	Flat roof	Con sl
Education							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Flo
Bricks and concrete + Insulation only in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulation in few cases	Honeycomb bricks/hollow block walls	Double glazing	Flat roof	Con sl

Table 29. Construction materials, construction methodology-service sector (Italy).

The table above shows that the service sector demonstrates similarities in construction materials and methodology regarding different types of buildings. All kinds of service buildings are erected by using relatively the same kind of material and construction methodology. The only contrast is the wall of educational buildings that are constructed not only out of bricks but also from concrete.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The effect differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). According to all historical periods, Table 30 shows the thermal transmittance value (W/m^2 K) of residential and service sectors.

Table 30 helps to figure out the impact of building elements on specific FEC. As seen from the table below, the thermal transmittance values demonstrate the reduction throughout all periods. Here we can observe how thermal insulation materials and different elements of buildings (walls, windows, roof, and floor) affect heat flow.

RESIDENTIAL SECTOR

Historical period	Walls	Windows	Roof	Floor
Before 1945	1.29	4.97	1.53	1.35
1945 - 1969	1.37	4.49	1.36	1.07
1970 - 1979	1.17	4.05	1.20	1.29
1980 - 1989	0.79	3.52	0.91	0.90
1990 - 1999	0.59	2.93	0.57	0.63
2000 - 2010	0.46	2.56	0.42	0.46
Post 2010	0.34	2.20	0.28	0.30

SERVICE SECTOR

Historical period	Walls	Windows	Roof	Floor
Before 1945	1.20	5.50	1.30	0.80
1945 - 1969	0.78	5.20	1.05	0.65
1970 - 1979	0.57	4.90	0.92	0.57
1980 - 1989	0.47	4.20	0.86	0.53
1990 - 1999	0.42	3.60	0.83	0.50
2000 - 2010	0.39	2.98	0.80	1.40
Post 2010	0.37	2.37	0.33	0.37

Table 30. Thermal transmittance of construction elements (Italy).

The analyzed data related to technologies for SH and DHW in the Italian residential sector reveals that the leading technologies are central non-condensing and combined gas boilers. Combined gas boilers are used in SFHs and MFHs, while in ABs, non-condensing gas boilers are primarily used. Individual non-condensing gas boilers are also used for DHW needs in MFHs and ABs erected before 1945 to the late 1990s, while individual condensing gas boilers installed in ABs that were erected during the last two periods (2000-2010, post-2010). Regarding renewable energy sources, solar collectors for DHW are mainly used in ABs erected from 2000 to the post-2010 period, and MFHs erected in the post-2010 period, respectively. Condensing gas boilers and solar collectors for DHW are characterized as less widespread types of technologies.

The most common energy carrier for SH and DHW in the Italian residential building stock is gas.

The results for SC technology show that in most cases, SC is not represented in the Italian residential market.

Findings demonstrate that technology for SH and DHW, besides utilizing traditional energy sources, also uses solar collectors for DHW needs. However, as mentioned above, this type of renewable energy is characterized as a less widespread technology.

According to expert questioning, the most common technologies for SH and DHW are central and individual gas condensing boilers and electricity. Individual gas condensing boilers are present only in office buildings, while electric heating is used in trade building types. SC is present in most cases, except educational buildings.

3.16. **3.16 LATVIA**

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Latvia.

In Figure 61, the Mm² of covered floor area in the Latvian residential and service sectors is presented in percentages regarding historical periods.

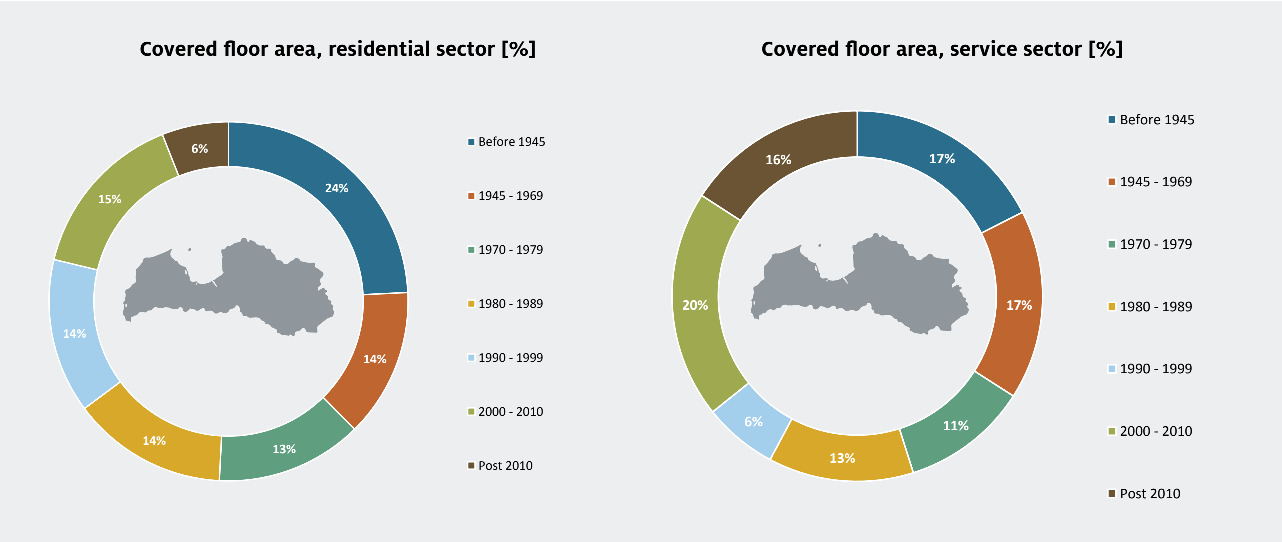

Figure 61. Split of the residential and service building stock raised per construction periods [%] (Latvia).

The result shows that the highest percentage of covered floor area refers to residential buildings constructed before 1945 with a percentage ratio of 24%. The period between 1945-1969 accounts for a lower percentage of covered floor area, i.e., 14%. Buildings erected in the 1970s occupy 13% of the total covered floor area. Residential buildings of the 1980s and 1990s occupy 14% respectively. While buildings of the 2000s indicate 15%. The minor percentage ratio is related to buildings erected in the post-2010 period, which covers only 6%.

The figure above shows that the highest percentage of covered floor area in the service sector refers to buildings constructed between 2000-2010 with 20%. After this, the ratio is 17% regarding buildings erected before 1945 and between 1945 – 1969. A decrease of 1% is found in buildings erected in the post-2010 period with 16%. Buildings erected in the 1980s indicate 13% of the total floor area, respectively. One of the smallest percentage ratios of covered floor area belongs to buildings erected in the 1970s, i.e., 11%. The minor percentage ratio indicates buildings constructed in the 1990s with only 6%.

Figure 62 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 62 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

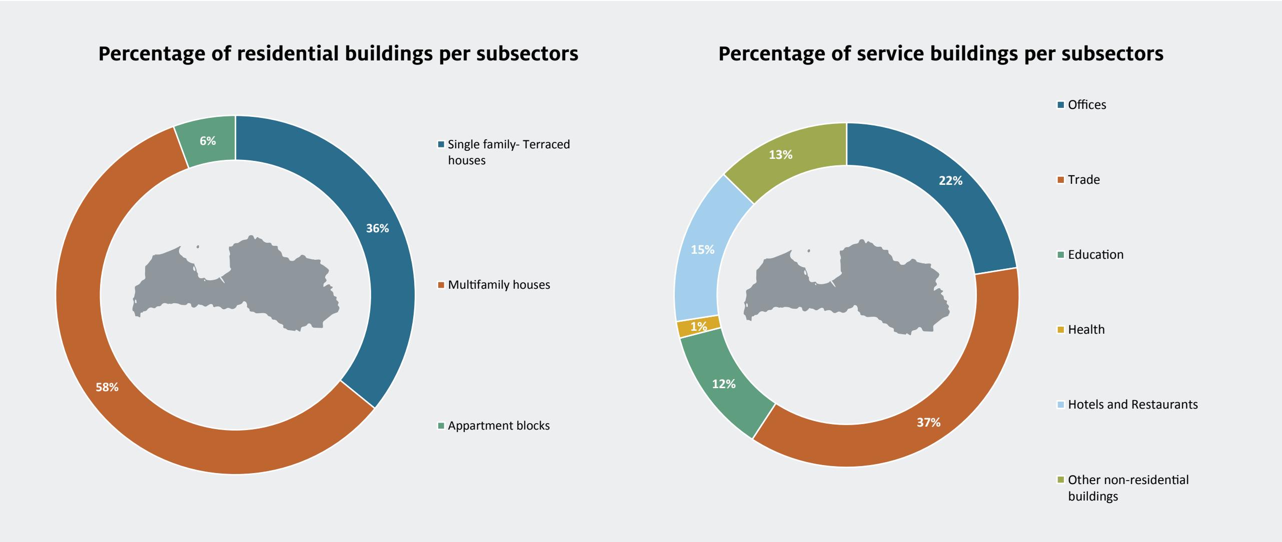

Figure 62. Split of residential and service buildings per different subsectors [%] (Latvia).

Figure 62 clearly shows that in the residential sector, more than half - i.e., 58% - is occupied by MFHs. SFHs is the second popular type of building with 36%, leaving behind the remaining 6% of the market for ABs.

Considering the service sector, we observe that trade buildings are the most widespread building type in Latvia. These types of buildings occupied 37% of the market. In comparison, the second-highest type of building is offices that occupy 22% accordingly. Over 15% of the market is designated for hotels and restaurants. Other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms), indicate 13% respectively. Education buildings cover 12% of the service building stock, respectively. The remaining 1% of the market refers to health buildings types.

Figure 63 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

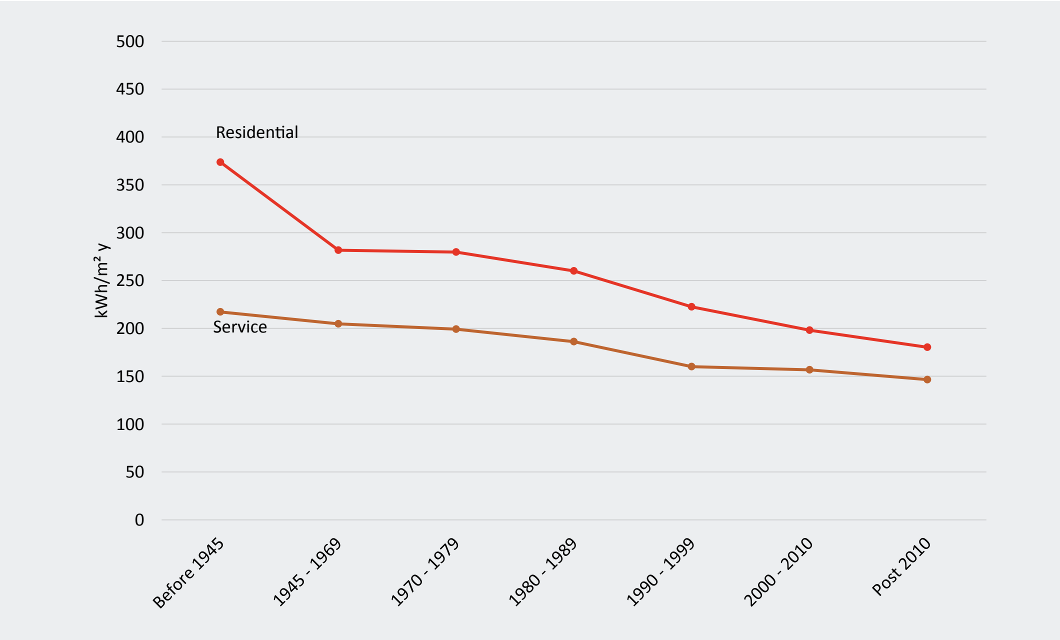

Figure 63. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Latvia).

The overall trend of specific FEC for SH and DHW in residential and service buildings decreases steadily regarding buildings erected before 1945 till 2010.

Residential buildings erected before 1945 to the post 2010 show that specific FEC for SH and DHW is dropped from about 374 kWh/m² y to approximately 180 kWh/m² y. Buildings erected before 1945 show the highest value of specific FEC for SH and DHW of about 374 kWh/m² y. In comparison, buildings erected between 1945-1969 show a drop to about 282 kWh/m² y. The trend of specific FEC continues decreasing consecutively. In contrast, buildings erected in the 1970s consume about 280 kWh/m² y. A relatively lower result indicates buildings erected in the 1980s with the value of approximately 260 kWh/m² y. The lower specific FEC is found in buildings erected in the 1990s with the value of 223 kWh/m² y. Buildings erected in the 2000s show about 198 kWh/m² y of the specific FEC. After this, the value has reduced to approximately180 kWh/m² y regarding buildings erected during the post-2010 period.

In contrast, the specific FEC of SH and DHW in the service sector shows that the value is dropped from about 217 kWh/m² y to approximately 146 kWh/m² y regarding buildings erected before 1945 to the post-2010. Buildings erected before 1945 indicate the value of specific FEC of about 217 kWh/m² y. It then slightly decreases to about 205 kWh/m² y regarding buildings erected between 1945-1969. Buildings erected from 1970 till 1979 are characterized by a further decrease in specific FEC, with the value of about 199 kWh/m² y. Specific FEC for SH and DHW is steadily decreasing regarding buildings constructed from 1980 till the 2000s with values of approximately 186 160, 157 kWh/m² y, respectively. Service buildings erected during the post-2010 period consume about 146 kWh/m² y compared to a residential building (180 kWh/m² y) erected at the same time.

Figure 64 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

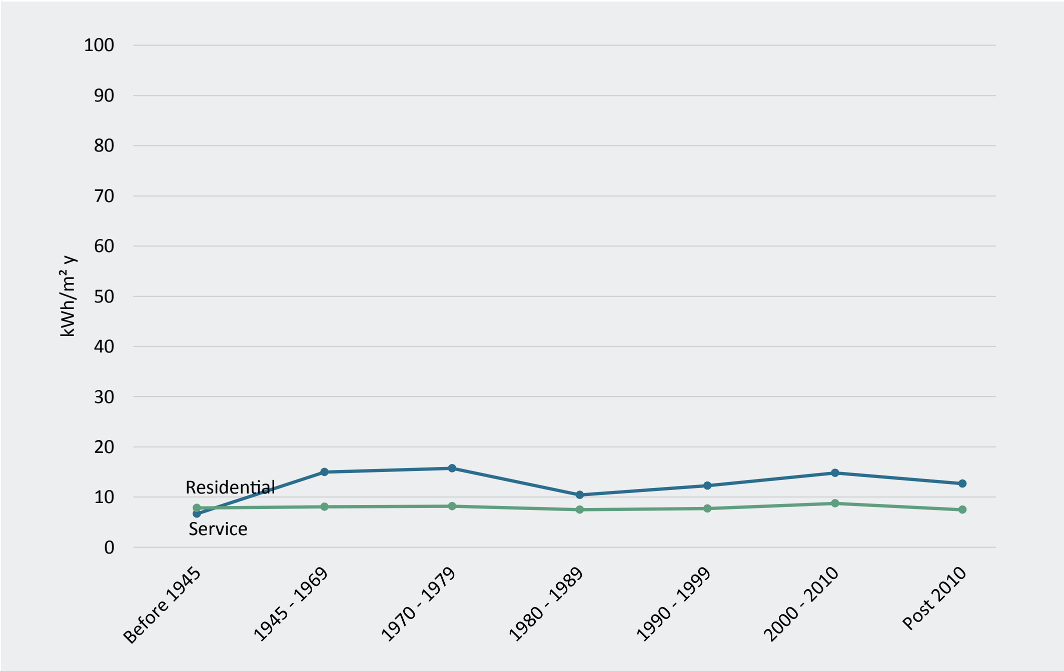

Figure 64. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Latvia).

In the residential sector, the trend of specific FEC for SC indicates that buildings erected before 1945 consume around 8 kWh/m² y. The value then increases to about 15 kWh/m² y regarding buildings erected between 1945-1969 and up to approximately 16 kWh/m² y regarding buildings of the 1970s. The specific FEC for SC then decreases to about 10.5 kWh/m² y in buildings of the 1980s. An increase in specific FEC is determined in buildings erected in the 1990s and 2000s. These buildings account for about 12 and 15 kWh/m² y, respectively. The decrease in specific FEC is determined in buildings erected after 2010 with the value of about 13 kWh/m² y respectively.

The rate of specific FEC for SC in the service sector regarding buildings erected before 1945 is the same as in the residential one, i.e., 8 kWh/m² y. After that, the consumption rate remaines the same regarding buildings constructed from 1945 to 1999. Buildings of the 2000s consume a slightly higher specific FEC, almost 9 kWh/m² y. The least specific FEC for SC is observed in the service buildings erected in the post-2010 period, with a value of about less than 8 kWh/m² y.

Construction methodology presented in the H2020 HotMaps project's dataset (8) shows that the most widespread type of construction topology for walls is a solid wall without insulation regardless of historic buildings and buildings erected from 1945 to the post-2010 period, respectively. Construction methodology for windows is primarily double-glazing windows, which are installed mainly in buildings erected between 1970-1979 and 1990-1999. The second popular type of windows is single glazing windows. Single glazing windows are present in historical buildings (erected before 1945) and in buildings that were constructed after WW II, respectively. The most energy-efficient type of windows – triple glazing windows are installed in newly erected buildings (erected in the 2000s and post-2010). The analysis reveals that low emittance glass is not present in the Latvian residential building stock. The constriction methodology for a roof is mainly tiled roof. A tilted roof is present almost in all types of buildings regardless of historical periods. Construction methodology for a floor is primarily characterized as concrete slabs without insulation. A concrete slab is determined in buildings erected during all analyzed periods (before 1945 – post-2010), respectively.

Information about construction materials and construction methodology of the service sector was received by questioning experts. The information concerning Northern Europe (Denmark, Finland, Sweden, Estonia, Latvia, and Lithuania) was summarized. Concerning the service sector in Latvia, the information is presented in the table below (Table 31).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, education, health, hotels and restaurants, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Aluminum (50%) and synthetic/ PVC (50%), low emittance glass in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulations in few cases	Honeycomb bricks/hollow block walls	Double and single glazing	Flat roof	Concrete slab

Table 31. Construction materials, construction methodology-service sector (Latvia).

The table above (Table 31) shows that the service sector show similarities in construction material and construction methodology regarding all types of service buildings.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 32 shows the thermal transmittance value ($W/m^2 K$) regarding two considered building sectors (residential and service) for all periods. Table 32 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and building elements regarding different periods affect heat flow and thus specific FEC variation.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.04	2.70	1.20	0.90
1945 - 1969	0.99	2.60	1.16	0.75
1970 - 1979	0.95	2.55	1.10	0.67
1980 - 1989	0.92	2.50	0.90	0.60
1990 - 1999	0.91	2.15	0.70	0.45
2000 - 2010	0.90	1.80	0.50	0.30
Post 2010	0.82	1.30	0.33	0.15
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.00	2.70	1.00	1.00
1945 - 1969	0.90	2.60	0.66	0.65
1970 - 1979	0.85	2.55	0.50	0.48
1980 - 1989	0.83	2.53	0.41	0.40
1990 - 1999	0.80	2.50	0.37	0.35
2000 - 2010	0.53	2.05	0.35	0.33
Post 2010	0.25	1.60	0.33	0.30

Table 32. Thermal transmittance of construction elements (Latvia).

The analyzed data concerning SH and DHW in the residential sector indicate that central non-condensing boiler is used regardless of all types of buildings and construction periods, being the main type of technology for SH and DHW needs accordingly.

Liquid and gas fuels are the most common energy carrier for SH and DHW in the Latvian residential building stock, while electricity is the third popular energy carrier respectively.

The results for SC technology show that in most cases, SC is represented in this residential market which is explaining by a climatic condition that doesn't often require SC application. For instance: the summer climate is mild and quite rainy. The coastal areas are a bit more temperate, but also more humid and windier, while the eastern area has a slightly more continental climate (17).

While the residential building stock mainly utilizes liquid and gas. Findings also determined that SH and DHW needs are partially provided by heat pump applications apart from using traditional energy sources.

According to expert questioning: The most common technologies for SH and DHW are central gas condensing boilers, district heating systems, heat pumps, and electricity. SC is not present in most cases, except health industry, where SC is often used.

3.17. **LITHUANIA**

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Lithuania.

In Figure 65, the Mm^2 of covered floor area in the Lithuanian residential and service sectors is presented in percentages regarding historical periods.

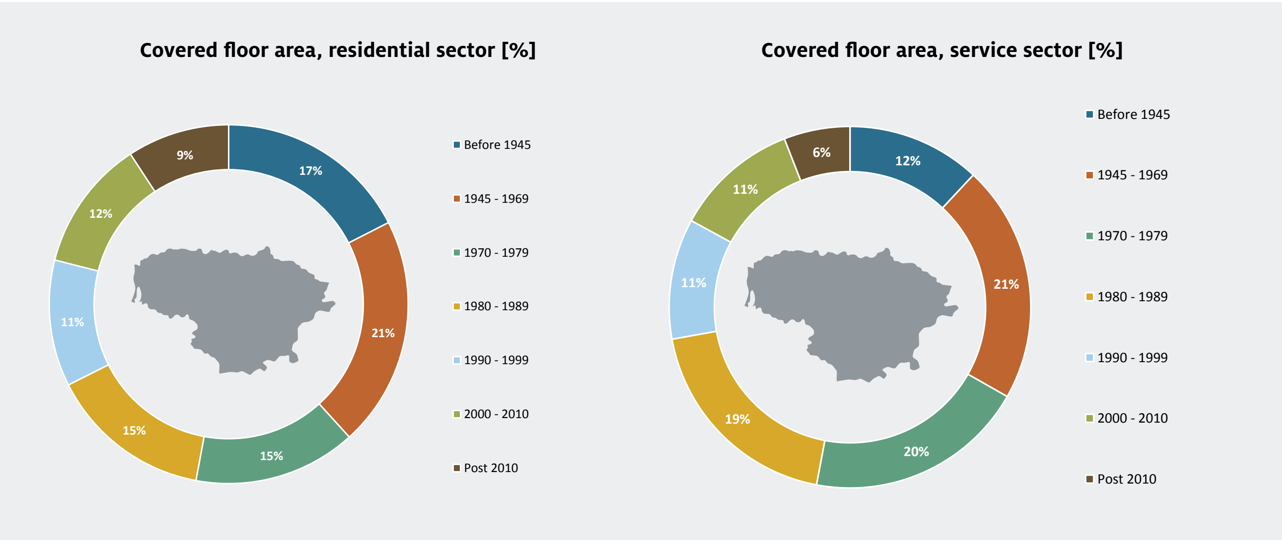

Figure 65. Split of the residential and service building stock raised per construction periods [%] (Lithuania).

The result demonstrates that the highest percentage of covered floor area is related to residential buildings constructed between 1945-1969, i.e., 21%. Buildings erected before 1945 accounts for a lower percentage of covered floor area, i.e., 17%. Buildings constructed during the 1970s and 1980s indicate a value of 15%, respectively. Buildings of the 2000s show 12% of the total covered floor area, accordingly. The construction period of the 1990s occupies 11% respectively. The minor percentage ratio is related to buildings erected during the post-2010 period, with only 9%.

The figure above shows that the highest percentage of covered floor area in the service sector refers to buildings constructed between 1945-1969 with 21%. After this, the ratio is 20% from the years between 1970-1979. Buildings erected in the 1980s indicate 19% of the covered floor area. The result of construction periods of the 1990s and 2000s indicates 11% each. The smallest percentage ratio refers to buildings constructed in the post-2010 period with only 6%.

Figure 66 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 66 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

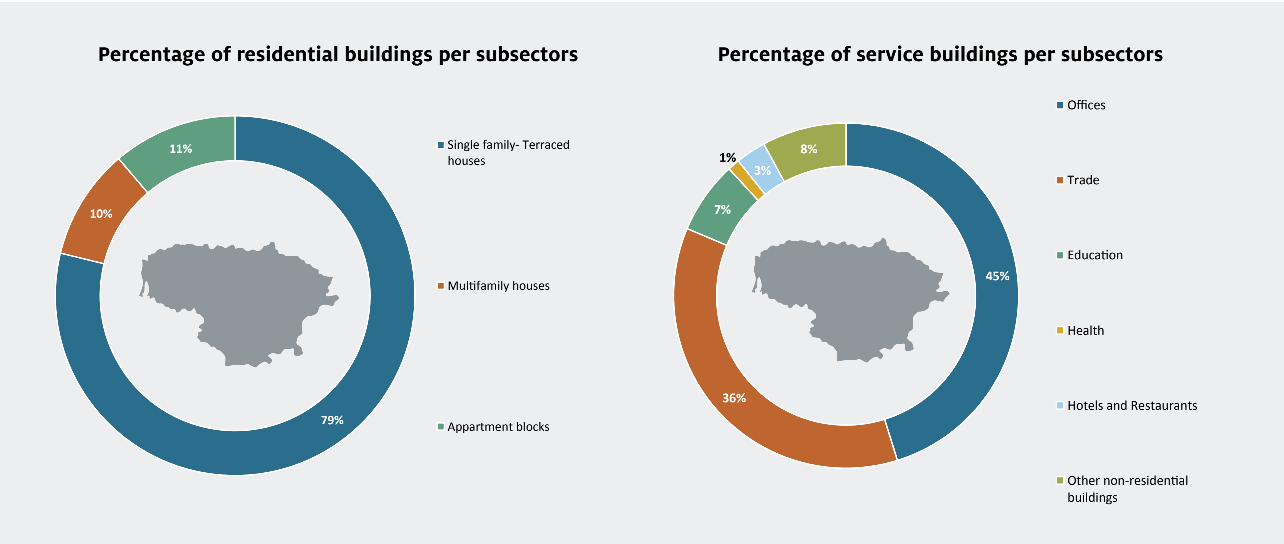

Figure 66. Split of residential and service buildings per different subsectors [%] (Lithuania).

The figure above clearly shows that in the residential sector 79% - is occupied by SFHs, leaving behind the remaining 21% of the market for ABs (11%) and MFHs (10%) respectively.

In the service sector, almost half of the buildings are characterized as office buildings covering 45%. Trade buildings are the second widespread building type that indicate a relatively smaller value of 36% of the whole service building stock. Other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms), show a significantly lower percentage ratio, i.e., 8%. Education buildings cover 7% of the service building stock, respectively. Hotels and restaurants occupy only 3% of the market. The remaining 1% of the market refers to health building types, respectively.

Figure 67 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

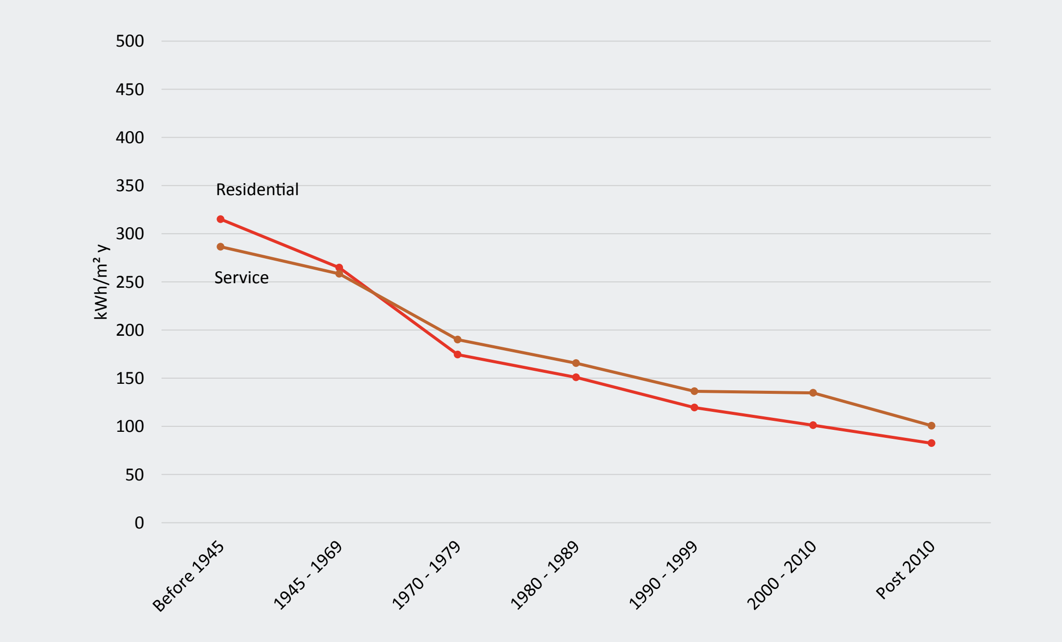

Figure 67. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Lithuania).

Residential buildings constructed before 1945 consume about 315 kWh/m² y of the specific FEC for SH and DHW. The specific FEC then drops to approximately 265 kWh/m² y in the buildings constructed in 1945-1969. After that, the consumption rate decreased to about 175 kWh/m² y regarding buildings erected in the 1970s. The value of the specific FEC for SH and DHW keeps decreasing almost linearly from 175 kWh/m² y to about 120 kWh/m² y in buildings constructed from the end of the 1970s till the 1990s, respectively. Buildings erected in 2000-2010 show a lower consumption rate, i.e., 101 kWh/m² y. The lowest value of the specific FEC for SH and DHW was observed in buildings erected in the post-2010 period, with the value of specific FEC of approximately 82.5 kWh/m² y.

The trend of specific FEC in the service sector is relatively close to the trend of the residential one. Buildings erected before 1945 consume about 286 kWh/m² y. Buildings constructed between 1945-1969 indicate the decrease in specific FEC to almost 258 kWh/m² y. Buildings erected in the 1970s show a further decrease to approximately 190 kWh/m² y. Since then, up to the late 1990s, the specific FEC for SH and DHW demonstrates a similar trend (e.g., linear decrease) with the residential sector. For instance, buildings constructed in the 1980s consume approximately 166 kWh/m² y, while those erected in the 1990s indicate 136.5 kWh/m² y, respectively. The rate of specific FEC stays relatively the same regarding buildings of the 2000s with the value of approximately 135 kWh/m² y. The most efficient consumption rate is found in buildings erected after 2010, with a value of about 101 kWh/m² y.

Figure 68 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

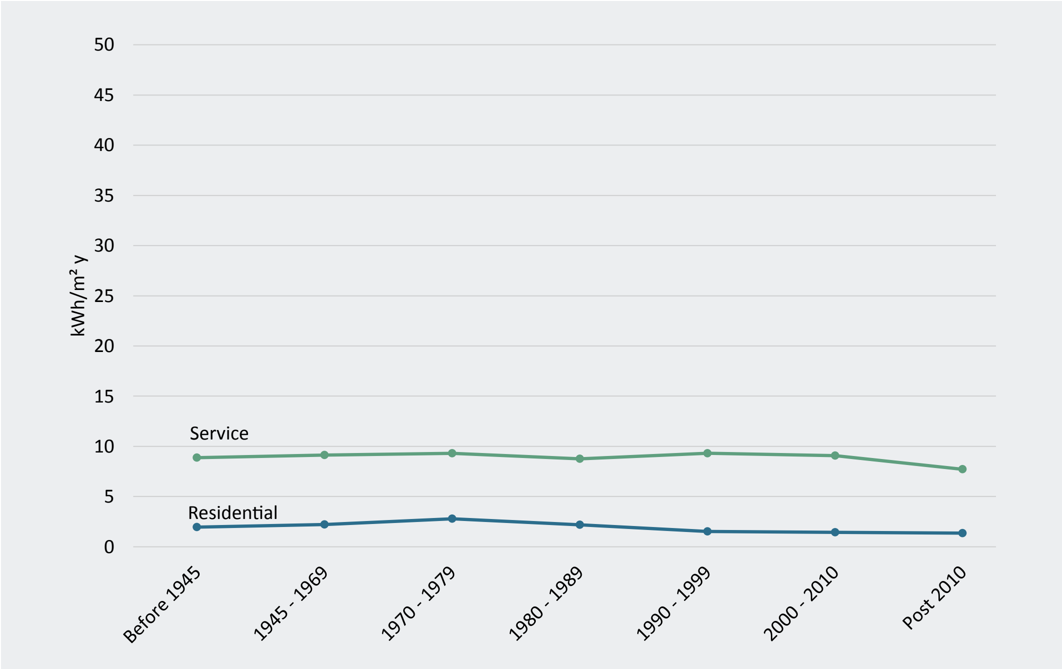

Figure 68. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Lithuania).

In the residential sector, the trend of specific FEC for SC indicates that buildings erected before 1945 consume less than 2 kWh/m² y. The value then increases to about 2.2 kWh/m² y regarding buildings erected between 1945-1969 and to approximately 2.8 kWh/m² regarding buildings of the 1970s. The specific FEC for SC then decreases to about 2 kWh/m² y in buildings of the 1980s. The further decrease in specific FEC is determined in buildings erected in the 1990s and 2000s. These buildings account for about 1.5 and 1.4 kWh/m² y, respectively. The decrease in specific FEC is determined regarding buildings erected after 2010 with the value of approximately 1.3 kWh/m² y respectively.

The trend of specific FEC for SC in the service sector regarding buildings erected before 1945 to the period of post-2010 shows relatively higher specific FEC compared to the residential one. For instance, buildings that were erected before 1945 show approximately 9 kWh/m² y of specific FEC for SC. The consumption rate then fluctuates around the same value, i.e., 9 kWh/m² y, regarding buildings constructed before 1945 to the period of the 2000s. The least specific FEC for SC is observed in the service buildings erected in the post-2010 period, with a value of about less than 8 kWh/m² y.

Regarding the construction methodology presented in the dataset provided by the H2020 Hot-Maps project (8), the main construction topology for walls is a solid wall without insulation. The construction methodology for windows is mainly double-glazing, presented in buildings erected from the 1970s to the 1990s. Single glazing windows are in buildings erected during the first two periods (before 1945, 1945-1969). Triple glazing windows are used in buildings erected in the 2000s and in the last post-2010 period, respectively. Low emittance glass is not present. We can observe that a tilted roof is the most popular decision in buildings regardless of historical periods. Concrete slabs are the most widespread technology for floors in Lithuanian houses throughout all periods, without insulation.

