FACTA UNIVERSITATIS
Series: **Architecture and Civil Engineering** Vol. 17, N^o 1, 2019, pp. 33-44
https://doi.org/10.2298/FUACE181020030B

INFLUENCE OF GLAZING TYPE ON ENERGY EFFICIENCY OF INDUSTRIAL BUILDINGS IN THE PROCESS OF REVITALIZATION – A CASE STUDY

UDC 725.4:620.9(497.11)
725.4:69.059.35(497.11)
692.232.4:691.6(497.11)

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Abstract. *This paper examines the possibilities of improving the energy performance of an existing industrial building by application of the double skin façade on the revitalization of the building envelope in the climatic conditions of the city Novi Pazar, Republic of Serbia. The aim is to examine the impact of choosing the type of glazing, in the processes of revitalization, on the energy needs of industrial buildings for heating and cooling, as well as the contribution of the measures implemented to improve the energy performance of the selected type and model of industrial building. The energy performance of buildings was obtained using the software DesignBuilder and EnergyPlus simulation platform, taking into account the parameters of required internal temperature and climate data for the Republic of Serbia. The comparative analysis of the results of energy simulation according to the criterion of achieving greater energy savings and reduced carbon dioxide emissions was performed. The methodological approach in this research involves creating revitalization scenarios of industrial buildings with a shed roof construction, selection of the specific building according to whose properties by numerical simulation possibilities for energy revitalization depletion were investigated and comparative analysis of the obtained results was performed. The primary objective of this research is to investigate the impact of choosing the type of glazing on the energy performance of industrial buildings with a shed roof construction and to determine the optimal approach to energy revitalization of existing industrial buildings with the implementation of the double skin façade under the climatic conditions of the city Novi Pazar, Republic of Serbia. The results of this paper indicate the negative characteristics of the kopilit glass to solar gains, whose retention requires a large amount of heating energy. While replacing of kopilit glass with a low-energy glass increases the amount of energy required to cooling of the building. With this research, through various revitalization scenarios, it is also indicated that using a double skin façade in the*

Received October 20, 2018 / Accepted January 29, 2019
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revitalization process of the selected building, has a very similar impact on reducing CO_2 emissions regardless of the type of glazing choice.

Key words: *type of glazing, adaptive reuse, energy efficiency, renewable energy, legislation*

1. INTRODUCTION

Buildings consume about 40% of the total energy in the European Union [1]. Energy efficiency and use of energy from renewable sources represent important measures needed to reduce energy consumption in buildings and environmental pollution [2]. Therefore, the primary parameters that mostly affect an office building energy performance are heating and cooling requirements during the working hours [3].

Analysis of the energy performance of buildings is a topic that has been investigated in numerous important scientific papers through simplified and detailed models based on window properties, building design, and climate conditions [4]. Parameters affecting the amount of energy required for heating and cooling the building are: location, orientation and micro-climate, shape of the building, windows and doors of the building, the orientation, utilization of internal thermal gains (especially the passive solar gain), thermal mass, thermal insulation of the building skin, doors and windows, providing through the envelope of the building, circulation of the heating system and the ventilation system. Simulation of thermal gain with the use of glass in the materialization of building, from the aspect of energy, was sufficiently tested in the previous research [5]. The optimization of energy characteristics of existing industrial buildings for the climatic conditions of the Republic of Serbia in the case of conversion of space has been examined [6]. Numerous experimental studies on the impact of glazing on the energy characteristics of the building have been carried out [7-9], as well as research of numerical simulations by creating dynamic computer models [10].

This paper presents the potential ways of application of double skin facade in the process of reconstruction, as an element of passive solar architecture, re purposing and energy revitalization of the existing building. The existing industrial structure needs to be converted into the building for administrative purposes. The chosen type of industrial building is an industrial hall with a shed roof. By adaptive reuse of existing industrial building in an administrative building is given a proposal of functional zones in the building on the basis of which the thermal loads of functional units have been performed. Model of the newly designed building has been a subject to numerical simulation by use of EnergyPlus software [11] and DesignBuilder software [12] and with those results the values of the energy needed for heating and cooling of the building, carbon dioxide emission, the amount of solar gain have been obtained. The influence of the building on the environment, the reduction of carbon dioxide emissions are discussed as a criteria for improving the energy efficiency of the building. Based on the obtained results of necessary energy and carbon-dioxide emissions in buildings that have a double skin facade as a cover, the optimization of the obtained solutions from the aspect of applying the type of glass is discussed, as the basic element of passive solar systems.

