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HVAC system influence during refurbishment on reaching nearly zero energy residential building in Serbia

Influența sistemelor HVAC asupra renovarării cu privire la atingerea nivelului aproape zero energie a clădirilor rezidențiale în Serbia

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Abstract: *Building sector in Serbia is the most energy intensive of all economic sectors with some data showing the buildings are accounted for nearly 50% of final energy consumption of country, large portion of consumption related to covering building heating and cooling needs. New EU Directives covering energy efficiency and energy use target refurbishment of existing buildings, as well as the construction of new ones in a direction to represent nearly zero energy buildings (nZEB). Although the building stock turnover rate is very low, even in the most developed countries, and the energy retrofits of existing building stock towards nearly Zero Energy Buildings are becoming more important compared to new buildings, the HVAC system selection while designing new buildings could be the corner-stone for achieving nZEB goals. In this paper, energy performance of one residential building type in Serbia was analyzed with different combinations of HVAC secondary and primary systems, with several levels of building envelope thermal properties, as well as for several locations spreading north-south across Serbia. The heating and cooling energy consumption in all cases was contrasted with electricity produced from roof-mounted PV central, and it is found that electricity produced from roof area is more than enough to balance the energy consumption of the legislative-required refurbished building, from the primary energy perspective.*

Keywords: *nZEB, refurbishment, residential buildings, EnergyPlus, Serbia*

Rezumat: *Sectorul construcțiilor din Serbia este cel mai mare consumator de energie din toate sectoarele economice, cu date care arată că aproximativ 50% din consumul final de energie al țării este reprezentat de clădiri , o mare parte a acestui consum este legată de acoperirea nevoilor de încălzire și răcire a clădirilor. Noile directive UE care acoperă eficiența energetică și utilizarea energiei vizează renovarea clădirilor existente, precum și construcția de noi clădiri într-o direcție care să reprezinteclădiri cu aproape zero energie (nZEB). Deși rata cifrei de afaceri a fondului de clădiri este foarte scăzută, chiar și în țările cele mai dezvoltate, iar reabilitarea energetică a stocurilor de clădiri existente către aproape Zero Energy Buildings devine din ce în ce mai importantă în comparație cu clădirile noi, selecția sistemului HVAC la proiectarea clădirilo noi ar putea fi piatră de temelie pentru atingerea obiectivelor nZEB. În această lucrare, a fost analizată* *performanța energetică a unui tip de clădire rezidențială din Serbia cu diferite combinații de sisteme secundare și primare HVAC, cu mai multe niveluri ale proprietăților termice ale anvelopelor clădirii, precum și pentru mai multe locații răspândite de la nord la sud, în toată Serbia. În toate cazurile, consumul de energie de încălzire și de răcire a fost în contrastcu energia electrică produsă de sistemul fotovoltaic montat pe acoperiș și se constată că energia electrică produsă de sistemul fotovoltaiv este mai mult decât suficientă-conform cerințelor legislative, pentru a echilibra consumul de energie al clădirii renovate din perspectiva energiei primare.*

Cuvinte cheie: *nZEB, renovare, clădiri rezidențiale, Energy Plus, Serbia*

1. Introduction

Continuous improvement of building energy performance represents one of the key (if not the key) challenges of the 21st century (at least in the energy sector), since buildings account for up to 40% of the final energy consumption in European Union [1], and more than 40% of primary energy consumption in USA [2], while residential buildings in USA accounted for 21% of the total building energy consumption and 20% of the total carbon dioxide emissions in 2016 [3]. The situation in Serbia is similar, where building sector participates with more than 50% of consumed energy [4]. Dominant energy source in Serbia are fossil fuels for both electricity production (needed for space cooling) and for space heating in both residential and non-residential buildings (natural gas or other fossil fuels are mainly used) thus making buildings one of the main emitters of greenhouse gases (GHG). Throughout the World, the situation is similar, labeling building sector as the most energy intensive, and consequently focusing more attention from both researchers and policy makers to this sector. For example, European Union [5] imposes that the share of renewables in the total gross of member states energy consumption should be 20%, the emissions of carbon dioxide, GHG and the final energy consumption must decrease by 20% and that all new buildings must be nearly Zero Energy Buildings (nZEB), starting from 2020. This Directive represented the turning point in the design and construction of new buildings. Considering existing buildings, all EU member states are dealing with minimum energy performances during refurbishment of these buildings, but one must have in mind that existing buildings are far more numerous than the new ones, and that many years will pass when the building fund is fully refurbished.

