Received: 04.04.2022.
Accepted: 25.04.2022.

e-ZBORNIK 23/2022

Review paper

Electronic collection of papers of the Faculty of Civil Engineering

https://doi.org/10.47960/2232-9080.2022.23.12.20

ISSN 2232-9080

Energy consumption for heating of school buildings in the south region of the Federation of Bosnia and Herzegovina

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Abstract: This paper presents the results of research on energy performance related to the energy consumption for space heating of school buildings (primary and secondary schools) located in the south region of the Federation of Bosnia and Herzegovina (SR FBiH). The research was conducted by collecting data from detailed energy audit documents on a sample of 47 school buildings in the SR FBiH and is part of a broader study aimed at analyzing the energy performance of school buildings in the FBiH and determining their relationship to heating energy costs through the development of new models for faster estimation of heating energy costs. The results of the research indicate poor energy performance of existing school buildings in the SR FBiH. The analysis of the delivered energy for space heating showed that the actual consumption is 67% of the predicted and indicates an energy gap between the actual and predicted values of energy consumption for heating. Reduction of energy consumption for space heating can be achieved by applying measures to improve energy efficiency.

Key words: energy performance of school buildings, energy consumption for heating, detailed energy audits, energy gap

Potrošnja toplinske energije školskih zgrada u regiji jug Federacije Bosne i Hercegovine

Sažetak: U ovom radu se prikazuju rezultati istraživanja energetskih karakteristika koje se odnose na potrošnju toplinske energije školskih zgrada (osnovne i srednje škole) u regiji jug Federacije Bosne i Hercegovine (RJ FBiH). Istraživanje je provedeno prikupljanjem podataka iz dokumenata detaljnih energetskih pregleda na uzorku od 47 školskih zgrada u RJ FBiH i dio je šireg istraživanja čija je svrha analiza energetskih karakteristika školskih zgrada u FBiH i određivanje njihove povezanosti sa troškovima toplinske energije kroz razvoj novih modela koji omogućavaju jednostavniju i bržu procjenu troškova toplinske energije. Rezultati provedenog istraživanja ukazuju na loše energetske karakteristike postojećih školskih zgrada u RJ FBiH. Analiza potrošnje isporučene toplinske energije za grijanje pokazala je kako stvarna potrošnja iznosi 67% od proračunski potrebne i ukazuje na energetski jaz (gap) ili odstupanje između stvarnih i proračunskih vrijednosti potrošnje toplinske energije. Smanjenje potrošnje toplinske energije moguće je postići primjenom mjera za poboljšanje energetske učinkovitosti.

Ključne riječi: energetske karakteristike školskih zgrada, potrošnja toplinske energije, detaljni energetski pregled, energetski jaz

1. INTRODUCTION

1.1 Energy performance of buildings

The current EU and global trends in construction industry are focused on sustainable construction, reduction of negative environmental impacts of buildings and reduction of total energy consumption in all phases of a building life cycle, from planning and construction, to the longest phase of operation, to the building removal phase. The energy consumption for space heating of a building depends on its technical characteristics, installed appliances and equipment, and user behavior. The increase in energy consumption in buildings, and thus of greenhouse gas emissions, has led to some activities to improve energy performance, which are aimed at implementing strategies, plans and measures covered by the concept of energy efficiency.

Buildings use energy throughout their life cycle. The life cycle energy of buildings has two important components: operational and embodied energy. Operational energy is the energy consumed during the occupancy stage of building's life to heat, cool, illuminate, and run equipment and appliances in buildings. Embodied energy is the energy used for the extraction of materials, manufacturing of materials and construction components, construction, maintenance, and demolition of a building, as well as all associated transportation [1]. When looking at the entire life cycle of a building, the greatest environmental impacts are due to energy consumption in the use phase. It has been estimated that the use phase in conventional buildings represents approximately 80–90% of the life-cycle energy use, while 10–20% is consumed by the material extraction and production, and less than 1% through end-of-life treatments [2].

In order to evaluate energy performance of a building, it is necessary to compare the calculated or measured performance of the building to some reference value or framework. These values may be the characteristics of construction elements of the building envelope (like the U-value) or the consumption of energy by specific systems in the buildings [3]. Figure 1 shows the procedure for evaluating the energy performance of buildings.

