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Source / Izvornik: **Buildings**, 2021, 11, 1 - 21

Journal article, Published version

Rad u časopisu, Objavljena verzija rada (izdavačev PDF)

<https://doi.org/10.3390/buildings11020042>

Permanent link / Trajna poveznica: <https://um.nsk.hr/um:nbn:hr:133:540256>

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Download date / Datum preuzimanja: **2025-03-06**



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## Article

# Energy Performance of School Buildings by Construction Periods in Federation of Bosnia and Herzegovina

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**Abstract:** This paper is part of broader research aimed at determining the relationship between energy performance and energy costs as a part of the operational and life cycle costs in school buildings in the Federation of Bosnia and Herzegovina (FBiH), as exceptionally important social and public buildings. The research was conducted by statistical analysis of data collected from documents of detailed energy audits (DEA) for 185 school buildings in FBiH in relation to construction periods. The paper analyzes the characteristics of buildings such as construction period, building envelope characteristics, climatic conditions, efficiency of installed space heating system, number of users and heating mode. The aim of this research was to determine the energy performance for the existing state and to compare them with the allowable values in accordance with the applicable legal regulations. There is a performance gap between predicted (calculated) and measured (actual) delivered energy for space heating. This research shows poor energy performance and provides a basis for developing strategies and plans to improve energy efficiency. The results of the energy performance of school buildings in the FBiH are the first step towards the development of a model for predicting energy costs.

**Keywords:** energy performance; building envelope characteristics; construction periods; energy consumption for space heating



**Citation:** Katić, D.; Krstić, H.; Marenjak, S. Energy Performance of School Buildings by Construction Periods in Federation of Bosnia and Herzegovina. *Buildings* **2021**, *11*, 42. <https://doi.org/10.3390/buildings11020042>

Academic Editor: Gianpiero Evola  
Received: 5 January 2021  
Accepted: 23 January 2021  
Published: 27 January 2021

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## 1. Introduction

### 1.1. School Buildings

School buildings are one of the most important facilities in a community given that students spend about 25% of their time inside classrooms. Moreover, a school usually has a considerably higher occupancy rate than any other type of building [1]. Among all public buildings, school buildings have a great social responsibility due to their educational purpose. That is why the energy characteristics of these buildings are of great importance, along with the appropriate levels of Indoor Environmental Quality (IEQ) [2]. The test results of children showed improved results in proportion to the increase in complaints IEQ factors [3].

It is very important for schools to have a level of indoor comfort that will not affect children's health or intellectual performance. Thermal comfort is the condition of mind that generates satisfaction with the thermal environment [1]. When the thermal satisfaction of the building user is achieved, it is said that the thermal comfort is achieved [4]. The thermal environment of the classroom is very important for the wellbeing and efficiency of students. Studies have shown a significant relationship between a controlled environment and student achievement and behavior [5].

In school buildings it is necessary to strike a good balance between cost reduction and high levels of comfort to influence student's performances through efficient control systems for air temperature, humidity, air speed and air purifying. Despite their importance,

school buildings are characterized by high levels of energy consumption that are not justified by good indoor air quality [6]. Research shows that school building age is an important variable that contributes to student achievement and behavior. Building age can also serve as a surrogate for a number of specific variables such as the condition of the building, thermal control, proper lighting and others. Nevertheless, school building age is a significant variable that influences student's learning and behavior [5].

The characteristics of the building envelope are crucial variables that should be taken into account because they are relevant to the energy requirements for maintaining the building at a comfortable temperature [7]. The building envelope is the most effective indicator of energy consumption used for heating, cooling and ventilation of buildings. Due to the direct interaction with external environmental conditions, the building envelope is defined as the interface of energy loss [8]. Furthermore, thermal comfort, among other factors, cannot be achieved without a satisfactory thermal envelope of the building.

Building energy performance (BEP) is an ongoing point of reflection among researchers and practitioners. The problem of building energy performance from the rating point of view can be observed through two main areas, asset rating (AR) and operational rating (OR). An asset rating (AR) can be defined as a calculation based on energy through a building energy model. Operational rating (OR) is related to a building's daily operations and measurements. Operational rating (OP) is an indicator of the amount of energy consumed during the occupation of the building over a specified period. Both methods look at the same problem from a different yet complementary perspective, and for that reason are essential [9].

