ASSESSMENT OF DECARBONIZATION SCENARIOS FOR THE RESIDENTIAL BUILDINGS OF SERBIA

by

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Thermal energy demand in the residential building sector represents a big challenge for Serbia. In order to understand how to reduce this demand, and thereby avoiding GHG gas emissions, a bottom-up simulation model was developed. The model built the business-as-usual and two decarbonization scenarios up to 2030. For each scenario, such results as useful and final energy consumption, associated CO_2 emissions, energy costs, investment costs and others were prepared at each level of the building stock segmentation. To develop such a detailed model, the topology of the residential building stock was developed and used as an input. For each individual building type, three retrofit packages of different stringency were analyzed. The paper delivers several important messages for the decarbonization of Serbia. First, it argues that the level of thermal energy services consumed by Serbian households is inadequate to address their needs. Second, the households of Serbia are likely to consume more wood than it was reported by national energy balances. Third, thermal energy efficiency retrofits can significantly reduce household energy demand at the same time as offering higher thermal comfort. However, the required investments are high and therefore benefits beyond energy cost savings should also be considered in order to make the transition to the low energy building stock economically feasible.

Key words: *residential buildings, climate change, energy efficiency, Serbia, CO_2 mitigation, building typology, decarbonization scenarios, bottom-up modeling*

Introduction

Energy demand in the building sector represents a big challenge for Serbia. In 2013, the sector was responsible for 35% of national final energy consumption and 53% of national electricity consumption [1]. The quality of energy services delivered in the residential buildings is, however, low [2]. The continued use of outdated wood stoves results in numerous environmental and health problems [2]. Cutting down Serbian forests for energy services in households brings environmental problems such as deforestation, biodiversity loss, air pollution and soil degradation [2].

Serbia is a Contracting Member of the Energy Community Treaty and thus it is obliged to introduce EU energy efficiency legislation. Achieving the requirements of this leg-

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islation requires ambitious policy efforts and large investments into demand-side energy efficiency.

Modelling and analyzing of energy efficiency and low carbon scenarios on a national level is a useful tool to assist such policy, and decision-making. There are two main ways to model building stock energy: top-down and bottom-up approaches [3]. Top-down approaches consider the residential sector as an energy sink, and use historic aggregate energy values to regress the energy consumption of the stock as a function of top-down variables (*e. g.* gross domestic product, unemployment rate, inflation, energy price *etc.*). Bottom-up models, on the other hand, calculate the energy consumption of representative individual buildings and extrapolate the results for a region or nation [4-7]. The main advantage of bottom-up modelling is the high level of detail and the possibility to model technological improvement options, but the input data requirement is much greater than for top-down models. In Europe, one of the most significant achievements in this field was the TABULA project, which created a harmonized structure for building typologies [8].

The authors were contracted to design and implement a piece of research for the project entitled the support for low-emission development in South Eastern Europe (SLED project). As a part of the research, a typology of representative building types was adopted and, using it as an input, a bottom-up model was designed to simulate scenarios for the sector's low energy and carbon transformation. The model was designed in such a way that it could be further used by national policy-makers and experts according to their needs. The paper describes the methodology and selected results.

Research approach

Research approach and boundaries

The present research relied on the bottom-up approach simulating energy consumption of representative building types based on thermodynamic equations and aggregating these figures on the country level. First, representative building types were identified, country building typology was described, and the number of buildings and their structure according to the typology were estimated at present as well as in the future. The unregistered building stock was included, whereas the non-inhabited stock was deducted. The same topology was used to model space cooling and heating. Whereas the topology fits perfectly to assess space heating (SH), it could be improved for the modelling of space cooling. This is because the most important factors that determine cooling demand – the ratio of glazed surfaces, orientation, shading devices and the neighboring environment – could not be comprehensively considered due to a lack of statistics.

Second, energy performance by end-use, possible building retrofit packages and the associated costs were assessed on the level of individual representative buildings. Only thermal energy services, *e. g.* SH, space cooling, and water heating, were assessed. The impact of climate change on SH and cooling patterns was not considered. Energy use for electrical appliances, lighting and cooking were not covered, however, they also consume a large share of the residential sector energy balance. The retrofit options included both the improvement of thermal envelope and the exchange of technical systems, which often imply a fuel switch. The improvement of thermal envelope implied the retrofit of walls, roofs, floors, and windows. Better technical systems were better mechanisms for water heating, SH, and space cooling. Depending on technical and economic feasibility, households might switch to solar, biomass, electricity, or natural gas.

Third, for the analysis on the sector level, a bottom-up simulation model was designed and applied. With the help of the model, energy balances and CO_2 emissions on the sector level in the base year were calculated. For environmental impacts, only CO_2 emissions, both direct and indirect, were considered. Indirect emissions were defined as those which include emissions from electricity and district heat (DH). These figures were compared and calibrated to official energy balances.

