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Building stock characteristics and energy performance of residential buildings in Eastern-European countries

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ABSTRACT

Countries in Eastern-Europe have similar characteristics due to their common historical and economic backgrounds. A large part of the housing stock has been built during the Soviet era, applying uniform solutions and similar standards, but similarities extend to other periods as well. On the other hand, the differences should also be noted – although the climate is mainly continental, there are significant variations between South and North and between mountainous and flat areas.

In this paper, a detailed comparative analysis is presented for Bulgaria, Serbia, Hungary and the Czech Republic. The results are based on the residential building typologies developed within the TABULA/EPISCOPE project co-funded by the Intelligent Energy Europe Programme. Typical building types will be presented, covering building structures and systems. Important energy performance indicators are identified and compared, supported by available statistical data about the housing stock.

The added value of the paper consists of the analysis of heterogeneous data sources and collecting and comparing the information of the housing stock under a common comparison framework of building typology data between countries, and the contribution in the harmonization of the building typology approach.

1. Introduction

Residential buildings in Eastern Europe exhibit numerous similarities in their design, building envelope, ownership structure and even user habits. A large part of the building stock has been built during the Soviet era using uniform solutions and similar standards. Some of these similarities persisted even after the democratic changes in these countries, mostly due to similar economic and political developments. After accession, European initiatives, particularly the EPBD [1] have determined the progress of energy regulations, but the economic limitations remained an important factor. In three of the countries discussed in this paper, the impact of Austria-Hungary (Austro-Hungary Empire) was also notable before the First World War, particularly in major cities in the region.

Large housing estates (panel buildings) are an important, almost iconic, common element of the building stock in Eastern Europe, meriting a closer look. These large, monotonous blocks of flats, mostly using prefabricated sandwich panels, have become a symbol of the Soviet era. They have similar characteristics and problems, and thus have been the focus of energy policy discussions in most countries with a large stock. The seventies and eighties were the "finest moments" of industrialized technology, when this was the construction method of choice. The technology was actually invented in the West, first used in Denmark, England, France and other countries in large numbers before the Soviet Union procured the right to use the technology and developed its own systems. In Russia, most of the apartment buildings were constructed between 1960 and 1985 and as a result, the urban housing stock today con-

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Abbreviations: AC, air conditioning; BG, Bulgaria; CDD, cooling degree days; CHP, combined heat and power; CZ, Czech Republic; DH, district heating; DHW, domestic hot water; EER, energy efficiency ratio; EPBD, energy performance of buildings directive; EPISCOPE, Energy Performance Indicator Tracking Schemes for the Continuous Optimization of Refurbishment Processes in European Housing Stocks; HDD, heating degree days; HU, Hungary; IND, building built with large panel blocks; MFH, multi-family house; NZEB, nearly zero energy building; PM, particulate matter; RS, Serbia; SFH, single family house; TABULA, Typology Approach for Building Stock Energy Assessment; U, thermal transmittance.

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sists mainly of a few standard building types [2–4]. The share of such dwellings in the countries described in this paper is 16.7% on average, representing a moderate figure in the region. Just to provide a frame of reference: Slovakia has 778,000 such buildings, representing 40% of the residential building stock [5] the same figure in Poland is 6,171,000, (49%) [6]. The proportion of these buildings is particularly high in the Baltic countries [7,8]. To give an example: in Estonia, 45% of the dwelling stock has been built between 1961 and 1990 – multi-storey apartment buildings, mostly with prefabricated technology [9]. In Romania, 29.4% of the dwellings are in apartment buildings, 68.3% of which consist of large panel buildings [10]. In former East Germany, more than 2 million of such flats exist today [11].

In light of the above, there is currently a gap in available literature: comparing different countries is problematic because of the heterogeneity of available data, even in countries that have a similar historical, economic and social background like the ones presented herein. Therefore. this paper aims to fill this gap by attempting to provide a comparative analysis for the residential building stock of four countries in Eastern Europe: Bulgaria, Serbia, Hungary and the Czech Republic. First, qualitative similarities and differences between these countries will be discussed, covering the most important aspects influencing the thermal performance of the building stock and future development perspectives. After this baseline has been established, a comparative analysis of selected important energy performance indicators will be presented based on the results of the TABULA/EPISCOPE building typology [12]. For the purposes of this paper, policy implications are forgone in favor of the technical aspects of the comparative analysis.

Beside the similarities, some important differences should also be noted. Although the climate is mainly continental in the region, it gets colder from South to North and solar gains become less significant. There are differences in economic development, as well as political priorities. The differences in the energy mix are also significant, having an impact on building service systems and the level of system centralization.

In order to perform a comparative analysis of the residential building stocks in the selected countries, we have used available statistics and the building typology in a bottom-up modelling approach. The typology itself has been developed as part of the TABLE and EPISCOPE projects, supported by the Intelligent Energy Europe Programme with the participation of 18 EU countries, Norway and Serbia [12]. The results of these projects have been published in several scientific articles, all with a different focus: the residential building stock of Greece has been modelled using the typology developed [13], while [14] demonstrated the energy performance of French residential buildings from a fuel poverty perspective using national statistics. In Ref. [15], the differences between top-down and bottom-up approaches in energy statistics has been showcased for Denmark. Research has also been carried out on a larger scale in Ref. [16], identifying 72 building types in the entire EU-25. The buildings were classified in terms of their representativeness, geographical distribution, size, material composition and thermal insulation, grading renovation options based on their life cycle impacts. Using yet another approach, statistics and surveys have been used to analyse the energy performance of Greek residential buildings in Ref. [17].

There have been several studies in the past that focused on the building stock in the analyzed countries. The national censuses were carried out in 2011 in all countries. They give a general overview of the housing stock [18–21]. The censuses, however, do not provide enough information about the energy performance of the housing stocks. The Czech residential building stock has been previously analyzed from different perspectives. From the energy consumption perspective, only small-scale studies are available. The ENERGO 2004 micro-census shed light into the energy consumption of the Czech households (types of fuel, frequency of system types and their age structure, energy consumption) [22]. A new ENERGO 2015 micro-census is underway, but results are not yet available. In the meantime, other efforts to analyse the energy consumption of the Czech residential sector have been carried out. PanelScan 2009 focused on analysing the renovation perspectives of residential large panel buildings including renovation progress and estimation of the required investment to renovate the rest of the large panel building stock [23]. More recently, studies have been performed to provide a current overview of the energy saving potential in the housing stock [24–27]. The study “Building Renovation Strategy” by Holub and Antonín [26] is of special interest since it tries to close the gaps of the previously mentioned censuses and studies, by using the concept of the TABLE/EPISCOPE residential typology, the same approach applied in the present paper. In fact, the aforementioned study was later included in the Czech National Energy Efficiency Action Plan [28] demonstrating that the assessment of the energy saving potential and investment required to renovate the overall Czech housing stock is not only of academic interest but also presents valuable information to policy makers.

In Refs. [29,30], a country profile for Serbia has been elaborated. It includes statistical information about the Serbian building stock, albeit in much less detail and without energy performance analysis. First attempts to formulate a methodology for energy performance characterization of the residential building stock have been made in the framework of the national research project titled “*Energy optimisation of buildings in the context of sustainable architecture* (NRP 283, 2002–2005), and the published material [31,32] served as the methodological milestone for further research. Although the formulated methodology included all relevant aspects of energy performance characterization, showcased in the example of Belgrade residential building stock, it lacked the tool for assessing the entire residential stock on the national level. The most detailed and comprehensive analysis has been carried out for Serbia through the collaboration within the TABULA/EPISCOPE project. The results of this research, which included a statistically relevant survey of the national residential building stock, and its energy performance characterization, have been published in several studies [29,33–35]. The results of this work are further developed in this paper. Formulation of typology and methodology for energy performance characterization of the building stock has enabled a more detailed analysis of specific groups of residential buildings within the typology, as the one selected in this paper. Also, case studies of the refurbishment potential of representatives of the selected group of residential buildings can be found throughout available literature [36–38].

The potential for decreasing carbon dioxide emissions from Hungarian residential buildings have been analyzed by [39]. The simplified building stock model in this reasearch can be considered as a preliminary step for the detailed typology developed in our research. The most detailed building energy performance analysis has been carried out recently in 2015 within a representative field survey within the KEOP-7.9.0/12-2013-0019 project, selecting 2000 buildings [40], using the experiences of TABULA/EPISCOPE. However, the results of this project are not publicly available as of this writing.