2. METHODOLOGY

Selected type of industrial facility has been created in a computer program and is subject to numerical simulations in order to gain insight into its energy performance. Numerical simulation is carried out in accordance with applicable regulations in the field of energy efficiency of buildings, based on climate characteristics of locations, data on building materials, components and systems, data on electrical equipment, apparatus, and purpose of use of the building. By use of computer simulations of the energy performance of buildings a great advantage when designing new or revitalization of already built facilities is provided. In the first phase of the design already the different alternatives in the design and meeting the expected aesthetic and energy requirements of buildings can be tested.

Simulation of different revitalizations of the chosen model is derived using EnergyPlus simulation platforms, with the help of graphic software DesignBuilder. This software combination was chosen primarily because of the reliability of EnergyPlus program, which is one of the most efficient tools which most other commercial software rely on [13]. And because of the reliability of software Design Builder which obtained simulation data significantly coincide with the real data in the functioning of the building. [14]. In Table 1 is specified five different scenarios of revitalization of the facility, of which 4 involve the application of a double skin facade while one revitalization scenario is a classic tread.

Table 1 Proposed measures of revitalization of selected industrial building

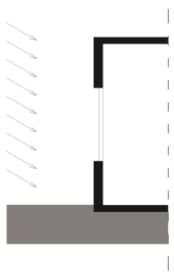
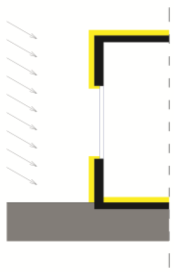
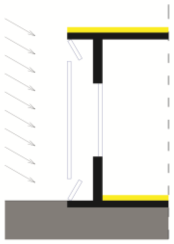
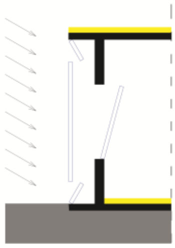
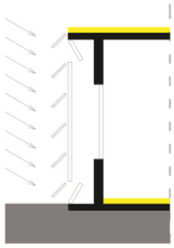
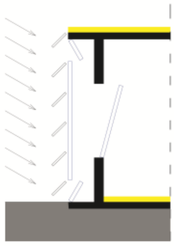
Diagram of revitalization		
Current situation		**Current situation** - Current situation of the building includes the current condition of the structural elements of the building envelope with constructive assembly building. By observing the selected types of industrial buildings, the lack of insulating layer in the roof, façade walls and floor on ground of the building, becomes evident resulting in a very high coefficient of heat transfer. The windows in the facade wall consist of a single glass thickness of 6 mm and the coefficient of heat transfer U = 5.8 W/m^{2}K (type 1) with a metal frame without thermal break, and a „kopilit" glass with a coefficient of heat transfer U = 2.8 W/m^{2}K (type 2) . Doors in the facade wall are metal structures with coefficient of heat transfer U = 3.124 W/m^{2}K.
Scenario 1		**Scenario 1 -** Revitalization of the building cover by adding insulating layers of 15 cm rock wool in façade wall and panel on the ground, while on the roof there is a need to add rock wool in the layer of 20cm. Reconstruction of the windows is followed by replacing the existing metal frames with PVC profiles with the overall heat transfer coefficient U=1.4 W/m^{2}K and replacing the existing glass (type 1 and type 2) with double low-e glass 4+12+4 (Kr) with a coefficient of heat transfer U=1.1 W/m^{2}K. Entrance metal doors were also replaced with a new with overall heat transfer coefficient U=1.25 W/m^{2}K.