Fourth, country level energy consumption and CO_2 emissions were calculated for the future, applying business-as-usual (BAU) assumptions. The calculations were made until 2030 because the bottom-up detail-rich analysis does not make sense for the long-term due to uncertainties associated with the future. Decarbonization policy packages were formulated, assessing energy savings, foregone CO_2 emissions, and their cost-effectiveness. In order to make sure the research results are used, the work on the design and assumptions of the models was conducted in co-operation with national policy-makers. To receive additional data and comments, they were interviewed during the research.

Building stock typology, its estimate and forecast

The typology matrix was prepared based on the previous typology [9]. The original building type matrix consisted of thirty nine building types and it was later decreased to thirty two. Since the official statistics, as a part of the regular census procedure, do not involve such features of buildings which can help evaluate their energy performance, field research had to be conducted. In 2011, around six thousand family houses were surveyed, followed by a census of about 13 thousand multi-family (MF) buildings in 2012. So far, this has been the largest study of energy performance of buildings ever conducted in Serbia. The procedure of defining the methodology and carrying out the field research in both censuses was described in two monographs [10, 11]. Based on it, a comparative building stock analysis was implemented for Serbia, Hungary, the Czech Republic, and Bulgaria [12].

Building types which had a small sample of family houses and accounted for a small share of the total floor area in multifamily housing were merged with other similar types. As a result, our matrix consists of eighteen building types. The main considerations behind the typology were:

- Size of building. Statistical data based on census were available for the number of dwellings in the building: buildings with one dwelling or two dwellings. Row or terraced dwellings with a minimum of three dwellings (three to nine dwellings and ten or more dwellings).
- Building type. Based on the census data the following categories were defined: single-family houses (SFH) containing one dwelling, terraced houses (TH) containing one dwelling, MF houses containing six to twenty five dwellings depending on construction period, and apartment blocks (AB) containing sixteen to twenty two dwellings depending on construction period.
- Construction period. Buildings are classified into five construction periods: buildings built before 1945, between 1946 and 1960, 1961-1970, 1971-1990, 1991-2000, and 2001-2011.

The building stock numbers and their structures according to their typologies were calculated based on statistical data, literature and the already mentioned on-site experience survey in 2011 [10, 11]. The main source of statistical data was the openly available censuses conducted during the last fifteen years and provided by the Serbian Statistical Office [13].

In order to project the building stock and its structure by building type to the future, the building stock turnover model was prepared in MS Excel. The construction of new dwellings was estimated as a gap between the demand for dwellings represented by the number of households in the future and the remaining stock of existing dwellings. The dwelling demolition rate was calculated using a Weibull curve describing a fraction of remaining units over time [14]. The total number of households was estimated based on the expected trends of population growth and persons per household.

Definition of retrofit packages and their costs

Three building retrofit packages for each individual building type were designed. The BAU improvement included the currently most frequently applied retrofit measures. The *standard* option included upgrading the building envelope in order to comply with the minimum requirements of the national building codes for major renovation. Efficient technical systems were introduced, involving fuel switch in some cases. The *ambitious* option went beyond building regulations regarding the building envelope, to a level that was foreseen in the future building codes. For the technical systems, better heating system efficiencies were considered, and solar hot water heating was assumed.

In line with local expert observations, it was assumed that the comfort expectations of the occupants would increase after the installation of the retrofit packages. As the households would need a lower amount of fuel to heat dwellings and they would obtain SH systems allowing heating larger dwelling areas, they will heat more hours per day and more rooms. The assumptions on the share of heated floor area and duration of heating in case of BAU, standard and ambitious improvements were developed in consultation with local experts.

Within the project also the investment costs of retrofit packages per building type and measure were also calculated [9]. While prices included all system elements, there could be some additional work to remove the old installations depending on the initial state of the building. The investment costs also included labor and value added tax (VAT).

Calculation methods of building and system energy and carbon performance

For each thermal energy end-use in each representative building, net (useful) and delivered (final) energy demand was calculated. The net energy demand calculation for SH and cooling was carried out according to the seasonal method of EN ISO 13790. Its assumptions are in line with the new building codes required by the Energy Performance of Buildings Directive [15].

The net energy demand for domestic hot water (DHW) was calculated based on the national rules and practices. Namely, hot water demand per net floor area was assumed as 10 kWh/m^2 per year for SFH and 20 kWh/m^2 per year for MF houses [16].

Delivered energy demand was calculated using the net heating energy demand, Q_{ND}, per source:

$$Q_{\mathrm{delivered}} = \frac{Q_{\mathrm{ND}}}{\eta_t}$$

The system efficiency, η_t, of the energy supply systems was calculated:

$$\eta_t = \eta_{\mathrm{b}}\, \eta_{\mathrm{p}}\, \eta_{\mathrm{c}}$$

where η_{b} is the boiler efficiency, η_{p} – the piping (distribution) efficiency, and η_{c} – the control efficiency.

For technical building service systems providing SH, six subtypes were modelled, pertaining to the typical energy sources for the current situation. These were electricity (air-to-air heat pumps and direct electric heating), wood (mostly wood stoves), LPG (LPG stoves) or natural gas (mostly individual boilers), oil (boilers), coal (coal stoves), and district heating [1]. The most frequently applied efficiencies for SH are summarized in tab. 1. The DHW system efficiencies were defined in a similar way. Cooling system efficiencies were assumed as 2.0 for the present state and the BAU retrofit and 3.0 for standard and ambitious retrofits.

