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Igor Tucaković, tucakovicigor93@gmail.com, University College of Civil Engineering and Geodesy, Belgrade

Marina Nikolić Topalović, marinatopnik@gmail.com, University College of Civil Engineering and Geodesy, Belgrade

Tanja Trkulja, tanja.trkulja@aggf.unibl.org, Faculty of Architecture, Civil Engineering and Geodesy, University of Banja Luka

CASE STUDY OF THE IMPACT OF THE STRUCTURE AND THICKNESS OF THE THERMAL ENVELOPE ON THE ENERGY CLASS OF THE INDIVIDUAL SINGLE-FAMILY HOUSING

Abstract:

The aim of the research is to obtain optimal ranges of thermal envelope for the desired energy classes, which will contribute to a more economical and rational approach to the design of buildings, as well as to prove that with the increase of thermal envelope there is an increase of the energy class. The model on which the research was formed and applied is a typical semi-detached house in Belgrade. By comparing the results of the reference family house, the framework parameters for the satisfaction of a certain energy class have been formed, based on the fulfillment of the energy efficiency requirements established by national regulations.

Keywords: improvement of energy properties, thermal insulation sheath, energy class of building, single family housing

СТУДИЈА СЛУЧАЈА УТИЦАЈА СТРУКТУРЕ И ДЕБЉИНЕ ТЕРМИЧКОГ ОМОТАЧА НА ЕНЕРГЕТСКИ РАЗРЕД ЗГРАДЕ ИНДИВИДУАЛНОГ ПОРОДИЧНОГ СТАНОВАЊА

Сажетак:

Циљ истраживања је добијање оптималних распона термичког омотача за жељене енергетске разреде, што ће допринети економичнијем и рационалнијем приступу пројектовању објеката, као и доказ да са повећањем термичког омотача долази до пораста енергетског разреда. Модел на којем је формирано и примењено истраживање је типична двојна кућа у Београду. Упоређивањем резултата референтне породичне куће формирани су оквирни параметри за задовољавање одређеног енергетског разреда, а на основу испуњености услова о енергетској ефикасности утврђених националном регулативом.

Кључне ријечи: унапређење енергетских својстава, термоизолациони омотач, енергетски разред зград, зграде индивидуалног становања

1. INTRODUCTION

In 2011, the European Commission adopts the Roadmap for Resource Efficient Europe, outlining the actions to be taken [1] to mitigate the effects of climate change. At a global level, construction is, along with traffic, the largest sector in terms of consumption of resources and consequently of environmental impact [2]. In an effort to reduce these impacts, the European Commission [1] calls for action at a global level in terms of progress in saving energy and resources in general, in the production of construction materials and in the use of facilities. Energy consumption is directly related to the production of greenhouse gases (GHG). In Serbia, the construction sector in 2008 participated with 38.50%, and in 2011. 49.16% in final energy consumption [3]. In 2009, Serbia had the highest per capita energy consumption, higher than Croatia and BiH [4]. With the adoption of the Planning and Construction of Buildings Act in 2009 [5], energy efficiency and the rational use of materials are being recognized as a sustainable building model. By the adoption of the legislation on the energy efficiency of buildings in 2011 [6-7] and its mandatory implementation some progress has been made. Per capita energy consumption indicators for Serbia in 2013 show that it is declining but still is the highest in the region [8]. More than 50% of Serbia's environmental footprint comes from CO2 production [9]. A part of Serbia's environmental footprint comes from the use of energy to heat buildings [10]. By introducing the obligation to energy-rank and rehabilitate buildings, an effort has been made to reduce the energy used to heat the buildings. Research on energy consumption in buildings has shown that much of the environmental impact of a buildings (about 80%) is due to the use of the buildings [11 - 12]. Energy efficiency is also discussed by many local authors who analyze buildings in Serbia [13-14].

However, recent research in this area points to the fact that the application rate for the thermo-insulation of buildings increases the amount of materials built into the buildings [15-16], and thus the embodied energy, i.e. the impact on the environment through the built-in materials, according to research of some authors [19-22]. The "embodied carbon" part of the carbon footprint has been left unjustly neglected when analyzing the impact of buildings over the life cycle, which is an observation made in new research into the environmental impact of buildings [21 - 24].

According to the National Typology of Residential Buildings of Serbia, single-family dwellings are represented by 96.3% compared to 3.7% of multi-family dwelling.[25] This relation between family and multi-family housing is the reason why research is being conducted on the project of family housing.

This paper will present the results of the research from the defended Master's Thesis at the College of Civil Engineering and Geodesy in the subject of Energy efficiency and certification of buildings. For the purpose of research and calculation of energy class, a model [26] of a new individual residential building in Belgrade was designed with conventional building materials which are used for the construction of buildings of this type. For the purpose of the research, three models of the same design have been formed, and for each of the models polystyrene sheets or hard mineral wool boards, in different thicknesses, are used as additional thermal insulation of thermal envelope, which will show what energy class can be achieved, and what differences in energy needs to heat the facility can be expected. In this sense, the energy required per m2 of the building was calculated for each of the project models formed and energy classification was performed according to the current legislation in the Republic of Serbia. [6-7]. Therefore, it is possible, even at the stage of conceptual design, to propose the thickness and structure of thermal envelope so that the energy class of the buildings can be planned in the design phase. Also it is possible to propose a thermal envelope assembly with less environmental impact and optimize the selection and use of thermal insulation materials as part of the thermal envelope project.

In addition to the thickness and structure of the thermal envelope, the thermal conductivity characteristics (λ) of the building materials used will be calculated for each model by the heat transfer coefficients (U) of the characteristic assemblies. This research aims at comparing the preliminary design of a new individual single-family housing to the extent on which progress in energy ranking can be achieved by adding a thermal insulation layer in different thicknesses from the outside of the thermal envelope. The second goal set in this research is to compare the two most commonly used thermal insulation materials, Polystyrene and Mineral wool, and their contribution to the energy ranking of the analyzed project of a newly designed individual single-family housing. The research also has the third objective of comparing three common systems of construction of individual residential buildings in Serbia, from the aspect of energy ranking.

Other criteria: the financial or life expectancy of the materials used in this paper will not be considered and evaluated.

This information is important because at the design stage, measures can be proposed to optimize the energy class of the buildings and the materials used in the thermal envelope structure. The goals of the research are to quantify the relation between the thickness and the structure of the thermal envelope with the reduction of the required energy for heating the building according to the current regulations in Serbia, and the calculation of the energy class of the building [6-7]. The analysis of different variants of the model of the house should indicate the relation of thickness and type of thermal insulation with the influence on the energy class, as well as the results obtained to explain and give indicative parameters when forming a knowledge base for the design of architectural projects in the conceptual design phase.

2. DESCRIPTION OF THE RESEARCH

The subject of this research covers measures for improving the energy efficiency and energy class of individual residential buildings in Serbia, as well as improving the thermal envelope in order to reduce energy loss during the operational phase. Efforts are made to calculate the approximate values of the required energy for heating an object by comparing different circuits and thicknesses of the thermal envelope, in accordance with the current regulations in the Republic of Serbia [6-7], for the construction of new facilities. According to the current regulation [6-7], the minimum acceptable energy class for new buildings is C. [6-7].