Finally, the ENTRANZE project should be mentioned with a focus on displaying building data (less detailed than this paper) with a user-friendly mapping tool and on the development of scenarios for building renovations for the EU-28 countries and Serbia [41–43]. About Bulgaria only the TABULA/EPISCOPE and ENTRANZE projects can be mentioned as previous works to assess the entire residential building stock.

The added value of the paper consists of the analysis of heterogeneous data sources and collecting and comparing the information of the housing stock under a common comparison framework of building typology data between countries, and the contribution in the harmonization of the building typology approach.

2. Methodology

In the Section 3, the regional characteristics are described covering several aspects: climate, building statistics, typical building constructions, energy sources, typical technical building systems, user habits and renovation actions carried out so far. This descriptive section is exhaustive and detailed as it is mainly based on national data sources and studies available in national languages only.

The second part covers the quantitative comparative analysis. Calculations are based on the TABULA/EPISCOPE project results [12]. The 20 project partners developed national building typologies representing the residential building stock of their countries. The buildings have been classified and a national building type matrix has been developed for each country. For each building type, a real example building has been selected to represent the characteristics of the type; subsequent calculations have been carried out with the common TABLE tool. An exception was Serbia, where a national calculation tool has been used (Serbia participated on a voluntary basis in the project) based on the same principles. Thus, energy performance indicators have been determined for each building type. However, it was not an objective of the TABULA/EPISCOPE project to elaborate cross-country comparisons. The comparative analysis of the four countries have been elaborated for this paper.

The parameters for classification of residential buildings according to the TABLE concept were the country, the region (national or region of the country), the construction year together with the building size class and several additional parameters.

The TABULA/EPISCOPE typologies consist of a high number (mostly between 15 and 40) of building types [12]. For the research presented in the paper, building types have been merged into a smaller number of classes to make the analysis more comparable and the results more illustrative. The indicators of the merged classes were determined as the weighted average of the TABULA/EPISCOPE building type indicators using the national total floor area as the weight. Vacant buildings were excluded from the analysis.

The energy need for space heating of all the building types were calculated by applying the seasonal method according to EN ISO 13790 on the basis of a one-zone model [44]. As explained above, the common TABLE calculation tool has been used for Bulgaria, Hungary and the Czech Republic [12], whilst for Serbia the KnaufTermPro2 software has been applied. The external boundary conditions (external temperature and solar radiation) are based on the climate data of the different countries. Standard values are used for the utilization conditions (e.g. room temperature, air change rate, internal heat sources, energy need of domestic hot water) as described in Table 1 [12]. The common reference area is the conditioned floor area calculated on the basis of internal dimensions.

The calculations have been carried out assuming continuous heating, which means that the impact of user habits is not taken into account. As explained in Section 3.3, available data on heating habits is insufficient in all of the countries.

Net delivered energy for heating and domestic hot water has been calculated from the energy need, covering all system and control losses inside the buildings. Then, primary energy calculations have been carried out taking into account the energy required for extraction, processing, storage, transport, generation, transformation, transmission, distribution, and any other operations necessary for delivery to the building applying primary energy factors as described in EN 15603 [45] in accordance with the EPBD [1]. To determine the primary energy demand for heating and domestic hot water, the distribution of energy carriers and technical building systems according to types of buildings were taken into consideration as described in Sections 3.2.2–3.2.4.

Cooling was not considered in the model, for two reasons: on the one hand, although cooling is a growing factor in the energy use residential buildings, it is still not dominant, and on the other hand, available statistical data on the ratio of residential buildings with cooling is insufficient for drawing conclusions. This is a data gap that merits further research, but a solution is beyond the scope of the present paper.

The first objective was the determination of the current energy performance of the building types. The applied building characteristics were based on the building stock analysis described in Section 3.2.

The second objective was to determine the energy saving potential achievable with deep renovation targeting a level close to nearly zero building energy (NZEB) requirements. These requirements are defined on national level based on the EPBD [1,46–48]. A common element of the national legislations is that they consist of different levels: U-values of the building shell are maximized, minimum requirements on technical building systems are set, overall energy performance or CO_2 emission levels are maximized and there are additional requirements on mandatory application of on-site or nearby renewable energy sources. In Serbia, the official NZEB requirements have not yet been defined, therefore the targeted level had to be defined based on top quality technical solutions available on the Serbian market. Definitions of other countries in the region have also been taken into account. The EPBD requires the NZEB level for new buildings only but not for renovations, therefore the NZEB level was merely an indicative target in our models, in cases of technical and economic difficulties the applied measures were slightly less ambitious. The exact renovation actions have been defined case by case. More detailed descriptions of the current state and retrofit levels per building type can be found on the EPISCOPE website [12] and in Ref. [33]. A meaningful comparison of the NZEB definitions is problematic to make because country definitions vary widely – the primary energy requirement depends on the A/V ratio in Hungary, as opposed to the use of the reference building methodology in the Czech Republic, for example. As for the heat transfer coefficients, the requirements also differ. Some countries define values for each structural element, while in the Czech Republic, the average U-value of the building envelope must be below 70% of that of the reference building. Therefore, potential comparisons are limited by these circumstances to renewable energy ratios.

First, the energy performance calculations have been carried out per building type for the current and the renovated state. Then sectorial level calculations were done by multiplying the specific indicators with the national total floor area. The energy saving potential has been calculated as the difference between figures belonging to the renovated state and the current levels. It is the so-called bottom-up approach widely applied in literature with the goal of evaluating the effect of different energy saving measures, e.g. [49–52].

3. Description of the region and the building stock

3.1. Climate

The energy performance of the building stocks cannot be analyzed without taking climatic conditions into account. The climate is generally continental with hot summers and cold winters, but there are important differences that should not be neglected. The Czech Republic is in the Northwest, where the climate is gener-

Table 1
Episcope standard values used in the calculations [12].

	Single-unit housing	Multi-unit housing
internal temperature [°C]	20	
air change rate [1/h]	0.4	0.4
net energy need domestic hot water [kWh/(m2year)]	10	15
average internal heat sources per m^2 reference area [W/m^2]	3	

ally colder and more humid. Bulgaria is in the Southeast, where summers are hotter and winters are milder. In addition to the geographical position, the influence of altitude can also be of great importance: Serbia and Bulgaria are strongly affected by mountains, the Czech Republic is hilly, whilst Hungary is dominated by plains.

All this is reflected in the national calculation standards and methods. The Czech Republic is divided into four climatic regions with rated outdoor temperatures of −12 °C, −15 °C, −18 °C and −20 °C (ČSN 730540, Annex H1). The average HDD (Eurostat, NUTS-2, 2010–2013) in the Czech Republic is 3495 days °C/year [53]. In general, the country has a temperate continental climate, usually with warm summers and cold winters. The temperature differences between these two seasons are relatively high.

In Hungary, three climate zones have been defined by the heat loss calculation standard for sizing heating systems with rated outdoor temperatures of −11 °C, −13 °C, −15 °C [54]. No climate zones are defined in the energy performance calculations and degree days of 3000 days °C/year are applied all over the country [46].

The Serbian climate is between a continental climate in the North with cold winters and hot, humid summers with well distributed rainfall patterns, and a more Adriatic climate in the South with hot, dry summers and autumns and relatively cold winters with heavy inland snowfall. New regulations on energy efficiency [55] have abandoned using climatic zones and introduced calculations based on HDD. Official heating degree days are available for most cities in Serbia [55], the average HDD is about 2600.

Bulgaria is divided into 9 climate zones. Only heating degree days are defined in the legislation from 2100 to 2900 days °C/year depending on the climate zone. The mildest zones are in the South and by the Black Sea. The importance of summer cooling cannot be overstated – although electricity plays an important role in heating, peak electricity consumption occurred in hot summer days in recent years due to higher comfort needs in offices, residential buildings and summer hotels near the Black Sea as well as climate change.

Average cooling degree days for the last 5 years for an indoor temperature of 26 °C are as follows: Prague (CZ): 17 days °C, Budapest (HU): 75 days °C, Belgrade (RS): 130 days °C, Sofia (BG): 89 days °C, Plovdiv (BG): 137 days °C [56].

The indicated HDDs relate to an average indoor temperature of 20 °C except for Bulgaria, where the design value is 19 °C [46,56–59].

In order to determine solar gains during the heating seasons solar irradiation values were taken into account according to orientation (e.g. for a horizontal surface the values are as follows: Bulgaria: 337–410 kWh/m^2year, Czech Republic: 354–416 kWh/m^2year, Hungary: 400 kWh/m^2year, Serbia: 398 kWh/m^2year) [46,55,57,58].