Diagram of revitalization	
Scenario 2 	**Scenario 2 -** This type of revitalization includes revitalization of the facility as in Scenario 1 except for the eastern and western façade wall. On the east and west walls there is no planned revitalization of non-transparent parts of the facade but only the reconstruction of the windows as in scenario 1. On the east and west facades a double skin façade was formed whose outer membrane makes the curtain wall at a distance of 60cm from the existing facade wall with a single glass with thickness of 6 mm and the overall heat transfer coefficient $U=5.8\ W/m^2K$.
Scenario 2a 	**Scenario 2a -** Scenario 2a is a revitalization scenario 2 advanced by the introduction of night ventilation in order to reduce the energy needed to cool the building in summer. Night ventilation means ventilation of the building, by controlled opening in the lower and upper zone of the double skin façade, opening of the windows and openings of internal openings / skylights of interior doors which would make a constant aeration of 0.5 ac/h between 18 - 06 h increased to a maximum of 1.2 ac/h in the period 1st April to 1st October.
Scenario 2b 	**Scenario 2b -** Scenario 2b also represents an improved revitalization scenario 2 with introduction of blinds on the east and west facades within the double skin facade, which would reduce the energy needed to cool the building in summer. Blinds include fixed horizontal sun-breakers along the double facade, with a width of 50 cm are positioned at an angle of 45 ° in a vertical distance of 80 cm.
Scenario 2c 	**Scenario 2c -** Scenario 2c is improved revitalization scenario 2b with additional introduction of night ventilation in order to reduce the energy needed to cool the building in summer. Night ventilation means ventilation by control of facility openings in the lower and upper zone of double skin facades, the internal control aperture and shutter windows / skylights of interior doors which would provide a constant aeration of 0.5 ac/h between 18 - 06 h increased to a maximum of 1.2 ac/h in the period 1st April to 1st October.

The methodological approach to the development of scenarios that are used for improving the energy performance of the building is guided by the desire to preserve the identity of the existing building, improving the design of the building by use of passive solar principles of architecture, preservation of geometry and ways of opening windows and doors, replacement of inadequate and environmentally unjustified roof cladding with new material.

Software DesignBuilder defined by a physical model of the building with an exact geographical location and use of materials, layers of façade envelope. The software include the scheme of thermal zones, their internal design temperature, time intervals of use and occupancy, a load of electrical appliances and lighting. Working hours of functioning of the building are defined based on the 40 hour working time per week, respectively, 8h per day in the period 8:00 to 16:00 hours from Monday to Friday. Interior design temperatures are defined by the Regulation on Energy Performance of Buildings (2011) [15], wherein said design temperature out of the working hours is adjusted by ± 4 ° C depending on the mode of heating or cooling facility (table 2). The presence of people, heat output per person, occupancy are also defined according to the Regulations, while the value of the heat output of the electrical equipment and lighting are taken over from the software DesignBuilder depending on the heat zone. Considering that the subject occupies only moderately sheltered location where more than one facade is exposed to the wind, the reported values of the facility ventilation by use of natural ventilation depending on the state of tightness of the building are defined with 0.9 ac/h for existing state and 0.5 ac/h for the state after revitalization. Those parameters are shown in Table 2.

Table 2 Loads of heat zones of people activity, occupancy, timetables, interior design temperature, heat load zone of lighting and electrical devices, ventilation

Data	Office	Corridor	Caffe	Conference room	Dressing room	Storage	WC	Unit
The internal projected temperature for winter conditions	20 / 16	16 / 16	20 / 16	20 / 16	20 / 16	18 / 14	18 / 14	°C
The internal projected temperature for summer conditions	26 / 30	30 / 30	26 / 30	26 / 30	26 / 30	26 / 30	26 / 30	°C
Occupancy per person	0.05	0.10	0.20	0.20	0.05	0.001	0.05	per /m^2
People	80	100	100	80	100	100	100	W/per
Occupancy	08:00 - 16:00	08:00 - 16:00	08:00 - 16:00	08:00 - 12:00	08:00 - 16:00	08:00 - 16:00	08:00 - 16:00	H
Light energy				5				W/m^2 -100 lux
Natural ventilation				0.7				ac/h
Electricity equipment	11.77	1.85	14.72	5	/	/	5.48	W/m^2
External infiltration existing / reconstructed				0.9/0.5				ac/h

2.1. Model for the analysis

The selected industrial building is an apparel hall that belonged to the complex of textile plant "Raska" in Novi Pazar [16]. This building, was built in 1974. and represents the typical industrial building with a shed roof, built in Yugoslavia in that period. The building is industrial building that houses manufacturing facility, toilets and warehouses for the needs of workers. The building is rectangular in shape, orientation north - south with deviation of the north-south direction by 13 °, G + 0 (fig. 1).