The asset rating is a measure of building quality. The higher the rating the worse the building is, and the greater the opportunity to reduce carbon emissions and improve the building itself. However, the asset rating provides no information about how the building is operated in practice [10].

In order to evaluate energy performance, it is necessary to compare the calculated or measured performance of a building to some reference value or framework. These values may represent characteristics of the buildings (such as wall U values) or the energy consumption of specific building systems. Generally, these evaluations are based on the Energy Use Intensity (EUI), measured in energy consumption per unit of floor area ( $\text{kWh}/\text{m}^2\cdot\text{year}$ ), as this is often the easiest information to obtain for large quantities of buildings. It is worth noting that the environmental performance and comfort of a building are highly relevant to its overall performance [11].

Sufficient measurement data is essential to predict and manage a building's performance levels. When training a model, inadequacies in the data acquisition process generally mean that important information will be lacking, and the capture of underlying features is badly carried out. Small data sets do not provide enough epochs to update the parameters, which means that the model can be perfectly trained, and the output can be mapped to an extremely high accuracy, but only on an observed dataset. Feeding sufficient data to the model is the equivalent of enabling it to discover more comprehensive mapping rules and enhancing, therefore, the model's generalization ability [12].

The purpose of this study was to determine the energy performance of school buildings in the FBiH and compare them with the allowable values in accordance with applicable legislation. This paper presents the results of research into the characteristics (construction period, geometric data, building envelope thermal characteristics) of school buildings in the FBiH and the energy consumption for space heating as factors that have a significant impact on achieving thermal comfort and energy costs. The analysis of energy costs as a part of the operational and life cycle costs of a building is not the subject of this paper.

### *1.2. Review of Energy Consumption in School Buildings*

In many European countries, educational buildings like schools share many similar construction, use and maintenance features. Unfortunately, they also often share the characteristics of high energy consumption resulting in the need for an energy efficient

retrofit. Despite climatic differences throughout Europe, all school buildings are primarily designed to meet winter conditions [8].

Worldwide studies and publications present different energy consumption ratios on different descriptors, sometimes with different units and several energy use types. At a European level, the Member States of the European Union have different Energy Performance Certificates exhibiting different information at distinct scales. A similar process has been taking place in the US and in Canada. Besides, different approaches/methods lead to barely comparable values. Discrepancies between design estimates and actual energy use have been verified, which makes the comparison of measured and calculated values substantially difficult [2].

According to Dias Pereira et al. [2], the annual heating energy use values of school buildings in European countries vary from about 52 to 197 kWh/m<sup>2</sup>. Typical annual heating consumptions for some European school buildings are reported as 96 kWh/m<sup>2</sup> for Ireland, varying from less than 112 kWh/m<sup>2</sup> to 196 kWh/m<sup>2</sup> for Slovenia [13], and 157 kWh/m<sup>2</sup> for the UK [14]. In Slovenian schools, energy consumption is higher in comparison with neighboring countries and the actual energy needs are less than they were estimated in the project design [13].

A study conducted on 80 school buildings (characterized by different features and construction technologies) located in central Italy (the Lazio region) shows that the average value of the specific heating energy use is about 23 kWh/m<sup>3</sup> (the mean value of the HDD is 1677 °C days) [15]. Furthermore, a survey of actual energy consumption for space heating conducted on about 140 buildings (120 high schools) in the Province of Torino (Italy) shows an average value of 38 kWh/m<sup>3</sup>, that, assuming a floor height of 3 m, corresponds to a consumption of 115 kWh/m<sup>2</sup> [16].

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<sup>3</sup> [17]. Comparing the stated value with the same in the region of Lazio (23 kWh/m<sup>3</sup>), we come to the conclusion that the specific average annual heating energy in northern Italy is about two times higher.

According to the results of a 2007 survey in Greek schools, the average annual energy consumption is 95 kWh/m<sup>2</sup> distributed between kWh/m<sup>2</sup> for heating and 27 kWh/m<sup>2</sup> for electricity. For school buildings, in the climatic region of Greece with the lowest air temperature during the winter, the average annual heating energy consumption is 123.3 kWh/m<sup>2</sup> [18].

A study carried out at 8 different primary schools in the Alpine regions of Tyrol with different construction periods shows for the current situation an average annual heat consumption of 104 kWh/m<sup>2</sup> [19]. A survey conducted in southern Finland (the HDD is 3645 °C days) related to energy consumption in existing educational buildings shows that the total energy consumption median was 214 kWh/m<sup>2</sup> year in school buildings [20].