3.2. Description of the building stock

The housing stocks of the analyzed countries have several similar characteristics. The overall stock consists of 15.3 million dwellings (4.4 million in Hungary, 4.0 million in the Czech Republic, 3.7 million in Bulgaria and 3.2 million in Serbia) [18,20,21,33]. Values of total floor area for different building classes are shown in Fig. 1.

Regarding the number of dwellings, more than the half (58.2%) are located in detached houses, but there are notable differences between the countries: the highest share belongs to the Republic of Serbia (73%), followed by Hungary (62%), Bulgaria (56%) and the Czech Republic (45%).

Dwellings in large panel buildings are less significant, but remarkable (17.6% in average), particularly in the Czech Republic (26.9%).

The remaining dwellings (16.1–29.3%, on average: 24.2%) are located in other types of multi-flat buildings.

Most dwellings were built during the Soviet era (61% on average), this type of buildings has a particularly notable share in Serbia (74%), while the other countries have roughly the same share (56–59%). A considerable portion of the building stock has been built before the end of WWII, with the highest share in Hungary (29%) followed by the Czech Republic (22%), Bulgaria (14%) and Serbia (12%). On average only 19% of the dwellings were constructed after the end of the Soviet era in the four countries. Such new dwellings have the highest proportion in Bulgaria (27%), followed by the Czech Republic (19%), Hungary (15%) and the Republic of Serbia (14%). In general, Bulgaria has the youngest building stock – about half of the buildings have been constructed in the past 40 years and only 3.9% before 1919, however their condition is deteriorating due to poor maintenance and facility management. Over 50% of the Czech housing stock was built after 1970, the average age of buildings is 49.3 years for family houses and 52.4 for other residential buildings [12,33,18,20,21].

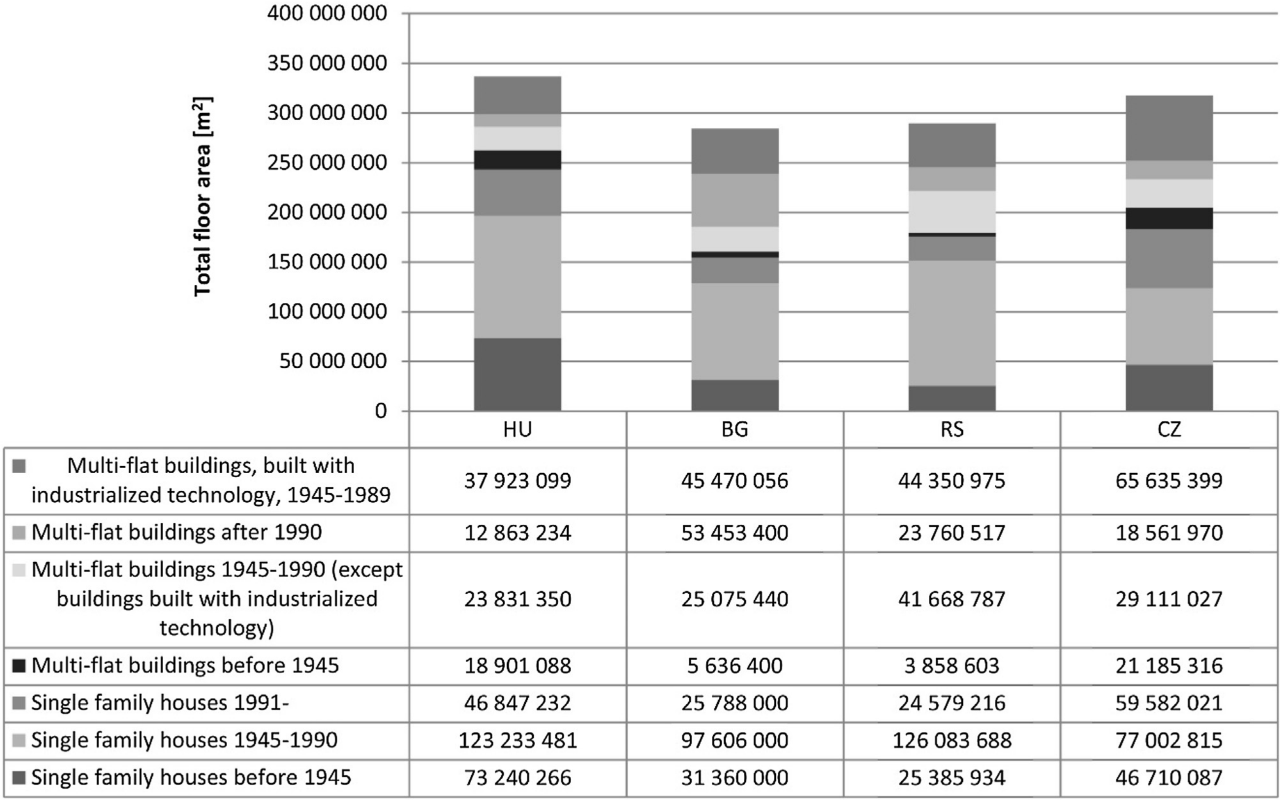
The significant share of vacant buildings is also worth noting. There is a continuous trend of abandoning apartments and houses in certain regions due to urbanization worsened by declining populations. Only 83.4% of the dwellings are occupied in the Czech Republic, the rest (16.6%) are vacant, either unsuitable for use or abandoned [18]. In Serbia, 75% of buildings are occupied, 14.7% temporarily unoccupied, 3.5% abandoned, 5.5% are used for vacation purposes and the majority of non-inhabited units is located in small communities [19]. In Hungary, 10.9% of the dwellings are uninhabited [20]. In Bulgaria, 83.7% of the residential buildings are occupied [21].

In Eastern European countries, most of the dwellings are privately owned. Both in Bulgaria and Hungary, 96% of the dwellings are private [20,21], even more in Serbia (99%, [60]). In the Czech Republic, 9% of the dwellings are owned by the state and municipalities. The rest (91%) is either owned by natural persons (46%), housing co-operatives (11%) and other types of ownership (34%) [18].

This property structure leads to a particular problem. Investments in the renovation of multi-family buildings require a complicated procedure and the support of all owners, whose financial situations are extremely varied, making the retrofit of multi-flat buildings impossible without significant subsidies.

3.2.1. Building structures

Building structure properties are less divergent for buildings built before the end of the Soviet era, after that, the differences between countries become more noticeable, resulting from



	HU	BG	RS	CZ
■ Multi-flat buildings, built with industrialized technology, 1945-1989	37 923 099	45 470 056	44 350 975	65 635 399
■ Multi-flat buildings after 1990	12 863 234	53 453 400	23 760 517	18 561 970
□ Multi-flat buildings 1945-1990 (except buildings built with industrialized technology)	23 831 350	25 075 440	41 668 787	29 111 027
■ Multi-flat buildings before 1945	18 901 088	5 636 400	3 858 603	21 185 316
■ Single family houses 1991-	46 847 232	25 788 000	24 579 216	59 582 021
■ Single family houses 1945-1990	123 233 481	97 606 000	126 083 688	77 002 815
■ Single family houses before 1945	73 240 266	31 360 000	25 385 934	46 710 087

Fig. 1. Total floor area according to age and type.

different economic performance and prospective dates for the introduction of EPBD requirements.

Façade walls were typically not insulated until the end of the communist era with the exception of panel buildings in the Czech Republic, Serbia and Hungary, where the prefabricated reinforced concrete sandwich panels contained a 5–8 cm insulation layer. In Bulgaria, the sandwich construction was introduced during the years with the last system improvement in 1987. However, these insulated structures had very significant punctual thermal bridge losses due to the steel reinforcing elements and the linear thermal bridge losses at the panel junctions. Typical U-values are 0.9–1.5 W/m^{2}K for masonry constructions and 0.7–1.64 W/m^{2}K for the large panel buildings [61]. Country-specific U-values are shown in Table 2.

After the end of the communist period, the U-values improved significantly when insulating walling blocks started to dominate the markets, mainly in the Czech Republic, followed by Hungary. Insulated façade walls became increasingly frequent in these countries, particularly after introducing the EPBD requirements after 2006. Typical U-values in this period: Czech Republic: 0.25–0.38 W/m^{2}K, Hungary: 0.3–0.5 W/m^{2}K, Serbia: 0.46–0.9 W/m^{2}K, Bulgaria: app. 0.9 W/m^{2}K [12,33,61].