Table 1. The SH system efficiencies

Efficiency	State	Electricity	Wood	Coal	Gas	Oil	District heat
Efficiency of generation	Present and BAU	2.2	0.6	0.6	0.8	0.8	0.9
	Standard	3.0	0.85	–	0.9	0.9	0.95
	Ambitious	4.0	0.85	–	0.98	0.98	0.98
Efficiency of distribution	Present and BAU	1.0	1.0	1.0	0.95	0.95	0.95
	Standard	1.0	1.0	–	0.95	0.95	0.95
	Ambitious	1.0	0.95	–	0.98	0.98	0.98
Efficiency of control	Present and BAU	0.95	0.90	0.90	0.90	0.90	0.90
	Standard and ambitious	0.95	0.95	–	0.95	0.95	0.95

Annual CO_2 emissions for each energy end-use were calculated as the sum of the delivered energy, $Q_{\text{delivered}}$, multiplied by CO_2 emission factors, $f_{CO_2,\text{source}}$, of the energy commodities, respectively. The primary source for CO_2 emission factors was the Law on Efficient Use of Energy [16] except for electricity for which the factors were determined by the SLED project [17].

Methodology for scenario modelling

Due to the existing capacity in Serbia to operate Long range Energy Alternatives Planning (LEAP) system software, it was decided to prepare the model in that way. After the research was completed, the model was provided to national policy-makers and experts, including the input data.

The LEAP system is a widely-used software tool for energy and climate policy analysis. It has often been employed for modelling policies in the transportation sector [18-20], different industry sectors [21] or national emissions [22]. However, detailed modelling of the building stock is rare. An example is a case study for Tehran where LEAP system software was used to model long-term development policies for the household sector [23], but their model was not disaggregated on the level of building types. The present piece of research therefore represents the first attempt to apply LEAP system to modelling the building sector decarbonization on a highly disaggregated level.

Using LEAP system, the energy demand per square meter floor area of each representative building was estimated as a sum of its energy demand per end-use. Then, the floor area of representative buildings was multiplied with their energy demand per square meter and the results were summed up across all building types, and building age categories.

To address the barriers to decarbonization in the building sector as assessed in [24], three policy scenarios were developed and validated with national policy-makers. In the reference scenario, BAU technological, policy, and market changes were assumed. In the moderate scenario, it was assumed that the energy performance of all new and existing buildings would correspond to that after the standard improvement by 2070. In the ambitious scenario, it was assumed that by 2050 the largest part of the new and existing buildings will achieve the level of ambitious improvement. Due to the number of uncertainties, such as energy prices, market developments, and technological developments for a period longer than 10-15 years, the model runs up to the year 2030.

The scenarios included the introduction of building codes according to the schedule defined in tab. 2 and financial incentives for building retrofit and construction described in tab. 3 The structure of the financial incentives, which included low-interest loans and grants, depended on the building type as well as on the maturity of the market. For small buildings a higher share of low interest loans was applied in the short term whereas for large buildings – a larger share of grants. In the long-term, a higher share of loans was assumed *vs.* a higher share of grants at present. The financial incentives were modelled in a way to cover the share of eligible costs of more energy efficient buildings. These costs approximately equal the share of incremental investment costs of efficiency retrofits, *i. e.* the costs of standard and ambitious improvements with a deduction of the BAU improvement costs.

Table 2. The schedule of introduction and implementation of building codes

Scenario	Time period	Performance level
Moderate	2016…	The building code introduced in 2011 correspond to the characteristics of the measures of *standard* improvement.
Ambitious	2016-2022	
	2023…	The building code introduced in 2023 correspond to the characteristics of the measures of *ambitious* improvement.

Table 3. Shares of households affected by financial incentives in the first and last scenario years

Scenario	Building type	Policy tools for building retrofit	Year		Notes
			First	Last	
Moderate	Scenario years->		2016	2070	Households are eligible for financial support over the modelling period, if they comply with the *standard* improvement.
	Detached or semi-detached	Grants	10%	10%	
		Low-interest loans	90%	90%	
	Row or apartment	Grants	90%	10%	
		Low-interest loans	10%	90%	
Ambitious	Scenario years->		2016	2050	Households are eligible for financial support, if they comply with the *standard* improvement in 2016 – 2022 and the *ambitious* improvement in 2023.
	Detached or semi-detached	Grants	10%	10%	
		Low-interest loans	90%	90%	
	Row or apartment	Grants	90%	10%	
		Low-interest loans	10%	90%	

Results

Building typology: priority building segments for policy-making

It was calculated that in 2011 the number of residential buildings was 2246 thousand and the number of dwellings was 3327 thousand for a population of 7114 thousand [3]. Approximately 25% of the stock is not inhabited [3] because first, it also includes dwellings for secondary purposes or seasonal use and second many dwellings were left empty due to emigration in the 1990s.