Energy consumption in a school can be characterized by different performance indicators, depending on several parameters, such as the typology (purpose) of the school (kindergarten, elementary or high school) that reflects different occupational schedules of activities and benefits. Then there are the geometric characteristics of buildings and construction periods that affect energy consumption [15].

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<sub>2</sub> emissions [21].

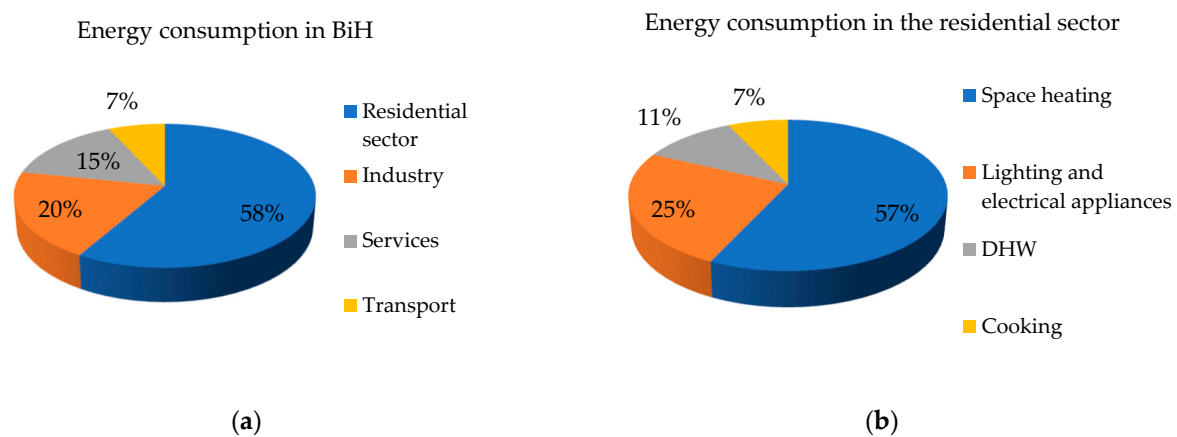
Buildings are the largest single energy consumer and are thus a major air and environmental polluter. Because of the long life of buildings, their impact on the environment in which we live is long and continuous and we cannot ignore it [22]. The heating and cooling energy demands of the building stock determine the major environmental impact of the

civil sector. The consumptions impact also on the costs for the operation and maintenance of the building HVAC system and on the indoor comfort conditions [23].

Before any type of rehabilitation can be carried out, extensive knowledge of a building's energy performance in its current condition and the appropriate prediction of the energy behavior of the retrofitted proposals are required. One of the themes proposed by the European Commission in its Horizon 2020 research and innovation policy is new tools and methodologies to reduce the gap between predicted and actual energy performances at the level of buildings and blocks of buildings [24]. Analyzing the above examples of heating energy consumption in school buildings, one can observe heterogeneity in the way of presentation and different units of measurement depending on the country, which makes comparison difficult. There is also a lack of data on the characteristics of buildings related to heating energy consumption. These data will serve as a rough comparison with the actual heating energy consumption in FBiH schools.

### 1.3. Energy Framework in Bosnia and Herzegovina

In Bosnia and Herzegovina (hereinafter: BiH), energy consumption data are not systematically collected by an official state institution and are not aggregated in one place. Over 50% of total energy consumption in BiH is related to the building sector [25]. Large losses are incurred in the cycle of production, distribution and consumption of energy in BiH [26]. Energy consumption for space heating in BiH is quite high compared to developed countries due to the large number of buildings constructed in the past without or with very thin thermal insulation. It is estimated that the average energy consumption for space heating in BiH is over 180.00 kWh/m<sup>2</sup>·year. Figure 1 presents the structure of energy consumption in BiH. The largest share refers to consumption in the residential sector (58%). In the residential sector, the largest share of energy consumption is related to space heating (57%). These data indicate great potential for energy savings by applying measures to improve the energy efficiency of buildings.



**Figure 1.** (a) Structure of energy consumption in Bosnia and Herzegovina [27]; (b) Energy consumption in the residential sector in Bosnia and Herzegovina [27].