In the immediate surroundings of the building there are buildings that used to represent the ancillary facilities of the textile plant "Raska". Based on the position of buildings in the tighter location, the number of floors of surrounding buildings has been stated. Alongside the northern façade of the observed building there is the administrative building TK "Raska", while along the east facade there is another building that represents separate content of TK "Raska". These buildings with their position, height and shadow affect the solitude of the observed building (Figure 1).

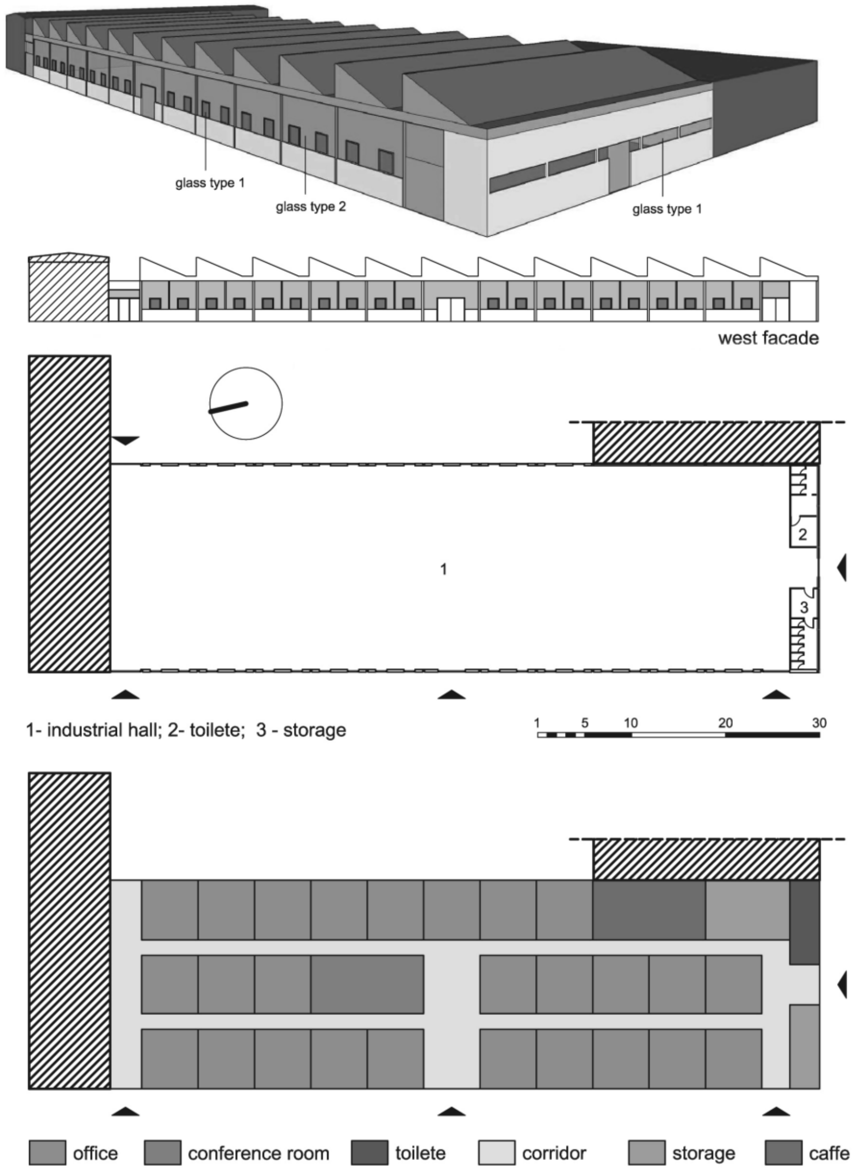


Fig. 1 Ground floor and west facade of Textile factory „Raška“– current conditions, adaptive reuse and model

The production plant is located in the northern part of the building, while the entrance to the building with toilets and utility rooms is located in the southern part of the building. The building has smaller openings for the toilets on the south facade and a larger number of openings on the east and west facades with a uniform scheme followed by a constructive grid. A chosen industrial building has a characteristic roof shape, with northern windows whose contains a specific glass type named kopilit glass.