Altogether eighteen representative building types were considered in Serbia, not taking into account subtypes for utilized energy sources. Figure 1 shows the building type matrix for Serbia adopted.

	Building period class	Family housing		Multifamily housing	
		SFH	TH	MF	AB
		1	2	3	4
A	< 1945				
B	1946–1960				
C	1961–1970				
D	1971–1980				
E	1981–1990				
F	1991–2011				

Figure 1. The Serbian residential building typology applied in the research

Figure 2 presents the structure of the residential building floor area in Serbia by building type and building age in 2015 and in 2030 prepared with the help of the building stock model. Those representative buildings are named, whose share in the total area will be more than 5% in 2030. Building groups which constituted less than 5% in 2030 are grouped into the *others* category. As the figure shows, the five largest building categories in 2030 are single family houses built after 2016, in 1991-2015, 1981-1990, 1961-1970, and 1971-1980.

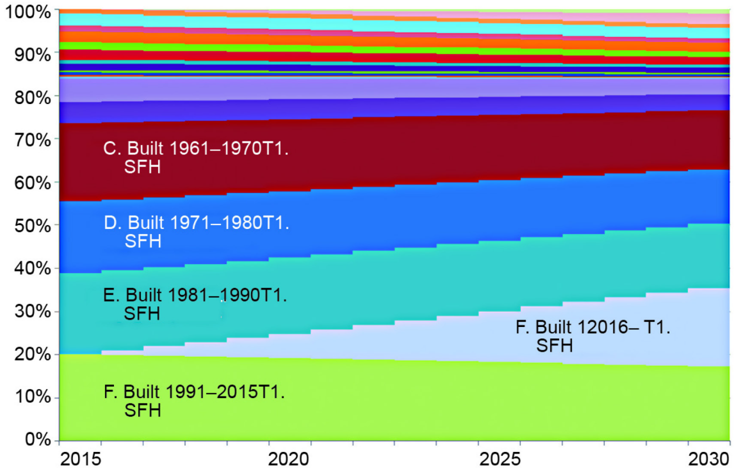


Figure 2. The structure of residential building floor area in 2015-2030
(*for color image see journal web site*)

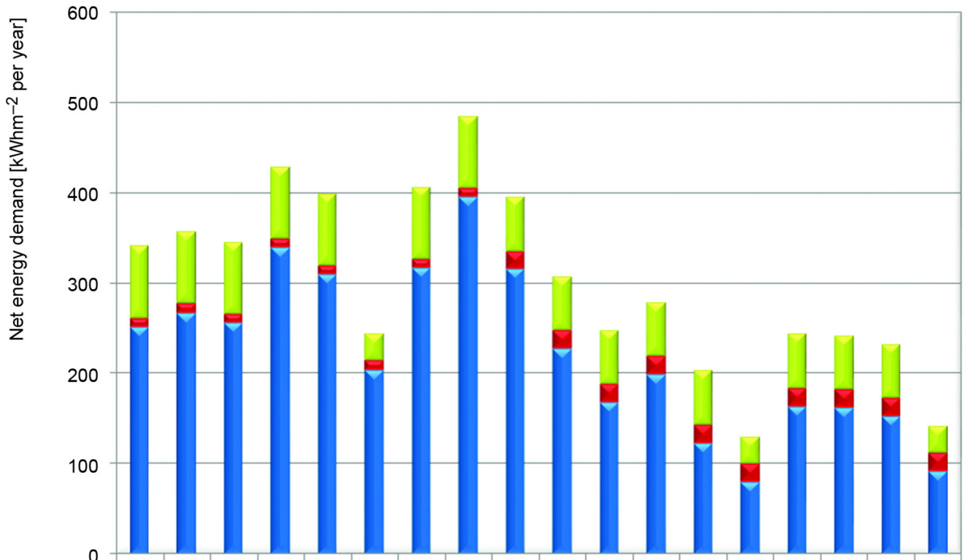
Energy performance of buildings by building type

The energetic quality of the building stock is low as buildings in general are poorly insulated. The majority of the building stock was constructed from brick and stone, but clay and adobe should also be mentioned such as in prefabricated buildings from the communist era. Apartment buildings constructed using prefabrication concrete technology usually have some insulation, as this was part of the sandwich wall construction. Even relatively young buildings are insufficiently insulated as building codes were not strict enough and compliance was not checked. Part of the building stock has already been refurbished using roof insulation and better windows.

Figure 3 presents the calculated net energy demand by building type. It illustrates that the thermal characteristics of the stock have slightly improved over time, although significant improvement can be seen only in the last decade. Detached houses have higher heating demand than large buildings due to their surface to volume ratio. In most building types, heating is dominant in the total energy demand. Cooling energy demand is also depicted, but it applies only to buildings with mechanical cooling.

The calculated energy balance vs the official one: fuel poverty and unaccounted biomass

After the final energy demand of representative building types was calculated based on their net energy demand, the assumptions about the technical building systems and sources which they use, the final energy demand was calculated on the national level and compared to the official statistics, *i. e.* the latest (2013) energy balances of Serbia [1].



