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THE IMPACT OF ENERGY IMPROVEMENT MEASURES IN SINGLE-FAMILY RESIDENTIAL BUILDINGS ON AIR POLLUTION IN THE CITY OF UŽICE

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The majority of existing architecture in Serbia has poor thermal characteristics, and heating systems are mostly based on polluting energy sources. This problem results in the unsatisfactory ecological image of cities, and it is endangering the health of the population. Therefore, improving energy performance is becoming an increasingly common principle of design, within both new and existing buildings. The starting point of this paper is that the use of more than sixteen thousand individual heating systems within single-family households in Užice is one of the most influential air pollutants in the city. The poor quality of energy sources and improper combustion processes release toxic substances into the atmosphere, but the cause of increased emissions of pollutants can be identified in the poor characteristics of thermal envelopes. This research explores whether there is a solution that reduces the pollution in single-family houses by changing the thermal envelope and heating system. The first part of the study points out the main characteristics of the Užice agglomeration, air pollution and energy sources, while the second part describes the selected single-family housing location in the city. The final part of the research examines the impact of various energy improvement measures on the air pollution in the city of Užice.

***Key words*: air pollution, single-family household, thermal envelope, individual heating system.**

INTRODUCTION

Long-standing discord between thermal comfort requirements and the sensitivity of the environment has led to the neglect of natural resources and excessive pollution. On the other hand, great progress in mechanical and structural systems has enabled their intensive use in the field of energy efficiency in many countries around the world. However, buildings in economically less-developed countries, such as Serbia, mostly have low energy performances, according to the Report on air quality in the city of Užice No. 8/19. This situation has led to a poor environmental picture and a negative health impact on the entire population.

Energy consumption in buildings in Serbia has been steadily increasing over the last decades. The dominant consumption is in households, the commercial sector, public buildings, industry and transport (Official Gazette of the City of Užice No 8/19, p. 141). The average heat energy consumption in Serbia is around 150 kWh/m^2, compared to about 50 kWh/m^2 in other European countries, which indicates the necessity for introducing energy efficiency improvement measures (Šumarac *et al.*, 2010).

The subject of the research is the impact of energy improvement measures in single-family residential buildings on air pollution in the city of Užice. The measures that can be applied are either connected to construction or to thermal engineering. Using the principles from the National Typology of Residential Buildings in Serbia, the thermal envelope improvements suggested include the appropriate insulation of façade walls and walls next to unheated spaces, as well as horizontal structures above the basement and below the loft (Jovanović Popović *et al.*, 2012a).

Furthermore, roof or floor reconstruction and window upgrades with suitable glass packages are some of the principles that can be applied. Thermal engineering measures are related to the introduction of new types of heating systems that have minor emissions of harmful gases compared to the existing ones. The goal is to find an

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environmentally friendly model that would be suitable for the city of Užice and its pollution problem.

The intended result of the research is to confirm information about the high air pollution in Užice from the individual combustion chambers of single-family buildings with inadequate energy performance, as well as to define the most ecologically efficient solutions for households that are a threatening factor for the surrounding environment. The main goal is to analyze the effects of reconstructing the thermal envelope and changing the heating system of single-family residential buildings on air pollution in the city of Užice. Furthermore, the goal of the proposed interventions is to achieve a higher energy class of buildings.

OVERVIEW OF THE AGGLOMERATION OF UŽICE

The aspect of city morphology

Užice is the capital of the Zlatibor district, which is the largest district in Serbia. The city is located at an average of 500 meters above sea level, which varies and at some points it exceeds 600 meters (Prostorni plan grada Užica, 2012). The city has a specific position; it is located in the valley of the river Djetinja and is surrounded by several hills. This hole-like relief has caused the present appearance of the city. There is no possibility for its expansion, and so the buildings have become taller. The city center is the only part that is not hilly (Figure 1).