The aim of this research is to form framework parameters in terms of thickness and type of thermal insulation that is necessary when determining the input data related to the thermal envelope calculation as part of the energy efficiency study.

It is necessary to make accurate calculations for each facility when designing an energy efficiency study, and this research should provide basic guidelines in terms of the thermal insulation thickness to be added within the thermal envelope to achieve the desired energy class.

The research uses the usual materials for the construction of family houses in Serbia to form models. The two most commonly used thermal insulation materials, Polystyrene and Mineral wool, in different thicknesses are used as additional thermal insulation materials to determine how much difference in the achieved energy class can be achieved by increasing the thickness of the thermal insulation layer, or by selecting the type of thermal insulation, or by selecting construction material as the basic structure in the thermal envelope.

The study analyzed the thermal envelope of a new semi-detached family house, in order to compare the most commonly used thermal envelope assemblies that are used both in the design of new buildings and in the energy rehabilitation of existing facilities to improve energy performance. For the purposes of the research, the Ursa Building Physics 2 software package [27] was used, which is one of the software packages in accordance with national regulations in the field of energy efficiency in Serbia [6-7].

The study is conducted under the assumption that the facility is in the city of Belgrade and all data will be used accordingly to the parameters in national legislations [6] for this territory of the Republic of Serbia.

2.1. Model

The building on which the study was conducted is a project of new semi-detached family house in the city of Belgrade in Zvezdara municipality, in Hajduk Stankova street. The semi-detached house is designed as a newly built freestanding building on a plot with surrounding low-growing and high-growing greenery. The facility consists of two symmetrical houses designed for individual housing for two five-member families. The base of the object is shown in Fig. 1 and the floor in Fig. 2. The adjacent plots contain freestanding facilities, which do not obscure the analyzed object in terms of forming a cut or additional reflection that would affect the analyzed object. The ground floor is intended for daily activities of the family and consists of hallway, staircase, guest toilet, living room, dining room, kitchen and terrace. The floor is designed as a bedroom block consisting of a hallway, one single and one double room, parent room, master bathroom, children's bathroom, office and balcony. The attic is an attic space below the roof and does not have a housing function, which means that the thermal envelope borders the attic space.

The structure of the building is skeletal with supporting reinforced concrete columns measuring 25x25 cm, at distances of 4 to 6 m, with a fill formed by façade walls, rusted bricks, solid bricks or Ytong blocks.

For three types of plastered facade walls: hollow bricks d = 25 cm, (densities ρ = 1400 kg / m3), solid bricks d = 25 cm, (densities ρ = 1200 kg / m3) and Ytong block d = 25 cm (density ρ = 350 kg / m3). Three models of the same design were formed in that way, and the thickness of the facade wall varies depending on the thickness of the thermal insulation, which is added to the basic structure of the facade wall in the model. The form factor of all the models analyzed, is the ratio between the surface of the thermal envelope of the building (exterior dimensions) and the gross volume covered by it, is fo = 0,436.

The thermal characteristics of thermal conductivity (λ) of the building materials used for each of the formed models, and according to the current legislation in the Republic of Serbia [6] are shown in Table 1.

Table 1. *Thermal conductivity of materials used in submodes (colored boxes indicate the presence of material in the assembly)*

Facade wall materials used in submodels		Submodels used in case study						λ [W/mK]
		M1S	**M1V**	**M2S**	**M2V**	**M3S**	**M3V**	
1.	Hollow brick	■	■					0,610
2.	Solid brick			■	■			0,470
3.	Ytong block					■	■	0,100
4.	Polystyrene	■		■		■		0,041
5.	Mineral wool		■		■		■	0,036
6.	Cement mortar	■	■	■	■	■	■	1,400
7.	Pigment fasade plaster	■	■	■	■	■	■	0,700
8.	PVC foil	■	■	■	■	■	■	0,190

For the formed models it should be emphasized that in the layer of floor construction according to the external terrain, the same thickness of thermal insulation is planned as in the model intended for the walls. For the floor-to-ceiling structure, for solid and hollow brick models, the calculation is done with the TM ceiling, and the thickness and type of thermal insulation is the same as that provided for in the walls.

For a model built from the Ytong block, it is calculated with the Ytong type ceiling and the thermal insulation applied in the wall structure.

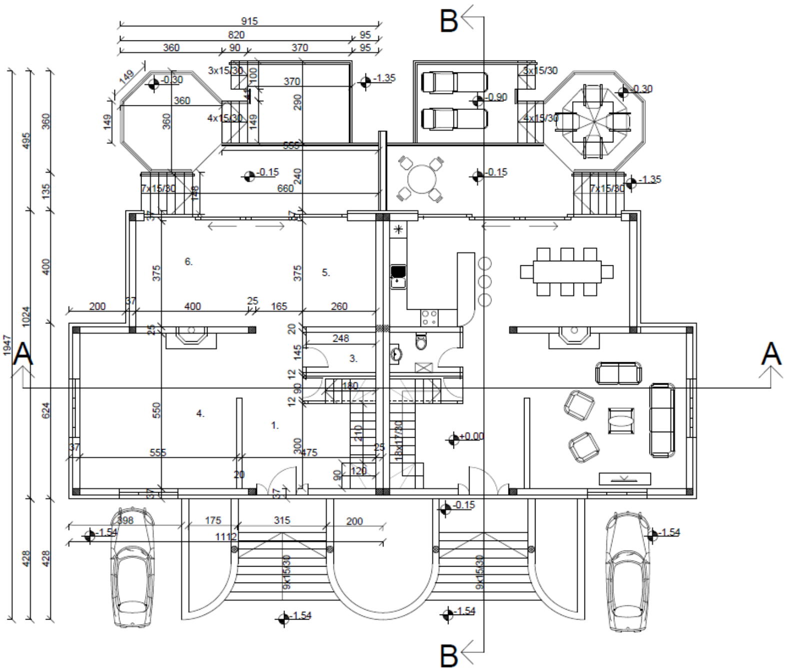

Figure 1. *Ground plan of the analyzed model*

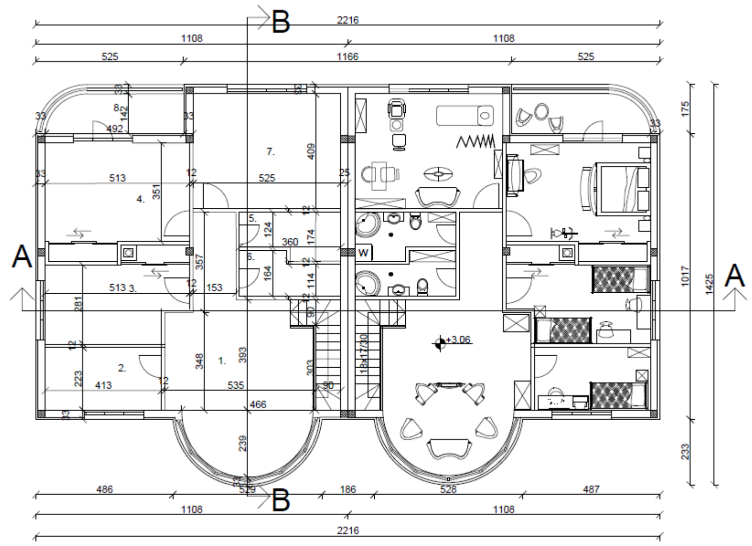

Figure 2. *Floor plan of the analyzed model*

For the purpose of research, three models of facade walls were formed, M1 (hollow brick facade wall d = 25 cm), model M2 (solid brick wall d = 25 cm) and model M3 (Ytong block facade wall d = 25 cm). Each of the analyzed walls is plastered on both sides, which is a common way of finishing the facade walls in Serbia. For each of the three facade wall models analyzed, it is planned to use two types of thermal insulation materials, polystyrene sheets in one variant and hard mineral wool plates in the other variant. Thus, a total of six submodels are obtained: M1S (hollow brick + polystyrene), M1V (hollow brick + mineral wool), M2S (solid brick + polystyrene), M2V (solid brick + mineral wool), M3S (Ytong block + polystyrene) and M3V (Ytong block + mineral wool).