Information about construction materials and construction methodology of the service sector was received by questioning experts. The information concerning Northern Europe (Denmark, Finland, Sweden, Estonia, Latvia, and Lithuania) was summarized. Concerning the service sector in Lithuania, the information is presented in the table below (Table 33).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, education, hotels and restaurants,							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Aluminum (50%) and synthetic/ PVC (50%), low emittance glass in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulations in few cases	Honeycomb bricks/hollow block walls	Double glazing	Flat roof	Concrete slab
Trade, health, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Aluminum (50%) and synthetic/ PVC (50%), low emittance glass in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulations in few cases	Honeycomb bricks/hollow block walls	Double and single glazing	Flat roof	Concrete slab

Table 33. Construction materials, construction methodology-service sector (Lithuania).

The table above (Table 33) shows that the service sector has similarities in construction material and construction methodology regarding all service buildings, except the methodology for windows, which varies from single to double glazing windows as mentioned in the table above.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 34 shows the thermal transmittance value (W/m^2 K) regarding two considered building sectors (residential and service) for all periods.

Table 34 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and building elements regarding different periods affect heat flow and thus specific FEC variation.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.00	2.20	1.00	0.80
1945 - 1969	0.75	2.00	0.80	0.65
1970 - 1979	0.50	1.80	0.60	0.50
1980 - 1989	0.35	1.70	0.50	0.35
1990 - 1999	0.28	1.65	0.45	0.28
2000 - 2010	0.20	1.60	0.40	0.20
Post 2010	0.78	2.37	0.35	0.60
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.00	2.40	0.70	1.00
1945 - 1969	0.90	2.35	0.50	0.70
1970 - 1979	0.60	2.30	0.40	0.55
1980 - 1989	0.50	2.10	0.35	0.40
1990 - 1999	0.40	1.90	0.30	0.30
2000 - 2010	0.30	2.13	0.20	0.45
Post 2010	0.78	2.37	0.35	0.60

Table 34. Thermal transmittance of construction elements (Lithuania).

The analyzed data related to SH and DHW in the residential sector reveals that the leading technology for SH and DHW is a centralized non-condensing boiler for SH and DHW needs regarding all types of buildings and construction periods.

The most common energy carrier for SH and DHW in the Lithuanian residential building stock is liquid and gas fuels, while electricity is accordingly the third popular energy carrier.

The results for SC technology show that in most cases, SC is represented in this residential market, which is explaining by a mild, moderately rainy summers with the average temperatures around 18 °C in July and August on the coast. In inland areas, the temperatures are a bit higher in summer (18). The given information explaining the measure reason of a lack of SC application in the Lithuanian residential building stock.

The residential building stock mainly utilizes liquid fuel and gas. Findings demonstrate that technology for SH and DHW, besides utilizing traditional energy carriers, also uses heat pump applications.

According to expert questioning: The most common technologies for SH and DHW are district heating systems, central gas condensing boilers, heat pumps, electricity. SC is not present in most cases, except health industry, where SC is often used.

3.18. **LUXEMBOURG**

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Luxembourg.

In Figure 69, the Mm² of covered floor area in the residential and service sectors is presented in percentages regarding historical periods.

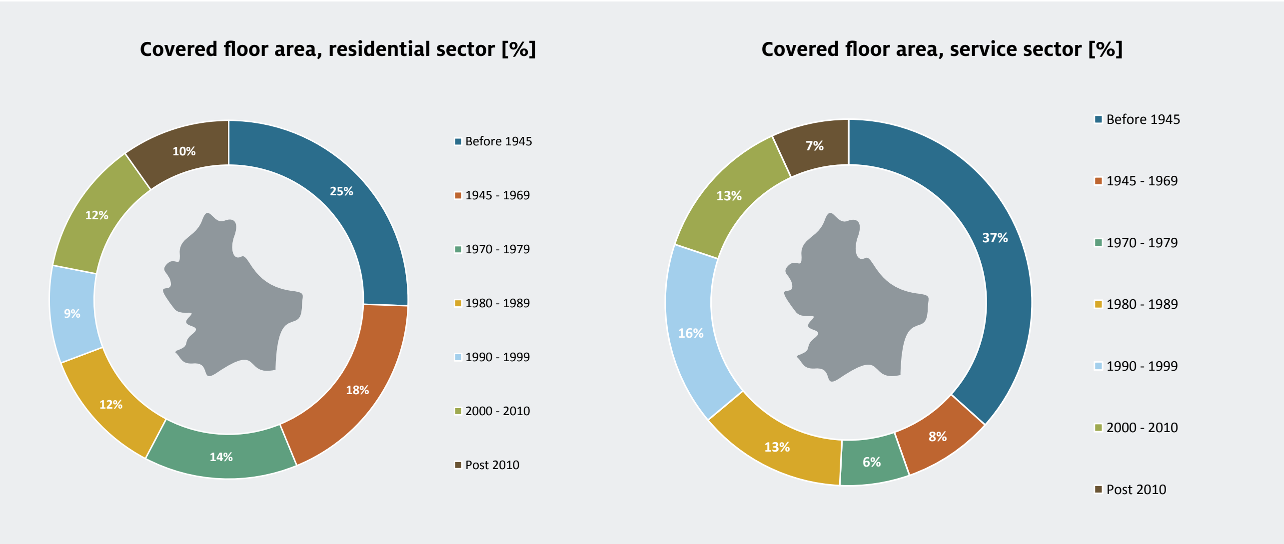

Figure 69. Split of the residential and service building stock raised per construction periods [%] (Luxembourg).

The data obtained from the residential sector shows that about 25% of the covered floor area are occupied by buildings erected before 1945. Buildings erected between 1945-1969 show a ratio of the covered floor area of about 18%. Buildings erected between 1970 till 1979 cover 14%. Then 12% of the total floor area is occupied by buildings constructed in the 1980s. Whereas the minor area is covered by buildings erected in the 1990s with 9% respectively. Buildings erected between 2000-2010 occupied the same percentage ratio as buildings of the 1980s, i.e., 12%. Buildings that were erected in the post-2010 period occupy 10% of the total floor area accordingly.

Service buildings erected before 1945 occupies most of the floor area, i.e., 37%. In contrast, a significantly lower percentage ratio is found in buildings erected between 1945-1969, with 8%. The smallest percentage ratios of covered floor area is found in buildings constructed between 1970-1979, with only 6%. Around 13% of the covered floor area is found in buildings constructed between 1980 till 1989. Buildings erected in the 1990s, i.e., indicate 16%. The period of 2000-2010 holds about 13% of the covered floor area. Whereas the minor percentage ratio indicates buildings constructed in the post-2010 with only 7% accordingly.

Figure 70 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 70 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

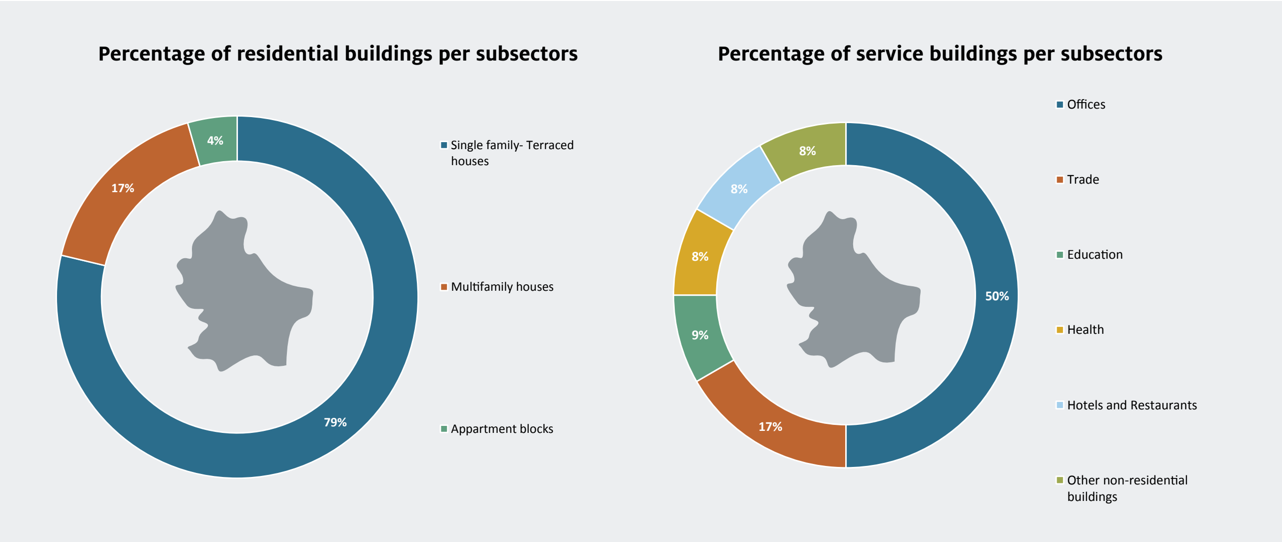

Figure 70. Split of residential and service buildings per different subsectors [%] (Luxembourg).

The figure above clearly shows that in the residential sector, 79% - is occupied by SFHs, leaving behind the remaining 21% of the market for MFHs (17%) and ABs (4%), respectively.

Office buildings occupy half of the service sector of Luxembourg, i.e., 50%. About 17% of the buildings are trade buildings type. Educational buildings indicate a significantly lower percentage ratio of 9%. Hotels and restaurants, health care and other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms), occupy 8%. of the service building stock, respectively.

Figure 71 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

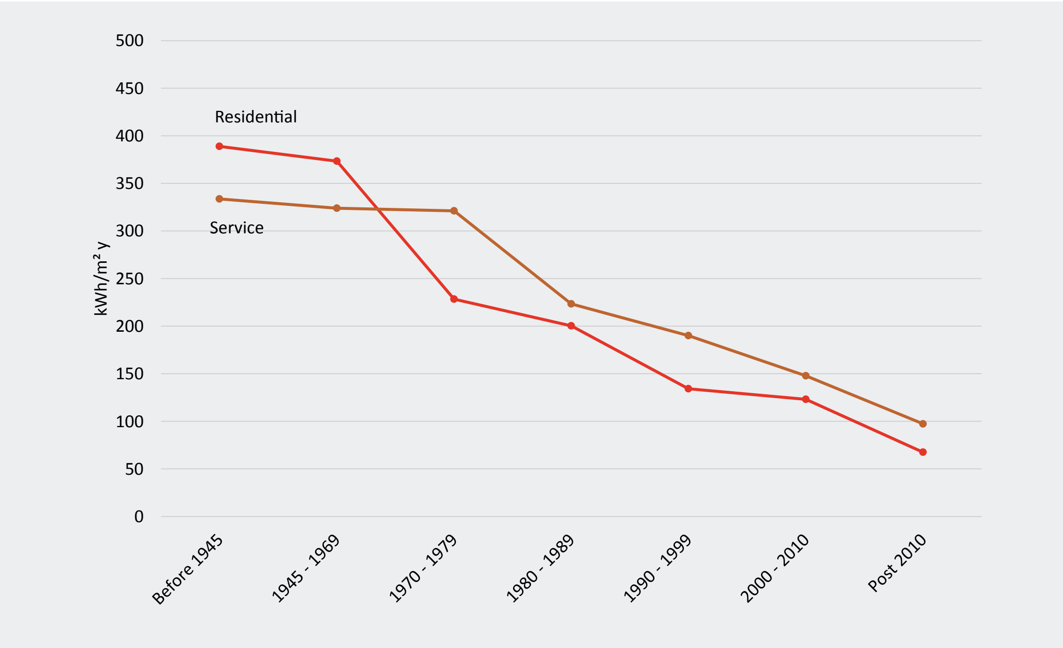

Figure 71. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Luxembourg).

The buildings constructed before 1945 consume about 389 kWh/m² y of the specific FEC for SH and DHW. The specific FEC then decreased to about 373 kWh/m² y in the buildings constructed in 1945-1969. After that, the consumption rate has dropped to approximately 228 kWh/m² y regarding buildings erected in the 1970s. The value of the specific FEC for SH and DHW keeps decreasing regarding buildings constructed from the end of the 1970s till the post-2010 period, respectively. Buildings erected in the 1980s show a lower consumption rate, i.e., 200 kWh/m² y. The specific FEC rate ten drops to about 134 kWh/m² y regarding buildings of the 1990s. Buildings that refer to the construction period of the 2000s indicate the value of a specific FEC of approximately 123 kWh/m² y. Buildings that were erected after 2010 show a significant reduction to about 67 kWh/m² y accordingly.

The trend of specific FEC in the service sector indicates that buildings erected before 1945 show the value of specific FEC for SH and DHW of about 334 kWh/m² y. Buildings erected from 1945-1979 indicate the same value of specific FEC, i.e., 324 and 322 kWh/m² y accordingly. Since then, the value of specific FEC for SH and DHW dropped to about 223 kWh/m² y regarding buildings erected in the 1980s. We then can notice that buildings erected afterward show a linear decrease in specific FEC. For instance, buildings constructed in the 1990s indicate the value of specific FEC of about 190 kWh/m² y, while buildings erected in the 2000s consume approximately 148 kWh/m² y. Moving forward, we can observe that the most efficient consumption rate is found in buildings erected after 2010, with a value of about 97 kWh/m² y.

Figure 72 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

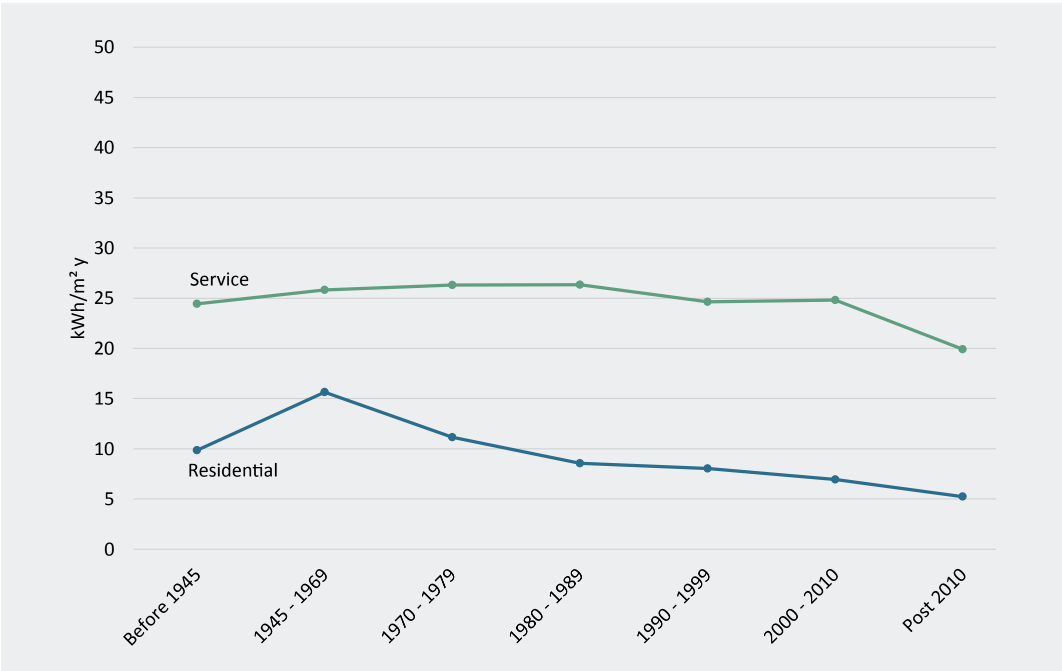

Figure 72. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Luxembourg).

The trend of FEC for SC in the residential sector shows that the buildings erected before 1945 consume approximately 10 kWh/m² y. The rate then increases to about 15.6 kWh/m² y regarding buildings erected between 1945-1969. After this, the consumption rate decreases to about 11 kWh/m² y for buildings of the 1970s. Buildings erected in the 1980s indicate about 8.6 kWh/m² y of specific FEC, respectively. The specific FEC for SC continues steadily decreasing regarding buildings of the 1990s with a value of approximately 8 kWh/m² y. Buildings of the 2000s indicate a value of about 7 kWh/m² y. Buildings erected in the period of post-2010 are characterized by the smallest value of specific FEC for SC, i.e., around 5 kWh/m² y.

The trend of specific FEC for SC in the service sector shows that buildings erected before 1945 consume about 24 kWh/m² y. The consumption rate then slightly increases regarding buildings erected during the periods from 1945 to the late 1980s. For instance, buildings that were constructed between 1945-1969 show the value of specific FEC of about 26 kWh/m² y. At the same time, those erected during the 1970s and 1980s indicate approximately 26 kWh/m² y accordingly. A decrease in specific FEC is determined regarding buildings of the 1990s and 2000s with a slightly lower value than 25 kWh/m² y. The most efficient specific FEC demonstrates buildings that were erected after 2010 with the value of approximately 20 kWh/m² y.

Regarding the construction methodology presented in the dataset provided by the H2020 Hot-Maps project (8), the main construction topology for walls is a solid wall. Insulation is present in buildings erected after the 1960s. Honeycomb bricks/hollow blocks walls are present in SFHs erected before 1945 and during the 1970s and 1980s. Insulation is present in buildings erected during the 1980s. The construction methodology for windows is mainly double-glazing, presented in buildings erected from 1945 to the post 2010 period. Low emittance glass is given only in buildings of the 2000s and post-2010 periods, respectively. Single glazing windows are given only in historical buildings (before 1945), and MFHs erected between 1945-1969. We can observe that a tilted roof is the most popular decision regarding SFHs with the presence of insulation (except historical buildings) and MFHs erected before 1945 to the late 1970s and during the period of 1990s. Insulation is presented in all cases. The flat roof is primarily presented in MFHs erected in the 1980s and afterward and in ABs. Insulation for a flat roof is used in buildings erected in the 1980s and afterward. Concrete slabs are the most widespread technology for floors throughout all periods. Insulation is present in buildings erected during the 1980s and afterward, except MFHs where insulation is present regarding buildings erected in the 1970s and afterward.

Information about construction materials and construction methodology of the service sector was received by experts questioning. The information concerning Central Europe (Austria, Belgium, Germany, Netherland, Luxembourg, France, UK and Ireland) was summarized afterward. Concerning the service sector in Luxembourg, the information is presented in the table below (Table 35).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, health							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete+ insulation in most cases	Aluminum, low emittance glass only in few cases	Concrete + insulation in most cases	Concrete+ insulations in most cases	Solid wall	Double glazing	Flat roof	Concrete slab
Trade, hotels and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete or bricks+ insulation in most cases	Aluminum and synthetic/PVC, low emittance glass only in few cases.	Concrete and bricks + insulation in most cases	Concrete+ insulations in most cases	Solid walls	Double glazing	Flat roof	Concrete slab
Educational, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete+ insulation in most cases	Aluminum and synthetic/PVC, low emittance glass only in few cases.	Concrete and bricks + insulation in most cases	Concrete +insulations in most cases	Solid walls	Double glazing	Flat roof	Concrete slab

Table 35. Construction materials, construction methodology-service sector (Luxembourg).

The table above (Table 35) shows that the service sector demonstrates similar construction methodology and relative similarities with construction materials regarding different types of buildings. For instance, trade, hotels, and restaurants show similarities in construction materials and methodology, while it is also valid for office, health, educational and non-residential buildings, respectively.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 36 shows the thermal transmittance value ($W/m^2 K$) regarding two considered building sectors (residential and service) for all periods.

Table 36 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and buildings elements regarding different periods affect heat flow and thus specific FEC variation.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.60	4.50	1.43	1.80
1945 - 1969	1.10	3.80	0.93	1.40
1970 - 1979	0.85	3.00	0.57	0.60
1980 - 1989	0.60	2.00	0.35	0.55
1990 - 1999	0.50	1.60	0.28	0.50
2000 - 2010	0.40	1.30	0.25	0.40
Post 2010	0.34	1.40	0.20	0.37
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.50	4.50	1.50	1.50
1945 - 1969	1.60	3.90	1.20	1.20
1970 - 1979	1.70	3.20	0.60	0.60
1980 - 1989	0.60	2.00	0.55	0.55
1990 - 1999	0.50	1.60	0.53	0.53
2000 - 2010	0.45	0.90	0.51	0.51
Post 2010	0.40	1.20	0.50	0.50

Table 36. Thermal transmittance of construction elements (Luxembourg).

According to the analysis, the individual SH and DHW system is mainly available in buildings constructed during all analyzed periods. The central SH systems are also used in most buildings except buildings erected in the 1970s. The central DHW system is present in buildings erected in the post-2010 period and MFHs erected between 1945 and 1969. The district heating system for SH and DHW is present in buildings erected from the 1970s to the 2000s.

Non-condensing boilers for SH are mainly used in buildings constructed before 1945 to the late 1970s and in buildings erected in the 2000s. Buildings erected in the other periods are mainly equipped with condensing boilers. Non-condensing boilers are predominantly used in all building types for DWH needs. Stoves are mainly present in SFHs (erected before 1945) during the 1980s and 1990s. Electric heaters are mainly used in SFHs erected in the 2000s and MFHs of the 1990s. Heat pump technology for SH and DHW is present in SFHs erected from 1990 to the post-2010 period, and MFHs constructed during the post-2010 period respectively.

The most widespread type of fuel for SH and DHW is gas. Gas is used in buildings erected before 1945, between 1945-1969, and in buildings erected after the 1970s. Liquid fuel is utilized in SFHs erected before 1945 to the late 1970s, as well as in MFHs and ABs erected in the 1970s. Solid fuel is the main energy carrier in buildings of the 1980s and 1990s, respectively. Electricity is the leading energy career for DHW for most building types except historical buildings (erected before 1945).

The results for SC technology show that buildings erected before 1945 to the 1990s do not use SC technology in most cases. However, buildings constructed after this time, in most cases, are equipped by a SC system.

These findings demonstrate a relatively low level of presence of renewable energy sources for SH, DHW, and SC in the residential building stock that mainly utilize gaseous and liquid fuels, characterized by higher carbon content. The presence of renewable energy (heat pump) is determined mainly in SFHs erected from 1990 to the post-2010 period.

According to expert questioning: the most common technology in the service sector for SH and DHW is central gas condensing boiler, heat pumps, and electricity. SC is not presented in most cases, except in the health industry, where SC is mainly used.

3.19. MALTA

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Malta.

In Figure 73, the Mm² of covered floor area in the residential and service sectors is presented in percentages regarding historical periods.

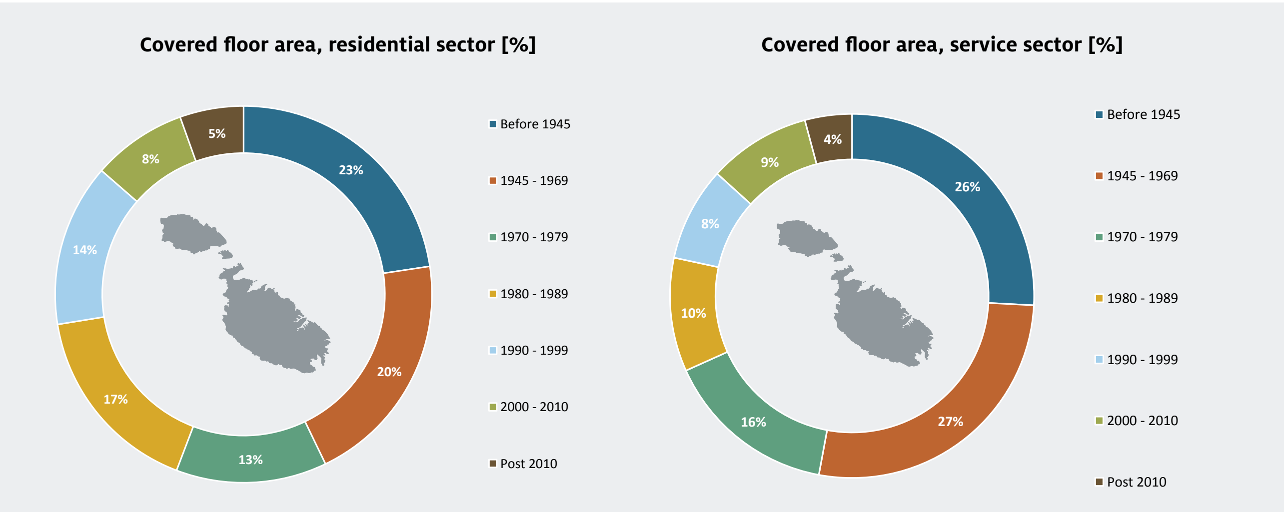

Figure 73. Split of the residential and service building stock raised per construction periods [%] (Malta).

As we can see from Figure 73, the highest percent of covered floor area, 23% regarding buildings erected before 1945. Buildings erected in the period between 1945-1969 cover 20% of the total floor area of the residential building stock. The period of the 1980s indicates 17% respectively. Buildings erected in the 1990s are characterized by a lower percentage of covered floor area (14%). Buildings erected between 1970-1979 occupied one percent less, i.e., 13%. Buildings that were erected in the 2000s and post-2010 period occupy 8 and 5% of the total floor area accordingly.

In the service sector, the most significant percentage of the covered floor area belongs to buildings erected between 1945-1969 with 27%. The second-highest percentage of covered floor area relates to buildings constructed before 1945 with a value of 26%. Building erected in the 1970s covers 16%, and buildings of the 1980s, 10% respectively. Minor percentages of covered floor area refer to buildings erected afterward. For instance, Buildings erected in the periods of the 2000s and 1990s cover 9 and 8% respectively. The smallest values of covered floor area belong to the post-2010 construction periods, with only 4%.

Figure 74 visualizes the breakdown of different types of buildings by residential and service sectors. The following percentages in Figure 74 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

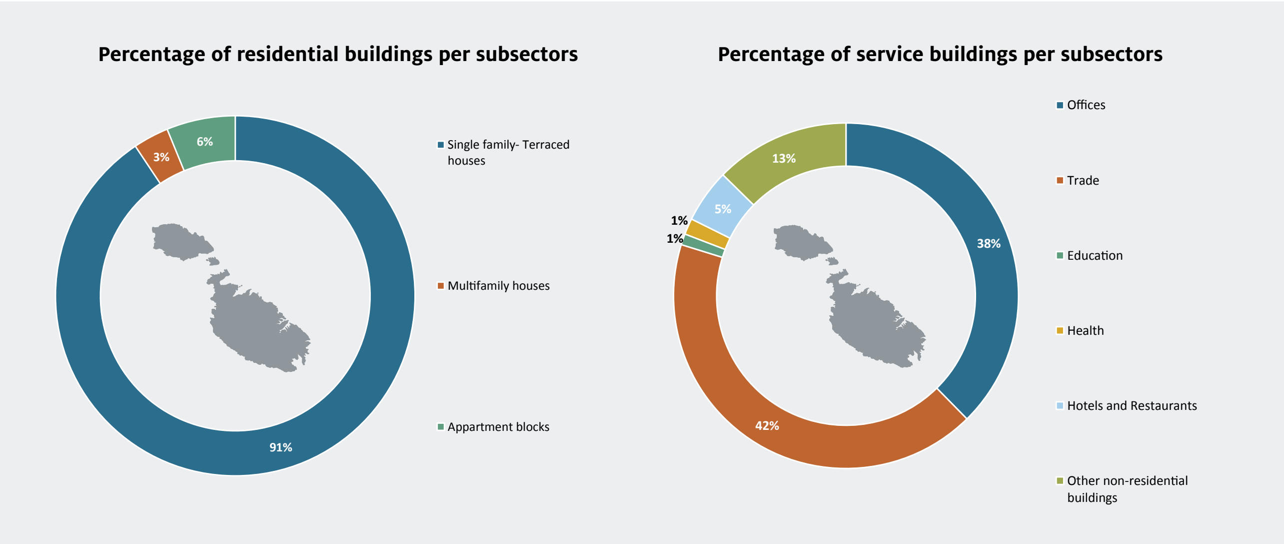

Figure 74. Split of residential and service buildings per different subsectors [%] (Malta).

Residential buildings are broken up into three types: SFHs, MFHs, and ABs. SFHs make up the majority of the residential sector, i.e., 91%. Whereas ABs and MFHs indicate only 6 and 3 % of the residential sector, respectively.

In the service sector, almost half of the buildings are characterized as trade buildings covering 42%. Office buildings are the second widespread building type, indicating a slightly smaller value of 38% of the whole service building stock. Other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms), show a significantly lower percentage ratio, i.e., 13%. Hotels and restaurants occupy only 5% of the market. Whereas the remaining 2% of the market is left for education and health building types with 1% for each.

Figure 75 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

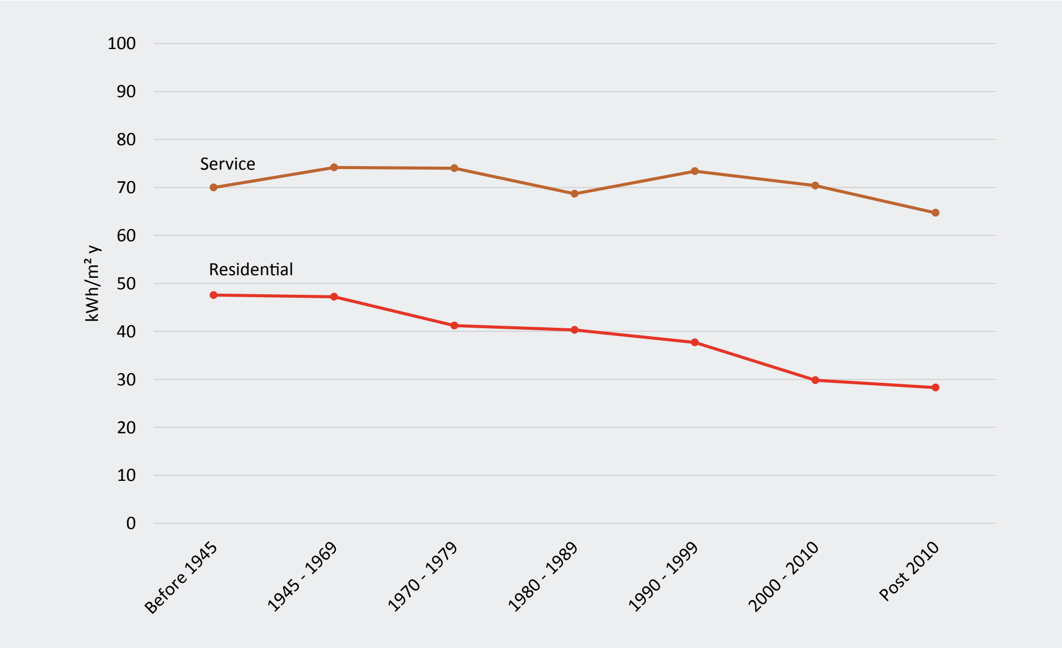

Figure 75. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Malta).

The figure above shows that the specific FEC for SH and DHW in residential buildings is lower than in the service ones. Buildings erected before 1945 to the late 1960s consume about 47.6 kWh/m² y of specific FEC. In comparison, buildings erected in the 1970s indicate a reduction to about 41 kWh/m² y. A slightly lower specific FEC indicates buildings erected in the 1980s, i.e., around 40 kWh/m² y. The trend of specific FEC for SH and DHW shows a reduction regarding buildings erected afterward. For instance, buildings erected in the 1990s show a value of approximately 37 kWh/m² y. At the same time, buildings of the 2000s and post-2010 indicate a decrease, with a resulted value of approximately 30 and 28 kWh/m² y, respectively.

The trend of specific FEC for SH and DHW regarding service buildings erected before 1945 demonstrates the value of specific FEC of about 350 kWh/m² y. Buildings erected between 1945-1969 result in the rapid reduction of specific FEC; their value is decreased to 300 kWh/m² y. A slight reduction in specific FEC characterizes buildings erected in the 1970s compared to buildings of the previous periods. The value is found to be around 288 kWh/m² y. Buildings erected from 1980 till 1989, having relatively the same specific FEC, i.e., 292 kWh/m² y. Buildings constructed from 1990 till 1999 are characterized by a significant decrease in specific FEC as the value dropped to 200 kWh/m² y. A slight increase in specific FEC is determined regarding buildings of two last periods (2000 till post-2010), with the value of around 215 kWh/m² y respectively.

Figure 76 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

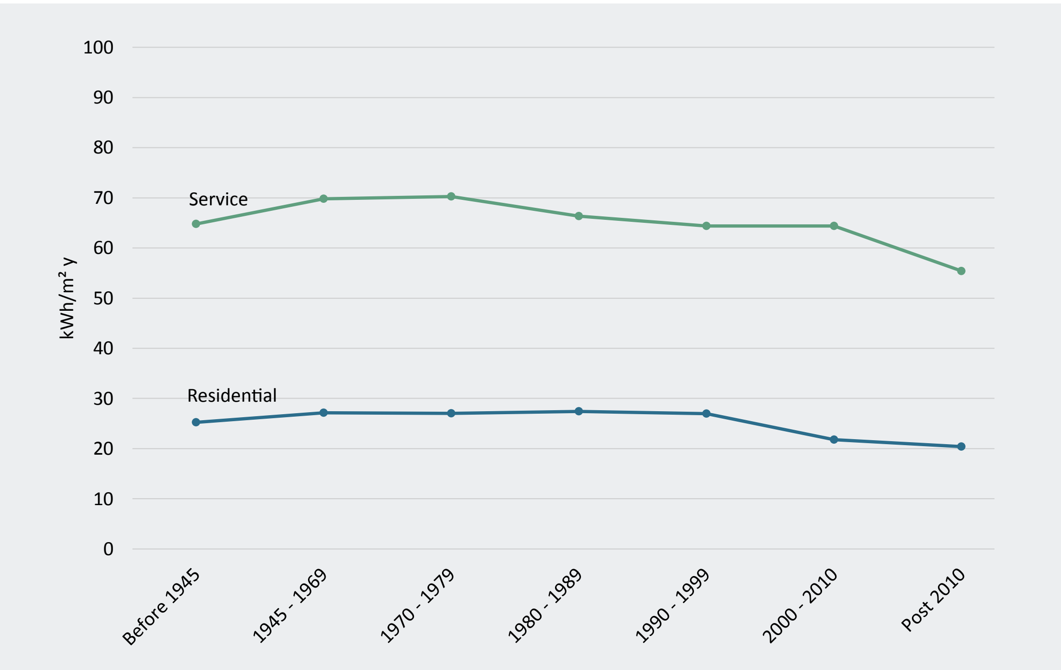

Figure 76. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Malta).

