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Design process for energy-efficient residential buildings

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Professional paper

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Design process for energy-efficient residential buildings

The analysis of the design process for energy-efficient residential buildings is presented in the paper. Buildings currently under construction in Bosnia and Herzegovina and Macedonia are analyzed. The complexity of the overall construction process, from the design solution to building construction, is considered in detail. The attention is drawn to great significance of the use of computer programs in the design process, particularly during computation of energy requirements aimed at achieving comfort of interior space.

Key words:
design, residential buildings, energy efficiency, construction

Stručni rad

Haris Bradić

Proces projektiranja energetski učinkovitih stambenih obiteljskih zgrada

Rad predstavlja analizu procesa projektiranja energetski učinkovitih stambenih obiteljskih zgrada. Analiziraju se građevine koje su trenutačno u fazi izgradnje u Bosni i Hercegovini i u Makedoniji. Detaljno se razmatra složenost cjelokupnog procesa građenja, od projektnog zadatka do izgradnje građevine. Skrenuta je pozornost na veliku važnost uporabe računalnih programa tijekom procesa projektiranja, posebice pri proračunu energetskih potreba s ciljem ostvarenja udobnosti unutrašnjeg prostora.

Ključne riječi:
projektiranje, stambene zgrade, energetska učinkovitost, izgradnja

Fachbericht

Haris Bradić

Entwurfsprozess energieeffizienter Familienwohngebäude

In der vorliegenden Arbeit wird der Entwurfsprozess energieeffizienter Familienwohngebäude analysiert. Es werden Bauten betrachtet, die derzeitig in der Konstruktionsphase sind und sich in Gebieten von Bosnien-Herzegowina und Mazedonien befinden. Der Aufwand des gesamten Bauprozesses wird ausführlich betrachtet, von der Entwurfsaufgabe bis zur Errichtung des Gebäudes. Die Aufmerksamkeit ist auf die Wichtigkeit der Anwendung von Computerprogrammen im Entwurfsprozess gerichtet, insbesondere bei Berechnungen des Energiebedarfs, die auf das Erzielen eines angenehmen Innenraumes ausgesetzt sind.

Schlüsselwörter:
Entwurf, Wohngebäude, Energieeffizienz, Erbauung

1. Introduction

Today we witness an increasing number of negative effects of human activity on planet Earth, some of the most notable being: climate changes, energy crisis, global warming, increase in CO_2 emissions, etc. On the other hand, this encourages us to search for new paths and solutions on the overall construction scene. Each area in which an energy-efficient building is to be erected offers a unique opportunity for the use of renewable sources of energy, but this opportunity has to be identified and translated into reality in a modern and efficient manner [1]. The atmosphere (Sun), water, and soil, are the sources of energy that have no limitations. The Sun is particularly important, as it is the source that offers endless reserves of energy to every locality of our planet.

The design of energy-efficient residential houses is analysed based on the case study of three houses situated in Sarajevo (Bosnia and Herzegovina) and Gostivar (Macedonia). Special features of the design of energy-efficient houses and buildings are: definition of external envelope with a low heat transfer coefficient, and the use of site-specific potential through maximum utilisation of sun energy, and other forms of renewable sources of energy such as wind energy and geothermal energy. Two computer programs for calculation of the total annual energy requirement, i.e. "ENSI EAB v.8.1 BiH" and "PHPP 2007" (fore the analysis of houses according to passive house standards) were used to gather data that are extremely significant for the simulation of energy-efficient houses. The following objectives were set for the above mentioned projects: design residential family houses with minimum or even zero CO_2 emissions, treat internal space with minimum quantity of energy (less than 50 kWh/m^2/year), increase internal space comfort from the aspects of architectural physics [2], create an active relationship between the residential house and its physical surroundings, and present possible results to the client. Simulations based on computer programs can be used to predict all significant elements of the future house/building such as: quality of internal space, economic plan through analysis of the scale of investment and return of investment, and annual energy savings.

The construction price of residential houses with such advanced characteristics is in fact the greatest obstacle that has to be overcome through joint efforts of all participants in construction, so as to find "the most painless" way to achieve high standards in the construction of energy-efficient houses. A particular hindrance in these efforts is the fact that Bosnia and Herzegovina and Macedonia have still not put in place a proper system for dealing with this issue. In other words, there are no institutions that would recognise and provide assistance to environmentally accountable operators in construction industry.

The process for the design of energy-efficient houses can be defined through several main steps: investigate in full detail the microclimate in the zone where the house will be erected [3], clearly define, in consultation with the client, the terms of reference for the project taking into account the size (budget) of investment, make detailed calculations and simulations of energy flow from and into the house and, in collaboration with installations/services designers, create a detailed concept of energy production for a given project and select the most favourable solution, both from the aspect of use of renewable sources of energy, and the price of the system within a given space and time bound.

Three residential family houses considered in the paper are highly interesting and significant for the analysis as they are characterised by three essentially distinct external envelope concepts or, more precisely, different relationships between the external envelope area and the volume of the heated part of the house, which can be observed and analysed through results presented in this paper. The flow of energy and water vapour through the external envelope of the house is calculated taking into account principles relating to the construction of passive houses (Passivhouse Institut, Darmstadt, Germany) [4] and energy-efficient houses [5].

2. Design process and micro-location analysis

The design of energy-efficient houses is characterised by several specific features the most important being: analysis of the terms of reference of the future house which are in most cases defined by the client itself, and sometimes also by the designer, and setting the objectives relating to energy savings and micro-location analysis. In all these activities, a proper significance should be given to an intensive collaboration between the designer and the client so that the final goal with regard to energy savings can be achieved. In the time and space bounds in which the mentioned examples have been designed, and also built, it can hardly be assumed what savings or benefits can actually be realized. It is therefore significant to analyze, calculate and inform future users about all types of advantages and benefits, and these are: economic benefits, better quality of life, energy supply advantages, lower CO2 emissions, etc. Computer programs for the calculation of total energy requirements, and for economic simulations, greatly contribute to the achievement of these benefits.