Each model group first calculates the energy class of the building, which does not have a layer of thermal insulation material in the thermal envelope structure, and determines the energy class, that is, the energy consumption for heating the object per m^2 of useful floor space in accordance with the Building Energy Efficiency Regulations [6]. Then, in further research, using different thicknesses of thermal insulation of polystyrene sheets or mineral wool in the thickness of 2, 5, 10, 12, and 15 cm, the energy requirements of the building per m^2 of heated surface are calculated and the energy class is calculated. The thickness of the facade wall directly influences the relationship between the net and the gross surface of the building, so the thickness of the façade walls will be presented in further research. In this way, the thickness of the façade wall, the required thermal insulation and the energy required to heat the object per m^2 can be compared, that is, the energy class of each sub-model analyzed. It should be emphasized that the same thickness of thermal insulation is planned both in the floor towards the ground and in the ceiling towards the unheated space.

3. THE RESULTS OF THE RESEARCH

By investigating three models: M1 (hollow brick facade wall), M2 (solid brick facade wall) and M3 (Ytong block facade wall) with the addition of polystyrene or hard mineral wool thermal insulation, six submodels were formed for which research was carried out: M1S (hollow brick + polystyrene), M1V (hollow brick + hard mineral wool boards), M2S (solid brick + polystyrene), M2V (solid brick + hard mineral wool boards), M3S (Ytong block + polystyrene), M3V (Ytong block + hard mineral wool boards).

By adding thermal insulation materials to the thermal envelope structure (facade walls, ground floors and attic to unheated space), 36 output results for the specific annual energy required for heating were formed and calculated per m^2 of heated space. Based on this calculation and according to the Regulation on Energy Efficiency of Buildings [6] the energy class for each variant is shown in the following tables. In addition to these important data, the tables also show the thickness of the facade walls, that is, the structure of the wall with a clearly shown type and thickness of the thermal insulation layer, which is in the structure of the thermal envelope for the energy classes from the lowest F to the highest B, which could be achieved in the analyzed models by adding thermal insulation in thermal envelope structure.

Table 2. shows the values for the M1S sub-model (hollow brick + polystyrene), the structure of the thermal wall sheath, the thickness of the polystyrene in the model structure, the energy class achieved, and the numerical value of the specific annual energy required for heating per m^2 of heated space.

The M1S submodel, in which the thermal envelope is without thermal insulation layer, has a hollow brick d = 25 cm mutually plastered in the facade wall structure. The sub-model without thermal insulation is in energy class F, with the values of specific annual energy required for heating Qn, an = 205 [kWh / m^2]. The wall heat transfer coefficient for this model has a value of U = 1.603 [W / m^2K]. These values are well above the permissible national legislation [6] for new buildings. By adding 2 cm thick polystyrene thermal insulation over a hollow brick in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 105 [kWh / m^2], corresponding to energy class D are obtained. The wall heat transfer coefficient for this model has a value of U = 0.900 [W / m^2K] which is higher than the prescribed values for new objects [6]. By adding 5 cm thick thermal insulation of polystyrene over a hollow brick in the structure of the facade wall, the values of the specific annual energy required for heating Qn, an = 74 [kWh / m^2] corresponding to the energy class C are obtained, which is required by national legislation [6] for new objects. The wall heat transfer coefficient for this model has a value of U = 0.543 [W / m2K] which is higher than the prescribed values for new buildings [6].

By adding thermal insulation of 10 cm thick polystyrene over a hollow brick in the facade wall structure gives the values of the specific annual energy required for heating Qn, an = 56 [kWh / m^2] corresponding to energy class C [6]. The wall heat transfer coefficient for this model has a value of U = 0.327 [W / m^2K] which is higher than the prescribed values for new objects [6]. With the addition of 12 cm thick polystyrene thermal insulation over a hollow brick in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 52 [kWh / m^2], corresponding to energy class C, are aquired, which is required by national legislation [6]. The wall heat transfer coefficient for this model has a value of U = 0.282 [W / m^2K], which is the satisfactory value for new objects [6]. In this model, both conditions required for energy class C for new facilities are met [6]. With 15 cm thick polystyrene thermal insulation added over a hollow brick in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 48 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.234 [W / m^2K], which is in accordance with national legislation [6]. In this model, both conditions required for energy class B for new objects are met [6].

Table 2. *Energy classes for thermal envelope structures and thicknesses for the M1S submodel*

M1S submodel						
The composition of the thermal envelope		The total thickness of the facade wall	Thickness of thermal insulation	Energy class	U [W/m^2K]	Q_H,an [kWh/m^2]
1.	Hollow brick without thermal insulation	29,00 cm	0,00 cm	**F**	1,603	205
2.	Hollow brick + 2 cm polystyrene	31,00 cm	2,00 cm	**D**	0,900	105
3.	Hollow brick + 5 cm polystyrene	34,00 cm	5,00 cm	**C**	0,543	74
4.	Hollow brick + 10 cm polystyrene	39,00 cm	10,00 cm	**C**	0,327	56
5.	Hollow brick + 12 cm polystyrene	41,00 cm	12,00 cm	**C**	0,282	52
6.	Hollow brick + 15 cm polystyrene	44,00 cm	15,00 cm	**B**	0,234	48

Table 3. shows the values for submodel M1V (hollow brick + mineral wool), thermal wall sheath structure, thickness of polystyrene in model structure, achieved energy class and numerical value of specific annual energy required for heating per m^2 of heated space.

The M1V submodel, in which the thermal envelope is without thermal insulation layer, has a hollow brick d = 25 cm mutually plastered in the facade wall structure. The sub-model without thermal insulation is in energy class F, with the values of specific annual energy required for heating Qn, an = 205 [kWh / m^2].