BiH is one of the non-European Union [EU] countries that signed the Energy Community Treaty in 2005. This agreement is binding on all contracting parties among other things to take and implement the relevant directives and regulations of the EU in the field of energy efficiency and environmental protection [28]. BiH is a complex state and consists of two entities, the Federation of Bosnia and Herzegovina (FBiH) and Republika Srpska (RS), and the Brcko District of BiH (BD BiH) as a separate administrative entity (district). This causes slowness in implementation of the commitments as well as in development and implementation of energy efficiency action plans. According to the BiH Framework Energy Strategy, until 2035, and in accordance with one of the requirements of

Directive 2012/27/EU relating to the reduction and achievement of savings in final energy consumption, the following measures are defined in BiH in the building sector:

- renovation of central administration and public buildings;
- implementation of a long-term strategy for housing sector renewal;
- renovation of public buildings, with the help of donors and technical assistance projects;
- introduction of energy management in public buildings [29].
- This research was conducted in the FBiH entity for several reasons:
- energy efficiency regulations are the responsibility of the entities and they are not the same;
- FBiH is the earliest of all entities to start applying EU directives in its regulations (since 2009);
- the largest number of detailed energy audit documents was done for school buildings in the FBiH.

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 local energy requirements adapted to the local climate [30]. 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) [31] and “Regulation on energy certification of buildings” (FBiH Official Gazette no. 50/10) [32]. The Law on Energy Efficiency in the FBiH (FBiH Official Gazette no. 22/17) [33] came into force in 2017, on the basis of which the “Regulation on minimum requirements for the energy performance of buildings” (FBiH Official Gazette no. 81/19) [34] and “Regulation on conducting energy audits and issuing energy certification” (FBiH Official Gazette no. 87/18) [35] were adopted.

In order to implement the planned strategic measures and carry out the renovation of existing public buildings, it is necessary to determine the energy performance and energy consumption. Therefore, the research into the energy performance of school buildings in FBiH can be the basis for defining energy measures for the renovation of public buildings. This study was conducted on school buildings (primary and secondary schools) in FBiH, including school sports halls (if any exist within schools). From the point of view of function and common building service systems (heating, ventilation and air conditioning, electrical services) they form one whole and thus make up the common consumption of energy.

## 2. Data Collection and Methods

### 2.1. Population of Educational Buildings in FBiH

In the first step, a survey of the basic characteristics and size of the population of school buildings in the FBiH was conducted. The typology of public buildings (TPB) in Bosnia and Herzegovina is a document developed in 2018, which represents the classification and systematization of all public buildings in BiH. TPB contains a database of public buildings in BiH classified into 6 construction periods and 7 purpose sectors. One of the seven sectors of purpose refers to buildings intended for education, which includes primary and secondary schools, colleges and other educational institutions [36].

The second classification was made in relation to the construction period. Different construction periods have different characteristics of the building envelope elements, different construction technologies and the appearance of new building materials. Moreover, the legislation regarding minimum thermal insulation changed over time, which affected the energy consumption for space heating. Table 1 shows the basic characteristics of public buildings in BiH according to the construction period.

**Table 1.** Construction periods in BiH [36].

Construction Periods	Description of the Basic Characteristics of Public Buildings in Relation to the Construction Period
to 1945	The construction period up to 1945 is characterized by traditional construction techniques without the application of thermal insulation. Exterior solid walls mostly built of brick or stone. Mezzanine slabs are predominantly wooden, or made of brick or stone, and sometimes (in the later part of this period) of concrete. Basements in these buildings are mostly unheated spaces with massive walls, the purpose of which was in some way to separate the living space from the ground. The ceilings towards the unheated space (attic) are usually wooden with double-sided board formwork and an interspace filled with rubble. Windows and doors were wooden with one glass, or double with two wings at a distance of about 10 cm.
1946–1965	In the period from 1946 to 1965, the thermal characteristics became worse than in the period before 1945. The reasons lie in changes in the construction of building elements of the envelope by reducing the thickness of the walls, the introduction of reinforced concrete and new construction technologies that allow faster construction while neglecting thermal insulation, which caused significantly poorer thermal characteristics. The consequence of this method of construction was increased of heating energy consumption, and the appearance of moisture or condensation due to uninsulated thermal bridges.
1966–1973	In the periods from 1966 to 1973 and from 1974 to 1987, the first regulations related to the thermal insulation of buildings were developed and applied, which had a small effect on the reduction of heating energy consumption. Buildings from this period are characterized by the appearance of thermal insulation double glazing, however the window frames are still without an uninterrupted thermal bridge. The characteristics of the buildings are very scattered architectural forms with a very poor shape factor, and large glass surfaces on the outer walls, which did not significantly affect the improvement in the value of the elements and the overall envelope.
1974–1987	
1988–2009	The period from 1988 to 2009 is characterized by a very low intensity of construction and a significant use of new materials in the period after 2000. Only after 2000 did the significant use of thermal insulation materials and windows with thermal insulation glass and broken thermal bridges appear. However, this still happens spontaneously, without legal obligation, only on the basis of the knowledge of investors and designers and their own need to reduce heating costs.
after 2010	Since 2010, buildings have been observed and calculated as unique energy units. There is a significant impact of programs and projects of international organizations in the field of energy efficiency improvement. In this period, the construction and reconstruction of buildings with thermal characteristics significantly better than in buildings from previous construction periods is intensified.

