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EFFICIENCY OF SOLAR THERMAL COLLECTORS ON STUDENT DORMITORY BUILDING IN THE UNIVERSITY CITY IN BANJA LUKA

Abstract

To achieve sustainable urban development goals, facilities must promote improved living conditions, reduce energy consumption, and preserve the environment. The Nikola Tesla student dormitory in Banja Luka's University City, a public landscape architecture area, meets these standards with its simple design, rational use of space, and moderate architectural expression. This study analyzes energy consumption in the 4th pavilion of the Nikola Tesla student dormitory in Banja Luka from 2018-2023. Solar thermal energy accounted for 4.63% of the total delivered energy. The paper highlights the importance of monitoring energy consumption over time.

Keywords: architectural design, student housing, STC (solar thermal collectors), DHW (domestic hot water)

ЕФИКАСНОСТ СОЛАРНИХ ТОПЛОТНИХ КОЛЕКТОРА НА ПРИМЈЕРУ ЗГРАДЕ СТУДЕНТСКОГ ДОМА У УНИВЕРЗИТЕТСКОМ ГРАДУ У БАЊАЛУЦИ

Сажетак

Да би се постигли циљеви одрживог урбаног развоја, објекти морају промовисати побољшане услове живота, смањити потрошњу енергије и сачувати животну средину. Студентски дом Никола Тесла у бањалучком Универзитетском граду, јавном простору пејзажне архитектуре, задовољава ове стандарде једноставним дизајном, рационалном употребом простора и умјереним архитектонским изразом. Ова студија анализира потрошњу енергије у 4. павиљону студентског дома Никола Тесла у Бањој Луци од 2018-2023. Соларна топлотна енергија је према прорачуну за посматрани период чинила 4,63% од укупно испоручене енергије. У раду се истиче важност праћења потрошње енергије током времена.

Кључне ријечи: архитектонско пројектовање, студентски смештај, соларни топлотни колектори, припрема топле воде

1. INTRODUCTION

The rapid growth of cities and the evolution of technologies and production methods had a huge impact on the development of the urban world. Cities develop in very complex patterns, with spatial, cultural, ecological and socio-economic characteristics. The growing popularity of the dispersive city model in the 20th century not only contrasted greatly with the earlier, more compact cities of the 19th century but also created negative consequences for infrastructure and resources. In response, solutions were sought for growth with less impact on the environment. Green urbanism is defined as the practice of creating communities beneficial to both people and the environment, where ecologically integrated and sustainable city planning can provide and enhance environmental benefits at local, national and international levels [1].

The city of Banja Luka adopted the Action Plan for a green city with a clear vision: "The city aims to be an example of innovative, smart and sustainable communal and traffic infrastructure, supported by an efficient land use system and increased resistance to climate change and other natural disasters." With a healthy and dynamic built environment, a network of green and blue infrastructure will protect and improve water resources, soil quality and biodiversity, maintain Banja Luka's reputation as a "green city" and define the task by which the City of Banja Luka should "establish an efficient system of energy use and reduce harmful impact on the environment to the minimum possible extent, improve comfort conditions and productivity in utility service systems" [2].

Nature in the University City is the most important park in Banja Luka and was placed under the protection of the Republic of Srpska by the Decision of the Ministry of Spatial Planning, Construction and Ecology in 2012, and in 2016 by the Decision of the Banja Luka City Assembly, a protected area with sustainable use of natural resources was declared a Monument of park architecture "University City" [3]. The park consists of rich horticulture from different periods, 1,500 trees, and rows of plane trees, some of which are several hundred years old, stand out. Along with the rich vegetation, 48 species of birds live here, some of which are legally protected, and the Vrbas River flows through one part of the border. The University City of Banja Luka is located in the complex of the former barracks of the JNA "Vrbas" and from the point of view of architecture, this area represents a heterogeneous group of buildings with very different purposes, time of construction, architectural form and material realization. The construction of an object in such a specific area implies the establishment of new qualities, ways of behaviour and the establishment of order, all by the spatial context dominated by the existing natural environment [4].