In the residential sector, the trend of specific FEC for SC indicates that buildings erected before 1945 show the value of specific FEC for about 25 kWh/m² y. Buildings erected from 1945-1969 to the late 1980s consume almost the same amount, i.e., 27 kWh/m² y. A slight decrease in specific

FEC for SC is observed in buildings erected in the 1990s, with a value of less than 27 kWh/m² y. The specific FEC of SC then decreases to about 22 kWh/m² y in buildings of the 2000s. The smallest value of specific FEC belongs to residential buildings erected in the post-2010 period with the value of approximately 20 kWh/m² y.

The rate of specific FEC for SC in the service sector regarding buildings erected before 1945 is about 65 kWh/m² y. The consumption rate then increases to around 70 kWh/m² y in the lately erected buildings, i.e., 1945-1969. The rate keeps relatively the same, i.e., 70 kWh/m² y in the buildings constructed between 1970-1979. The reduction in specific FEC is observed in buildings of the 1980s with the value of about 66 kWh/m² y. Approximately 64 kWh/m² y is consumed by buildings that were erected in the 1990s and 2000s. The least specific FEC for SC is observed in the service buildings erected in the post-2010 period, with a value of about 55 kWh/m² y.

Regarding the construction methodology presented in the data set provided by the H2020 Hot-Maps repository (8), the main construction topology for walls, concerning all historical periods, is honeycomb bricks and hollow blocks walls that are present in SFHs and MFHs erected from the 1970s and afterward. Honeycomb bricks and hollow blocks wall is also determined in ABs regardless construction periods. Insulation was used in buildings erected in the 1980s and afterward. A solid wall is mainly present in historical buildings erected before 1945 and SFHs and MFHs erected between 1945-1969.

The construction methodology for windows is mainly double and single glazing windows. Single glazing windows are presented in MFHs and ABs that were erected before 1945, between 1945-1969, and in the 1970s. Single glazing windows are also present in SFHs erected only during the first two periods (before 1945, between 1945-1969). Buildings erected after mainly use double-glazing windows. Low emittance glazing is present in buildings erected in the 1990s and afterward, except SFHs, where low emittance glazing is present only in buildings of the last post-2010 period.

We can observe that a tilted roof is the most popular decision regarding SFHs and MFHs, respectively. A flat roof is presented in ABs regardless of historical periods. Insulation is determined in buildings erected from the 1980s and afterward. Concrete slabs (insulation presented from the 1980s) were primarily used in the residential buildings throughout analyzed periods.

Information about construction materials and construction methodology of the service sector was received by experts questioning. The information concerning Southern Europe (Spain, Italy, Greece, Cyprus, Malta, and Portugal) was summarized. Concerning the service sector in Malta, the information is presented in the table below (Table 37).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, health, hotels and restaurants, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation only in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete+ insulations in few cases	Honeycomb bricks/hollow block walls	Single and double glazing	Flat roof	Concrete slab
Education							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks and concrete + Insulation only in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulation in few cases	Honeycomb bricks/hollow block walls	Double glazing	Flat roof	Concrete slab

Table 37. Construction materials, construction methodology-service sector (Malta).

The table above shows that the service sector demonstrates similarities in construction materials and methodology regarding different types of buildings. All kinds of service buildings are erected by using relatively the same kind of material and construction methodology. The only contrast is the wall of educational buildings that are constructed not only out of bricks but also from concrete.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The effect differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). According to all historical periods, Table 38 shows the thermal transmittance value ($W/m^2 K$) of residential and service sectors.

Table 38 helps to figure out the impact of building elements on specific FEC. As seen from the table below, the thermal transmittance values demonstrate the reduction throughout all periods. Here we can observe how thermal insulation materials and different elements of buildings (walls, windows, roof, and floor) affect heat flow.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	2.00	5.80	1.90	3.00
1945 - 1969	1.75	3.60	1.85	2.50
1970 - 1979	1.62	2.50	1.82	2.25
1980 - 1989	1.56	1.95	1.81	2.12
1990 - 1999	1.53	1.67	1.81	2.06
2000 - 2010	1.50	1.53	1.80	2.00
Post 2010	0.34	1.40	0.20	0.37
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	2.00	6.10	1.70	2.60
1945 - 1969	1.90	6.00	1.85	2.50
1970 - 1979	1.75	5.90	2.00	2.40
1980 - 1989	1.67	5.80	1.85	2.00
1990 - 1999	1.60	5.70	1.70	2.10
2000 - 2010	1.70	5.60	2.10	2.30
Post 2010	1.58	5.20	1.96	2.08

Table 38. Thermal transmittance of construction elements (Malta).

The analyzed data related to technologies for SH and DHW in the Italian residential sector reveals that the leading technologies are central combined gas boilers. Individual non-condensing gas boilers are also used for DHW needs in MFHs and ABs erected before 1945 to the late 1990s, while individual condensing gas boilers installed in ABs that were erected during the last two periods (2000-2010, post-2010). Regarding renewable energy sources, solar collectors for DHW are mainly used in ABs erected from 2000 to the post-2010 period, and MFHs erected in the post-2010 period, respectively. Condensing gas boilers and solar collectors for DHW are characterized as less widespread types of technologies.

The most common energy carrier for SH and DHW in the residential building stock of Malta is gas.

The results for SC technology show that in most cases, SC is not represented in the residential sector in Malta.

Findings demonstrate that technology for SH and DHW, besides utilizing traditional energy sources, also uses solar collectors for DHW needs. However, as mentioned above, this type of renewable energy is characterized as a less widespread technology.

According to expert questioning, the most common technologies for SH and DHW are central and individual gas condensing boilers and electricity. Individual gas condensing boilers are present only in office buildings, while electric heating is used in trade building types. SC is present in most cases, except educational buildings.

3.20. NETHERLANDS

This section represents a selection of main results that were obtained from the building stock analysis dataset regarding Netherlands (8).

In Figure 77, the Mm² of covered floor area in the residential and service sectors is presented in percentages regarding historical periods.

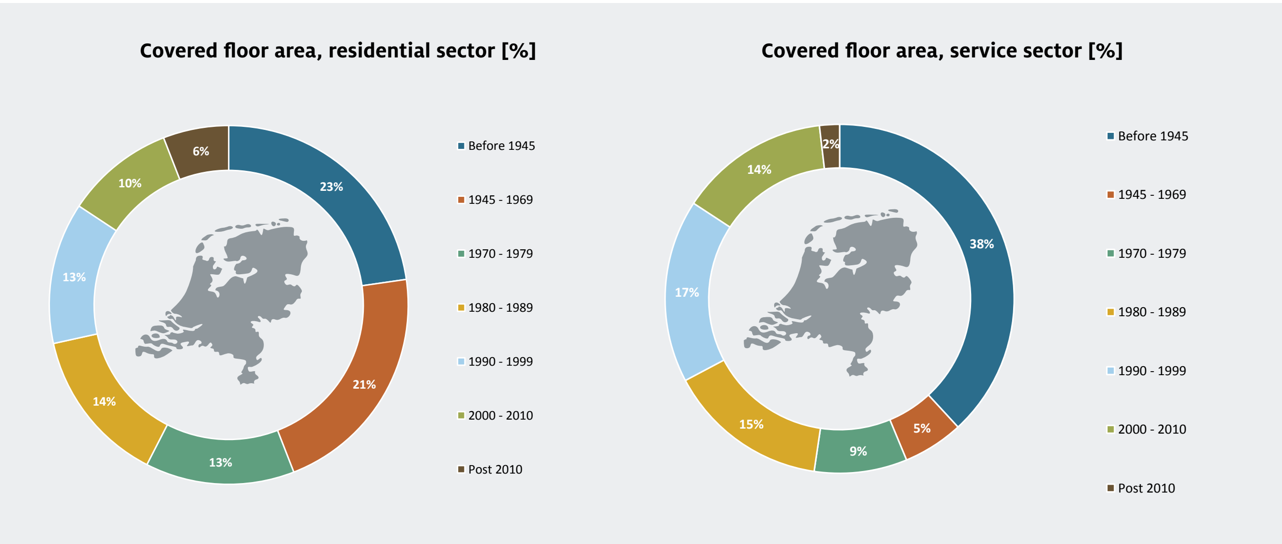

Figure 77. Split of the residential and service building stock raised per construction periods [%] (Netherlands).

The result demonstrates the relatively high percentage of covered floor area regarding buildings constructed before 1945, i.e., 23%. The post-WWII period (1945-1969) accounts for a slightly lower percentage of covered floor area, which is 21%. Interestingly, the two earliest periods occupied a significant portion of the entire residential building stock – 44%. On the other hand, the minor portion indicates the last two periods, 2000-2010 and post 2010, which is characterized by only 10 and 6%, respectively. Buildings that were erected during the 1980s cover 14% of the total floor area in the residential building stock. Buildings of the 1970s and 1990s cover equally by 13%.

Service buildings erected before 1945 occupies most of the floor area, i.e., 38%. In contrast, a significantly lower percentage ratio is found in buildings erected between 1945-1969, with 5%. Buildings constructed between 1970-1979 indicate only 9%. Around 15% of the covered floor area is found in buildings constructed between 1980 till 1989. Buildings erected in the 1990s show 17% of the covered floor area. The period of 2000-2010 holds about 14% of the covered floor area. Whereas the minor percentage ratio indicates buildings constructed in the post-2010 with only 2% accordingly.

Figure 78 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 78 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

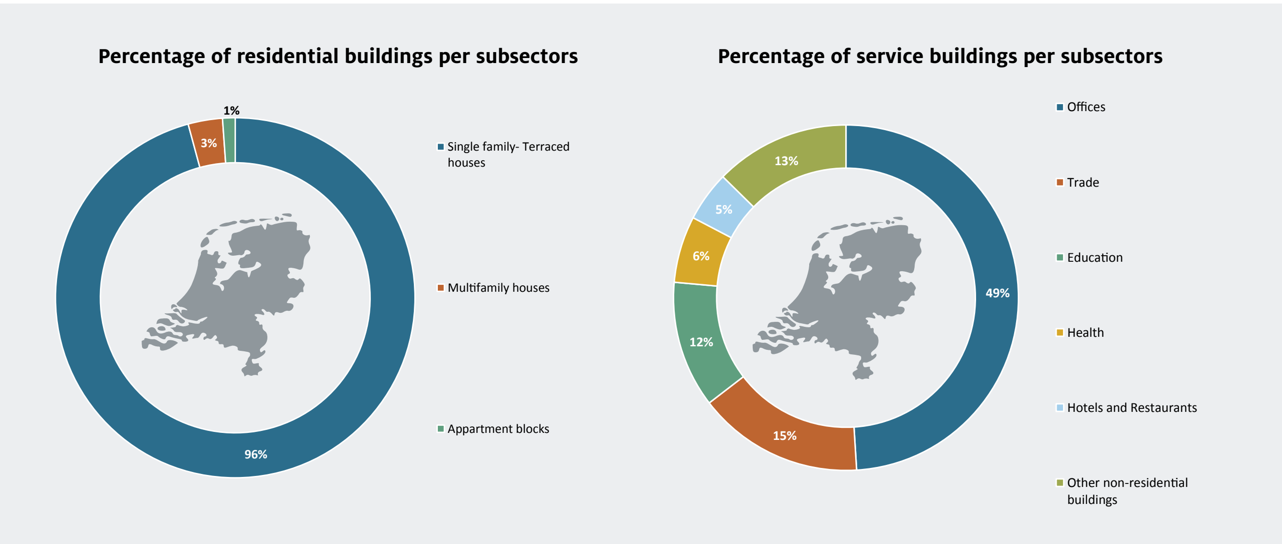

Figure 78. Split of residential and service buildings per different subsectors [%] (Netherlands).

The residential sector shows that almost all residential sector, i.e., 96% is characterized as SFHs. This leaves only 4% of the sector behind, including 3% for MFHs, and only 1% for ABs.

In the service sector, almost half of the buildings are characterized as office buildings covering 49%. Trade buildings are the second widespread building type that indicate a significantly lower percentage ratio of 15%. Other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms), show a slightly lower percentage ratio, i.e., 13%. Education buildings cover 12% of the service building stock, respectively. One of the lowest percentage ratios, i.e., 6% refers to health building types. The minor portion of the market are occupied by hotels and restaurants with 5% respectively.

Figure 79 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

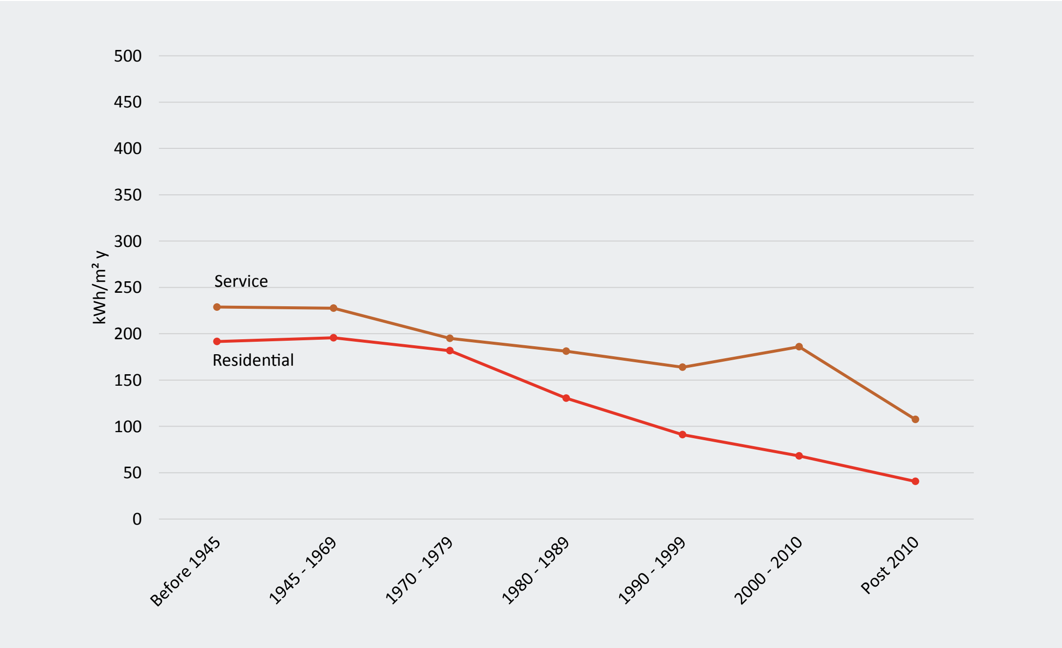

Figure 79. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Netherlands).

Residential buildings erected before 1945 to the post-2010 show that specific FEC values for SH and DHW are dropped from about 192 kWh/m² y to approximately 40.5 kWh/m² y. Buildings erected before 1945 show the highest value of specific FEC for SH and DHW of about 192 kWh/m² y. In comparison, buildings erected between 1945-1969 show a slight increase to about 196 kWh/m² y. The trend of specific FEC then started decreasing consecutively. In contrast, buildings erected in the 1970s consume about 182 kWh/m² y. A noticeably lower result indicates buildings erected in the 1980s with the value of approximately 130 kWh/m² y. The lower specific FEC is found in buildings erected in the 1990s with the value of 91 kWh/m² y. Buildings erected in the 2000s show about 68 kWh/m² y of the specific FEC. After this, the value has reduced to approximately 40 kWh/m² y regarding buildings erected during the post-2010 period.
In contrast, the specific FEC of SH and DHW in the service sector shows that the value has dropped from about 229 kWh/m² y to approximately 107 kWh/m² y regarding buildings erected

before 1945 to the post-2010. Buildings erected before 1945 indicate the value of specific FEC of about 229 kWh/m² y. After that, the rate of specific FEC stays almost the same with a value of 228 kWh/m² y regarding buildings erected between 1945-1969. Buildings erected from 1970 till 1979 are characterized by a further decrease in specific FEC, with the value of about 195 kWh/m² y. Specific FEC for SH and DHW is steadily decreasing regarding buildings constructed from 1980 till the end of the 1990s with values of approximately 181 and 164 kWh/m² y, respectively. A sudden increase in specific FEC is determined in buildings erected during the 2000s with a value of approximately 186 kWh/m² y. Service buildings erected during the post-2010 period consume about 107 kWh/m² y compared to a residential building (40.5 kWh/m² y) erected at the same time. Figure 80 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

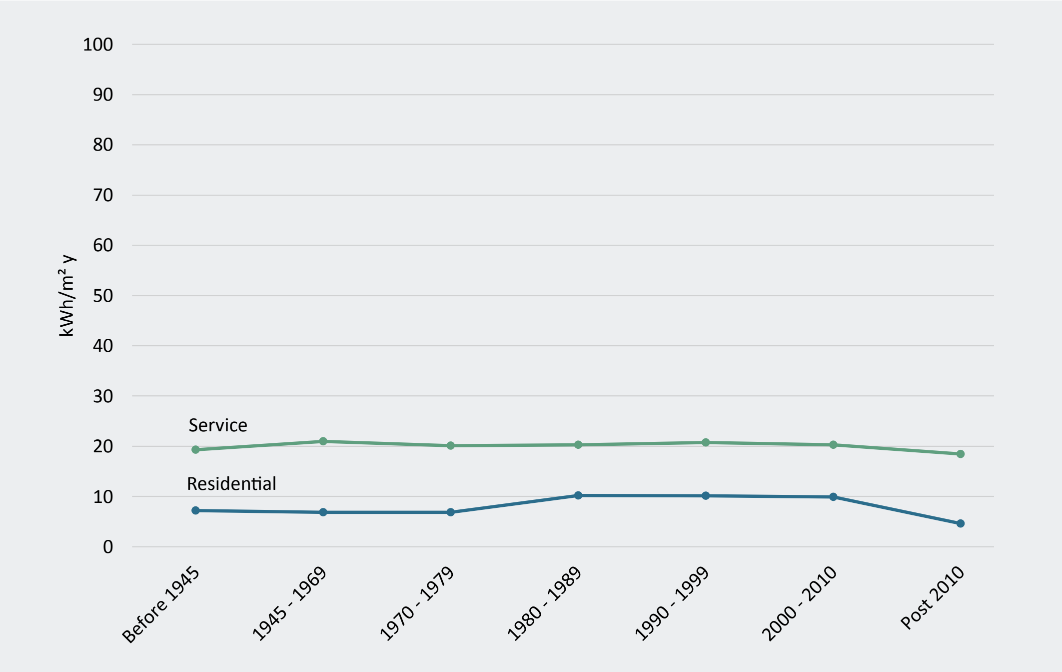

Figure 80. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Netherlands).

In the residential sector, the trend of specific FEC for SC indicates that buildings erected before 1945 show the value of specific FEC for about 7 kWh/m² y. Buildings erected from 1945-1969 to the late 1970s consume almost the same amount, i.e., about 9 kWh/m² y. A slight increase in specific FEC for SC is observed in buildings erected in the 1980s, 1990s, and 2000s, with values of approximately 10 kWh/m² y, respectively. The smallest value of specific FEC belongs to residential buildings erected in the post-2010 period with the value of approximately 5 kWh/m² y.

The service sector results show that buildings erected between 1945-1969 have the highest value of specific FEC of about 21 kWh/m² y. Buildings erected before 1945 consume about 19 kWh/m² y. The value of specific FEC for SC remains the same in buildings constructed from the 1970s till the 2000s, which is about 20 kWh/m² y. The noticeable reduction in specific FEC is determined in buildings erected in the post-2010 period with the value of about 18 kWh/m² y respectively.

Regarding the construction methodology presented in the data set provided by the H2020 HotMaps repository (8), the main construction topology for walls concerning buildings erected before 1945 to the late 1970s is a cavity wall without insulation, while honeycomb bricks and hollow blocks walls are used in buildings erected during the 2000s and post 2010 period respectively. The construction methodology for windows is mainly single and double-glazing windows, regarding buildings erected before 1945 to the late 1980s. Double glazing windows are mainly installed in buildings erected in the 1990s and afterward. Low emittance glass is in buildings erected during the 1990s and afterward.

We can observe that the flat roof is the most popular decision regarding MFHs and ABs, erected from 1945 to the post-2010 period with insulation in buildings erected in the 1970s and afterward. Two types of roofs (flat rood and tilted roof) are almost equally present in SFHs erected in the 1970s with insulation. However, tilted roofs are primarily constructed in SFHs, erected before 1945 and between 1945-1969. A wooden floor is the most popular construction decision regarding historic buildings and buildings erected till the late 1970s. Concrete slabs (insulation presents from the 1990s) were primarily used in houses erected afterward.

Information about construction materials and construction methodology of the service sector was received by questioning experts. The information concerning Central Europe (Austria, Belgium, Germany, Netherland, Luxembourg, France, UK and Ireland) was summarized afterwards. Concerning the service sector in the Netherlands, the information is presented in the table below (Table 39).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office and health							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete+ insulation in most cases	Aluminum, and synthetic/PVC, low emittance glass only in few cases	Concrete + insulation in most cases	Concrete+ insulations in most cases	Solid wall	Double glazing	Flat roof	Concrete slab
Trade, hotels, and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete or bricks+ insulation in most cases	Aluminum low emittance glass only in few cases.	Concrete and bricks + insu-lation in most cases	Concrete+ insulations in most cases	Solid walls	Double glazing	Flat roof	Concrete slab
Educational, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete+ insulation in most cases	Aluminum and synthetic/PVC, low emittance glass only in few cases.	Concrete and bricks + insu-lation in most cases	Concrete +in-sulations in most cases	Solid walls	Double glazing	Flat roof	Concrete slab

Table 39. Construction materials, construction methodology-service sector (Netherlands).

The details from the table above clearly let us know that the service sector demonstrates similarities in construction materials and methodology regarding different types of buildings. For offices and health, relatively the same construction materials and methodology are found. At the same time, it is also valid for trade, hotels, and restaurants. Educational and other non-residential buildings demonstrate the same pattern as well.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). According to all historical periods, Table 40 shows the thermal transmittance value (W/m^{2}K) regarding residential and service sectors.

Table 40 helps to figure out the impact of building elements on specific FEC. Here we can observe how thermal insulation materials and building elements regarding different periods affect heat flow. As seen from the table below, the thermal transmittance values demonstrate the reduction throughout the historical periods.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.89	3.99	1.79	2.02
1945 - 1969	1.67	2.90	1.34	2.14
1970 - 1979	1.45	2.44	0.89	2.30
1980 - 1989	0.64	2.16	0.64	0.98
1990 - 1999	0.36	1.98	0.36	0.36
2000 - 2010	0.27	1.90	0.23	0.31
Post 2010	0.21	1.80	0.16	0.27
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.80	3.80	2.10	2.00
1945 - 1969	1.70	3.70	1.70	1.70
1970 - 1979	1.60	3.55	1.20	1.50
1980 - 1989	0.60	3.40	0.70	1.00
1990 - 1999	0.50	2.90	0.50	0.90
2000 - 2010	0.45	1.80	0.45	0.50
Post 2010	0.40	2.20	0.40	0.40

Table 40. Thermal transmittance of construction elements (Netherlands).

The analyzed data for SH and DHW in the Dutch residential sector is characterized by an individual SH and DHW system. Regarding all buildings, types, and construction periods, combined boilers are used. The analyzed data also reveal that condensing boilers for DHW needs are mainly utilized in ABs regardless of construction periods.

The gas is widely used in all considered building types for SH and DHW needs.

The results for SC technology show that in most cases, SC is not represented in Dutch residential building stock.

Findings demonstrate that gas is the main energy carrier for SH and DHW needs, while renewable technologies are still lucking.

According to expert questioning: The most common technologies for SH and DHW are central gas condensing boilers, heat pumps, electricity. SC is not present in most cases, except health industry, where SC is often used.

3.21. **POLAND**

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Poland.

In Figure 81, the Mm^2 of covered floor area in the Poland's residential and service sectors is presented in percentages regarding historical periods.

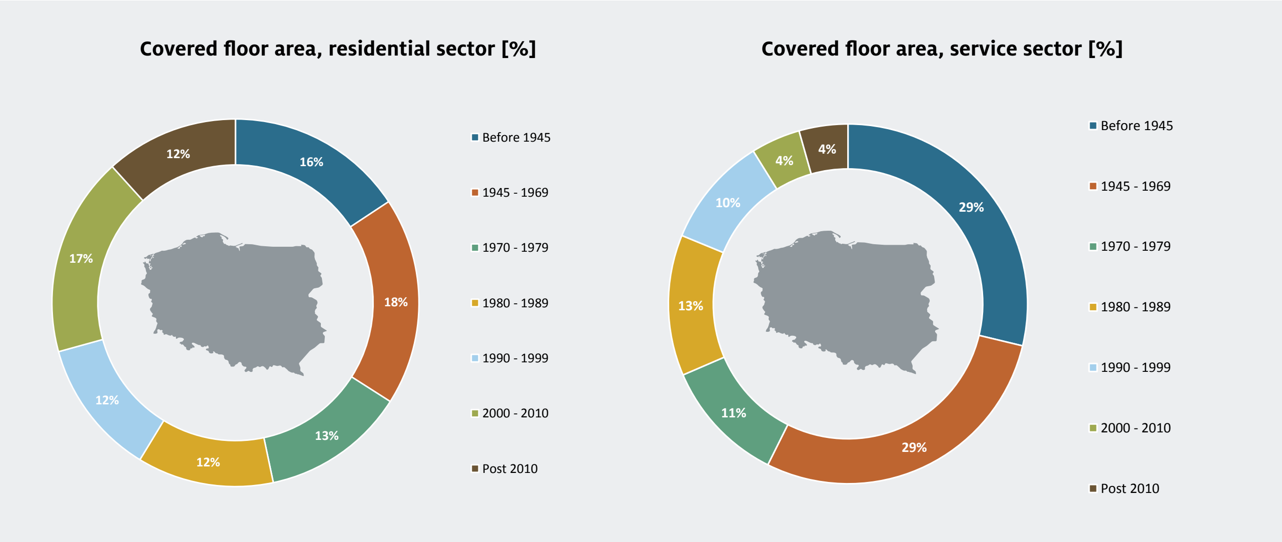

Figure 81. Split of the residential and service building stock raised per construction periods [%] (Poland).

The figure above shows that the highest percentage of covered floor area in the residential sector relates to the post-WWII period (1945-1969), with 18%. The second-highest percentage of covered floor area is 17%, which relates to the 2000s. It can be seen that buildings erected before 1945 indicate 16% of the covered floor area, which is the third-highest value. Buildings erected in the 1970s indicate 13% of the total covered floor area. While the other periods, such as periods of the 1980s, 1990s, and the last post-2010, are characterized by an equal percentage ratio of the covered floor area, i.e., 12% respectively.

The service sector results indicate that the most significant portion of covered floor area belongs to buildings erected during the historical period before 1945 and between 1945-1969. These two periods indicate an equal percentage ratio of the covered floor area, which is 29%. The second highest percentage is found to be 13% in the 1980s. From 1970 till 1979, the percentage of covered floor area is reduced to 11%. The construction period between 1990-1999 is characterized by a slightly lower percentage ratio of covered floor area, around 10%. Buildings erected during the period of 2000s and the post-2010 show 4% accordingly.

Figure 82 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 82 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

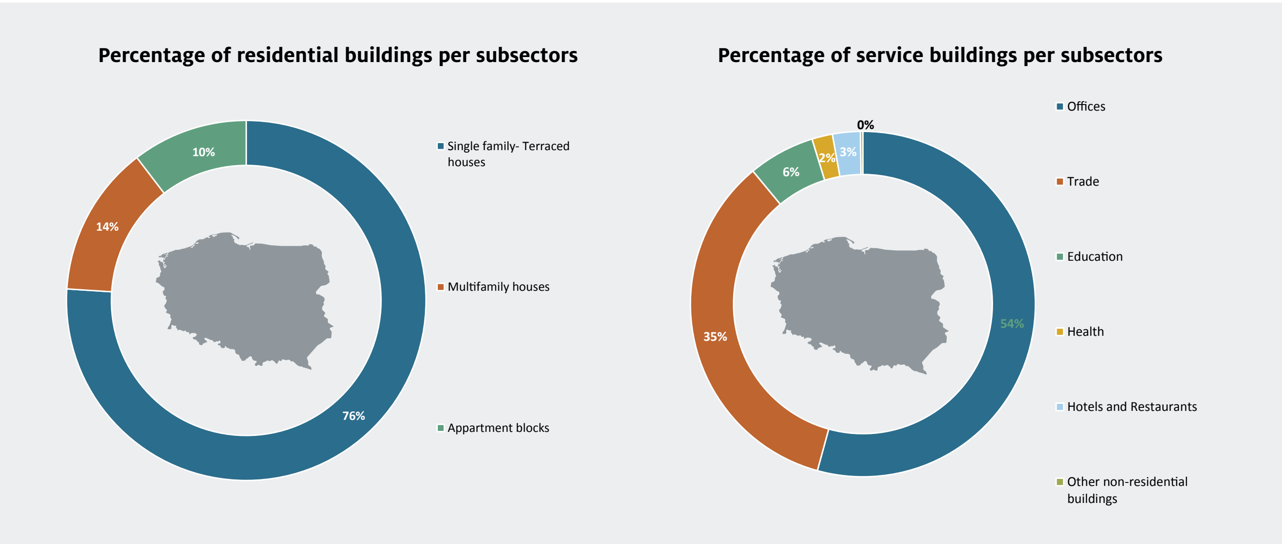

Figure 82. Split of residential and service buildings per different subsectors [%] (Poland). (Please note that Other non-residential buildings account for 0.2%)

The residential sector shows that 76% of the sector is categorized as SFHs. This leaves only 24% of the sector behind, including 14% for MFHs, and only 10% for ABs.

Whereas in the service sector, a significant portion of the market is allocated for offices, with a value of 54%. The trade buildings are the second-largest subsector in the service sector, with 35% respectively. Educational buildings and schools show a significantly lower percentage ratio, i.e., 6%. Hotels and restaurants occupy only 3% of the service sector. Whereas health care buildings cover 2% of the service building stock, respectively. Other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms), occupy less than 1% of the market respectively.

Figure 83 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

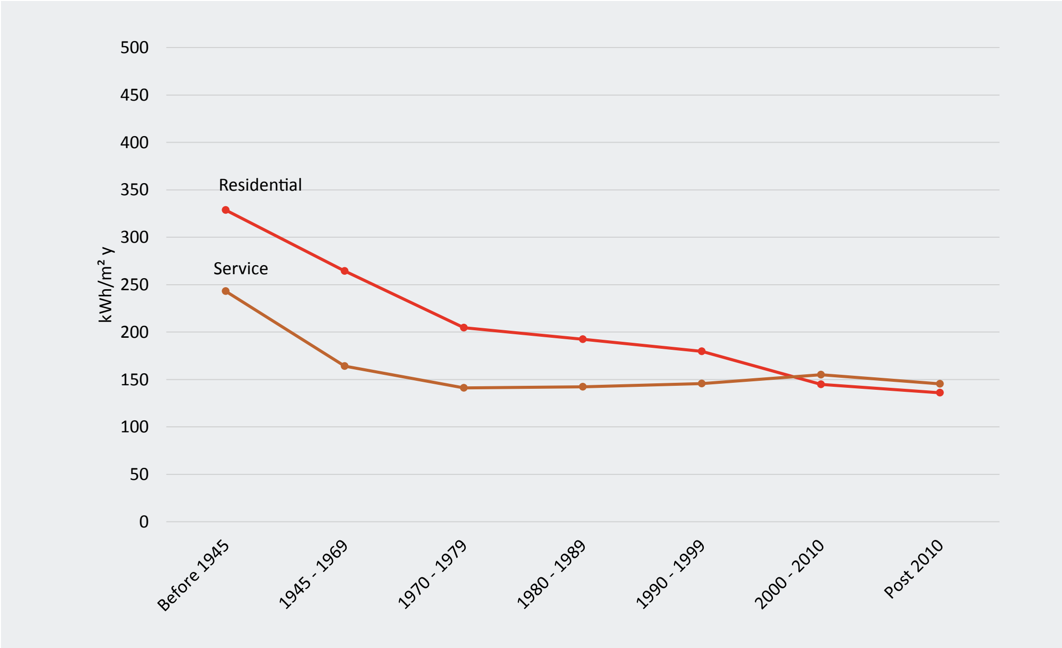

Figure 83. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Poland).

The figure above shows that the specific FEC for SH and DHW in residential buildings erected before 1945 till 1979 shows a rapid reduction. For instance, buildings constructed before 1945 indicate the highest consumption rate, of about 328 kWh/m² y. In comparison, buildings erected between 1945-1969 consume around 264 kWh/m² y of specific FEC. Whereas buildings of the 1970s show the value of specific FEC of approximately 205 kWh/m² y. The rapid reduction in specific FEC then slows down regarding buildings erected after the 1970s. As shown in the figure above, buildings that were erected in the 1980s indicate the value of a specific FEC of about 192 kWh/m² y. A slight decrease is found in buildings erected in the 1990s with the value of approximately 180 kWh/m² y. The further decrease in specific FEC is again observed in buildings of the 2000s, with the resulting value of about 145 kWh/m² y. The most efficient rate of specific FEC is determined in buildings that were erected in the post-2010 period with a value of 136 kWh/m² y respectively.

