ENERGETSKE PERFORMANSE OMOTAČA ZGRADE OBRAZOVANJA PREMA PASIVNOM I NISKOENERGETSKOM STANDARDU

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Rezime:

Visoki energetski zahtjevi i potreba za energetskim certifikovanjem zgrade značajno utiču na projektovanje i izvođenje objekta. Rad ima za cilj da prikaže energetske performanse omotača zgrade obrazovanja u pasivnom i niskoenergetskom standardu u klimatskim uslovima zone sjever za Republiku Srpsku (Bosna i Hercegovina). Studija slučaja projekta nove zgrade Arhitektonsko-građevinsko-geodetskog fakulteta, čija je izgradnja počela 2011. godine u Banjoj Luci, predstavlja osnovu za predstavljeno istraživanje. Vizionarski pogled na izgradnju pasivne zgrade za obrazovanje zahtijevao je značajne investicije koje, nažalost, nisu bile obezbijeđene. Troškovi planirane izgradnje novog koncepta su smanjeni, ne samo na osnovu smanjenja energetskih performansi omotača zgrade, nego i na osnovu tehničkih sistema grijanja, završnih slojeva poda, opreme i sl. U radu su prezentovane izmjene energetskih performansi omotača zgrade i njihovog uticaja na transmisione i ventilacione gubitke, a samim tim i na potrebnu energiju za grijanje objekta.

Ključne riječi: projektni parametri, energetske performanse omotača zgrade, pasivni standard, niskoenergetski standard, zgrada obrazovanja

ENERGY PERFORMANCE OF THE EDUCATIONAL BUILDING ENVELOPE ACCORDING TO A PASSIVE AND LOW-ENERGY STANDARD

Abstract:

High energy demands and obligation for building energy certification make an impact on architectural design and building construction. The paper aims to present energy performance of the educational building envelope in a passive and low-energy standard in the climatic conditions of the north zone of the Republic of Srpska (Bosnia and Herzegovina). The case study of design project for the building of Faculty of Architecture, Civil engineering and Geodesy, which construction started in 2011 in Banja Luka, serves as the basis for the presented research . The original plan for passive educational building development required large investments, which unfortunately were not provided. Planned

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construction costs with new concept were reduced, not only with lower requirements of the envelope energy performance, but also technical systems such as heating type, lower costs on finishing layers of floors, furnishing etc. The paper presents changes in energy performance of the building envelope and its impact on transmission and ventilation heat losses, as well as the energy needs for heating.

1. INTRODUCTION

Contemporary approaches in architecture design are tightly connected to high energy efficiency demands requested by the governments, environmental organizations and EU initiatives. Those approaches greatly affect decisions making in terms of design and materialization of a building. As the research background, this study uses project for the new building of the Faculty of Architecture, Civil engineering and Geodesy at University of Banja Luka, which has been designed by adopting highest energy efficiency requirements and EU demands. The new approach implies construction of new building by using principles of energy efficiency (low energy, zero, zero plus or intelligent building) with specific standards and intelligent systems of optimization in contemporary construction.

The building has been designed as a two part structure consisted from - an old facility, the building from Austro-Hungarian period and the new facility designed for educational purposes. Even though a building design has been made as a contemporary, passive energy building, economical situation has also made influence to the process of the building construction. Therefore, the requirement of the high energy class and overall high building performance had to be changed to lower level.

Since the work analyses and proposes a solutions for modifications of energy grade, it is necessary to explain two grades which will be analyzed in the article. A passive house can be described as energy saving building where the heat comfort is provided without ordinary systems for heating or air conditioning. Heat needed in yearly period can be maximum as 15 $kWh/(m^2 a)$. The structure needs to be built without heat bridges ($\Psi \leq 0.01 W/(mK)$). Mutual usage of the primary energy cannot exceed 120 $kWh/(m^2 a)$. Low energy house is a term which is related to the house with annual year heat demands between 40-60 $kWh/(m^2 a)$ (what varies by the country), and at least $15 kWh/(m^2 a)$. In order to reach low energy parameters, a good insulated and air-tight building envelope as well as windows with thermal insulating glass are necessary to be provided. Also, the difference compared with a passive standard is that low energy standard implies traditional systems of heating. [1]

In the following text, a brief overview of the energy class change are shown for building envelope performance only.

2. BUILDING ANALYSIS

The first step towards modification of building energy performance is fundamental analysis of design documentation. A main task was to analyze and modify an original design plan, to reach more feasible building design with least possible design modifications. The special emphasis is made on building envelope since it has the greatest influence on the total energy loss of the building.

