

Article

Building Energy Performance Certificate—A Relevant Indicator of Actual Energy Consumption and Savings?

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Abstract: A building energy performance gap can be illustrated as the difference between the theoretical (methodologically defined) and the actual energy consumption. In EU countries, Energy Performance Certificates are issued when buildings are constructed, sold, or leased. This information is the first step in order to evaluate the energy performance of the building stock. In Serbia, when issuing an energy certificate, the adopted national methodology recognizes only energy consumption for heating. The main purpose of this paper is to evaluate the energy gap and estimate the relevance of an Energy Performance Certificate to meet the national energy efficiency or carbon target. An Energy Performance Certificate determines the theoretical residential and commercial building energy efficiency or its “design intent”. This research stresses the necessity of measuring and achieving reductions in actual energy consumption through system regulation and consumers’ self-awareness in buildings. The research compares the performance of the building stock (135) that is connected to the District Heating System (DHS), with its own integrated heat meter, to Individual Gas Boiler (IGB) systems (18), in the city of Novi Sad, Serbia, built after 2014. For the purpose of comparing energy consumption, 16 buildings were selected that are very similar in terms of design, operation, and location. The data used are derived from metered consumption data, official evidence of city service companies, and Energy Performance Certificates of the considered buildings. We have determined that IGB systems have a much wider specific annual performance gap (11.19–101 kWh/m²a) than the buildings in the DHS (3.16–18.58 kWh/m²a).

Keywords: building energy performance; energy performance certificate; district heating systems; natural gas boiler; energy policy



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1. Introduction

District Heating Systems’ heat capacity development considerably depends on the operational energy performance of buildings and trends in the construction sector related to new buildings where DHS energy infrastructure is available. Predicting DHS capacity development could guide the determination of emerging strategies, preferably using the demand-side method based on the heating load of buildings connected to the DHS [1]. Consequently, any type of disturbances, uncertainties, or design error from the building sector would be translated indirectly to the DHS development. This complex relation of DHS development (i.e., competitiveness, consequently) and energy performance of buildings “is an open question” [2]. One of the available instruments in this domain is Energy Performance Certificates (EPCs). An EPC aims to inform associated actors in the building sector and provide required inputs about the building’s thermal characteristics, which are necessary for DHS development.

1.1. Related Work and Background

The impacts of EPC are evident and proven through home-buyers' perceptions [3] and changes in the real estate market [4]. The impacts are also visible even in cases when individual actors in the building sector are indifferent [5] or when any yield from property assets (rental or capital) is not significant [6]. Fuerst et al. concluded that there is a significant influence of energy efficiency labels on the sale of apartments in England [3]. A similar approach was taken by the author in paper [4]. Olausen et al. reported that there is no concrete evidence of the EPC's influence on the price of facilities in Norway [5]. Moreover, Fuerst et al. had a similar conclusion in his work on capital and rental objects in the United Kingdom [6]. The EPC impacts on the building sector have been considered in various studies based on city/region-level EPC databases, in order to reveal characteristic interdependences and interrelationships of the EPCs to stakeholders, policies, strategies, and so on. Such considerations are important in the methodological and applied context, but also because of the wide possibilities for creating new knowledge. Relevant and valuable findings are established by data elaboration from the Swiss national EPC database [7], using a knowledge tool for EPC verifying in Aragón (Spain) [8], mapping the energy performance of Hellenic residential buildings from EPC data in Greece [9], mapping of existing building stock in Sweden using data from the EPC base [10], analysis of errors in the United Kingdom EPC database [11], and by using an EPC database to create indicators for energy planning purposes in Italy [12]. The cause-and-effect relationships of EPCs with the building sector have been identified, primarily between owners or occupiers, housing associations, and real estate. Relationships were also considered through sensitive aspects like city 'authorities' attitudes, city energy policy, energy action plans, and investment strategies, where utility companies are widely involved and represent a key factor for successful implementation. EPC impacts need to be known to assess the implications of energy consumption, capacity development, and potential savings measures in the building sector and associated utility services. However, as an indicative basis for decision-making, the EPC's reliability can affect proper estimations of the impacts. The challenges are unpredictable deviation and variation of the real performance compared to the ones reported by the EPC. However, these issues can still be identified and mostly well defined.

The impacts on the Serbian urban environment are spread beyond building-related actors inside the energy supply chain and market, primarily with regards to the utility sector and DHS. This is a significant fact since the DHS is the critical facility of Serbian cities in achieving EU energy and environment targets and goals.

Each DHS is characterized by its own individuality, but common to all DHSs is their dependence on the efficiency of conversion, distribution, and delivery, and issues determined by energy policy, planning options and choices, investment in infrastructure, and handling of potential unexpected behaviors of users and investors related to heat capacity, where EPC plays a considerable role [7]. This paper intends to determine the character and range of EPC-associated impacts and the consequences to the utility company's business, primarily seen through new user connection and further urban heat capacity development. This paper presents the results of energy audits of comparable categories and critical consumer indicative performance.

1.2. Problem Characterization, Related to the Relevance of the EPC

The impacts are embodied in changing EPC credibility, with considerable consequences to building and associated utility sectors. Schuitema et al. demonstrated that "trust is a key determinant for attitudes to EPCs" [8]. They reported that credibility depends on the key interested parties' perceptive and affective involvement in building energy efficiency. By ignoring the mentioned aspects, EPC's supporting character may be lost and cause sub-optimal policy implementation. Considering uncertainties of EPC data in Sweden, Mangold et al. concluded that it "is necessary to assess and remediate the data quality" [9]. Claesson observed and reported criticism from energy experts [10]. Criticisms are argued by claims that most EPCs contain assessments and distributed en-

ergy usage values associated with uncertainty and the need for data plausibility analysis. Hårsman et al. examined EPC-related impacts on energy consumption and conservation opportunity and assumed “that the certificates’ quality plays an important role in their impact” [11]. Insufficient information in EPC and required improvements are reported by Li et al. [12]. From Swiss experiences, Cozza et al. consider EPC as “a poor predictor of actual consumption compared to the theoretical calculation” [13]. In verification analyses, Las Heras Casas et al. revealed that “49.71% of the EPC in Aragón (Spain) contain incorrect information” [14]. Inconsistency for primary energy consumption (kWh/m²·year) and CO₂ emissions (kgCO₂/m²·year) is discovered and reported according to the building type (25% of multi-family blocks received a higher energy class for primary energy consumption, and for CO₂ emissions, 27% of multi-family blocks received a high score), more often than according to the climate zone (data are lower from 28% to 37%) and according to the construction period (for buildings built from 1961 to 1980 data are 33% and 44% higher, and for those built from 1981 to 2007, data are 16% and 19% higher). Atannasio et al. have proposed a methodology that relies on a two-layer approach to estimate the needs for space heating primary energy demand and its connection with the main building features reported by Energy Performance Certificates [15]. Methodology is based on a database containing over 90,000 EPCs in the Piedmont region of Italy. Gaspari et al. presented a methodology for displaying consumption in the form of a map in an urban environment. The objective in this paper is to shift attention from individual buildings to the environment in order to identify larger homogeneous areas of energy use and to address policies and plans to improve quality and performance levels at the city level [16].

Changing EPC credibility is reflected, *inter alia*, in city energy policy development, energy planning, and creating an investment strategy. The result has been evident in Serbia over the last three years, and has been observed as implementation challenges to the policy of new customer connection to the DHS, causing difficulties and disturbances in developing district heating capacities.