Table 3. *Energy classes of thermal envelope structures and thicknesses for M1V submodel*

M1V submodel						
The composition of the thermal envelope		The total thickness of the facade wall	Thickness of thermal insulation	Energy class	U [W/m^2K]	$Q_{H,an}$ [kWh/m^2]
1.	Hollow brick without thermal insulation	29,00 cm	0,00 cm	**F**	1,603	205
2.	Hollow brick + 2 cm mineral wool	31,00 cm	2,00 cm	**D**	0,848	102
3.	Hollow brick + 5 cm mineral wool	34,00 cm	5,00 cm	**C**	0,497	71
4.	Hollow brick + 10 cm mineral wool	39,00 cm	10,00 cm	**C**	0,294	54
5.	Hollow brick + 12 cm mineral wool	41,00 cm	12,00 cm	**B**	0,253	50
6.	Hollow brick + 15 cm mineral wool	44,00 cm	15,00 cm	**B**	0,209	47

The wall heat transfer coefficient for this model has a value of U = 1.603 [W / m^2K]. These values are well above the permissible national legislation [6] for new objects. By adding 2 cm thick thermal insulation of mineral wool over a hollow brick in the structure of the facade wall, the values of the specific annual energy required for heating Qn, an = 102 [kWh / m^2] corresponding to energy class D are obtained. The wall heat transfer coefficient for this model has a value of U = 0.848 [W / m^2K] which is higher than the prescribed values for new objects [6]. By adding 5 cm thick thermal insulation of mineral wool over a hollow brick in the structure of the facade wall, the values of specific annual energy required for heating Qn, an = 71 [kWh / m^2] corresponding to energy class C are obtained, which is required by national legislation [6] for new objects. However, the wall heat transfer coefficient for this model has a value of U = 0.497 [W / m^2K] which is higher than the prescribed values for new buildings [6]. By adding thermal insulation of 10 cm thick mineral wool over a hollow brick in the facade wall structure, the values of specific annual energy required for heating Qn, an = 54 [kWh / m^2], corresponding to energy class C, are obtained for new objects [6]. The wall heat transfer coefficient for this model has a value of U = 0.294 [W / m^2K], which is a satisfactory value for new objects [6]. In this model, both conditions required for energy class C for new objects are met [6]. With 12 cm thick thermal insulation of mineral wool added over a hollow brick in the structure of the facade wall, the values of the specific annual energy required for heating Qn, an = 50 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.253 [W / m^2K], which is a satisfactory value for new objects [6]. And this model has both the energy class B requirements for new objects fulfilled [6]. With 15 cm thick thermal insulation of mineral wool over a hollow brick in the structure of the facade wall, the values of the specific annual energy required for heating Qn, an = 47 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.209 [W / m^2K], which is a satisfactory value for new objects [6]. And this model has both the energy class B requirements for new objects fulfilled [6].

Table 4. shows the values for the M2S sub-model (solid brick + polystyrene), the thermal wall sheath structure, the thickness of the polystyrene in the model structure, the energy class achieved, and the

numerical value of the specific annual energy required for heating per m^2 of heated space. The M2S submodel, in which the thermal envelope is without a thermal insulation layer, has a hollow brick d = 25 cm mutually plastered in the structure of the façade wall. Submodel without thermal insulation is in energy class E, with the values of specific annual energy required for heating Qn, an = 154 [kWh / m^2]. The wall heat transfer coefficient for this model has a value of U = 1,341 [W / m^2K]. These values are well above the permissible national legislation [6] for new objects. By adding 2 cm thick polystyrene thermal insulation over solid brick in the façade wall structure, the values of the specific annual energy required for heating Qn, an = 101 [kWh / m^2] corresponding to energy class D are obtained. The wall heat transfer coefficient for this model has a value of U = 0.811 [W / m^2K] which is higher than the prescribed values for new objects [6].

Table 4. *Energy classes by thermal sheath structures and thicknesses for the M2S submodel*

M2S submodel						
The composition of the thermal envelope		The total thickness of the facade wall	Thickness of thermal insulation	Energy class	U [W/m^2K]	Q_H,an [kWh/m^2]
1.	Solid brick without thermal insulation	29,00 cm	0,00 cm	**E**	1,341	154
2.	Solid brick + 2 cm polystyrene	31,00 cm	2,00 cm	**D**	0,811	101
3.	Solid brick + 5 cm polystyrene	34,00 cm	5,00 cm	**C**	0,509	72
4.	Solid brick + 10 cm polystyrene	39,00 cm	10,00 cm	**C**	0,314	55
5.	Solid brick + 12 cm polystyrene	41,00 cm	12,00 cm	**C**	0,272	52
6.	Solid brick + 15 cm polystyrene	44,00 cm	15,00 cm	**B**	0,227	48

By adding 5 cm thick thermal insulation of polystyrene over a hollow brick in the structure of the facade wall, the values of the specific annual required energy for heating Qn, an = 72 [kWh / m^2] corresponding to the energy class C are obtained, which is required by national legislation [6] for new objects. The wall heat transfer coefficient for this model has a value of U = 0.509 [W / m^2K] which is higher than the prescribed values for new objects [6]. With 10 cm thick polystyrene thermal insulation over solid brick in the facade wall structure, values of the specific annual energy required for heating Qn, an = 55 [kWh / m^2] corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.314 [W / m^2K] which is higher than the prescribed values for new objects [6]. With 12 cm thick polystyrene thermal insulation over solid brick in the facade wall structure, values of the specific annual energy required for heating Qn, an = 52 [kWh / m^2], corresponding to energy class C, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.272 [W / m^2K], which is a satisfactory value for new objects [6]. This model has both energy class C requirements for new objects fulfilled [6]. With 15 cm thick polystyrene thermal insulation added over solid brick in the façade wall structure, the values of the specific annual energy required for heating Qn, an = 48 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.227 [W / m^2K], which is a satisfactory value for new objects [6]. This model has both energy class B requirements for new objects fulfilled [6].

Table 5. shows the values for the M2V submodel (solid brick + mineral wool), the thermal wall sheath structure, the mineral wool thickness in the model structure, the energy class achieved, and the numerical value of the specific annual energy required for heating per m^2 of heated space.

The M2V submodel, in which the thermal envelope is without a thermal insulation layer, has a hollow brick d = 25 cm mutually plastered in the structure of the façade wall. Submedel without thermal insulation is in energy class E, with the values of specific annual energy required for heating Qn, an = 154 [kWh / m^2]. These values are well above the permissible national legislation [6] for new objects. The wall heat transfer coefficient for this model has a value of U = 1.34 [W / m²K] which is higher than the prescribed values for new objects [6]. By adding 2 cm thick thermal insulation of mineral wool over solid brick in the facade wall structure, the values of specific annual energy required for heating Qn, an = 97 [kWh / m²] corresponding to energy class C are obtained, which is an acceptable energy class for new objects [6]. The wall heat transfer coefficient for this model has a value of U = 0.768 [W / m²K] which is higher than the prescribed values for new objects [6]. By adding 5 cm thick thermal insulation of mineral wool over the hollow brick in the structure of the facade wall, the values of specific annual energy required for heating Qn, an = 69 [kWh / m²] corresponding to the energy class C are obtained. The wall heat transfer coefficient for this model has a value of U = 0.468 [W / m2K] which is higher than the prescribed values for new objects [6]. By adding thermal insulation of 10 cm thick mineral wool over a hollow brick in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 53 [kWh / m²], corresponding to the energy class C, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.284 [W / m²K], which is a satisfactory value for new objects [6]. This model has both energy class C requirements for new objects fulfilled [6].