	A1	B1	C1	D1	E1	F1	A2	C2	A3	B3	C3	D3	E3	F3	C4	D4	E4	F4
Cooling [kWhm^{-2}a]	80	80	80	80	80	30	80	80	60	60	60	60	60	30	60	60	60	30
DHW [kWhm^{-2}a]	10	10	10	10	10	10	10	10	20	20	20	20	20	20	20	20	20	20
Heating [kWhm^{-2}a]	251	267	255	339	309	204	317	395	315	227	168	199	123	80	163	162	152	92

Note: full heating means the heating of the whole dwelling floor area for the whole day.

Figure 3. Net energy demand of the building types (present state, full heating)

To estimate only the share of thermal energy uses in the energy balance, we deducted from the sector electricity consumption that for cooking, appliances, and lighting. The latter was assumed as 25% of the sector final energy consumption based on other countries of South East Europe: Bulgaria (23%), Greece (25%), Slovenia (20%), Croatia (29%) [25]. Further, we refer to the energy balance, which is associated with thermal energy uses as to an estimated energy balance.

The calculated final energy consumption appeared to be different from the estimated energy balance. Based on the stakeholder consultation, we concluded that first, Serbian households heat and cool their dwellings only partially. Second, they do not heat and cool their dwellings for the whole day. Third, they are likely to use more wood than it is reported in the official balance.

In regard to the first and second factors, there is no official data, which could lead to any assumption. This is why we made our assumptions based on our experience in running similar models in Albania and Montenegro [26, 27] and consulting local experts. To correct the calculated final energy consumption for heating we assumed that 50% of the dwelling area is heated 12 hours a day in all SFH, all TH, and multi-residential buildings built before 1960. In multi-residential buildings built in 1961-1970, we assumed that 80% of the dwelling area is heated for 14 hours. In multi-residential houses built after 1990 and in all AB, we assumed that the whole floor area is heated for 14 hours. The final energy consumption for cooling was corrected assuming that 30% of the dwelling floor area is cooled for 12 hours a day for all buildings.

Initially, we conducted our calculations using the breakdown of households by energy source for space and water heating assumed based on the energy balance of Serbia [1]. After correcting the final energy consumption for thermal comfort, it was clear that the shares of energy sources have to be different. The DH, LPG, natural gas, coal, and electricity are traded and thus well-measured commodities. Since biomass can be easily obtained in other ways than trade, its consumption is less certain. Therefore, when the calculated energy consumption of more certain commodities was higher than that in the balance (*e. g.* natural gas), we reallocated a share of such energy source to wood. Based on these considerations, we arrived at the energy source mix for SH presented in tab. 4.

Table 4. Energy source mix for SH in 2015, % of total

	Natural gas/LPG	Electricity	Coal	Oil	Wood	DH
DH-buildings	0	0	0	0	13	83
All other buildings	9	17	7.5	3	63.5	0

Figure 4 compares the estimated energy balance of Serbia in 2013 and the calculated energy consumption of thermal energy uses with and without the calibration. The non-calibrated calculated energy consumption was five times higher than the estimated energy balance. The calibrated calculated energy consumption was 1.5 higher than the estimated energy balance. The difference comes from wood consumption, which was ca. 2.5 times higher than it is reported in the balance.

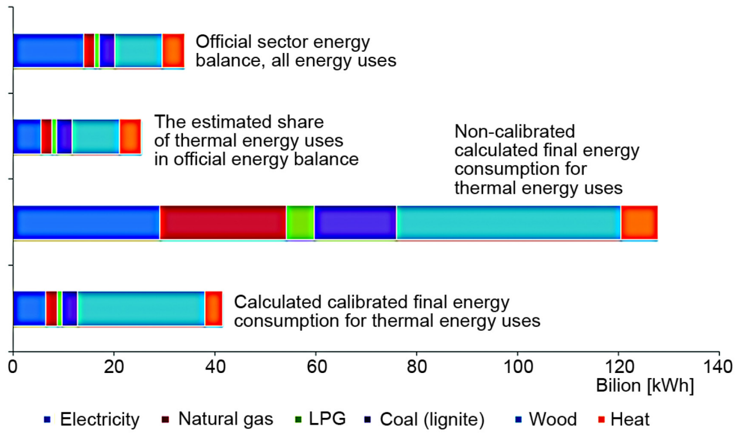


Figure 4. Sector energy balance and calculated final energy consumption, billion kWh
(*for color image see journal web site*)

Sector energy consumption and priority sector segments for policy-making

According to our estimates, in 2015 the final energy consumption for thermal energy services was 42 billion kWh. Out of this, 61% was wood, 16% electricity, 9% DH, 7% coal, 6% natural gas, and 2% LPG. The sector emitted 9.8 million tons of CO_2 emissions. The largest share is associated with electricity consumption followed by coal and DH.