As a sector closely related to the building sector, utility companies’ EPC impacts are time dispersed, fragmented, and highly dependent on technical and non-technical issues. Consequently, for non-technical professionals, these impacts are not easily visible and recognized. This connection between buildings and DHS is characterized by complexity, multiple influences, cross-domain relationships, and transboundary effects. Therefore, it is not easy to establish the share and intensity of a separated impact embodied in EPC.

Semple et al. revealed substantial dissimilarity across EU countries in EPC procedures used to categorize and evaluate energy consumption, “drawing different conclusions about their building stock and how to market transform these dwellings in the future” [17]. Appropriateness of EPC methodologies was investigated by Abela et al., and the need for consolidation of fundamental assumptions was suggested [18]. Other limitations and irrationality were discovered by Koo et al., especially in diagnosing procedures for operation and maintenance practices of the existing buildings [19].

1.3. Energy Policy Implications

In their conclusion, Pasichnyi et al. found that “EPC data have wider applications than initially intended by the EPC policy”, highlighting the EPC’s supporting character [20]. Valuable conclusions are drawn from examining the database comprising 650,000 EPCs, where Droutsas et al. found that EPCs could be “a valuable resource for various stakeholders by linking and quantifying the success of existing and new policies” [21]. Hjortling et al. considered EPC potential and reported suitable public authorities’ usability in formulating business strategies and energy policies [22].

City authorities can often use EPCs as a generally accepted basis for considering some strategic axis in the energy policy and base, their analysis and assessment methodology being used on a comprehensive series of officially issued EPCs. In this process, inconsistent interpretation and many errors in the data (performance differences between operational and design state) can cause misjudgments and underestimation of the need to undertake

more extensive and more in-depth interventions. Dascalaki et al. reported practical importance and different problems with policy implementation related to EPC [23]. Inconsistency with policy implications was reported by Majcen et al., where the examined building's heat capacity was less energy than projected by the EPC [24]. A study that included a comparative analysis of over 200 facilities in the UK showed that there is a minimal similarity between energy certificates and real consumption [25]. Errors in the EPC are particularly challenging because the sign and magnitude of the differences are not known, and the judgment itself is not correct, consequently. In the UK, the data in the certificate database was extensively analyzed, and Hardy et al. concluded that the "error rate of the EPC record is between 36 and 62%" [26].

1.4. Energy Planning Implications

Urban heat capacity development is a significant fragment of energy planning related to urban infrastructure and the viability of the utility company. EPC could be a valuable tool for urban planners to reach the city's required heat capacity targets and to effectively manage energy consumption [26,27]. Dall'O' et al. concluded that the EPC cadaster could be an effective energy planning tool at the district level [12]. The mentioned experience and the one known from Serbian practice highlight the importance of a well-established EPC database in the district supply system's planning process. Knowledge of the specific heat consumption, grounded on a developed EPC database, is a valuable guiding framework.

It is required to consider the finally delivered energy when developing the necessary capacities (based on anticipated future heat capacity). Still, not only the primary energy consumption is identified and reported by EPCs. In this context, EPCs do not take into account the entire process of thermal energy delivery. They do not consider user behavior and inclusiveness, available regulation and balancing options, automation control equipment, building management systems, and other aspects and technologies. In this way, the developer of the energy plan exploits somewhat unrealistic data with often rough assumptions. An EPC does not recognize different building's energy use method by the end-user, which is a category that changes, sometimes very dynamically. This is especially delicate, considering that heat capacity is composed of buildings of different ages and technological levels. López-González et al. observed the mentioned issues and found the EPC approach to be inadequate [28]. As proof of this claim, the authors pointed out the European standard EN 15232, in which this deficiency was eliminated and assessment of primary energy savings was suggested.

1.5. Investment Strategy Implications

The design and construction of a new building or reconstruction and extension of existing buildings, which is entirely in compliance with legal provisions (EPC procedure and methodology), should result in a building with good energy properties with an acceptable increase in investment costs. The expected effects are reduced energy consumption accompanied by low operating costs for energy, and increased interest of users, buyers or renters, and investors. Fleckinger et al. analyzed a combination of characteristic economy-related policy instruments in the short and long terms, like EPC, energy taxation, education, investment subsidies, tax credits, and building codes [29]. They found the distinguishing economic effect of EPCs in the form of the real estate market's positive reaction to building energy performance. Outcomes raise the rate of investments and reduce aggregate energy consumption. Certification has a positive impact on investment strategies because it affects the realization of cost-saving potentials, as foreseen by the model-based prediction analysis [30]. Streicher et al. also suggested a considerable investment potential in energy revitalization, based on approximately 10,400 EPCs in the Swiss residential building stock [31]. By investigating the reconstruction's impact, Prieler et al. reported a clear relation between EPC and reconstruction funding [32]. Broberg et al. conducted extensive research on EPC's relationship with investment in energy efficiency in the building sector [33]. They found that the EPC's established credibility has an almost minor impact

on all measures to improve the building's energy performance, except investment in the heating system, where significant positive implications are evidenced. The implications on the investment in building energy infrastructure are positive because they assess whether the project is financially viable and economically justified. EPC procedure also compares the cost-effectiveness of different measures and subprojects and allows investors, financial institutions, and donors to evaluate the project's eligibility for funding.

The analysis in the reviewed papers were conducted at the state, regional, or city level. These studies only show general conclusions in the form of an estimated share or methodology that would improve them. Furthermore, we introduced the discrepancy in terms of actual and projected energy consumption for heating based on a detailed presentation in residential buildings. All information and analyses are supported with measured data and official evidence of EPCs. The objective of this study is the comparison of similar buildings that are heated in two different ways (DHS and IGB systems), as well as the comparison of the gap between specific, actual, and EPC energy consumption. The data used are derived from metered consumption data, official evidence of city service companies and Energy Performance Certificates of considered buildings.

1.6. Other Implications

According to Soares et al. [34], EPC has the potential to incorporate and track some other important aspects like health and well-being characteristics, as well as environmental impact of materials or energy used in buildings. In addition to energy performance, suggested parameters that could be included in the EPC are indoor environmental quality and the share of applied natural resources.

Research results reported by Camboni et al. [35] confirm that EPC information corresponds with the socio-economic figures at the local level. Findings suggest the possibility of using EPC at the household and municipal level, for identification of the areas associated with energy poverty risks and appropriate policy instruments to tackle this challenge.

Ahern et al. [36] concluded that the use of a required methodology and pre-defined or default input values in the EPC calculations can cause an exaggerating of potential benefits from energy-efficiency-led revitalization or renewals. As a main consequence, unrealistic improvements in energy efficiency and an associated shorter payback period are reported.

2. Materials and Methods

The total number of buildings in Novi Sad that are connected to the DHS is 4067, of which 2065 belong to residential buildings, with a total area of 3,323,487 m² and installed capacity of 438,511 kW. The rest consists of business buildings (749), with a total area of 1,840,883 m² and installed capacity of 259,738 kW, and business-residential buildings (1254), with total area of 1,395,878 m² and installed capacity of 209,378 kW.

The case study, commissioned by the city of Novi Sad, was done to express the impact of EPC on energy consumption, capacity development, and potential savings measures in the building sector and associated utility services. It includes buildings connected to the local DHS (Novi Sad district heating operator "Novosadska Toplana") and buildings with only IGB systems (connected to the city gas network of the local distribution utility, "Novi Sad-Gas").

The city of Novi Sad faced market growth in the building and construction sector over the period 2015–2020. One of the critical indicators showing market growth is the number of issued construction permits (Figure 1) [37].