Applying insulation on the roof attic slab and on the roof started in the seventies and eighties, particularly in Hungary, Bulgaria and the Czech Republic. After the end of the communist period, roof and attic slab insulation also became common in multi-flat buildings in Serbia with lower insulation thicknesses. Typical U-values after the end of the communist period: Czech Republic, Hungary: 0.2–0.35 W/m^{2}K, Serbia: 0.3–2.5 W/m^{2}K, Bulgaria: 0.65–1.08 W/m^{2}K. Non-insulated roofs and attic slabs (typical until the seventies) have a U-value of 1.2–2.5 W/m^{2}K [12,33,61,64].

All countries used secondary glazing windows due to the cold continental winters with U-values between 2.5 and 3.0 W/m^{2}K. Double glazed windows with low-emissivity coating and argon filling became dominant in the Czech and Hungarian market in the last two decades. Such insulating windows have become commonplace in Bulgaria since 2005 and in Serbia only since 2011 when the new building code made their use obligatory. [12,33,40,61,64].

3.2.2. Energy supply and heating systems

The centralization of heating decreases from Northwest to Southeast. District heating is notable in all countries, particularly in the Czech Republic. Natural gas is dominant in Hungary, but also important in the Czech Republic. Wood and electricity are the dominant energy sources for heating in Serbia and Bulgaria, used in decentralized units.

In the Czech Republic, 21.9% of the dwellings have room heating, 43.2% central or apartment heating, whilst 34.9% have district or collective heating. As of 2009, natural gas was the most important energy source (39%) for heating, followed by district heating (36.84%), solid fuels (17.62% – mostly wood), electricity (6.25%) and other sources (0.2%) [65]. In the case of gas heating, 82.2% of the dwellings have boilers and the rest (17.2%) have individual heating units (e.g. gas convectors). In case of wood-based heating systems, central systems are more common (59.8%) than in individual stoves (40.2%) [22].

In Hungary, 17.3% of the dwellings are heated by district heating, 3.0% by central heating, 35.4% by apartment heating and 44.2% by room heating. The dominant energy source is natural gas, but wood is also important in detached houses. Electric heating is rare [20].

In Serbia, the main energy sources for heating are electricity (41.5%) and wood (27.7%), followed by district heating (12.8%), coal (8.8%), natural gas (6.6%) and oil (2.5%). In the majority of the dwellings, room heating is applied with low-efficiency wood stoves, electric stoves or split units [66].

In Bulgaria, wood (34.1%) is the most important energy source for heating, followed by electricity (28.6%), coal (19.8%) and district heating (16.4%). Natural gas and other sources are negligible

Table 2
Country-specific U-values [46,33,24,40,61–63,25].

Building constructions	U-values [W/m^{2}K]			
	Hungary	Bulgaria	Serbia	Czech Republic
Old buildings before 1990 (buildings built with traditional technology)				
Façade walls	0.94–1.36	1.0–1.6	0.9–1.7	0.96–1.43
Attic slab/roof	0.36–2.1	0.5–2.1	0.65–2.47	0.35–1.25
Windows	2.5–3.0	2.3–2.65	3.0–3.5	2.7–2.8
Buildings built with industrialized technology				
Period	1967–1991 [36]	1962–1996 [46]	1960–1990 [53]	1957–1991 [28]
Façade walls	0.7–1.5	0.8–1.3	1.1–1.64	0.8–1.1
Attic slab/roof	0.4–0.9	1.5–2.5	0.38–1.73	0.35–0.85
Windows	2.5–3.3	2.5–2.8	3.0–3.3	2.6–3.0
New buildings (after 1990)				
Façade walls	0.22–0.49	0.8–1.0	0.46–0.92	0.25–0.38
Attic slab/roof	0.2–0.35	0.65–1.08	0.3–2.47	0.2–0.35
Windows	1.4–2.0	1.3–2.0 (since 2005)	1.3–1.5 (since 2011)	1.2–1.8

[21]. Wood logs and coal are mostly used in low-efficiency stoves, leading to environmental problems in several villages and towns during the winter season due to high levels of PM and resulting health problems [67].

Renewable energy use in households in the region is dominated by biomass, the penetration of solar systems and heat pumps is still low in the residential building stock [18,20,66,21].

Although wood has an important share in these countries, it should be noted that wood logs are mainly burned in old stoves with 30–40% efficiency – a suboptimal way to use biomass. A large part comes from private forests, sold on the black market (directly from trucks at certain locations in the cities or even directly ordered separately), which means that the role of wood is probably much higher in reality than the national statistics would imply [68,69,34,70].

3.2.3. Domestic hot water (DHW)

Available statistics on domestic hot water systems are limited. In the Czech Republic, only 0.23% of occupied dwellings lack tap water, and only 1.64% have no hot water, in both cases, most of the dwellings are in buildings built before 1945 [18]. The three main sources of energy for DHW are district heating (32%), electricity (30.55%) and natural gas (23.43%). Only 0.21% (8505 dwellings) use a solar thermal system as a main source for DHW [18].

In Hungary, hot water is produced mostly by individual gas boilers with or without indirect storage tanks or by individual electrical storage and occasionally, non-storage water heaters. In buildings supplied by district heating, the heat source is mostly district heating with central storage tanks and a circulation pipeline [40].

In Serbia, most domestic hot water systems include individual electrical, storage and occasionally, non-storage water heaters even in buildings supplied with district heating. In households with gas heating, there is a significant percentage with an integrated DHW system. According to census data (2011), 75% of occupied dwellings are connected to the public water system, and about 10% has gas heating installed [19].

In Bulgaria, DHW systems mainly use electric heaters and storage. Dwellings connected to district heating mostly use that for DHW as well [12].

3.2.4. District heating (DH)

District heating networks were built in the seventies and eighties in order to supply heat for the large panel blocks (large panel buildings). As described above, district heating still plays an important role in all the countries, with a small downtrend in the last few years, particularly in the Czech Republic and Hungary. National energy strategies predict that despite current trends towards decentralization, district heating will remain an important heating technology in the future, as evidenced by the scenarios and predictions in key strategic documents. The technical conditions of heating networks are diverging. Some networks are modern and efficient, but many are deteriorated and will require considerable investments in the coming years. Development pathways include modernization, network widening (which is a challenge) and changing the energy source: increase in biomass, use of communal waste and cogeneration [71–76]. The distribution losses of the district heating network are significant in the region, approximately 20% for Serbia [36]. In Bulgaria, distribution losses in district heating for the period 2005–2011 increased from 19 to 23% due to reduced consumption, the deterioration of the system and lack of investment (excluding the district heating in Sofia) [77]. In the Czech Republic, the distribution networks have been modernized and thus are in a better state: losses vary between 6 and 14% [78].

In the Czech Republic, Hungary and Bulgaria, most buildings have substations with heat exchangers for heating and hot water with modernized controllers and valves. The control corresponds to the external temperature and the building needs, and is implemented at three levels: on the district level (the temperature of the supply water), in the building substations and in the premises with thermostatic valves. Hungary is an exception regarding the third level (thermostatic valves), which is found only in a part of the buildings. Most buildings are connected to district heating by heat exchangers in individual substations (indirect systems) in Serbia as well, and the substations are equipped with heat meters, but in a few small cities there is direct connection (no heat exchanger). In addition, in most flats there are no thermostatic valves and heat cost allocators, thus floor area is used as the basis for payment instead of measured consumption [71,72,77,34].

District heating has not been lucrative in Hungary due to its price being high, but that has started to change as a result of the actions of the government (prices have been cut multiple times since 2012). Payment has been based on real consumption since 2003.

In Serbia, district heating is still regarded as an indication of a higher living standard. It is favored mostly because of its reliability and relatively low price due to the flat rate payment system. Plans for the future include introducing a system of payment based on real consumption, increasing the share of natural gas, wood and landfill gas in the energy mix, and including DHW systems that are generally based on electricity in collective housing units. In order to reach the target of 40% of households being connected to DH system, some 100,000 new households have to be connected [71].

After 1989, most of the district heating utility companies in small cities in Bulgaria were closed due to reduced loads both from the household and the industrial sector, lack of investments and increasing fuel costs. Although most networks have been renovated in the past decades, transmission losses are still high, as described above. The national energy strategy foresees keeping the role of DH and modernization of the network and facilities (including the replacement of existing CHP capacities) [77].