The first step is to study weather characteristics in the micro-location based on real-life data obtained from relevant meteorological and hydrological services. As the analysed houses are situated in Sarajevo and Gostivar, the data were gathered from the meteorological station located in Sarajevo – Bjelave, and the meteorological station in Gostivar. The following data were analysed: average minimum and maximum air temperatures, annual insolation, and the quality and frequency of winds over the past three years. The objective was to obtain the highest accuracy data which were then entered in the program for calculation of external conditions in which the residential houses will be built. Figure 1 shows variation of average temperatures in the past 10 years. It can be concluded that, on an average, temperature have been increasing, especially in recent years. The facts are in favour of the incentive to increase the design external air temperature from -20°C to a higher value. Thus, the external air temperature of -12°C was adopted for the first weather zone to which the town of Sarajevo belongs, and used in calculations made by means of the mentioned two computer programs. Similar changes were

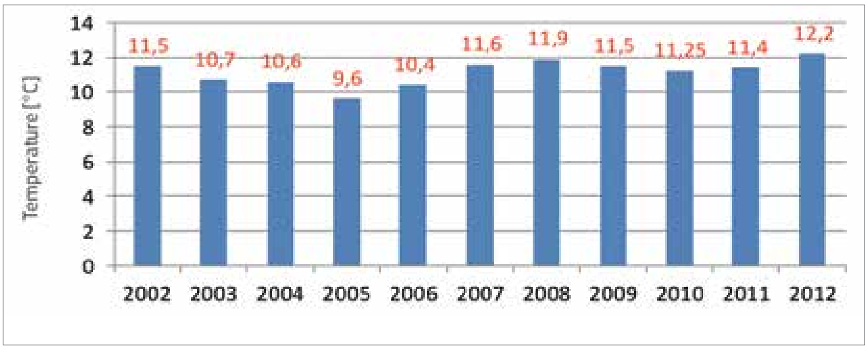

Figure 1. Average temperatures in Sarajevo for the period 2002-2012

also registered for the town of Gostivar and so the design winter temperatures were also modified and the temperature of -13°C was adopted. In the town of Sarajevo the heating season starts on 15 October and ends on 15 April, but it is not rare that the heating season is extended to the mid May. In the town of Gostivar, an average temperature is somewhat lower, and hence the heating season is longer.

The information about solar radiation points to a relatively high solar energy potential. The solar potential is reflected in a number of completely sunny days in a year (in Sarajevo it ranges from 19% to 40%), and in summer period it is almost equivalent to geographic areas such as the north of Spain, and south of France or Italy. The process of creating a form of an energy-efficient house implies continuous confrontation of key components of the mentioned process with the final objective, which is to create a satisfactory architectural shaping of a high quality interior space, with desired energy efficiency and CO_2 emission parameters. The classification of energy efficient houses was made according to the Byelaw on Energy Certification of Buildings (in B&H – Energy Certificate), and it includes a passive house that has the heating energy requirement of 15 kWh/m^2/year, as well as houses/buildings with great quantity of heating energy of 300 kWh/m^2/year.

3. Examples of energy-efficient architecture in B&H and Macedonia

3.1. Residential family house "Kromolj" in Sarajevo

The first example analysed in this paper is a residential family house in Sarajevo. It is a detached residential house, with the ground storey + first storey (with the ground storey half buried on the north side). By its position at the foothills of the Kromolj – Poljine mountain, the house is separated from the central urban core, Figure 2. Along most of its longer side, the house plot is oriented toward the east, and partly toward the south. The plot can be accessed via a local road from the south, and is equipped with some infrastructure facilities, such as the electricity and water, while gas installations run about 80 m away from the plot. The altitude is 695 m, and its geographic position is: latitude: 43°53'23.08" N, longitude: 18°24'38.56" W. As the plot is situated at a relatively high level, snowfall is abundant in winter, and the snow cover lingers on until early spring. The terrain was analysed from the aspect of stability and ground water level. It was established that it is a relatively stable terrain with a low ground water level. The newly designed house was rotated southward for 15° with respect to its initial position in order to obtain south orientation of the longest facades. Thus a certain quantity of thermal energy would be gained through transparent surfaces in winter period, which would reduce overall heating requirements. The form and content are the result of a well targeted creation of an energy-efficient architecture, with passive protection against excessive solar gains in summer period, by shielding the glazed areas with an overhanging reinforced-concrete structure. Tall vegetation dominates on the north and party west sides, which creates in summer period a natural shade, and prevents excessive heating of the house envelope from the west side. The visualisation of the residential family house Kromolj is shown in Figure 3.

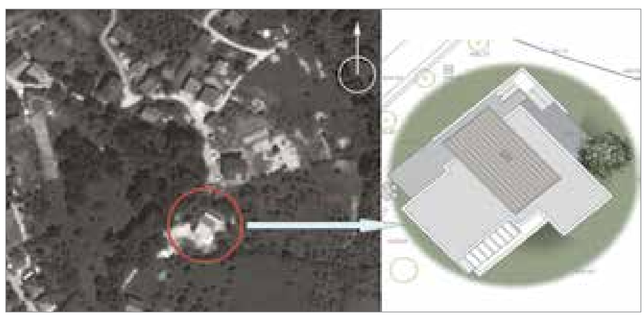

Figure 2. Location of the "Kromolj" House in Sarajevo

Figure 3. Visualisation of the Kromolj House

Table 1. Basic data about the Kromolj House

Area of the heated part of the house (A)	282 m²
Volume of the heated part of the house (V)	812 m³
Area of the external house envelope (Ae)	580,99 m²
Area of openings along the external house envelope (Aw)	68 m²
Window factor (Aw/A)x100	24
House shape factor (Ae/V)	0.71

The relationship between individual parameters that characterize the house is shown in Table 1. The most important parameter is the house shape factor of 0.71, which shows the relationship between the external envelope area, and the volume of the heated part of the house (, i.e. the limit between the heated and unheated areas). This parameter is mostly the result of architectural concept used on the project. The shape of the house depends on several input data such as, for instance, the client's requirements that are the basis for forming the terms of reference, specific visual identity parameters, and topographic survey map serving as basis for designing the house. The architectural concept is presented through the play of full and empty areas the aim being to create the best possible visual contact between the house's interior and the surrounding landscape. The total area of the external envelope amounts to 580.99 m². The window factor is 24, which is a high proportion of transparent areas compared to the non-transparent ones. However, as these areas are characterized by the highest heat transfer coefficient values (U-values), this has created additional difficulties with regard to the need to bring down the annual heating requirement. It can be seen from Figure 4 that transparent areas account for 13% of the envelope, which is quite significant, and so it has to be adequately "materialised" with the lowest possible coefficients of heat transfer through windows, U_w. This would however greatly increase the investment cost. Today's technology is so advanced that an external opening with the U_w value of 0.6 W/m²K can be realized, which was quite unimaginable a decade ago. It should nevertheless be noted that the mentioned quality of external openings comes at a high price.

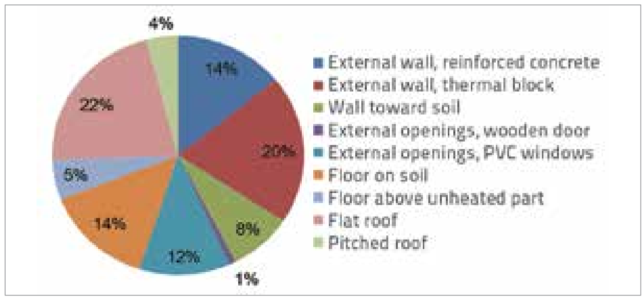

Figure 4. House envelope structure (limits between heated and unheated areas)

The envelope has been designed in such a way that it has approximately similar U values in all areas, with the following relationships: the U value amounts to 0.13 W/m²K for the flat roof, it amounts to 0.15 W/m²K for external walls, and to 0.25 W/m²K for the floor areas, as can be seen in Table 2. Heat transfer coefficients could have been even lower, but that would increase investment costs with small effect on the reduction on the heating requirement, unless external openings with the passive house certificate were to be installed. According to this certificate for external openings the U_w value for the entire external openings should not exceed U_w = 0.8 W/m². This has not been achieved, and so the envelope could be considered as a very-low energy element. The envelope has in fact been conceived as a "passive" active structure with regard to control of the two-directional movements of energy.

