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Evaluation of Energy Performance of School Building

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Abstract: *Buildings play a major role in total annual energy used worldwide. There are a lot of important factors that have an influence on building energy consumption: climate, building envelope and energy services systems, operation and maintenance, indoor comfort conditions and occupants' behaviour. The aim of this paper is to describe the current condition of the school building in order to identify whether there are suitable conditions for energy rehabilitation of the building. The analysis performed showed that there is a significant potential for building energy rehabilitation. The effect of energy efficiency measures on reducing the building energy demand was analysed. Results shows that the annual heating energy consumption of the simulated building could be reduced by up to 50 %. By being more energy efficient, schools can help prevent greenhouse gas emissions and improve the students' learning environment. Also, it should be mentioned that improving the energy efficiency of the school can serve as a key learning tool for students in terms of science and environment and social responsibility.*

Keywords: *energy performance; school building; energy saving measures; energy efficiency; energy improvements.*

1. INTRODUCTION

The Directive 2002/91/CE (EPBD - Energy Performance of Buildings Directive) was the first European regulation on the energy performance of buildings. The EPBD define the procedures in order to establish the requirements for energy performance in buildings to be followed by the member states. In May 2010, the EU Directive 2010/31/EU was issued, which targets are to reduce the greenhouse gas emissions by 20% by 2020 and in 80% to 2050, in relation to the 1990 emissions levels, in order to achieve the goals outlined in the Kyoto Protocol [1]. The Energy Efficiency Standards in Buildings, which has been applied in Serbia since 2013, has set a methodological framework which prescribes energy properties and the method of calculating the thermal properties of buildings, as well as energy requirements for new and existing buildings.

A plenty of studies have considered the effect of improving thermal building envelope on heating energy consumption and some of them provide strong evidence on why we need to improve buildings' energy efficiency [2-4]. It is well known that existing buildings often have a low level of energy efficiency. However, there is a high potential for cost-effective energy savings in the building sector in the whole of Europe. Although there are a large number of buildings with high energy consumption in Serbia, there is a possibility to reduce it by investing in the renovation of such buildings [5].

As school buildings usually have great potential for improving energy efficiency and children in school can benefit from increased knowledge on how to use energy efficiently, schools are a promising location for addressing energy savings. The efficient use of energy is a goal of the expected outcome of educational procedures and is adopted within various subjects in Serbia's educational system. In order to develop a positive awareness of the importance of energy efficiency, education in this field should be implemented at all levels of education.

There are many challenges to including energy education in the school curriculum [6-8]. Among these challenges are funds for resources and support materials. Fortunately, one of the best resources to teach students about energy is readily available to teachers: their school building.

One way to improve energy efficiency is the rehabilitation of public buildings because schools are among the most important public facilities in Serbia. In this paper, the possibilities of improving energy efficiency of the school building are analysed. The current energy condition of the object has been presented, and increased energy efficiency and the energy state of the object after the application of the proposed measures are shown.

2. MATERIALS AND METHODS

2.1. Case study

The subject of energy efficiency analysis is the building of the Technical School in Čačak (Fig. 1). The location of the building is in the urban part of the city and has an open space in the environment on all sides. The facility was built in 1947 and the structural system of the building is a medium-heavy type of construction. The position of the building to the wind exposure is moderately sheltered.

The total area of the building is 5218 m^2 with the heating area of 4372 m^2. Thermal envelope of the building is an area of 14259 m^2. The school is equipped with two heating oil boilers with a capacity of 0.93 MW. The installed heating capacity of the Technical school is 0.825 MW. The adaptation of the building during 1986 was performed due to the new needs for the use of space, unreliable installations and parts of equipment, damage to the walls, floors, roof and carpentry.

Figure 1. *The school building used for energy performance analysis*

Most of the exterior walls, with a total area of 2059 m^2, are made of hollow bricks 20 cm thick, while other exterior walls of 994 m^2 are made of 30 cm thick concrete. Exterior walls have no thermal insulation. The partitions are constructed using the hollow brick with a thickness of 12 cm.