In Serbia, residential buildings represent the most numerous types of buildings (both in number and in building area) and make an excellent starting point for the analysis of improving their energy performance toward nZEB. Assuming all new buildings will be nZEB, it is very interesting to analyze what are the potentials for refurbishing existing residential buildings in such a manner to make them nZEB. There are numerous definitions for nZEB [6], numerous metrics [7] and tools [8-10] to obtain and represent results, cost-optimal and life-cycle approaches to create nZEB and all have in common that building should produce energy on-site in quantity that is approximately equal to building energy consumption.

Since there are numerous types of residential buildings (single- family, multi-family, high-rise, apartment etc.), constructed in various decades, this paper will deal with only one type of building (single/multi-family). The building is constructed during 1980's, and the possibilities to make this type of building nZEB depending on the type of HVAC systems used will be presented. In the analysis, the primary energy consumption only for providing space heating and space cooling will be used, thus neglecting modeling assumptions influencing other energy end-uses in the building (lighting, appliances, domestic hot water, HVAC auxiliaries etc.). The nZEB refurbishment possibilities were quantified by applying building energy performance simulation software EnergyPlus [11], which is a well-known in research and engineering circles and is readily used in all phases of building life cycle.

2. Building and systems description

The building is shown in figure 1. It is a three-story residential multi-family building, with main façade exposed to the South, with total floor area of roughly 350m^2. It was built in the early 1980's. It is not surrounded by other buildings. Each building story represents an apartment with living room, dining room, two bedrooms, bathroom, corridor which is conditioned and two additional unheated rooms. All the apartments have joint unconditioned staircase. Basement and roof are unconditioned as well. For the energy simulation purposes, all the rooms are modelled as separate thermal zones, which enables defining occupancy, lighting, equipment usage, and heating and cooling setpoint schedules individually for each zone of the building.

In order to simplify the model, heating and cooling setpoints were set at 22° C and 26° C, considering that heating season starts on October 15th and ends on April 15th. During heating period, no cooling is provided in the building and vice-versa. The roof of the building is free for generating electricity from PV panels, and it is assumed that PV panels will have small-to-none effect on the overall building energy balance, since there is unconditioned area under the roof. For this research whole roof (app. 140m^2; roof is tilted 15° and 25° toward W and E respectively) is assumed to be covered with PV panels.

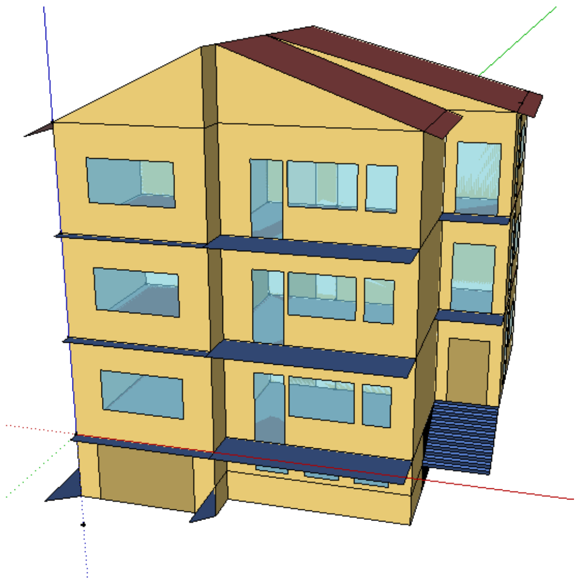

Figure 1. Model of the building in GoogleSketchUp (South-East view)

2.1 Building thermal properties and improvements:

Since the period during which building was constructed, thermal properties of the building do not satisfy the propositions of Ordinance on Energy Efficiency in Buildings [12]. For better overview, all the, maim, envelope constructions with corresponding U-values are shown in table 1. Building airtightness which influences infiltration loads is selected for façades in medium condition and for exposed position of the building and is set to 0.8 ACH (air changes per hour) in all cases.