Table 2. Characteristics of the house envelope

	Description	U factor [W/m²K]	Area [m²]
1	External wall type 1, reinforced-concrete and rock wool	0,149	82,2
2	External wall type 2, thermal block and rock wool	0,175	116,61
3	External wall, wall in soil, reinforced concrete and XPS	0,296	47,77
4	External openings, entrance door, solid wood	1,8	5,23
5	External openings, Windows, Rehau Geneo system, triple glazing, Low-e, g=0,50	1,0	67,77
6	Floor on soil	0,26	81,36
7	Floor above unheated part	0,149	31,2
8	Flat roof	0,182	125,5
9	Inclined roof	0,13	23,35
	Total area of the envelope: 580,99 m²		

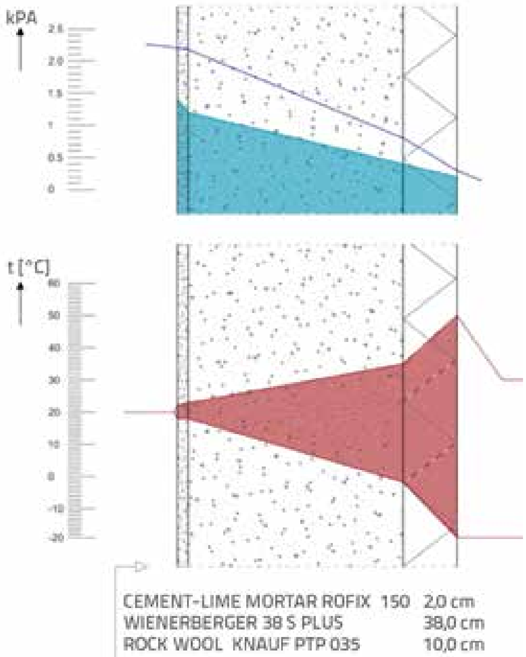

Figure 5. Graphical presentation of the water vapour flow (external wall detail – thermal block

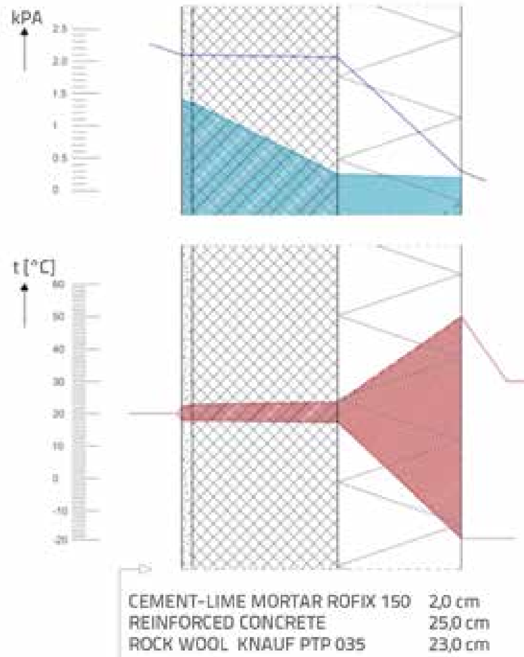

Figure 6. Graphical presentation of the water vapour flow (external wall detail – reinforced concrete

It can be concluded from diagrams shown in Figures 5 and 6 that the problem of excessive moisture generation between layers has been resolved through an appropriate choice of materials, and hence a continuous flow of water vapour through layers has been enabled. The temperature work of the load bearing structure has on the other hand been reduced to minimum by placing thermal insulation elements from the external side, i.e. by using thermal blocks 10 cm in thickness and a reinforced-concrete structure 23 cm in thickness. Thus the expansion and shrinking of the structure has been prevented, as that would have ultimately resulted in cracking at both external and internal layers of the envelope. In many examples of modern day construction work, the movement of moisture has been greatly neglected, despite the fact that it causes structural damage to internal areas of houses/buildings. This is mostly manifested through the appearance of fungi that create a good medium for development of other bacterial that are harmful to the health of the interior space users. The thermal stability of the structure in summer months has been fully ensured through two parameters, namely a very low heat transfer coefficient (U value) and wall mass per m^2 ranging from 650 to 720 kg/m2, which classifies this envelope among massive structural systems [2].

The ventilation system is not mechanical but rather the ventilation was resolved using controlled openings on the ground floor and on a part of the sloped roof, so as to enable circulation of air through internal spaced based on the difference in atmospheric pressure and opposite positioning. Due to geographic positioning of the house (characteristics of the micro-location), it is not necessary to plan a controlled cooling system in summer period. Air injecting recuperators are planned on the north side to enable automatic and controlled "injection" of fresh air. Here the question of absolute control of fresh air entry into the house was opened, which was not accepted by the client, and so this possibility was left as a possible alternative.

The calculation of energy needed by the house was made using both of the above mentioned computer programs and it was established that the energy requirement is 21.3 kWh/m2/year for heating, which is an excellent result. If the factor of safety is added, then the resulting internal space heating requirement is about 30 kWh/m^2/year (house), while the energy needed for water heating is 12 kWh/m^2/year. The following factors were taken into account during calculation of the total energy requirement: ventilation losses, design temperature, number of air exchanges, thermal bridges, internal energy gains, and energy gains from solar power. The factor of safety should be taken into account so as to ensure that:

a) the installation of elements along the house envelope (external wall layers and external openings) is compliant with quality requirements,
b) the power source entering the house is of appropriate quality.

In this example, the 20 percent factor of safety was adopted so that a highly reliable final result can be obtained. The household water heat energy requirement was calculated by means of a separate software segment that simulates energy requirement in kWh, which is quite helpful for estimating cost-effectiveness of installation of solar panes at a given locality. Hot water is prepared by means of solar panels and electric heaters (for additional heating).