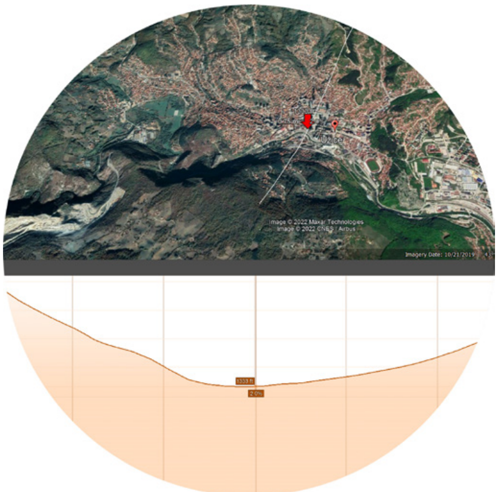

Figure 1. Review of the city morphology through a section across the city center
(Source: Author using Google Earth – earth.google.com)

The most influential factors that have had an impact on the urban development of the city are the valley, the river and the hills. The valley has affected the architecture, building sequences, building height, traffic, and communal installations. The river has green shores and is a recreational motif among the surrounding hills.

The structure of the city indicates that it was built spontaneously, in response to the terrain morphology. The chaotic position of irregular lines has been transformed into narrow residential streets over time. The lack of flat terrain has caused the territorial expansion of neighborhoods, streets and houses onto hilly ground. In the years after the Second World War, the city center was formed at the bottom of the valley, around the church, the municipality buildings and the grammar school. Similar to other smaller cities, Užice has one noticeable center where all activities are located. During the 1960s, the city changed the position of the main square, but the morphology did not allow these positions to be drastically distant from one another, so a larger center was created with two squares and the main functions that innervate them (Milivojević, 2014).

The aspect of city vegetation

As a result of the spontaneous expansion of the city, there is not enough fertile land in Užice. In addition, due to inadequate land use, negative processes such as soil erosion and landslides are very common in the peripheral area. The formation of green zones is largely determined by natural conditions, but also by the urban concept, since the city center is a lot more built-up, while greenery is mostly located along the riverside and on the peripheral slopes of the city. There is a large park on one of the slopes, which resembles an untouched forest, but contains paths and rest areas. However, the city's greatest green wealth is represented by the Green Trail through the Djetinja River Canyon.

Block greenery in the surroundings of residential buildings and greenery along city roads is often destroyed in order to increase pedestrian paths and parking spaces, so the city valley is lacking in green areas.

The aspect of city traffic

Užice is one of the largest traffic junctions in the southwestern part of Serbia. Dimitrija Tucovića Street (1 in Figure 2) and Kralja Petra Street (2 in Figure 2) stand out from the main city roads (Figure 2). These two streets are located at different altitudes and they limit the main square from the north and south sides. In order to create a connection between the main arteries, the square was designed in the form of several planes.

Figure 2. Main traffic roads in Užice
(Source: Author using National Infrastructure of Geospatial Data - a3.geosrbija.rs)

Considering the valley position of the city and the dense street network, traffic in Užice presents a significant environmental problem, especially when it comes to air pollution. Research by the Belgrade firm for designing traffic solutions, Model 5, shows that Užice needs five times more public parking spaces than it actually has (Model 5, 2021). Experts have stated that the daily volume of parking is about 6,400, and that the city has about 1,200 outdoor parking spaces and about 160 in the public garage. The overload of vehicles has caused the narrow and steep streets and sidewalks to turn into parking lots. For this reason, pedestrian and especially bicycle traffic in the city center is almost non-existent; the entire urban landscape is dominated by vehicular traffic.

The aspect of the city's climate

The territory of Užice is characterized by a moderately continental climate with elements of a hilly-mountainous climate from Stari Vlah. Cold air masses move to the south and bring cold weather, while at the same time, warm air masses move to the north and bring warm weather. In the territory of Serbia, including Užice, a continuous change of cold and warm air masses takes place. The nearest meteorological stations are located in Požega and Zlatibor, so the general climate characteristics for the city of Užice can be formed based on the data obtained from these two stations. The characteristics of the climate in Užice are warm summers and moderately cold winters, with very pronounced transitional periods, spring and autumn. The warmest month with the most sunshine hours is July, with an average temperature of about 20°C, and the coldest is December, with a temperature of about 1°C (Republički hidrometeorološki zavod, 2020).