Table 1.

Composition and U-value of the main building envelope elements

Construction	Material	Thickness [m]	U-value [W/m2K]
External wall	Mortar	0.015	0.76
	Polystyrene	0.03	
	Brick	0.25	
	Mortar	0.015	
Floor toward unconditioned basement/floor on ground	Ceramic floor tiles	0.015	0.74
	Insulation	0.02	
	Concrete	0.1	
	Concrete	0.25	
	Mortar	0.015	
Ceiling towards unconditioned roof area	Stone wool	0.05	0.77
	Concrete plate	0.25	
	Mortar	0.015	
Windows	Double glazed, air filled	4-12-4mm	3.0, SHGC=0.71

Since, building envelope components do not satisfy minimum energy performance requirements, for the purpose of this research, two refurbishment options have been analyzed:

- Refurbishment for minimum energy performance according to [12], named “Legislative”, by adding 7cm insulation on outside walls, 3cm insulation in floor toward unheated basement and 5cm insulation toward unheated roof and replacing windows with new ones (U-value of 1.5W/m^{2}K, SHGC=0.61);
- Refurbishment for high energy performance, named “Passive”, by adding 17cm insulation on outside walls, 6cm insulation in floor toward unconditioned basement and 5cm insulation toward unconditioned roof and replacing windows with new ones (U-value of 0.7W/m^{2}K, SHGC=0.48).

2.2. Building HVAC systems

For the analysis, the following ideally sized and controlled HVAC systems (or combinations) have been modelled for thermal zones (with the exception that in bathroom no cooling is possible):

- Radiator heating system for space heating in combination with split-type DX air-conditioners,

• Fan-coil system for both space heating and space cooling,

As the primary energy source, the following energy supply combinations have been modelled:

• For providing energy for space heating either gas condensing boiler (CGB) or district heating (DH) for locations where DH exists,

• For providing energy for space cooling air-cooled water chiller has been modeled.

All HVAC components, with their characteristics were taken from EnergyPlus libraries, and represent generic components, without any manufacturer data preference. Depending on the types of energy supply systems and space heating/cooling system, outputs from simulations have been tailored in order to quantify energy (per carrier: natural gas, district heating and electricity) consumption only for space heating and space cooling, thus neglecting energy consumption for auxiliaries in each system and energy consumption for other end-uses (preparing domestic hot water, electricity for lighting, electricity for appliances etc.). In addition, these outputs have been combined in order to quantify primary energy consumption for space heating and space cooling, by multiplying relevant results with primary energy conversion factors [12] which are: 1.1 for natural gas, 1.8 for district heating systems based on fossil fuels, 2.5 for electricity. The same coefficients (electricity) are used for converting produced electricity from PV central mounted on roof.

2.3. Locations

In order to obtain more general conclusions, all combinations of different envelope properties (“No refurbishment”, “Legislative” and “Passive”) and different HVAC and supply systems described above, have been simulated for different locations in Serbia. For this purpose, typical meteorological years [13] have been obtained for: locations in Serbia specified in table 2. In addition, table 2 contains data on annually produced electricity from roof mounted PVs.

Table 2.

Electricity generated from PV central

Location	PV produced	Location	PV produced
Subotica	15520.	Negotin	16577
Kikinda	15879	Valjevo	16381
Sombor	15874	Kragujevac	16672
Zrenjanin	16238	Užice	13846
Novi Sad	14963	Ćuprija	16629
Vršac	15680	Kraljevo	16146
Sremska Mitrovica	15908	Kruševac	16420
Banatski Karlovac	16074	Niš	16119
Beograd	16226	Kuršumlija	15933
Veliko Gradište	16280	Leskovac	17012
Smederevo	16132	Dimitrovgrad	16908
Loznica	15376	Vranje	17564

3. Results and discussion

Based on the described approach, total of 288 combinations of various levels of building refurbishment, HVAC secondary systems, HVAC supply systems and 24 different locations have been created and simulated. Simulation outputs, for several locations are given in tables 3 and 4, and figures 2-5.