The mentioned quantity of thermal energy should be supplied to the house, and adequately transferred to appropriate areas within

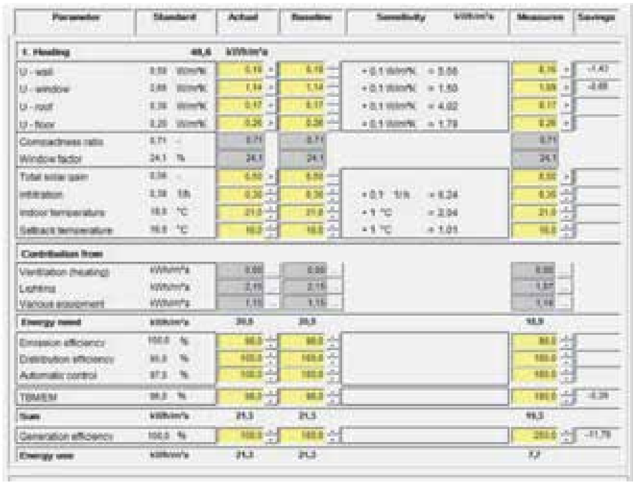

Figure 7. Heating energy requirement (residential house Kromolj, *ENSI software*

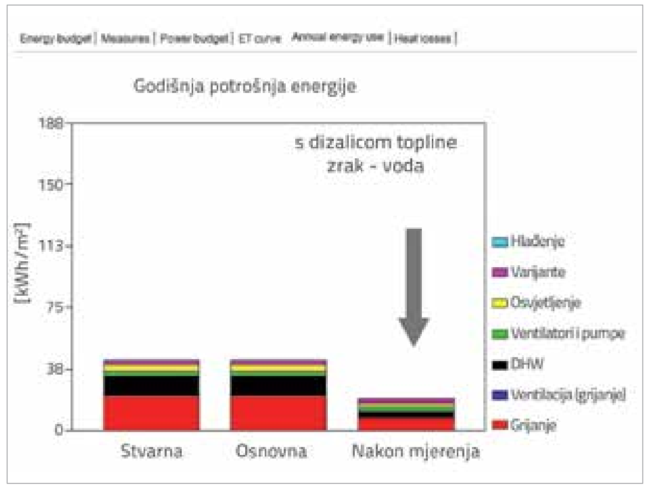

Figure 8. Diagram showning the total energy requirement (residential house Kromolj, *ENSI software*)

the house. That is why a special attention was paid to the technical solution. Although the sum of the investment had already been significantly increased by the mentioned improvement of the house envelope, an increase in total investment is even more pronounced in this segment. The modern technology offers a great variety of possibilities for an energy efficient production and distribution of energy, which is why it was quite difficult to select the concept and the company that would prove most suitable for the project. Based on the information gathered about the micro-climate, local soil composition, and access to the site, it was concluded that, in the long run, one of the best solutions would be to install a heat pump. The "air-water" heat pump system was selected (type: Stiebel Eltron, WPL 18 E, output at external air temperature of 10°C is 13.40 kWh, and 8.2 kWh at -15°C) as this system can be used even at external air temperatures of -20°C. In this way, the heating energy cost would be reduced by two to four times, and thus one of the initially specified goals would be met. The central system also includes preparation of hot sanitary water assisted with solar collectors (type: Stiebel Eltron SOL 27 basic, power output 500 W/m^2, total useful area 3x2.38 = 7.14 m^2), which introduces the thermal energy generated by daylight into the central storage device (type: Stiebel Eltron SBB 401 WPSOL, volume: 400l) where the energy from the heat pump is used to heat the water to +35°C. Finally, the total energy requirement would be reduced from 43.2 kWh/m^2 to 19.4 kWh/m^2/year, which would be a great result for the time and space in which this project was conceived and realized. Economic parameters relating to this project show that the total investment into the heating and hot water preparation system would amount to € 23,500.00, while the money invested in solar collectors and heat pump would be reimbursed within eight years. Based on the above results, it can be concluded that this is a well designed project, especially in the part related to house envelope by which energy requirement has been brought to minimum. Consequently, the investment needed for the mentioned water heating system was also reduced considerably. An another model, i.e. soil-water heat pump with two underground probes to be placed at no less that 100 m in depth, was also considered during preparation of the design. It was concluded that it this case the realization would be more complicated, and the investment would be increased for two reasons: difficult access by vehicle to the site, and small number of probes (only two), which would extend the return of investment to 18 years, while the final reduction of energy consumption would be low.

3.2. Residential family house Vrbanjuša in Sarajevo

The second example is the project that is currently being realized in the old part of Sarajevo called "mahala Vrbanjuša", Figure 9a. The initial four-century old house was a typical example of family house architecture in Sarajevo from the times of the Ottoman Empire. The facility that had to be rebuilt occupied 210 square meters in area, and it consisted of the ground floor and first floor (GF+1). As the client wished to build a house of approximately 500 square meters, with basement under almost the entire space of the building plot, the former house had to be completely pulled down and a new design was prepared. The project was partly realized during the first phase of construction in 2011, Figure 9b. It is interesting to note that the Institute for the Preservation of Cultural, Historic, and Natural Heritage of the Sarajevo Canton required protection of the north-western and south-western facades, which has greatly limited possibilities for forming a new envelope for the house. During the first visit to the site, it was established that the house is completed from the structural standpoint, Figure 10. In the second phase, the client requested house reshaping, and hence the architect prepared the interior design and partly the envelope design (external walls were already completed), yard design, and a new design of all installations/services, which included an appropriate energy-efficiency design, Figure 11.
The house is situated at 611 m of altitude, and its geographic position is: latitude: 43°51'58.46" N, longitude: 18°24'45.72" E,

Figure 9. General layout of the family house "Vrbanjuša" in Sarajevo, with plan view of the yard and ground floor

Figure 10. First phase of works at the Vrbanjuša House (2012.)

Figure 11. Visualisation of the Vrbanjuša House reshaping design

which is quite similar to the previous example, with a minor difference in altitude. As to orientation of the house, its position enables undisturbed insolation from all sides throughout the day. It is mostly oriented toward the east, south and west, which enables considerable sun energy gains at the house envelope level. The number of floors/levels is BA (basement) + GF (ground floor) + F1 (first floor) + A (attic), and the floor height ranges from 2.6 to 2.9 m, which finally resulted in a considerable volume of internal air to be treated (heated or cooled). In the scope of the energy efficiency study, the existing situation was surveyed and a special report regarding living habits of residents was made, which is of high significance for calculating the total energy requirement (habits regarding hot water use and interior air temperature preferences).

It can be seen from Table 3 that the house shape factor is much better than in the previous example, as here we have a volume shaped between a regular cube and cuboid, without many intersections, except in the entrance zone, which is a separate part that is linked with the primary structure of this composition.