Figure 1 shows an increase in the number of issued construction permits for all types of buildings for the period 2015–2020. Residential buildings with three or more apartments, according to Statistical Office of the Republic of Serbia, are classified as a separate statistical category, and they are included in the category of residential buildings. The average time from issuing permits until the end of the construction phase and connecting to heating systems (DHS or natural gas network) is two years. This information gives utility companies a period to predict and make strategic plans for development and investment.

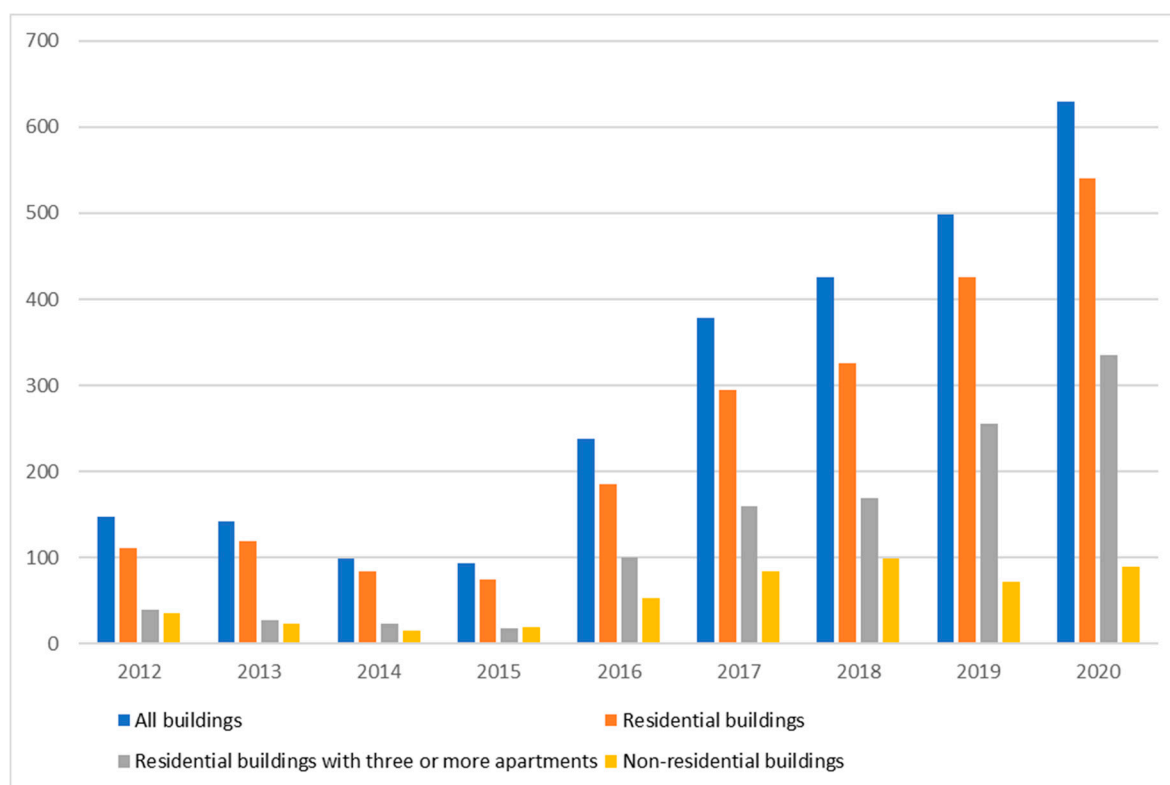


Figure 1. Number of issued construction permits.

Table 1 provides data on installed capacities for the residential and commercial sector, as well as their total installed capacity. The percentage shows the increase or decrease in installed capacity compared to the previous years. The installed capacity of the commercial sector is declining, except for 2018 and 2019, when there was a slight increase compared to the previous years, while the residential sector recorded a trend of growth, except for slight declines in 2014, 2015, and 2017 [38].

Table 1. Total installed capacity for residential and commercial consumers connected to DHS in the period from 2012 to 2020.

Year	Commercial (MW)	%	Residential (MW)	%	Total	%
2012	256.3	-	638.3	-	894.6	-
2013	255.5	−0.3%	645.6	1.15%	901.1	0.73%
2014	247.3	−3.2%	652.2	1.02%	899.5	−0.18%
2015	243.1	−1.7%	656.1	0.59%	899.1	−0.04%
2016	238.9	−1.7%	660.4	0.66%	899.3	0.02%
2017	232.3	−2.8%	663.9	0.54%	896.2	−0.35%
2018	234.2	0.8%	667.6	0.55%	901.8	0.63%
2019	240.0	2.5%	673.6	0.90%	913.6	1.31%
2020	237.1	−1.2%	680.0	0.95%	917.0	0.38%

As mentioned earlier, the period's installed capacity is 2.51% of the DHS total installed capacity. An increase in installed capacity is not proportional to the buildings' heating surface area connected to the DHS. A disproportion is expected, given that newly constructed buildings are more energy-efficient, resulting in lower energy consumption and

lower installed capacity, than an average building connected to the DHS. Figure 2 shows the increase in residential buildings' heating surface area from 2012 to 2020 [38].

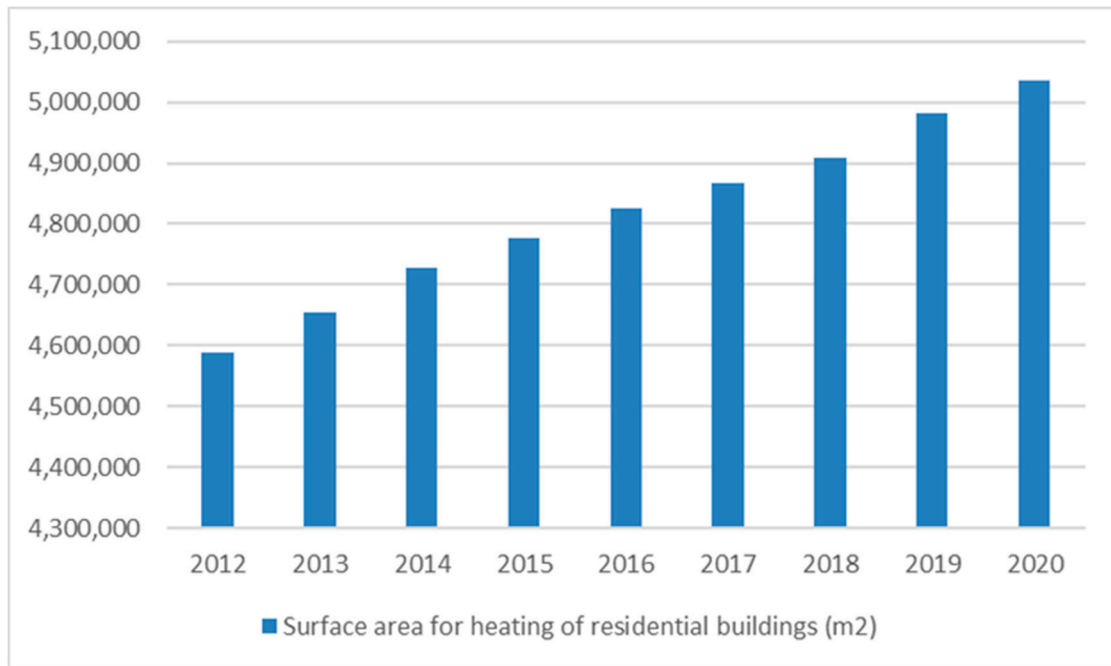


Figure 2. Increase of surface area for heating of residential buildings over the period from 2012 to 2020.