Table 3.

Heating and cooling energy consumption in [kWh], different energy carriers

Location	Refurbishment Level	Fan Coil Boiler&Chiller Heating Energy consumption [kWh]	Fan Coil Boiler&Chiller Electricity consumption for cooling [kWh]	Fan Coil District Heating&Chiller Heating Energy consumption	Fan Coil District Heating& Chiller, Electricity consumption for cooling [kWh]
01-Subotica	0- NoRef	26816	3612	23335	3611
	1-Leg.	14711	3750	13293	3746
	2-Pass.	9398	3430	8630	3424
04-Zrenjanin	0-NoRef	24482	4310	21641	4303
	1-Leg.	13152	4308	11994	4298
	2- Pass.	8204	3866	7590	3856
05-Novi Sad	0-NoRef	26527	3017	23553	3016
	1- Leg.	14458	3423	13131	3416
	2- Pass.	9026	3198	8274	3189

Location	Refurbishment Level	Fan Coil Boiler&Chiller Heating Energy consumption [kWh]	Fan Coil Boiler&Chiller Electricity consumption for cooling [kWh]	Fan Coil District Heating&Chiller Heating Energy consumption	Fan Coil District Heating& Chiller, Electricity consumption for cooling [kWh]
07- Sremska Mikrovica	0-NoRef	25565	3801	22367	3798
	1-Leg	13793	3957	12456	3950
	2- Pass.	8605	3549	7898	3542
09-Beograd	0-NoRef	21577	4288	19070	4281
	1-Leg	11099	4352	10183	4342
	2- Pass.	6642	3933	6184	3925
12-Loznica	0-NoRef	23107	3919	20224	3914
	1-Leg	12660	4036	11409	4028
	2- Pass.	7959	3681	7244	3673
15-Kragujevac	0-NoRef	20441	4553	18070	4548
	1-Leg	10591	4547	9597	4539
	2- Pass.	6421	4108	5867	4099
16-Užice	0-NoRef	29655	1629	26333	1628
	1-Leg	15799	2183	14487	2181

Location	**Refurbishment Level**	**Fan Coil Boiler&Chiller Heating Energy consumption [kWh]**	**Fan Coil Boiler&Chiller Electricity consumption for cooling [kWh]**	**Fan Coil District Heating&Chiller Heating Energy consumption**	**Fan Coil District Heating& Chiller, Electricity consumption for cooling [kWh]**
	2- Pass.	9564	2180	8891	2177
19-Kruševac	0-NoRef	23933	3848	21028	3845
	1-Leg	12990	3890	11736	3883
	2- Pass.	8175	3479	7468	3473
20-Niš	0-NoRef	23743	3248	20900	3245
	1-Leg	12418	3601	11298	3595
	2- Pass.	7560	3319	6974	3313
24-Vranje	0-NoRef	23998	3166	21252	3165
	1-Leg	12996	3255	11865	3249
	2- Pass.	8073	2886	7477	2880

Table 4.

Heating and cooling energy consumption in [kWh], different energy carriers

Location	Refurbishment Level	Radiators&Split, Boiler Heating Energy Consumption [kWh]	Radiators&Split, Boiler Electricity consumption for cooling [kWh]	Radiators&Split, District Heating, Heating Energy Consumption [kWh]	Radiators&Split, District Heating, Electricity consumption for cooling [kWh]
01-Subotica	0-NoRef	27168	2928	21594	2928
	1-Leg.	15046	3367	12785	3366
	2-Pass.	9622	3304	8488	3302
04-Zrenjanin	0-NoRef	24979	3403	20468	3402
	1-Leg.	13473	3774	11773	3773
	2-Pass	8421	3632	7569	3631
05-Novi Sad	0-NoRef	27145	1816	22799	1816
	1-Leg.	14813	2434	13079	2428
	2-Pass	9267	2530	8318	2528
07-Sremska Mitrovica	0-NoRef	26006	2971	21133	2973
	1-Leg.	14131	3426	12151	3423
	2-Pass	8859	3357	7838	3354