The first step towards building analysis - defining the material types and the exact thickness and properties of different types of materials and structural building elements which have to be built in is shown on Figure 1.

An important segment of this analysis is the type of the analyzed construction, since there is significant difference between recently constructed (new) part and old part of the building which already has a 51 cm thick wall (without an insulation).,
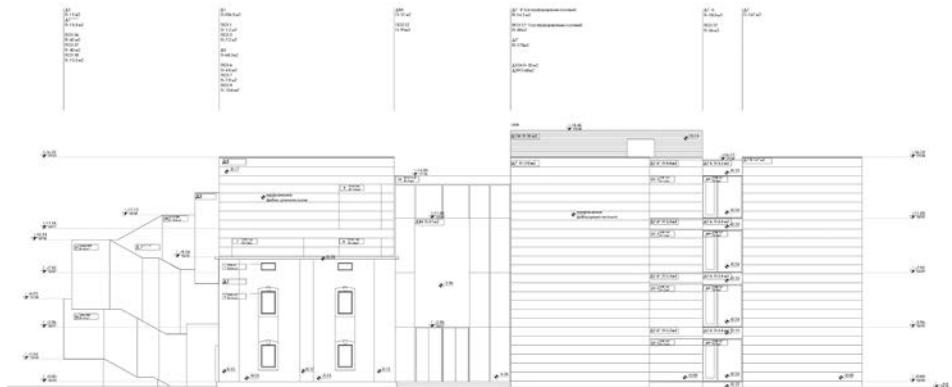
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Figure 1. Analysis of South Elevation.

Figure 2. shows a comparison between two main construction elements consisted within an old part, where the major difference is in the structure type - a contact and ventilating facade.

Distribution of transparent and opaque elements on the envelope were analyzed and exact percentage of contribution of each has been found. According to the orientation and solar insolation, a further reduction of layers of insulation has been made. The replacement several transparent elements at the envelope has been planned to be done with lower thermal insulation elements, such as the envelope of the aula, which connects the old and new part of the building. According to the design plan the new building of Faculty of Architecture, Civil engineering and Geodesy has gross volume of V_e=34053 m^3 with conditioned floor area of A_u=7197 m^2 and the building shape factor of f_0=0.247. The share of transparent elements in total area of building envelope is 28.3 % [2].

finishing layer
insulation - 30 cm
existing wall - 61cm
plasterboard cardboard

finishing layer
ventilating layer 25 cm
insulation - 36 cm
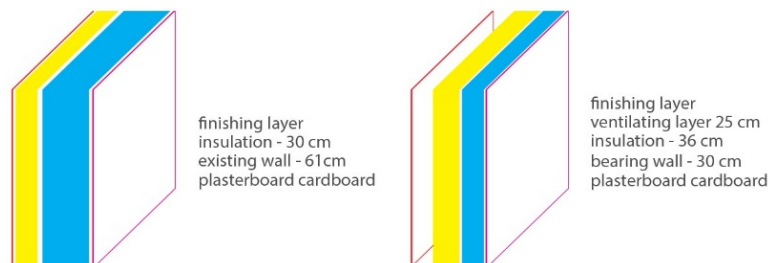bearing wall - 30 cm
plasterboard cardboard

Figure 2. Difference in bearing part of the wall - camparison between existing wall (61cm of bearing part thickness) and new (proposed) type of the wall (36 cm of bearing part thickness).

2.1. REDUCTION OF SOLAR HEAT GAINS

The solar heat gains represent the increase in thermal energy of a building due absorption of incident solar radiation. [4] When analyzing the building envelope, next to the orientation as main natural parameter which directly makes influence on energy performance of a building is the shading, which has a purpose to prevent or reduce excessive amount of direct solar radiation inside a room. By analyzing a building, it is concluded that major part of the facades are oriented towards north and south, which is according to main energy efficiency principles, correct orientation since it provides the biggest solar heat gains during the winter and lower ones during the summer. The solar

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heat gains through the windows are expected to have the greatest impact on energy performance of the building except in buildings with very poor insulation standards.

The average intensity of global solar radiation in July reaching an outer surface of westerly oriented window is 168 W/m^2 [6]. For example, a 5 x 5 m office with 6 m^2 of glazing would receive around 0.55 kW of solar heat gains, about 3.5 times greater than the heat gains from occupants and electrical appliances. [6] Considering that the building is intended for educational purposes, good lighting in classrooms must be provided too [7]. The educational section of building is oriented toward the east, but with significant amount of dense trees which absorb direct solar radiation. Offices and classrooms are west/east oriented with a triple glazing unit and thicker insulation on external walls.