The final energy consumption for thermal services of the residential sector will slightly decline in the BAU reference scenario and reach 40 billion kWh in 2030. The reason for such trend is that a share of existing less efficient buildings will be demolished whereas the share of new more efficiency buildings will increase by 2030. While one may assume that the energy consumption of the remaining existing buildings should decrease due to their BAU improvement, these savings are offset by higher thermal comfort: occupants' comfort expectations are likely to rise in the future and the duration of heating and the heated area will increase. This underlines the need for complex retrofit packages where energy reduction is achievable even at higher comfort levels.

The largest shares of the final energy consumption in 2030 will originate in single family houses built in 1971-1980, 1981-1990, and 1961-1970 (more than 15% each category, calculations by decade). Single family houses built after 2016 will also contribute a big share to final energy consumption (80%). These categories give an understanding on key building categories, to which standardized approaches for efficiency improvement and thus policies could be applied, fig. 5.

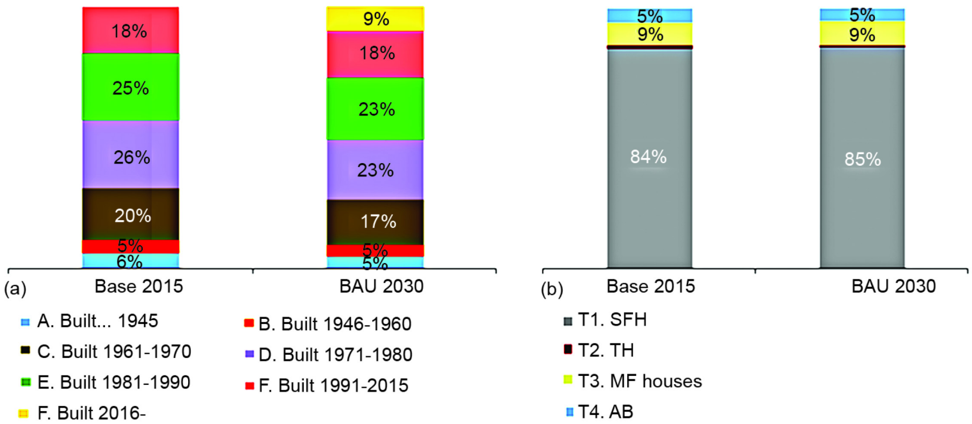
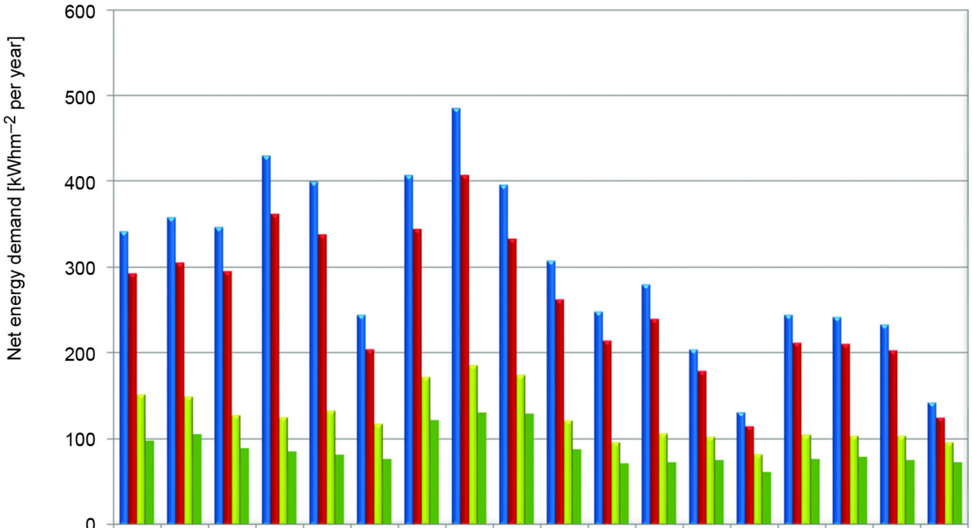


Figure 5. Structure of final energy consumption by building age (a) and type (b)
(*for color image see journal web site*)

Opportunities offered by the decarbonization scenarios

Figure 6 presents the impact of retrofit packages on the net energy demand per m^2 by building type. In the standard improvement, a shift from individual heating systems to central heating with low temperature gas boiler or biomass was assumed. In buildings with DH, standard retrofit involved installing thermostatic valves on radiators and upgrading the substation and heat supply control based on external air temperature. The ambitious retrofit package considered higher heating system efficiencies and the use of solar hot water heating. As a result, SH energy demand could be reduced to a low-energy building standard. Cooling energy demand could also decrease (if shading of windows and efficient night ventilation is assumed). Hot water demand would remain the same.