3.3. Energy poverty and human factors

3.3.1. Heating habits

Many buildings in the region are underheated due to energy poverty – this is particularly true for detached houses in rural areas where specific heat losses are higher due to the high surface-to volume ratio; many of these buildings are inhabited by elderly people or those affected by fuel poverty. Underheating is dependent on climatic conditions as well – it is more typical to have only intermittent heating in several rooms in areas with a milder climate. Fully heated homes are typically heated to 18–20 °C. Available statistical data about the issue is insufficient in all countries, but there is available research on this specific topic, such as [33,79,68,40].

According to a field survey prepared for the national typology in Serbia, only 50% of houses heat more than 50% of the living area, which leads to the conclusion that even houses which are small in size or have a central heating system are forced to leave some space unheated. The daily heating regime in individual houses is difficult to estimate, but it can be stated that family houses in Serbia are typically underheated [33].

Fuel poverty is also a very significant problem in Bulgaria, where most dwellings are underheated. Generally, only rooms occupied during most of the day are heated [79].

Dwellings with district heating show a completely different picture. Blocks of flats are usually heated to 21–22 °C in the Czech Republic, 22–24 °C in Hungary, 20 °C in Serbia, 18–19 °C in Bulgaria. Partial heating is not typical, except for a part of the common rooms (corridors, staircases). In district heating, heating is turned off during the night from 10pm–6am on working days and 10pm–7am on weekends and holidays, 24-h heating is only provided under very specific circumstances. In large panel buildings with district heating, heat cost allocators are generally installed in Bulgaria [47]. In the Czech Republic, both heat cost allocators and thermal regulation valves are required by law in dwellings served by district heating [80,81]. In Hungary and particularly in Serbia, the lack of heat cost allocators means that a significant portion of such dwellings are overheated, wasting energy [40,82,83]. In Serbia, bad ventilation habits are frequently observed in collective housing units during the heating season and low outside temperatures, especially long lasting ventilation with tilted windows and a fully opened radiator valve [74,82,83].

3.3.2. Cooling habits

It is a general problem in the region that there are no statistics available about cooling in residential buildings. However, climatic differences can be easily recognized – the need for cooling in the Czech Republic is relatively low, the majority of dwellings are not equipped with cooling or air conditioning devices. In Hungary, there are already a couple of very hot summer weeks, but cooling in residential buildings is still not dominant [40]. In Serbia, where the summer is even hotter (see cooling degree days in Section 3.1) there are no official data on the percentage of occupied dwellings with AC installed, but it is not insignificant. Data on cooling systems and habits in Bulgaria is unavailable as of the time of this writing.

Individual installations and portable equipment (wall mounted single reversible split units with EER = 2–3) are the most frequent option in all countries and there are no significant differences between single and multifamily housing types. The number of units per dwelling depends on the size of living area, commonly one unit per household, cooling 1–2 rooms. In Bulgaria and Serbia, these appliances are often also used for heating, which is not the case in Hungary [40,41,36]. Cooling systems in the housing sector are marginal in the Czech Republic [41]. However, the significance of these systems is expected to increase in the future [76].

The increasing popularity of individual cooling systems is often criticized from an aesthetic point of view, because the outdoor units are an unsightly addition to the facades. It is a particular problem in historic centers of large cities where cooling demand is even higher because of the urban heat island effect.

3.4. Renovation actions

According to recently conducted studies [24,62] in the Czech Republic, about one third of the housing stock has been refurbished so far. About 50% of large panel buildings, 75% of other multi-flat buildings and approximately 60% of family houses have not been refurbished yet.

In Hungary, there are no official statistics on retrofit rates, but a representative field survey has been carried out within the KEOP-7.9.0/12-2013-0019 project in 2015, selecting 2000 buildings to obtain a picture about the energy performance of the residential building stock. Regarding the building stock built before 1990, it can be stated that for detached houses, 11.5% of the façade walls, 9.2% of the attic slabs and 6.6% of the cellar ceilings have been retrofitted with thermal insulation and 19.6% of the windows have been changed. In multi-flat buildings (including large panel buildings), 10.6% of the façade walls, 3.6% of the attic slabs and 5.4% of the cellar ceilings have been retrofitted with added thermal insulation and 26.9% of the windows have been changed. In large panel buildings, 14.9% of the façade walls, 14.1% of the flat roofs and 10.1% of the cellar ceilings have been retrofitted with added thermal insulation and 33.5% of the windows have been changed [40].

In the Czech Republic and Hungary, the most commonly applied energy saving measures are additional exterior wall insulation (polystyrene foam or, occasionally, mineral wool), the replacement of windows and entrance doors, additional roof insulation and insulation of ceiling above basement, hydraulic balancing of the heating system and controllable heating with heat cost allocation. In housing blocks, switching from exterior heat transfer stations to DH substations inside the buildings is quite common. Building-level heat metering is common. The replacement of heating and DHW sources with more efficient technologies can be observed especially in family houses [24,40,75].

Recent renovations have been focused mainly on large panel buildings partly due to available subsidies and also for practical reasons because these standardized buildings offer good opportunities for optimized solutions that can be used repeatedly. In the Czech Republic, the refurbishment of apartment blocks and multifamily buildings have been analyzed in the PanelScan study [84] in 2009 and in two more recent, but less comprehensive studies [25,26]. The studies showed that many buildings were only partially renovated (e.g. window replacement) and that the quality of the work is rather varied – the same is true for Hungary as well [40].

No official data is available on refurbishment actions and their results in Serbia. Large discrepancies exist between the refurbishment rates of multifamily and single family housing. Although there have been renovation activities in both types of buildings, these were not in any way organized or subsidized by the state, remaining sporadic in nature. A survey [85] provided data about the status of retrofit levels: 16.3% of the buildings have exterior insulation with a typical thickness of 5 cm. Roof insulation exists in 11% of the buildings with an average thickness of 10 cm.

The 2011 census in Bulgaria also included questions related to energy efficiency, the results show that 16% of occupied dwellings have thermal insulation and 30% are fitted with energy efficient windows [21]. Owners usually commit only to step-by-step partial renovation, starting from windows and then applying insulation.

Table 3
Building classes for the cross country comparison.

Building classes for the cross-country comparison		Construction period	Abbreviation
Single family houses	Single family houses, built before World War II	–1944	SFH.1944
	Single family houses, built after World War II and before the end of the communist period	1945–1989	SFH.1945-89
	Single family houses, built after the end of the communist period	1990–	SFH.1990
Multi-flat buildings	Multi-flat buildings, built before World War II	–1944	MFH.1944
	Multi-flat buildings, built after World War II and before the end of the communist period (except buildings built with industrialized technology)	1945–1989	MFH.1945-89
	Multi-flat buildings, built with industrialized technology (e.g. large panel block buildings)	1945–1989	IND.1945-89
	Multi-flat buildings, built after the end of the communist period	1990–	MFH.1990