The trend of specific FEC for SH and DHW regarding service buildings erected before 1945 demonstrates the value of specific FEC of about 243 kWh/m² y. Buildings erected between 1945-1969 resulted in the rapid reduction of specific FEC; their value is decreased to approximately 164 kWh/m² y. A smaller reduction in specific FEC characterizes buildings erected in the 1970s compared to buildings of the previous periods. The value is found to be around 141 kWh/m² y. Buildings erected from 1980 till 1989, having relatively the same specific FEC, i.e., 142 kWh/m² y. Buildings constructed from 1990 till 1999 are characterized by a slight increase in specific FEC to approximately 146 kWh/m² y. A further increase in specific FEC is determined regarding buildings of the 2000s with the value of around 155 kWh/m² y respectively. Service buildings erected during the post-2010 period consume about 145 kWh/m² y compared to residential buildings (136 kWh/m² y) that were erected during the same time.

Figure 84 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

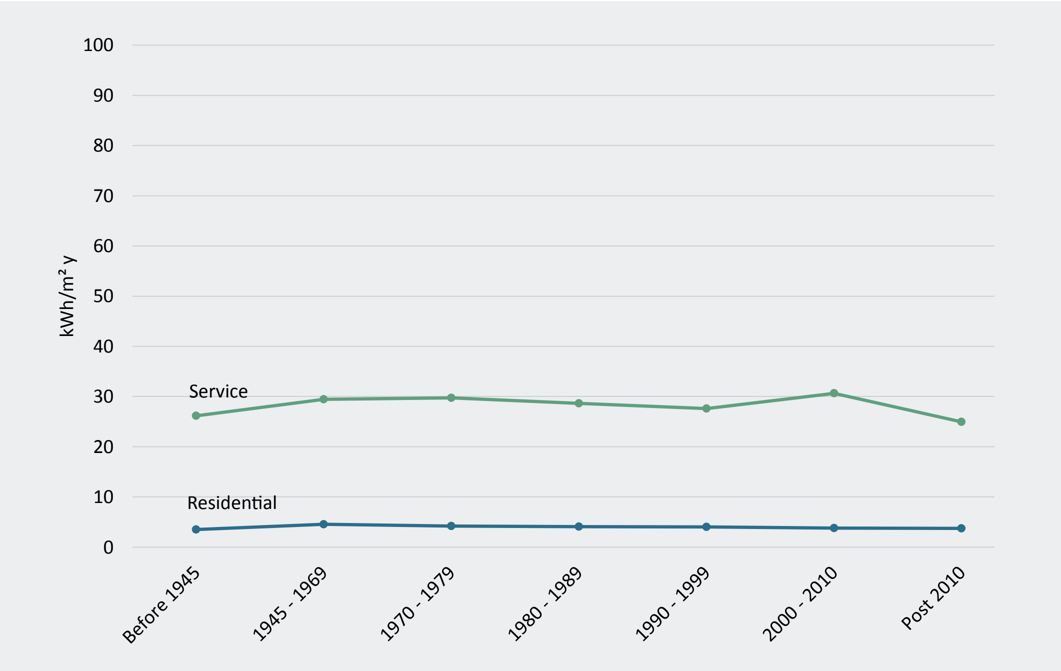

Figure 84. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Poland).

The rate of specific FEC for SC in the residential sector is less than in the service one. Buildings constructed before 1945 consume about 3.5 kWh/m²y of specific FEC. Regarding buildings erected from 1945 till 1969, the rate increases from about 4 kWh/m²y to approximately 5 kWh/m²y. Buildings erected in later years (1970-1979) consume about 4 kWh/m²y of specific FEC. Buildings constructed in further periods (from 1980 till post-2010) consume approximately the same 4 kWh/m²y with a minor fluctuation. Relatively small deviations characterize the residential sector in terms of specific FEC regarding buildings erected from 1945 till post-2010.

The rate of specific FEC for SC in the service sector regarding buildings erected before 1945 is about 26 kWh/m² y. The consumption rate then increases to around 30 kWh/m² y in the lately erected buildings, i.e., 1945-1969. The rate keeps relatively the same, i.e., 30 kWh/m² y in the buildings constructed between 1970-1979. The reduction in specific FEC is observed in buildings of the 1980s with a value of about 29 kWh/m² y. Approximately 28 kWh/m² y is consumed by buildings that were erected in the 1990s. An increase in specific FEC is determined regarding buildings of the 2000s with a value of about 31 kWh/m² y. The least specific FEC for SC is observed in the service buildings erected in the post-2010 period, with a value of about 25 kWh/m² y.

Regarding the construction methodology presented in the data set provided by the H2020 HotMaps repository (8), the main construction topology for walls concerning buildings erected before 1945 to the late 1960s is a solid wall without insulation, while cavity walls with insulations are present in buildings erected during the 2000s and post 2010 period respectively. Honeycomb bricks / hollow blocks wall are present in buildings of the 1970s, 1990s and also during the 2000s and post 2010 period respectively.

The construction methodology for windows is mainly double and single glazing windows. Single glazing windows are presented in MFHs and ABs that were erected before 1945, between 1945-1969, and in the 1970s. Single glazing windows are also present in SFHs erected only during the first two periods (before 1945, between 1945-1969). Buildings erected after mainly use double-glazing windows. Low emittance glazing is not present.

We can observe that a flat roof is the most popular decision regarding MFHs and ABs, respectively. Insulation is present in MFHs erected from 1970s and afterward and in ABs of the 2000s and post 2010 period respectively. A tilted roof is presented in ABs regardless of historical periods with a presence of insulation. Concrete slabs were primarily used in the residential buildings throughout analyzed periods. Insulation presented mainly in SFHs of 2000s and post 2010 period.

Information about construction materials and construction methodology of the service sector was received by questioning experts. The information concerning Eastern Europe (Poland, Czech Republic, Hungary, Slovenia, Slovakia, Croatia, Bulgaria, Romania) was summarized afterwards. Concerning the service sector in Poland, the information is presented in the table below (Table 41).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, health, other non-residential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation in few cases	Wood, low emittance glass in few cases.	Concrete and metallic roof boards + insulation	Concrete+ insulations in few cases	Solid wall	Double glazing	Flat roof	Concrete slab
Education							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation in few cases	Synthetic/PVC, low emittance glass in few cases.	Concrete and tiles + insulation in few cases	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roof	Concrete slab
Hotels and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation in few cases	Aluminum (50%) and synthetic/ PVC (50%), low emittance glass in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roof	Concrete slab

Table 41. Construction materials, construction methodology-service sector (Poland).

The table above (Table 41) shows that the service sector demonstrates similarities with construction methodology and relative similarities with construction materials regarding different types of buildings. For the office, trade, health, and other non-residential buildings, the use of construction materials and methodology stay the same. Education buildings, hotels, and restaurants have similar construction methodology while demonstrating the small difference in construction materials.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). According to all historical periods, Table 42 shows the thermal transmittance value ($W/m^2 K$) regarding residential and service sectors.

Table 42 helps to figure out the impact of building elements on specific FEC. Here we can observe how thermal insulation materials and building elements regarding different periods affect heat flow. As seen from the table below, the thermal transmittance values demonstrate the reduction throughout the historical periods.

RESIDENTIAL SECTOR

Historical period	Walls	Windows	Roof	Floor
Before 1945	1.72	4.86	0.81	2.01
1945 - 1969	1.49	3.73	0.70	1.64
1970 - 1979	1.14	3.16	0.50	1.33
1980 - 1989	0.85	2.60	0.64	1.17
1990 - 1999	0.25	1.60	0.44	0.80
2000 - 2010	0.21	1.35	0.43	0.55
Post 2010	0.19	1.28	0.33	0.45

SERVICE SECTOR

Historical period	Walls	Windows	Roof	Floor
Before 1945	1.30	4.70	1.00	1.60
1945 - 1969	1.05	3.70	0.90	1.20
1970 - 1979	0.93	2.60	0.70	1.15
1980 - 1989	0.80	2.45	0.50	1.10
1990 - 1999	0.60	2.30	0.30	1.00
2000 - 2010	0.45	2.10	0.28	0.70
Post 2010	0.30	1.70	0.25	0.45

Table 42. Thermal transmittance of construction elements (Poland).

The analyzed data for SH and DHW in Poland's residential sector is characterized by central and district heating systems. District heating system is mainly present in MFHs and ABs, while SFHs is characterized by using central SH and DHW system. Regarding all buildings, types, and construction periods, combined boilers are used.

The gas is widely used in all considered building types for SH and DHW needs, respectively.

The results for SC technology show that in most cases, SC is not represented in Poland's residential building stock.

Findings demonstrate that gas is the main energy carrier for SH and DHW needs, while renewable technologies were not determined.

According to expert questioning: The most common technology for SH and DHW is a non-condensing gas boiler. SC is not present in most cases, except health industry, where SC is often used.

3.22. **PORTUGAL**

This section represents a selection of main results that were obtained from the building stock analysis dataset regarding Portugal (8).

In Figure 85, the Mm² of covered floor area in the Portuguese residential and service sectors is presented in percentages regarding historical periods.

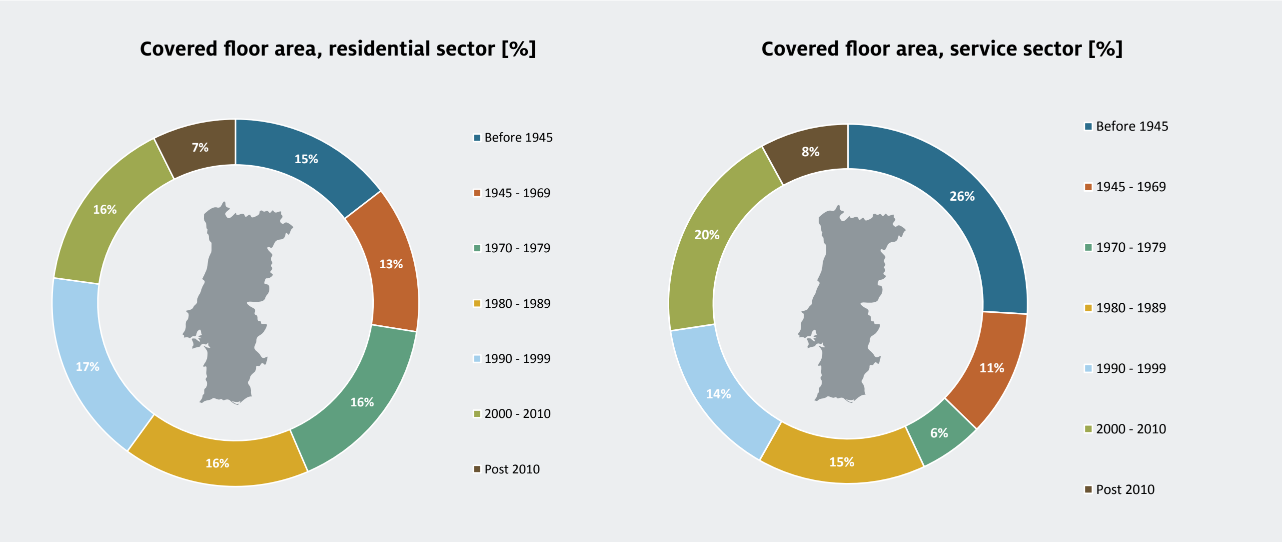

Figure 85. Split of the residential and service building stock raised per construction periods [%] (Portugal).

As visible from the figure above, the residential sector demonstrates close similarities across all historical periods. The data indicate that a relatively equal building area characterizes each consecutive period that differs from the previous one by no more than 3%, except the period of post 2010. The period of the 1990s indicates the highest percentage of covered floor area, i.e., 17%. Interestingly, periods of the 1970s, 1980s, and 2000s indicate an equal percentage ratio of covered floor area (16%) respectively. The period before 1945 shows a relatively smaller percentage ratio of 15%. Buildings erected in the periods between 1945-1969 show 13% of the total covered floor area, respectively. The last period (post-2010) indicates the smallest percentage ratio of covered floor area with a value of only 7%.

In contrast, the service sector does not demonstrate equalities in different periods. As shown from the figure above, the historical period «before 1945» displays the highest percentage of covered floor areas, 26%, which means that significant numbers of service buildings are characterized as historical buildings. The second-largest portion of the covered floor area is found in buildings erected between 2000-2010, with 20%. The period of the 1980s indicates 15% of covered floor area. The period of the 1990s indicates 14%. Buildings erected in the periods between 1945-

1969 show 11% of the total covered floor area. The minor portion demonstrates the post-2010 period and the period of the 1970s with values of 6% and 8%, respectively.

Figure 86 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 86 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

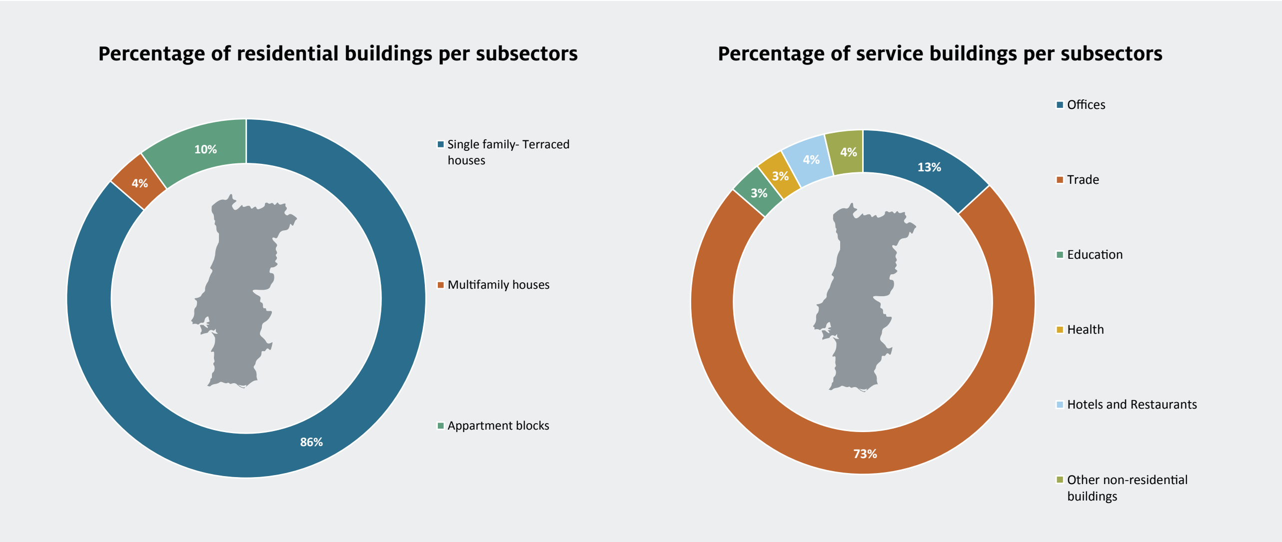

Figure 86. Split of residential and service buildings per different subsectors [%] (Portugal).

The figure above clearly shows that in the residential sector, 86% - is occupied by SFHs, leaving behind the remaining 14% of the market for ABs (10%) and MFHs (4%), respectively.

Considering the service sector, we notice that trade buildings are the most widespread building type in Portugal. These buildings occupy almost three-fourth of the market, i.e., 73%. About 13% of the buildings in the service sector are offices. Hotels and restaurants indicate 4% while the same percentage ratio (4%) belong to other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms). Educational buildings, healthcare and hospitals cover only 3% of the market, respectively.

Figure 87 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

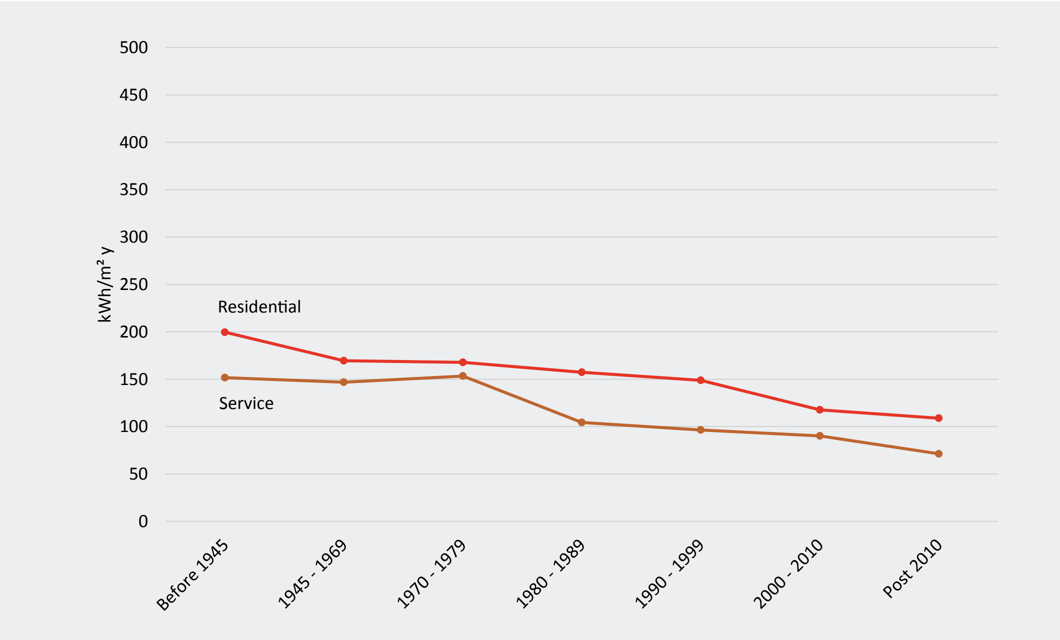

Figure 87. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Portugal).

The development trend of the specific FEC for SH and DHW decreases regarding buildings erected before 1945 till post-2010. The highest value of specific FEC is determined in buildings erected before 1945, i.e., 200 kWh/m² y. Buildings erected between 1945-1969 to the late 1990s indicate the stable decrease in specific FEC. The consumption rate decreases from around 200 kWh/m² y to 169 kWh/m² y in buildings that were erected between 1945-1969. Buildings erected in the 1970s indicate approximately 167 kWh/m² y of specific FEC. The specific FEC of buildings erected in the 1980s and 1990s shows 157 and 149 kWh/m² y accordingly. The trend of specific FEC then decreases to about 118 kWh/m² y regarding buildings of the 2000s. The lowest specific FEC for SH and DHW, i.e., 109 kWh/m² y, is consumed in buildings of the post-2010 period, respectively.

Service buildings erected before 1945 to the post-2010 period demonstrate a similar trend of specific FEC for SH and DHW with the residential ones. Buildings erected before 1945 indicate the consumption rate of about 152 kWh/m² y. This rate slightly decreases to the value of 147 kWh/m² y regarding buildings that were erected between 1945-1969. An increase in specific FEC is determined regarding buildings of the 1970s with a value of approximately 153 kWh/m² y. Buildings erected in the 1980s consume about 104 kWh/m² y, whereas those erected in the 1990s consume around 96 kWh/m² y. The consumption rate decreases to about 90 kWh/m² y regarding buildings of the 2000s. Buildings erected after 2010 indicate the lowest rate of specific FEC for SH and DH, which is 71 kWh/m² y.

Figure 88 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

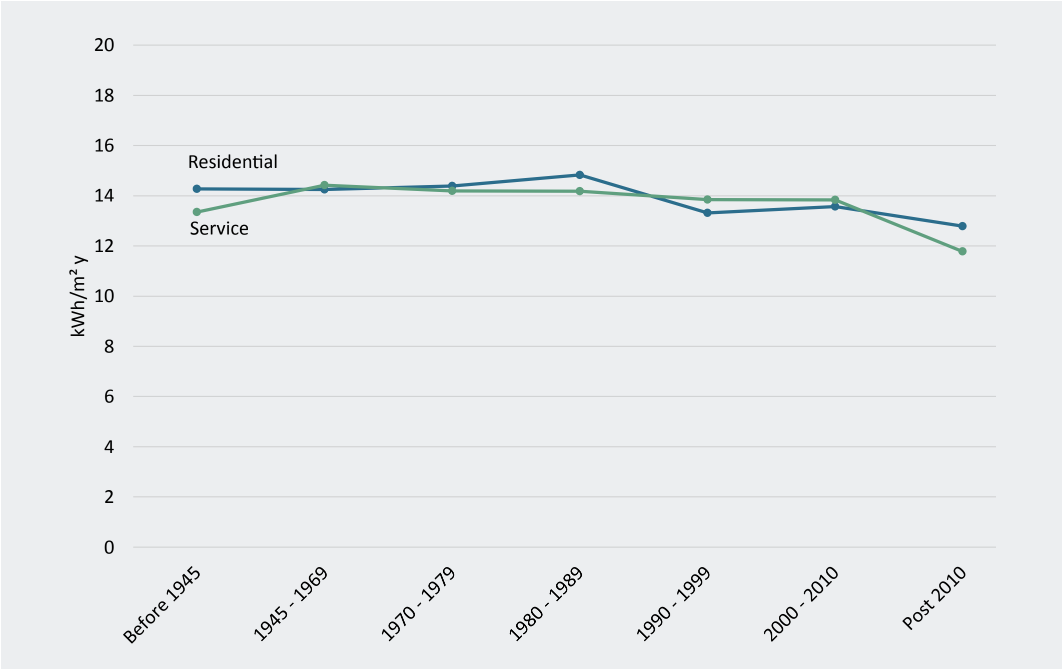

Figure 88. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Portugal).

The trend of specific FEC for SC in residential and service sectors is relatively equal regarding buildings erected from 1945 to the late 2000s.

Specific FEC for SC in the residential buildings erected before 1945 is about 14 kWh/m² y, whereas in the service sector, it is slightly lower, i.e., 13 kWh/m² y. Buildings erected from 1945 till 1969 consume about 14 kWh/m² y in both sectors. The consumption rate remains relatively the same in the residential and service buildings erected in the 1970s, i.e., 14 kWh/m² y. Residential and service buildings constructed in the 1980s consume about 15 and 14 kWh/m² y of specific FEC for SC, respectively. The trend then decreases to near 13 and 14 kWh/m² y, regarding buildings (residential and service) erected in the 1990s. Residential and service buildings of the 2000s consume relatively the same amount of energy, approximately 14 kWh/m² y. The smallest value of specific FEC is found in residential and service buildings erected in the post-2010 period, with values of about 13 and 12 kWh/m² y, respectively

Regarding the construction methodology presented in the dataset provided by the H2020 Hot-Maps project (8), the main construction topology for walls is a solid wall without insulation. The construction methodology for windows is mainly single glazing windows. Double glazing is found only in buildings erected in the post-2010 periods. We can observe that a flat roof is the most popular decision in buildings regarding MFHs and ABs. A flat roof is also present in SFHs, except buildings of the 1970s. Insulation is present in SFHs and MFHs erected after 1980. The tilted roof is mainly used in historical buildings and in SFHs erected up to the late 1970s. Insulation for a tilted roof has not been determined.

Information about construction materials and construction methodology of the service sector was received by experts questioning. The information concerning Southern Europe (Spain, Italy, Greece, Cyprus, Malta, and Portugal) was eventually summarized. Concerning the Portuguese service sector, the information is presented in the table below (Table 43).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, health, hotels and restaurants, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation only in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete+ insulations in few cases	Honeycomb bricks/hollow block walls	Double and single glazing	Flat roof	Concrete slab
Education							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks and concrete+ insulation only in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete+ insulations in few cases	Honeycomb bricks/hollow block walls	Double glazing	Flat roof	Concrete slab

Table 43. Construction materials, construction methodology-service sector (Portugal).

The table above (Table 43) shows that the service sector show similarities in construction material and construction methodology regarding all types of service buildings, except educational buildings that indicate small differences in construction materials for walls.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 44 shows the thermal transmittance value (W/m^2K) regarding two considered building sectors (residential and service) for all periods.

Table 44 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and building elements regarding different periods affect heat flow and thus specific FEC variation.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	2.00	4.30	3.10	2.10
1945 - 1969	1.50	4.20	3.00	2.05
1970 - 1979	1.45	3.50	2.70	2.03
1980 - 1989	1.40	3.15	2.60	2.01
1990 - 1999	1.20	2.97	2.40	2.00
2000 - 2010	0.80	2.88	1.30	1.30
Post 2010	0.54	2.80	0.55	0.62
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	2.00	4.50	2.50	1.25
1945 - 1969	1.80	4.45	2.65	1.58
1970 - 1979	1.60	4.48	2.80	1.74
1980 - 1989	1.50	4.40	2.70	1.82
1990 - 1999	1.30	1.60	1.50	1.90
2000 - 2010	0.80	3.80	1.20	0.80
Post 2010	0.54	2.80	0.55	0.62

Table 44. Thermal transmittance of construction elements (Portugal).

The analyzed data related to SH and DHW in the residential sector reveals that the leading technology for SH and DHW is a centralized non-condensing boiler for SH and DHW needs regarding all types of buildings and construction periods. DHW system is also characterized by using solar collectors regarding buildings erected in the post-2010 period. The results for SC technology show that in most cases, SC is not represented in this residential market.

The residential building stock mainly utilizes gas. Findings demonstrate that technology for SH and DHW, besides utilizing traditional energy carrier (gas), also uses solar collectors.

According to expert questioning, the most common SH and DHW are the individual gas condensing boiler and electric heating (trade buildings). SC is present in most cases, except educational buildings.

3.23. **ROMANIA**

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Romania.

In Figure 89, the Mm² of covered floor area in the Romanian residential and service sectors is presented in percentages regarding historical periods.

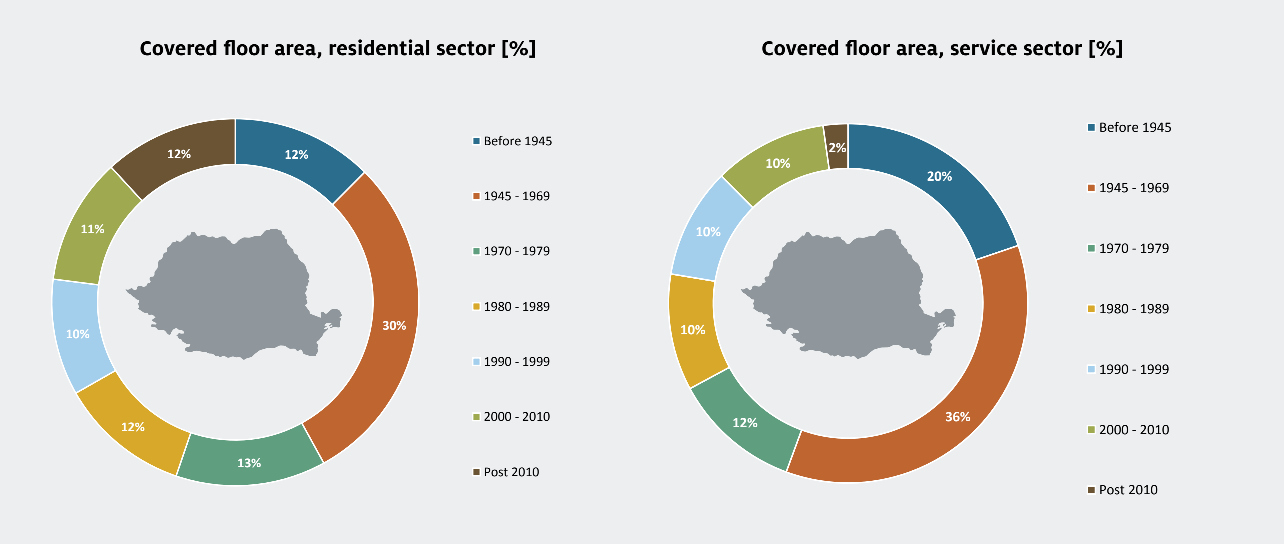

Figure 89. Split of the residential and service building stock raised per construction periods [%] (Romania).

The data analysis shows that buildings that were built in 1945-1969 occupy the most significant part of the residential sector, i.e., 30%. About 13% of the covered floor area is related to buildings erected between 1970-1979. The three analyzed periods indicate an equal percentage ratio of covered floor area, such as: before 1945, the 1980s, and the last post-2010 period, with 12% each. In the residential buildings of the 2000s, the ratio is 10% accordingly. Buildings erected in the 1990s occupy the least percentage ratio of covered floor area.

The most significant portion of covered floor area in the service sector is also related to buildings erected between 1945 till 1969, with a percentage ratio of 36%. Buildings constructed between 1945-1969 occupy 20% of the covered floor area. About 12% of the covered floor area was occupied by buildings erected during the 1970s. Buildings erected during the three consecutive periods (1980-1989, 1990-1999, 2000-2010) indicate 10% of the covered floor area. The minor percentage ratio is found in buildings erected in the post-2010 period with 2% only.

Figure 90 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 90 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

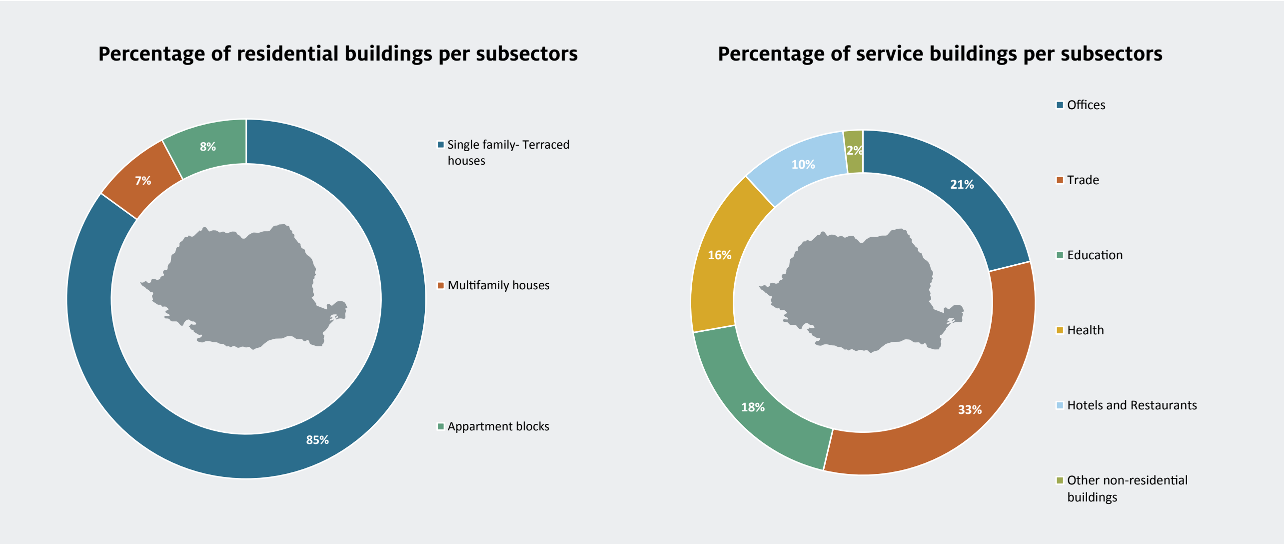

Figure 90. Split of residential and service buildings per different subsectors [%] (Romania).

The graph shows that in the Romanian residential sector, 85% of the buildings are characterized as SFHs. Whereas about 8% of the buildings are ABs, and the remaining 7% is characterized as MFHs, respectively.

In the service sector, most of the service buildings are characterized as trade buildings that covered 33% of the market. About 21% of the service sector are offices. Educational buildings occupy 18% of the service building stock. A slightly lower percentage ratio refers to health care buildings with 16% respectively. Hotels and restaurants indicate 10% of the service sector, whereas the least represented building type is other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms) with only 2%.

Figure 91 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

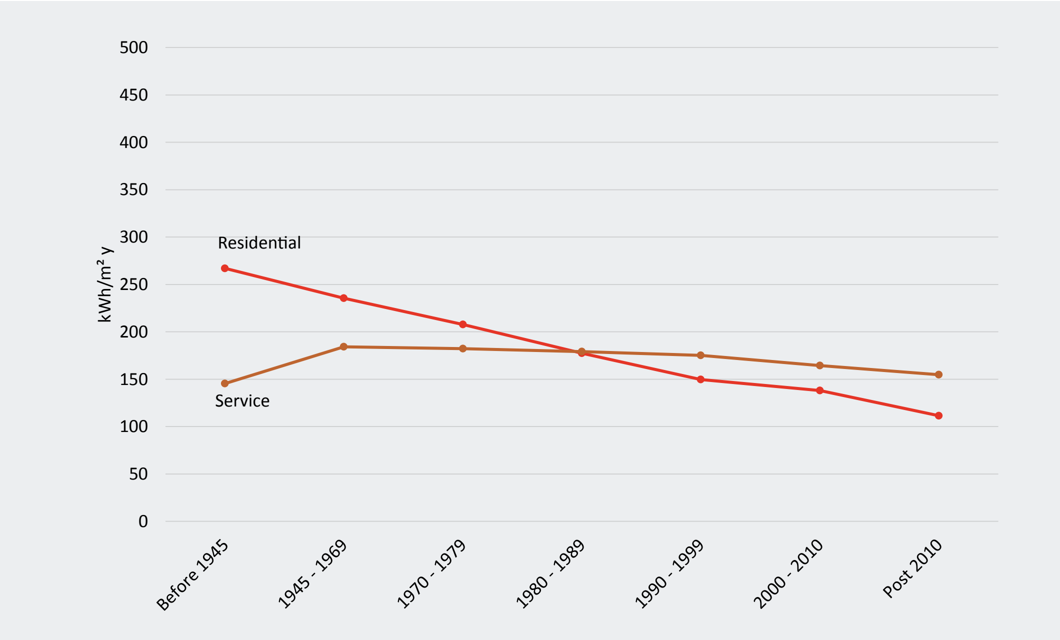

Figure 91. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Romania).

The overall trend of specific FEC for SH and DHW decreases regarding buildings erected before 1945 till post-2010. The highest value of specific FEC is determined in buildings erected before 1945, i.e., 267 kWh/m² y. Buildings erected between 1945-1969 to the late 1980s indicate the stable decrease in specific FEC. The consumption rate decreases from about 235 kWh/m² y to 179 kWh/m² y accordingly. Buildings erected in the 1970s indicate around 207 kWh/m² y of specific FEC. The specific FEC of buildings erected in the 1980s shows the value of approximately 179 kWh/m² y accordingly. Buildings that were constructed in the 1990s indicate a further decrease. The value of specific FEC has reduced to approximately 150 kWh/m² y. Buildings of the 2000s, indicate for about 138 kWh/m² y. The lowest specific FEC for SH and DHW is consumed by buildings of the post-2010 period with approximately 111 kWh/m² y, respectively.