The results of the assessment of the retrofit packages allowed for the evaluation of the scenarios. Figure 7 presents the impact of the scenarios on final energy consumption, energy commodities and CO_2 emissions associated with the thermal energy consumption of the whole residential building stock. The moderate and ambitious scenarios allow for the



	A1	B1	C1	D1	E1	F1	A2	C2	A3	B3	C3	D3	E3	F3	C4	D4	E4	F4
Present state	341	357	345	429	399	244	407	485	395	307	248	279	203	130	243	242	232	142
Improvement BAU	291	304	294	361	337	203	343	406	332	262	214	239	178	114	211	209	202	124
Improvement 1	151	148	127	125	132	117	171	185	173	121	95	106	101	82	104	103	103	96
Improvement 2	98	106	88	86	81	77	122	130	129	88	71	73	75	61	76	78	75	72

Figure 6. Net energy demand of building types in Serbia (present state and retrofitted states)

reduction of final energy consumption in 2030 *vs.* the reference amount by 17% and 27% respectively. Figure 7 also shows that the scenarios allow for significant electricity, wood, LPG, and lignite savings. Instead, the moderate and ambitious scenarios would instead require an increase of natural gas consumption by 26% and 1%, respectively. A reduction in final energy consumption and fuel switch will result in a reduction of associated CO_2 emissions. In the moderate scenario, their level would be 27% lower than their reference level in 2030. In the ambitious scenario, CO_2 emission reductions are 9% lower.

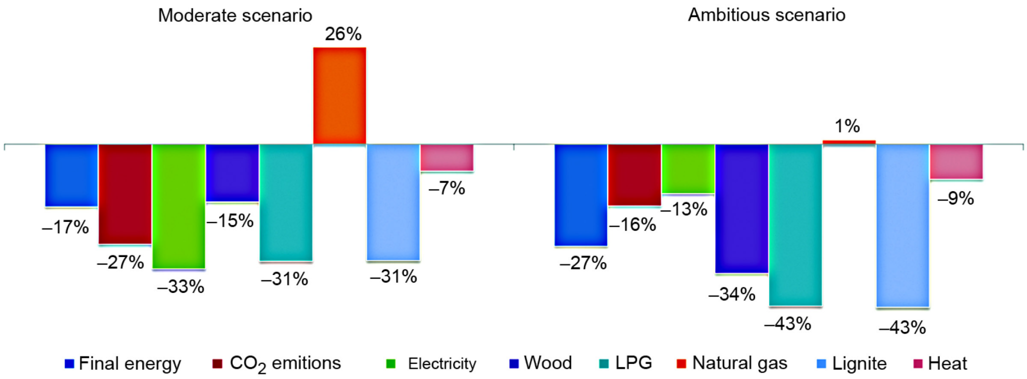


Figure 7. The difference in final energy consumption, energy commodities consumed, and CO_2 emissions in 2030 in the moderate and ambitious scenarios *vs.* the reference case
(*for color image see journal web site*)

Costs associated with the implementation of the decarbonization scenarios

Table 5 present the results of estimating the costs of retrofit packages for representative buildings. These estimates allowed conducting an economic evaluation of decarbonization scenarios.

Table 5. The costs of standard retrofit for each building type: Serbia, €/m^2 floor area, incl. VAT

Measures	A1[1]	B1	C1	D1	E1	F1	A2	C2	A3	B3	C3	D3	E3	F3	C4	D4	E4	F4
Walls	57.8	34.5	35.2	39.5	29.8	5.4	44.0	30.9	70.7	43.7	24.7	27.1	19.7	24.1	23.3	27.2	24.6	24.5
Windows	40.6	41.7	38.3	44.1	39.0	28.1	45.2	43.8	58.9	55.4	36.7	38.2	46.5	29.4	36.9	44.5	41.1	32.0
Attic	30.0	37.1	13.8	10.8	9.7	10.7	28.4	19.3	8.0	4.1	2.7	4.0	3.2	3.3	0.0	1.7	2.2	2.7
Cellar	0.0	0.0	0.0	13.9	2.0	3.2	41.8	6.3	25.7	5.3	3.5	5.1	3.5	4.3	3.1	3.2	2.7	4.8
Flat roof	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	11.1	4.0	0.0	0.3
Pitched roof	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	1.9	2.7
Ground floor	0.0	0.0	0.0	0.0	0.0	26.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
SH system	58.8	39.2	33.2	34.7	33.7	9.8	37.3	53.8	33.3	31.9	31.2	4.8	4.8	4.8	4.8	4.8	4.8	4.8
DHW system	28.8	9.2	3.2	4.7	3.7	9.8	7.3	23.8	3.3	1.9	1.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Total	216	162	124	148	118	91	204	178	208	148	108	83	82	69	79	90	83	76
Cooling[2]	7.7	8.1	8.4	8.3	6.6	7.9	6.5	6.3	17.4	10.3	7.9	7.7	6.7	7.1	7.2	10.0	9.1	6.7

Notes: [1]For building type names, see fig. 1; [2]Cooling was optional.

Table 6 presents the summary of results of the economic evaluation. The incremental investments of the moderate and ambitious scenario over 2016-2030 are €12.3 and 16.1 billion, respectively. These costs represent a very high burden for the country, however, when the costs of the reference scenario are deducted from the costs of the decarbonization scenarios, the incremental costs would be significantly lower. The largest investments required, ranked according to building categories are 1961-1970, 1971-1980, and 1981-1990.