The structure of industrial hall is made of the steel skeleton structure with a steel grille as a beam carrier. The exterior walls are made of bricks 25 cm thick plastered inside of the longitudinal mortar layer of 2 cm. The rest of the outer walls is an aluform sandwich panel with a 5 cm thick thermal insulation layer. The roof of the building is sloping shed roof construction with an aluform sandwich panel with a 5 cm thick thermal insulation layer. The panel on the ground consists of reinforced concrete layer 10cm thick on gravel pad layer 10 cm thick, with a cast terrazzo as a final layer.

The windows of the industrial building are single with a single-layer glass 6mm thick with heat transfer coefficient U=5.8 W/m^{2}K (type 1) and metal frame without thermal disconnection with coefficient of heat transfer U=6.0 W/m2K, and a „kopilit" glass (type 2). „Kopilit" glass is characterized by a very low coefficient of transmission of solar radiation g = 0.40 and a high heat transfer coefficient U = 2.8 W / m^{2}K, which would greatly increase solar gain and reduce transmission losses of heat.

Table 3 presents basic informations about the building, the surface of the thermal cover of the building, volume of heated space, building shape factor and the percentage of transparent surfaces in the building cover.

Table 3 Information about the building

Information about the building	Existing condition
Area of the thermal building envelope A [m^2]	5099.31
The volume of the heated part of the building V [m^3]	8573
Total volume of the building V [m^3]	9271.5
Building shape factor [m^{-1}]	0.55
The share of transparent surfaces [%]	23.22

Renovation and adaptation of the building anticipates repurposing the building for administrative purposes. In the renovation, the attention was paid to the utilization of the existing structure of the building and the existing infrastructure. In fact, when changing the purpose of the space, the existing physical structure and purpose of the existing additional space of the industrial building have been used, while the space reserved for industrial production has been transformed into office space, with conference room and horizontal communication (figure 1). In the aim of better utilization of the space three-tracts with the two corridors and administrative units that are positioned on the central of building, east and west facades of the building have been formed. Achieved surfaces and volumes of the rooms are given in Table 4.

Table 4 Area and volume of the building zones– adaptive reuse

Zone		Area [m²]	Volume [m³]
1	Offices	958.2	5160.2
2	Conference room	72.5	387.9
3	Corridor	403.7	2089.6
4	Caffe	54.1	302.9
5	Toilet	24.5	118.6
6	Storage	98.3	513.8
Total		1611.3	8573

3. RESULTS AND DISCUSSION

The paper examines the possibilities of reducing thermal gain if the replacement of the „kopilit“ glass is performed and if the existing glass is retained. Accordingly, a simulation of the energy performance of the building was performed for each repair scenario with a difference in glazing, when the single glass (glass type 1) and „kopilit“ glass (glass type 2) are replaced with a double low-emission glass. Or the „kopilit“ glass is retained and the existing single glazing is replaced by the double low-emission glass. The other structural elements on the envelope are treated in accordance with the previously defined remediation scenarios. The results of these simulations relevant to the discussion are shown in Table 5.

Table 5 The results of the simulations in the case of replacement of the „kopilit” glass and when the „kopilit“ glass is retained

	Scenario/current situation	Heating [kWh/m²]	Cooling [kWh/m²]	Primary energy [MWh]	CO2 emission [t]	Solar gains [MWh]
Replaced kopilit glass	0	151.92	17.83	341.10	91.92	133.56
	1	41.62	**18.88**	150.24	55.21	205.60
	2	34.64	14.68	125.29	45.34	105.11
	2a	34.64	14.02	122.51	43.87	105.11
	2b	37.11	9.64	108.73	35.07	91.24
	2c	37.11	9.25	107.12	34.21	91.24
Retained kopilit glass	0	151.92	17.83	341.09	91.92	133.56
	1	64.72	10.76	158.51	46.05	123.56
	2	51.70	11.45	143.20	44.46	64.17
	2a	51.70	11.08	141.65	43.64	64.17
	2b	53.86	7.36	130.06	36.18	54.30
	2c	53.86	7.14	129.13	35.69	54.30

By results in Table 5, we can conclude that by replacing a „kopilit“ glass in the revitalization by scenario 1 needed energy for cooling is increasing compared to condition before revitalization.