In comparison, the overall trend of specific FEC for SH and DHW in the service sector decreases more steadily. Buildings that were erected before 1945 indicate a consumption rate of about 145 kWh/m² y. This rate then slightly increased to a value of about 184 kWh/m² y regarding buildings that were constructed from 1945 till 1969. Buildings erected in the 1970s show relatively the same value of specific FEC, i.e., 182 kWh/m² y, whereas those erected in the 1980s and 1990s consume approximately 179 and 175 kWh/m² y respectively. The consumption rate continues steadily decreasing regarding buildings of the 2000s and last post-2010 period. Buildings erected in these periods show the values of specific FEC for SH and DHW of approximately 164 and 155 kWh/m² y, respectively.

Figure 92 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2010

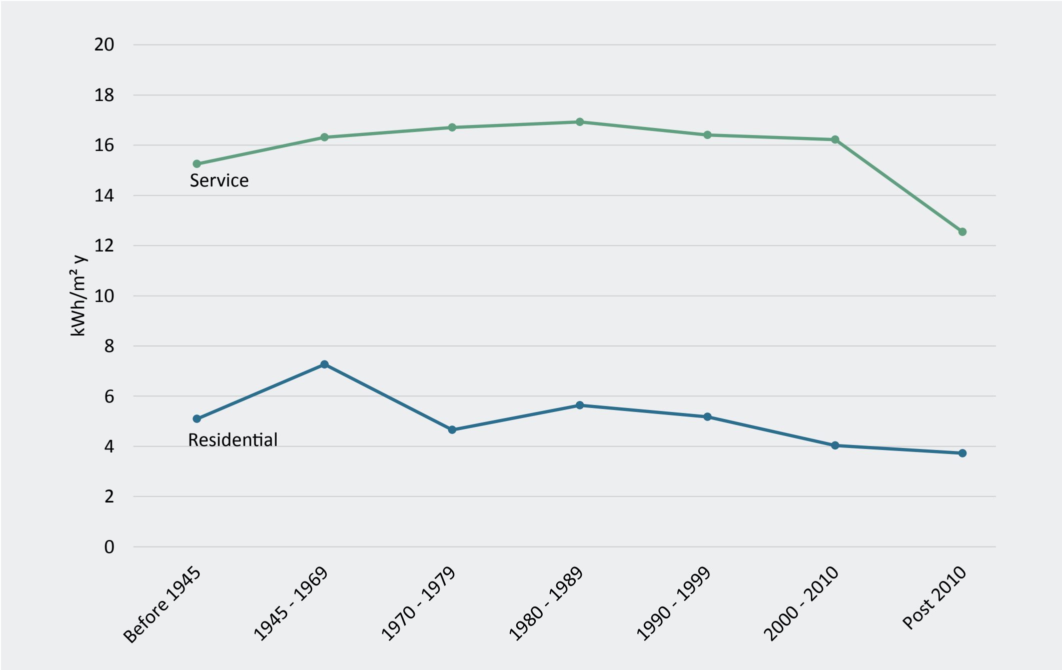

Figure 92. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Romania).

In the residential sector, the trend of specific FEC for SC indicates that buildings erected before 1945 show the value of specific FEC for about 5 kWh/m² y. An increase in specific FEC is determined regarding buildings erected between 1945-1969 with a value of about 7 kWh/m² y. After that, the overall trend of specific FEC for SC is dropped to approximately 4.5 kWh/m² y regarding buildings of the 1970s. The last increase to about 5.6 kWh/m² y is determined in buildings that were erected in the 1980s. The specific FEC for SC then decreases to approximately 5 kWh/m² y regarding buildings of the 1990s. The smallest value of specific FEC belongs to residential buildings erected in the 2000s and post-2010 periods, respectively, with the value of approximately 4 kWh/m² y.

The rate of specific FEC for SC in the service sector regarding buildings erected before 1945 is about 15 kWh/m² y. The consumption rate then increases to around 16 kWh/m² y in the lately erected buildings, i.e., 1945-1969. The rate then steadily increases to around 16.7 and 17 kWh/m² y regarding buildings of the 1970s and 1980s accordingly. The reduction in specific FEC is observed in buildings of the 1990s and 2000s with the value of approximately 16 kWh/m² y. The least specific FEC for SC is observed in the service buildings erected in the post-2010 period, which indicates a drop to about 13 kWh/m² y.

Regarding the construction methodology presented in the data set provided by the H2020 Hot-Maps repository (8), the main construction topology for walls, concerning all periods, is solid walls with insulation, except historical buildings (constructed before 1945). The construction methodology for windows is mainly single and double-glazing windows. Single glazing windows are present in buildings erected before 1945 to the late 1970s. Double glazing windows were installed in buildings erected in the 1980s and afterward. Low emittance glazing windows are not presented.

We can observe that the flat roof is the most popular decision regarding MFHs, ABs and SFHs constructed in the 1990s and afterward. Insulation is present in buildings erected in the 1980s and afterward, with insulation in buildings erected in the post-2010 period. The tilted roof is primarily present in SFHs with insulation regarding buildings erected during the three last periods. Concrete slabs are used in houses erected throughout all historical periods. Insulation is present only in buildings erected after 2010.

Information about construction materials and construction methodology of the service sector was received by questioning experts. The information concerning Eastern Europe (Poland, Czech Republic, Hungary, Slovenia, Slovakia, Croatia, Bulgaria, Romania) was summarized afterwards. Concerning the Romanian service sector, the information is presented in the table below (Table 45).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, health, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation in few cases	Wood, low emittance glass only in few cases.	Concrete and metallic roof boards + insulation	Concrete+ insulations in few cases	Solid wall	Double glazing	Flat roof	Concrete slab
Education							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation in few cases	Synthetic/PVC, low emittance glass only in few cases.	Concrete and tiles + insulation in few cases	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roof	Concrete slab
Hotels and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roof	Concrete slab

Table 45. Construction materials, construction methodology-service sector (Romania).

The table above (Table 45) shows that the service sector demonstrates similarities with construction methodology and relative similarity with construction materials regarding different types of buildings. For the office, trade, health, and other non-residential buildings, the use of construction materials and methodology stay the same. Education buildings, hotels, and restaurants have similar construction methodology while indicate small differences in construction materials.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 46 shows the thermal transmittance value (W/m^2K) regarding two considered building sectors (residential and service) for all periods.

Table 46 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and buildings elements regarding different periods affect heat flow and thus specific FEC variation.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.90	2.60	1.40	1.60
1945 - 1969	1.70	2.50	1.30	1.40
1970 - 1979	1.50	2.45	1.25	1.30
1980 - 1989	1.40	2.43	1.23	1.10
1990 - 1999	1.30	2.40	1.20	1.00
2000 - 2010	0.90	1.40	1.00	0.61
Post 2010	0.67	1.30	0.29	0.22
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.90	2.60	1.10	1.40
1945 - 1969	1.60	2.70	1.20	1.25
1970 - 1979	1.50	2.55	1.15	1.18
1980 - 1989	1.45	2.48	1.17	1.10
1990 - 1999	1.40	2.40	1.10	1.05
2000 - 2010	1.00	1.85	0.30	1.00
Post 2010	0.56	1.30	0.18	0.22

Table 46. Thermal transmittance of construction elements (Romania).

According to the analysis, the individual non-condensing gas boilers for SH and DHW is used in buildings constructed during all analyzed periods.

The results for SC technology show that in most cases, SC is not represented in this residential market. The value for specific FEC for SC in most cases is between 4-6 kW/m²y, according to the information presented in Figure 92.

These findings demonstrate a lack of renewable energy sources for SH, DHW, and SC in the Romanian residential building stock that mainly utilize gas.

According to expert questioning: the most common technology in the service sector for SH and DHW is non-condensing gas boiler. SC is not presented in most cases, except in the health industry, where SC is mainly used.

3.24. 3.24 SLOVAKIA

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Slovakia.

In Figure 93, the Mm² of covered floor area in the Slovak residential and service sectors is presented in percentages regarding historical periods.

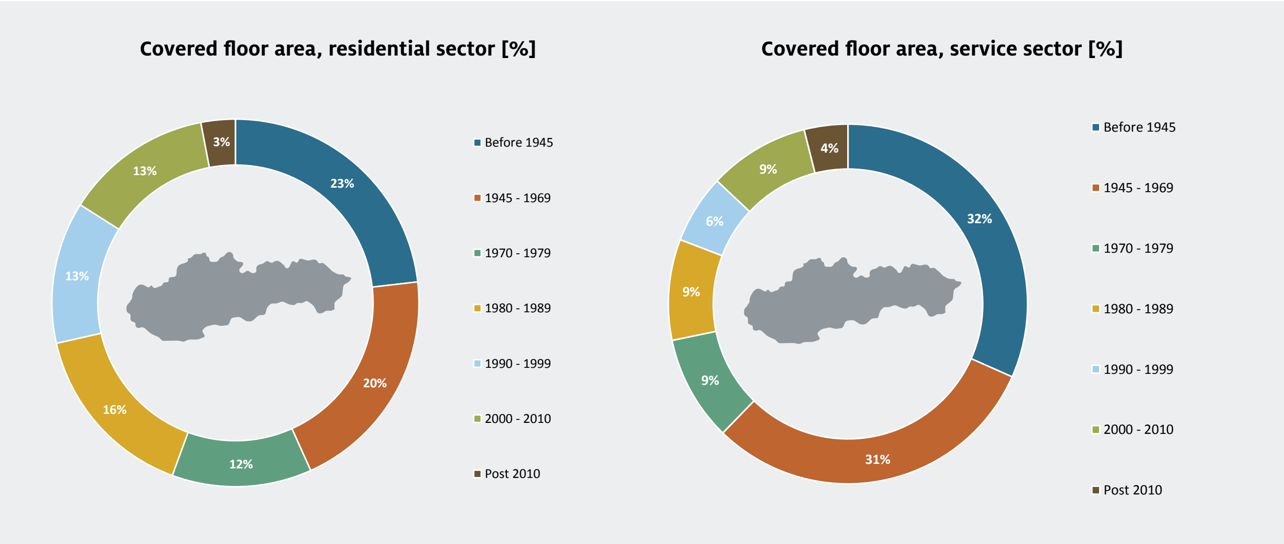

Figure 93. Split of the residential and service building stock raised per construction periods [%] (Slovakia).

The figure above shows that the highest percentage of covered floor area in the residential sector relates to the period before 1945 with 23%. The second-highest percentage of covered floor area is 20%, which relates to the post-WWII period (1945-1969). It can be seen that buildings erected in the 1980s indicate 16% of the covered floor area, which is the third-highest value. Buildings erected in the 1990s and 2000s account for 13% of the total covered the floor area, respectively. In contrast, the period of the 1970s is characterized by 12%. Buildings that were constructed in the last post-2010 period, show the minor percentage ratio, i.e., 3%.

The service sector results indicate that the most significant portion of covered floor area belongs to buildings erected during the historical period before 1945 with 32%. Buildings erected between 1945-1969 indicate 31% of the covered floor area, which is the sec ond-highest percentage ratio. Interestingly, buildings of the 1970s, 1980s and 2000s show an equal percentage ratio of covered floor area, i.e., 9%. From 1990 till 1999, the percentage of covered floor area is found to be around 6%. Buildings erected during the period of post-2010 show 4% accordingly.

Figure 94 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 94 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

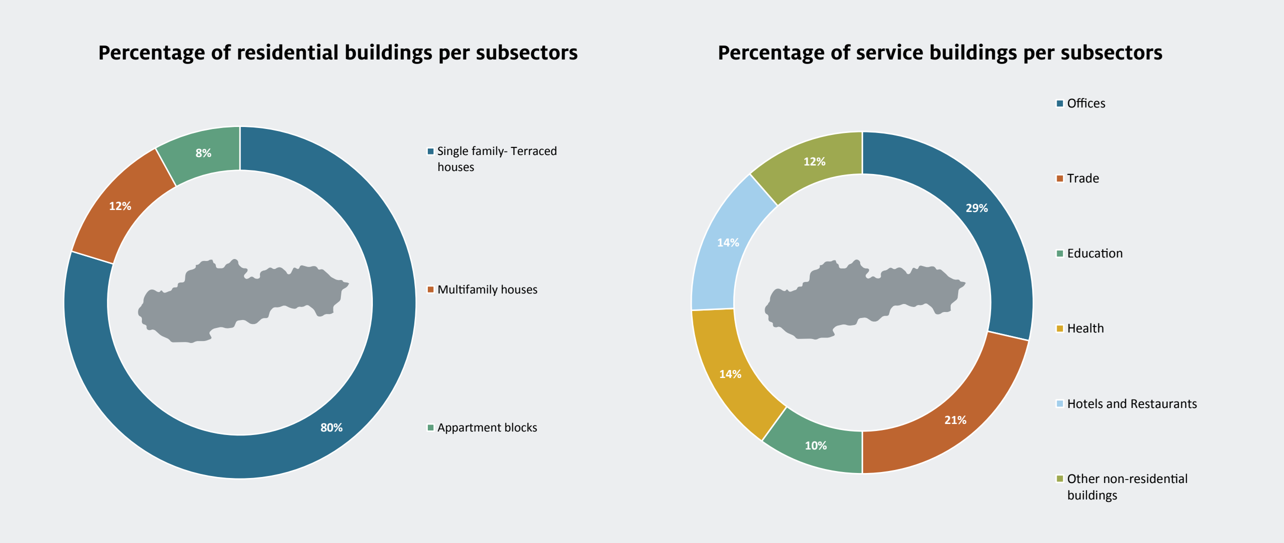

Figure 94. Split of residential and service buildings per different subsectors [%] (Slovakia).

The residential sector shows that 80% of the sector is categorized as SFHs. This leaves only 20% of the sector behind, including 12% for MFHs, and only 8% for ABs.

The service sector is dominated by offices (29%) and followed by trade buildings (21%). The health as well as hotels and restaurants sectors follow with 14% each. Other non-residential buildings follow with 12% and educational buildings are last positioned with 10%.

Figure 95 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

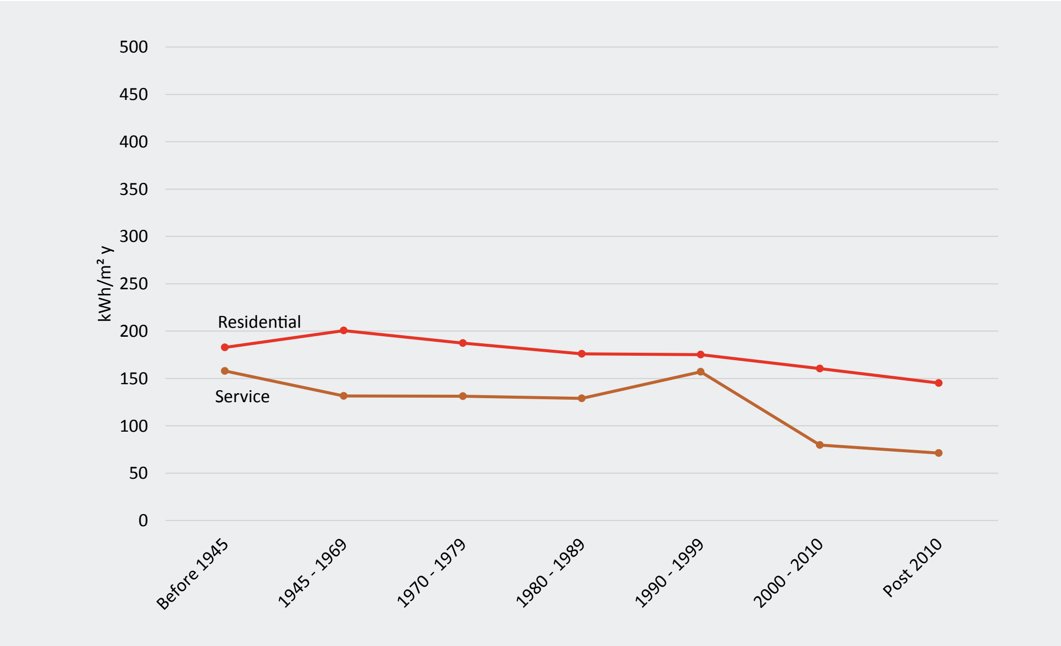

Figure 95. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Slovakia).

The figure above shows that the trend of specific FEC for SH and DHW in residential buildings shows a slow reduction. For instance, buildings constructed before 1945 indicate a consumption rate of about 183 kWh/m² y. In comparison, buildings erected between 1945-1969 indicate the highest rate of specific FEC of around 200 kWh/m² y. In comparison, buildings of the 1970s show a lesser value of specific FEC of approximately 187 kWh/m² y. A slight reduction in specific FEC was detected in buildings erected in the 1980s with 176 kWh/m² y respectively. As shown in the figure above, buildings that were erected in the 1990s indicate the value of a specific FEC of about 175 kWh/m² y. A slight decrease is found in buildings erected in the 2000s with the value of approximately 160 kWh/m² y. The most efficient rate of specific FEC is determined in buildings that were erected in the post-2010 period with a value of 145 kWh/m² y respectively.

The trend of specific FEC for SH and DHW regarding service buildings erected before 1945 demonstrates the value of specific FEC of about 158 kWh/m² y. Buildings erected between 1945-

1969 resulted in the reduction of specific FEC; their value is decreased to approximately 132 kWh/m² y. A smaller reduction in specific FEC characterizes buildings erected in the 1970s and 1980s compared to buildings of the previous periods. Their value is found to be around 131 kWh/m² y. Buildings constructed from 1990 till 1999 are characterized by an increase in specific FEC to approximately 157 kWh/m² y. A rapid reduction in specific FEC is determined regarding buildings of the 2000s with the value of around 80 kWh/m² y respectively. Service buildings erected during the post-2010 period consume about 71 kWh/m² y compared to residential buildings (145 kWh/m² y) that were erected during the same time.

Figure 96 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

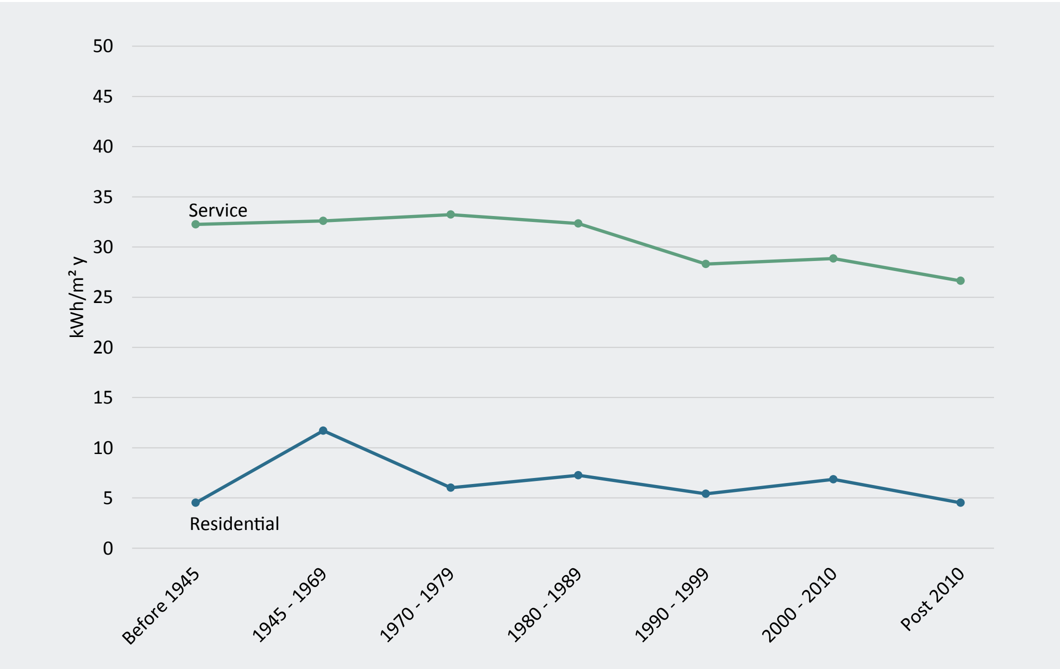

Figure 96. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Slovakia).

The rate of specific FEC for SC in the residential sector is less than in the service one. Buildings constructed before 1945 consume about 4.5 kWh/m²y of specific FEC. Regarding buildings erected from 1945 till 1969, the rate has increased drastically from about 4.5 kWh/m²y to approximately 12 kWh/m²y. Buildings erected in later years (1970-1979) consume about 6 kWh/m²y of specific FEC. Buildings constructed in further periods (from 1980 till the 2000s) consume approximately between 7 and 5 kWh/m²y with a minor fluctuation as shown in the figure above. Buildings erected in the last post-2010 period indicate the most efficient rate of specific FEC for SC with a value of 4.5 kWh/m²y.

The rate of specific FEC for SC in the service sector regarding buildings erected before 1945 is about 32 kWh/m² y. The consumption rate then stays mainly the same, regarding buildings erected between 1945-1969. The rate increased to about 33 kWh/m² y in buildings constructed between 1970-1979. The reduction in specific FEC is observed in buildings of the 1980s with a value of about 32 kWh/m² y. Approximately 28 kWh/m² y is consumed in buildings that were erected in the 1990s. A slight increase in specific FEC is determined regarding buildings of the 2000s with a value of about 29 kWh/m² y. The least specific FEC for SC is observed in the service buildings erected in the post-2010 period, with a value of approximately 27 kWh/m² y.

Regarding the construction methodology presented in the data set provided by the H2020 Hot-Maps repository (8), the main construction topology for walls concerning SFHs erected before 1945 to the late 1970s is solid walls without insulation, while in MFHs and ABs, solid walls are only present in buildings of the first two periods (before 1945, 1945-1969). In solid walls, insulation is not determined. Honeycomb bricks/hollow blocks walls are present in SFHs erected from the 1980s (with insulation from the 1990s) and afterward. Honeycomb bricks/hollow blocks wall is also determined in MFHs, and ABs erected from the 1990s and afterward. Insulation is present in all cases. The construction methodology for windows is mainly single glazing windows. Single glazing windows are presented in MFHs, and ABs that were erected before 1945 to the late 1980s and in SFHs erected before 1945 to the late 1990s. Buildings erected after mainly use double-glazing windows. Low emittance glazing is present only in SFHs. We can observe that a flat roof is the most popular decision regarding SFHs and ABs, erected from 1970 and after, with insulation in all cases. A flat roof was also determined in MFHs erected in 1970, the 1980s, and during the post-2010 period, respectively, with insulation. A tilted roof is presented in SFHs, and ABs erected before 1945 to 1969 with insulation in buildings erected after 1945. A tilted roof is also present in MFHs erected before 1945, between 1945-1969, and during the 1990s and 2000s. Insulation is present in all cases. Concrete slabs were primarily used in the residential buildings throughout the analyzed periods. Insulation was presented in buildings erected in the 1980s and afterward.

Information about construction materials and construction methodology of the service sector was received by questioning experts. The information concerning Eastern Europe (Poland, Czech Republic, Hungary, Slovenia, Slovakia, Croatia, Bulgaria, Romania) was summarized afterward. Concerning the service sector in Slovakia, the information is presented in the table below (Table 47).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, health, other non-residential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation in few cases	Wood, low emittance glass in few cases.	Concrete and metallic roof boards + insulation	Concrete+ insulations in few cases	Solid wall	Double glazing	Flat roof	Concrete slab
Education							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation in few cases	Synthetic/PVC, low emittance glass in few cases	Concrete and tiles + insulation in few cases	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roof	Concrete slab
Hotels and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation in few cases	Aluminum and synthetic/PVC (50/50%), low emittance glass in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roof	Concrete slab

Table 47. Construction materials, construction methodology-service sector (Slovakia).

The table above (Table 47) shows that the service sector demonstrates similarities with construction methodology and relative similarities with construction materials regarding different types of buildings. For the office, trade, health, and other non-residential buildings, the use of construction materials and methodology stay the same. Education buildings, hotels, and restaurants have similar construction methodology while demonstrating the small difference in construction materials.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). According to all historical periods, Table 48 shows the thermal transmittance value ($W/m^2 K$) regarding residential and service sectors.

Table 48 helps to figure out the impact of building elements on specific FEC. Here we can observe how thermal insulation materials and building elements regarding different periods affect heat flow. As seen from the table below, the thermal transmittance values demonstrate the reduction throughout the historical periods.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.50	3.70	2.00	2.00
1945 - 1969	1.20	3.70	1.50	1.70
1970 - 1979	1.10	3.30	1.10	1.60
1980 - 1989	0.80	2.90	0.70	1.55
1990 - 1999	0.65	2.30	0.60	1.50
2000 - 2010	0.50	2.00	0.42	1.00
Post 2010	0.32	1.70	0.23	0.40
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.50	3.20	1.60	1.50
1945 - 1969	1.00	3.05	0.70	1.45
1970 - 1979	0.85	2.90	0.60	1.42
1980 - 1989	0.70	2.60	0.55	1.41
1990 - 1999	1.10	2.30	0.50	1.40
2000 - 2010	0.50	2.00	0.37	1.10
Post 2010	0.32	1.70	0.23	0.40

Table 48. Thermal transmittance of construction elements (Slovakia).

The analyzed data for SH and DHW in Slovak residential sector is mainly characterized by central and district heating systems. District heating system is present in SFHs, MFHs erected before 1945 to the 1980s and in ABs erected before 1945 to the 1990s. Central SH and DHW system are used in buildings erected afterward. In addition, individual DHW system is used in some SFHs erected before 1945 to the late 1980s.

Regarding SFHs erected before 1945 to the late 1980s non-condensing boiler is used. Thereafter a combined condensing one is primarily utilized. MFHs are mainly equipped with a non-condensing boiler. MFHs are also use a combined technology regarding buildings erected from 1990s and afterward. ABs is uses non-condensing boiler regarding buildings erected before 1945 to the late of 1990s and a condensing boiler afterward. Combine technology is also present in buildings erected from 1990s.

The gas is widely used in all considered building types for SH and DHW needs, followed by electricity that mainly uses in buildings erected before 1945 to the 1980s respectively.

The results for SC technology show that in most cases, SC is not represented in this residential building stock.

Findings demonstrate that gas is the main energy carrier for SH and DHW needs, while renewable technologies were not determined.

According to expert questioning: The most common technology for SH and DHW is a non-condensing gas boiler. SC is not present in most cases, except health industry, where SC is often used.

3.25. **SLOVENIA**

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Slovenia.

In Figure 97, the Mm² of covered floor area in the Slovenian residential and service sectors is presented in percentages regarding historical periods.

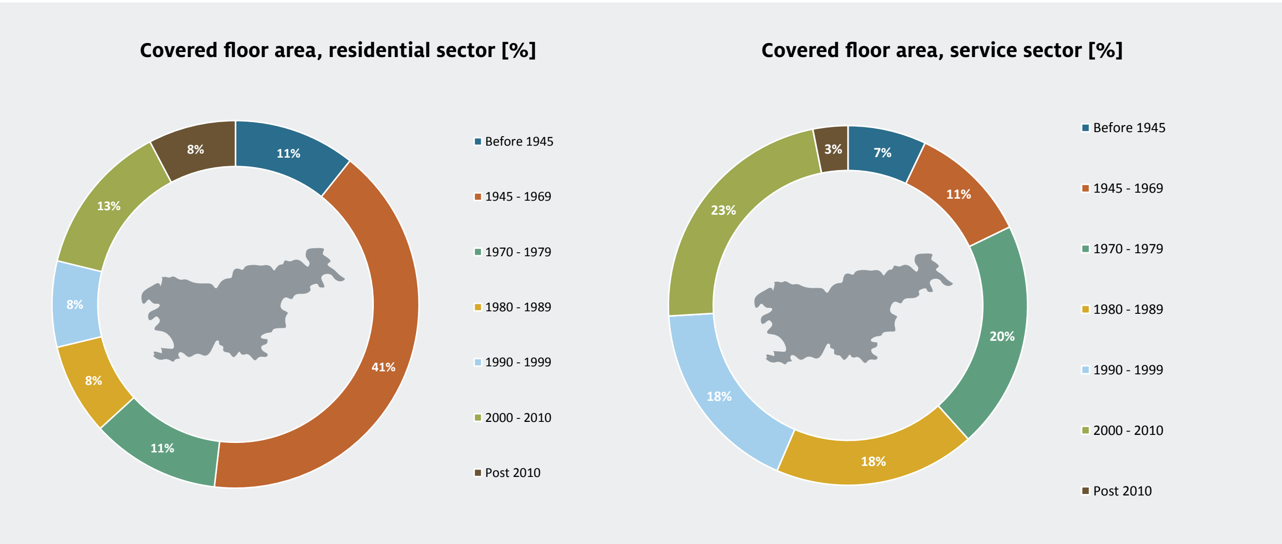

Figure 97. Split of the residential and service building stock raised per construction periods [%] (Slovenia).

The figure above shows that the highest percentage of covered floor area in the residential sector relates to the period between 1945-1969 with 41%. The second-highest percentage ratio of covered floor area is significantly smaller, i.e., 13%, which relates to the 2000s. Buildings erected before 1945 and in the 1970s indicate the same 11% of the covered floor area, which is the third-highest value. Interestingly, buildings erected in the 1980s, 1990s, and the post-2010 period show the minor percentage ratio, i.e., 8% respectively.

The service sector results indicate that the most significant portion of covered floor area belongs to buildings erected during the period of the 2000s with 23%. Buildings erected between 1970-1979 indicate 20% of the covered floor area, which is the second-highest percentage ratio. Interestingly, buildings of the 1980s and 1990s show an equal percentage ratio of covered floor area, i.e., 18%. Buildings erected between 1945-1969 indicate the percentage ratio of the covered floor area of about 11%. While 7% belong to buildings erected before 1945. The minor percentage ratio belongs to buildings of the post-2010 period with only 3%.

Figure 98 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 98 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

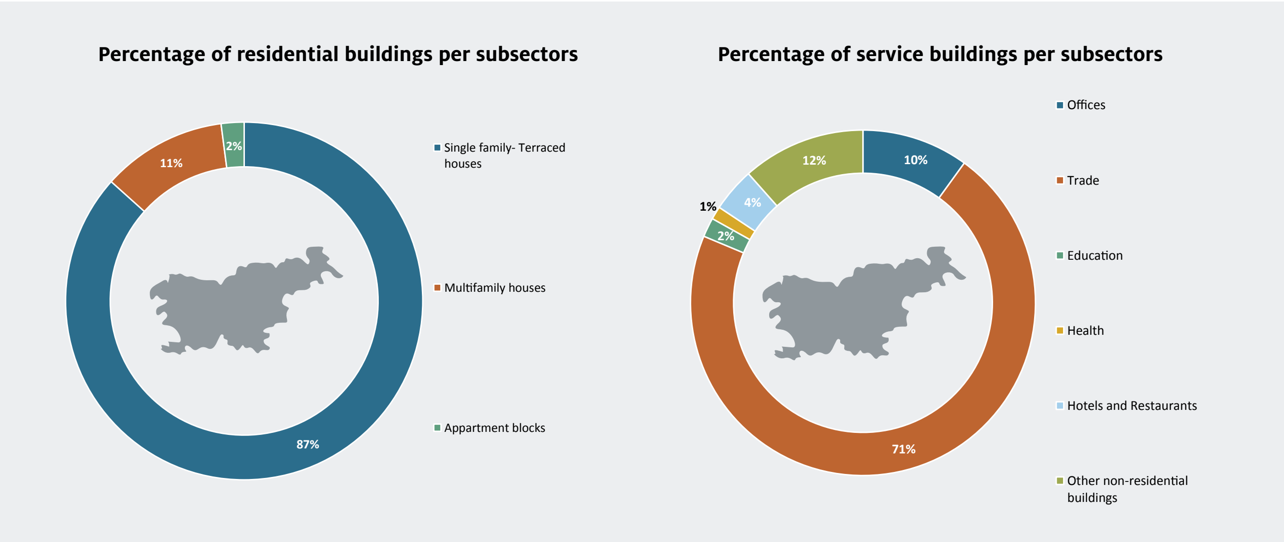

Figure 98. Split of residential and service buildings per different subsectors [%] (Slovenia).

The residential sector shows that 87% of the sector is categorized as SFHs. This leaves only 13% of the sector behind, including 11% for MFHs and 2% for ABs.

In the service sector, a significant portion of the market is allocated for trade buildings that cover 71% of the total market. Other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms), are the second-largest subsector in the service sector, with 12%. Offices show a lower percentage ratio, i.e., 10%. Hotels and restaurants occupy only 4%. At the same time, educational buildings are just 2% of the total service sector. Health care buildings are the minor buildings type in the service sector of Slovenia that occupies only 1% of the market respectively.

Figure 99 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

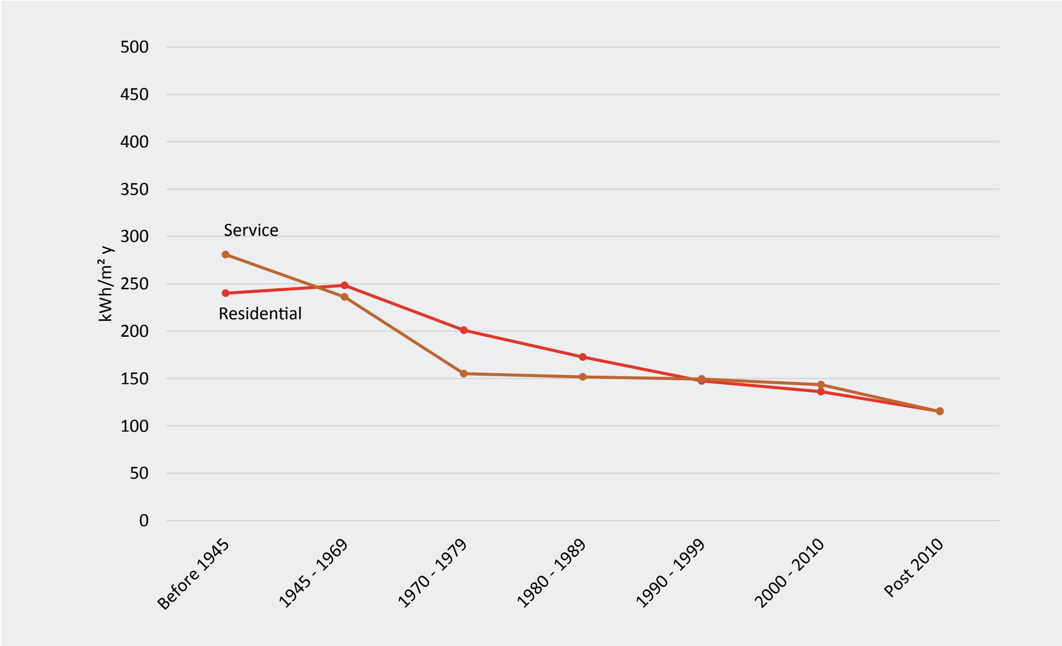

Figure 99. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Slovenia).