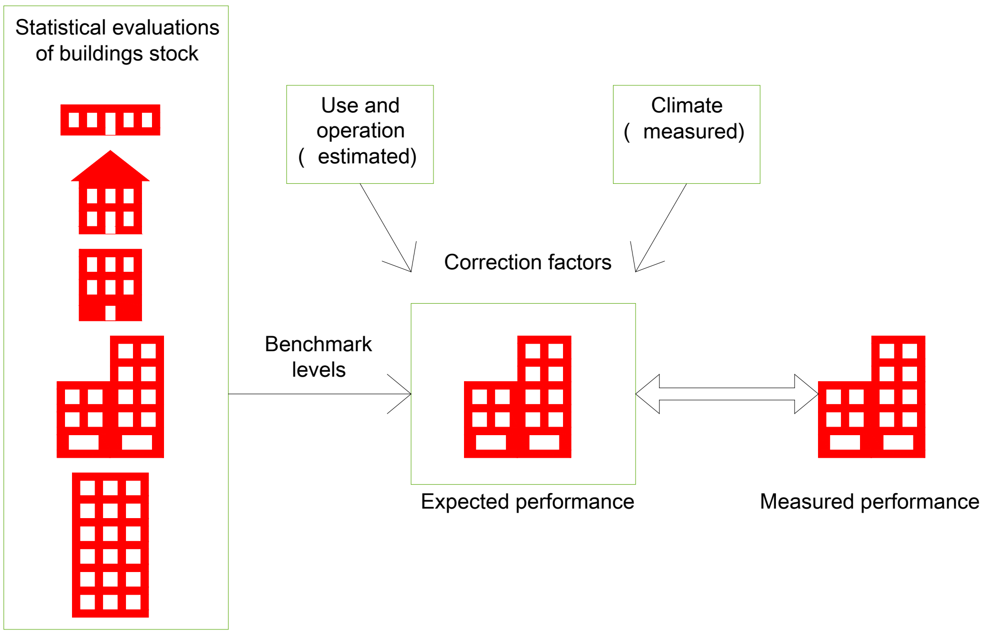

Figure 1. Evaluation of energy performance of buildings [3]

The increasing availability of large amounts of data on the energy performance of buildings has enabled the development of methodologies that use statistical techniques to predict and evaluate energy performance based on existing datasets of multiple buildings. Most statistical models use some kind of regression to model and explain the energy performance of buildings [3].

The problem of building energy performance from the rating point of view can be observed through two main areas, asset rating and operational rating. An asset rating can be defined as a calculation based on energy through a building energy model. Operational rating is related to a building's daily operations and measurements. Both approaches look at the same problem from a different but complementary perspective [4].

The energy performance of school buildings together with adequate indoor environmental conditions are of great importance [5]. It is important in schools to provide an indoor climate that will not affect the comfort, health or intellectual performance of students [6].

This research is aimed at analyzing the energy performance expressed through the energy consumption for heating, in relation to construction periods, of school buildings located in the south region of the Federation of Bosnia and Herzegovina (SR FBiH), as extremely important social and public buildings. School buildings in this research include school sports halls (if they exist next to school buildings) which from the point of view of function and common building service systems (heating, ventilation, air conditioning, electrical installations) form a whole and thus common energy consumption.

Numerous parameters such as thermal characteristics of construction elements of the building envelope, transmission and ventilation heat losses, indoor and outdoor climatic conditions are required to assess the energy performance of buildings and calculate energy consumption. Identifying and quantifying the multiple benefits of energy efficiency has become a new trend.

1.2 Review of heating energy consumption

A review of the literature and research related to energy consumption for heating reveals different ways of presenting energy consumption and different units of measurement depending on the country and legal regulations, which leads to barely comparable values. At a European level, the European Union member states have different energy performance certificates exhibiting different information at distinct scales. A similar process has been taking place in the US and in Canada [5].

The main problem with the high energy consumption of existing buildings built several decades ago is the failure to meet current energy efficiency requirements under current legislation. Average energy consumption for heating in residential buildings is 180-250 kWh/m^{2}year. A significant percentage of existing buildings will continue to be used for many more years, and unless they are renovated in terms of energy performance, they will continue to needlessly consume great amounts of energy. Therefore, energy renovation of existing buildings has a great potential for energy consumption reduction and therefore reduction of CO_2 emissions [7].

Energy consumption in a school can be characterized by different performance indicators, depending on several parameters, such as the purpose of the school (kindergarten, primary or high school) that reflects different occupational schedules of activities and uses. Then there are the geometric characteristics of buildings and construction periods that affect energy consumption [8].

The following is an overview of the annual heating energy consumption based on available data by reviewing the literature with special emphasis on school buildings. According to data from 1988, the consumption of the heating energy in Great Britain for primary and secondary schools is between 200 and 300 kWh/m^2 per year [9].

According to Dias Pereira et al., the annual heating energy use values of school buildings in European countries vary from about 52 to 197 kWh/m^2 [5]. Typical annual heating consumptions are reported as 96 kWh/m^2 for Ireland [10], varying from less than 112 kWh/m^2 to 196 kWh/m^2 for Slovenia [11], 157 kWh/m^2 for the UK [12], and approximately 100 kWh/m^2 for central Italy [13].

A study conducted on 80 school buildings located in central Italy (the Lazio region) shows that the average annual value of the specific heating energy use is about 23 kWh/m^3 [8]. Furthermore, a survey of actual energy consumption for space heating conducted on about 140 buildings in the Province of Torino shows an average annual value of 38 kWh/m^3, that, assuming a floor height of 3 m, corresponds to a consumption of 115 kWh/m^2 [14].

A survey conducted on 76 school buildings located in northern Italy, in the province of Milan, and data collected from energy audit documents, shows that the annual average value of the specific heating energy use is 47 KWh/m^3 [15]. Comparing the stated value with the same in the region of Lazio (23 kWh/m^3), we come to the conclusion that the specific average annual heating energy is about two times higher in northern Italy, where climatic factors are the most likely reason for such a relationship.