Table 3. Data about the Vrbanjuša House

Area of the heated part of the house (A)	449,26 m^2
Volume of the heated part of the house (V)	1124 m^3
Area of the external house envelope (Ae)	723 m^2
Area of openings along the external house envelope (Aw)	91 m^2
Window factor (Aw/A)x100	20,3
House shape factor (Ae/V)	0.64

A considerable quantity of heating and cooling energy is required for treating the interior space. In addition, envelop walls are characterized by not so low U values ranging from 0.31 W/m^2K to 0.39 W/m^2K, as walls take up 46 percent of the total envelope area. In the initial phase of design, errors were made in the realization of the external walls from the aspect of thermodynamics and water vapour diffusion, which was subsequently impossible to correct by simple procedures, and so this position was adopted, Figure 13. It can be seen from Table 3 that the window factor amounts to 20.3 and is lower than in the preceding example, which is why an adequate realization of external walls is highly significant. In the part of the envelope relating to facade, external openings take up 23 percent. This is really a small proportion as two sides of the house had to keep the previous appearance with the initial number and shape of external openings, as the house is under protection of the Institute for the Preservation of Cultural, Historic, and Natural Heritage of the Sarajevo Canton. At the contacts between the heated and unheated space, external openings are always the most expensive segments, and are therefore the subject of discussions between the client and the designer. An average U value of the entire envelope amounts to 0.40 W/m^{2}K, which is a low value for traditional construction practices, but it is considered high for low energy or passive houses.

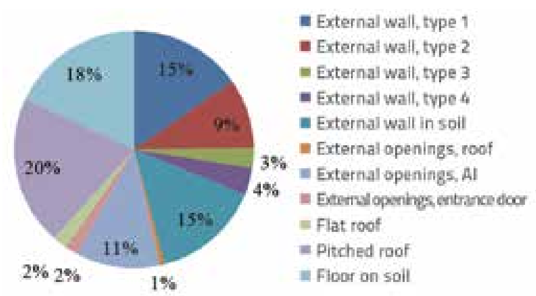

Figure 12. Structure of the entire envelope

As already mentioned, an inadequate material was selected for external walls (type 1, wrong selection of thermal insulation in the wall structure), which in fact takes up 15% of the total area of the envelope (Figure 12). The zone in which the problem occurs is shown in Figure 13: although the value of U=0.326w/m^{2}k is satisfactory, the diagrams point to the presence of condensation within wall layers. The thermoacoustic insulation type XPS, 8.0 cm in thickness (third graph), was installed. The analysis has shown that the water vapour condensation would have occurred even if an another type of thermal insulation material, with lower resistance to water vapour diffusion, had been placed. The only correct solution is to install the thermal insulation from the external side of the envelope. The following interventions were proposed: installation of additional thermal insulation layers 5.0 cm in thickness from the external side, or installation of the vapour barrier from the inside, prior to final plastering. It was finally concluded that the wall should be left as it is as the vapour drying period is less than 30 days, and so this item was disregarded.

A positive example in the selection of material can be seen at the flat roof where the system of inverted flat roof was applied, Figure 14. The utilisation of the mentioned system is especially important in weather conditions prevailing in Sarajevo due to very high temperature difference at external layer, which may amount to +100°C and -30°C. An extreme temperature influence on waterproofing layers was avoided by selection of the inverted flat roof, and thus excessive temperature expansion of materials during the year was avoided. It can be seen in Figure 16 that the temperature value of Δt in the winter and summer periods for the waterproofing layer amounts to 69.4°C for traditional flat roofs, while it amounts to only 3.8°C for inverted flat roof systems, which confirms the above statement about significance of proper adjustment of the envelope concept to weather conditions at a particular locality.

If more attention had been paid at the beginning of the project to the selection of materials and to the envelope concept, a house will a lower energy requirement could have been obtained. The analysis shows that the real energy requirement with the presented envelope amounts to 52 kWh/m^2/year for heating, and to 13.7 kWh/m^2/year for hot water. The total energy requirement for all consumers amounts to 75.7 kWh/m^2/year, which is a relatively high value for a house based on an energy efficient building concept.

Table 4. Structure of the entire envelope with thermal properties

Description		U factor [W/m^{2}K]	Area [m^2]
1	External wall type 1, solid brick, XPS polystyrene and solid brick	0,454	111,47
2	External wall type 2, solid brick, XPS polystyrene and reinforced concrete	0,520	68,75
3	External wall type 3, solid brick and XPS polystyrene	0,290	19,78
4	External wall type 4, solid brick and XPS polystyrene	0,205	26,55
5	External wall in soil, reinforced concrete and XPS polystyrene	0,280	107,5
6	External openings, roof window	1,7	4,32
7	External openings, Al profile, type: Schuco AWS 75 S.I., triple glazing, Low-e, g = 0,5	1,0	82,71
8	External openings, entrance door, solid wood and triple glazing, Low-e, g =	1,2	12,72
9	Flat roof	0,105	14,52
10	Pitched roof	0,11	148,29
11	Floor on soil	0,32	134,52
			Total envelope area: 723 m^2

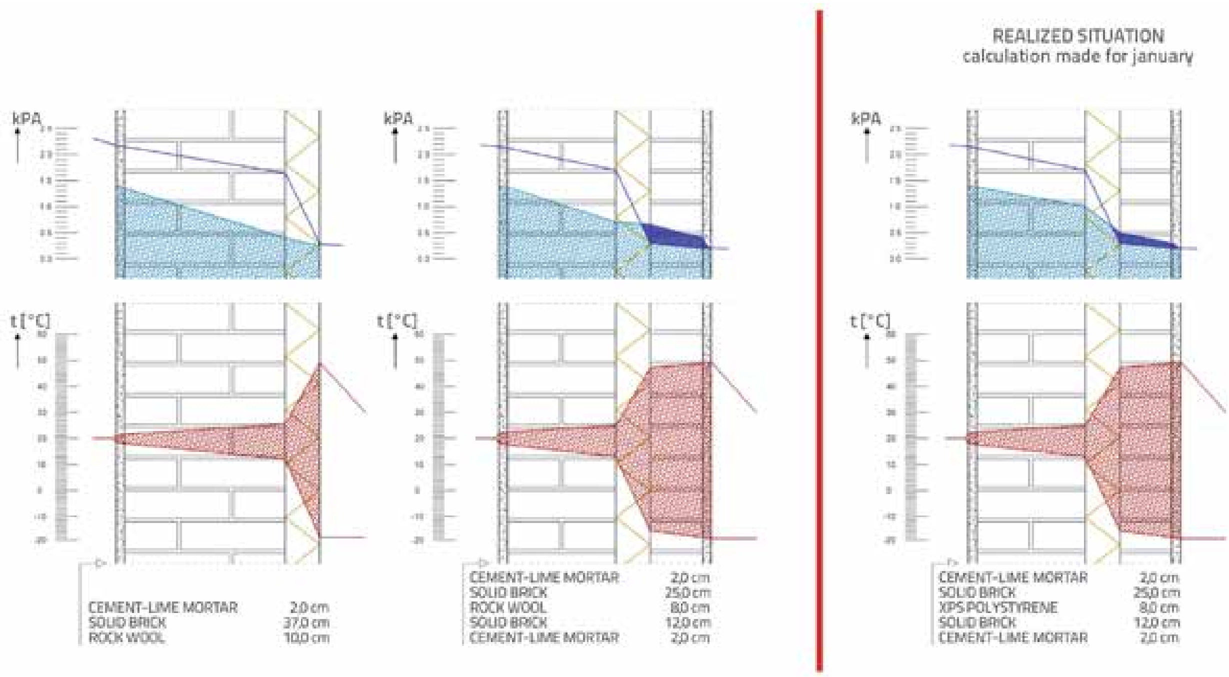

Figure 13. Graphic presentation of the water vapour flow analysis (different wall material concepts with the same U factor value)