The figure above shows that the trend of specific FEC for SH and DHW in residential buildings reduces steadily. For instance, buildings constructed before 1945 indicate a consumption rate of about 240 kWh/m² y. In comparison, buildings erected between 1945-1969 indicate the highest rate of specific FEC of around 248 kWh/m² y. In comparison, buildings of the 1970s show a lesser value of specific FEC of approximately 200 kWh/m² y. A further reduction in specific FEC was determined in buildings constructed in the 1980s with about 172 kWh/m² y respectively. As shown in the figure above, buildings that were erected in the 1990s indicate the value of a specific FEC of about 149 kWh/m² y. A slight decrease is found in buildings erected in the 2000s with the value of approximately 136 kWh/m² y. The most efficient rate of specific FEC is determined in buildings that were erected in the post-2010 period with a value of 115 kWh/m² y respectively.

The trend of specific FEC for SH and DHW regarding service buildings erected before 1945 demonstrates the value of about 280 kWh/m² y. Buildings erected between 1945-1969 resulted in the reduction of specific FEC to approximately 236 kWh/m² y. A drop in specific FEC is found in buildings erected in the 1970s and 1980s with values around 155 and 152 kWh/m² y, respectively. Buildings constructed from 1990 till 1999 show the same consumption rate as the residential buildings, i.e., 149 kWh/m² y. Buildings of the 2000s indicate a consumption rate of about 143 kWh/m² y respectively. Service buildings erected during the post-2010 period consume approximately the same 145 kWh/m² y as the residential buildings.

Figure 100 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

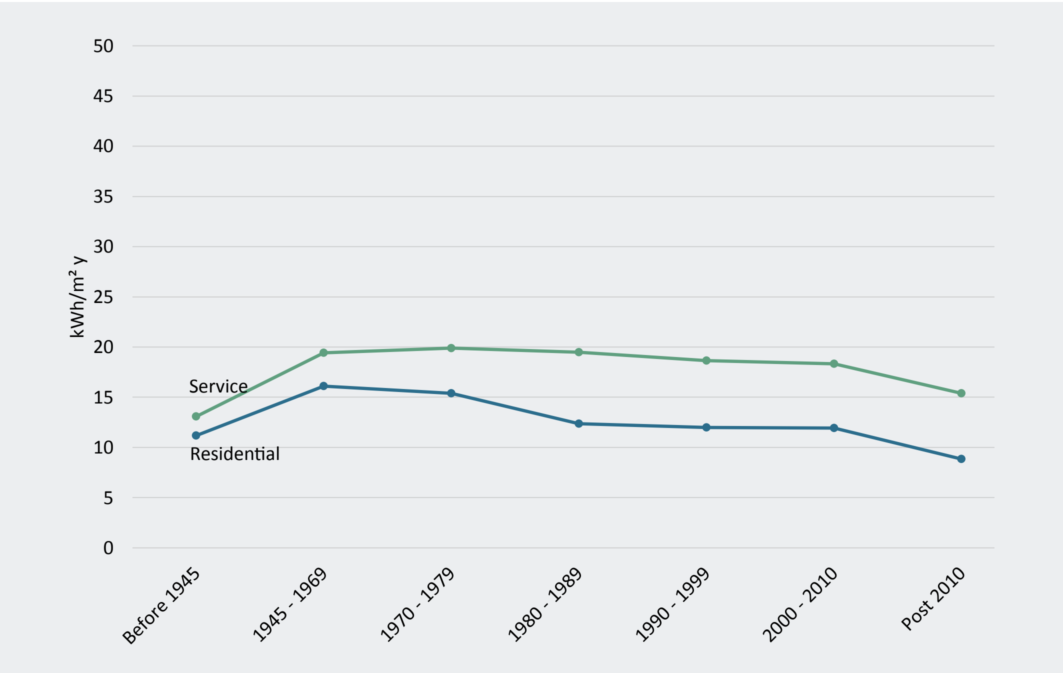

Figure 100. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Slovenia).

The rate of specific FEC for SC in the residential sector is less than in the service one. Buildings constructed before 1945 consume about 11 kWh/m²y of specific FEC. Regarding buildings erected from 1945 till 1969, the rate has increased to approximately 16 kWh/m²y. Buildings erected in later years (1970-1979) consume about 15 kWh/m²y of specific FEC. Buildings constructed in further periods (from 1980 till the 2000s) consume approximately 12 kWh/m²y. Buildings erected in the last post-2010 period indicate the most efficient rate of specific FEC for SC with a value of approximately 9 kWh/m²y.

The rate of specific FEC for SC in the service sector regarding buildings erected before 1945 is about 13 kWh/m² y. The consumption rate then increased to around 19 kWh/m² y, regarding buildings erected between 1945-1969. The rate then slightly increased to about 20 kWh/m² y regarding buildings that were constructed between 1970-1979. The reduction in specific FEC is observed in buildings of the 1980s with a value of about 19 kWh/m² y. Approximately 18.6 kWh/m² y is consumed by buildings that were erected in the 1990s. A further decrease in specific FEC is determined regarding buildings of the 2000s with a value of about 18 kWh/m² y. The least specific FEC for SC is observed in the service buildings erected in the post-2010 period, i.e., 15 kWh/m² y.

Regarding the construction methodology presented in the dataset provided by the H2020 Hot-Maps project (8), the main construction topology for walls is a solid wall without insulation in buildings erected till the 1980s. A cavity wall is mainly present in SFHs erected in the 1980s and 1990s with insulation. Honeycomb bricks/hollow blocks wall are present mainly in SFHs and MFHs erected between 1945-1969 and during the 1970s. Insulation is determined in SFHs erected in the 1970s.

The construction methodology for windows is mainly double-glazing, presented in buildings erected during all considered periods. Single-glazing windows are only in buildings erected before 1945 and between 1945-1968. Low emittance glass is present in buildings erected in the 1980s and afterwards.

We can observe that a tilted roof is present in SFHs regardless of historical periods, with insulation in buildings erected after 1945 and in MFHs erected before 1945. A flat roof is mainly constructed in MFHs erected between 1945-1969 and till post-2010 and in ABs regardless of building's ages. Insulation for roofs in MFHs and ABs is present in buildings erected after 1980. Concrete slabs are the most widespread technology for floors in Croatian houses throughout all periods, with insulation only in buildings erected after 1945.

Information about construction materials and construction methodology of the service sector was received by questioning experts. The information concerning Eastern Europe (Poland, Czech Republic, Hungary, Slovenia, Slovakia, Croatia, Bulgaria, Romania) was summarized afterward. Concerning the service sector in Slovenia, the information is presented in the table below (Table 49).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, health, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Wood, low emittance glass only in few cases.	Concrete and metallic roof boards + insulation in few cases	Concrete+ insulations in few cases	Solid wall	Double glazing	Flat roof	Concrete slab
Education							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Synthetic/PVC, low emittance glass only in few cases.	Concrete and tiles	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roof	Concrete slab
Hotels and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete +insulations in few cases	Solid walls	Double glazing	Flat roof	Concrete slab

Table 49. Construction materials, construction methodology-service sector (Slovenia).

The table above (Table 49) shows that the service sector demonstrates similar construction methodology and relative similarity with construction materials regarding different types of buildings. For the office, trade, health, and other non-residential buildings, the use of construction materials and methodology stay the same. Education buildings, hotels, and restaurants show a similar construction methodology while demonstrating a small difference in construction materials.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 50 shows the thermal transmittance value (W/ m^2 K) regarding two considered building sectors (residential and service) for all periods.

Table 50 helps to figure out the impact of building elements on specific FEC. As seen from the table below, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and buildings elements regarding different periods affect heat flow and thus specific FEC variation.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.80	2.34	1.62	1.12
1945 - 1969	1.22	2.77	0.77	1.15
1970 - 1979	0.86	2.57	0.67	0.71
1980 - 1989	0.51	1.80	0.45	0.54
1990 - 1999	0.34	1.28	0.30	0.24
2000 - 2010	0.25	0.92	0.17	0.23
Post 2010	0.21	0.73	0.20	0.29
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.50	2.20	1.74	1.17
1945 - 1969	1.02	2.80	0.69	1.22
1970 - 1979	0.54	2.50	0.54	0.70
1980 - 1989	0.41	1.90	0.21	0.44
1990 - 1999	0.22	1.10	0.14	0.18
2000 - 2010	0.24	0.85	0.17	0.23
Post 2010	0.27	0.60	0.20	0.29

Table 50. Thermal transmittance of construction elements (Slovenia).

The analyzed data related to SH and DHW in the Slovenian residential sector is characterized by central space heating systems in buildings erected before 1945 until the 2000s. Buildings constructed in the 2000s and during the post-2010 period use a district heating (DH) system. In most buildings (erected before 1945 to the late 1990s), a non-condensing boiler is installed. Regarding buildings constructed after the 1990s, condensing and combined boilers are mainly utilized.

The liquid fuel and biomass are used for SH and DHW need in buildings erected before 1945 till the late 1990s, followed by gas (all type of buildings erected between 2000-2010 and post-2010) being less prevalent in the market. Liquid fuel and gas are mainly used for MFHs energy needs, while biomass is the main fuel regarding ABs.

The results for SC technology show that in most cases, SC is not represented in this residential market.

The further findings demonstrate the quite noticeable portion of renewable energy sources in the Slovenian residential building stock. As can be seen from Figure 98, the major portion of the residential sector is occupied by SFHs (87% of the total) that is characterized by using biomass for SH needs.

According to expert questioning: the most common technology in the service sector for SH and DHW is non-condensing gas boilers. SC is not present in most cases, except in the health industry, where SC is mainly utilized.

3.26. **SPAIN**

This section represents a selection of main results that were obtained from the building stock analysis dataset regarding Spain (8).

In Figure 101, the Mm² of covered floor area in the Spanish residential and service sectors is presented in percentages regarding historical periods.

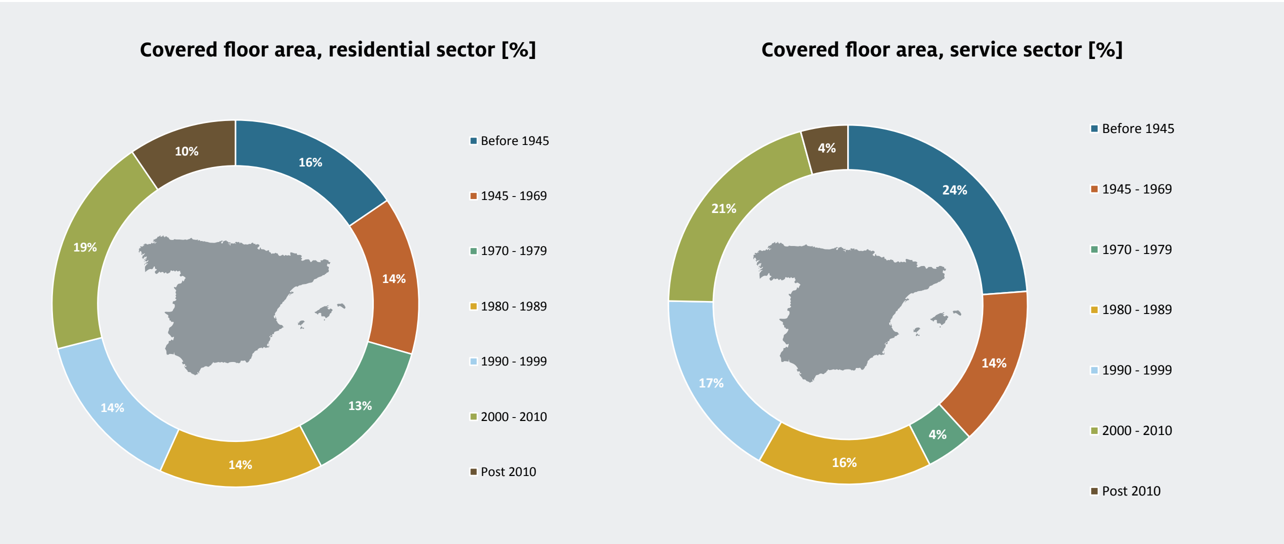

Figure 101. Split of the residential and service building stock raised per construction periods [%] (Spain).

The residential sector shows that the highest percentage of covered floor area can be found in buildings erected in the 2000s with 19%. The second-largest portion belongs to the historical buildings erected before 1945, which occupy 16% of the residential building stock. The third-largest percentage ratio belongs to buildings that were erected between 1945-1969, in the 1980s and 1990s, respectively. These three construction periods indicate an equal value of covered floor area of 14%. Whereas buildings of the 1970s indicate 13% respectively. The post-2010 period accounts for the minor portions of covered floor area compared to the other periods with a value of 10%.

In the service sector, the most significant percentage ratio of the covered floor area belongs to buildings erected before 1945 with a value of 24% respectively. The second-highest percentage ratio of covered floor area relates to buildings constructed between 2000-2010, with a value of 21%. A slightly lower percentage ratio of covered floor area indicates buildings of the 1990s, i.e., 17%. Building erected in the 1980s covers 16% of the service sector. Whereas buildings erected between 1945-1969 occupy 14% respectively. The smallest value of covered floor area belongs to buildings erected in the 1970s, and during the last post-2010 construction period, with only 4%.

Figure 102 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 102 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

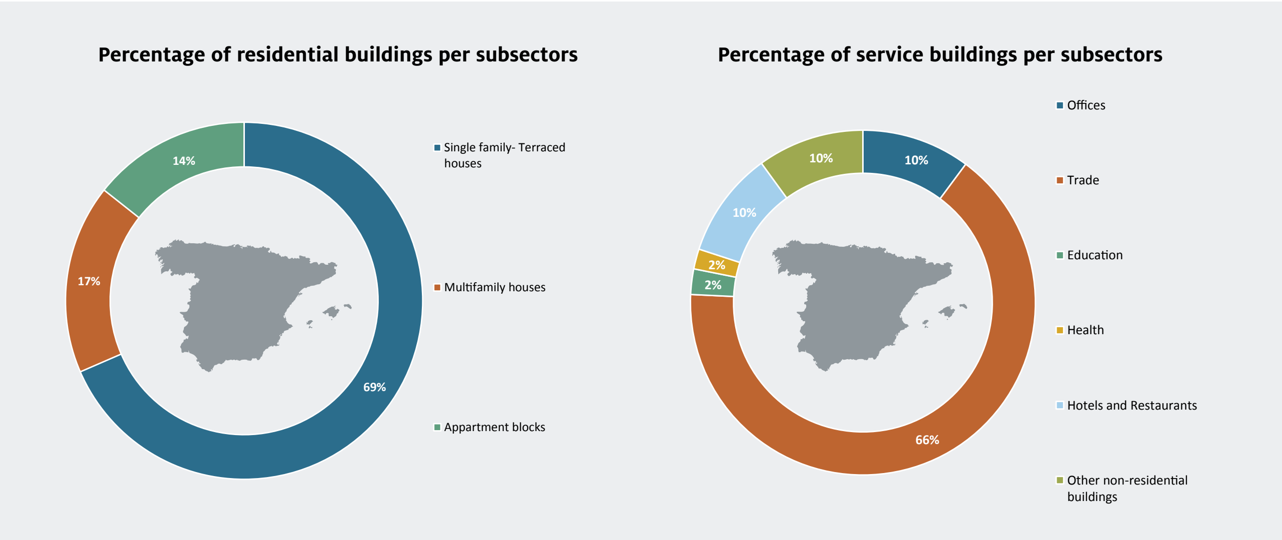

Figure 102. Split of residential and service buildings per different subsectors [%] (Spain).

The figure above clearly shows that in the residential sector, 69% - is occupied by SFHs, leaving behind the remaining 31% of the market for MFHs (17%) and ABs (14%), respectively.

Considering the service sector, we notice that trade buildings are the most widespread building type in Spain. These buildings occupy 66% of the total service sector. Interestingly, that offices, hotels and restaurants, and other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms) account for the same percentage ratio, i.e., 10% each. Educational buildings, healthcare, and hospitals cover only 2% of the market, respectively.

Figure 103 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

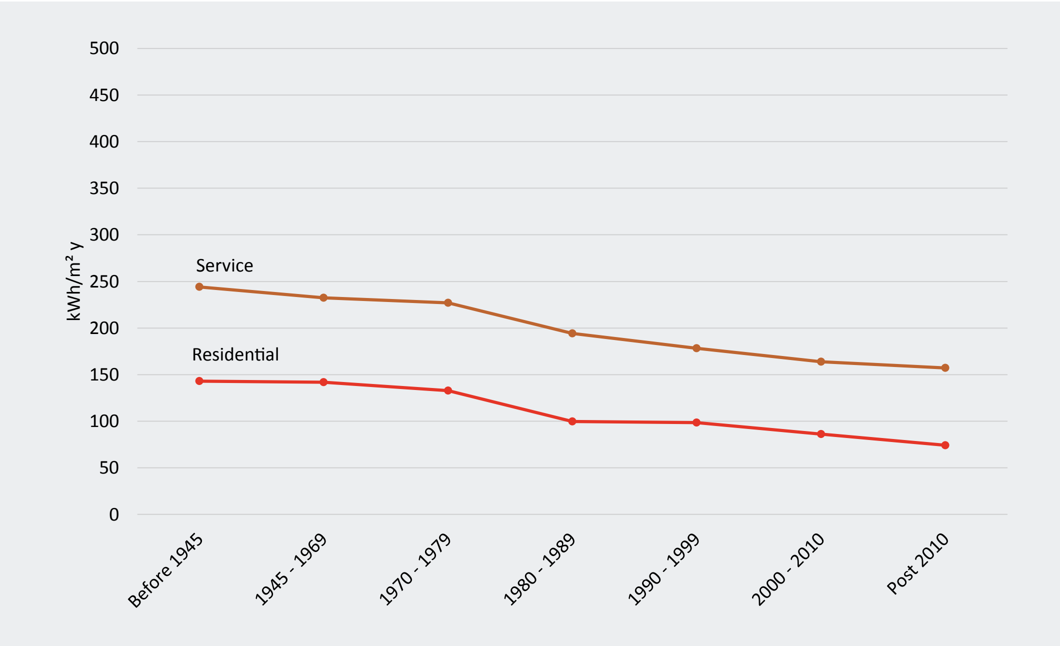

Figure 103. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Spain).

The development trend of the specific FEC for SH and DHW in the residential sector decreases steadily regarding buildings erected before 1945 till post-2010. The highest value of specific FEC is determined in buildings erected before 1945, i.e., 143 kWh/m² y. The consumption rate stays almost the same regarding buildings that were erected between 1945-1969, i.e., 142 kWh/m² y. Buildings erected in the 1970s indicate approximately 133 kWh/m² y of specific FEC. The specific FEC of buildings erected in the 1980s and 1990s shows approximately 99 kWh/m² y respectively. The trend of specific FEC then decreases to about 86 kWh/m² y regarding buildings of the 2000s. The lowest specific FEC for SH and DHW, i.e., 74 kWh/m² y, is consumed in buildings of the post-2010 period, respectively.

Service buildings erected before 1945 to the post-2010 period demonstrate a similar trend of specific FEC for SH and DHW with the residential ones. Buildings erected before 1945 indicate a consumption rate of about 244 kWh/m² y. This rate then decreases to the value of 232 kWh/m² y regarding buildings that were erected between 1945-1969. A further decrease in specific FEC is determined regarding buildings of the 1970s with a value of approximately 227 kWh/m² y. Buildings erected in the 1980s consume about 194 kWh/m² y, whereas those erected in the 1990s consume around 178 kWh/m² y. The consumption rate decreases to about 164 kWh/m² y regarding buildings of the 2000s. Buildings erected after 2010 indicate the lowest rate of specific FEC for SH and DH, which is around 157 kWh/m² y.

Figure 104 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

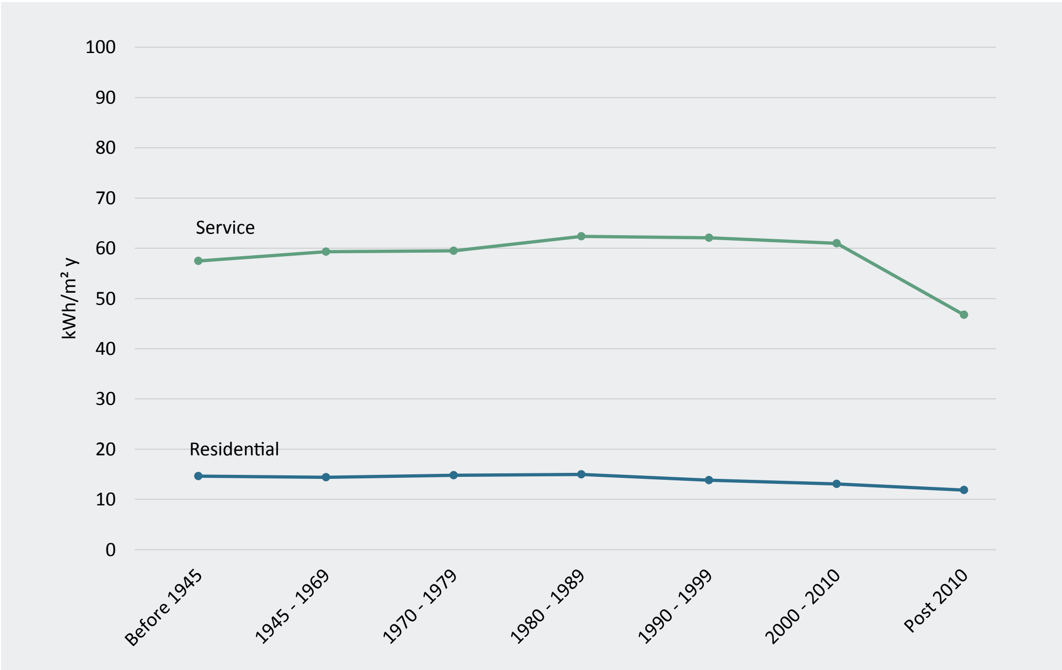

Figure 104. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Spain).

The rate of specific FEC for SC in the residential sector is less than in the service one. Buildings constructed before 1945 consume about 15 kWh/m²y of specific FEC. Regarding buildings erected from 1945 till 1969, the rate slightly decreases to approximately 14.4 kWh/m² y. Buildings erected in later years (1970-1979) consume about 15 kWh/m²y of specific FEC. Buildings constructed in 1980 consume approximately 15 kWh/m²y. Specific FEC in buildings of the 1990s is slightly smaller, i.e., 13.8 kWh/m²y. At the same time, those erected in the 2000s indicate the value of specific FEC of approximately 13 kWh/m² y, respectively. Around 12 kWh/m² y indicate buildings erected in the last post-2010 period accordingly.

Relatively small deviations characterize the specific FEC in the residential sector regarding buildings erected before 1945 to the post-2010 period.

The rate of specific FEC for SC in the service sector regarding buildings erected before 1945 is about 57 kWh/m² y. The consumption rate slightly increases to around 59 kWh/m² y in buildings erected between 1945-1969, and in the 1970s. The rate keeps increasing to approximately 62 kWh/m² y in the buildings constructed between 1980-1989. The same specific FEC is observed in buildings of the 1990s, i.e., 62 kWh/m² y. About 61 kWh/m² y is consumed in buildings which are erected in the 2000s. The least specific FEC for SC is observed in the service buildings erected in the post-2010 period, with a value of about 25 kWh/m² y.

Regarding the construction methodology presented in the dataset provided by the H2020 Hot-Maps project (8), the main construction topology for walls is a solid wall without insulation. The construction methodology for windows is mainly single glazing windows. Double glazing is found only in buildings erected in the post-2010 periods. We can observe that a flat roof is the most popular decision in buildings regarding MFHs and ABs. A flat roof is also present in SFHs, except buildings of the 1970s. Insulation is present in SFHs and MFHs erected after 1980. The tilted roof is mainly used in historical buildings and in SFHs erected up to the late 1970s. Insulation for a tilted roof has not been determined. Concrete slabs are the most widespread technology for floors in Spanish houses with insulation only in MFHs and ABs erected after 2010. Wooden floor is present in some SFHs erected before 1945.

Information about construction materials and construction methodology of the service sector was received by experts questioning. The information concerning Southern Europe (Spain, Italy, Greece, Cyprus, Malta, and Portugal) was eventually summarized. Concerning the Spanish service sector, the information is presented in the table below (Table 51).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, trade, health, hotels and restaurants, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ Insulation only in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete+ insulations in few cases	Honeycomb bricks/hollow block walls	Double and single glazing	Flat roof	Concrete slab
Education							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks and concrete+ insulation only in few cases	Aluminum (50%) and synthetic/PVC (50%), low emittance glass only in few cases.	Concrete and bricks + insulation in few cases	Concrete+ insulations in few cases	Honeycomb bricks/hollow block walls	Double glazing	Flat roof	Concrete slab

Table 51. Construction materials, construction methodology-service sector (Spain).

The table above (Table 51) shows that the service sector show similarities in construction material and construction methodology regarding all types of service buildings, except educational buildings that indicate differences in construction materials for walls.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 52 shows the thermal transmittance value ($W/m^2 K$) regarding two considered building sectors (residential and service) for all periods.

Table 52 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and building elements regarding different periods affect heat flow and thus specific FEC variation.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	3.28	4.95	3.11	1.27
1945 - 1969	2.43	4.64	2.09	1.12
1970 - 1979	1.35	5.47	2.31	0.99
1980 - 1989	0.63	3.84	0.92	1.21
1990 - 1999	0.56	3.53	0.69	0.99
2000 - 2010	0.52	3.45	0.55	0.87
Post 2010	0.49	3.23	0.46	0.74
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	2.50	5.80	1.40	2.50
1945 - 1969	2.20	5.95	1.20	1.65
1970 - 1979	2.00	6.10	1.10	1.23
1980 - 1989	1.80	3.30	1.00	0.80
1990 - 1999	1.70	3.05	0.90	0.73
2000 - 2010	0.90	2.80	0.60	0.70
Post 2010	0.97	4.48	0.54	0.66

Table 52. Thermal transmittance of construction elements (Spain).

The analyzed data related to SH and DHW in the residential sector reveals that the leading technology for SH and DHW is a centralized non-condensing boiler for SH and DHW needs regarding all types of buildings and construction periods. DHW system is also characterized by using solar collectors regarding buildings erected in the post-2010 period. The results for SC technology show that in most cases, SC is not represented in this residential market.

The residential building stock mainly utilizes gas. Findings demonstrate that technology for SH and DHW, besides utilizing traditional energy carrier (gas), also uses solar collectors.

According to expert questioning, the most common SH and DHW are the individual gas condensing boiler and electric heating (trade buildings). SC is present in most cases, except educational buildings.

3.27. **SWEDEN**

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding Sweden.

In Figure 105, the Mm^2 of covered floor area in the Swedish residential and service sectors is presented in percentages regarding historical periods.

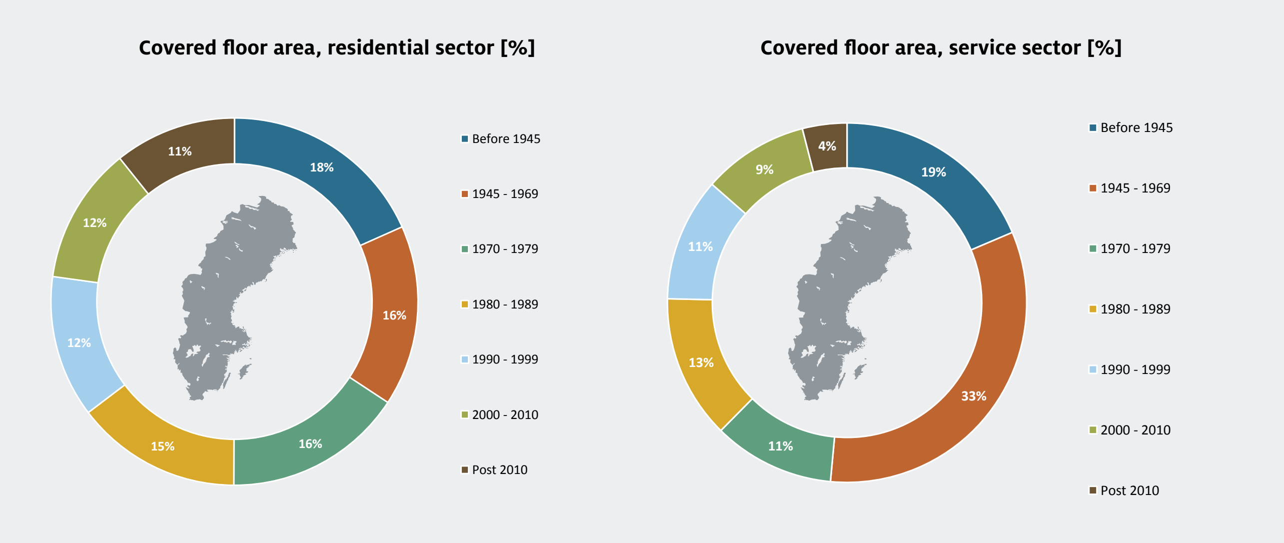

Figure 105. Split of the residential and service building stock raised per construction periods [%] (Sweden).

The result shows that the highest percentage ratio of covered floor area refers to residential buildings constructed before 1945 with 18%. Buildings erected between 1945-1969 and in the 1970s account for a lower percentage of covered floor area, i.e., 16%. Residential buildings of the 1980s indicate a value of 15%. While residential buildings of the 1990s and 2000s occupy 12% respectively. The minor percentage ratio is related to buildings erected in the post-2010 period, which covers 11%.

The figure above shows that the highest percentage of covered floor area in the service sector refers to buildings constructed between 1945-1969 with 33%. After this, the second-highest percentage ratio is 19% regarding buildings erected before 1945. Buildings erected in the 1980s indicate 13% of the total covered the floor area, respectively. In contrast, buildings of the 1970s and 1990s present a percentage ratio of 11 % each. Buildings erected in the 2000s indicate 9% of the total covered floor area, respectively. The minor percentage ratio indicates buildings constructed in the post-2010 period with only 4%.

Figure 106 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 106 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

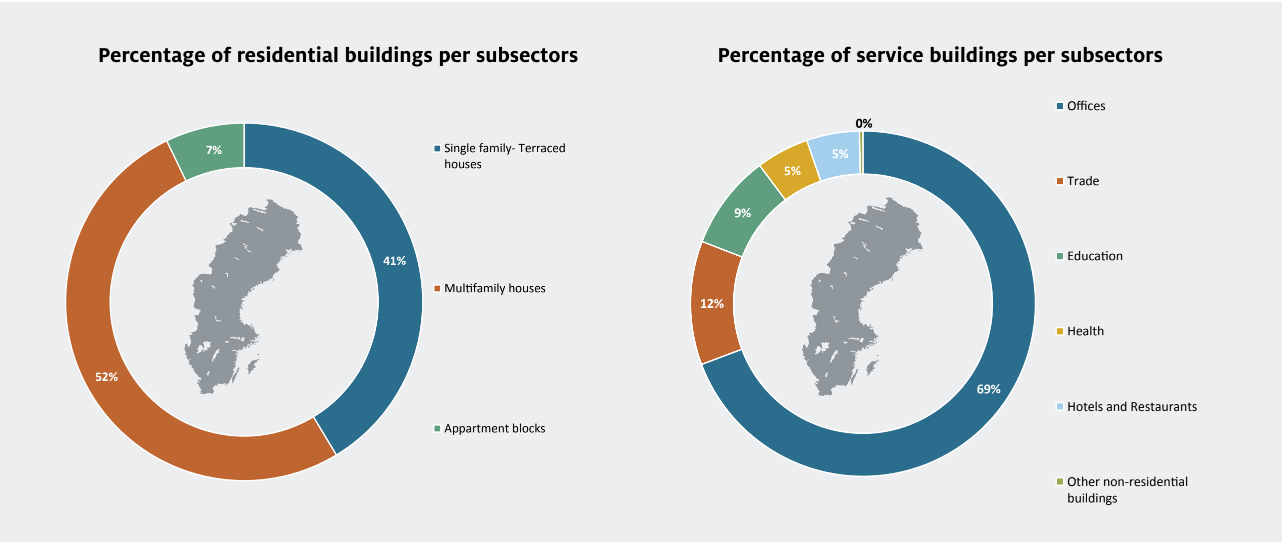

Figure 106. Split of residential and service buildings per different subsectors [%] (Sweden). (Please note that Other non-residential buildings account for 0.3%)

Figure 132 clearly shows that in the residential sector, more than half - i.e., 52% - is occupied by MFHs. SFHs is the second popular type of building with 41%, leaving behind the remaining 7% of the market for ABs.

More than half of the service building stock is characterized as office buildings covering 69% in the service sector. Trade buildings are the second widespread building type but indicate a significantly lower percentage ratio, i.e., 12% of the whole service building stock. Education buildings cover 9% of the service building stock, respectively. Health, Hotels, and restaurants both occupy the same amount of the service building stock, i.e., 5%. Other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms), show a significantly lower percentage ratio, that is less than 1%.