The average annual primary energy consumption of Portuguese schools in 2012 was 67 kWh/m^2, of which 16 kWh/m^2 related to gas use and 51 kWh/m^2 related to electricity use [16].

According to 1995 data, the average annual value of the specific heating energy consumption in Greek school buildings is about 92 kWh/m^2 of heated space, but in many cases it reaches 100 or even up to 200 kWh/m^2 of heated space. According to the results of a 2007 survey in Greek schools, the average annual energy consumption is 95 kWh/m^2 distributed between 68 kWh/m^2 for heating and 27 kWh/m^2 for electricity [17].

A study conducted after 2010 in Luxembourg analyzed the heating energy consumption of 68 school buildings where the average annual value of the heating energy use is 93 kWh/m^2 while the average annual electricity consumption is 32 kWh/m^2 [18].

Analyzing the above examples of heating energy consumption in school buildings, we can see heterogeneity in the way of displaying different units of energy consumption depending on the country, which makes comparison impossible, especially due to the lack of other indicators of energy performance of buildings (such as U-value) or climatic conditions (such as the number of heating degree days).

2. COLLECTION OF RESARCH DATA

In the document Typology of Public Buildings in Bosnia and Herzegovina (hereinafter TPB BiH), all public buildings in BiH were classified and systematized into a total of 42 types, i.e. 6 construction periods and 7 use sectors. According to the purpose of the buildings, 7 sectors/ types of buildings are defined, namely buildings for preschool education, buildings intended for education, buildings in the health sector, buildings for sports activities, buildings for cultural activities, buildings for administrative activities and buildings for all-day stay which includes hospitals and other buildings intended for all-day stay.

The second classification was made in relation to the construction period, until 1945, from 1946 to 1965, from 1966 to 1973, from 1974 to 1987, from 1988 to 2009 and after 2010. Different construction periods have different characteristics of building elements of the envelope, different construction technologies and emergence of new construction materials.

Also, the legislation was changing over time, making the requirements to thermal protection stricter [19].

According to TPB BiH, the largest number of buildings in FBiH is related to the buildings intended for administrative activities with a share of 35.7%, followed by the buildings intended for education (primary and secondary schools, faculties and other educational institutions) with a share of 32.9%. In terms of floor area (A_k), the largest floor area is related to the buildings intended for education with a share of 33.5%, followed by the buildings for administrative activities with a share of 27.7% [19]. Considering that the share of the area of buildings intended for education in the total area of public buildings in FBiH is higher than 33%, the importance of this research is emphasized.

The TPB BiH document also divided the total number of educational buildings in FBiH into climate regions north (characterized by continental climate) and south (characterized by Mediterranean and sub-Mediterranean climate) related to climatological characteristics of the locations. The division is made in relation to the mean monthly temperature of the coldest month of the year and if it is less than 3.0 °C then the location belongs to the "north" region (abbreviation NR FBiH), or if the mean monthly temperature of the coldest month is higher than 3.0 °C then the location belongs to the "south" region (abbreviation SR FBiH). Table 1 shows the distribution of the total number of educational buildings in the FBiH and in relation to the climate regions "north" and "south" and the construction periods.

Table 1. Total number of educational buildings in FBiH in relation to climatic regions and construction periods [19]

SCHOOL BUILDINGS IN FBiH	Number of buildings in FBiH	Share (%)	Number of buildings in NR FBiH	Share (%)	Number of buildings in SR FBiH	Share (%)
until 1945	109	7.5%	89	7.5%	20	7.6%
from 1946 to 1965	498	34.2%	408	34.2%	90	34.2%
from 1966 to 1973	250	17.2%	205	17.2%	45	17.1%
from 1974 to 1987	343	23.6%	281	23.6%	62	23.6%
from 1988 to 2009	212	14.6%	174	14.6%	38	14.4%
after 2010	43	3.0%	35	2.9%	8	3.0%
TOTAL:	**1,455**	**100.0%**	**1,192**	**100.0%**	**263**	**100.0%**

The previous table shows that the largest number of educational buildings in FBiH was built in the period from 1946 to 1965 (34.2%), followed by the period from 1974 to 1987 (23.6%). The largest number of educational buildings, or 1,091 schools (75%), was built in the period from 1946 to 1987. With regard to climate regions, the largest number of educational buildings is located in the climate region "north", approximately 81.9% (1,192/1,455).

Public buildings of different purposes also have different annual needs for heating energy, among other things due to different modes of operation and use. The classification of public buildings by purpose is primarily defined by legislation, specifically the EU Directive 2010/31/EU on energy performance of buildings and the standard BAS EN ISO 13790 for calculating the energy required for space heating and cooling [19].

The basic assumption is that the identification of certain crucial parameters (construction period, purpose of the building, geometric characteristics of the building, type of use, characteristics of construction components of the building envelope) allows for drawing conclusions on energy consumption in individual buildings [20].

Bosnia and Herzegovina has great potential for energy savings, especially in the building sector. To this end, it is necessary to analyze the current state of residential and non-residential buildings, assess the necessary investments in energy efficiency and develop a long-term strategy for the renovation of buildings with implementation of the Directive 2010/31/EU [21].