The windows have a total area of 838 m^2 and are oriented to all four corners of the world, with the majority orientation to the east and west. Wooden windows with low-emission double-glazed glass 4 mm thick, with a 12 mm thick with air filling, are located on the most of the buildings' window area, i.e. 522 m^2. On the remaining glass surfaces of 317 m^2, wooden windows were replaced with six-chamber PVC windows with low-emission double-glazed glass 4 mm thick with a 12 mm thick krypton filling. Most of the replaced windows are east orientated.

The floors of the building have a total area of 2366 m^2. Most of the floors are located in classrooms and offices and have an area of 831 m^2 and are covered with a floorboard without waterproofing. The roof structure above the heated space is sloped, with a total area of 3405 m^2 and is made without thermal insulation.

To calculate the annual energy required for heating and determine the energy efficiency of the building and energy classes, *KnaufTerm2 Pro* software is used. The software is fully compliant with the current regulatory framework in Serbia.

This software enables testing of each thermal envelope component's performance, and also enables complete building performance calculation for the existing and proposed state of the building. Climatic data used for the calculation are: location of the city of Čačak, number of heating degrees day is 2755, number of heating season days is 190, an average temperature of heating period 5.5 ºC and internal winter design temperature 20 ºC.

2.2. KnaufTerm2 Pro software

KnaufTerm2 Pro is a specialized software intended for designers in the phases of designing the preliminary and main project and development of technical documentation of energy efficiency studies and energy passports. The program contains numerous databases from which the parameters required for the calculation are being selected: location and type of building, wind effect, parameters of the heating system, etc. There is also an extensive database of thermophysical characteristics of materials and structures that make up the thermal envelope of the building, including exterior elements and structures (walls, roof, windows and doors), internal partition structures and ground structures. After defining the geometric parameters of the thermal envelope, the program enables the visualization of the characteristics of the assemblies as a function of orientation (Fig. 2).

Figure 2. *Building model - north view*

Regulations on energy efficiency of buildings defines the maximum allowed values of the heat transfer coefficient for all elements of the thermal envelope of a building. These values are different for existing and new buildings. When the thermal envelope is defined, the program checks whether the overall heat transfer coefficient is below the maximum allowed value for each envelope element (Fig. 3). The calculation results include temperature change in all elements of the wall, water vapor diffusion, checking of condensation and checking of heat transfer coefficient.

The software calculates the exterior wall's thermal resistance and the properties of the product which used in walls can be select by performance. Also, the software can define the insulation material's type and thickness which will be used on the outer face of a wall according to the climate conditions, as well as the reduction of heat bridges and condensation risks.

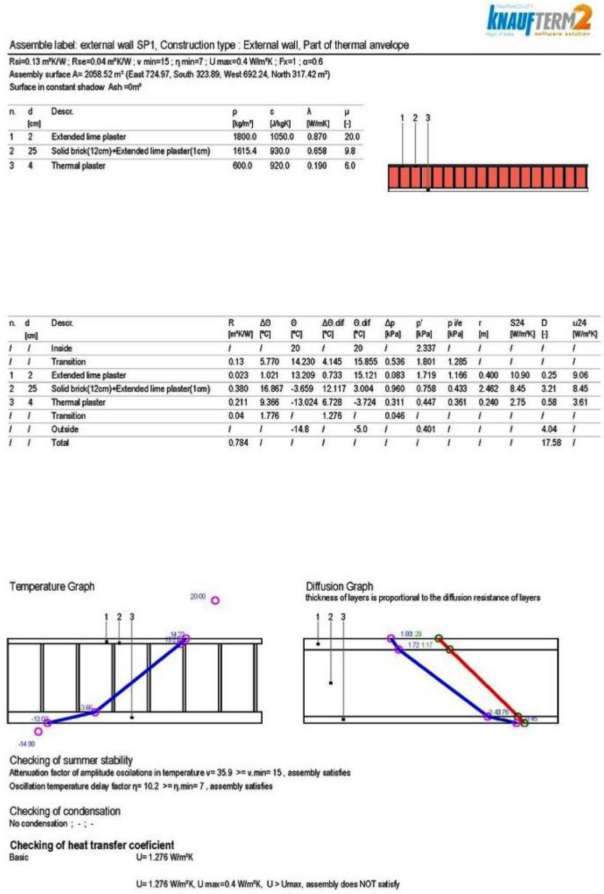

Figure 3. *Modeling of exterior walls in current state of building*

For the current condition of the building described in this paper, the overall heat transfer coefficient for the exterior wall is not satisfied, so certain improvement measures were proposed. In this case it was necessary to apply a 7 cm thick thermal insulation and thermal facade (Fig. 4). The parameters based on the materialization of other elements of the thermal envelope are changed in a controlled manner according to a precisely determined plan in order to obtain the desired results.