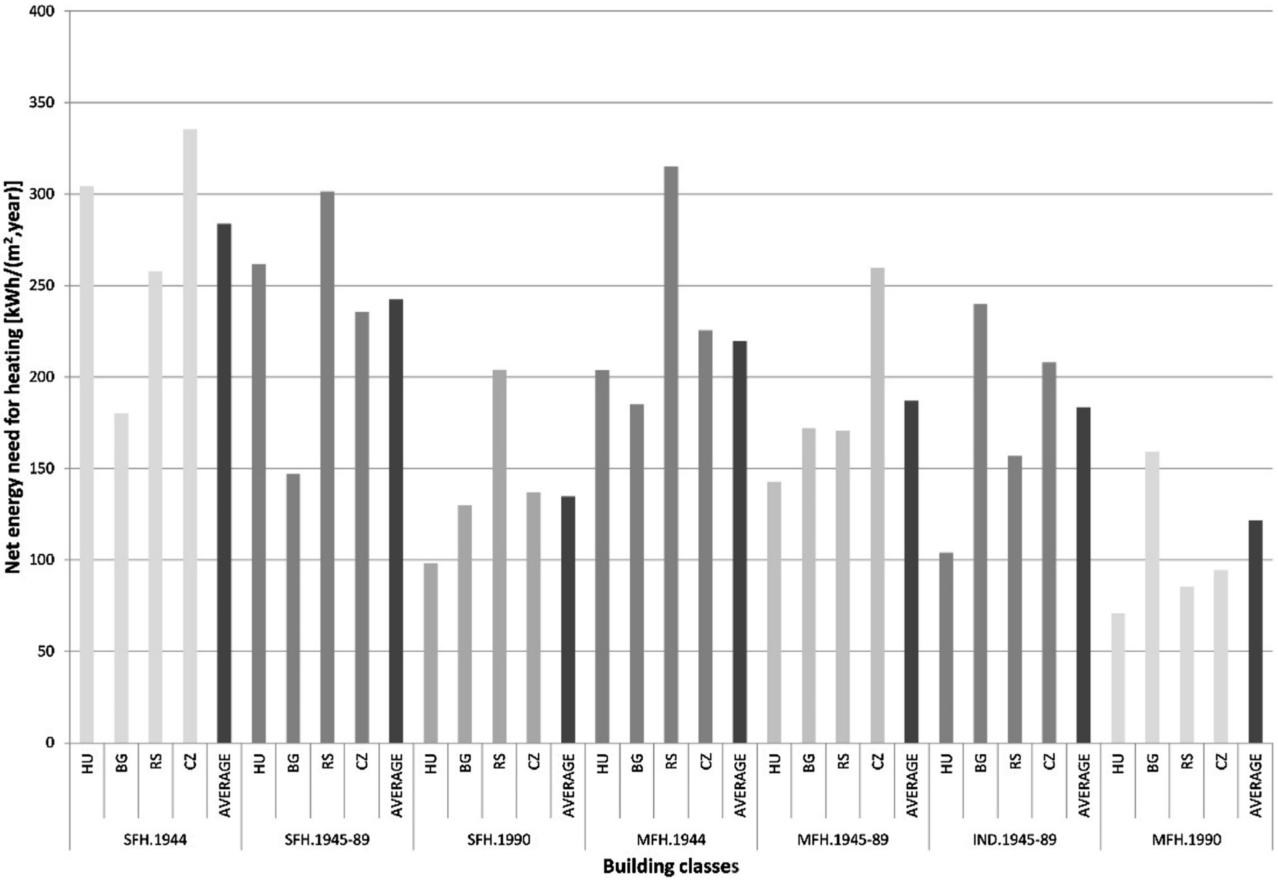


Fig. 2. The energy need for heating of the building classes – existing state.

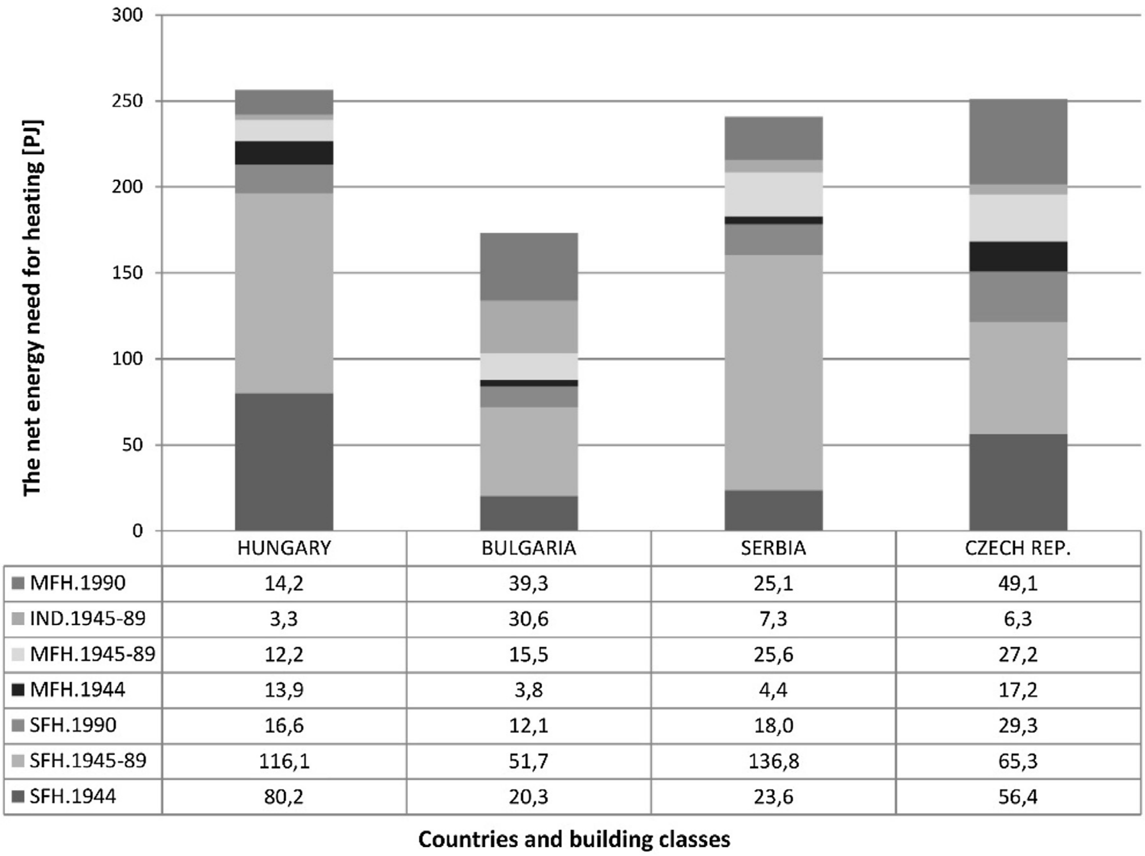
Complex renovations have only been carried out for a small number of detached (investments by the owners) and multi-flat houses (50–60 buildings annually in the past years with EU or national grants). Apartment buildings made with industrialized technology and multi-family buildings constructed before 1999 are prioritized for renovation. The housing fund in Bulgaria is relatively new, but due to ownership problems (almost 100% of the stock is privately owned) the Bulgarian government decided to provide 100% funding rate with limited resources for some industrialized technology and multi-family residential buildings, therefore, a notable increase is foreseen for the near future [42].

4. Results

As explained in the methodology section the TABULA/EPISCOPE building types were grouped into 7 larger building classes (Table 3). The results for the 7 building classes are the weighted average of the TABULA/EPISCOPE building type indicators using the national total floor area as the weight. The classes are defined according to the building size (single family house or multi flat building) and construction period (before World War II; after World War II and before the end of the communist period; and after the end of the communist period). The communist period ended in 1989 or 1990 in the analyzed countries. During the communist era, the industrialized building technology was heavily used in the Eastern countries in order to decrease the general housing shortage, meriting a different building type: large panel buildings (mostly using prefabricated reinforced concrete sandwich panels).

4.1. Energy need for heating

Fig. 2 shows the calculated energy need for heating of the building classes for the current state. The average values of the building types are the weighted average of the countries using the total floor



	HUNGARY	BULGARIA	SERBIA	CZECH REP.
■ MFH.1990	14,2	39,3	25,1	49,1
■ IND.1945-89	3,3	30,6	7,3	6,3
■ MFH.1945-89	12,2	15,5	25,6	27,2
■ MFH.1944	13,9	3,8	4,4	17,2
■ SFH.1990	16,6	12,1	18,0	29,3
■ SFH.1945-89	116,1	51,7	136,8	65,3
■ SFH.1944	80,2	20,3	23,6	56,4

Fig. 3. The energy need for heating of the residential building stock – existing state.

area as the weight. The energy need for heating of single family houses built before World War II is between 180.0–335.1 kWh/m^2 per year, their weighted average is 283.73 kWh/m^2 per year. Multi family buildings of the same period have lower energy need because of their lower surface to volume ratio (between 142.7–315.1 kWh/m^2, year) and thicker walls, yielding a weighted average of 219.63 kWh/m^2 per year. The average single family house built between 1945 and 1989 needs 242.36 kWh/m^2 per year, while the ‘traditional’ multi flat buildings require 187.0 kWh/m^2 per year and the large panel blocks 183.4 kWh/m^2 per year. The buildings built in the last two decades have significantly lower energy need (134.6–121.36 kWh/m^2, year).

The sizes of the residential building stocks in Bulgaria, Serbia, Hungary and the Czech Republic are similar, the total floor areas of the residential buildings are 284.9 – 289.6 – 317.7 – 336.8 million m^2 in order (see Section 3).

SFH 1945-89 building types have the highest total floor area in all countries (between 24.2% and 43.5% of the total floor area), therefore, the energy need of these types is the most significant, see Fig. 3.

4.2. Total primary energy demand for heating and domestic hot water

Primary energy demand for heating and domestic hot water has been calculated for each TABLE building type, taking into account the distribution of energy carriers and technical building systems. These values were then used to calculate the primary energy demand for building classes using weighted averages. As explained in Section 3.2.2, natural gas is dominant in Hungary and in the Czech Republic as opposed to Serbia and Bulgaria, where wood and electricity are the prevailing energy sources for heating. Domestic hot water for multi flat buildings is mainly produced by electric water heaters in most of the countries, but in some cases district heating or natural gas was considered.