Directive 2010/31/EU on the energy performance of buildings requires that, given that buildings have an effect on long-term energy consumption, and given the long cycle of renovation of existing buildings, new and existing buildings undergoing major renovation should meet the minimum energy efficiency requirements adapted to the local climate [22].

In Bosnia and Herzegovina, the legal framework for energy efficiency is within the competence of the entities. The previous Directive 2002/91/EC on the energy performance of buildings in the FBiH since 2009 was implemented through the "Regulation on technical requirements for thermal insulation of buildings and rational use of energy" (FBiH Official Gazette no. 49/09) [23]. The Law on Energy Efficiency in the FBiH (FBiH Official Gazette no. 22/17) came into force in 2017 [24], on the basis of which the "Regulation on minimum requirements for the energy performance of buildings" (FBiH Official Gazette no. 81/19) was adopted [25].

Before any kind of renovation or rehabilitation of a building can be carried out, it is necessary to comprehensively examine the energy performance of the building in its current state and subsequently make an appropriate prediction of energy behavior by applying the planned improvement measures. One of the themes proposed by the European Commission in its research and innovation policy (*Horizon 2020*) is new tools and methodologies to reduce the gap between predicted and actual energy performances of buildings [26].

As school buildings have great social importance, the largest number of initiated activities (preparation of detailed energy audits) and implementation of energy efficiency measures (thermal insulation of building envelopes) in the public sector in FBiH was carried out on educational buildings in FBiH in the period from 2010 to 2018.

2.1 Data from detailed energy audit documents

The question is how to get a sample that will be the basis for collecting data for the research? Research shows that the existing buildings energy consumption data sets can generally be categorized according to three major strategies (measurement strategy, survey strategy and simulation strategy) by which the data samples are generated or obtained [27].

In order to obtain representative and reliable data, the research strategy by collecting data from detailed energy audit documents was used for this research. Detailed energy audit (DEA) is a documented procedure carried out in order to determine the energy performance of a building and the degree of fulfillment of this performance in relation to the requirements prescribed by special regulations and contains a proposal of measures for cost-effective improvement of energy performance of the building. Energy audit is the main tool for understanding the energy consumption in buildings and it is an in-depth analysis conducted on the building itself in order to determine the actual characteristics and define possible intervention measures aimed at improving the external envelope and replacing existing technologies in order to reduce energy and electricity consumption [28].

Energy audits are conducted by authorized professional persons (persons who have passed the training program and received authorizations) according to the guidelines prescribed for their preparation. The guidelines for conducting energy audits of buildings provide a common implementation methodology, and the main goal is to determine the energy performance of the building, and to make recommendations for increasing energy efficiency. The procedure for conducting a detailed energy audit of a building results in a document that includes, among other things, a large number of data on construction characteristics of the building in terms of thermal protection of the building envelope, characteristics of installed air conditioning, heating and cooling and ventilation systems and data on energy consumption and costs.

A total of 47 DEA documents for school buildings in SR FBiH, shown in Table 2, were collected for this research, which represent the basis for the development of this study. General location data, general and geometric data on school buildings, which include data on the year of construction, floor area (A_k), envelope area (A) and areas and energy performance of construction parts of the envelope were collected and selected. Data on the actual consumption of delivered energy for space heating ($Q_{H,del}$) and data on the calculated required value of delivered ($Q_{H,del,cal}$) energy for space heating for each building from the sample were collected.

Table 2. Data on the number of buildings and floor areas (A_k) of school buildings in SR FBiH according to TPB and from the sample with respect to construction period

SCHOOL BUILDINGS IN SR FBiH	Number of buildings in SR FBiH according to TPB	Number of buildings in SR FBiH from the sample	Share (%) of the number of buildings from the sample to the total number of buildings of TPB	Total floor area Ak (m^2) in SR FBiH according to TPB	Total floor area A_k (m^2) SR FBiH from the sample	Share (%) of the area A_k from the sample to the total area of TPB
until 1945	20	4	20.0%	19,282	4,626	24.0%
from 1946 to 1965	90	13	14.4%	84,302	23,119	27.4%
from 1966 to 1973	45	8	17.8%	63,908	12,646	19.8%
from 1974 to 1987	62	17	27.4%	103,078	40,008	38.8%
from 1988 to 2009	38	4	10.5%	35,503	3,820	10.8%
after 2010	8	1	12.5%	5,937	4,030	67.9%
TOTAL:	**263**	**47**	**17.9%**	**312,010**	**88,249**	**28.3%**

The statistical set or population is represented by statistical units, in this case school buildings in SR FBiH, whose scope and basic characteristics are defined in the TPB BiH document, while the collected DEAs represent the basic statistical sample for collecting data on the characteristics of the statistical set or population. A basic statistical analysis (descriptive statistics) of the collected data from the sample was performed.

The size of this statistical sample is 47 school buildings in the south region of FBiH. The share of the number of buildings from this sample in relation to the total statistical set is approximately 17.9% (47/263). The share of the floor area (A_k) from the sample in relation to the total statistical set is approximately 28.3% (88.249/312.010), which in terms of area represents slightly more than ¼ of the total statistical set.