2. ENVIRONMENTALLY AND ENERGY EFFICIENT ARCHITECTURE

In the urban-architectural approach, the building of the Dormitory of Students and its author's concept followed certain principles of construction. The building of the student dormitory forms part of the street facade of the western approach to the Campus from the direction of the city centre. The extensive program of the House and the unambiguous design directions resulted in the longitudinal volume of the residential building, the dimensions of which are comparable to the neighboring residential district of Borik, an urban residential area typical of the socialist period and built in the spirit of the international style, which is characterized by an urban style of clean and bare forms, as well as a new dimension functionalism. The design of the Student Dormitory building was preceded by the harmonization of its purpose with the proportions of neighbouring buildings and the visual landscape from the Campus where it appears. The basis of the proposed concept is the functional differentiation of the building's contents into common (public) areas and private spaces (premises) so that a large closed structure of the building with a transparent front facade opens in the central part, which vertically connects the common contents.

The break that was made in the formation of the sequence of student rooms is filled by the remaining public facilities of the building - entrance hall, communications, common dining area and common living room. These zones are surrounded by glass walls that allow the view to the outside, but also indicate the internal dynamics of the use of the building to the views from the outside. The ground floor and the basement are part of the public content of the building, which serves as an administrative office, student clinic, classrooms and services. The proposed solution provides a capacity of 280 beds. The rooms are oriented to the east and west, and have natural lighting and ventilation. Long corridors are equally organized on all floors and are rhythmically moved by striking entrances to accommodation units. Each room is designed to accommodate two students and is equipped with a kitchenette in the hall and a bathroom. The authors have used color, thus giving vividness to the interior space of the building, and different floor colors are used to create the visual identity of each individual floor. The view of the outside space in the premises is defined by the existence of a transition zone, loggia. Movable metal shades on the facade give the user the option of choosing the amount of light or shadow that enters the room. Protection from the sun is realized through the form of dynamic design elements on the facade, which is executed in accordance with the layout of the front facade. In addition, the authors created freedom in the architectural expression of the very rational volume of the building by using colour on the facade. A playful set of panels of various colors and dimensions is a direct association with the young tenants of this building.

The goal of the Student House building project is to improve living conditions, reduce energy consumption and preserve the environment through a clear definition of the basic elements of functional organization and architectural materialization of the space. Design principles and ways of realization influenced the expected level of energy optimization and all elements of comfort for people's stay and work in this specific space. One of the goals of the authors of this architecture was to enable a satisfactory level of comfort in the space with minimal energy consumption in a rational way. In terms of achieving optimal conditions of spatial comfort and energy optimization:

• influential factors of comfort were examined /on-site conditions, microclimate, daylight, air pollutants, noise, etc./,

• established limits of desirable or acceptable comfort conditions in the space /temperature, lighting, air quality and acceptable noise levels/,

• controlled variable parameters / heat, air, light and sound / with the help of passive means / characteristics of the object / as far as possible and feasible,

• reduced energy consumption only for the control and maintenance of active means for providing comfort /heating, cooling, ventilation, lighting, noise protection, etc./.

In this paper, the five-year results of the savings obtained by the introduction of 100 roof solar thermal collectors (STC) on about 60 percent of the total area of the flat roof are analyzed in detail. The goal of their installation was to enable the domestic hot water (DHW) in a facility that has 150 bathrooms and is the main consumer of that water with energy from renewable sources.

Figure 1. Student Dormitory 4TH Pavilion, Campus, Banja Luka

3. ENERGY USED FROM RENEWABLE SOURCES

The fourth pavilion of the Nikola Tesla Student Dormitory has a heated gross volume Ve=23030 m3 with a conditioned area Au=7114 m^2 and a building form factor f_0=0.237 m^{-1}. The share of transparent elements in the total area of the building envelope is z=32.0 %. To reduce heat losses in transmission and categorize energy-efficient buildings, the building was designed with a U-value of the outer wall of 0.225 W/m^2K with a thermal insulation thickness of 15 cm. Transparent elements are double-glazed windows with multi-chamber aluminium frames. Flat roof elements are designed with a thermal insulation thickness of 15 cm and a U-value of 0.248 W/m^2K. In addition to the defined geometry, materials and climate parameters, the assessment of energy performance, according to its energy characteristics and the annual energy required for heating the building of the student dormitory, belongs to the *C* energy class [4][5].