From 2012 to 2020, the total residential building surface area for heating connected to the DHS was 447,090 m² [38]. The annual growth of the surface area connected to the DHS represents the average European growth of 1%. However, when we look at the annual percentage share of the increase in the surface area for heating since 2014, a decline can be observed, despite the significant increase in new buildings' construction (Figure 3). The year 2019 shows an increase of newly connected surface area, but already in 2020, there is a decrease compared to 2019.

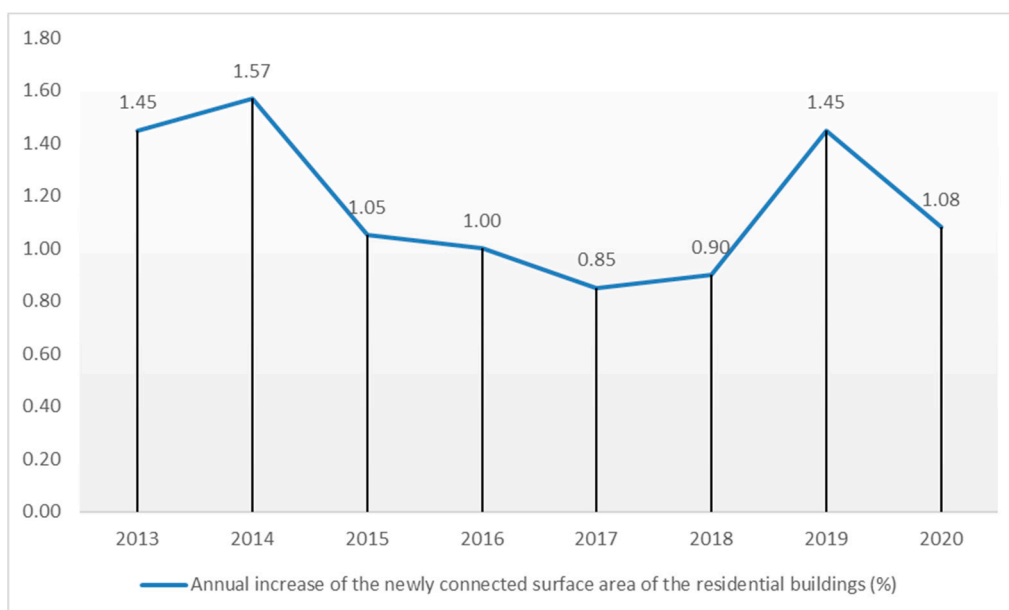


Figure 3. Annual increase of the newly connected surface area of residential buildings.

Figure 4 shows that the average specific energy consumption for heating of residential buildings connected to the DHS for 2020 was 58.4 kWh/m² [38]. Annual specific energy consumption ranged from 35 to 143 kWh/m². This data was collected and analyzed based on the readings from heat meters.

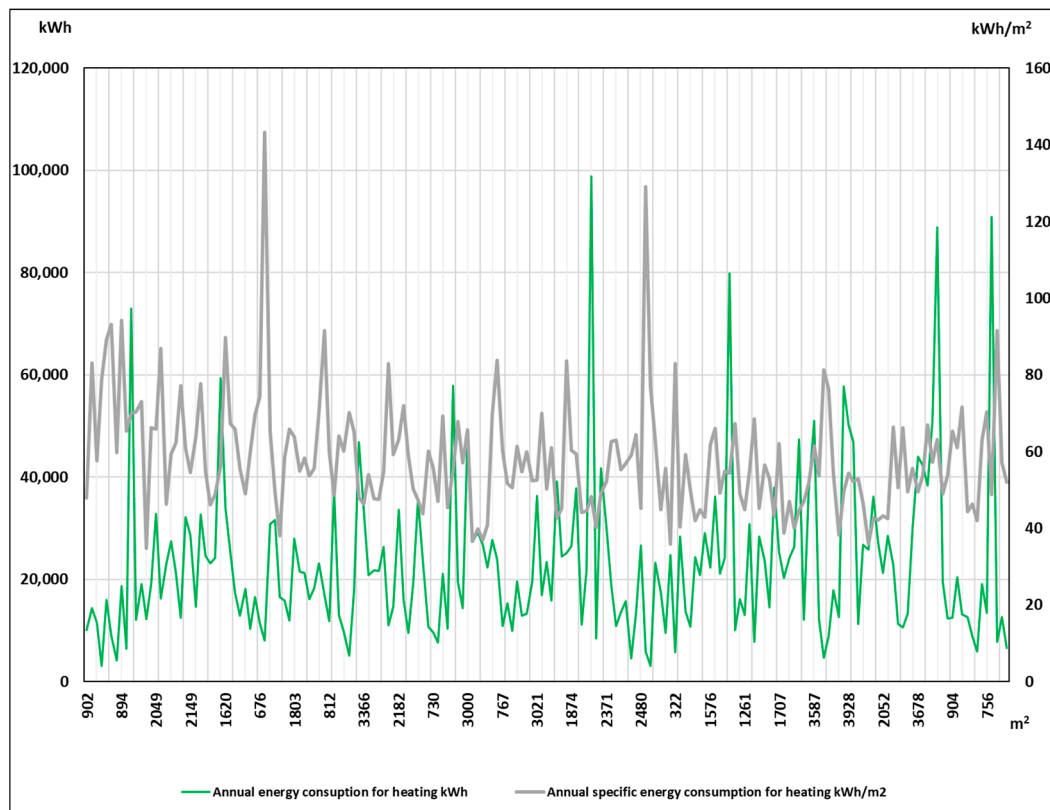


Figure 4. Average specific energy consumption for heating of residential buildings connected to the DHS for 2020.

For commercial buildings connected to the DHS, this energy consumption for 2020 was 69.9 kWh/m². Annual specific energy consumption ranges from 37 to 120 kWh/m². For buildings with mixed residential and commercial use, this energy consumption for 2020 was 62.3 kWh/m². Annual specific energy consumption ranges from 40 to 82.2 kWh/m². Table 2 shows key indicators and parameters for the DHS utility company regarding the number of consumers, installed capacities, fuel consumption, specific energy consumptions, heating degree days, and the system's efficiency over the period from 2012 to 2019 [38].

Table 2. Annual balances for the Novi Sad DHS utility company from 2012 to 2020.

Description/Year	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020
Number of consumers—residential	1000	90.7	92.2	93.9	94.8	95.7	96.6	97.5	99.2	99.8
Number of consumers—commercial	1000	7.7	7.9	7.9	7.9	7.8	7.7	7.8	7.8	7.8
Installed capacity—residential consumers	MW	638	645	652	656	660	663	667	674	680
Installed capacity—commercial consumers	MW	256	255	247	243	238	232	234	240	237
Installed capacity—total	MW	894	901	899	899	899	896	901	914	917
Heated surface area—residential consumers	1 mil. m ²	4.5	4.6	4.7	4.7	4.8	4.8	4.9	4.9	5.0

Table 2. Cont.