3. RESULTS OF THE RESEARCH ON ENERGY CONSUMPTION FOR SPACE HEATING OF SCHOOL BUILDINGS IN SR FBiH FROM THE SAMPLE

3.1 Analysis of general and geometric characteristics

Methodologies of engineering calculations, simulations, statistical methods and machine learning are used to evaluate the energy performance of buildings. Although the goal of energy assessment of buildings is usually related to attempts to improve their performance [3], this research evaluates the energy performance of school buildings in the SR FBiH through the analysis of energy consumption for heating.

The assessment of the energy performance of a building is a measure of the quality of the building in terms of energy efficiency. The worse the energy class, the worse the building in terms of achieved thermal characteristics, but also the greater the opportunity to reduce carbon emissions and improve the energy performance of the building itself. However, the assessment does not provide information about how the building functions in actual conditions of use [26] because the energy class is determined according to the standardized conditions of use of the building and the calculated values of energy consumption.

In order to assess the energy performance of the current condition of school buildings in SR FBiH, the measured values of individual characteristics are compared with the reference or allowable values. The calculated or measured values are taken from the detailed energy audit (DEA) documents, and the reference values are determined or defined according to the applicable legal regulations.

One of the parameters for estimating the energy needs for heating is the number of heating degree days (HDD), which depends on the climatic conditions at the building site. The average value of HDD for 47 school buildings from the sample located in SR FBiH is 1,759 °C·days. According to the study [29], the average value of HDD in NR FBiH is 2,842 °C·days, which means that the average value of HDD in SR FBiH is about 62% compared to the value in NR FBiH. 68% of school buildings from the sample located in SR FBiH are situated in the zone where the number of HDDs ranges from 1,500 to 1,750 °C·days.

Figure 2 shows general data on the year of construction and floor area (A_k) of school buildings in SR FBiH from the sample. From Figure 2 it can be seen that the largest number of analyzed buildings from the sample was constructed in the period from 1974 to 1987, followed by the period from 1946 to 1965. In terms of construction period, 50% of school buildings in SR FBiH from the sample were constructed in the period from 1961 to 1980, and 35 schools, or 74.5% in the period between 1946 and 1988. The average floor area (A_k) of school buildings together with school halls is approximately 1,878.00 m^2.

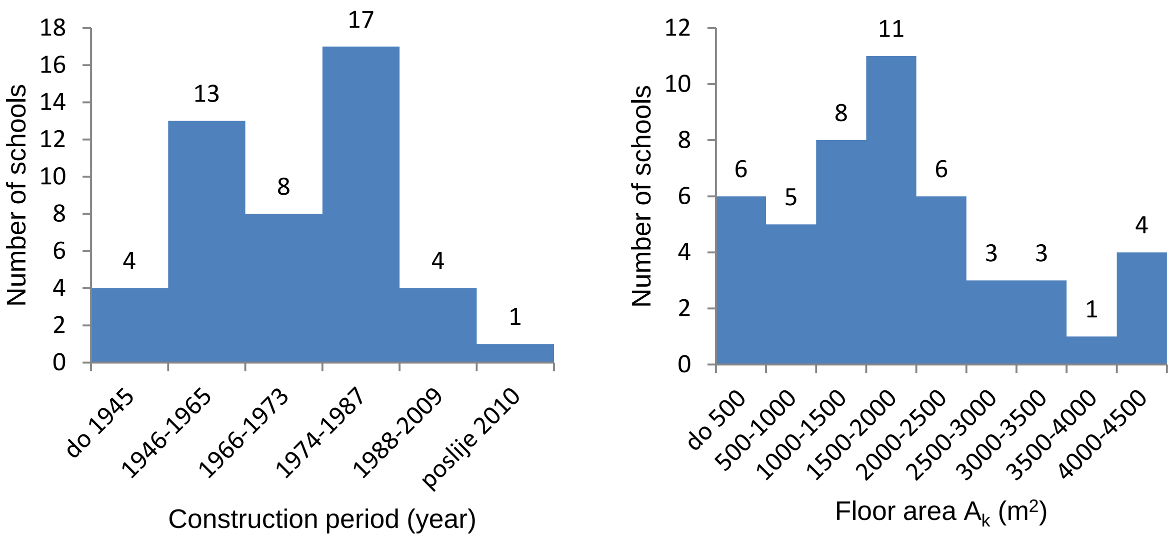

Figure 2. Number of school buildings in SR FBiH from the sample with respect to construction period and floor area (A_k)

Data on the thermal characteristics of construction parts of the building envelope are expressed through the heat transfer coefficients U (U-value) and are required to quantify losses and calculate thermal energy. Transfer of heat through a structure depends on the characteristics of installed materials, their thermal conductivity and the thickness of their layers. U-value of construction elements of the building envelope plays a key role in evaluating the thermal performance of the envelope [30].

The U-values of construction parts of the envelope and of the overall envelope of school buildings in SR FBiH from the sample were analyzed separately in paper [31] and shown in Table 3.

The average U-value of the envelope of school buildings in SR FBiH is 1.88 W/m^{2}K. The average U-values of construction parts of the envelope exceed the allowable values several times, which is indicative of the absence of thermal insulation layers. The U-values of building elements of the envelope represent one of the essential features or character variables that have an effect on the consumption of thermal energy.