In the winter period, there is a radiation temperature inversion, whereby cold air remains trapped in the ground layers of the atmosphere, while a front of warmer air forms above. In these conditions, vertical air circulation is disabled, so all emitted pollutants accumulate in the lowest layer of the atmosphere (Figure 3).

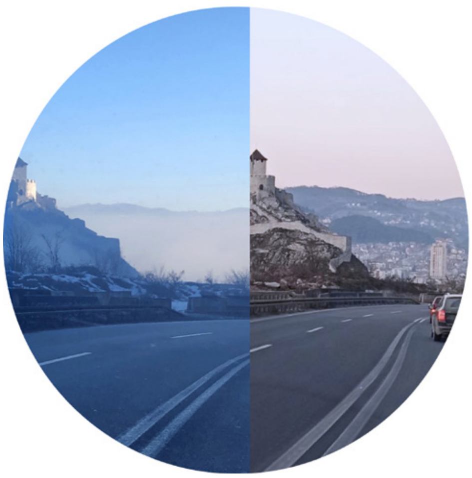

Figure 3. City views with and without temperature inversion (Source: Author – photographed in December and March)

OVERVIEW OF AIR POLLUTION IN THE AGGLOMERATION OF UŽICE

The causes of air pollution are numerous and can be classified into pollutants of natural and artificial origin. The leading artificial pollutants are created by the extraction and processing of mineral raw materials, the operation of communal and industrial facilities, traffic and the operation of heating systems and devices that primarily use fossil fuels (Vallero, 2014).

Air quality measurements in Serbia show that the concentration of polluting particles exceeds all European standards, and that Užice is one of the most polluted cities in the country.

In the Užice agglomeration, the air has been assessed as excessively polluted due to the presence of particles PM10 and PM2.5 (Knežević *et al*., 2021). In the winter season, an additional source of polluting emissions appears. Accordingly, an increase in the concentration of suspended particles is expected, and due to meteorological conditions, there may be a multi-day cumulative increase in concentrations during the heating season.

There are many different factors that cause this air pollution; some of them are related to the terrain configuration and climatic characteristics, but most of them happen because of heating systems, excessive traffic and industry. The specific location and high architectural structures disturb the ventilation and lead to the accumulation of harmful particles. In the central streets, ventilation is difficult and vortices trapping air pollutants are created. However, one of the most influential factors of air pollution in Užice is the use of individual fireplaces in households that use fossil fuel as the main source of heating energy. It is estimated that there are more than sixteen thousand individual fireplaces in Užice (Official Gazette of the city of Užice, No. 8/19). Due to the relatively low chimney positions, specific terrain configuration and disadvantageous flow of air masses, the products from individual fireplaces mostly stay in the lowest part of the atmosphere. Another issue is the poor quality of energy sources; the air quality report from 2018 states that more than 70% of households use wood and coal, but sometimes the poor economic situation results in waste materials being used. Increased emission of air pollutants can also be identified in the low energy performance of individual buildings. The poor characteristics of thermal envelopes usually cause higher energy consumption. Therefore, in order to reduce energy consumption and reduce air pollution, there is a great need for implementing energy improvement measures.

OVERVIEW OF HEATING SYSTEMS IN THE AGGLOMERATION OF UŽICE

The heating season is the driving force behind the increase in air pollution levels. According to the Statistical Office of the Republic of Serbia (2017), 22% of the total number of households in the country are connected to central heating, and electricity, or individual fireplaces burning various energy sources, are most often used for heating.