Also, we can conclude that by retaining a „kopilit“ glass in the revitalization of an industrial building, in the case of the adaptive reuse into a administrative building, the energy characteristics of the building are significantly changed.

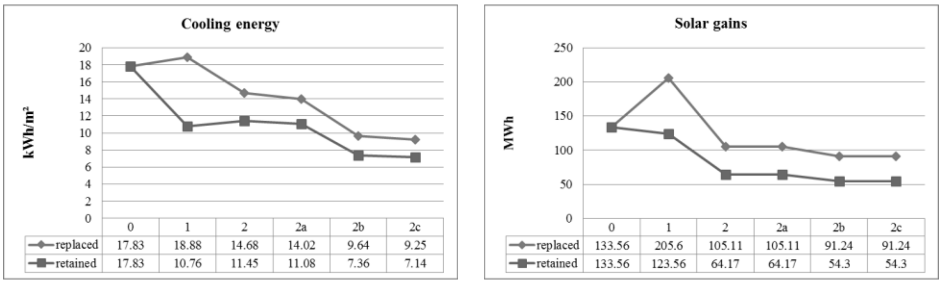


Chart 1 Final energy needed for cooling (left) and solar gains (right)

Reduction of the necessary final energy for cooling the building (Chart 1) is significant (20.97 % - 43.01 %), given that solar gains are reduced (38.95 % - 40.49 %). But reducing solar gains and increasing the heat transfer coefficient by retaining „kopilit“ glass resulted in a large increase in the required final energy for heating the building (45.14 % - 55.50 %). The largest increase in the final energy required for building heating (Chart 2) is noticeable in scenario 1 (55.50 %) where the required amount of final energy per unit area is 64.72 kWh/m2. According to this scenario, was achieved the biggest reducing of the necessary energy for cooling the building (43.00 %) in relation to the condition when the „kopilit“ glass is replaced.

As far as primary energy is concerned, it increases from 1.06 to 1.21 times in case if „kopilit“ glass is retained, depending on the revitalization scenario in relation to the case when „kopilit“ glass is replaced. The least increase in primary energy is still noticeable according to the revitalization scenario 1, which is the result of the conversion of final energy into the primary.

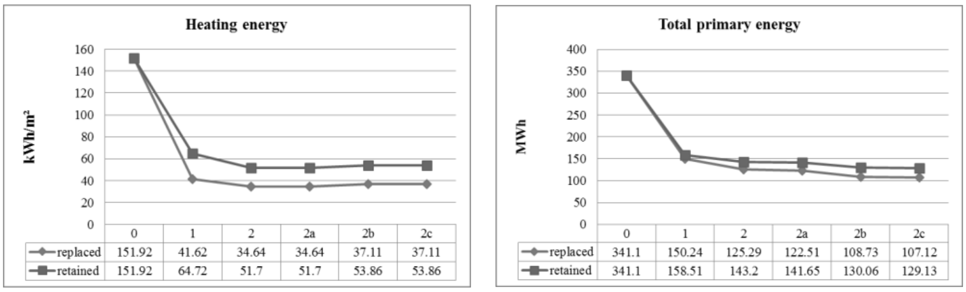


Chart 2 Final energy needed for heating (left) and (right) total primary energy

The CO_2 emission is fairly equal in both glazing cases in all revitalization scenarios that involve the application of a double facade, with the fact that this criterion slightly contributes to the revitalization according to scenarios 2 and 2a when the „kopilit“ glass is retained, and in support of the revitalization according to scenarios 2b and 2c when „kopilit“ glass is replaced. The only difference is noticeable in the case of the revitalization according to scenario 1 where the CO_2 emission was recorded by 9.16 t (16.60%) higher in the case of replacing „kopilit“ glass.

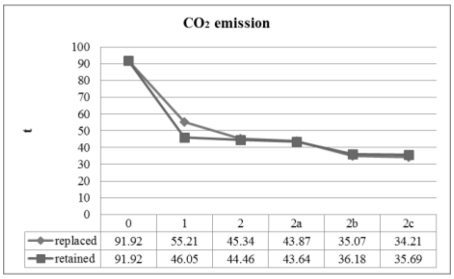


Chart 3 Total CO_2 emission

4. CONCLUSION

The choice of the type of glazing in the materialization of the building envelope is an important factor for influencing the energy characteristics of the building, that is, the amount of energy required for heating and cooling the building.