Table 3. U-values of building elements of the envelope of school buildings in SR FBiH from the sample in relation to construction period

SCHOOL BUILDINGS IN SR FBiH	Average U-value (W/m^{2}K) for walls in SR FBiH	Average U-value (W/m^{2}K) for floors in SR FBiH	Average U-value (W/m^{2}K) for ceilings in SR FBiH	Average U-value (W/m^{2}K) for openings in SR FBiH	Average U-value of the envelope (W/m^{2}K) in SR FBiH
until 1945	1.63	1.43	1.93	3.06	**1.80**
from 1946 to 1965	1.71	2.32	2.58	2.91	**2.27**
from 1966 to 1973	1.57	1.75	2.07	2.73	**1.89**
from 1974 to 1987	1.61	1.93	1.68	2.69	**1.83**
from 1988 to 2009	1.01	1.37	0.61	2.64	**1.25**
after 2010	0.33	0.63	0.34	1.46	**0.51**
TOTAL	**1.55**	**1.89**	**1.90**	**2.76**	**1.88**

Comparison of the average U-value of the envelope of school buildings in SR FBiH with the average U-value of the envelope in NR FBiH, which is 1.87 W/m^{2}K (according to the study [29]), shows that, in terms of thermal characteristics, the analyzed school buildings in SR FBiH from the sample have the same characteristics as buildings in NR FBiH (because they are built with the same technology and materials) regardless of location and climate regions in FBiH.

3.2 Analysis of actual energy consumption for heating

The energy consumption for space heating is measured through the delivered energy. Delivered energy for space heating ($Q_{H,del}$) is energy, expressed per energy carrier, supplied to the technical building systems through the system boundary, to satisfy the needs of space heating, cooling, ventilation, domestic hot water, lighting, appliances etc. [25]. The actual annual specific delivered energy for space heating ($Q'_{H,del}$) in relation to the floor area of building (A_k) is determined according to the following expression:

$$Q'_{H,del} = \frac{Q_{H,del}}{A_k}\left[kWh/m^2 year\right] \quad (1)$$

Specific values of energy consumption for heating are better indicators than the overall energy consumption values because they are expressed in terms of floor area of the building (A_k), which allows their comparison.

The actual specific delivered energy for space heating ($Q'_{H,del}$) of school buildings in SR FBiH has an average value of 85.08 kWh/m^{2}year which is about 51% compared to the average value of actual specific delivered energy for space heating ($Q'_{H,del}$) in NR FBiH, which is 166.20 kWh/m^{2}year [29].

Table 4 shows the results of descriptive statistics for the actual specific delivered energy for space heating ($Q'_{H,del}$) of school buildings in SR FBiH from the sample and Figure 3 shows the histogram of the number of school buildings by construction periods.

3.3 Analysis of calculated energy consumption for space heating

The energy performance of school buildings in SR FBiH are determined by comparing the actual or measured and calculated energy consumption for heating. It is necessary to determine whether the actual energy consumption for space heating corresponds to the needs for the intended use of the building and to what extent, which is why the calculation or modeling of energy for heating is performed in accordance with applicable regulations or standards. Calculation of the required heating energy, which determines the actual needs, is performed in the Detailed Energy Review (DEA) documents.

A bottom-up approach based on a large database and detailed geometric data on individual buildings was used in the development of the model that predicts or estimates (calculates) the energy consumption for heating. Analysis of existing characteristics of buildings and data on actual energy consumption make it easier to develop energy consumption estimation models [20].

The first step according to the methodology for the calculation of energy needs of buildings is to calculate the annual energy needs for space heating $Q_{H,nd,cal}$ which represents the calculated amount of heat to be delivered via the heating system to a conditioned space to maintain the intended temperature conditions during the building heating period. The annual energy needs for space heating ($Q_{H,nd,cal}$) is calculated according to the standard BAS ISO 13790, calculation method by months [25].

The internal design temperature for school buildings is Θ_{int}= 20 °C. Climate conditions are defined by average monthly temperatures depending on the location of the building. Data from the DEA show that the heating season for school buildings located in SR FBiH lasts on average 5 months (November, December, January, February and March) and the average number of hours of heating system operation is about 9.5 hours per day.

The calculated specific energy needs for space heating ($Q'_{H,nd,cal}$) in relation to the floor area of building (A_k) are determined according to the following expression [23]:

$$Q'_{H,nd,cal} = \frac{Q_{H,nd,cal}}{A_k}\left[kWh/m^2 year\right] \quad (2)$$

Table 4 shows the results of descriptive statistics for the calculated values of the specific energy needs for space heating ($Q'_{H,nd,cal}$) for school buildings in SR FBiH from the sample. For this research, the approximate energy classes of school buildings in SR FBiH from the sample were determined in relation to the actual climate conditions and according to the calculated values of the specific energy needs for space heating ($Q'_{H,nd,cal}$) and are shown in Table 4.

The calculated specific energy needs for heating ($Q'_{H,nd,cal}$) school buildings in SR FBiH from the sample have an average value of 98,04 kWh/m^{2}year (energy class C) which is about 50% compared to the average value of the calculated specific energy needs for heating ($Q'_{H,nd,cal}$) in NR FBiH which is 197.05 kWh/m^{2}year (energy class E).