In Užice, 63.5% of households use either firewood, coal (most) or electricity as an energy source. Although there is a gas pipeline network, only 1,634 households use it for heating (MEEMP, 2022). Most of the heating devices are technologically outdated or are designed for a certain type of fuel, which the local population does not usually comply with. Fuel that is not adequate for a suitable firebox does not burn as it should. It leaves toxic products along the chimney, from where those products are emitted into the atmosphere and they manifest as soot. More than 50% of suspended particles originate from heating plants with a capacity of less than 50 MW and individual furnaces (Knežević *et al*., 2021). Chimneys from combustion plants are often at low altitudes, so in combination with frequent temperature inversions, they contribute to the fact that the emitted poisonous gases remain in the ground layer of the atmosphere.

Heating devices in Serbia are not subject to strict standards of environmental protection or ecological design. Accordingly, the assumption is that the first step towards a solution that reduces air pollution is the introduction of stricter standards for heating devices, and then the application of innovative technologies within the economic capabilities of the population (Jovović, 2021).

ANALYSIS OF THE SUBJECT LOCATION OF SINGLE-FAMILY HOUSING IN UŽICE

Methodology of data collection for the analysis

The selection of relevant houses is a key segment of the research work, because the typology for analyzing potential energy optimization is based on the selected houses. In this section, the basic criteria for defining reference units for single-family housing are presented, as well as elementary data about them, primarily referring to their thermal envelopes and heating systems. These parameters are important for energy rehabilitation and the reduction of air pollution in the chosen site. Furthermore, since the city of Užice contains a large number of single-family residential buildings located in a similar urban pattern as the location in question, the research results could be applicable to the entire city.

Using the methodology for data collection and analysis carried out in the Atlas of Family Houses of Serbia (Jovanović Popović *et al*., 2012b), the typology is based on architectural and urban parameters, thermal performance and the construction period. In addition to these categories, as one of the key aspects of research related to air pollution in the city, the heating systems in the houses are also included.

The first step of the research was to determine and analyze the existing condition of the housing, and direct contact with residents allowed an adequate insight into the various characteristics of the buildings. There are 40 houses on the site, of which it was possible to survey the residents of 30 family houses. Since some of the residents were not familiar with the construction method and building materials used, it was assumed that they were constructed in the same way as the corresponding houses in the Atlas of Family Houses of Serbia that were built in a time period and climate close to them. Certain similarities were noticed among the houses, so the research work was reduced to three representative types, which will be discussed further in section 5.3.

Using the principles from the National Typology of Residential Buildings of Serbia (Jovanović Popović *et al*., 2012a), each type of house was theoretically upgraded with basic and advanced improvement. All three representative house types were found in very bad condition and after the calculations were done in KnaufTerm software, they were classified with energy class G. Since there was an upgrade related to the thermal envelope and heating system, six variants were created for each house: basic and advanced improvement of the heating system without changing the envelope, basic and advanced improvement of the envelope with the existing heating system, and two improvement levels with both the envelope and heating upgraded. Some of the proposed changes aimed at energy rehabilitation and the reduction of air pollution, as well as an increase in the energy grade of the buildings.

When calculating the emission of pollutants, following the Regulation on the Energy Efficiency of Buildings, the amount of carbon dioxide emissions calculated was substantial. It was assumed that the theoretical upgrades emissions, while reducing the level of carbon dioxide, also reduced the level of other pollutants affecting air pollution. In this study, the emission of carbon dioxide was determined for each type of energy improvement for the selected houses.

Analysis of the current state of the site

Due to the specific morphological position of Užice, the subject location was selected in an area near the city center, at an altitude lower than the surrounding hills. The emission of harmful gases in this part of the city, due to the temperature inversion during the heating period, remains trapped and directly affects the atmosphere. In the narrowest part of the city core, which is most susceptible to air pollution, the presence of multi-family housing is dominant, while single-family housing is more common going from the center to the periphery of the city. Accordingly, the selected area is made up of single-family housing situated close to the city center, but which is still in the valley (Figure 4).