According to TPB BiH, the largest number of public buildings in FBiH refers to buildings intended for administrative activities (buildings with office space from various sectors) with a share of 35.7%, followed by buildings intended for education with a share of 32.9% (a total of 1.455 education buildings in the FBiH). In relation to the useful surface area ( $A_k$ ) of public buildings, the largest useful surface area is occupied by buildings intended for education with a share of 33.5%, followed by buildings for administrative activities with a share of 27.7%.

Given the large share of educational buildings (1.455) in the total number of public buildings (4.419) as well as their special importance in the society of each country, this research was conducted on educational buildings in FBiH. Moreover, in the period from 2010 to 2018, the largest number of initiated activities on the implementation of measures to improve energy efficiency in the public sector in the FBiH was carried out in educational buildings.

## 2.2. Data from Detailed Energy Audit Documents

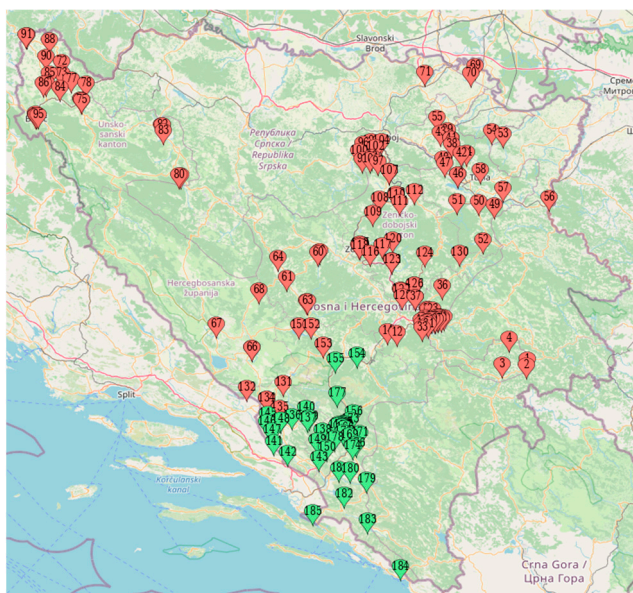
The second step of this research was to collect credible and reliable data that will be the basis for the analysis of the properties of school buildings of the primary population.

The existing building energy consumption datasets can generally be categorized according to three major strategies by which the data samples are generated or obtained, i.e., measurement, survey, and simulation [37]. For this research, a survey strategy will be used by collecting data from detailed energy audit documents (DEA) in order to obtain representative and reliable data. The energy check or audit represents the main tool to understand and consequently to effectively intervene on the energy situation of a building. In fact, it was a thorough analysis conducted with site inspections and examination of energy consumptions, in order to get an overview of the current state of energy uses of the building, and identify possible interventions aimed at replacing the existing technologies or improving their management with the purpose of reducing fuel and electricity consumptions [38].

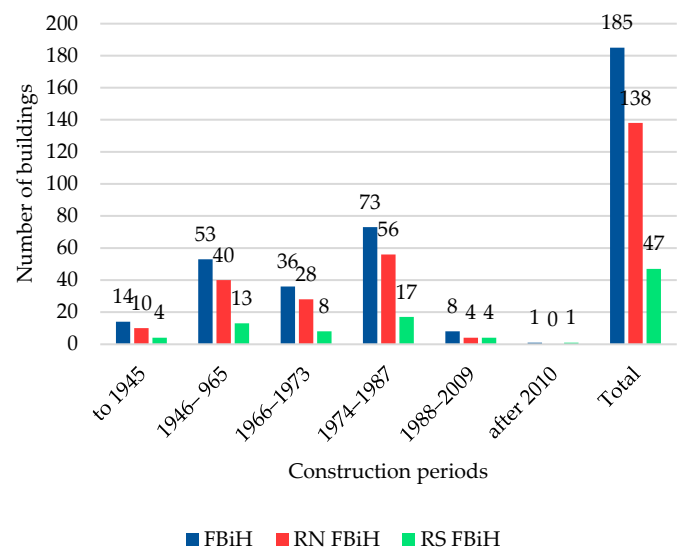
A request has been sent for obtaining documents for detailed energy audits of school buildings in the FBiH to various institutions and companies. The Environmental Fund of