The building sector offers many opportunities to enhance energy efficiency by integrating distributed renewable energy sources. The solar water heating systems are an effective technology for utilizing renewable energy, leading to savings on fossil fuels and a reduction in CO2 emissions [6]. Deploying electric water heating technologies is a key instrument for achieving these targets by enabling fuel switching, increasing efficiency, and supporting more renewables in the grid [7]. Solar thermal collectors (STC) are installed on the roof of the student dormitory building to produce energy for the preparation of DHW, visible in Figure 2.

Figure 2. Solar thermal collectors (STC) on the roof of Student Dormitory

One hundred polycrystalline STC with a total effective area of 235 m^2 were placed on a flat roof, oriented to the south and placed at an angle of θ=300. To estimate the energy generated by STC annually, data on the monthly global radiation received on a surface titled at an angle of 30^0 degrees for the coordinates (latitude = 44.77^0, longitude = 17.21^0) were obtained based on satellite observations. The actual efficiency was estimated in 2017 based on the characteristics of the STC and external influences (estimated difference between the inlet temperature of the collector fluid and the ambient temperature, received global solar radiation and shading) [8]. Average monthly efficiency of solar cells is highest in February (η=19.8%) and lowest in July (η=13.9%). The preparation of domestic hot water (DHW) is achieved by using solar energy, through STC, thermal energy from the district heating system and electricity. A system with 100 plates, arranged in 10 fields of 10 plates, was designed for the daily needs of approx. 9m3 of sanitary water. The minimum volume of energy accumulators is 6,000 liters and one sanitary water intermediate accumulator with a volume of 1,000 liters is planned. For the 2-hour consumption of 8700 litres, and the available capacity of the electric boiler 50kW, 4 tanks of sanitary water are provided, each with a volume of 1000 litres, filled via the exchange group Vitotrans 222 with regulation Vitotronic 200HK1B. The solar system is managed by the Vitosolic regulation - Viessmann Vitosol 100-G, absorber 2.3 m^2. The energy generated from STC is obtained using the equation:

$$Q_{sol}=\eta \cdot H_t \cdot A \qquad (1)$$

Where Ht represents the mean sum of solar radiation on the south-facing surface, and A is the total effective surface of the roof STC. The energy generated by STC at the level of one year is 78.2 MWh and represents a part of the total energy that is consumed for the preparation of DHW.

Figure 3. Boiler rooms at the Student Dormitory

The water in the recirculation system is heated by three boilers of 1000 litres to the temperature $\theta w,del=50^0C$. The temperature of the supply water during the year oscillates from $\theta w,0=8^0C$ in winter to $\theta w,0=14^0C$ in summer. Energy consumption for DHW is estimated based on the following equation:

$$Q_W=\rho_W c_W V_W\left(\theta_{W,del}-\theta_{W,0}\right) \qquad \text{......................................(2)}$$

Where ρw is the density of water and cw is the specific heat capacity of water (ρw.cw=1.16 kWh/m^3K) [9]. In this way, the annual energy consumption for the preparation of DHW was estimated for each year of the observed period. The total water consumption in the facility by year, 2018, 2019, 2020, 2021, 2022 and 2023 is shown in Figure 4.

The gross final energy consumption of the building during the year can be divided into supplied thermal energy, energy used for the preparation of DHW and electricity used for everything except the preparation of DHW. The values read from the bill for the consumed thermal energy for heating and the total consumed electricity were used to obtain the total annual delivered energy for the observed period. The total electricity used is the sum of the values read from the account by year and the energy obtained from the STC. These values are shown in Figures 3 and 4, while the share of energy obtained from renewable sources in the annual delivered energy, as well as its share in the total consumed electrical energy, i.e. in the energy for DHW, during 2018, 2019, and 2020, 2021, 2022 and 2023 are shown in Figures 4 and 6, and indicators of the value and structure of consumed energy in Table 1.