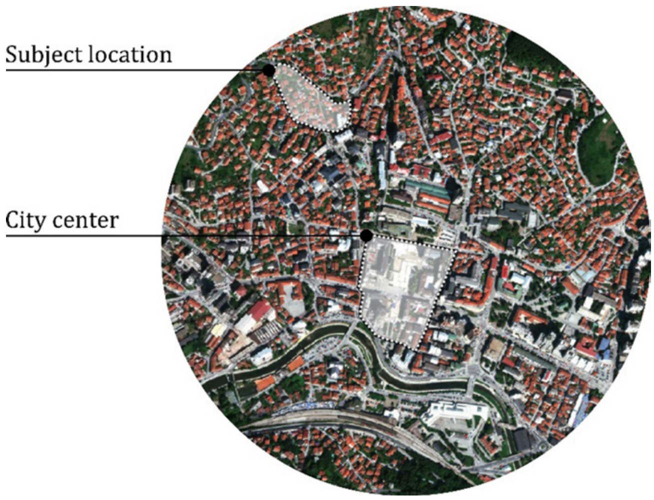

Figure 4. Position of the subject location in relation to the city center (Source: Author – using National Infrastructure of Geospatial Data - a3.geosrbija.rs)

The subject location is surrounded by streets of low intensity. Parking is mostly arranged within the limits of individual lots, and there are no sidewalks for pedestrians. Built structures prevail, as opposed to green areas. Some lots have backyard greenery, but there are no public and recreational green spaces in this context. There are differences between the houses and their number of floors, but most of the houses are freestanding and semi-detached with up to two floors. Certain similarities were observed between the family houses, and three characteristic types were distinguished.

Overview of selected houses on the site

The first selected type is a freestanding rectangular base house on a sloping terrain that is typical for Užice's region. The house was built between 1919 and 1945 with solid brick walls and a gable roof, just like a similar house from the Atlas of Family Houses of Serbia (Figure 5). Its single-paned wooden windows are small and glazed. Less than 50% of the house façade is made up of doors and windows that are between 30 and 40 years old. The slope was used for creating a basement that is not heated, and the roof is suitable for having a loft but the attic space has not been not adapted for use. The façade is unfinished and has no thermal insulation (TI). The entire residential part of the house is heated by local coal stoves located in each room.

Figure 5. The first house type and similar house from the Atlas of Family Houses of Serbia
(Source: left image is by the author and the right image is from Jovanović Popović et al., 2012b)

The second type is a freestanding rectangular base house on a particularly sloping terrain that was used for building a basement garage and summer kitchen, which can be accessed directly from the street (Figure 6). The house was built between 1946 and 1970, with brick walls and a simple gable roof. Less than 50% of the façade is made up of doors and windows that are between 30 and 40 years old. The carpentry is mostly small, and it is glazed with single-panel glass, similar to the first house type. The façade is finished, but there is no thermal insulation (TI). The ground floor and the first floor are heated by a local coal heating system (LHS), while the basement and attic are not heated. Similarly, the house from the Atlas of Family Houses of Serbia was built in 1970 in Užice, with the same characteristics as the second house type from this paper.

The third type is a freestanding house with a square base built between 1981 and 1990, just like a similar house from the Atlas of Family Houses of Serbia (Figure 7). Unlike the previously mentioned houses, this one is located on a flat

Figure 6. The second house type and a similar house from the Atlas of Family Houses of Serbia
(Source: left image is by the author and the right image is from Jovanović Popović et al., 2012b)

surface and there is no basement floor. The attic space is present but it is not adapted for use and it is not heated. A few years after its construction, the house became overshadowed by a five-story building. Less than 50% of the openings on the façade are as old as the house (about 30 years old). The façade walls are made of bricks and insulated with 5-centimeter-thick thermal insulation (TI). The entire facility is heated using a central heating system (CHS) with solid fossil fuel.

Figure 7. The third house type and a similar house from the Atlas of Family Houses of Serbia
(Source: left image is by the author and the right image is from Jovanović Popović et al., 2012b)

According to the results obtained using the software for testing the energy performance of buildings, based on the current regulatory framework in Serbia (KnaufTerm), all house types belong to energy class G. An overview of three house types is presented in Table 1.