Description/Year	Unit	2012	2013	2014	2015	2016	2017	2018	2019	2020
Delivered energy—residential consumers	GWh	611	573	485	605	622	648	606	606	671
Residential—commercial consumers	GWh	208	191	160	186	190	199	185	181	198
Delivered energy for heating—total	GWh	820	764	646	791	813	848	792	787	869
Specific annual energy consumption—residential consumers	kWh/m ²	133	123	103	127	129	133	124	122	133
Fuel consumption	1 mil. Sm ³	74	73	81	97	94	87	79	73	91.5
Distribution system efficiency	%	87.0	88.2	86.2	89.9	90.5	90.0	89.1	91.4	91.3
DHS total efficiency	%	86.0	86.5	83.9	88.4	88.3	87.1	85.7	88.6	88.9
Average outside temperature	°C	4.62	6.07	7.48	5.99	6.70	6.00	6.53	7.82	7.92
HDD—heating degree days	Day	190	194	190	194	213	202	193	202	216
HDH—heating degree hours	1000 °H	70	64	57	65	67	67	62	61	58

On the other hand, buildings with IGB heating systems are connected to the local natural gas network. Public utility company “DP Novi Sad-Gas” (<http://www.novisadgas.rs>, accessed on 5 April 2020) has 57,000 active consumers and 1500 to 2000 newly connected consumers annually. Besides gas distribution, the company is responsible for maintaining the 2000 km gas pipeline network and 60 metering and regulating stations. The utility company is responsible for gas distribution in 6 municipalities: Novi Sad, Beocin, Sremski Karlovci, Backi Petrovac, Backa Palanka, and Malilđoš. The average specific energy consumption for buildings with IGB systems connected to the DP Novi Sad-Gas was 86.01 kWh/m² for 2018 [39].

Buildings from both groups were constructed after 2014 and comply with the Planning and Construction Law [40] and rulebook on energy efficiency [41]. They all possess an EPC, which means that they are rated with minimum energy consumption label C. Similar practices can be observed in EU countries [42–45]. Conversely, in the UK, Display Energy Certificates (DECs) are used for public buildings. This kind of indicator is an example of a certificate based on actual energy consumption [46]. Buildings are graded from A to G, where A represents the most efficient energy performance.

For the case study, a database of energy consumption, installed capacities, building type and construction style, technical systems, and fuel consumption was formed based on previously mentioned documents and databases. EPC and construction permits were sources of data for the predicted and predefined energy consumption. The sources of data for actual energy consumption were databases of the utility companies.

All case study buildings use natural gas as a heating fuel. As some use it directly and others indirectly, they were split into two groups. The first group represents the buildings connected to the DHS, and the other group consists of buildings with an IGB heating system. Buildings were selected based on several technical and non-technical criteria: building location, building design and construction style, heating capacity, technical system and equipment, maintenance, and management services.

Case study buildings are grouped and located in three residential neighborhoods (Figure 5a,b). Figure 5a represents a schematic diagram of applied heating system for one building connected to the DHS and one with an IGB system. Locations of other analyzed buildings can be seen in Figure 5b. Building locations were chosen based on the network availability (DHS and local natural gas network), building construction year, building type (residential), and building orientation (same exposure to the open space). Additionally, buildings in these locations are designed and constructed by the same investor.

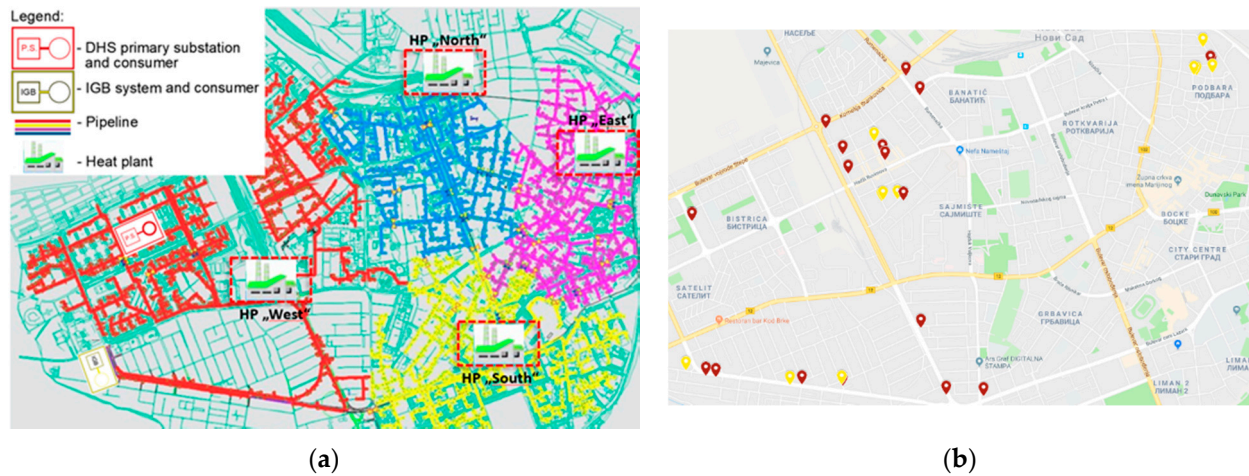


Figure 5. Schematic diagram of applied heating system (a) and locations of analyzed buildings (DHS—red pointers; IGB—yellow pointers) (b).

Selected buildings have the same or approximately the same design and construction style. Buildings from both groups are five-story residential buildings. Construction materials used for non-transparent and transparent building surfaces have roughly the same thermophysical properties. U values for non-transparent surfaces range from 0.235 to 0.295 W/m²K for buildings connected to the DHS. For the buildings with IGB systems, U values range from 0.254 to 0.49 W/m²K. For transparent surfaces, U values range from 1.347 to 1.500 W/m²K for buildings connected to the DHS, while for the buildings with IGB systems, U values are from 1.300 to 1.500 W/m²K. A detailed preview of the U values is presented in Tables 3 and 4. Buildings were selected to have the same or almost the same ratio between non-transparent and transparent surfaces. Heating capacity and installed equipment were also taken into consideration to be as similar as possible.

Table 3. Selected buildings connected to the District Heating System.

Description	Unit	Building							
		1	2	3	4	5	6	7	8
Construction year	year	2018	2018	2015	2016	2018	2016	2016	2017
Heated surface area	m ²	2953	4130	1254	3021	19,138	3855	2480	3643
Heated surface area—EPC	m ²	3888	2159	1542	4851	18,771	2752	2,479	3615
Non-transparent surface U value	W/m ² K	0.277	0.284	0.298	0.29	0.254	0.490	0.283	0.296
Transparent surface U value	W/m ² K	1.5	1.3	1.5	1.1	1.34	1.31	1.3	1.3
Heating energy consumption—EPC	kWh	197,985	112,408	58,936	143,200	413,354	123,406	65,519	139,364
Heating energy consumption—2018	kWh	129,216	194,748	63,094	103,523	778,582	171,695	103,492	143,396
Heating energy consumption—2019	kWh	115,638	177,063	59,468	97,109	710,975	158,605	100,877	143,578
Heating energy consumption—2020	kWh	119,026	198,349	64,739	108,427	768,643	183,739	112,364	157,158
Specific heating energy consumption—EPC	kWh/m ²	50.92	52.07	38.22	29.52	23.50	44.84	26.42	38.55
Specific heating energy consumption—2018	kWh/m ²	44	47	50	34	41	44	42	39
Specific heating energy consumption—2019	kWh/m ²	39	43	47	32	38	41	41	39
Specific heating energy consumption—2020	kWh/m ²	40	48	52	36	41	48	45	44

Table 4. Selected buildings with only IGB system.