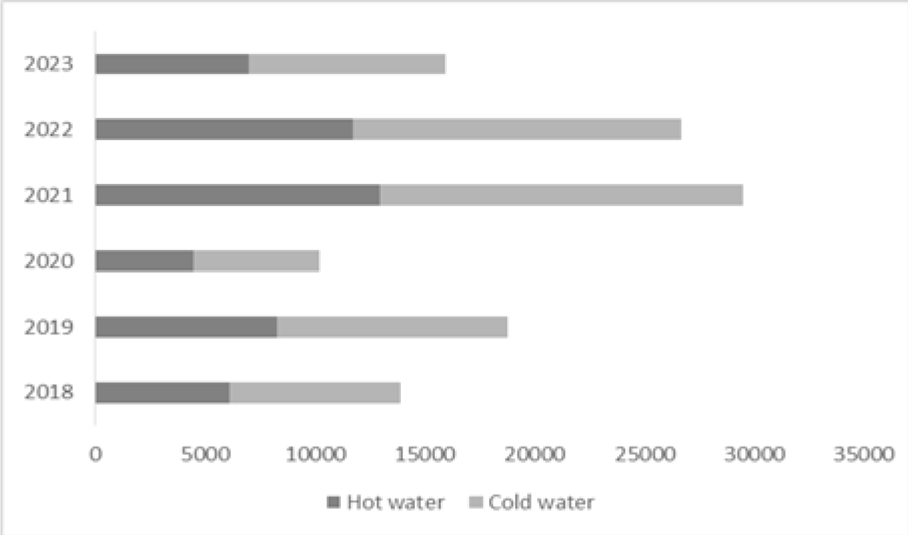

Figure 4. Water consumption in m³ based on bills

Table 1. Indicators of the value and structure of consumed energy

	2018	2019	2020	2021	2022	2023	TOTAL
annual delivered energy of the building [MWh]	2,345.12	1,498.84	1,696.96	1,905.74	1,876.60	811.54	10,134.80
total electricity used [MWh]	708.84	953.74	915.36	1,040.24	1,172.80	492.70	5,283.68
total energy for DHW [MWh]	276.51	373.85	202.94	587.41	530.96	317.55	2,289.22
energy for DHW obtained from STC [MWh]	78.20	78.20	78.20	78.20	78.20	78.20	469.20
share of energy from STC in the delivered energy [%]	3.33	5.22	4.61	4.10	4.17	9.64	**4.63**
share of energy from STC in the total consumed electricity. [%]	11.03	8.20	8.54	7.52	6.67	15.87	**8.88**
participation of energy from STC in energy for DHW [%]	28.28	20.92	38.53	13.31	14.73	24.63	**20.50**

The annual amount of energy delivered was at its highest in 2018 and at its lowest in 2023. This was in proportion to the consumption of thermal energy for heating, which was highest in 2018 and five times higher than in 2023. According to the previously described calculation of solar energy that can be obtained and the energy data bills obtained, in 2023, the proportion of energy derived from renewable sources was at its highest for the period studied (9.64%), while in 2018, it was at its lowest (3.33%). The total amount of electrical energy used was highest in 2022 and lowest in 2023. The extreme values were recorded in 2018 when the lowest electricity consumption was recorded, and the highest annual amount of delivered energy. The total amount of electricity calculated for DHW has been highest in 2021 and lowest in 2020. This was in proportion to the consumption of DHW, resulting in 13.31% for 2021 and 38.53% for 2020.