Table 1. Three house types and their characteristics

House type	Period of construction	House base	Site	Basement space	Attic space	Openings	façade	Roof	Heating system
First house type	1919-1945	Rectangular base	Sloped terrain	Not adapted for use	Not adapted for use	Less than 50% of the façade	Masonry walls 38 cm and no TI	Gable roof	LHS with solid fossil fuel
Second house type	1946-1970	Rectangular base	Sloped terrain	Not adapted for use	Not adapted for use	Less than 50% of the façade	Masonry walls 38 cm and no TI	Gable roof	LHS with solid fossil fuel
Third house type	1981-1990	Square base	Flat surface	No space	Not adapted for use	Less than 50% of the façade	Hollow brick walls 25 cm and TI 5 cm	Gable roof	CHS with solid fossil fuel

ENERGY IMPROVEMENT MEASURES

Construction measures

When it comes to construction measures for energy improvement, two possible levels of improvement for the family houses were considered. The first level is a set of standard measures that are common on the domestic market and the second level involves the use of unconventional measures that require a larger volume of investment.

In the context defined by the Regulation on the Energy Efficiency of Buildings, the goal of the first level of improvement is defined as improving the energy class by at least one energy level. Accordingly, the first level of improvement includes replacing the existing carpentry, as well as improving the thermal characteristics of the walls, ceilings and roofs by adding layers of thermal insulation where available. Wall intervention is the most common and economical method to improve the energy efficiency of new and existing buildings. Ceilings and roofs are also insulated with additional layers of thermal insulation, installed subsequently or integrated into the existing structure.

The second level of energy renewal foresees measures that maximize the energy class of the house being renovated. Measures mostly involve the replacement of woodwork with the highest quality windows and doors that can be found on the domestic market, as well as the installation of thermal insulation layers of unusual thickness within the thermal envelope of the house.

Improvement of heating systems

Improvements in the energy performance of single-family residential houses in the study location were considered at the same time as improvements in the heating systems. In this area of research, there is a wide range of energy sources and heating systems.

In the first stage of improvement using KnaufTerm software, the energy source was changed and the heating system was modernized, while in the second, the use of technologically modern equipment available on the market was considered. Local wood, coal and electricity stoves used either individually or as part of a floor or central heating system, were upgraded to a central system with a low-temperature natural gas boiler. The second level of improvement involved the introduction of a central heating system with a condensing boiler and an air to water heat pump system.

Energy balance

Using software for screening the energy status of buildings (KnaufTerm), the following parameters were calculated: total energy required for heating and annual energy required for heating (per square meter), final and primary energy, energy class and emission of carbon dioxide.

The results were initially calculated for the existing condition of the houses and then for six varieties of each house. By reviewing the results, it can be concluded how much energy can be saved with each level of improvement. Also, potential interventions on energy sources and heating systems show how much carbon dioxide emissions would be reduced, which is relevant to the topic of the research paper.

COMPARATIVE ANALYSIS OF THE RESULTS

This section presents a comparison of the results, primarily, the energy required for heating and the specific annual energy required for heating, as well as the primary and final energy, energy class and carbon dioxide emission.

Table 2. Comparative presentation of the results

First house type			
Thermal envelope – energy balance			
	Specific annual energy required for heating [kWh/m²a]	Energy class	Final energy [kWh]
Existing condition of the house	460	G	27310
Basic improvement of the heating system without changing the thermal envelope	460	G	17230
Advanced improvement of the heating system without changing the thermal envelope	460	G	5920

Basic improvement of the thermal envelope without changing the heating system	150	E	8940
Advanced improvement of the thermal envelope without changing the heating system	115	D	5210
Basic improvement of the thermal envelope and heating system	150	E	5640
Advanced improvement of the thermal envelope and heating system	115	D	1440

Heating system – energy balance

	Energy required for heating [kWh]	Energy for heating	Primary energy [kWh]	Carbon dioxide emission [kg]
Existing condition of the house	16020	Coal	35500	11720
Basic improvement of the heating system without changing the thermal envelope	16020	Natural gas	18960	3800
Advanced improvement of the heating system without changing the thermal envelope	16020	Electricity	1790	7840
Basic improvement of the thermal envelope without changing the heating system	5240	Coal	11610	3840
Advanced improvement of the thermal envelope without changing the heating system	3900	Coal	6770	2240
Basic improvement of the thermal envelope and heating system	5240	Natural gas	6200	1240
Advanced improvement of the thermal envelope and heating system	3900	Electricity	3600	1910