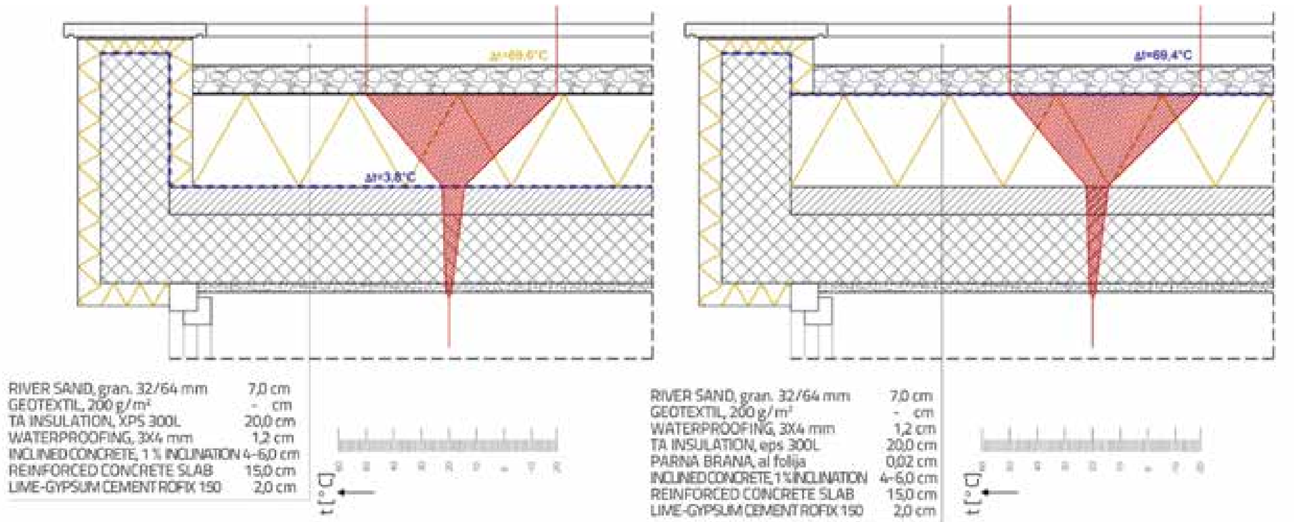

Figure 14. Calculation of temperature curve for various flat roof forms

Two crucial expressions are used in the paper for calculations relating to thermodynamics (1) and water vapour diffusion (2):

$$U = \frac{1}{R_{si} + R_1 + R_2 + R_j \; ...... + R_{se}} \quad [W/m^2K] \tag{1}$$

$$p_j = p_{j} - 1 \; \frac{p_i - p_e}{\sum R} R_j \quad [kPa] \tag{2}$$

The expression (1) is used to calculate the heat transfer coefficient, i.e. the passage of heat through individual layers of structural parts of the house. According to former JUS standards, the U value of walls should not exceed 0.8 W/m²K [2], while present-day regulations for passive houses specify that the U value for external walls should not exceed 0.15 W/m²K, which points to the significance of the house envelope in the process of creating an energy efficient architecture. In developed countries, the construction of passive houses is increasingly becoming a normal practice, and it may reasonably be assumed that external envelope will soon become a specially designed membrane for accurate and proper regulation of the heat and water vapour movements. The quality of external envelope is calculated according to expression (2) as it provides information about the water vapour flow through individual layers of structural parts of the house. This is significant as this issue is nowadays greatly neglected, which eventually results in houses that are absolutely closed from the aspect of water vapour diffusion.

Table 5. Calculation of investment cost and comparison of heating systems

Total energy requirement is 33.750,00 kWh or, in monetary terms (2.362,50 €)							
	Name of the system	Price of the system, including installation	Investment cost differences	Annual savings	Return of investment	Monthly energy requirement
1	Electric block + floor heating system with convectors and radiators	30.000,00 €				
2	Electric block + floor heating system with convectors and radiators	32.307,00 €	2.307,00 €	7% 186,55 €	10-12 god	206,54 €
3	Heat pump (air - water) + floor heating system with convectors and radiators + solar collector for hot water + passive cooling	64.100,00 €	34.100,00 €	51% 1.376,86 €	22 god	106,60 €
4	Heat pump (soil - water) + floor heating system with convectors and radiators + solar collector for hot water + passive cooling	91.120,00 €	61.120,00 €	75% 1.986,67 €	28 god	56,53 €

The next step consists in designing the concept for the production of the mentioned energy. To this end, a detailed analysis was conducted, focusing on parameters such as: micro-location potential, cost of investment, annual savings, and return of investment. Relationships between these parameters are shown in Table 4, where it can be seen that both proposed heat pump alternatives are characterized by a long return of investment time, which is a direct consequence of several factors:

- the price of electricity in Bosnia & Herzegovina is still low and amounts to 0.07 €/kWh,
- the current cost for the purchase and installation of systems for the use of renewable sources of energy is high, especially in case of geothermal energy,