Location	Refurbishment Level	Radiators&Split, Boiler Heating Energy Consumption [kWh]	Radiators&Split, Boiler Electricity consumption for cooling [kWh]	Radiators&Split, District Heating, Heating Energy Consumption [kWh]	Radiators&Split, District Heating, Electricity consumption for cooling [kWh]
09-Beograd	0-NoRef	21890	3628	17971	3629
	1-Leg.	11365	3974	9966	3971
	2-Pass	6807	3811	6169	3808
12-Loznica	0-NoRef	23519	3084	19163	3084
	1-Leg.	12967	3418	11120	3414
	2-Pass	8177	3328	7171	3327
15-Kragujevac	0-NoRef	20866	3753	17416	3755
	1-Leg.	10855	4019	9538	4018
	2-Pass	6597	3825	5899	3823
16-Užice	0-NoRef	30389	1026	25247	1026
	1-Leg.	16231	1649	14315	1651
	2-Pass	9853	1895	8928	1895
19-Kruševac	0-NoRef	24372	3135	19996	3129

Location	Refurbishment Level	Radiators&Split, Boiler Heating Energy Consumption [kWh]	Radiators&Split, Boiler Electricity consumption for cooling [kWh]	Radiators&Split, District Heating, Heating Energy Consumption [kWh]	Radiators&Split, District Heating, Electricity consumption for cooling [kWh]
	1-Leg.	13297	3472	11536	3469
	2-Pass	8390	3347	7447	3345
20-Niš	0-NoRef	24211	2626	19762	2627
	1-Leg.	12715	3218	11062	3212
	2-Pass	7764	3234.99	6934	3237
24-Vranje	0-NoRef	24499	2879.29	20168	2875
	1-Leg.	13308	3224.70	11652	3222
	2-Pass	8292	3097.43	7428	3098