FBiH responded to the request and provided all the DEA documents at its disposal. A total of 185 DEA documents of school buildings in the FBiH were collected, which represent a sample for this research.

The energy consumption for space heating, among other things, depends on the climatic conditions, which are defined in relation to the average monthly temperature of the coldest month of the year. If the average monthly temperature of the coldest month is less or equal to 3 °C then the location belongs to the region “north” (RN FBiH), that is the continental part. If the average monthly temperature of the coldest month is higher than 3 °C then the location belongs to the region “south” (RS FBiH), that is the warmer part with the influence of the Mediterranean climate. The requirements for minimum thermal insulation defined by the regulations (regulations on technical requirements for thermal insulation of buildings and rational use of energy) are set in relation to the average monthly temperature of the coldest month of the year. Figure 2 shows the locations of school buildings and the number of school buildings from the sample by climatic regions. In Figure 2, the red markings of schools represent locations in the RN FBiH while the green markings represent locations in the RS FBiH.



(a)



(b)

**Figure 2.** (a) Map of school building locations from the sample; (b) The number of school buildings from the sample by climatic regions.

From Figure 2, it can be seen that the largest number of analyzed buildings was built in the period from 1974 to 1987, followed by the period from 1945 to 1965. In the construction period after 2010, there is only 1 building (school) in the statistical sample. In relation to climate regions, the share of the number of school buildings in this statistical sample from the climate region “north” (RN FBiH) in relation to the total statistical sample is approximately 74.6% (138/185), or approximately  $\frac{3}{4}$  of the total sample.

Data presented in Table 2 show the distribution of the total number of school buildings in the sample with the distribution of useful surface area ( $A_k$ ) in relation to construction periods and the share in relation to the total statistical set according to the TPB.



**Table 2.** General data of number and total useful surface area of buildings from the sample in FBiH.

Data/Construction Periods	Number of Educational Buildings in FBiH according to TPB	Number of Educational Buildings in FBiH from the Sample	Share (%) of the Number of Educational Buildings	Total Useful Surface Area of Educational Buildings— $A_k$ (m <sup>2</sup> ) according to TPB	Total Useful Surface Area of Educational Buildings— $A_k$ (m <sup>2</sup> ) from the Sample	Share (%) of the Total Useful Surface Area of Educational Buildings ( $A_k$ )
to 1945	109	14	12.8%	105,089	29,446	28.0%
1946–1965	498	53	10.6%	466,471	128,310	27.5%
1966–1973	250	36	14.4%	355,042	69,070	19.5%
1974–1987	343	73	21.3%	570,257	185,714	32.6%
1988–2009	212	8	3.8%	198,070	14,808	7.5%
after 2010	43	1	2.3%	31,913	4030	12.6%
TOTAL	1455	185	12.7%	1,726,842	431,378	25.0%

The total part of the number of school buildings in FBiH from this statistical sample in relation to the total statistical set is approximately 12.7%. From the point of view of the total useful surface area ( $A_k$ ) from the sample, the share in relation to the total statistical set is then approximately 25.0%. It can be stated that the number of school buildings from the sample with its size of useful surface area ( $A_k$ ) represents a representative sample.

The detailed energy audit (DEA) is a documented procedure that is carried out in order to determine the energy performance of a building and the degree of fulfillment of these properties in relation to the requirements prescribed by special regulations and contains a proposal for measures to improve the energy performance. DEAs are carried out by trained and authorized persons in accordance with prescribed guidelines. The guidelines for conducting energy audits provide a common methodology for implementation, with the primary objective of identifying energy properties for new or existing facilities and making recommendations for improving energy efficiency [39].