This is followed by the calculation of the delivered energy for space heating ($Q_{H,del,cal}$) which considers energy losses in the system via the degree of efficiency of the system. The annual delivered energy for space heating ($Q_{H,del,cal}$) represents the quotient of the annual energy needs for space heating ($Q_{H,nd,cal}$) and the total degree of efficiency of the heating system (η_{sys}) according to the following expression:

$$Q_{\mathrm{H,del,cal}} = \frac{Q_{\mathrm{H,nd,cal}}}{\eta_{\mathrm{sys}}}\left[kWh / year\right] \quad (3)$$

According to the data from the DEA, the degree of efficiency of the heating system (η_{sys}) for school buildings in SR FBiH from the sample has an average value of 0.75 or approximately 75%, which means that an average of 25% of heat losses occur in the heating system.

The calculated specific delivered energy for space heating ($Q'_{H,del,cal}$) in relation to the floor area of the building (A_k) is determined according to the following expression:

$$Q'_{H,del,cal} = \frac{Q_{H,del,cal}}{A_k}\left[kWh / m^2 year\right] \quad (4)$$

Table 4 shows the results of descriptive statistics for the calculated specific delivered energy for space heating ($Q'_{H,del,cal}$) of school buildings in SR FBiH from the sample and Figure 3 shows the histogram of the number of school buildings by construction periods. The average value of the calculated specific delivered energy for heating ($Q'_{H,del,cal}$) school buildings in SR FBiH from the sample is 136.32 kWh/m^{2}year, which is about 49% compared to the average value of calculated specific delivered energy for heating ($Q'_{H,del,cal}$) in NR FBiH which is 279.21 kWh/m^{2}year (according to study [29]).

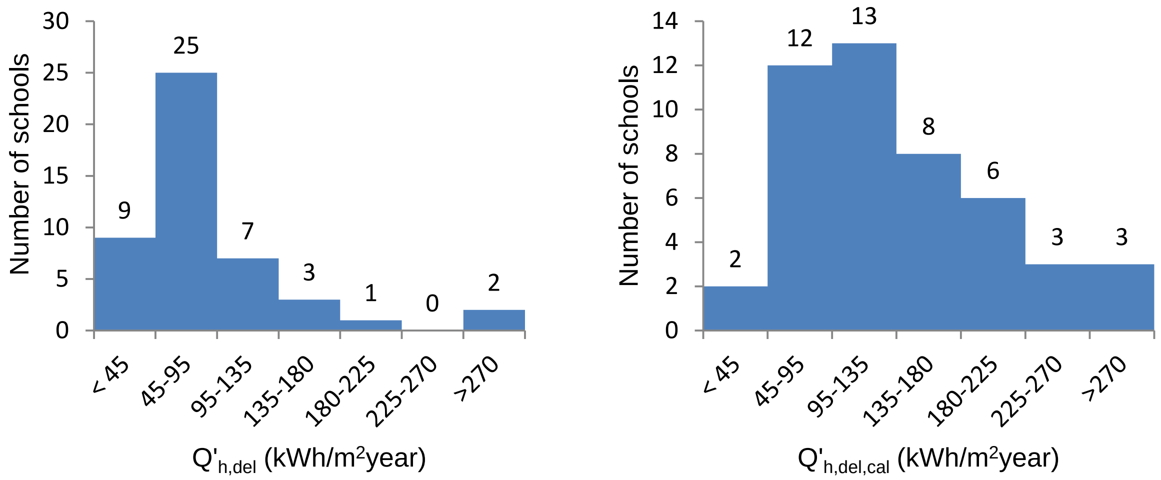

Figure 3. Histograms of the number of school buildings in SR FBiH from the sample in relation to the actual specific delivered energy for space heating ($Q'_{H,del}$) and the calculated specific delivered energy for space heating ($Q'_{H,del,cal}$)

Table 4 summarizes the average actual and calculated values of specific annual energy for heating, energy class and compares the actual and calculated delivered energy for heating school buildings in SR FBiH from the sample in relation to construction periods.

Table 4. Data on average values of calculated specific annual energy needs for space heating ($Q'_{H,nd,cal}$), energy class, calculated annual delivered energy for space heating ($Q'_{H,del,cal}$), actual annual delivered energy for space heating ($Q'_{H,del}$) and average ratio of actual to calculated value of delivered energy for heating school buildings in SR FBiH from the sample in relation to construction periods

SCHOOL BUILDINGS IN SR FBiH	Average Calculated Energy Needs $Q'_{h,nd,cal}$ (kWh/m^{2}year)	Energy Class (Rating)	Average Calculated Delivered Energy $Q'_{h,del,cal}$ (kWh/m^{2}year)	Average Actual Delivered Energy $Q'_{h,del}$ (kWh/m^{2}year)	Average Ratio (%) of Actual to Calculated Delivered Energy ($Q'_{h,del}$)
until 1945	135.91	D	167.79	77.40	46%
from 1946 to 1965	134.93	C	187.78	87.30	51%
from 1966 to 1973	85.81	B	125.88	119.21	90%
from 1974 to 1987	78.11	B	115.37	80.61	72%
from 1988 to 2009	67.07	B	73.61	46.00	78%
after 2010	27.59	A	32.09	16.13	50%
TOTAL	**98.04**	**C**	**136.32**	**85.08**	**67%**

Actual consumption of delivered energy for space heating $Q_{H,del}$ is compared with calculated annual delivered energy for space heating ($Q_{H,del,cal}$) on the basis of which it is determined whether the actual consumption meets current needs.