Second house type

Thermal envelope – energy balance

	Specific annual energy required for heating [kWh/m^{2}a]	Energy class	Final energy [kWh]
Existing condition of the house	490	G	70780
Basic improvement of the heating system without changing the thermal envelope	490	G	44670
Advanced improvement of the heating system without changing the thermal envelope	490	G	15340
Basic improvement of the thermal envelope without changing the heating system	145	E	21050
Advanced improvement of the thermal envelope without changing the heating system	105	D	15190
Basic improvement of the thermal envelope and heating system	145	E	12960
Advanced improvement of the thermal envelope and heating system	105	D	3290

Heating system – energy balance

	Energy required for heating [kWh]	Energy for heating	Primary energy [kWh]	Carbon dioxide emission [kg]
Existing condition of the house	41520	Coal	92000	30370
Basic improvement of the heating system without changing the thermal envelope	41520	Natural gas	49130	9830
Advanced improvement of the heating system without changing the thermal envelope	41520	Electricity	38340	20320
Basic improvement of the thermal envelope without changing the heating system	12050	Coal	27370	9030
Advanced improvement of the thermal envelope without changing the heating system	8910	Coal	19750	6520
Basic improvement of the thermal envelope and heating system	12050	Natural gas	14260	2850

Advanced improvement of the thermal envelope and heating system	8910	Electricity	8230	4360
Third house type				
Thermal envelope – energy balance				
	Specific annual energy required for heating [kWh/m^{2}a]	Energy class	Final energy [kWh]	
Existing condition of the house	305	G	72310	
Basic improvement of the heating system without changing the thermal envelope	305	G	45630	
Advanced improvement of the heating system without changing the thermal envelope	305	G	15670	
Basic improvement of the thermal envelope without changing the heating system	160	F	37670	
Advanced improvement of the thermal envelope without changing the heating system	105	D	30070	
Basic improvement of the thermal envelope and heating system	160	E	23770	
Advanced improvement of the thermal envelope and heating system	105	D	5360	
Heating system – energy balance				
	Energy required for heating [kWh]	Energy for heating	Primary energy [kWh]	Carbon dioxide emission [kg]
Existing condition of the house	42420	Coal	93970	31020
Basic improvement of the heating system without changing the thermal envelope	42420	Natural gas	50200	10040
Advanced improvement of the heating system without changing the thermal envelope	42420	Electricity	39170	20760
Basic improvement of the thermal envelope without changing the heating system	22100	Coal	48970	16160
Advanced improvement of the thermal envelope without changing the heating system	14500	Coal	39090	12900
Basic improvement of the thermal envelope and heating system	22100	Natural gas	26150	5230
Advanced improvement of the thermal envelope and heating system	14500	Electricity	13390	7100

CONCLUSION

Discussion

From the energy aspect, it can be stated that most of the houses included in this research do not meet the standards, which is not a surprising phenomenon for certain construction periods and the way they were built, since they do not comply with regulations and adequate documentation.

The basic improvement of the thermal envelope refers to the addition of layers of thermal insulation to elements that are not or are insufficiently insulated. Furthermore, the change includes replacing the existing carpentry. This upgrade increases the energy class by two levels. Advanced improvement involves increasing the thickness of the thermal insulation and installing even better-quality carpentry, with improved sealing of joints and multi-layer glazing filled with inert gas. Advanced improvement increases the energy class by one more level. Considering the fact that the initial houses belong to class G, with this kind of improvement, the maximum achieved energy class is D. An attempt to reach energy class C would require the installation of thermal insulation of irrational thicknesses and even then, it would be a problem to reach the maximum range on the energy scale. Therefore, reaching energy level C would mean a total reconstruction of the house and a potential change in the geometry of the study houses.