Figure 15. Borehole drilling and assembly of geothermal probes

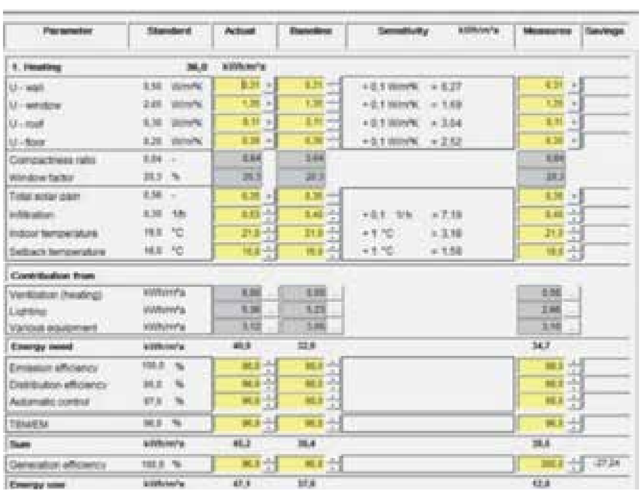

Figure 16. Heating energy requirement for the Vrbanjuša family house

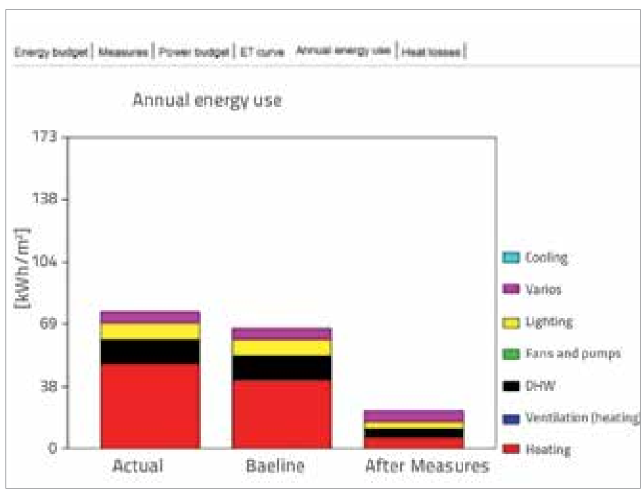

Figure 17. Total energy requirement for the Vrbanjuša family house

- there is no program in B&H that would support and encourage construction of low energy and low emission houses/buildings.

In this example, the design calls for utilisation of the most modern equipment, best installation facilities, and an automated heating and cooling system, which greatly increases the initial price. This is however a separate issue regarding quality of construction, which can be related to the level of luxury specified by the client.

The decision was made to provide energy for the heating, cooling and sanitary hot water mostly by using the geothermal energy of soil, via five geothermal probes to be placed down to 100 m in depth (type: Rehau RAUGEO PE-Xa 5x100 m, Figure 15) and two soil–water heat pumps (type: Stiebel Eltron WPF 32 Set, output power: 33.98 kWh, utilisation factor: 4.35 at B0, in the set with the buffer type: SBP 700 E, volume: 700 l), connected in a single system supported by heat energy obtained from solar collectors (type: Stiebel Eltron, SOL 27 basic, output power: 500 W/m^2, total useful area: 4x2.38 = 9.52 m^2, and cylinder type SBB 501 WP SOL, volume: 500 l) placed on top of the house. In this way, a family house with the total energy requirement of 25.9 kWh/m^2/year, instead of 75.7 kWh/m^2/year, was obtained. In other words, 75 percent or € 1,850.25 would be saved each year. However, in this case it was impossible to meet the objective of building the house with the energy requirement of 15kWh/m^2/year because of the "poorly" conceived and realised envelope. It should also be noted that the pipes used for heating would also be used in the summer period for cooling with water at the temperature of 12 to 15°C obtained directly from soil, and via floor convectors type: TKH – 2C/60, 3 pieces, or wall fan coils type: CLIMMY ES-CY-4.4-2T, which would cool the space using only energy that is needed to start to pumps (the so called "passive cooling system), based on soil temperature that amounts to 10 to 12° C at the depths ranging from 10 do 100 m.

The final result is the house with an extremely high quality of internal comfort with regard to air temperature that will not oscillate throughout the useful life of the house, with the minimum consumption of electricity needed to start the system, i.e. pumps and ventilators. As in B&H most electricity is generated in hydropower plans, this gives an even higher rating to this house so that, in the end, we may say that this is a facility with minimum emission of CO2, which should as such be classified among energy efficient houses with the total energy requirement of no more than 25.9 kWh/m^2/

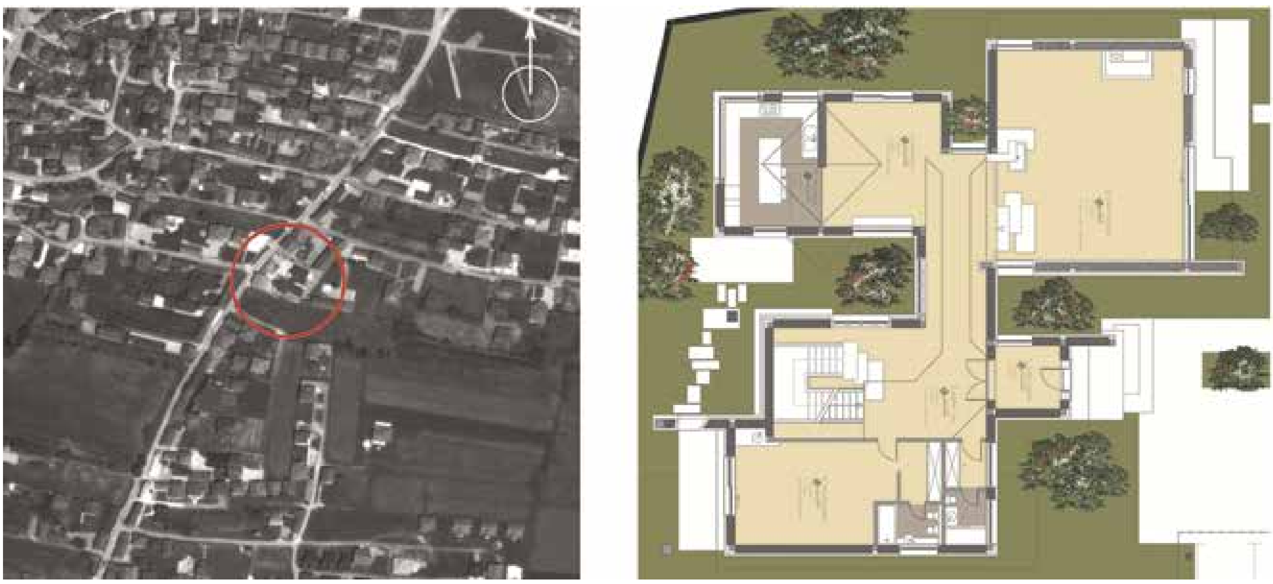

Figure 18. General layout of the Senokos House near Gostivar, and plan view of the yard and ground floor

Figure 19. Visualisation of the Senokos House after reshaping

year. Results presented in Figures 16 and 17 are some of the calculations made using the computer program ENSI 8.1.

3.3. Residential family house "Senokos" in Gostivar

The third example is a family house that is currently under construction in Senokos, which is a sparsely populated community near the town of Gostivar, Figure 18. Weather conditions are similar to those prevailing in the town of Sarajevo, with very cold winters and hot summers, and with somewhat lover minimum average temperatures in winter period. The house is situated at 562 m of altitude, and its geographic position is: latitude: 41°52'46.67" N, longitude: 20°53'34.35" E, and is hence located a little more to the south and east in comparison to the preceding two examples. The concept of the house is based on elements of the traditional architecture that has been present for full five centuries in this area with dominantly Albanian population. The complexity of the assignment provided a challenge and an inspiration for the energy efficiency analysis on this project. This is an architecture of detached houses with hipped roofs and highly pronounced first floor porches, surrounded by greenery and high walls. These traditional elements were conveniently combined on this project with modern shaping principles, and were also adapted to modern-day needs. The house is made of: GF (ground floor) + F1 (first floor) + A (attic). The ground floor is interestingly fragmented so as to blend the exterior with the interior through transparent glass surfaces, Figure 19.