Table 5. *Energy classes by thermal envelope structures and thicknesses for the M2V submodel*

M2V submodel						
The composition of the thermal envelope		The total thickness of the facade wall	Thickness of thermal insulation	Energy class	U [W/m²K]	Q_H,an [kWh/m²]
1.	Solid brick without thermal insulation	29,00 cm	0,00 cm	**E**	1,341	154
2.	Solid brick + 2 cm mineral wool	31,00 cm	2,00 cm	**C**	0,768	97
3.	Solid brick + 5 cm mineral wool	34,00 cm	5,00 cm	**C**	0,468	69
4.	Solid brick + 10 cm mineral wool	39,00 cm	10,00 cm	**C**	0,284	53
5.	Solid brick + 12 cm mineral wool	41,00 cm	12,00 cm	**C**	0,246	50
6.	Solid brick + 15 cm mineral wool	44,00 cm	15,00 cm	**B**	0,204	46

Adding thermal insulation of 12 cm thick mineral wool over a hollow brick in the façade wall structure gives the values of the specific annual energy required for heating Qn, an = 50 [kWh / m²], corresponding to the energy class C. The wall heat transfer coefficient for this model has a value of U = 0.246 [W / m²K], which is a satisfactory value for new objects [6]. And this model has both requirements for energy class C for new objects fulfilled [6]. With 15 cm thick thermal insulation of mineral wool added over solid brick in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 46 [kWh / m²], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.204 [W / m²K], which is a satisfactory value for new objects [6]. This model has both energy class B requirements for new objects fulfilled [6].

Table 6. shows the values for the M3S sub-model (Ytong + polystyrene), the structure of the thermal wall sheath, the thickness of the polystyrene in the model structure, the energy class achieved, and the numerical value of the specific annual energy required for heating per m² of heated space.

The M3S submodel, in which the thermal envelope is devoid of a thermal insulation layer, has Ytong d = 25 cm mutually plastered in the facade wall structure. The sub-model without thermal insulation is in energy class C, with the values of specific annual energy required for heating Qn, an = 78 [kWh / m²]. These values are permitted according to new legislation [6] for new objects. But the wall heat transfer coefficient for this model has a value of U = 0.368 [W / m²K] which is higher than the prescribed values for new objects [6]. By adding 2 cm thick polystyrene thermal insulation over

Yitong in the façade wall structure, the values of the specific annual energy required for heating Qn, an = 65 [kWh / m^2] corresponding to the energy class C are obtained. The wall heat transfer coefficient for this model has a value of U = 0.312 [W / m^{2}K] which is higher than the prescribed values for new objects [6]. By adding thermal insulation of 5 cm thick polystyrene over Yitong in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 55 [kWh / m^2], which are in the energy class C are obtained. The wall heat transfer coefficient for this model has a value of U = 0.254 [W / m2K], which is a satisfactory value for new objects [6]. This model has both energy class C requirements for new objects fulfilled [6]. With 10 cm thick polystyrene thermal insulation added over Yitong in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 46 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.194 [W / m^{2}K], which is a satisfactory value for new objects [6]. This model has both energy class B requirements for new objects fulfilled [6]. With 12 cm thick polystyrene thermal insulation across the Yitong in the facade wall structure, values of the specific annual energy required for heating Qn, an = 46 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.177 [W / m^{2}K], which is a satisfactory value for new objects [6]. This model has both energy class B requirements for new objects fulfilled [6]. With 15 cm of polystyrene added over Yitong in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 44 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.157 [W / m^{2}K], which is a satisfactory value for new objects [6]. And this model has both the energy class B requirements for new objects fulfilled [6].

Table 6. *Energy classes by thermal structures and thicknesses for the M3S submodel*

M3S submodel						
The composition of the thermal envelope		The total thickness of the facade wall	Thickness of thermal insulation	Energy class	U [W/m^{2}K]	Q_H,an [kWh/m^2]
1.	Ytong block without thermal insulation	29,00 cm	0,00 cm	**C**	0,368	78
2.	Ytong block + 2 cm polystyrene	31,00 cm	2,00 cm	**C**	0,312	65
3.	Ytong block + 5 cm polystyrene	34,00 cm	5,00 cm	**C**	0,254	55
4.	Ytong block + 10 cm polystyrene	39,00 cm	10,00 cm	**B**	0,194	48
5.	Ytong block + 12 cm polystyrene	41,00 cm	12,00 cm	**B**	0,177	46
6.	Ytong block + 15 cm polystyrene	44,00 cm	15,00 cm	**B**	0,157	44

Table 7. shows the values for the M3V submodel (Ytong + mineral wool), the structure of the thermal wall sheath, the thickness of the polystyrene in the model structure, the achieved energy class, and the numerical value of the specific annual energy required for heating per m^2 of heated space.

The M3V submodel, in which the thermal envelope is without a thermal insulation layer, has Ytong d = 25 cm mutually plastered in the facade wall structure. The sub-model without thermal insulation is in energy class C, with the values of specific annual energy required for heating Qn, an = 78 [kWh / m^2]. These values are permitted according to new legislation [6] for new buildings. But the wall heat transfer coefficient for this model has a value of U = 0.368 [W / m^{2}K] which is higher than the prescribed values for new objects [6].

Table 7. *Energy classes by thermal envelope structures and thicknesses for the M3V submodel*

M3V submodel						
The composition of the thermal envelope		The total thickness of the facade wall	Thickness of thermal insulation	Energy class	U [W/m^{2}K]	$Q_{H,an}$ [kWh/m^2]
1.	Ytong block without thermal insulation	29,00 cm	0,00 cm	**C**	0,368	78
2.	Ytong block + 2 cm mineral wool	31,00 cm	2,00 cm	**C**	0,306	64
3.	Ytong block + 5 cm mineral wool	34,00 cm	5,00 cm	**C**	0,244	54
4.	Ytong block + 10 cm mineral wool	39,00 cm	10,00 cm	**B**	0,182	47
5.	Ytong block + 12 cm mineral wool	41,00 cm	12,00 cm	**B**	0,165	45
6.	Ytong block + 15 cm mineral wool	44,00 cm	15,00 cm	**B**	0,145	43

By adding thermal insulation of 2 cm thick polystyrene over Yitong in the façade wall structure, the values of the specific annual energy required for heating Qn, an = 64 [kWh / m^2] corresponding to the energy class C are obtained. But the wall heat transfer coefficient for this model has a value of U = 0.306 [W / m^{2}K] which is higher than the prescribed values for new objects [6]. By adding thermal insulation of 5 cm thick polystyrene over Yitong in the facade wall structure, the values of the specific annual energy required for heating Qn, an = 54 [kWh / m^2], which are in the energy class C are obtained. The wall heat transfer coefficient for this model has a value of U = 0.244 [W / m^{2}K], which is a satisfactory value for new objects [6]. This model has both energy class C requirements for new objects fulfilled [6]. With 10 cm thick polystyrene thermal insulation added over Yitong in the façade wall structure, the values of the specific annual energy required for heating Qn, an = 45 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.182 [W / m^{2}K], which is a satisfactory value for new objects [6]. This model has both energy class B requirements for new objects fulfilled [6]. With polystyrene thermal insulation 12 cm thick over Yitong in the facade wall structure, values of the specific annual energy required for heating Qn, an = 45 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.165 [W / m^{2}K], which is a satisfactory value for new objects [6]. And this model has both the energy class B requirements for new objects fulfilled [6]. With 15 cm of polystyrene added over Yitong in the façade wall structure, the values of the specific annual energy required for heating Qn, an = 43 [kWh / m^2], corresponding to energy class B, are obtained. The wall heat transfer coefficient for this model has a value of U = 0.145 [W / m^{2}K], which is a satisfactory value for new objects [6]. And this model has both the energy class B requirements for new objects fulfilled [6].