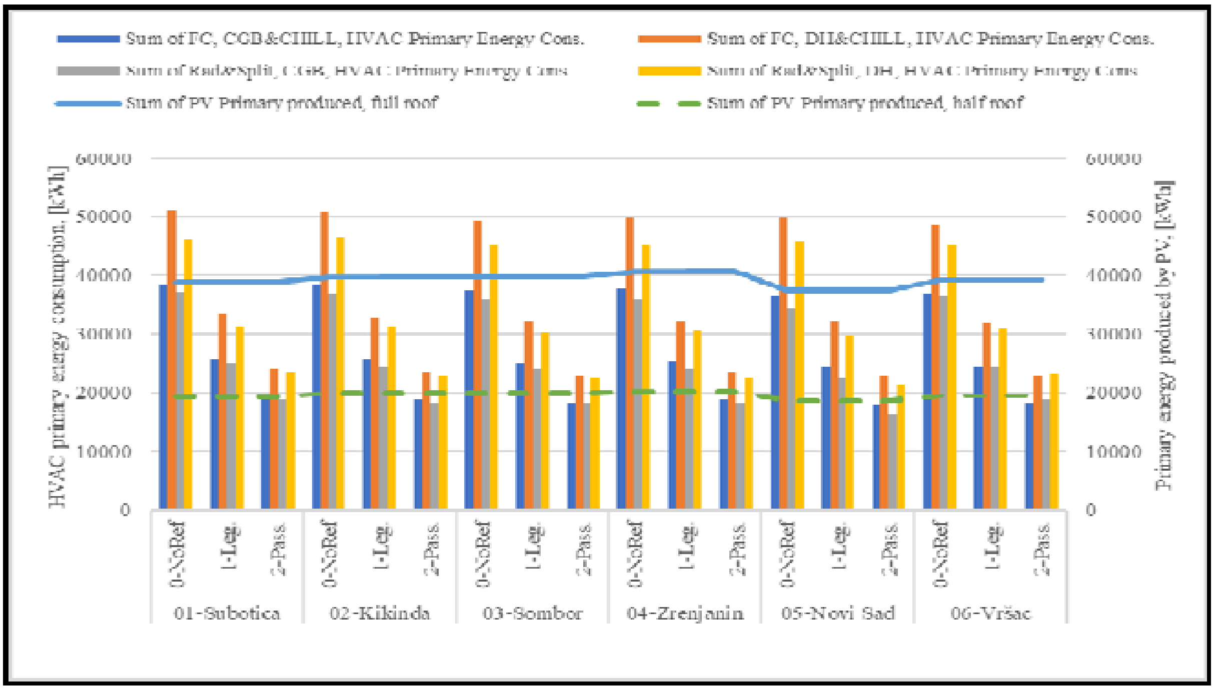

Figure 2. Comparison of primary energy consumption for space heating and cooling for various combinations and on-site produced electricity

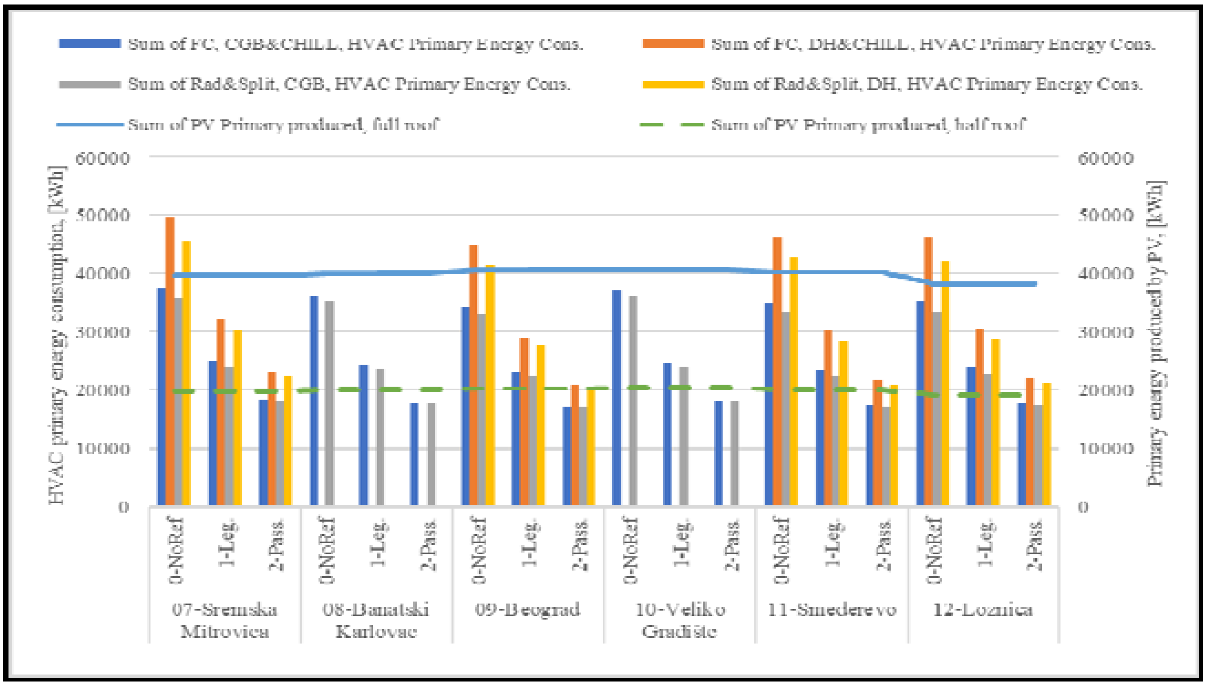

Figure 3. Comparison of primary energy consumption for space heating and cooling for various combinations and on-site produced electricity