Description	Unit	Building							
		1	2	3	4	5	6	7	8
Construction year	year	2017	2016	2016	2017	2016	2017	2015	2017
Heated surface area	m ²	11,625	912	798	830	950	1050	933	4222
Heated surface area—EPC	m ²	7860	912	912	1074	988	925	879	4720
Non-transparent surface U value	W/m ² K	0.235	0.295	0.295	0.255	0.250	0.258	0.272	0.242
Transparent surface U value	W/m ² K	1.414	1.500	1.500	1.440	1.400	1.347	1.400	1.460
Heating energy consumption—EPC	kWh	334,389	49,966	49,966	38,431	47,818	63,080	29,344	125,965
Heating energy consumption—2018	kWh	851,016	53,039	69,918	61,307	93,866	102,331	66,076	390,834
Heating energy consumption—2019	kWh	823,268	52,707	62,883	66,684	90,759	90,524	56,221	400,488
Heating energy consumption—2020	kWh	905,826	55,099	57,589	67,812	100,920	96,699	54,466	474,887
Specific heating energy consumption—EPC	kWh/m ²	42.53	54.81	54.81	35.77	48.38	52.14	33.00	21.98
Specific heating energy consumption—2018	kWh/m ²	73	58	88	74	99	97	71	93
Specific heating energy consumption—2019	kWh/m ²	71	58	79	80	96	86	60	95
Specific heating energy consumption—2020	kWh/m ²	78	60	72	82	106	92	58	112

The non-technical criterion for the selection was how the building is maintained. According to the Law on Housing and Maintenance of Apartment Buildings, every building must have professional management that will control and maintain every system inside the building [47].

Methods for calculating energy consumption for the previously mentioned building stock were different. According to the Law of Energy Efficiency, buildings connected to the DHS are obligated to provide heat meters installed in the district heating substations for residential or commercial buildings [48]. Data was collected directly from them.

“Novosadska toplana” measures the temperature on a daily basis. The number of heat degree days for years 2018, 2019, and 2020 were obtained based on the difference between the internal base temperature (20 °C) and the average daily temperature during the heating days. The total measured consumption of these buildings was corrected for the obtained correction factor. The correction factor is actually the quotient of the calculated degrees of the day during the heating period and the values given in the regulation on energy efficiency of buildings [41]. The equation used for this calculation is shown below.

$$Q_{DHS_c} = Q_{DHS} \cdot f$$

- Q_{DHS_c} —energy consumption for heating in kWh after correction,
- f —correction factor,
- Q_{DHS} —measured energy consumption for heating in kWh.

According to the rulebook on energy efficiency of buildings, the number of degrees per day for the area of Novi Sad is 2679. The correction factor is then defined by the equation:

$$f = \frac{HDD_{actual}}{2679} f$$

- f —correction factor
- HDD_{actual} —actual heat degree days

Since there are no installed heat meters for buildings with IGB systems, energy consumption data was calculated indirectly, based on meters for natural gas consumption for 2018–2020. In order for the data to be comparable, a correction factor was applied to these objects as well. The equation used for this calculation is shown below.

$$Q_{GB_C} = \frac{B_{NG} \cdot LCV}{3600} \cdot f$$

- Q_{GB_C} —energy consumption for heating after correction in kWh,
- B_{NG} —fuel consumption in m³,
- LCV—lower calorific value of natural gas (33,338.35 kJ/m³) (<http://www.novisadgas.rs/korisnici/obracun-isporucene-zapremine-prirodnog-gasa/>, accessed on 7 April 2020),
- f —correction factor.

3. Case Study—City of Novi Sad

The assessment methodology compares the collected data on actual heating energy consumption in 2018–2020. Energy consumption is defined and calculated through EPC. The main goal is to show the difference that occurs between actual energy consumption and energy consumption predicted by the EPC. These differences could have a significant impact on the energy policy and the energy plan of the utility companies.

For both groups of buildings, collected data are divided into:

- general data;
- data collected from EPC and construction permits; and
- data on heating energy consumption in 2018–2020.

The general data group provides information related to the location of the building, cadastral parcel and municipality, building stories, heating surface area, type of connection to the network, and the method of heat distribution, regulation, and calculation of energy consumption.

Data collected from EPC and construction permits directly refer to the building construction and envelope, heat transfer coefficients, and installed capacities of substations or boiler rooms. This data group also contains details related to heat loads, specific consumption of energy for heating, and the building's energy performance label. Data on heating energy consumption in 2018–2020 are shown in Tables 3 and 4.

Comprehensive Analysis of Future Building Heating System Connection

Two scenarios were assessed techno-economically to comprehensively estimate the future building heating system connection and life cycle costs. The assessment was performed with "RETScreen" software using Method 2 for heating systems.

Scenario 1 examines two very similar buildings. The first is connected to the DHS, while the second uses an IGB system. Both buildings have the same location and orientation, and similar construction types, envelopes, and installed capacities. In addition, the buildings are constructed by the same investor. To make the comparison fair, annual specific DHS energy consumption was multiplied by the IGB system building's heated surface area, and the total energy consumption comparison was made. All scenarios were made based on average energy consumption for the period from 2018 to 2019. The investment costs for buildings with IGB are formed according to the tenders from Phase IV of the KfW project [49], and the investment costs for connecting buildings to the DHS are defined according to the decisions from DHS utility company "Novosadska Toplana" [50]. The individual boiler system is expected to operate for 15 years before replacement, the costs of which are covered by the investor/user. Replacement of the DHS building heat substation is covered by the utility company "Novosadska Toplana". This is why maintenance costs

are higher when opting for the DHS system. Costs are specified per kW of installed capacity for heating and are used in both scenarios. Table 5 shows the buildings' data used for assessment in Scenario 1.

Table 5. Buildings data used for assessment in Scenario 1 and 2.

Description	Unit	Scenario 1		Scenario 2	
		IGB System	DHS System	IGB System	DHS System
Heated surface area	m ²	3051	2953	11,625	after 2014 *
Installed capacity	kW	220	261	876	after 2014 *
Annual heating energy consumption	kWh/yr	253,291	133,193	999,868	651,000
Annual specific energy consumption	kWh/m ²	83	45.1	86	56
Annual heating energy consumption per square meter of IGB system buildings	kWh/an.	253,291	137,613	-	20
Fuel cost	€/kWh	0.031	0.040	0.031	0.032
Monthly fixed cost of maintenance	€/mth.	311	413	1163	1646
Annual fuel cost calculated per square meter of buildings with gas boilers	€/yr	7501	5504	30,787	20,921
Investment cost	€	24,772	6104	98,638	24,305
Year of boiler / DHS substation replacement	Yr	15	-	15	-
Emission factor	tCO ₂ /MWh	0.197	0.215	0.197	0.105
CO ₂ emission	tCO ₂ /yr	51	29.4	201.4	68.2

* Total building stock connected to the DHS in the city of Novi Sad after 2014.

Table 5 shows that the building connected to the DHS consumes less energy for heating. Maintenance costs are lower for the building with an IGB-only system, while the heating system investment costs are four times higher. Annual savings for the DHS based on Scenario 1 are approximately EUR 800. The financial parameters used for Scenario 1 are shown in Table 6, while the cumulative cash flow for Scenario 1 is shown in Figure 6. Based on the CO₂ allocation price given in Table 6, the cumulative cash flow with and without CO₂ incentives was calculated for these two scenarios. Savings in CO₂ production per tonne are multiplied by the incentive price, and the results are provided in Figure 6.

Table 6. Financial parameters used for assessment in Scenario 1 and 2.