The software generates an energy efficiency study that contains data on transmission and ventilation heat losses (Q_t and Q_v), solar energy gains (Q_{sol}) and heat gains from people and electrical devices (Q_p and Q_{el}). Solar gains are an important part of the calculation of the energy performance of the building, and have a large impact on the calculated values of annual needs of energy, and therefore, the energy class of the building.

The calculations also include energy needed for sanitary hot water and energy losses in the heating system. Monthly heat losses and energy gains are given in Fig. 5. Based on the calculated gains and losses of thermal energy, the program generates the energy passport of the building which is a certificate which contains information about the energy class of the building and points to the final annual consumption of thermal energy for heating, as well as the primary energy for heating as well as the calculation of CO_2 emissions based on the selected energy source.

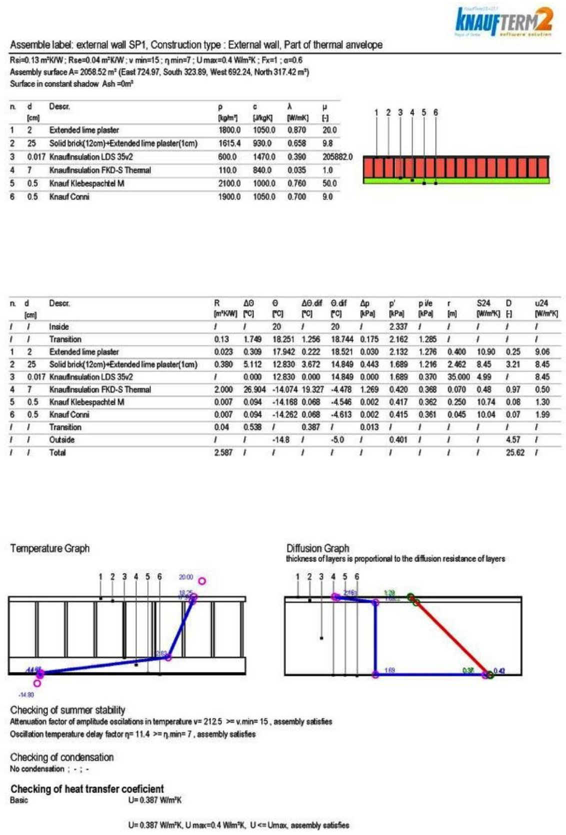

Figure 4. *Modeling of exterior wall with applied measures for increasing energy efficiency*

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Te =	0.7	2.8	7.1	12.3	17.4	20.4	22.0	21.5	17.4	12.5	7.0	2.4
HDD =2755.00	599.680	482.866	401.288	143.569	0.000	0.000	0.000	0.000	0.000	189.197	391.355	547.045
HD= 190	31	28	31	16	0	0	0	0	0	23	30	31
Te.hd=	0.655	2.755	7.055	11.027	0.000	0.000	0.000	0.000	0.000	11.774	6.955	2.353
1. Qt=386.42 MWh	84.11	67.73	56.28	20.14	0.00	0.00	0.00	0.00	0.00	26.54	54.89	76.73
2. Qv=169.81 MWh	36.96	29.76	24.73	8.85	0.00	0.00	0.00	0.00	0.00	11.66	24.12	33.72
3. Qt+Qv=556.23 MWh	121.07	97.49	81.02	28.99	0.00	0.00	0.00	0.00	0.00	38.20	79.01	110.45
4. Qsol=53.88 MWh	5.55	8.98	12.83	8.08	0.00	0.00	0.00	0.00	0.00	8.22	5.85	4.36
5. Qp=46.51 MWh	7.59	6.85	7.59	3.92	0.00	0.00	0.00	0.00	0.00	5.63	7.34	7.59
6. Qel=22.76 MWh	3.71	3.35	3.71	1.92	0.00	0.00	0.00	0.00	0.00	2.75	3.59	3.71
7(4+5+6): Qgn=123.15 MWh	16.85	19.19	24.13	13.91	0.00	0.00	0.00	0.00	0.00	16.61	16.79	15.66
8(3-7): Qnd=433.09 MWh	104.22	78.30	56.89	15.08	0.00	0.00	0.00	0.00	0.00	21.59	62.22	94.78