How much important is the glass on the facade of the building is shown by the results of computer simulations where, based on the obtained results, it was determined that the reduction of the final energy is necessary for cooling, if the „kopilit“ glass is replaced by a double low-e glass 4+12+4 (Kr). Accordingly, it is important to make design decisions in the choice of materialization of the building, in the initial phase of designing a new building or revitalization of the existing building, in order to avoid unwanted effects to the energy characteristics that could have an impact on the necessary comfort in the building.

The results obtained by the simulations indicate an increase in the required cooling energy if the required heating energy is reduced and the solar gain increases, which is directly caused by the use of a particular type of glass. Applying different recovery scenarios suggests the possibility of reducing the required cooling energy by using specific technical solutions, by using night ventilation and blinds. In accordance with this, it is pointed that the application of the double skin facade in the revitalization of industrial buildings in the process of adaptive reuse into an office building is a reasonable approach from an ecological aspect, because scenario 2c achieves a significant reduction in CO_2 emissions compared to other revitalization scenarios.

The recommendation for improving the energy characteristics of the observed model is, of course, replacing the „kopilit“ glass with a double low-e glass 4+12+4 (Kr) and introducing alternative ways of cooling the building, using geothermal energy and active solar energy systems, by placing the FN panels on a shad roof, which has an ideal southern orientation, which would provide a certain amount of electricity energy it would use for cooling the building.

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UTICAJ VRSTE ZASTAKLJENJA NA ENERGETSKU EFIKASNOST INDUSTRIJSKIH ZGRADA U PROCESU SANACIJE – STUDIJA SLUČAJA

Ovim radim se ispituju mogućnosti poboljšanja energetskih karakteristika postojeće industrijske zgrade primenom dvostruke fasade pri sanaciji omotača u klimatskim uslovima grada Novog Pazara, Republika Srbija. Cilj je ispitati uticaj izbora vrste zastakljenja, pri sanaciji, na energetske karakteristike industrijske zgrade i potrebnu finalnu energiju za grejanje i hlađenje, kao i doprinos poboljšanja energetskih performansi odabranog tipa i modela industrijske zgrade. Energetski karakteristike zgrade dobijene su korišćenjem softvera DesignBuilder i EnergyPlus simulacione platforme, uzimajući u obzir parametre potrebnih unutrašnjih temperatura i klimatskih podataka za Republiku Srbiju. Izvršena je komparativna analiza rezultata energetskih simulacija prema kriterijumu postizanja veće uštede energije i smanjene emisije ugljen-dioksida. Metodološki pristup u ovom istraživanju podrazumeva projektovanje scenarija sanacije industrijskih zgrada sa šed krovnom konstrukcijim, izborom konkretnog objekta na kome će se numeričkim simulacijama ispitati mogućnosti za smanjenje energetskih potrena i izvršiti komparativna analiza dobijenih rezultata. Primarni cilj ovog istraživanja je ispitivanje uticaja izbora vrste zastakljenja na energetske performanse industrijske zgrade sa šed krovnom konstrukcijom i utvrđivanje optimalnog pristupa energetskoj sanaciji postojećih industrijskih zgrada sa primenom dvostruke fasade u klimatskim *uslovima grada Novog Pazara, Republika Srbija. Rezultatima ovog rada se ukazuje na negativne karakteristike kopilit stakla u pogledu solarnih dobitaka, čijim zadržavanjem je potrebna velika količina energije za grejanje. Dok se zamenom kopilit stakla niskoenergetskim staklom povećava potrebna količina energije za hlađenje zgrade. Ovim istraživanjem se kroz različite scenarije sanacije ukazuje i na to da se primenom dvostruke pri sanaciji odabrane zgrade vrši vrlo približan uticaj na smanjenje emisije* CO_2 *nezavisno od odabira vrste zastakljenja.*

Ključne reči: *vrsta zastakljenja, adaptacija i prenamena, energetska efikasnost, obnovljivi izvori energije, regulativa*