Financial Parameter	Unit	Value
Fuel inflation rate	%	2.00
Inflation rate	%	2.00
Discount rate	%	4.39
Project lifetime	Year	25
CO ₂ allocation (https://markets.businessinsider.com/commodities/co2-european-emission-allowances accessed on 6 September 2018)	€/tCO ₂	25.05
Financial Viability		Unit
Net present Value (NPV) for Scenario 1	€	59,118
Net present Value (NPV) for Scenario 2	€	220,310

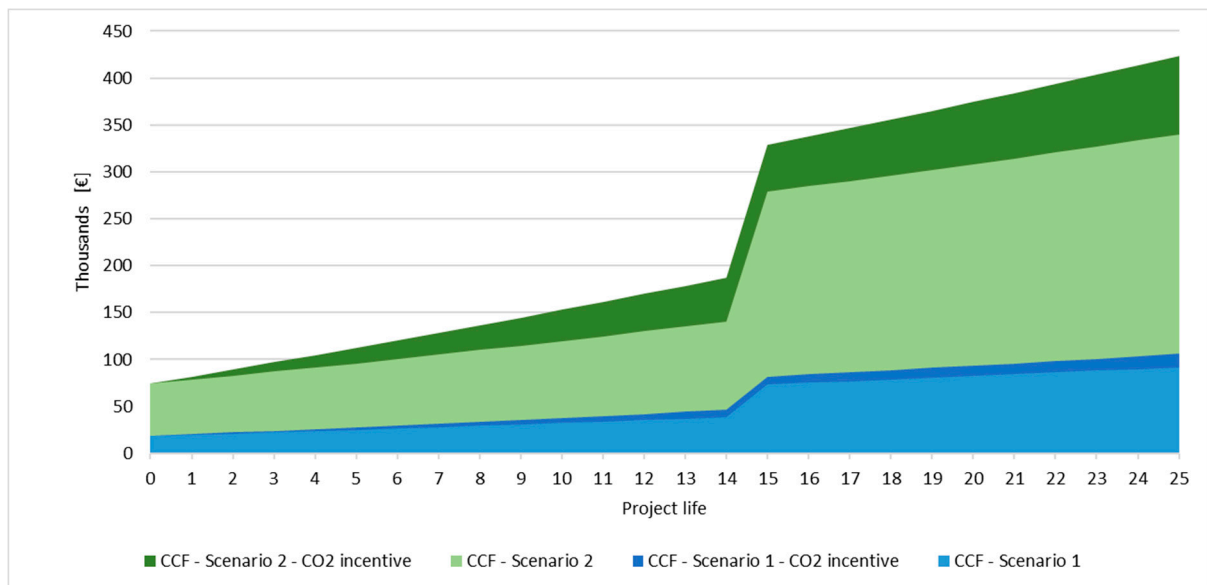


Figure 6. Cumulative cash flow (CCF) for Scenario 1 and 2.

Scenario 2 applies a methodology similar to the one used in Scenario 1. However, it assesses the annual average heating energy consumption in the building stock constructed after 2014 and connected to the DHS and in selected buildings with IGB heating systems. Additionally, Scenario 2 considers work on the modernization of DHS in terms of improving the energy efficiency of heat supply and the use of renewable energy sources. The effects of implementing these measures and the transition to the 4th generation of DHS have been observed in many European countries [51]. The fourth generation of the DHS is a concept that applies modern and smart, sustainable systems and renewable energy sources to upgrade existing systems. It provides optimal energy supply with low production and grid losses. Based on the BASREC survey results, it can be concluded that it is possible to improve the DHS and reduce the price of thermal energy per square meter by 20%. Table 5 shows the data used for assessment in Scenario 2.

The generation of DHS bridges the fuel cost gap to individual boiler systems. With the 20% fuel cost decrease and lower annual specific energy consumption, higher DHS maintenance costs become negligible. Based on the assessment results, the DHS system saves annually EUR 4500 for 11,625 m² of heating area. The financial parameters used for Scenario 2 are shown in Table 6. Furthermore, sensitivity analysis was performed based on a change in the price of natural gas and the cost of thermal energy in the range from −10 to +10%. The results are shown in Table 7.

Table 7. Sensitivity analysis of Scenario 2.

		Change in the Price for Thermal Energy €/an				
Fuel price variation		18,829	19,875	20,921	21,967	23,013
€/an		−10%	−5%	0%	5%	10%
27,708	−10%	201,802	182,179	162,556	142,933	123,310
29,248	−5%	230,679	211,056	191,433	171,810	152,187
30,787	0%	259,557	239,933	220,310	200,687	181,064
32,326	5%	288,434	268,810	249,187	229,564	209,941
33,866	10%	317,311	297,688	278,064	258,441	238,818

Sensitivity analysis shows that with a most unfavorable 10% decrease in natural gas price and a 10% increase in thermal energy price, Scenario 2 is still cost effective, with half

the NPV of the base model value. With a 10% increase in fuel price and a 10% decrease in thermal energy cost, NPV increases by approximately 30%.

4. Results and Discussion

When comparing real energy consumption with EPC data, it can be concluded that both groups show differences in actual energy consumption and specific energy consumption for heating. IGB systems differ from 11.19 kWh/m² to 101 kWh/m² in terms of specific energy consumption for heating, while DHS-connected ones differ from 3.16 kWh/m² to 18.58 kWh/m². Annual differences for DHS range from 4706 kWh to 542,820 kWh for total energy consumption for heating and differ less from EPC. The results for actual energy consumption and specific energy consumption for heating are shown in Tables 3 and 4. Due to the large heating surface area of building 5 connected to the DHS, buildings 1 and 8 with IGB systems have significantly higher total energy consumption than the other buildings from both groups. In addition, it can be concluded that the difference between total and specific energy consumption for 2018–2020 is minimal, mostly because of the similar climatic conditions during the observed heating seasons.

The differences in energy consumptions as mentioned earlier, both total and specific, occur as a consequence of one of the following factors: building design changes during the construction phase, measuring and regulation system for heating, heating system efficiency, installed equipment for heating, and the temperature regimes inside the heated areas.

Divergence of specific energy consumption for heating (Tables 3 and 4) is mainly caused by building design changes during the construction phase. These changes induce differences between the actual heating surface area (surface area after the construction phase) and the heating surface area defined in the EPC. Another reason for the differences in heating surface area is human error. Designers made errors while inputting data in EPC for heating surface area. Divergence of specific energy consumption directly affects the building’s energy consumption label (Figure 7). Differences in the energy consumption label are much more noticeable in buildings with IGB systems than in buildings connected to the DHS.

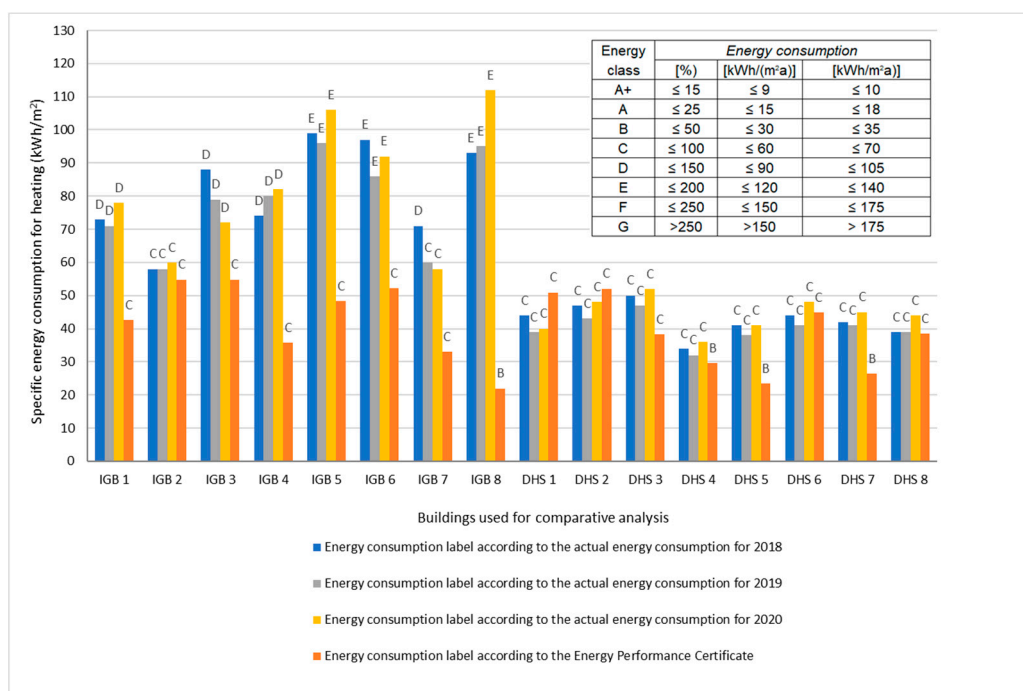


Figure 7. Comparative representation of actual energy consumption label and energy consumption label from EPC for IGB systems and DHS.