Table 6. Data on the Senokos family house

Area of the heated part of the house (A)	505 m^2
Volume of the heated part of the house (V)	1361 m^3
Area of the external house envelope (Ae)	1079 m^2
Area of openings along the external house envelope (Aw)	133,93 m^2
Window factor (Aw/A)x100	26
House shape factor (Ae/V)	0.79

Fractured volumes combining internal with external spaces, where the first floor overhangs perched above the ground floor

Table 7. Properties of the entire envelope

	Description	U factor [W/m^{2}K]	Area [m^2]
1	External wall type.1, thermal block, rock wool	0,17	301,37
2	External wall type.2, reinforced concrete, rock wool	0,15	61,39
3	External openings type: Schuco, Corona SI 82, triple glazing, Low-e, g=0,45	0,9	105,13
4	External openings type: Schuco, Al curtain wall, FW 50 triple glazing, Low-e, g=0,45	1,3	24,28
5	External openings type: Entrance door, solid wood and triple glazing, Low-e, g=0,45	1,8	4,32
6	Flat roof	0,18	115,84
7	Pitched roof-	0,13	188,74
8	Floor above an unheated area	0,15	32,66
9	Floor on soil	0,31	245,12
			Total area of the envelope: 1079 m^2

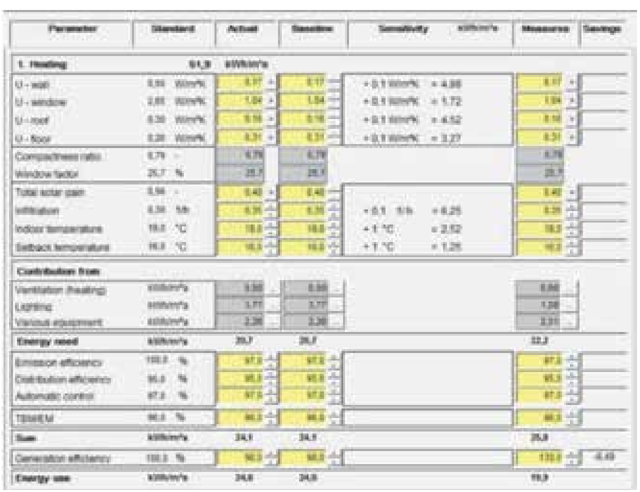

Figure 20. Heating requirement for the Senokos House

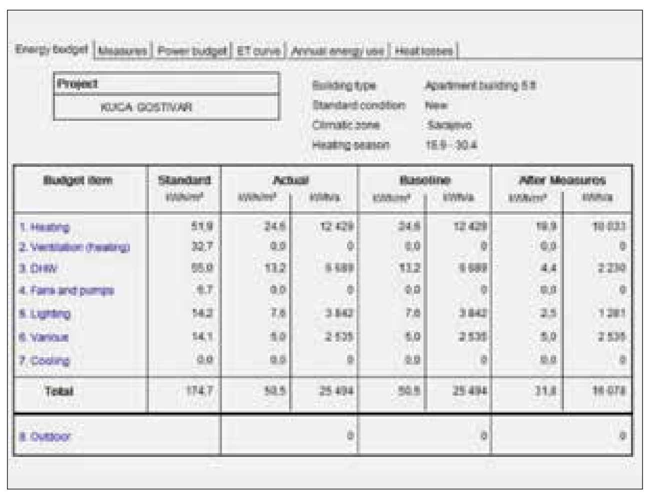

Figure 21. Total energy requirement for the Senokos Hous

are dominant, have greatly increased the area of the external envelope of the house, which has obviously had a negative effect on the overall calculation of energy requirement of the project. The shape factor amounting to 0.79 points to a considerable relationship between the external envelope area and the volume of the interior, i.e. to the limits between the heated and unheated air, and emphasizes significance of the proper selection of materials and adequate composition of the overall external envelope (Table 6). It was agreed with the client that a significant attention will be paid to the house envelope and, in this respect, it was concluded that the U value of walls, floors, and roofs should not exceed 15 W/m^2K, while the value of Uw = 0.9 W/m^2K should not be exceeded with regard to external openings (Table 7). This has finally resulted in the house with the shape that is quite complex from the standpoint of energy efficiency, and in the volume for which a very low quantity of energy is needed for heating and preparation of hot water. Consequently, the final energy requirement for this house amounts to 50.5 kWh/m2/year. This can be regarded as a very good final result and the confirmation that every architectural concept can be energy efficient if combined with a well defined external envelope system, conceived as a membrane of an architecturally well defined space, Figures 20 and 21.
The studied house will not have a controlled cooling system, which may be considered a shortcoming in the summer period, but it is expected that the boundary between the heated and unheated space will greatly prevent entry of hot air into the interior space, and so the influence of external heat on the internal air quality will be disregarded. The heating will be provided by using a central system with a primary boiler powered by biomass/pellets (output: 28 kW) (compressed shredded wood), which is also supported by solar collectors installed on the roof (type: auro STEP VSL S 250 E, Vaillant). The thermal energy obtained by burning pellets, and the solar energy, will be transferred to a single point in the boiler, from where it will be emitted into the internal distribution system. This energy will also be used for preparation of hot water. Pellet-powered boilers are highly efficient devices that generate very small quantities of waste. However, the experience has shown that a greater care should be paid to the selection of pellets from the aspect of their quality, as this quality is directly related to the efficiency of heating. Finally, the total consumption of energy for heating and preparation of hot water will be reduced, thanks to this system, to 23.4 $kWh/m^2/year$, while the total energy requirement will amount to 31.8 $kWh/m^2/year$ (without the pellet-powered boiler and solar system, the final energy requirement would be 50.5 $kWh/m^2/year$). This will be one of the first examples of low energy and low emission house construction projects in Macedonia. It should be noted that the installation of the heat pump was also considered so as to reduce even more the energy requirement. However, unlike the preceding two examples, here the model could not be found to finance such a plant. The cooperation between the designer and the client was quite exemplary and efficient, which has lead to the results presented in this paper, especially with regard to the quality of realization of the entire envelope of the house.

4. Conclusion

The construction of energy efficient residential buildings and houses is now a standard procedure in developed countries, while in developing countries, such as in Bosnia and Herzegovina, Macedonia and other countries in the region, this is the process that is mostly dependent on the cooperation of various participants in the project, such as the clients, designers, equipment manufacturers, etc.
Results presented in the paper with regard to the design and construction of energy efficient residential houses are the proof of positive practical examples that can serve as a role model of how to include the clients into the overall process. Objectives realized and presented in the paper constitute the synthesis of an efficient interaction between clients and designers focusing on a single objective: realization of long lasting and energy efficient buildings.

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