DEA documents were drafted between 2012 and 2018 and used the data obtained from users of the buildings from the previous 3 years in relation to the year of DEA development. Part of the above-presented and available data were used in this research, which can be classified into the following several categories:

- General location information including: facility name and location (city), mean monthly temperature of the coldest month, number of heating degree days (HDD) and climate region.
- General information on the building including: information on the existence of a school hall (all data on the school building including the school hall information, if one exists), year of construction, category in relation to the construction period according to the TPB and the year of significant reconstruction.
- Geometric information on the building including: number of floors, useful surface area— $A_k$  (m<sup>2</sup>) ( $A_c$ —conditioned area according to EN 15217), thermal envelope area— $A$  (m<sup>2</sup>) ( $A_E$ —thermal envelope area according to EN 15217), heated volume of the building— $V_e$  (m<sup>3</sup>) ( $V_c$ —conditioned volume according to EN 15217), building shape factor ( $f_o$ ) ( $c = A_E/V_C$ —according to EN 15217), and building shape factor ( $f$ ) ( $f = A_E/A_C$ —according to EN 15217).
- Data on thermal characteristics of building envelope in the current state include data on individual areas of building elements of the building envelope and total areas classified into 4 groups: walls (external walls, walls against garages and ground, walls against unheated internal zones), floors (floors on the ground and against unheated basement), ceilings (flat and inclined roofs above heated internal space, ceilings towards the attic, ceilings against exterior, ceilings against unheated internal zones) and transparent and nontransparent parts of facade (windows, doors, etc.). Data on the thermal transmittance coefficients (U) of the individual building elements of the envelope, the average thermal transmittance coefficient (U) for the entire envelope, the transmission heat transfer coefficients ( $H_{Tf}$ ) and the ventilation heat transfer coefficients ( $H_{Ve}$ ).

- Data on energy sources that includes information: on the energy source used to obtain thermal energy, the number of hours of operation of the heating system and the efficiency of the heating system.
- Data on actual energy consumption for space heating, which includes data on: actual average annual consumption of delivered energy ( $Q_{H,del}$ ) for heating (kWh/year) and specific average annual consumption of delivered energy ( $Q'_{H,del}$ ) for heating (kWh/m<sup>2</sup> year).

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, this research evaluates the energy performance of school buildings in the FBiH through the analysis of their characteristics and energy consumption [11].

Based on the data collected above from the sample (dataset), research into energy performance of school buildings in the FBiH in relation to construction periods was performed. Parameters or variables that affect energy performance are the year and method of construction, construction composition (primarily envelopes), climatic conditions and duration of the heating season, efficiency of installed space heating systems, purpose of the building, number of users and heating mode.

### 3. Results and Discussion

#### 3.1. Statistical Analysis of Dataset

The statistical set or population is represented by school buildings in FBiH, and the collected DEA documents represent the basic statistical sample for collecting data (dataset) on the characteristics of the statistical set or population.

In the statistical analysis, the following symbols were used: ( $n$ ) is the number of units, ( $x_{min}$ ) minimum value, ( $x_{max}$ ) maximum value, ( $R_x$ ) range of values, ( $X$ ) average value, ( $M_e$ ) median, ( $\sigma_x$ ) standard deviation, and ( $V$ ) coefficient of variation.

The task of descriptive statistics is to describe, organize, and summarize research results in order to be clearer, more understandable and more suitable for interpretation and further analysis. The coefficient of variation ( $V$ ) is a relative measure of dispersion. Values of up to 10% represent very weak variability, from 10% to 30% weak, from 30% to 50% moderate, 50% to 70% strong and over 70% very strong (indicating that the distribution is not uniform). A smaller measure of dispersion means a higher representativeness of the mean and vice versa [40].

Below are the results of statistical analysis of the dataset (parameters or variables) from a sample presented in summary tables and graphs.

#### 3.2. Analysis General and Geometric Characteristics of School Buildings

The increase in availability of large volumes of data on building energy performance has allowed the development of top-down methodologies for the analysis of building energy performance. These methodologies use statistical techniques to predict and evaluate energy performance based on existing datasets of multiple buildings [11].

One of the parameters for estimating the energy needs for heating and cooling is the number of degree days (DD). It is assumed that the energy needs for a building are proportional to the difference between the basic temperature and the mean temperature of outdoor air [41]. Of the general parameters related to the location and which represents the climatic conditions and the duration of the heating season, the number of heating degree days (HDD) was used. The parameter that characterizes the year and period of construction is the age of the building. Geometric parameters characterize the size and shape of the building.