Figure 5. *Monthly energy balances*

2.3. Existing state energy audit

The analysed object belongs to the category of objects for education, as defined by the State Energy Efficiency Standards in Buildings. It is necessary to perform energy rehabilitation for school buildings, which is also defined in the Energy

Efficiency Standards in Buildings for existing buildings.

Based on the conducted research, it is possible to analyse and evaluate the energy efficiency of the building of the Technical school in Čačak in the current state. The results show that the annual transmission heat losses through certain parts of the building envelope in the current state are:

1. Exterior walls: 290044 kWh;
2. Pitched roof: 124503 kWh;
3. Windows and doors: 92004 kWh;
4. Partitions: 38094 kWh;
5. Ceilings: 81269 kWh;
6. Ground walls (basement): 68361 kWh;
7. Ground floors: 44697 kWh.

Fig. 6 shows the heat loss percentage through certain components of the facility of the total heat losses. The analysis shows that the largest transmission losses are due to heat transfer through the exterior walls of the school building, although this area covers 21.40% of the total area of the thermal envelope of the building and is not the largest of all surfaces of the thermal envelope. The largest area of the buildings' thermal envelope is a pitched roof with 16.85% of the total heat transmission losses. Then, there are the heat losses through windows and front doors, although their total area is 5.10% of the total area of the thermal envelope, where one part of the old wooden windows was previously replaced. Large heat losses occur through the mezzanine structure under the unheated space since its surface is significantly large and takes to 20.37% of the total area of the building thermal envelope. The smallest transmission heat losses are through the ground walls, ground floors and through the walls towards the unheated space.

The total energy demand for transmission losses of the building is 833.25 MWh and for ventilation losses 170 MWh, in its present state. Annual energy gains in the current state of the building are:

1. Solar gains: 72.76 MWh;
2. Persons: 46.51 MWh;
3. Electrical appliances: 22.76 MWh.

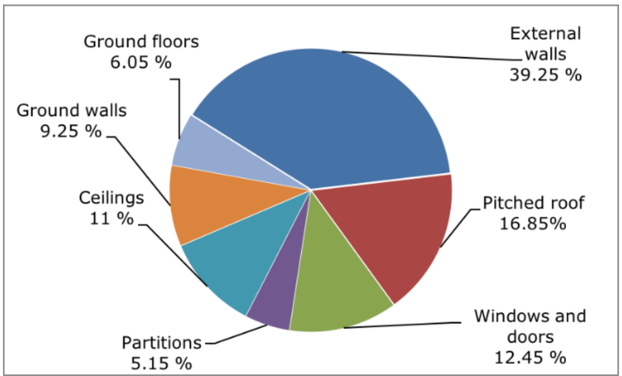

Figure 6. *Heat losses of construction components in the current state of building*

Annual energy consumption of the building in the current state is 861 MWh (the oil central heating system), while specific annual heat consumption is 179 kWh/m^2. Since the adoption of energy-class benefits of the specific thermal energy for heating systems are operating with a recess, that is the basis of which this building belongs to the energy class F. Energy Efficiency Standards in Buildings defined that the maximum annual consumption of heat energy for educational buildings is 75 kWh/m^2. Based on the results of the analysis, the annual energy heat consumption of Technical school in Čačak is 2.6 times higher than allowed for this type of object.

2.4. Energy saving measures

Based on the analysis of energy efficiency of the building, it was noticed that it is necessary to improve the thermal characteristics of all components of the building envelope: exterior walls, wooden windows, mezzanine structures, roof structures, ground walls and walls oriented to unheated space and floors [9].