Assuming a discount rate of 4%, the annualized incremental costs are €2.9/m^2 and €4.2/m^2 in average. Since saved energy costs are higher than the annualized investments in the moderate scenario, tab. 6, it represents a cost-effective opportunity. This is not the case for the ambitious scenario. There are, however, numerous other benefits of these scenarios such as positive impacts on human health, environment, higher productivity, higher comfort and many others. If these benefits will be quantified, the cost-effectiveness of the scenarios will be significantly higher.

It is important to note that the saved energy costs in the moderate scenario were found to be higher than the annualized investment costs as a whole on the country level, but not for all building categories. For a few of them, in particular for relatively new buildings, saved energy costs were lower than the annualized investment costs and therefore the investments were not cost-effective.

Table 6. Economic analysis of the moderate and ambitious scenarios

	Scenario	Moderate		Ambitious	
	Unit\time	2016-2030	Average per year	2016-30	Average per year
Floor area retrofitted	million m^2	99	6.6	105	7.0
Share of the floor area	%		2.0		2.1
New floor area affected	million m^2			77	5.2
Annualized incremental costs[1]	€/m^2		2.9		4.2
Saved energy costs[2]	€/m^2		3.8		2.7
Total costs, retrofits	million €	12,334	822	16,138	1,076
Incremental costs, retrofits	million €	4,941	329	8,745	583
Incremental costs, new buildings	million €			4,233	265
Public costs of loans, retrofits	million €	2,191		3,629	
Public costs for loans, construction	million €			1,147	
Public costs for grants	million €	1,008	67	1,756	117
Investment raised by loans, retrofits	million €	4,692	146	8,457	564
Investment raised by loans, construction[3]	million €			1,737	116
Private investment, construction[4]	million €			6,735	842

Notes: [1] the discount rate is 4%; [2] costs are per m^2 of new and retrofitted buildings; [3] for 2016-2022, [4] moderate scenario: for 2016-2030, ambitious scenario: for 2023-2030.

The table also provides the results of modelling the costs of policies included into the scenarios. The analysis illustrates that the scenarios require high involvement and costs for the government to trigger and leverage additional private investments into building energy efficiency. The analysis argues for an urgent implementation of the building code that would allow for large scale efficiency construction, reducing its costs. The analysis also argues that even if the government will limit provision of grants to low-income households and will allocate for the rest of buildings the funds to compensate for low-interest rates of loans, this still represents very high costs for the government. This argues for the necessity of establishing revolving loan funds to multiply the amount of available finance from the government. As previously said, other benefits of retrofits must be taken into account to allow for the consideration of all economic effects beyond saved energy costs.

Conclusions

The research aimed to assist the design of energy efficiency and decarbonization policies for the residential sector of Serbia. For this purpose, the residential building stock was classified by age and type categories for which energy demand was estimated. Using this information as an input, a bottom-up model was prepared in the LEAP system software to analyse current and the future energy demand and associated CO_2 emissions.

It was found that the households do not receive thermal energy services adequate to their needs, while partial and intermittent heating also represent a big problem. Energy demand could be significantly reduced in case of standard and ambitious retrofit packages even though they assume higher thermal comfort. It was found that the official energy balances did not perfectly reflect the real energy consumption of the residential sector. In particular, the share of biomass was underreported. To better reflect the situation, the censuses should gather information abuot non-commercial biomass use, partial and intermittent heating and cooling, and possible use of secondary systems for SH.

Based on the results of the bottom-up modelling, it was concluded that both moderate and ambitious policy scenarios may deliver significant energy savings and GHG emissions. The priority of sector segments is the building stock constructed in 1971 – 1990, and in particular small buildings. These energy savings and GHG emission reduction could contribute significantly towards Serbia energy and climate-related commitments under the Energy Community Treaty as well as international climate commitments under the Paris agreement.

The investment required to decrease the energy consumption is very high, this is why it is important to couple thermal efficiency improvement with building BAU renovation to take the advantage of costs that occur anyway. The investments into the moderate scenario is cost-effective, but this is not the case for the ambitious scenario. Furthermore, even for the moderate scenario, the scenario investments are cost-effective as a whole on the country level, but not for all building categories. Therefore, it is important to consider other benefits of mitigation scenarios beyond saved energy costs such as higher comfort, health, energy security, economic growth, and others. The realization of the scenarios requires a careful design and massive provision of financial products for the residential energy efficiency as well as the introduction and enforcement of building codes.

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Nomenclature

$f_{CO_2,\mathrm{source}}$ – CO_2 emission factors, [$gCO_2kW^{-1}h^{-1}$]
Q_{ND} – net heating energy demand, [$kWhm^{-2}yr^{-1}$]
$Q_{\mathrm{delivered}}$ – delivered heating energy demand, [$kWhm^{-2}yr^{-1}$]

Greek symbols

η_t – system efficiency, [%]
η_b – boiler efficiency, [%]
η_p – piping (distribution) efficiency, [%]
η_c – control efficiency, [%]

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