Figure 107 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

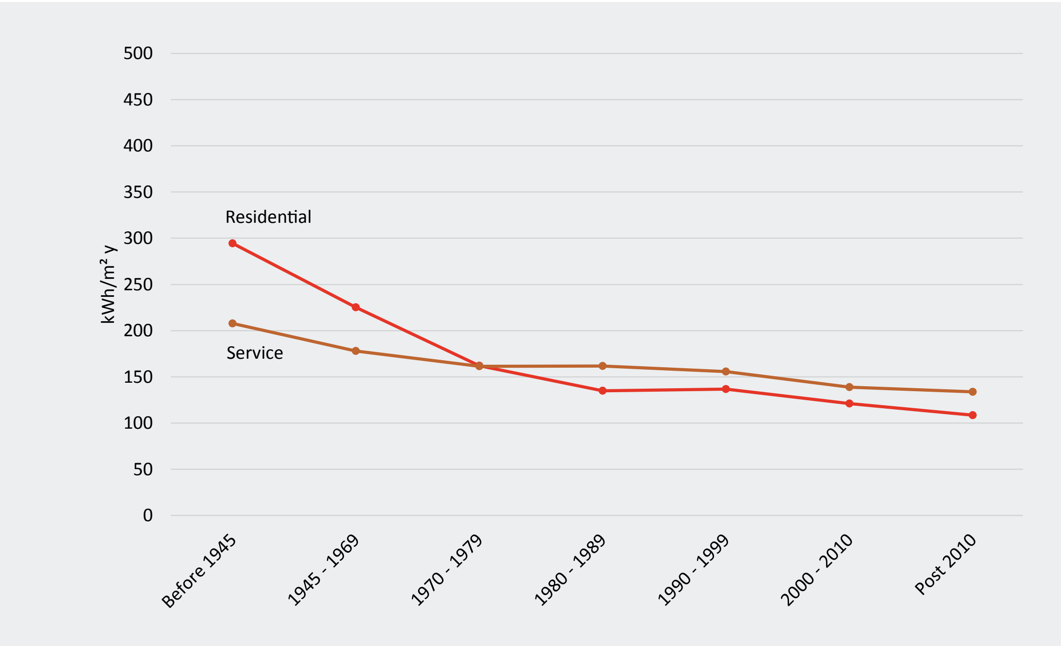

Figure 107. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (Sweden).

The overall trend of specific FEC for SH and DHW in residential and service buildings decreases steadily regarding buildings erected before 1945 till 2010.

Residential buildings erected before 1945 to the post-2010 show that specific FEC value for SH and DHW is dropped from about 294 kWh/m² y to approximately 108.5 kWh/m² y. Buildings erected before 1945 show the highest value of specific FEC for SH and DHW of about 294 kWh/m² y. In comparison, buildings erected between 1945-1969 indicate a reduction to about 225 kWh/m² y. The trend of specific FEC continues decreasing consecutively. In contrast, buildings erected in the 1970s consume about 161 kWh/m² y. A lower result indicates buildings erected in the 1980s with the value of approximately 135 kWh/m² y. Almost the same specific FEC is found in buildings erected in the 1990s with the value of 137 kWh/m² y. Buildings erected in the 2000s show about 121 kWh/m² y of the specific FEC. After this, the value has reduced to approximately 108.5 kWh/m² y regarding buildings erected during the post-2010 period, respectively.

In contrast, the specific FEC of SH and DHW in the service sector shows that the value has dropped from about 208 kWh/m² y to approximately 134 kWh/m² y regarding buildings erected before 1945 to the post-2010. Buildings erected before 1945 indicate the value of specific FEC of about 208 kWh/m² y. It then decreases to about 178 kWh/m² y regarding buildings erected between 1945-1969. Buildings erected from 1970 till 1979 are characterized by a further decrease in specific FEC, to a value of about 161 kWh/m² y. Buildings erected in the 1980s indicate a specific FEC value of about 162 kWh/m² y. In contrast, service buildings erected during the 1990s consume about 156 kWh/m² y. The most efficient rate of specific FEC shows buildings erected in the 2000s and in the post-2010 period with values of approximately 139 and 134 kWh/m² y, respectively.

Figure 108 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

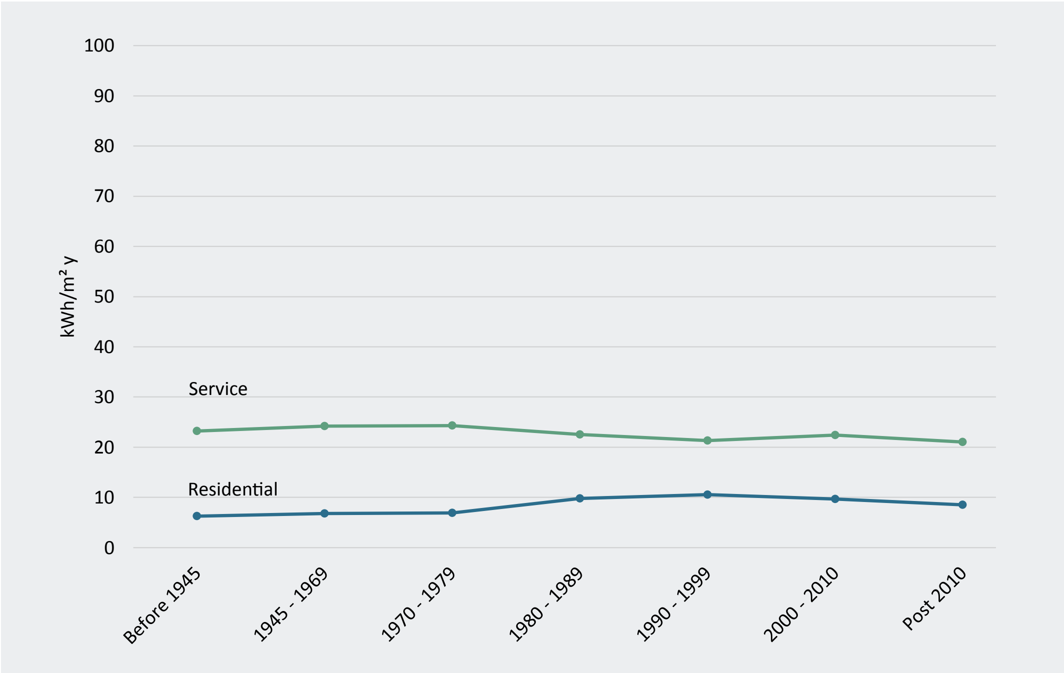

Figure 108. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (Sweden).

In the residential sector, the trend of specific FEC for SC indicates that buildings erected before 1945 consume around 6 kWh/m² y. The value then increases to about 7 kWh/m² y regarding buildings erected between 1945-1969 and the 1970s. The specific FEC for SC then continued increasing to about 10 kWh/m² y in buildings of the 1980s. An increase in specific FEC is also determined in buildings erected in the 1990s. These buildings account for about 11 kWh/m² y, respectively. The decrease in specific FEC is determined in buildings erected in the 2000s and after 2010, with values of about 10 and 8.5 kWh/m² y, respectively.

The rate of specific FEC for SC in the service sector regarding buildings erected before 1945 is higher than in the residential one, i.e., 23 kWh/m² y. After that, the consumption rate increased to the value of about 24 regarding buildings constructed from 1945 to 1979. Buildings of the 1980s consume a slightly lower specific FEC, about 22.6 kWh/m² y. Specific FEC regarding buildings erected in the 1990s is about 21 kWh/m² y. A small increase in specific FEC is determined in buildings erected in the 2000s with a value of about 22 kWh/m² y respectively. The least specific FEC for SC is observed in the service buildings erected in the post-2010 period, with a value of approximately 21 kWh/m² y.

As we can see, the deviation in specific FEC in the service sector is almost negligible and stay relatively the same, regarding buildings erected before 1945 to the last post-2010 period respectively.

Regarding the construction methodology presented in the dataset provided by the H2020 Hot-Maps project (8), the main construction topology for walls is a solid wall without insulation. The construction methodology for windows is mainly double-glazing, presented in buildings erected from the 1970s to the 1990s. Single glazing windows are in buildings erected during the first two periods (before 1945, 1945-1969). Triple glazing windows are used in buildings erected in the 2000s and in the last post-2010 period, respectively. Low emittance glass is not present. We can observe that a tilted roof is the most popular decision in buildings regardless of historical periods. Concrete slabs are the most widespread technology for floors in Swedish houses throughout all periods, without insulation.

Information about construction materials and construction methodology of the service sector was received by questioning experts. The information concerning Northern Europe (Denmark, Finland, Sweden, Estonia, Latvia, and Lithuania) was summarized. Concerning the service sector in Sweden, the information is presented in the table below (Table 53).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, education, hotels and restaurants,							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Aluminum (50%) and synthetic/ PVC (50%), low emittance glass in few cases.	Concrete and bricks + insu-lation in few cases	Concrete +insulations in few cases	Honeycomb bricks/hollow block walls	Double glazing	Flat roof	Concrete slab
Trade, health, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Bricks+ insulation only in few cases	Aluminum (50%) and synthetic/ PVC (50%), low emittance glass in few cases.	Concrete and bricks + insu-lation in few cases	Concrete +insulations in few cases	Honeycomb bricks/hollow block walls	Double and sing-le glazing	Flat roof	Concrete slab

Table 53. Construction materials, construction methodology-service sector (Sweden).

The table above (Table 53) shows that the service sector has similarities in construction material and construction methodology regarding all service buildings, except the methodology for windows, which varies from single to double glazing windows as mentioned in the table above.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 54 shows the thermal transmittance value (W/ m^2 K) regarding two considered building sectors (residential and service) for all periods.

Table 54 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and building elements regarding different periods affect heat flow and thus specific FEC variation.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	0.59	2.51	0.34	0.30
1945 - 1969	0.49	2.20	0.28	0.30
1970 - 1979	0.38	2.16	0.20	0.28
1980 - 1989	0.30	2.03	0.16	0.27
1990 - 1999	0.21	1.82	0.15	0.24
2000 - 2010	0.20	1.96	0.14	0.21
Post 2010	0.18	1.30	0.13	0.15
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	0.60	3.20	0.30	0.20
1945 - 1969	0.40	3.10	0.40	0.18
1970 - 1979	0.30	3.00	0.20	0.16
1980 - 1989	0.25	2.50	0.15	0.16
1990 - 1999	0.20	1.70	0.10	0.15
2000 - 2010	0.19	0.90	0.12	0.15
Post 2010	0.18	1.30	0.13	0.15

Table 54. Thermal transmittance of construction elements (Sweden).

The analyzed data related to SH and DHW in the residential sector reveals that the leading technology for SH and DHW is a centralized non-condensing boiler for SH and DHW needs regarding all types of buildings and construction periods.

The most common energy carrier for SH and DHW in the Swedish residential building stock is liquid and gas fuels, while electricity is accordingly the third popular energy carrier.

The results for SC technology show that in most cases, SC is represented in this residential market.

The residential building stock mainly utilizes liquid fuel and gas. Findings demonstrate that technology for SH and DHW, besides utilizing traditional energy carriers, also uses heat pump applications.

According to expert questioning: The most common technologies for SH and DHW are district heating systems, central gas condensing boilers, heat pumps, electricity. SC is not present in most cases, except in the health buildings, where SC is often used.

3.28. UNITED KINGDOM

This section represents a selection of the main results that were obtained from the building stock analysis dataset regarding Austria (8).

In Figure 109, the Mm^2 of covered floor area in the residential and service sectors is presented in percentages regarding historical periods.

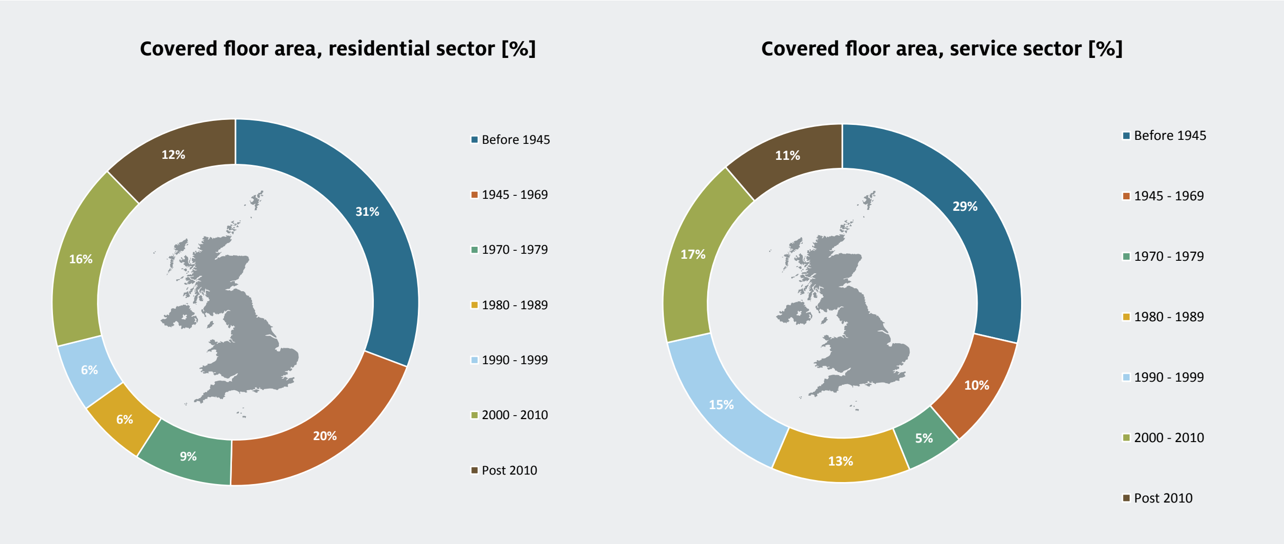

Figure 109. Split of the residential and service building stock raised per construction periods [%] (UK).

The historic buildings of the residential sector (i.e., construction period Before 1945) show the highest percentage ratio of covered floor area, around 31%. The result appeared because the period before 1945 covered the entire historic building stock. The period between 1945-1969 refers to the beginning of the post-WWII era, with the second highest percentage ratio, i.e., 20%. Interestingly, the two earliest periods occupied half of the entire residential building stock. On the other hand, the minor portion demonstrates periods, of the 1980s and 1990s, with just 6% respectively. A slightly higher percentage ratio of covered floor area belongs to buildings of the 1970s, i.e., 9%. Middle percentage ratios referred to the periods of 2000s and post 2010 period with 16 and 12 % respectively.

Service buildings erected before 1945 also show the highest percentage ratio of covered floor area, about 29%. While buildings erected between 1945-1969 indicate only 10%. Service buildings of the 2000s show the second-highest percentage ratio, i.e., 17%. Buildings erected between 1990-1999 indicate 15% of the covered floor area, which is the third-highest percentage ratio. Service buildings of the 1980s show 13% of covered floor area. Buildings erected in the post-2010 period indicate 11% respectively. The minor percentage ratio belongs to buildings of the 1970s with only 5%.

Figure 110 visualizes the breakdown of different building types within the residential and service sectors. The following percentages in Figure 110 have been derived from the number of buildings per type. Residential buildings are usually characterized by 2-3 floors in SFHs, 4-8 floors in MFHs, and more than 4 floors in ABs.

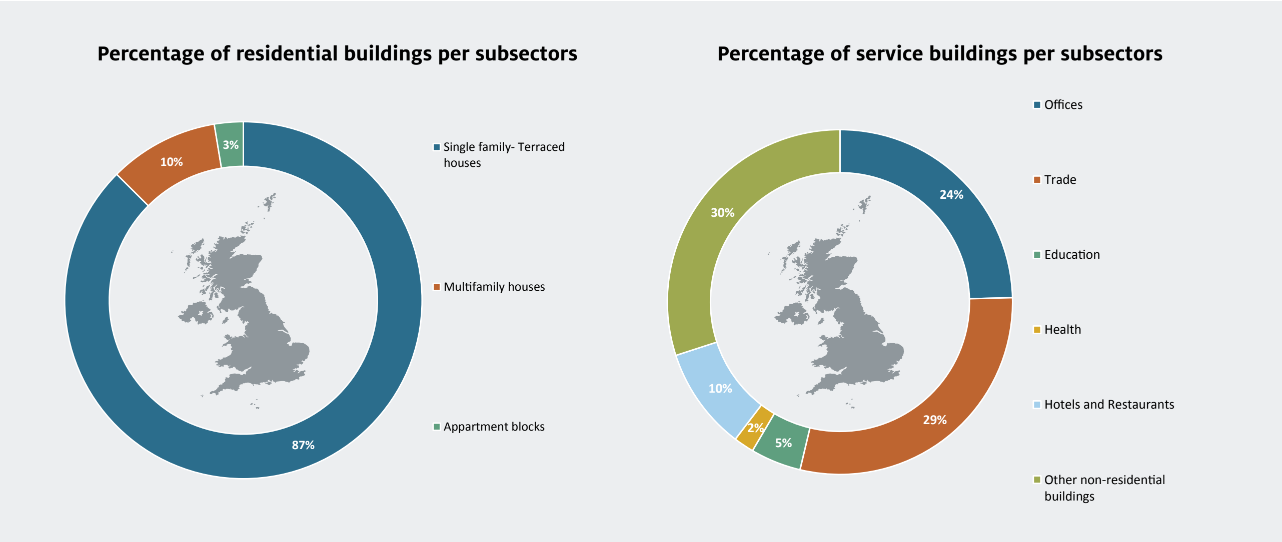

Figure 110. Split of residential and service buildings per different subsectors [%] (UK).

The residential sector is dominated by SFHs with 87%, followed by MFHs and ABs with approximately 10% and 3%, respectively.

The service sector is occupied by Other non-residential buildings, including warehouses, transport, garage buildings, military barracks, agricultural buildings (farms, greenhouses), and sports facilities (e.g., sports halls, swimming pools, and gyms), that account for 30% of the service building stock in the UK. Trade buildings are the second largest buildings type that indicates 29% respectively. Offices occupy about 24% being the third represented building type. Hotels and restaurants occupy 10% of the market, respectively. The liest represented types of buildings are educational buildings and medical institutions (health) that indicate 5 and 2 % respectively.

Figure 111 shows the development of the specific FEC (kWh/m²y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

Figure 111. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (UK).

The trend of specific FEC for SH and DHW in the residential sector decreases with the passing years. The maximum specific FEC is around 280 kWh/m² y, and the least is 92 kWh/m² y. Historical buildings erected before 1945 show the value of specific FEC of about 280 kWh/m² y. Moving forward, we can see that the value of specific FEC is decreasing consecutively. Compared to historic buildings, buildings constructed between 1945-1969 indicate a reduction to 264 kWh/m² y. Buildings erected in the 1970s show a drop in specific FEC to about 177 kWh/m² y. It is quite noticeable that the decline in specific FEC has slowed down regarding buildings erected from 1979 to 2010, respectively. For instance, Buildings erected in the 1980s have a value of specific FEC of about 169 kWh/m² y, while buildings erected in the 1990s and 2000s indicate values of specific FEC 162 and 147 kWh/m² y accordingly. Buildings erected after 2010 indicate the smallest value of specific FEC for SH and DHW, i.e., approximately 92 kWh/m² y.

The service sector indicates that historical buildings erected before 1945 show the highest value of specific FEC of about 360 kWh/m² y, which then stedely decresed to 324 kWh/m² y, regarding buildings erected between 1945-1969. The consumption again drops reduces to approximately 296 kWh/m² y regarding buildings of the 1970s. The trend continues to demonstrate fluctuations among buildings of the consecutive periods. Buildings erected in the 1980s have a higher value of specific FEC of about 330 kWh/m²y, which then dropped to about 187 kWh/m² y, regarding building erected during the 1990s. The rate of specific FEC then decreases to about 128 kWh/m² y in buildings of the 2000s and post-2010 periods, respectively.

Figure 112 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2016.

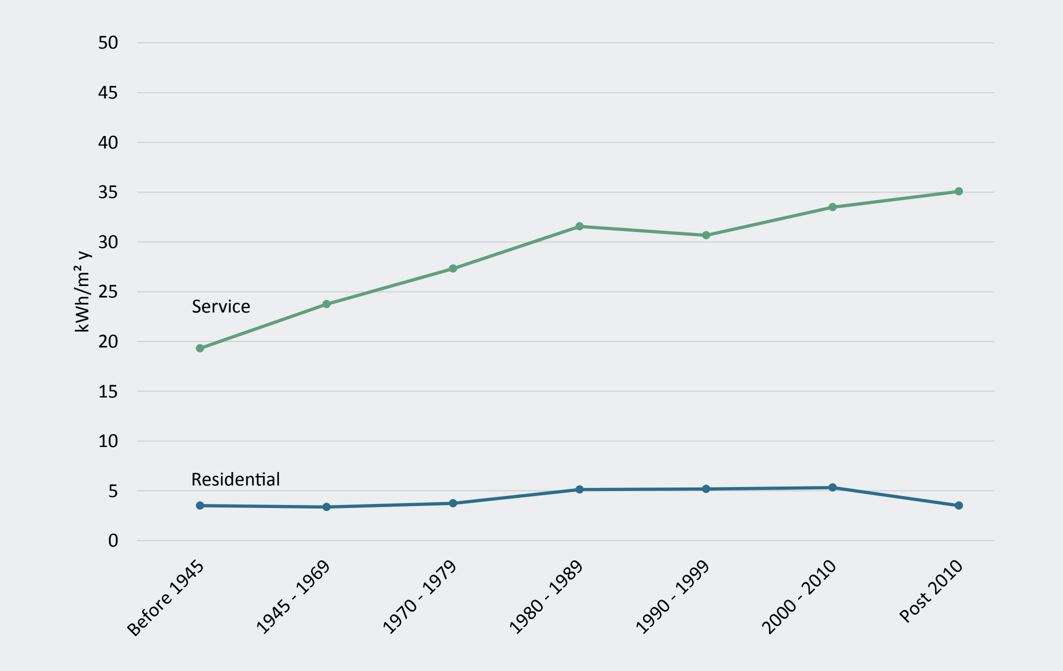

Figure 112. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (UK).

As this graph shows, the trend of specific FEC for SC in the residential sector has shown some ups and downs. Buildings erected before 1945 until the period of the 1970s show values of specific FEC for SC between 3-4 kWh/m² y respectively. The rate then slightly increases to approximately 5 kWh/m² y, regarding buildings erected in the 1980s, 1990s, and in the post-2010 period, respectively.

It then gradually increases to 3.5 kWh/m²y regarding buildings constructed during the post-2010 period, which is relatively close to the specific FEC in historical buildings (erected before 1945).

In comparison between the residential and service sectors, the service sector shows a gradual increase in specific FEC regarding buildings erected before 1945 with a value of about 19 kWh/m² y to those erected in the post-2010 construction period with a value of approximately 35 kWh/m² y. The difference in specific FEC from 1945 to its peak is approximately 16 kWh/m² y. Interestingly, the only reduction in specific FCE is observed in buildings of the 1990s, with a value of about 30 kWh/m² y compared to buildings of the 1980s with 32 kWh/m² y accordingly.

Regarding the construction methodology presented in the dataset provided by the H2020 Hot-Maps project (8), the main construction topology for walls is a cavity wall with insulation in buildings erected after 1970. A solid wall is mainly present in historical buildings (erected before 1945) and between 1945-1969 without insulation. The construction methodology for windows is mainly single glazing windows. Double glazing is found only in buildings erected in the 2000s and in the post-2010 periods. Low emittance glass is not present. We can observe that a tilted roof is the most popular decision in buildings regarding SFHs and MFHs. A tilted roof is also present in ABs that were erected before 1945. ABs erected afterward are mainly constructed with a flat roof. Concrete slabs are the most widespread technology for floors in UK houses throughout all periods, without insulation only in buildings erected after 1945.

Information about construction materials and construction methodology of the service sector was received by questioning experts. The information concerning Central Europe (Austria, Belgium, Germany, Netherland, Luxembourg, France, UK, and Ireland) was eventually summarized. Concerning the UK service sector, the information is presented in the table below (Table 55).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, health							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete+ insulation in most cases	Aluminum, low emittance glass only in few cases	Concrete + insulation in most cases	Concrete+ insulations in most cases	Solid wall	Double glazing	Flat roof	Concrete slab
Trade, hotels and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete or bricks+ insulation in most cases	Aluminum and synthetic/PVC, low emittance glass only in few cases.	Concrete and bricks + insulation in most cases	Concrete+ insulations in most cases	Solid walls	Double glazing	Flat roof	Concrete slab
Educational, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete+ insulation in most cases	Aluminum and synthetic/PVC, low emittance glass only in few cases.	Concrete and bricks + insulation in most cases	Concrete +insulations in most cases	Solid walls	Double glazing	Flat roof	Concrete slab

Table 55. Construction materials, construction methodology-service sector (UK).

The table above (Table 55) shows that the service sector demonstrates similar construction methodology and relative similarities with construction materials regarding different types of buildings. For instance, trade, hotels, and restaurants show similarities in construction materials and methodology, while it is also valid for office, health, educational and non-residential buildings, respectively.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). Table 56 shows the thermal transmittance value (W/m^2K) regarding two considered building sectors (residential and service) for all periods.

Table 56 helps to figure out the impact of building elements on specific FEC. As seen from the table, the thermal transmittance values demonstrate the reduction throughout the historical periods. Here we can observe how thermal insulation materials and buildings elements regarding different periods affect heat flow and thus specific FEC variation.

RESIDENTIAL SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	2.09	4.80	2.30	0.56
1945 - 1969	1.60	4.38	1.91	0.46
1970 - 1979	0.97	3.95	1.50	0.40
1980 - 1989	0.66	3.11	0.40	0.38
1990 - 1999	0.50	2.49	0.35	0.37
2000 - 2010	0.35	2.16	0.20	0.23
Post 2010	0.28	1.85	0.16	0.21
SERVICE SECTOR				
Historical period	Walls	Windows	Roof	Floor
Before 1945	1.80	4.90	1.90	2.00
1945 - 1969	1.70	4.75	1.80	1.70
1970 - 1979	1.30	4.67	0.90	1.40
1980 - 1989	0.70	4.60	0.50	1.10
1990 - 1999	0.50	2.70	0.30	0.50
2000 - 2010	0.40	1.80	0.25	0.30
Post 2010	0.35	2.20	0.20	0.25

Table 56. Thermal transmittance of construction elements (UK).

According to the analysis, the central SH and DHW system is mainly available in buildings constructed during all analyzed periods. Non-condensing boilers for SH and DHW are mainly used in buildings constructed before 1945 to the post-2010 period, respectively. The most widespread type of fuel for SH and DHW is gas and liquid fuel.

The results for SC technology show that buildings erected before 1945 to the 1990s do not use SC technology in most cases. However, buildings constructed after this time, in most cases, are equipped with a SC system.

These findings demonstrate a relatively low level of presence of renewable energy sources for SH, DHW, and SC in the residential building stock that mainly utilize gas and liquid fuels, characterized by higher carbon content.

According to expert questioning: the most common technology in the service sector for SH and DHW is central gas condensing boiler, heat pumps, and electricity. SC is not presented in most cases, except in the health buildings, where SC is mainly used.

4.

Summary of the results (EU27+UK)

4. Summary of the results (EU27+UK)

This section represents a selection of main results that were obtained from the building stock analysis dataset (8) regarding the entire European + UK building stock.

In Figure 113, the Mm² of covered floor area of the EU27+UK building stock (residential and service sectors) is presented in percentages regarding historical periods.

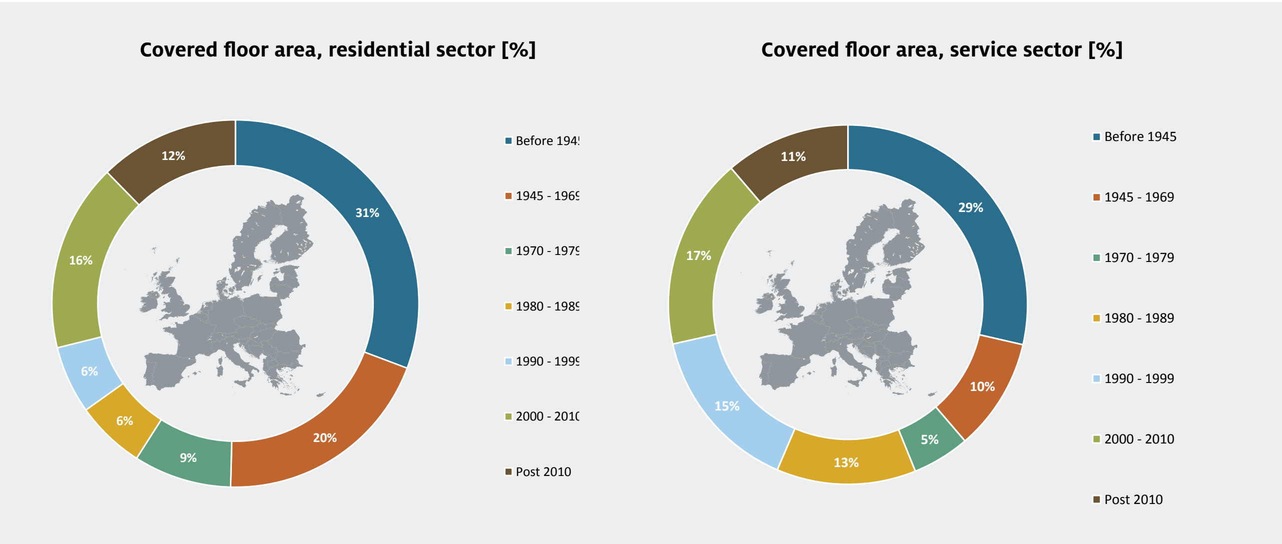

Figure 113. Split of the residential and service building stock raised per construction periods [%] (EU+UK).

The data analysis shows that in overall, residential buildings that were built before 1945 occupy the largest part of the residential sector, which is 31%. Buildings erected between 1945-1969 show the second largest percentage of covered floor area, i.e., 20%. Thus, we can notice that 51% of the covered floor area occupied by historical buildings and buildings erected between 1945-1969 respectively. Residential buildings of the 2000s indicate 16% of the covered floor area, while 12% belong to buildings erected in the post-2010 period. Only 9% of buildings were erected in the 1970s, While the smallest percentage ratio of covered floor area, i.e., 6%, belongs to buildings erected in the 1980s and 1990s. Respectively.

The most significant portion of covered floor area in the service sector is also related to buildings erected before 1945, with a percentage ratio of 29%. Buildings constructed in the 2000s occupy 17% of the covered floor area. About 15% of the covered floor area is occupied by buildings erected during the 1990s. Buildings erected during the 1980s indicate a slightly smaller percentage ratio, i.e., 13% respectively. Service buildings erected after 2010 indicate 11% accordingly. In contrast, 10% of the covered floor area belongs to buildings erected between 1945-1969. The minor percentage ratio is found in buildings erected in the 1970s, which is 5%.

It is also would be interesting to highlight those countries with the largest covered floor area in the residential and service sectors related to old buildings (before 1945, between 1945-1969), which are: Austria, Cyprus, Germany, Hungary, Malta, Romania, Slovakia, and the UK. These counties indicate approximately from 40 to 60 % of covered floor area respectively. The covered floor area related to the most recently constructed buildings (2000- post-2010) appears to be in Cyprus, Ireland, Spain, and the UK, with 20 to 30 % accordingly.

It is estimated that there are more than 25 billion m^2 of useful floor space in the EU27+UK, including approximately 18.7 billion m^2 regarding the residential sector and for about 6.3 billion m^2 in the service sector accordingly (8). The total gross floor space (EU+UK) could be imagined as a land area that is more than that of Slovenia (20,273 km^2) (19). Annual growth rates in the residential sector are around 1% while in the service sector is less than 1%, i.e., around 0.7%. Most countries encountered a decrease in the rate of new build in the recent years, reflecting the impact of the current financial crisis on the construction sector (20).

Figure 142 visualizes the breakdown of different building types in EU+UK building stock within the residential and service sectors. Residential buildings are the biggest segment of EU building stock, that occupy for about 75% of it (8). Within the residential sector, different types of SFHs (2-3 floors), MFHs (4-8 floors) (e.g., detached, semi-detached, and terraced houses) and ABs that consists of more than 4 floors. ABs may accommodate several households typically ranging from 2-15 units or in some cases holding more than 20-30 units (e.g., social housing units and high-rise buildings).

The typological diversity of the non-residential sector is enormous. Compared to the residential sector, this sector is more complex and heterogeneous. Moreover, the differences from country to country are more significant, making it difficult to compare the different types of buildings between countries. The different type of buildings includes trade buildings, offices, educational institutions, medical facilities, hotels and restaurants, and other non-residential buildings, although there are multiple functions in the same building in some cases.

In each of these sectors (residential and service), a broad division between the various subcategories was examined based on an information presented in the Figure 114, which shows the following percentages derived from the number of buildings per type.

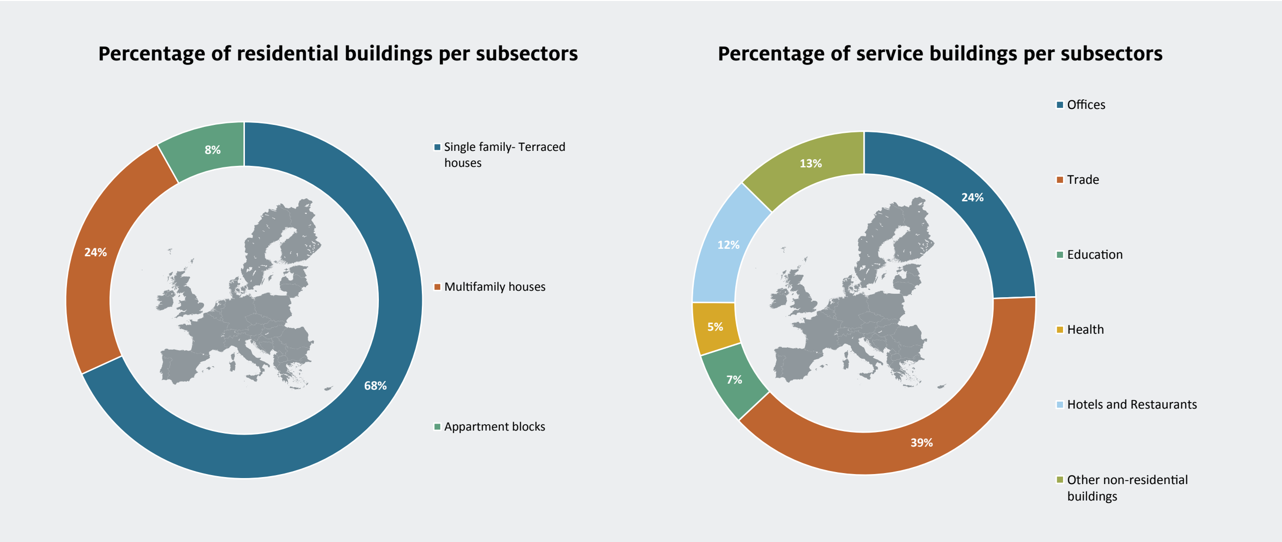

Figure 114. Split of residential and service buildings per different subsectors [%] (EU+UK).