In order to reduce the energy required for heating and improve the energy class of the building, it is proposed to install the following types of insulation:

1. To all exterior walls of the building made out of brick, a 7 cm thick layer of Knauf thermal insulation made of stone wool is necessary to be added on outer surface of the walls. A similar reconstruction was proposed on the exterior walls of the building, which are made of concrete, with the required thermal insulation thickness of 8 cm.

2. In order to reduce the overall heat transfer coefficient and prevent the occurrence of condensation in the roof structure, it is necessary to reconstruct the roof. It is necessary to remove the layer of reed board, wood wool board and PVC foil from the roof structure. Under the roof, install a layer of vapor permeable foils and between them place two layers of thermal insulation of stone and mineral wool, 14 cm thick. On the inner side of the roof structure, install stone wool insulation - stone lamellas 2 cm thick.

3. For glass surfaces, it is necessary to replace the existing wooden windows with low-emission double-layer glass 4 mm thick, with air filling 12 mm thick, with six-chamber PVC windows with krypton filled low-emission double-layer glass (4+12+4).

4. On the walls towards the unheated space, it is necessary to install 5 cm thick stone mineral wool thermal insulation . Also, a thermal insulation made of mineral wool 8 cm thick is required to be installed under the unheated space on mezzanine construction.

5. On the walls in the basement of the building, it is necessary to add 5 cm thick thermal insulation made of stone mineral wool on the inside.

6. On the floors of the building in classrooms and offices, a waterproofed 3 cm thick mineral wool boards was proposed to be installed. On the floors in the corridors and rooms in which the toilets and

auxiliary rooms are located, a 4 cm thick thermal insulation panels made of stone mineral wool is proposed to be installed.

7. On the remaining floors of the school was proposed to install a 3 cm thick with waterproofed thermal insulation made of stone mineral wool.

The proposed measures refer only to the installation of insulating material. The results of the research included all the accompanying elements on the improvement of the energy efficiency of the building, which include the dismantling of the old layers and the installation of other accompanying elements of the structure, which is performed for the complete energy rehabilitation of the building.

The proposed measures for improving the energy efficiency of buildings are the minimum measures that are necessary to apply in order to obtain the heat transfer coefficients of the analysed assemblies that are less than the corresponding maximum values defined by the National Energy efficiency standard in buildings.

Table 1. *The overall heat transfer coefficients U (W/m²K) through the thermal envelope of the building*

Building envelope structure	Umax W/m²K	Current state	Proposed state
Exterior walls: Brick Concrete	0.40	1.23 1.87	0,38 0.38
Pitched roof	0.20	0.55	0.11
Window Old wooden	1.50	1.80	1.30
Partitions	0.55	1.92	0.52
Ceilings	0.40	0.53	0.36
Ground wall	0.50	1.29	0.48
Floors: Classrooms Toilets Hallways	0.40	0.55 0.60 0.61	0.38 0.37 0.37

2.5. Results of implemented energy performance improvement

The application of the proposed measures to increase the energy efficiency of the building of the Technical School in Čačak is fully justified. After the implementation of measures to improve the energy efficiency of the building annual transmission heat losses through thermal envelope component of the building envelope should have the following values:

1. Exterior walls: 76956 kWh
2. Pitched roof: 24765 kWh
3. Windows and doors: 74758 kWh
4. Partitions: 10242 kWh
5. Ceilings: 55921 kWh
6. Ground walls (basement): 20074 kWh
7. Ground floors: 29421 kWh.

A comparative analysis of heat transfer losses and their percentages in total building heat losses, for the current and proposed case, is shown in Fig. 7 and 8. After the application of measures used to improve the energy efficiency of the building, transmission losses through all elements decreased, but their share in total losses is changed.