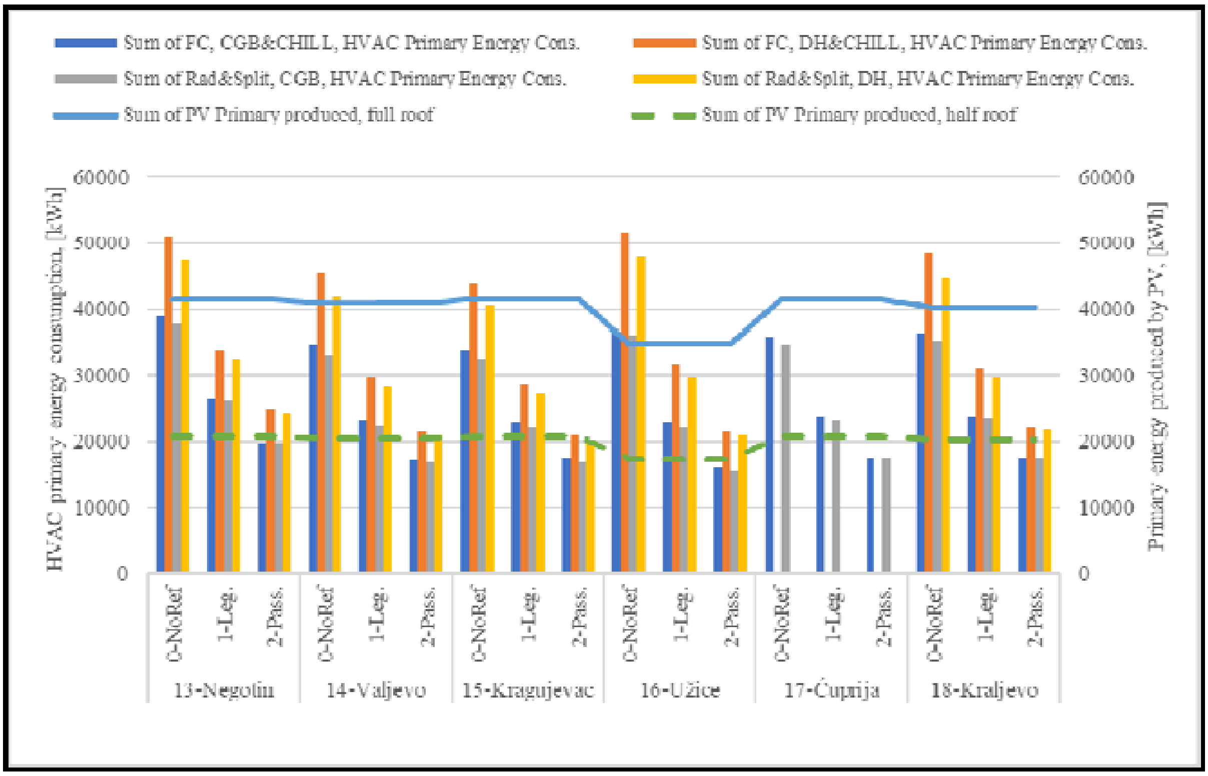

Figure 4. Comparison of primary energy consumption for space heating and cooling for various combinations and on-site produced electricity