From the Tables showing the thermal envelope thicknesses for energy classes F to B, we can see the movement of the thermal envelope thickness ratio depending on the thickness of the thermal insulation layer within the façade wall and the type of thermal insulation material. A detailed overview of the results and values of the studies is given in Table 8.

Table 8. *Optimal ranges of thermal envelope for energy classes F to B for the observed model of individual housing in Belgrade*

Sub-models / Energy class	M1S	M1V	M2S	M2V	M3S	M3V
F	without thermal insulation	without thermal insulation	/	/	/	/
E	up to 2 cm	up to 2 cm	without thermal insulation	without thermal insulation	/	/
D	from 2 cm to 5 cm	from 2 cm to 5 cm	from 2 cm to 5 cm	up to 2 cm	/	/
C	from 5 cm to 12 cm	from 5 cm to 10 cm	from 5 cm to 12 cm	from 5 cm to 12 cm	up to 10 cm	up to 10 cm
B	more than 12 cm	more than 10 cm	15 cm and above	15 cm and above	more than 10 cm	more than 10 cm

A graphical representation of the results obtained for the analyzed models using polystyrene as the insulating material for the facade walls is shown in Diagram 1. for submodels: M1S (hollow brick + polystyrene), M2S (solid brick + polystyrene) and M3S (Ytong block + polystyrene).

From Diagram 1. it can be seen that the difference that exists in submodels in which there is no thermal insulation layer, diagrams of submodels M1S, M2S and M3S initially has significant deviations. Sub-model M1S has the values of specific annual energy required for heating in energy class F. Sub-model M2S has the values of specific annual energy required for heating in energy class E. The M3S submodel has the values of specific annual energy required for heating in energy class C. With the application of only 2 cm thick polystyrene, the M1S (hollow brick + polystyrene) and M2S (solid brick + polystyrene) submodels almost coincide and have the values of specific annual energy required for heating in energy class D and approaching significantly energy class C. With 5 cm of polystyrene thermal insulation, the M1S and M2S submodels reach the values which are sufficient for the energy class C in the middle zone. Further increases in the thickness of polystyrene at 10 and 12 cm in the thermal envelope of the submodels M1S and M2S, obtain the values of the specific annual energy required for heating which are still in the energy class C, slightly approaching the energy class B.

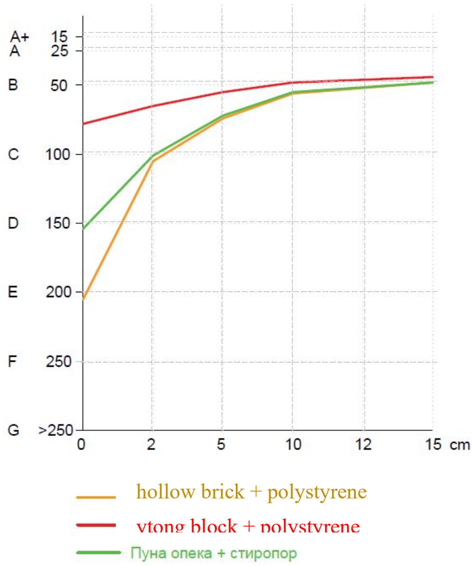

Figure 3. *Comparative analysis of the increase of the energy class and the thickness of the thermal insulation layer (polystyren) for the models M1S, M2S and M3S*

Only with a thickness of 15 cm of polystyrene in the thermal envelope of the submodels M1S and M2S, the values required for the energy class B in the lower zone are obtained, which carries a certain risk that it can easily slip into the lower energy class.

Diagram showing the increase of energy class for M3S sub-model (Ytong block + polystyrene) from the very beginning, even without polystyrene thermal insulation, has values that are sufficient for energy class C. With the addition of 2 and 5 cm polystyrene in the thermal envelope of the M3S submodel, the values are still in the energy class C, still slightly approaching the energy class B. Only with 10 cm, energy class B is achieved, and with polystyrene thickness of 12 and 15 cm, but all in the energy class B zone. For M1S, M2S and M3S submodels, from Diagram 1 it can be seen that with 10 cm of polystyrene in the thermal envelope all three models have a very small difference in the value of the specific annual energy required for heating. This means that by increasing the thickness of the polystyrene layer, it is possible to achieve small savings in energy consumption if the polystyrene of 12 and 15 cm is planned as an additional layer in the thermal envelope of the M1S, M2S and M3S submodels. From this it can be concluded that it is also necessary to analyze the financial effects that appear with higher costs for obtaining thermal insulation of larger thicknesses.

A graphical representation of the results achieved for the analyzed models using hard pressed mineral wool as insulation material for the facade walls is shown in Diagram 2 for sub-models M1V (hollow brick + hard pressed mineral wool), M2V (solid brick + hard pressed mineral wool) and M3V (Ytong block + hard pressed mineral wool).

From Diagram 2. it can be seen that the difference that exists in submodels in which there is no thermal insulation diagrams of submodels M1V, M2V and M3V initially also has significant deviations. The M1V submodel has the values of specific annual energy required for heating in energy class F. The M2V submodel has the values of specific annual energy required for heating in energy class E. The M3V submodel has the values of specific annual energy required for heating in energy class C. The M1V submodel of the initial energy class F manages to achieve the energy class D values, approaching the energy class C significantly, with the application of a thermal insulation layer of 2 cm hard-pressed mineral wool in the thermal envelope structure. The M2V submodel with the application of a 2 cm thick thermal insulation layer of hard pressed mineral wool in the thermal envelope structure changes from the initial energy class E to the values sufficient for the energy class C. With the application of 5 cm thick thermal insulation of hard pressed mineral wool, the M1V and M2V submodels almost coincide to reach the energy class C values in the middle zone, which is very significant. By further increasing the thickness of hard pressed mineral wool to 10 cm in the thermal envelope of submodels M1V and M2V, the specific annual energy requirements for heating are still in energy class C, approaching both each other and the values of the M3V diagram and the values to be achieved for energy class B. Only with a thickness of 12 cm of hard-pressed mineral wool in the thermal envelope of submodel M1V, it is possible to achieve the values required for energy class B. With the same thickness of hard pressed 12 cm thick stone wool, the M2V submodel has the values of specific annual energy required for energy class C, in the upper zone, approaching energy class B. With a thickness of 15 cm of hard pressed mineral wool in the thermal envelope of submodel M1V, and M2V, they have the values required for energy class B, and approach the values of submodel M3V.