Total primary energy demand results are shown on Fig. 4. Since natural gas is the dominant heating energy carrier in Hungary and the Czech Republic for SFH.1944 types, these have a higher primary energy demand than in Serbia and Bulgaria where the most common heating source for these types is wood (average: 438.8 kWh/m^2, year). The same characteristics can be observed in case of SFH.1945-89 types (average: 337.35 kWh/m^2, year). The primary energy demand is significantly lower for newly built single family houses (SFH.1990), the average figure is 224.65 kWh/m^2, year.

The main heating system in Serbia for MFH.1944 is individual heating by electricity, therefore the primary energy demand of this type is 65.2% higher than the average (393.2 kWh/m^2, year). Multi flat buildings built after World War II (MFH.1945-1989) are mainly heated by district heating based on coal or natural gas in the Czech Republic and in 12 large cities in Bulgaria, while in Hungary, only the buildings of industrialized technology (IND.1945-1989) are heated by district heating. A significant portion of MFH.1945-1989 buildings are heated by individual electrical heating in Serbia, resulting in high primary energy demand. Other building types (e.g. IND.1945-1989) are heated by district heating. The average primary energy demand of the ‘traditional multi flat buildings’ (MFH.1945-1989) is 335.48 kWh/m^2, year and the “industrialized multifamily houses” (IND.1945-89) is 286.19 kWh/m^2, year. The newly built multi flat buildings (MFH.1990) have a notably lower primary energy demand (with an average of 204.48 kWh/m^2, year).

The total primary energy demand for heating and domestic hot water of the residential building stock is the highest in the Czech Republic (448.3 PJ/year) and the lowest in Bulgaria among the ana-

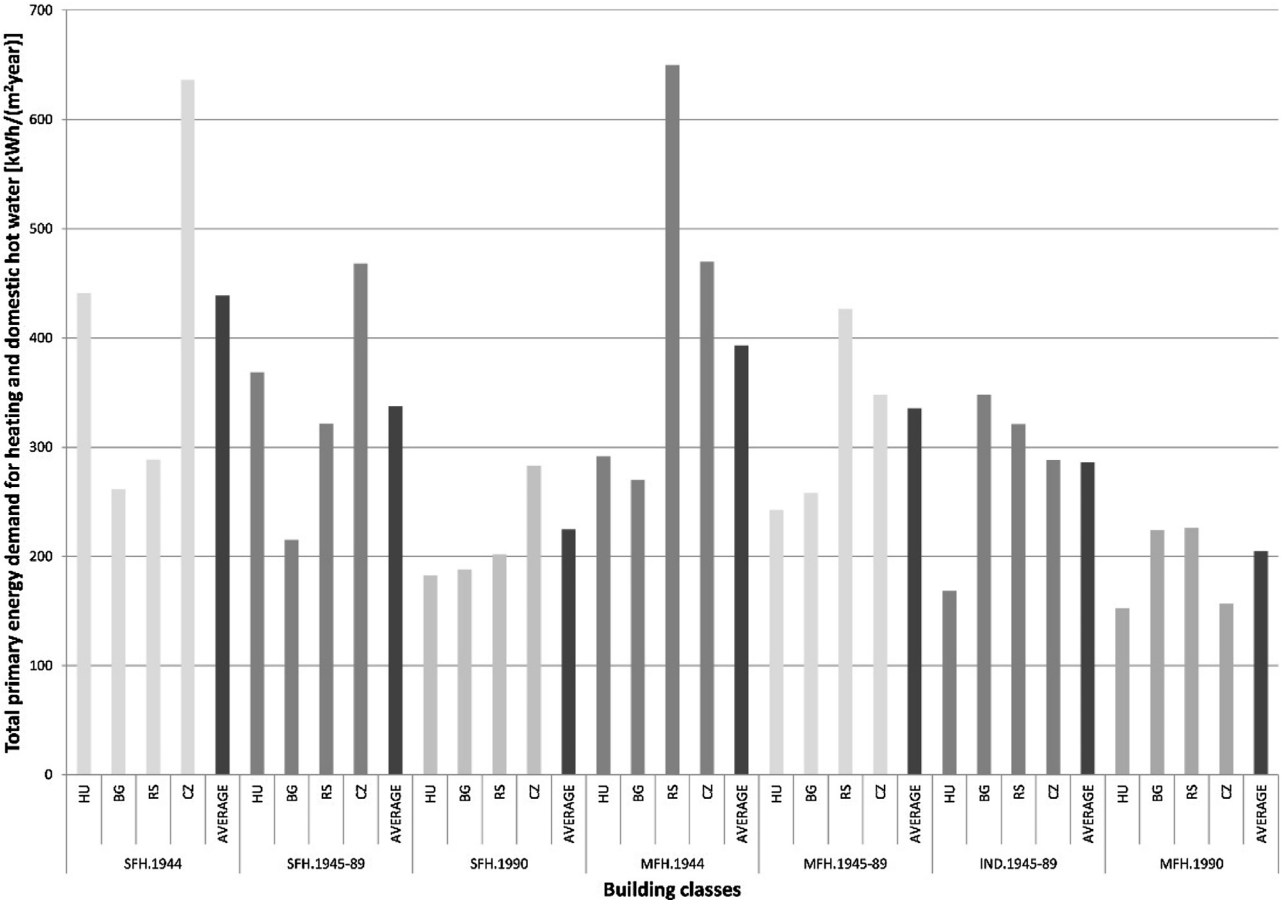
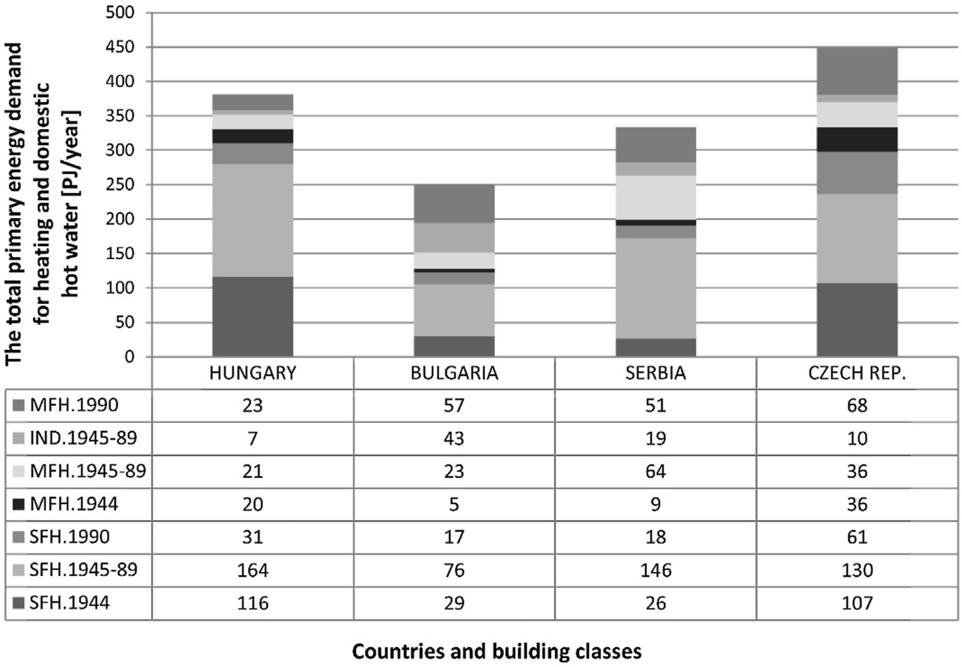


Fig. 4. Total primary energy demand for heating and domestic hot water of the building classes – existing state.



	HUNGARY	BULGARIA	SERBIA	CZECH REP.
■ MFH.1990	23	57	51	68
■ IND.1945-89	7	43	19	10
■ MFH.1945-89	21	23	64	36
■ MFH.1944	20	5	9	36
■ SFH.1990	31	17	18	61
■ SFH.1945-89	164	76	146	130
■ SFH.1944	116	29	26	107

Fig. 5. The total primary energy demand for heating and domestic hot water of the residential building stock – existing state.

lyzed countries (see Fig. 5). The reasons for the differences are rather complex (climatic factors, energy sources, different distribution of building types), but it can be easily seen that the heating energy need figures reflect climatic differences and the fact that the considered HDDs relate to an average indoor temperature of 20 °C except for Bulgaria, where the design value is 19 °C [46,55,57–59].