From Table 4 it can be seen that the average ratio (%) of actual to calculated delivered energy for heating school buildings in SR FBiH from the sample is on average about 67%, or that the actual consumption of energy for heating is on average about 33% lower than required. This indicates that there is a gap or discrepancy between the actual (measured) and predicted (calculated) values of consumption of delivered heating energy.

Based on this, it can be concluded that the actual consumption of energy for space heating is less than the calculated energy required to meet the thermal comfort conditions. The reasons for this lie in the poor thermal characteristics of construction parts of the envelope, which causes high heat losses, and with the lack of funds received by the observed institutions from the founders (these are usually units of local government and self-government) for the purchase of necessary energy sources, they are the main reasons for lower actual consumption of energy for space heating. The consequences are the "hypothermia" which is reflected in lower room temperatures and failure to heat all parts of the building (especially hallways, school halls and sanitary facilities) or some classrooms due to the smaller number of students.

A review of the literature also indicates the existence of a gap or discrepancy between the predicted (calculated) and actual (measured) performance. Van Dronkelaar et al. found that the magnitude of the difference in discrepancy was + 34%, with a standard deviation of 55% based on an analysis of 62 buildings. This paper finds that the dominant causes of discrepancies are specific uncertainty in modeling, occupant behaviors, and poor operational practice [3].

According to data from the Energy Institute in the UK from 2013, it is shown that the actual heating energy consumption in school buildings is 48% higher than the calculated heating energy needs [32]. A survey of 15 school buildings in the UK shows that there is a significant gap between the calculated and actual energy performance of buildings, mainly due to a lack of understanding of the factors affecting energy use. The factors that have the largest impact on the gap or discrepancy in energy consumption according to this survey are simplified calculation models, changes between the designed and constructed building, occupants (have a major influence on the energy performance of buildings as they control internal temperature, ventilation, lighting, equipment and hot water), use, maintenance and control of the building [33].

A survey conducted in Slovenia on 24 school buildings in the period 1997 to 1999, based on energy audits, energy consumption and air quality, showed that these buildings are high energy consumers. On average, the total annual energy consumption of the analyzed school buildings is 192 kWh/m^{2}year or 54 kWh/m^{3}year. It was also found that actual energy needs or energy consumption are lower than estimated or calculated energy needs [11].

As Slovenia and Bosnia and Herzegovina were parts of a common previous state with a similar common architectural heritage, the aforementioned survey in Slovenia confirms the results of this research on school buildings in terms of energy consumption.

4. CONCLUSION

The results of the research indicate poor energy performance of existing school buildings in SR FBiH. The average U-values of construction parts of the envelope exceed the allowable values many times, which leads to heating energy consumption being higher than the allowable values. Also, it was found that the actual consumption of delivered energy for space heating is less than the calculated energy required to meet the thermal comfort conditions. The reasons for this lie in the lack of financial resources for the purchase of the necessary energy sources, which, along with the poor energy performance of construction elements of the envelope, cause the difference between the actually delivered and calculated energy needed for heating.

Energy consumption for space heating can be reduced by applying measures to improve the energy efficiency of construction elements of the envelope (thermal insulation of external walls, thermal insulation of ceilings to the attic, roofs or unheated spaces and replacement of external openings) and/or by replacing the energy source through improvement of the heating system efficiency levels. The analysis of savings in delivered heating energy resulting from implementation of the planned energy efficiency improvement measures for 47 analyzed school buildings in SR FBiH, based on data collected from detailed energy audit documents, shows an average saving in delivered heating energy of 63% compared to the calculated delivered energy needed for heating. Also, implementation of all planned measures to improve the energy efficiency of the analyzed buildings would achieve average savings of 75% of annual heating energy costs compared to calculated heating energy costs. These measures would ensure thermal comfort with lower energy consumption for space heating compared to the calculated energy needs.

The described procedure for calculating the energy performance of buildings related to energy consumption for space heating requires a large amount of input data and they are suitable when design technical documentation is sufficiently elaborated or when preparing detailed energy audits of buildings.

However, in order to more easily analyze the consumption and costs of energy for space heating in engineering practice in earlier initial phases of development of project documentation (in the initial phases of design when evaluating variant design solutions and making investment decisions) or for management and maintenance of existing buildings, it is necessary to develop mathematical models that can more easily and quickly calculate the consumption and cost of heating energy with sufficient accuracy based on a smaller number of parameters or characteristics of buildings. For estimating the energy performance of buildings, studies show that the most common are regression models that correlate energy consumption with one or more variables. Least squares regression is common because it provides a technically rigorous approach and yields descriptive linear equations that are statistically valid and easily replicable [3].

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