In accordance with the main theme of the research paper, the selected examples of houses have heating systems that burn fossil fuels. There are houses on the site that are heated by electricity or gas, but the dominant heating source is coal.

Taking into account that the method for calculating the annual energy for heating per square meter considers the energy required for heating and the surface area of the heated house space, the results show that the annual energy for heating per square meter is lower for larger heating spaces. The first house type, which has about 35 m^2 of heated space, requires less energy for heating, but the annual energy for heating per square meter is high. The second type requires more energy for heating because it has about 85 m^2 of heated space, and the annual energy required for heating per square meter is slightly higher compared to the first type. The third type of building has the largest heating volume and heated surface of 140 m^2, so it requires the largest amount of energy for heating. However, the annual energy per square meter is lower compared to the first two examples. According to the calculation in KnaufTerm, significantly higher final and primary energy values are obtained for the existing second and third type, as well as higher carbon dioxide emissions, compared to the first type (Table 3).

Table 3. Comparison of energy required for heating, annual energy required for heating, final energy and primary energy for three house types

	Type 1	Type 2	Type 3
Energy required for heating [kWh]	16020	41520	42420
Annual energy required for heating [kWh/m^2a]	460	490	305
Final energy [kWh]	27310	70780	72310
Primary energy [kWh]	35500	92000	93970

Concluding remarks

Carbon dioxide emissions are a direct consequence of primary energy needs. According to the Rulebook on Energy Efficiency of Buildings from 2011, primary energy is from renewable and non-renewable energy sources that have not undergone a conversion or transformation process; primary energy is contained in the energy source. The annual primary energy is the sum of all the primary energies required for the operation of technical systems for heating, air conditioning and the preparation of sanitary hot water in one year. This type of energy is obtained by multiplying the annual energy supplied with the conversion factor for certain types of sources. It can be concluded that the emission of carbon dioxide depends on the energy used for heating.

The consequences of burning fossil fuels, with a conversion factor of 1.3, directly affect the pollution of the site. On the other hand, the use of electricity, with a conversion factor of 2.5, has no direct impact on the immediate environment, but the consequences of the production of electricity for heating are very bad for the entire living environment. Therefore, it turns out that a heat pump which uses electricity indirectly produces a larger amount of carbon dioxide than a natural gas condensing boiler.

For the proposed varieties, the results show that, in terms of carbon dioxide emissions, it is best to carry out a basic construction improvement with a change of the heating system to a natural gas condensing boiler. On the other hand, the problem with a natural gas supply is the limited reserves worldwide, which indicates higher costs for transportation and storage, considering the fact that there is only a small amount of natural gas of domestic origin. The largest number of individual households use coal because the price is lower than using natural gas, but only by 15%. Therefore, it is necessary to burden outdated technologies with air pollution taxes, while at the same time promoting clean technologies with subsidies, as outlined in the Spatial Heat Supply Program for the city of Užice 2022-2030.

Using a heating system like a thermal pump is unaffordable for most of the population, because the price of this system is high for individual households. However, the Spatial Heat Supply Program suggests that renewable energy sources and heat pumps might be used in remote heating and that individual households that are in the area of the district heating network should be offered incentives to connect to it (MEEMP, 2022).

By analyzing the results of the research, it can be seen that a change in the heating system does not affect the energy needs of the house. Accordingly, the first step towards efficiency would be to implement building improvement measures. On the other hand, when it comes to the emission of carbon dioxide, switching the use of fossil fuels to natural gas reduces the emission of carbon dioxide almost threefold in each of the selected examples. The best results are shown by advanced improvement, whereby the primary energy needs are up to five times lower, and carbon dioxide emissions more than ten times lower.

By comparing the results with types of buildings in the National typology of residential buildings, it can be concluded that the results are very similar. The National typology of residential buildings also discusses improving the heating and hot water system; however, it is not discussed in this research. Even without such improvements, the carbon dioxide emissions are still more than ten times lower (Jovanović Popović *et al*., 2012a).

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