Table 4
The total primary energy demand for heating and domestic hot water of the residential building stock – existing state.

Total primary energy demand [PJ/year]				
Groups of building types	Hungary	Bulgaria	Serbia	Czech Rep.
Single family house	310.6	122.5	190.2	297.5
Multi flat buildings	63.6	85.7	124.3	140.4
Large panel buildings	7.1	43.1	19.4	10.4
Total	381.3	251.3	333.8	448.3

Table 5
Country-specific U-values of the deep renovation scenario.

	U-values [W/m^{2}K]			
Building constructions	Hungary	Bulgaria	Serbia	Czech Republic
Old buildings before 1990 (buildings built with traditional technology)				
Façade walls	0.17–0.21	0.27–0.35	0.14–0.18	0.12–0.25
Attic slab/roof	0.12–0.15	0.26–0.38	0.10–0.18	0.10–0.21
Windows	1.00	0.80	1.00	0.60–1.10
Buildings built with industrialized technology				
Period	1967–1991 [36]	1962–1996 [46]	1960–1990 [53]	1957–1991 [28]
Façade walls	0.18–0.19	0.27	0.12–0.15	0.24–0.25
Attic slab/roof	0.12–0.15	0.27	0.12–0.15	0.14–0.15
Windows	1.00	0.80	1.00	0.80
New buildings (after 1990)				
Façade walls	0.12–0.17	0.26	0.12–0.14	0.12–0.24
Attic slab/roof	0.10–0.14	0.15	0.11–0.14	0.10–0.16
Windows	1.00	0.80	1.00	0.60–0.80

Table 6
The U-values of the building envelope of the mid-rise industrialized apartment block built between 1945 and 1979 in Hungary (IND.1945-89 building class).

Elements of the building envelope	Existing state		Deep renovation (NZEB)	
	Structure	U-value [W/m^{2}K]	Structure	U-value [W/m^{2}K]
Wall	sandwich panel: reinforced concrete (15 cm); polystyrene insulation (8 cm); reinforced concrete (7 cm)	0.80	additional 16 cm external insulation on existing structure	0.19
Flat roof	waterproofing; lightweight concrete (10 cm); reinforced concrete (15 cm)	0.91	additional 24 cm insulation on top of existing structure	0.14
Cellar ceiling	linoleum (0,5 cm); reinforced concrete (15 cm); polystyrene insulation (5 cm)	0.55	additional 20 cm insulation on the underside of existing structure	0.15
Window	double-pane wooden casement windows	3.30	new window with triple-glazing, low-e coating and argon gas filling	1.00

Due to the high proportion of single family houses in the building stock, those types are responsible for 48.7–81.4% of the total primary energy demand of the building stock (see Table 4).

4.3. Energy saving potential

The objective was to determine the energy saving potential achievable with deep renovation targeting nearly zero building energy (NZEB) requirements. The selection of the refurbishment measures was based on the characteristics of the analyzed countries (Table 5).

The deep renovation concept is based on the extensive thermal insulation of the building envelope, the replacement of old windows and doors together with the modernization of the heating and DHW systems and installing renewable energy systems (e.g. solar collectors, heat pumps).

For example, the mid-rise industrialized apartment block built between 1945 and 1979 in Hungary (Table 6). Mostly built with basement and ground floor and 10 stories, with a flat roof and heated by district heating. The external structure is reinforced concrete sandwich panel. The refurbishment aiming for nearly zero energy use will include extensive insulation for the building envelope, doors and windows will be changed (Table 6). In addition to the circulation pump and thermostatic valves, solar collectors will be installed.

Table 7
The primary energy saving potential of the residential building stock in the analyzed countries.

Building classes	Hungary	Bulgaria	Serbia	Czech Rep.
SFH.1944	71.2%	69.3%	69.3%	79.8%
SFH.1945-89	71.6%	66.5%	81.9%	74.6%
SFH.1990	59.3%	66.0%	64.4%	54.1%
MFH.1944	60.4%	73.3%	81.7%	75.0%
MFH.1945-89	66.8%	73.3%	78.3%	68.7%
IND.1945-89	49.1%	73.7%	59.8%	47.3%
MFH.1990	47.3%	69.0%	76.8%	64.4%
Residential building stock	67.8%	69.4%	77.2%	70.4%

The possible primary energy saving potential (Table 7) depends on the proposed change of energy carriers: savings are lower for a shift from prevailing wood logs to biomass, and higher for a shift from electricity to natural gas (or coal to natural gas). The change from electricity results in extremely high savings (e.g. in case of MFH.1944 and SFH.1945-89 building classes in Serbia).

The primary energy saving potential in the analyzed countries is between 67.8% and 77.2% in the case of deep renovation to NZEB requirements.

5. Discussion and conclusions

In this paper, the housing stocks of four countries in Eastern Europe have been analyzed, highlighting the similarities and differences in climate, housing stock, building shell, utilized energy sources, applied technical building systems and building usage. Energy performance calculations have been carried out for heating and domestic hot water according to EN ISO 13790 and the EPBD rules using the TABLE calculation tool.

Slight climatic differences have been identified with an increasing number of heating degree days and decreasing cooling degree days from Southeast (Bulgaria) to Northwest (Czech Republic). The major share in the energy balance belongs to heating as mechanical cooling systems still have a low, but increasing importance due to fuel poverty, particularly in Bulgaria.

Single family houses have the greatest significance, both in their ubiquity and energy consumption. According to our calculations, these building types are responsible for 48.7–81.4% of the total primary energy demand of the housing stock, depending on the country.

Large panel buildings constitute a special building class in the region. The district heating networks supplying these buildings are partly obsolete, partly modernized. They are generally prioritized in energy efficiency interventions due to the suitability of uniform solutions and the resulting cost efficiency.

Applying thermal insulation to the building envelope has become typical in new buildings only in the last 5–15 years (a small majority of the housing stock). The energy performance of the housing stock is therefore determined by the old stock and the renovations already carried out. The share of already retrofitted buildings is moderate in Hungary, Serbia and Bulgaria: mainly partial renovation actions have been carried out so far in a minority of the dwellings. The situation is slightly better in the Czech Republic due to the systematic subsidy actions in the last two decades. Complex renovations are still not the norm, although it is a priority in recent subsidy programs. The large share of private ownership in the housing stock is a common problem in the region that makes the retrofit actions difficult in multi-family buildings.

The role of natural gas is significant in Hungary and in the Czech Republic, whilst electricity plays an important role in Bulgaria and in Serbia. Wood and district heating are used in all of the countries. The centralization level of heat supply systems increases from Southeast (Bulgaria) to Northwest (Czech Republic). The only significant renewable energy source is wood, but it is mostly used in low-efficiency stoves.

The current total primary energy demand for heating and domestic hot water of the residential building stock is 1415 PJ/year in the four countries combined. The energy saving potential is between 67.8% and 77.2%, considering deep renovation.

It is necessary to highlight the limitations of the research. The calculations have been carried out assuming continuous heating, which means that the impact of user habits is not taken into account. In reality, partial heating plays a significant role in the region, particularly in single family houses. This means that the real energy consumption of the housing stock is significantly lower than the calculated figures. Renovations carried out so far constitute another neglected aspect. As explained in Section 3.4, there are statistical data about refurbishment actions, but without sufficient technical details for a quantitative analysis. However, the impact of the actions carried out in the past is rather low, particularly in Bulgaria, Serbia and Hungary. In order to determine the impact of partial heating, underheating and past renovation actions further research must be carried out to investigate heating and cooling habits and hot water consumption. Also, more appropriate statistics are required concerning retrofit measures in the past, especially regarding technical details. And finally, although we tried to use the most up-to-date data, some of the data sources used in the calculations are several years old, such as [22,84,61,29,86]. In some cases, there are more recent relevant data available, but at a lower level of detail.

The study described in the paper could be a starting point to develop policy actions. However, further analysis is needed in the fields of investment and operation costs, state policy, funding system structures, stakeholders, macro-economic aspects, labor impact and social acceptance. Further analysis of policy implications, while important, are beyond the purposes and scope of the article.

A possible future research could include cooling that is particularly important in Serbia and Bulgaria. It would also be interesting to extend the scope to other countries in the region with similar building stocks like Poland, Slovakia, Romania, Baltic countries and additional countries of the former Yugoslavia.

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