Figure 8 shows a comparative analysis of specific energy consumption for heating in 2018 (blue color), 2019 (gray color), and 2020 (yellow color).

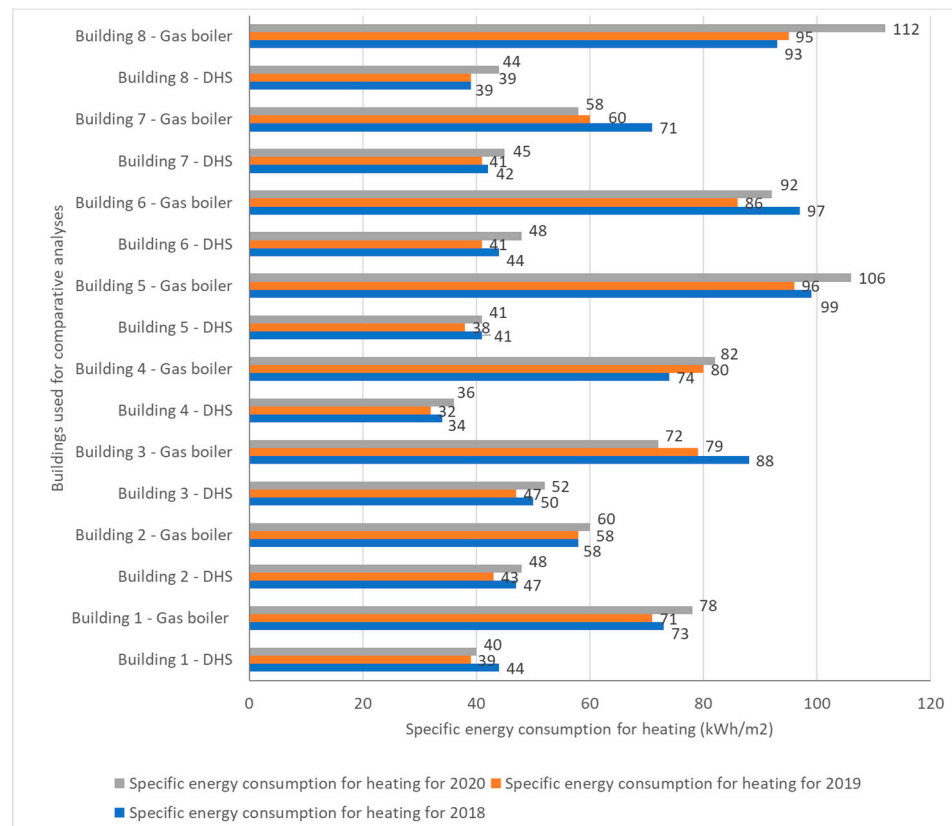


Figure 8. Comparative representation of specific energy consumptions for heating in 2018–2020 for both groups of buildings.

The analysis also shows that the heating system metering and regulation is a factor that affects total energy consumption for heating in both groups of buildings. Control of the heating system parameters (pressure, temperature, mass flow rate) can significantly impact energy consumption. This factor is something that EPC does not prioritize and consequently can be a cause for differences between total actual energy consumption and total energy consumption, calculated by EPC.

This factor is much more noticeable in the buildings with an IGB system. For this group of buildings, heating system parameters are set and regulated locally in the boiler room. Every building can have different temperature regimes inside heated areas depending on the subjective feeling of the occupants. In this case, the occupants' temperature and mass flow rate can be easily regulated with the assistance from the building management and maintenance service. Changes in temperature regimes inside heated areas affect fuel consumption and energy consumption for heating.

In the buildings connected to the DHS, this factor has less influence on energy consumption for heating. The measuring and regulation system is central and directly controlled by the power plant. Temperature regimes are strictly controlled and cannot be changed by the occupants (e.g., inside air temperature is set at 20 °C, ±1 °C [40]). As mentioned earlier in the section Materials and Methods, all selected buildings have the same or approximately the same heating equipment (e.g., valves, pumps, boilers, controllers, radiators). Due to the different equipment manufacturers, operational characteristics and efficiency can vary from 10 to 20% (based on EPC and manufacturer technical documentation).

Furthermore, the law and regulations do not clearly define whether it is necessary to perform technical control of EPCs, which further affects the fact that technical and

non-technical errors are made during their preparation. Those inaccuracies can easily lead end users to believe that a building is rated with a higher grade EPC, which will not be achieved in actuality.

The conducted research on the performance gap shows a significant difference between measured and predicted energy consumption. It is noticeable that there are more significant differences in buildings with IGB systems than in buildings connected to the DHS. All of the analyzed buildings connected to the DHS comply with the minimum permitted energy class “C”. However, there are two exceptions where the actual consumption cannot meet EPS’s targeted energy class “B”.

Most analyzed buildings with IGB show substantial differences. Only one building meets the goal of energy class “C” in only one season, while the others get the grade “D” or worse. The most significant difference is observed in building 8 EPC in the energy class “B”, for which measurements show energy consumption of grade “E”. One of the main reasons for such considerable difference is poor management and control of heat consumption (local regulation and metering by housing units are not available).

5. Conclusions

Any methodology for predicting energy consumption cannot be expected to be identical to real consumption. However, dramatic differences are unacceptable. The dramatic differences shown are not confined to only Serbia, and such examples are exhibited across Europe. This study examined 153 (135 DHS and 16 IGB systems) buildings in total. The sixteen most similar buildings were selected for presentation in this paper. The buildings connected to the DHS have much smaller gaps in terms of specific energy consumption for heating (3.16–18.58 kWh/m²), compared to IGB systems buildings (11.19–101 kWh/m²). It is determined that the building stock connected to the DHS in most cases meets the EPC grade, but with some offset. The same cannot be concluded for buildings with IGB systems. They perform one or even two grades below their theoretical EPC and fall below the country’s threshold. Only three of the eight buildings that were selected for DHS have a difference in energy class (buildings 4, 5, and 7). While on the other hand, six buildings connected to the IGB systems are one energy class below EPC, while two are two energy classes below EPC. Building EPC is a reliable indicator of actual energy consumption, but primarily for building stock connected to the DHS. In this context, the EPC could be a relevant instrument for building stock energy analytics and directing energy policy at the city level.

Conducted comparative analyses of the future building heating system roadmap showed that buildings connected to the DHS have a more efficient system than the buildings with IGB systems. A better control and automation system contributes to 30–50% less energy consumption for heating during the heating season. With a more efficient system, energy consumption will decrease, which will lead to lower greenhouse gas emissions.

The practice has shown that the new real estate buyers’ expectations may not be met when heating energy costs are considered. It is recommended to work on the new energy efficiency methodology revision and strengthen the design projects’ technical control due to the observed irregularities. The energy efficiency methodology should also provide an additional energy performance certificate based on annual (monthly) measured energy consumption. With this, users would be continuously informed about the actual building energy class and their heating consumption.

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