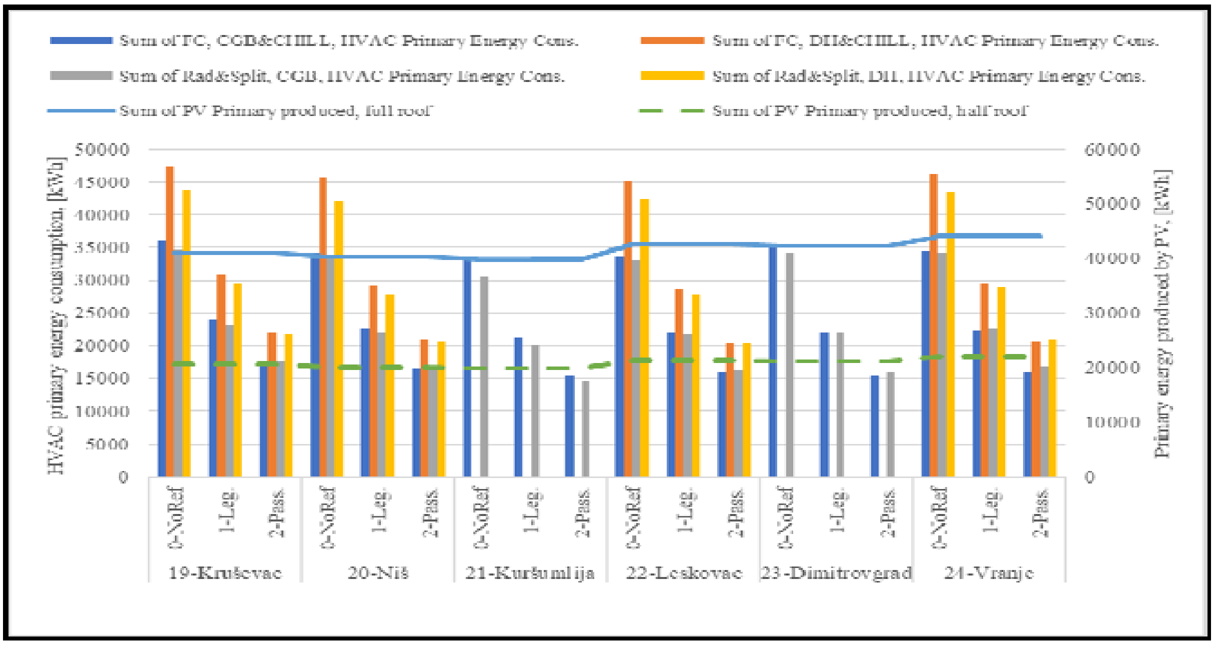

Figure 5. Comparison of primary energy consumption for space heating and cooling for various combinations and on-site produced electricity

The above presented results show that envelope improvement leads to significant reduction in heating energy consumption, while cooling energy consumption (expressed as electricity consumption for cooling) in some cases is higher, and in some lower than in case without envelope improvements. In cases when heating energy is provided by district heating, there is a slight reduction compared to cases when heating is provided by condensing gas boiler. The difference is in the modelled system availability: when district heating is used, heat emitters are available only in part of the day (from 6AM until 10PM), compared to cases with condensing boiler when heat emitters are always available during the heating season. This increased energy consumption would certainly lead to better occupant thermal comfort and satisfaction, which is not analyzed in this paper.

From the primary energy consumption standpoint, from figures 2-5 it is obvious that in Serbia, produced electricity (converted to primary energy) from roof-mounted PV central can balance the primary energy needs for heating and cooling even with minimum envelope refurbishment (referred as “legislative”) for every analyzed HVAC system combination. If the refurbishment goes beyond minimum requirements (referred as “passive”), there is a significant surplus of primary energy produced onsite from PV central, which would probably balance other energy end-uses in analyzed type of building, but most certainly would balance HVAC auxiliary energy consumption, thus enabling HVAC systems to be zero, and the whole building nearly zero.

4. Concluzii

From the presented results it can be concluded that in Serbia, there is an energy potential (especially in Solar energy) to refurbish residential buildings of analyzed type towards nZEB, by implementing PV panels on the roof to balance the energy consumption for space heating and cooling. It this paper, only several combinations of HVAC secondary and primary systems have been analyzed, and in all cases, it is found that for all locations only small envelope improvements can give the wanted results. Further research should be widened to include: other types of residential buildings with different levels of envelope thermal properties, more secondary and primary HVAC systems and their combinations, other energy uses in residential buildings (to make building really nZEB), renewables better suited locally for every location, occupant thermal comfort and more importantly to apply cost-optimal approach in order to find optimal levels and scenarios for every combination of parameters stated above. Conclusions from this type of research would help policy and decision makers to create financially attractive incentives for residents and finally it can help Serbia go “green” in building energy sector.

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