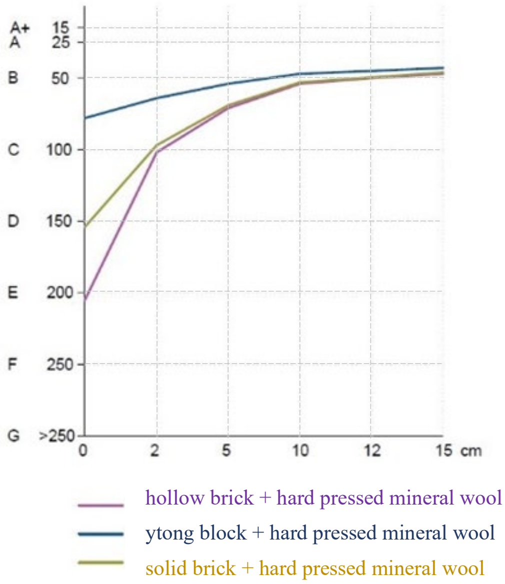

Figure 4. *Comparative analysis of the increase of the energy class and the thickness of the thermal insulation layer (mineral wool) for the models M1V, M2V and M3V*

A diagram showing the increase of the energy class for the M3V (Ytong block) submodel from the very beginning, even without thermal insulation, has the values sufficient for the energy class C. With the addition of 2 and 5 cm hard pressed mineral wool in the thermal envelope of the M3V submodel, the values are in the energy class C. It is only with 10 cm thickness that energy class B is achieved, and with a thickness of hard pressed mineral wool of 12 and 15 cm, they are still found in the energy class B zone.

For the M1V, M2V and M3V submodels, it can be seen from Diagram 2. that with only 10 cm of hard-pressed rock wool in the thermal envelope, all three models have a very small difference in the value of the specific annual energy required for heating. This means that with the increase in the thickness of the layer of hard-pressed mineral wool, it is possible to achieve small savings in energy consumption if 12 and 15 cm are planned as an additional layer in the thermal envelope of submodels M1V, M2V and M3V. In this case, the financial aspect needs to be further analyzed, which was not foreseen in this research.

From Diagrams 1 and 2, we can see that with the increase of the thickness of the layer of thermal insulation material in the structure of the thermal envelope there is an increase of the energy class.What can be further noted in the diagrams is that with increasing the thickness of the thermal envelope, the effect of the thermal envelope on the energy class is also dramatically reduced, but at the same time the thickness of the thermal insulation layer is significantly increased.

From Diagrams 1 and 2, we can see that the starting points of the curves (when there is no thermal insulation layer in the thermal envelope) show significant differences in the energy class. With the addition of 2-5 cm thick thermal insulation, the curves show a tendency to fade. With thermal insulation thickness of 10-12-15 cm, all the curves tend to meet in one line,therefore, the approximate value of the specific annual energy required for heating, on the same energy class B.

We can observe that the curves represented by the M3S and M3V submodels (Ytong block + thermal insulation) have better starting energy classes and a milder curve in both diagrams, indicating better initial ytong block characteristics compared to the M1S and M1V submodels (hollow brick + thermal insulation) and M2S and M2V submodels (full brick + thermal insulation). However, this initial lack of a thermal envelope in which hollow or solid bricks are used with the addition of 5-10 cm of thermal insulation reaches the values of the specific annual required energy for heating and energy class, as a model in which the Ytong block was used in thermal envelope.

The energy class diagrams for polystyrene (Diagram 1) and hard pressed mineral wool (Diagram 2) , as can be seen, do not show significant deviations from the wall elements, and therefore some parameters need to be introduced for the selection of materials, which may be further investigated.

4. CONCLUSION OF THE RESEARCH

For the purpose of the conducted research, models M1, M2, and M3 were formed, which represent common ways of constructing family housing in Serbia. Each of the analyzed models, in the further course of the research applied in the structure of thermal envelope two commonly used thermal insulation materials in the construction industry of Serbia, polystyrene and pressed mineral wool, thus forming the submodels M1S, M1V, M2S, M2V, M3S and M3V. Added layer of thermal insulation material to the basic structure of the thermal envelope of the building is polystyrene or pressed mineral wool in thicknesses of: 2, 5, 10, 12, 15 cm. Thus, as a result of computer simulations done in URSA software Building Physics 2, 36 output results and energy class results, were obtained for the same project, but with a different thermal envelope assembly. The results of the research have led to certain conclusions that are directly related to the set goals of the research.

The research conducted through this paper aimed to obtain approximate thermal envelope thicknesses for energy classes from the lowest F to the highest B. The research should provide support and assistance in selecting the thickness and structure of the thermal envelope when designing new objects of this type during the conceptual design phase to achieve a certain energy class, and for new buildings, this is energy class C in accordance with applicable regulation [6]. The exact thickness and structure of the thermal envelope are determined at the stage of preparation of the project for construction of the object, when in order to obtain a building permit it is necessary to make an Energy Efficiency Study in accordance with the applicable regulations of the Republic of Serbia [6]. In order to achieve the energy class C, the M1S submodel should have 5-10-12 cm in the thermal envelope. The M1V submodel with 5-10 cm of thermal insulation have energy class C values. With higher thermal insulation thicknesses, the M1S submodel with 15 cm and M1V with 12-15 cm reach the energy class B.

In order to achieve the energy class C, the M2S submodel should have 5-10-12 cm in the thermal envelope. The M2V submodel with 5-10-12 cm of thermal insulation have energy class C values. With higher thermal insulation thicknesses, the M2S submodel with 15 cm and the M2V with 15 cm reach energy class B. In order to achieve the energy class C, the M3S submodel without thermal insulation or with 5-10 cm in thermal envelope is in the energy class C zone. The M3V submodel without thermal insulation or with 5-10 cm thermal insulation is in the energy class C values. With higher thermal insulation thicknesses, the M3S submodel with 10-12-15 cm and M3V with 10-12-15 cm reach energy class B.

The results of the research can be useful information for designers and civil engineers when designing new buildings or redeveloping existing ones. Based on the research, it can be concluded that the structure and thickness of the thermal envelope influence the increase of the energy class, which could be expected as a result of the research.

However, it is observed that with the increase of the thickness of the thermal insulation layer in the structure of the thermal envelope, from 10 cm to 12-15 cm, there are no significant shifts in the energy class, that is, there is no major contribution in terms of savings in the consumption of specific annual required energy for heating calculated in m2. A significant increase in the thickness of the thermal envelope with the addition of thermal insulation materials of 12-15 cm does not result in significant savings in energy consumption for heating.

However, since the permitted value of the Umax wall heat transfer coefficient [W / m^2K] is by the Regulations on Building Energy Efficiency [6], some models do not satisfy both conditions, in addition to the fulfilled condition for energy class C.

One of the results of the research, which is not expected, is that in the results obtained by the application of polystyrene or hard-pressed mineral wool there are no large deviations in the consumption of specific annual energy required for heating, or the achieved energy class. The difference in the price of these two insulation materials is an important factor for investors to decide which material to apply, so new research with such an objective would be very useful. In some future research, several different individual housing projects could be compared. This was not foreseen by this research, but it would certainly be useful to do some further research. In some future research, the results obtained can also be compared in terms of finances and life expectancy, which would be of multiple use. In this large-scale research this was not foreseen.

These research findings suggest that rational and reasonable consideration should be given to selecting the type and thickness of thermal insulation material when designing buildings in an effort to achieve the desired energy class.

The research raises new questions and topics for some future professional work in this field, such as: cost comparison in the construction and exploitation phase for these analyzed models, comparison of the life of the assemblies used, comparison of the results obtained using other software packages with the results obtained in this research , as well as many other topics raised by the profession, when it comes to energy efficiency, but also the impact of buildings on the built and natural environment.