The graph shows that in total, the residential sector indicates that 68% of the buildings are characterized as SFHs. In comparison, about 24% of the buildings are MFHs. The remaining 8% is referred to as ABs.

In the service sector, most of the service buildings are characterized as trade buildings that cover 39% of the market. Please note that according to our partitition the trade sector includes a number of activities (shops, department stores, shopping centres, grocery shops, car sales and garages, bakeries, hairdresser, service stations, laundries, congress and fair buildings, and other wholesale and retail infrastructures) and as such appears relatively large. About 24% of the service buildings are offices. Other non-residential buildings occupy 13% of the service building stock accordingly. Hotels and restaurants account for 12% respectively. Educational buildings cover about 7% of the service sector, while the least represented building type is health care buildings which occupy only around 5% of the total service building stock.

According to the information presented in the previous chapter, the highest percentage ratio of SFHs belongs to The Netherlands (96%), Ireland (95%), Cyprus, and Malta, with 91% respectively. While the lowest percentage ratio of SFHs are found in Belgium (27%).

Information regarding MFHs reveal that Belgium and Sweden indicate the highest ratio of 64% and 52% accordingly. At the same time, the lowest percentage ratio of MFHs belong to Malta and the Netherlands with only 3%, while Portugal and Ireland indicate 4%.

Italy and Estonia hold the highest percentage ratio regarding ABs with 16% and 17%, respectively. In contrast, the lowest percentage ratio relates to many countries. For instance, The Netherlands and Ireland indicate that apartment blocks occupy only 1% of their market. A slightly higher percentage ratio, i.e., 2%, relates to Slovenia. While residential building stock in Cyprus, Finland, and the UK have 3%.

Interestingly that the following countries indicate a similar percentage ratio of 8% for ABs: Austria, Bulgaria, Germany, Romania, and Slovakia.

The specific energy use within these age bands is likely to differ between countries in different regions of Europe due to a number of political, economic, and social factors (20).

Figure 115 shows the development of the specific FEC (kWh/m² y) for SH and DHW of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

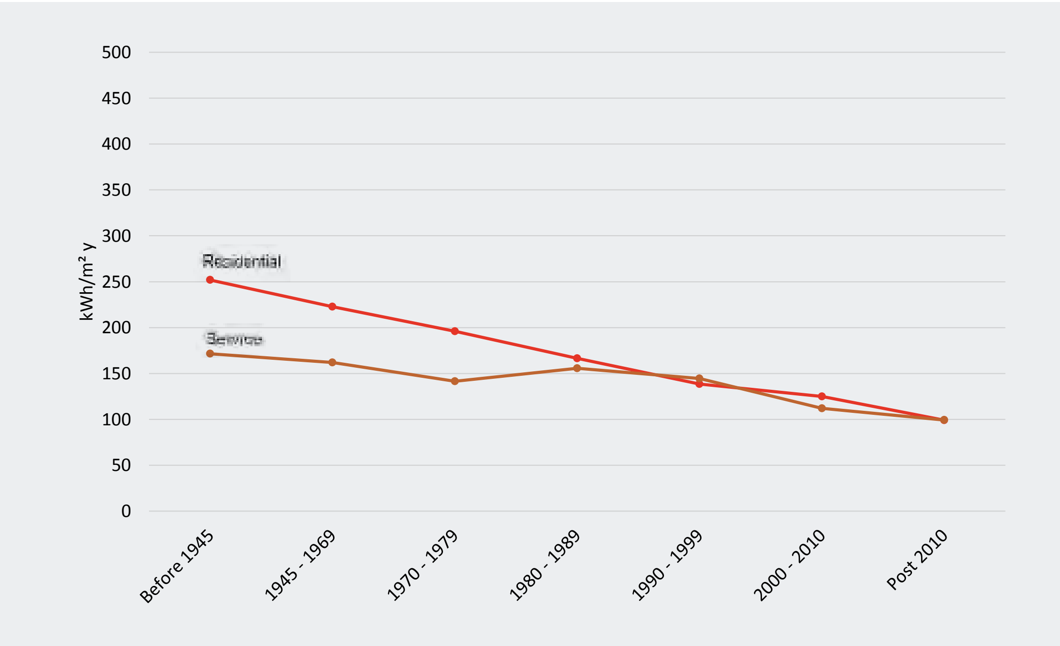

Figure 115. Development of specific final energy consumption for space heating and domestic hot water, residential and service sectors [kWh/ m² y] (EU+UK).

The overall development trend of specific FEC for SH and DHW in the EU and UK decreases regarding buildings erected before 1945 till post-2010. The highest FEC is consumed by buildings erected before 1945, i.e., 252 kWh/m² y. The consumption rate decreases to about 223 kWh/m² y regarding buildings erected between 1945-1969. Buildings erected in the 1970s indicate approximately 196 kWh/m² y of specific FEC. The specific FEC of buildings erected in the 1980s indicates around 166 kWh/m² y accordingly. Buildings that were constructed in the 1990s show approximately 145 kWh/m² y respectively. The trend of specific FEC slightly decreased to about 125 kWh/

m² y in the buildings of the 2000s. The lowest specific FEC for SH and DHW is consumed by buildings of the post-2010 period with around 99 kWh/m² y, respectively.

In comparison, the trend of specific FEC for SH and DHW in the service sector also decreases from Buildings erected before 1945 to the post-2010 period, respectively. Buildings erected before 1945 indicate the consumption rate of about 171 kWh/m² y. This rate decreases to approximately 162 kWh/m² y, regarding buildings erected between 1945-1969. Buildings constructed in the 1970s show a further reduction in specific FEC, i.e.,141 kWh/m² y. Buildings erected in the 1980s show a rise in specific FEC to about 156 kWh/m² y, whereas those erected in the 1990s consume approximately 145 kWh/m² y. The consumption rate drops to about 112 kWh/m² y regarding buildings constructed in the 2000-2010 period. The lately erected buildings in the post-2010 period consume the same FEC for SH and DH as the residential building, i.e., 99 kWh/m² y.

Figure 116 shows the development of the specific FEC (kWh/m² y) for SC of the residential and service sectors regarding buildings constructed before 1945 until post-2010.

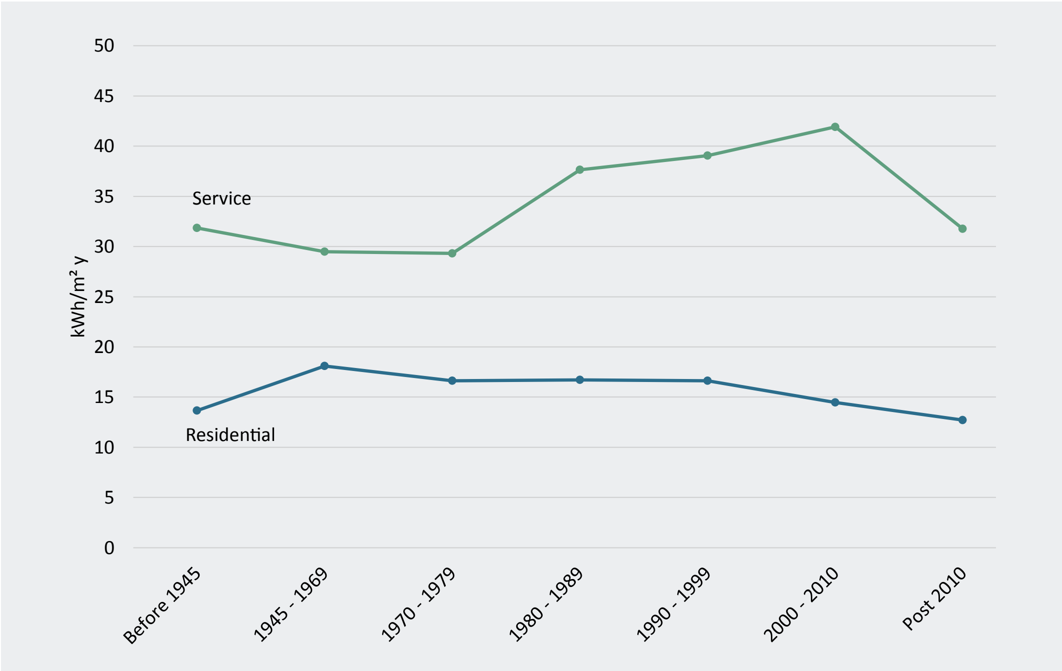

Figure 116. Development of specific final energy consumption for space cooling, residential and service sectors [kWh/m² y] (EU+UK).

In the residential sector of EU+UK, the trend of specific FEC for SC shows that the buildings constructed before 1945 consume about 14 kWh/m² y. The consumption rate increases to approximately 18 kWh/m² y regarding buildings erected between 1945 and 1969. The trend of specific FEC for SC is then falling to about 16 kWh/m² y regarding buildings constructed in the 1970s, 1980s, and 1990s. Buildings erected in the 2000s show a slight reduction in specific FEC to the value of approximately 14 kWh/m² y. The lowest specific FEC is observed in buildings erected in the post-2010 period with a value of about 13 kWh/m² y

In comparison between the residential and service sectors, buildings erected before 1945 indicate a value of about 32 kWh/m² y. The consumption rate decreases to approximately 29 kWh/m² y regarding buildings erected between 1945 and 1969 and in the 1970s. Buildings erected in the 1980s show an increase in specific FEC to about 37 kWh/m² y. The further increase in specific FEC is found in buildings of the 1990s with about 39 kWh/m² y. Buildings erected in the 2000s show a peak in specific FEC with a value of approximately 42 kWh/m² y. While buildings erected in the post-2010 period indicate a drop to a value of around 32 kWh/m² y.

Regarding the main findings, from the data, it is clear to identify final energy consumption for SH, DHW and SC where the highest position is held by SH and DHW with approximately 3280 and 890 TWh/y, respectively, in comparison to SC, which has a significantly lower final energy consumption of about 107 TWh/y.

The analysis by sectors reviled that the residential sector demonstrates for about 2307 and 545 TWh/y FEC for SH and DHW respectively. The noticably smaller values held by the service sector with 973 and 345 TWh/y accordingly. However, FEC for SC has an opposite trend. The measured energy consumed by the service sector than by the residential one (80 TWh/y versus 27 TWh/y).

Comparative analysis of specific FEC for SH, SC and DHW is based on geographic proximity.

The geographical proximity of the countries are the following:

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

The analysis results show that regarding the North European countries, Estonia indicates the highest average specific FEC for SH, SC, and DHW. Regarding SH and DHW, the average specific FEC is about 265 kWh/m² y and 197 kWh/m² y in the residential and service sectors. While the average specific FEC for SC is 20 and 22 kWh/m² y, respectively. In contrast, Denmark's lowest average specific for SH and DHW is about 155 and 115 kWh/m² y, respectively. The lowest value of the average specific FEC for SC belongs to Lithuania with 2 and 9 kWh/m² y accordingly.

In the Central European countries, the highest specific FEC for SH and DHW belongs to Luxembourg with around 216 and 234 kWh/m² y. In contrast, the Netherlands indicates the lowest average specific FEC for SH and DHW of about 128 and 184 kWh/m² y. The result regarding SC shows that France indicates the highest average specific FEC of approximately 19 and 42 kWh/m² y in both sectors. The lowest value belongs to Ireland with approximately 3 and 20 kWh/m² y accordingly.

Regarding the Eastern European countries, the highest specific FEC for SH and DHW is found in the Czech Republic that shows approximately 186 and 266 kWh/m² y. In contrast, the lowest average specific FEC of about 92 and 100 kWh/m² y belongs to Bulgaria. Since then, Bulgaria is more related to the south-east part of Europe, which energy consumption examines an impact of a mild winter; it is more accurate to indicate a country where the climate is not the main driver for energy consumption which is Slovakia with around 175 and 122 kWh/m² y for residential and service sectors respectively. Regarding the average specific FEC for SC, Croatia shows the highest value of about 20 and 32 kWh/m² y in the residential and service sectors, while Romania indicates the lowest value of approximately 5 and 16 kWh/m² y.

In the South European countries, the highest specific FEC belongs to Greece with approximately 155 and 140 kWh/m² y, respectively. Malta shows the lowest specific FEC for SH and DHW of about 39 and 71 kWh/m² y. The result regarding SC shows that Malta indicates the highest average specific FEC of approximately 25 and 65 kWh/m² y in both sectors. The lowest value belongs to Portugal with approximately 14 and 13 kWh/m² y accordingly.

The data regarding construction methodology in the EU and UK market has been calculated for the total residential sector, weighted on the total floor area of each building typology, and has been grouped based on the percentage of diffusion as follows:

— > 75%: most widespread technology/fuel;

— 25% to 75%: widespread technology/fuel;

— < 25%: less widespread technology/fuel.

Regarding the construction methodology presented in the dataset provided by the H2020 HotMaps project (8) The construction methodology for walls, windows, roofs, and floors are the following:

SOLID WALL			CAVITY WALL		HONEYCOMB BRICKS / HOLLOW BLOCKS WALL	
Years of construction	**Level of presence**	**Level of insulation**	**Level of presence**	**Level of insulation**	**Level of presence**	**Level of insulation**
Before 1945	83%	0.1%	6%	1%	3%	0%
1945 - 1969	61%	1%	23%	1%	16%	0%
1970 - 1979	57%	11%	14%	1%	24%	1%
1980 - 1989	38%	20%	13%	2%	38%	20%
1990 - 1999	46%	26%	24%	15%	21%	20%
2000 - 2010	49%	29%	28%	28%	22%	19%
Post 2010	51%	35%	26%	27%	23%	23%

Table 57. The construction methodology for walls (EU+UK).

Residential buildings show that the main components for walls are a solid wall, characterized as a widespread type of technology. Cavity walls and Honeycomb bricks / hollow blocks walls as shown in the table above are mainly characterized as a less widspread type of technology. We can observe that quantity of insulation starts to grow premarely in buildings erected after 1980s.

SINGLE GLAZING		DOUBLE GLAZING		TRIPLE GLAZING	
Years of construction	Level of presence	Level of presence	Low-e	Level of presence	Low-e
Before 1945	76%	24%	0%	0%	0%
1945 - 1969	63%	37%	0%	0%	0%
1970 - 1979	39%	61%	0%	0%	0%
1980 - 1989	28%	72%	3%	0%	0%
1990 - 1999	26%	74%	36%	0%	0%
2000 - 2010	16%	80%	46%	4%	0%
Post 2010	0%	86%	46%	14%	9%

Table 58. The construction methodology for windows (EU+UK).

Information regarding the type of glazing indicates that singles glazing windows are the most widespread type of technology regarding historical buildings (erected before 1945) and a widespread technology regarding buildings erected between 1945-1969 up to the 1990s accordingly. We can observe that single glazing windows indicate a reduction in use concerning buildings erected afterward. Double glazing windows show an opposite trend, being a widespread technology in buildings erected after 1945 to the 1990s. In comparison, newly erected buildings (the 2000s, post-2010) are characterized as the most widespread technology. Low emittance glass is primarily used in buildings erected in the 1990s and after. Triple glazing is not mainly present in the EU and UK residential building stock, characterized as a less widespread technology regarding buildings erected after 2010.

TILTED ROOF			FLAT ROOF	
Years of construction	Level of presence	Level of insu- lation	Level of presence	Level of insulation
Before 1945	87%	8%	13%	0%
1945 - 1969	70%	17%	30%	1%
1970 - 1979	50%	21%	50%	33%
1980 - 1989	50%	42%	50%	41%
1990 - 1999	53%	50%	47%	44%
2000 - 2010	55%	40%	45%	40%
Post 2010	55%	36%	45%	42%

Table 59. The construction methodology for roof (EU+UK).

An interesting pattern is found regarding roofs. Tilted roofs, for instance, are characterized as the most widespread technology concerning buildings erected before 1945. after that, tilted roof indicates relatively the same level of presence, regardless of construction periods, i.e., approximately 50% (widespread technology). A flat roof indicates a small presence in historical buildings but is stably present in buildings erected in the 1970s and afterward, being a widespread technology accordingly. Regarding both technologies, we observe that the level of insulation raised consecutively.

CONCRETE SLAB			WOODEN FLOOR (RAFTERS + BOARDS)	
Years of construction	Level of presence	Level of insulation	Level of presence	Level of insulation
Before 1945	71%	1%	15%	0%
1945 - 1969	90%	1%	6%	1%
1970 - 1979	94%	37%	4%	2%
1980 - 1989	100%	57%	0%	0%
1990 - 1999	100%	64%	0%	0%
2000 - 2010	99%	62%	1%	1%
Post 2010	100%	71%	0%	0%

Table 60. The construction methodology for floors (EU+UK).

Information regarding technology for floor indicate that concrete slab is the most widespread technology regardless of construction periods. A wooden floor is a less widespread type of technology that is mainly present in buildings erected before 1945 and between 1945-1969, as shown in Table 60.

Information about construction materials and construction methodology of the EU27+UK service sector was summarized. The summary is based on the results of the questionnaires obtained from expects. Concerning the EU27+UK service sector, the information is presented in the table below (Table 61).

CONSTRUCTION MATERIALS				CONSTRUCTION METHODOLOGY			
Office, health							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete+ insulation in some cases	Aluminum and wood, low emittance glass only in few cases	Concrete + insulation in most cases	Concrete+ insulations in most cases	Solid wall	Double glazing	Flat roof	Concrete slab
Trade, hotels, and restaurants							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete or bricks+ insulation in some cases	Aluminum and synthetic/PVC, low emittance glass only in few cases.	Concrete and bricks + insulation in most cases	Concrete+ insulations in most cases	Solid walls	Double glazing	Flat roof	Concrete slab
Educational, other nonresidential							
Walls	Windows	Roofs	Floors	Walls	Windows	Roofs	Floors
Concrete+ insulation in some cases	Aluminum and synthetic/PVC, low emittance glass in few cases.	Concrete and bricks + insulation in most cases	Concrete +insulations in most cases	Solid walls	Double glazing	Flat roof	Concrete slab

Table 61. Construction materials, construction methodology-service sector (EU+UK).

The details from the table above clearly let us know that in overall EU27+UK service sector demonstrates similarities in construction materials and methodology regarding different types of buildings. For offices and health, relatively the same construction materials and methodology are found. At the same time, it is also valid for trade, hotels, and restaurants. Educational and other non-residential buildings demonstrate the same pattern as well.

Construction materials, as mentioned earlier, have a direct impact on the specific FEC. The impact differs due to the difference in the thermophysical properties of materials and thus building elements (walls, windows, roof, and floor). According to all historical periods, Table 62 shows the thermal transmittance value (W/m²K) regarding residential and service sectors.

Table 62 helps to figure out the impact of building elements on specific FEC. Here we can observe how thermal insulation materials and building elements regarding different periods affect heat flow. As seen from the table below, the thermal transmittance values demonstrate the reduction throughout the historical periods.

RESIDENTIAL SECTOR				
Historical period	**Walls**	**Windows**	**Roof**	**Floor**
Before 1945	2.18	5.34	1.98	1.63
1945 - 1969	1.86	4.70	1.58	1.46
1970 - 1979	1.32	4.26	1.19	1.23
1980 - 1989	0.85	3.70	0.79	0.99
1990 - 1999	0.63	3.20	0.61	0.74
2000 - 2010	0.48	2.78	0.42	0.53
Post 2010	0.36	2.39	0.28	0.36
SERVICE SECTOR				
Historical period	**Walls**	**Windows**	**Roof**	**Floor**
Before 1945	1.35	3.55	1.17	1.13
1945 - 1969	0.95	2.55	0.73	0.79
1970 - 1979	0.78	2.31	0.57	0.65
1980 - 1989	0.66	2.46	0.47	0.55
1990 - 1999	0.49	2.06	0.34	0.44
2000 - 2010	0.33	1.78	0.26	0.36
Post 2010	0.27	1.73	0.18	0.28

Table 62. Thermal transmittance of construction elements (EU+UK).

Regarding the technology for SH, SC, and DHW, a summary of the dataset provided by the H2020 HotMaps project (8) reveals that central SH and DHW systems are characterized as the most widespread technology. In contrast, individual and district heating systems are widespread and less widespread technologies, respectively.

Non-condensing boilers are the most present equipment for SH and DHW system, followed by a condensing one primarily installed in buildings erected after the 1980s and characterized as less widespread technology. We can observe that combined technology in overall is a widespread type of technology among EU and UK residential buildings.

Information regarding renewable technologies for SH and DHW show that the heat pump indicates a level of approximately 3-4% (less widespread technology) regarding buildings erected before 1945 to the 1990s and 8% (less widespread technology) regarding buildings erected afterward. Solar collectors are primarily present in newly erected buildings (post-2010) with a level of presence of 13% (less widespread technology).

EU+UK residential building stock mainly uses gas and liquid fuel (widespread technology), followed by electricity for DHW (less widespread technology). Biomass for SH is almost lucking with a level of presence of approximately 1% in buildings erected from 1945 to the 1990s.

According to expert questioning: The most common technologies for SH and DHW in the EU+UK building stock are central gas condensing boilers, heat pumps, electricity. SC is not present in most cases, except health industry, where SC is often used. While Southern European countries such as: Spain, Italy, Greece, Cyprus, Malta, and Portugal indicate a variouse differences: the most common technologies for SH and DHW are the individual gas condensing boiler and electric heating (trade buildings only). SC is present in most cases, except educational buildings.

The result of the analysis reveals the following:

— Approximately 51% of the European residential building stock was built before 1945 and between 1945-1969.

— The EU27+UK residential building stock is characterized by 68% as SFHs. While in the service sector, most of the buildings are trade buildings (45%) and offices (21%).

— Specific FEC for SH and DHW decreases consecutively. In overall, residential buildings erected before 1945 and between 1945-1969 consume around 252 and 223 kWh/m² y of specific FEC. In contrast, those erected in the 2000s and post 2010 consume approximately 125 and 99 kWh/m² y respectively. Service buildings erected before 1945 and between 1945-1969 consume about 171 kWh/m² and 162 kWh/m² y. In comparison, those erected in the 2000s and post-2010 periods consume about 112 and 99 kWh/m² y accordingly.

— Specific FEC for SC is significantly smaller than for SH and DHW (e.g., 15 and 35 kWh/m² y on average for residential and service sectors, respectively).

— The level of insulation materials in buildings erected before 1945 to the 1980s is significantly low. The most insulated buildings can be found in countries such as Germany, France, and United Kingdom.

— The most widespread type of fuel for SH and DHW is gas, followed by liquid fuel. Renewable systems such as HPs and solar thermal systems are still lucking in the EU buildings stock, characterized as less widespread technology (e.g., with a level of presence of 8% and 13%) mainly in newly erected buildings (the 2000s, post-2010).

5.

Final Discussion

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Improving the energy performance of buildings has significant macro-economic advantages and can considerably add to all three priorities of the EU 2050 roadmap targets. Society will benefit from macro-economic advantages and an increase in energy savings (21). Energy-saving restoration programs established in countries such as Germany, the UK, and Austria have currently shown a favorable impact in terms of work and private capital. There are also different estimations about the positive employment results of energy-saving renovation procedures, stimulating direct employment in the building and construction and related markets from the products supply chain. Energy-saving activities in buildings have a huge potential for industries such as education & research, energy services companies, and waste management. The government support is an important aspect that can trigger investments in these fields. Company efforts with clear targets and providing long-term predictability are required to trigger a step-change in renovation practices (22).

The EU Member States show considerable distinctions in terms of efforts, financial capacity, and market conditions. There are significant market frictions at the Member State level: the landlord-tenant issue, numerous stakeholders and decision-makers, conditionality in the renovation of specific buildings (i.e., historic structures, and so on), problems in accessing funding or unappealing interest rates, damaging aids for energy production and heating energy costs in some countries are simply some of the barriers (23).

The existing legislation insufficiently covers the substantial renovation of the EU27+UK building stock, and hence the potential development of affordable energy savings and financial growth is not sufficiently established. More targeted steps are needed for promoting the deep renovation of the existing building stock (20), (24).

At EU level, it is essential to strengthen the existing legislation with critical steps and establish roadmaps to monitor and renovate the EU27+UK building stock. The renovation roadmap must be built long-term with binding targets for energy-efficient retrofit of the EU27+UK building stock by 2050. A renovation roadmap must have a precise tracking and reporting plan in connection with the monitoring based on measured performance with interim targets indicating the renovation rates and depths to be reached slowly by 2030 (25), (26).

Having a predictable, long-lasting, profound renovation roadmap will offer self-confidence to the business sector and will prevent the risk of failing after 2020 and creating undesirable economic problems (such as employment distortions, additional costs, and so on). In order to increase the cost-effectiveness of the renovation roadmap, renovation targets can be developed in accordance with the financial and technical capacity of the country and the possible mechanisms of cooperation between the Member States. Custom-made roadmaps can specify different stages which move from voluntary to binding procedures. The procedures should be continually evaluated and improved, where the renovation requirements ought to be eventually tightened to meet new requirements (27).

The BPIE report (28) answered the question that the long-term renovation strategies (LTRS) of EU Member States are not in line with the EPBD requirements on total decarbonization of the

EU building stock by 2050. Even full compliance with Article 2a of the EPBD is not sufficient to achieve climate neutrality by 2050. Member States now must steadily proceed towards 100% decarbonization of their building stock by going beyond the EPBD Article 2a, develop and maintain long-term renovation strategies to achieve the final target of climate neutrality and raise their ambition for the reduction of the energy consumption as soon as possible.

Member states must deliver at least 3% annual deep renovation rate by 2030 and fully aligning the buildings sector with the climate-neutrality objective by 2050 is a must.

The process of embracing minimum energy-saving guidelines and energy labeling for cooling and heating equipment and construction materials under the Energy Labelling and Eco-design of the energy-related items Framework Directives must be enhanced and supported (29).

The EU must support the harmonization of nationwide building data collection systems, including the characteristics and energy performance of buildings, guaranteeing enough high-quality data availability, and closing the space in existing systems revealed through this research study. These data are required to develop and execute effective working policies and incentive plans that drive the required change in the EU27+UK building stock (30).

Deliberate renovation methods are cost-effective when considering the whole life process, which requires a significant advancement in financial investments. For increasing the deep renovation of the EU27+UK building stock, the establishment of funding instruments, i.e., as EU deep renovation programs and funds could further be implemented under the national level. The funding must be offered only for deep level renovation resulting in low energy standards. Such a fund will provide more monetary flexibility and additional flexibilities for investors (31).

EU funds for the purpose of renovation should include the minimum requirements to implement procedures at cost-effective levels. Which should remain in line with the requirement for the Multiannual Financial Framework - MFF (2021-2027 long term budget for EU) (32).

The European Commission could also facilitate the development of innovative financial instruments at the Member State level by elaborating guidelines for financing, promoting best practices, stimulating the cooperation between the Member States for sharing experience, and implementing standard, harmonized regulatory measures for deep renovation. The upcoming strategy for the sustainable competitiveness of the construction sector, which the European Commission planned, may provide a strong foundation for improving the knowledge level and the practice of renovation activities. One of the key recommendations at the national level policy measures is that EU governments should eliminate market barriers and administrative bottlenecks for the renovation of the building stock (33).

To cultivate the deep renovation of the building stock, Member States need to develop long-term, extensive regulatory and monetary programs, as well as professional training, educational, and advertising programs dealing with macroeconomic benefits. Vital components of these programs need to be cost-effective and implemented at a high-quality level through constant strengthening and implementation of effective requirements, new building codes, and effective quality control systems (34).

Imposing compliance with building regulations and requirements will be essential to counter the understanding that energy-saving renovation measures come with a price premium. Accurate tracking of enforcement, compliance, and quality control processes through a certified labor force should be any policy bundle to foster profound renovation. The reasonably low compliance level in almost all the EU Member States is a significant barrier in reaching the estimated energy savings potential (35).

The confidence of customers and financiers in the quality level of renovation measures needs to be re-established so that the readiness to make the essential financial investment boosts. Assurance systems for the efficiency of effectiveness measures must be developed (27).

A better application of the structure's energy accreditation and audit plans is needed as these are vital information and awareness tools that can increase the efficiency of buildings and promote the market towards green financial investments (36), (37).

Energy services companies (ESCOs) can play a necessary function in cultivating deep renovation programs by supplying the needed technical and financial expertise and by setting off third-party financing. Hence, eliminating the market barriers facing ESCOs might help to develop the renovation programs faster and much better. Regulatory frameworks must encourage the set-up and advancement of a well-functioning energy services market, not restricted to industrial buildings (38).

The success of deep renovation programs will depend on creating suitable funding schemes, resolving all the classifications of commercial and private real estate owners, and presenting procedures utilizing appropriate support, low-interest and longer-term loan schemes, and other procedures of monetary incentive plans (39).

Financing packages must offer suitable market-based instruments tailored to various requirements and overcome the primary market barriers. In addition, the renovation programs need to be based upon an initial macro-economic analysis to guarantee the sustainability and strengthen steps towards integrating all the benefits and cost reductions protecting the program's spending plan and proposing the most appropriate market instruments. Low energy renovation standards should be applied, preferably based on a preliminary and actual assessment of the building's energy performance (40).

A correct public financing approach might take advantage of significant personal capital, as proven by numerous effective programs established in some European nations. Drawing in personal capital to invest in building renovation is crucial for any funding program that intends to transform and stimulate the economy's energy performance measures into a sustainable company activity. Federal governments should draw up a balance sheet that calculates the costs of efficient deep renovation incentive plans against the increased tax profits from the substantial growth of the building market (e.g., earnings tax, business tax, etc.) (41).

Relevant nationwide stakeholders need to enhance their understanding of using the EU Structural and Regional Funds and the EIB funding lines to improve the energy performance of the building stock. Investing in buildings indicates an investment into the development of society. (42).

For executing reliable and high-quality deep renovation, it is required to enhance the skills of the building professionals at the level of both basic professional education and long-life knowing activities. Training and educational activities should be developed both in the construction sector and in the supply chain industries (43).

Promotion and dissemination of information should be an important part of the renovation programs. The German experience shows that popularization of energy efficiency brands for building renovation is a vital success factor (44).

Awareness raising and promotional activities should address the psychological barriers which exist concerning the deep renovation. Existing EU policies must be implemented in a best practice manner to achieve the intended energy savings, while new instruments are needed to stimulate a deep renovation wave across Europe and its Member States (45). The EU27+UK buildings stock should grab the renovation opportunity to innovate products and services, to build a well-functioning energy-saving renovation market, to offer attractive solutions to private and commercial customers, and to use their ingenuity to make highly efficient buildings a common standard of the EU market (46).

A renovation roadmap must have a precise monitoring and reporting plan with interim targets indicating the renovation rates and the renovation depths to be reached gradually by 2020 and by 2030 (47). To increase the cost-effectiveness of the renovation roadmap, renovation targets can be built according to the financial and technical national potential and support potential cooperation mechanisms between the Member States. For boosting the deep renovation of the EU27+UK building stock, the establishment of specific financing instruments, i.e., an EU Deep Renovation Fund (possibly via the European Investment Bank and designed for different building types) could be considered, which complements the national financing schemes and shares the risks (48). All participants in the EU27+UK building stock must create the opportunity for renovation through the innovation of products and services, create a well-functioning and energy-efficient renovation market, offer attractive solutions to commercial and private clients, and use their ingenuity to ensure high efficiency (49) .

6.

Conclusion

6. Conclusion

One of the vital aspects that have been revealed in this book is the current situation with the renovation of older buildings (e.g., built before 1945 to 1970). As was mentioned earlier, these buildings cover about 51% of the whole residential building stock and still, in most cases, do not have proper insulation. Moreover, uPVC windows in most cases are not present even in residential buildings erected after 1970. Thus, the first effective step towards the deep renovation that can save a significant amount of thermal energy must be a replacement of old wood windows (dominant in the EU residential building stock) with uPVC windows. These procedures can reduce annual energy bills by up to 40% (50). In addition, this research shows that approximately 68% of houses in EU27+UK are single-family-terraced houses that open an opportunity to increase the number of flat plates solar collectors and ground source heat pump applications, which are currently rarely represented.

A positive impact on climate change can be achieved while providing many other social benefits (51). To trigger the renovation process, we need to have national and international support, innovative investment instruments, and public awareness to lower the building stock's energy consumption. Existing EU policies need to be implemented in the most practical way possible to achieve the desired savings in energy costs, while entirely new tools are needed to boost a deep wave of renovation across Europe and its Member States. Excellent knowledge of the status quo of construction efficiency is required to formulate policies.

The BPIE (Building Performance Institute Europe) study found that there are data gaps that make it difficult to create targeted programs, monitor policy implementation, and evaluate development (52). The EU and its Member States must make significant efforts to close these data gaps and balance monitoring, reporting, and evaluation.

Participants involved in the renovation of the existing European building stock should be allowed to use innovative products, services, and attractive solutions for private and commercial clients to create a well-functioning market. High-performance buildings must become a typical European standard. In essence, what is required is strengthening the Long-Term Renovation Strategies by providing joint financial and technological support between the Member States, ensuring precise mutual control, and reporting on the current situation with national building stocks in order to continue searching for improvements of the tools and techniques used.

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Notes

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