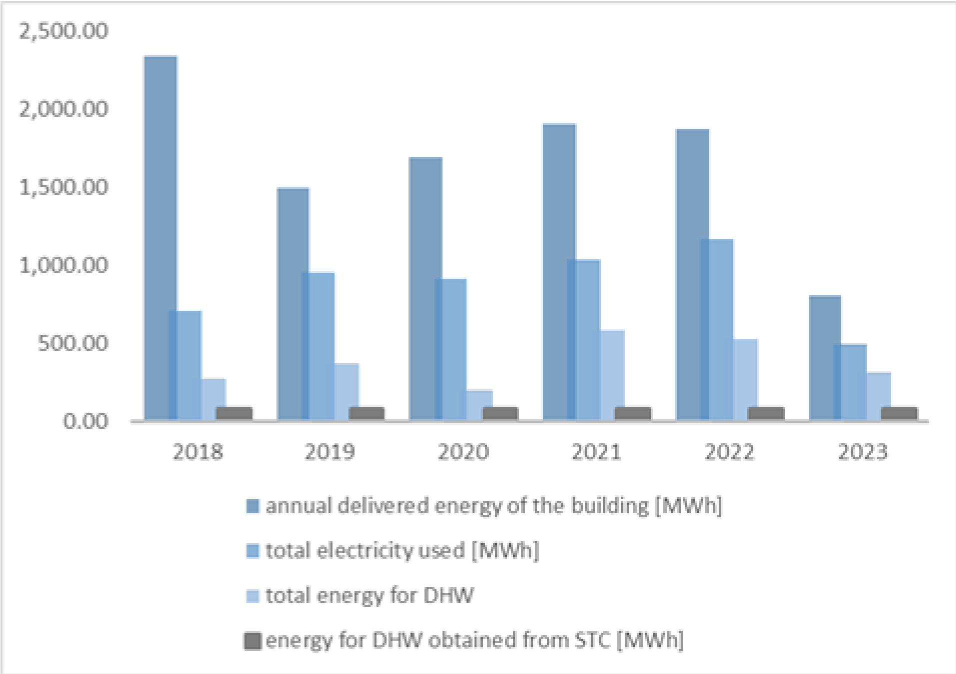

Figure 5. Value and structure of consumed energy

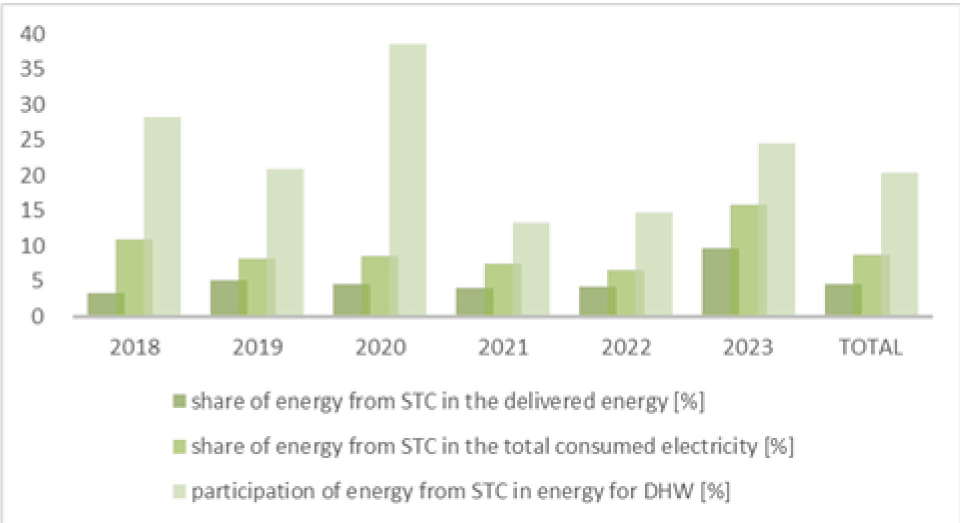

Figure 6. Participation (%) of energy from STC in energy consumption

4. CONCLUSION

The construction of the fourth pavilion of the Nikola Tesla student dormitory in Banja Luka sets an example of energy and environmental responsibility. The building takes into account the specific spatial needs, market and social characteristics of the local environment, along with the energy issue. It uses energy obtained from renewable sources for preparing DHW.

This paper presents the results of a simplified analysis of energy consumption from 2018 to 2023. The study examined the share of energy obtained from STC not only for the preparation of DHW but also for the total energy used by the building. The analysis was based on monthly bills for delivered thermal energy for heating, DHW, and electricity, as well as the calculated energy needed for the preparation of DHW and the energy obtained from one hundred polycrystalline STC on the roof of the building. The losses of the heating system and the system for the preparation of DHW were not included in the analysis.

The paper aims to demonstrate the values and changes in the structure of energy consumption on a yearly basis. The paper also highlights the importance of observing the period for an accurate assessment of energy consumption.

The results showed that the share of solar energy from renewable sources in the total delivered energy was 4.63% over the six years. The mean value of the share of energy from STC in the total electricity used during the same period was 8.88%, while the energy obtained from renewable sources contributed 20.50% to the total energy used for the preparation of DHW.

The share of produced DHW from the total amount of water used for DHW was not quantified, but it was used for research purposes from the values provided by the project. The manufacturer's data was used for the value of thermal energy obtained from the STC since the regulations on the energy certification of buildings in RS and FBiH do not contain a methodology for determining the STC contribution of DHW collectors during the year.

The extreme variability of the value of this participation, viewed individually by year, is due to the variability in the total consumption of energy and water, and other factors.

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