LITERATURE

[1] European Commission, „Analysis associated with the Roadmap to a Resource-Efficient Europe Part II“, Commission Staff Working Paper. Brussels; 20.9.2011. SEC (2011) 1067 final.

[2] European Construction Tehnology Platform, „MATERIALS“, Vision 2030 & Strategic Resarsh Agenda, Focus Area Materials. Version 1, http://www.ectp.org.20.1.2013. Brussels; 2005.

[3] Drugi akcioni plana za energetsku efikasnost Republike Srbije za period od 2013-2015, „Sl. glasnik RS“, br. 98/2013 Available at: https://mre.gov.rs/doc/efikasnost-izvori/efikasnost/B_01_Drugi_akcioni_plan_za_energetsku_efikasnost_za_Republiku_Srbiju_za_period_od_2013_do_2015_godine.pdf [accessed: 25. 4. 2020.]

[4] IEA. International Energy Agency, „Final Report 2009“, Commission of the European Communities, 2009.

[5] Zakon o planiranju i izgradnji objekata „Sl. glasnik RS“ br. 72/2009, Available at:<http://www.mgsi.gov.rs>

[6] Pravilnik o energetskoj efikasnosti zgrada „Sl. glasnik RS“ br. 61/2011, [On-line] Available at:<http://www.mgsi.gov.rs>

[7] Pravilnik o uslovima, sadržini i načinu izdavanja sertifikata o energetskim svojstvima zgrada, Službeni glasnik RS, No. 69/2012.[On-line]Available:<http://www.mgsi.gov.rs> [accessed: 25. 10. 2016].

[8] IEA, International Energy Agency, Final Report 2013, Commission of the European Communities, 2013.

[9] Energy balance of the Republic of Serbia, [On-line]Available: <www.mre.gov.rs/.../EN%20BILANS%20ZA%2014>[accessed: 20. 12. 2017].

[10] Global Footprint Network today at an event at Oxford University. Availableat:<https://www.footprintnetwork.org/2018/04/09/has_humanitys_ecological_footprint_reached_its_peak/> [accessed: 14. 3. 2018.]

[11] Asdrubali, F., D'Alessandro, F., Baldinelli, G., Bianchi, F.“Case Study- Evaluating in situ thermal transmittance of green buildings masonries A – case study“, Univerzitet Perugia, Italija/Case Studies in Construction Materials1. (pp. 53-59). 2014.

[12] Adalberth, K.; „Energy use during the Life Cycle of Buildings: A Method“, Building and Environment. 32. pp. 317-320, 1997.

[13] Šumarac, D. M., et al, „Energy Efficiency of Residencial Buildings in Serbia“, Thermal Science, 14 (2010), Suppl, pp.S97-S113.

[14] Krstić-Furundzic, A., Kosic, T., „Assessment of Enegy and Environmental Performance of Building Models“,A Case Study, Energy and Buildings, 115 (2016), Mar., pp 11-22.

[15] Ibn-Mohammed, T., Greenough, R., Taylor, S., Ozawa-Meida, L. & Acquaye, A., „Operational vs. Embodied emissions in Buildings – A Review of Current Trends“, Energy and Buildings, (2013). No.66, pp.232-245.[On-line]Available:< https://doi.org/10.1016/j.enbuild.2013.07.026(10.08.2018)>[accessed: 6. 6. 2018].

[16] Ramersh, T., Prakash, R., Shukla. K.K., „Life cycle energy analysis of buildings: An overview“, Energy and Buildings, (2010) No. 42. pp. 1592-1600.[On-line]Available:< https://doi.org/10.1016/j.enbuild.2010.05.07>[accessed: 10. 8. 2018].

[17] Slavković, K., Radivojević. A., „Evaluation of energy embodied in the external wall of the single-family buildings in the process of energy optimization“, Energy Efficiency. (2014) Published online: 03

[18] Nikolić Topalović, M., Stanković, M. „A Case study of the increase of Carbon dioxide due to the Application of energy efficiency regulations in Serbia“, Contemporary materials, UDK 616.314-089.87(497.11), IX-2, 2018. pp. 159-164, doi 10.7251/COMEN1802159N.

[19] Nikolić Topalović, M., Momčilović, A., Stefanović, G., Case Study: „The Effects the Improvements in Energy Rating Band C to Band B has on the Flow of Necessary Materials and Embodied“, ANNALS, ISSN 1584-2665(printed version); ISSN-L 1584-2665(online); ISSN 2601- ANNALS OF FACULTY ENGINEERING HUNEDOARA – INTERNATIONAL JOURNAL OF ENGINEERING Faculty of Engineering, Hunedoara, www.fih.upt.ro 2. Avgust 2018.

[20] Nikolić Topalović M., Stanković M. „A Case study of the increase of Carbon dioxide due to the Application of energy efficiency regulations in Serbia“, Banja Luka, 2018. Contemporary Materials, IX-2 (2018) nn 159-167, UDK 616.314-089.87(497.11) DOI 10.7251-COMEN1802159N, ANURS of the Republic of Srpska, Banja Luka, [www.savremeni materijali.info].

[21] Nikolić Topalović M., Ćirović G., „Embodirani ugljenik kao kriterijum za vrednovanje projekta individualnog stambenog objekta sa aspekta uticaja na životnu sredinu“, ″Embodied Carbon as a Criteria for Evaluation of a Family Dwelling Project from the Aspect of the Environmental Impact“, XLVI Symposiuom of Operational Research, Međunarodna konferencija. SIMOPIS 2019, 15-18 Septembra, Kladovo, Srbija, Međunarodna konferencija

[22] Zhang, X., Shen, L., Zhang, L., „Life cycle assessment of the air emissions during building construction process - A case study in Hong Kong. Renew. Sustain. Energy“ Rev. 17, pp. 160-169. 2013.

[23] Battle, G., Chair, J. (2014) „Embodied Carbon Industry Task Force Recommendations – Proposals for Standardised Measurement Method and Recommendations for Zero Carbon Building Regulations and Allowable Solutions“. https://asbp.org.uk/wp-content/uploads/2016/01/Embodied-Carbon-Industry-Task-Force-Proposals_June-2014_Final.pdf.

[24] Sturgis, S. (2017), „Targeting Zero, Embodied and Whole Life Carbon Explained“, RIBA Publishing.http://sturgiscarbonprofiling.com/news/targeting-zero-embodied-and-whole-life-carbon-explained/>.

[25] Jovanović Popović, M., Ignjatović, D., Radivijević, A., Rajčić, A., Đukanović, LJ., Žuković Ignjatović, N., Nedić, M. (2013), „Nacionalna tipologija stambenih zgrada Srbije“,Arhitektonski fakultet Univerziteta u Beogradu, GIZ - Deutsche Gesellschaft für internationale Zusamemenarbeit, Beograd.

[26] Al-Esaifer E. „Project of individual residential house in Belgrade“,University College of Civil Engineering and Geodesy Belgrade, Belgrade, 2017

[27] URSA construction physics 2, Available: <https://www.ursa.rs/softver> [On-line] [accessed: 10. 3. 2019].