In these positions the unit of glazing are not changed, in order to ensure the transmission of solar energy (g-coefficient of 0.5) which is more suitable for the summer period with the aim to prevent overheating of the space. Due to limits on energy demands, a design proposes a facade which can use a solar energy and light in the most optimized way, as it is shown in the figure 3, towards the angle of the sun's rays at 45 degrees north latitude [3]. An original design proposed a design with automatic movable shutters, but due to economic reasons, this solution has been replaced with basic, manually operated shutters.
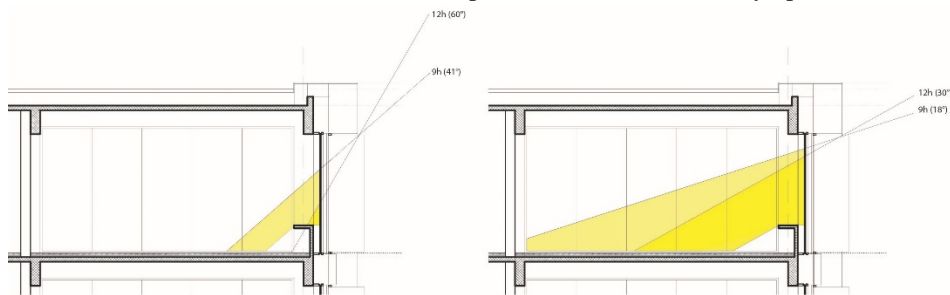

Figure 3. A solar gains during summer and winter with a shader on east elevation

According to Baker and Steemers [4] the use of tinted and reflected glass is not recommended as a shading strategy, since the ratio between useful daylight reduction and thermal reduction is not in good relation. When it comes to curtain walls, a clear, non-reflective glasses are proposed, with three layers of low-e glass, filled with krypton in spaces between. In this case, curtain walls are used not just in northern, eastern and southern facade, but also as a significant part of the roof. Therefore, the decision was to change a glazing type only on the space of "aula", because it was the space that makes the main entrance hall in the building, it connects the old and new part of the building, and it is planned to be heated at 18°C.

3. A DETAILED REVIEW OF ENERGY PERFORMANCE ANALYSIS AND MODIFICATION

In order to reduce transmission heat losses and categorize building in passive energy concept with annual energy need for heating below 15 kWh/m^2 designers aimed for the lowest possible U-values of the envelope elements. Originally planned building was designed with U-value of external walls ranging from 0.075 to 0.176 $W/(m^2K)$ and with thermal insulation thickness of 30 to 40 cm. Transparent elements were planned to be triple glazed windows (low-e filled with krypton) with thermally broken multi-chamber aluminum frames with U-values ranging from 0.960 to 1.220 $W/(m^2K)$. The opaque roof

elements were designed with thermal insulation thickness from 34 to 42 cm and U-value ranging from 0.078 to 0.116 $W/(m^2K)$. With such low U-values, heat losses by transmission are not significant even in the coldest months [8]. For the envelope designed in this way annual energy need for heating per conditioned floor area is $Q''_{h,nd}$=10.97 kWh/m^2 (table 1), which classifies the building into the energy class A according to the current Rulebook on energy survey and energy certificate publication [9]. The building is conceived as one of the first buildings of such of size in the country that requires that low amount of energy need for heating. This is a direct consequence of incorporation of the latest and futuristic energy efficient concepts in design of new buildings.

Table 1. Energy characteristics of originally and modified design of Faculty building

	Initial design plan	After modification	Relative increase [%]
$Q''_{h,nd}$ [kWh/m^2]	10.97	20.52	87.1
$Q'_{h,nd}$ [kWh/m^3]	1.928	3.602	87.1
H'_T [$W/(m^2K)$]	0.347	0.467	34.6
H [W/K]	7496.78	9626.6	28.4
Length of heating season [days]	123	160	50.9