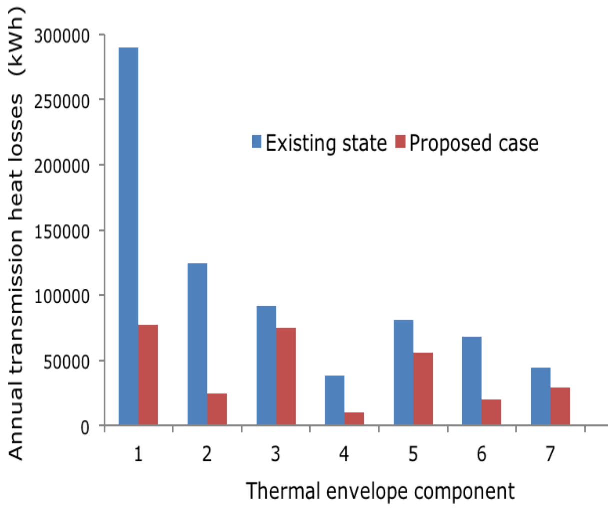

Figure 7. *Transmission heat losses for current and propose state*

After the application of the proposed measures for the improvement of the energy efficiency of the building, the largest reduction of transmission losses can be expected with a pitched roof, when the losses can be reduced by up to 80%. The reduction of heat transfer losses through exterior walls and partition walls towards unheated space after the application of the proposed measures is 73%, while a reduction of less than 63% can be achieved after the reconstruction of the walls in the ground of the building. The smallest reduction of transmission losses of 18% is achieved with windows because part of the old energy inefficient wooden windows has been replaced previously.

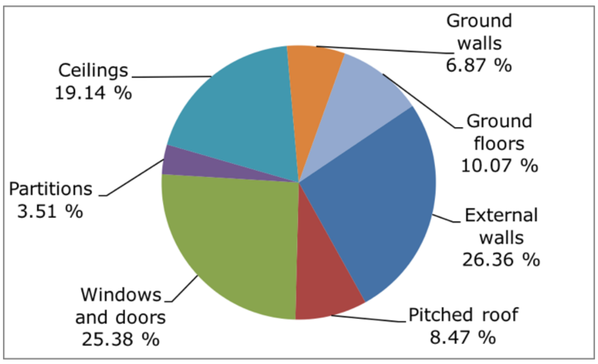

Figure 8. *Heat losses of construction components* in the proposed state of building

The total energy required to compensate for the transmission losses of the building in the proposed case is 386 MWh. By applying the proposed measures, annual energy savings can be achieved to compensate for transmission losses of up to 54 % for the entire facility.

Solar heat gain in the proposed case were reduced by 26 %, while energy gains from people and electrical appliances remained unchanged.
The annual energy required for heating the building of the Technical School in Čačak in the proposed case is 433 MWh, which is 50 % less than the building consumes in its current state.
In this research, the energy certificates of the building were also determined (Fig. 9). In the proposed state, the annual specific consumption of thermal energy for heating is 99 kWh/m2, which is a reduction of 45% compared to the specific consumption of thermal energy consumed by the building of the Technical School in the current state. To adopt the energy class, specific heat energy is used for systems that work with interruption, on the basis of which the building belongs to the D energy class.

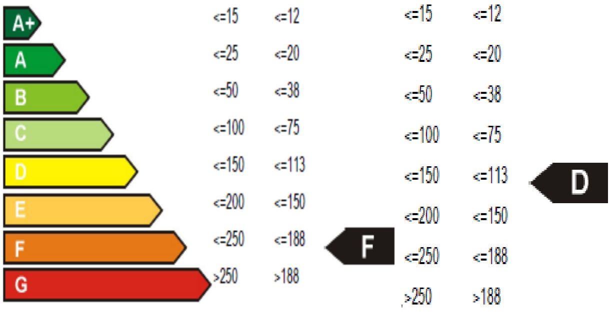

Figure 9. Energy classes of the building in current and proposed state

Energy retrofit and renovation of existing buildings have an effective role in reducing carbon dioxide emissions and ultimately global warming [10]. Results show that after applying the proposed measures CO_2 emission can be reduced from 264 t CO_2/year to 137 t CO_2/year.

3. CONCLUSION

The purpose of this study is to evaluate the energy performance of Technical school building in Čačak and assess the effects of selected energy efficiency measures on energy performance. This paper considered the impact of retrofit schedule influence on energy use. The results show that improving all building envelope structure insulation level will reduce energy consumption for heating that implies improvements in energy efficiency of the object, from F to D energy classes. However, even in objects that have achieved specific standards, the energy consumption may be dramatically different depending on the occupants' energy use behaviour, so more research is needed to analyse more targeted interventions to be applied. By teaching students to be mindful of how they use energy early on, we can ensure a better future for the energy industry and for the planet.

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