According to this requirement for non-residential buildings with shape factor between 0.20 – 1.05 the annual energy need for heating per external volume should not be greater than 17.19 kWh/m^3 [5]. However, calculation shows that (Table 1) this quantity is equal to $Q'_{h,nd}$=1.928 kWh/m^3 which indicates that the annual energy demand for heating is around 9 times lower than the permitted value for this type of buildings. The heat transfer coefficient by transmission per overall area of building envelope is H'_T=0.347 $W/(m^2K)$ (Table 1). Rulebook on minimum requirements of energy characteristics of buildings prescribes limit value of 0.907 $W/(m^2K)$ for non-residential buildings with shape factor between 0.20 - 1.05 and the share of transparent elements lower than 30 %. By comparing the prescribed and calculated values of the heat transfer coefficient normalized to the area of the envelope it can be concluded that the transmission heat losses are around 2.5 times lower than the permitted ones. Beside transmission heat losses which depends on the thermal-insulating quality of the elements (or U-values), buildings lose heat by air-change as well [10]. Such losses are known as ventilation heat losses (including infiltration) and they depend on the tightness of envelope, characteristics of ventilation systems and the position of the building with respect to the environment and the microclimate [11]. As can be expected with passive energy building of the class A, the ventilation heat losses are significant (64.5 %) and dominant over the heat losses by transmission (35.5 %). The Overall heat transfer coefficient (by transmission and ventilation together) equals to H=7496.78 W/K (Table 1).

Modification of the initial design plan meant the reduction of a thermal insulation thickness of the external and basement walls, ground and basement floor, flat roof, replacement of a certain number of triple glazed low-e windows filled with krypton with double glazed low-e windows filled with air and the modification of ventilation system in building. Table 2. shows an example of exterior wall D1 with reduced thickness of thermal insulation. Each building envelope element has been modified in way that it still meets the prescribed conditions in terms of thermal properties, while the overall energy performance

of the buildings meets the B class level. Table 2 shows representative element of envelope whose U-value after modification of initial design equals to $0.192\,W/(m^2K)$. Interventions reduced the thickness of stone wool as a thermal insulation from 30 to 15 cm, which increased U-value from 0.109 to $0.193\,W/(m^2K)$. Satisfactory U-value is reached according to regulations [12] even after interventions.

Newly designed U-values of external walls and flat roof elements range from 0.091 to $0.262\,W/(m^2K)$ and 0.106 to $0.191\,W/(m^2K)$, respectively. By these interventions on the envelope transmission heat losses are significantly increased compared to the initial state. After modification of initial design plan annual energy need for heating per conditioned floor area increases almost twice with respect to the previous design value ($Q_{h,nd}''$=20.52 kWh/m^2) (Table 1) and therefore the energy class of building changes from class A to class B. The same relative increase characterizes the annual energy need for heating per conditioned floor area and per external volume ($Q_{h,nd}'$=3.602 kWh/m^3). By deteriorating the thermal characteristics newly designed can be classified into low energy buildings. The new heat transfer coefficient by transmission per overall area of building envelope is H_T'=0.467 $W/(m^2K)$ and the overall heat transfer coefficient by transmission and ventilation is H=9626.6 W/K (Table 1).

Table 2. Structure of a „D1" wall. An example of modified thermal performance of wall.

layer	material	thickness (before) [cm]	thickness (after) [cm]	density $[kg/m^3]$	thermal conductivity $[W/(mK)]$	thermal resistance (before) $[(m^2K)/W]$	thermal resistance (after) $[(m^2K)/W]$
	internal resistance					0.130	0.130
1	plaster cardboard	1	1	900	0.210	0.048	0.048
2	unventilated air layer	3	3	1	0.164	0.183	0.183
3	brick	65	65	1800	0.760	0.842	0.842
4	stone wool	30	15	30	0.038	7.895	3.947
	external resistance					0.040	0.040
Total thermal resistance R $[(m^2K)/W]$						9.138	5.190
Thermal transmittance U $[W/(m^2K)]$						0.109	0.193

As can be seen from Figure 4, the greatest share of transmission heat losses occurs, as expected, through the transparent elements (roof and vertical windows) both for initial and modified design plan (79.1 and 67.2 %, respectively). Next in line are external walls and opaque elements of roof with overall share of 14.3 and 19.2 % in total transmission heat losses of originally planned and modified Faculty building, respectively. Heat losses through ground walls and floors are not significant due to thermal mass of the ground. Third (gray) column in Figure 5 represents relative change of transmission heat losses compared to the original state. The largest modifications are made for the external walls

and opaque elements of roof, where the thickness of thermal insulation is reduced by 10 up to a maximum 25 cm. The relative increase in transmission heat losses are 86.7 and 65.2 % for external walls and opaque elements of roof, respectively. A much smaller relative change in transmission heat losses occurs through transparent elements (2.2 and 17.5 % for roof and vertical transparent elements, respectively), because the replacement of triple glazed windows was made only in the central part of the building "aula".

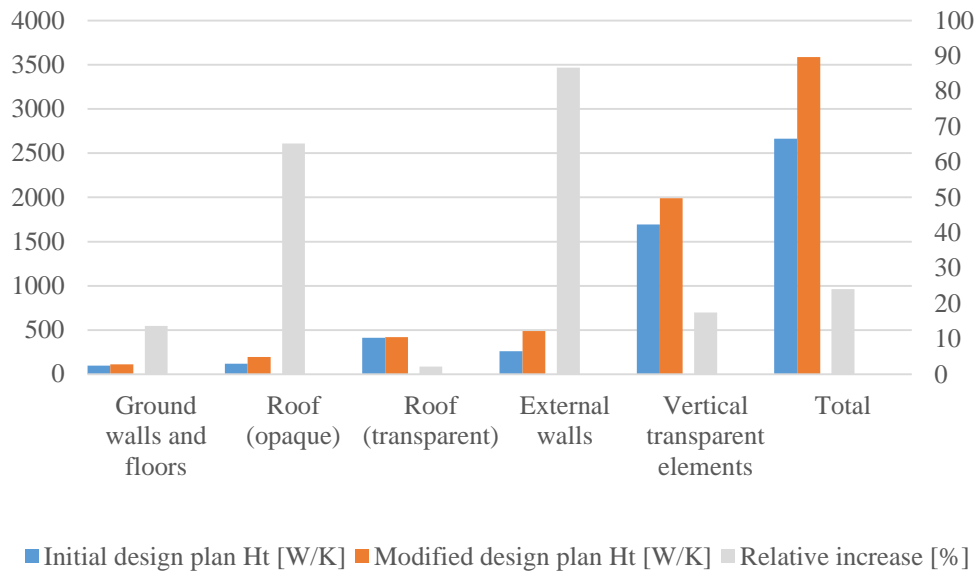■Initial design plan Ht [W/K] ■Modified design plan Ht [W/K] ■Relative increase [%]

Figure 4. Transmission heat losses categorized by type of envelope

Length of the heating season for originally planned Faculty building is 123 days long (Table 1), which is 65 days shorter than the heating season length derived from the average housing insulation properties and climatic conditions of Banja Luka [13]. The heating season starts at early-November and ends in early-March. After modification of design plan the length of the heating season extends for additional 27 days (Table 1) and lasts from late October to late-March. According to the original design plan, larger amounts of heating energy are required only in December and January, while according to modified design plan this period covers two more months (February and November). After modification of design plan the energy need for heating in January and December becomes for about 1.9 greater.
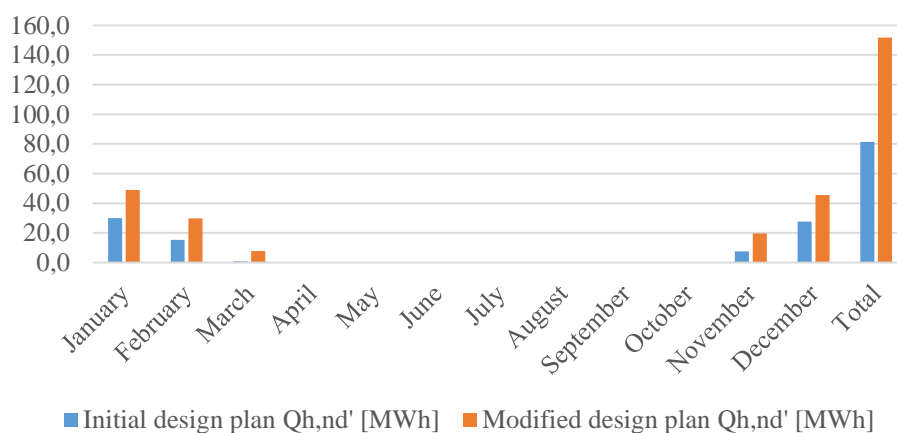
Figure 5. Monthly energy need for heating

4. CONCLUSION

The paper gives a brief review of architectural design decisions in accordance with energy efficiency demands. Since the original design plan for passive building required large investments, which unfortunately were not provided, it was necessary to change design of the building and its envelope according to new economic circumstances. As it is described in the paper economical demands, although crucial for building of an object, can be respected without major changes in design. Furthermore, the cost reductions can be achieved not only on the basis of lower energy performance, but also by reducing technical systems such as heating and ventilating type, lowering costs of finishing layers of floors, furnishing and other elements which passive standard implied.

Modifications of initial design plan lead to larger transmission and ventilation heat losses causing the annual energy need for heating per conditioned floor area increased almost twice with respect to the previous design value and thus resulting in the change of the building energy class from A to B.

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