The Regulation on technical requirements for thermal insulation of buildings and rational use of energy defines a variable for estimating the compactness of the shape factor marked with  $f_o$ , which represents the ratio of the thermal envelope area ( $A$ ) and the heated volume ( $V_e$ ) and is called the shape factor [31]. According to EN 15217, the building shape

factor ( $f$ ) defines the ratio of the thermal envelope area ( $A$ ) and the useful surface area ( $A_k$ ) and the compactness factor ( $c$ ) defines the ratio of the thermal envelope area ( $A$ ) and the heated volume ( $V_e$ ). In the research into the significance of the shape factor of buildings, it is stated that the building shape factor ( $f$ ) is one of the parameters that has an impact on the height of the value of the energy indicator [42].

The results of the statistical analysis of general and geometric characteristics of school buildings in FBiH from the sample are shown in Tables 3 and 4.

**Table 3.** General and geometric data of buildings from the sample in relation to construction periods.

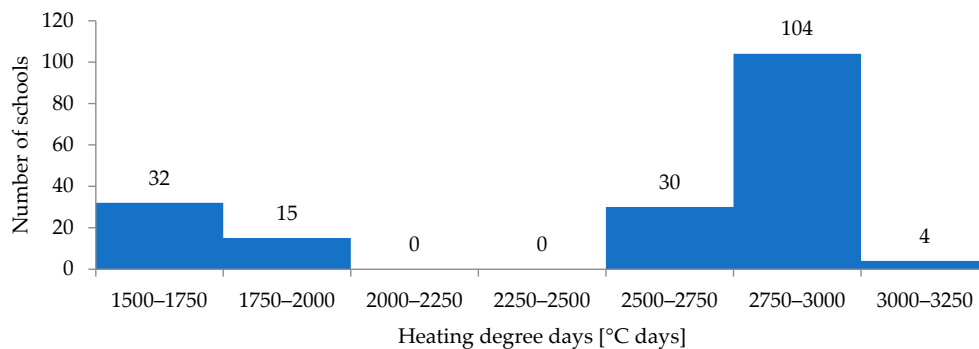
General and Geometric Data/ Construction Periods	Average HDD (°C days)	Average Age (Years)	Average $A_k$ (m <sup>2</sup> )	Average $V_e$ (m <sup>3</sup> )	Average $A$ (m <sup>2</sup> )	Average $f_o$ (m <sup>-1</sup> )	Average $f$
to 1945	2596	104	2103	8181	4567	0.58	2.28
1946–1965	2589	63	2421	9970	4862	0.52	2.12
1966–1973	2606	51	1919	7276	3948	0.57	2.17
1974–1987	2570	41	2544	9532	5094	0.57	2.20
1988–2009	2276	20	1851	7194	3342	0.53	2.07
after 2010	1689	6	4030	21,383	8464	0.40	2.10
TOTAL	2567	53	2332	9079	4707	0.56	2.17

**Table 4.** Basic statistical parameters of general and geometric data set.

Variable	$x_{min}$	$x_{max}$	$R_x$	$X$	$M_e$	$\sigma_x$	$V$
Heating d.d. HDD (°C days)	1689.00	3095.00	1406.00	2566.92	2825.00	486.45	19.0%
Construction periods (year)	1886	2014	128	1966.92	1971.00	19.54	1.0%
Useful surface area $A_k$ (m <sup>2</sup> )	83.60	7710.00	7626.40	2331.77	2204.60	1177.69	50.5%
Heated volume $V_e$ (m <sup>3</sup> )	325.30	27,354.50	27,029.20	9079.02	8387.50	4566.93	50.3%
Thermal envelope area $A$ (m <sup>2</sup> )	327.9	11,459.90	11,132.00	4707.00	4681.50	1942.52	41.3%
Building shape factor $f_o$ (m <sup>-1</sup> )	0.32	1.01	0.69	0.56	0.53	0.12	21.9%
Building shape factor $f$	1.18	6.38	5.20	2.17	2.09	0.55	25.5%

In relation to the number of heating degree days (HDD) on Figure 3, two parts can be seen. The first smaller part refers to 47 buildings located in the region of the south (RS), and the second part to 138 buildings located in the region of the north (RN). Compared to the construction period, 50% of school buildings from the sample were built in the period from 1960 to 1979, and from the period between 1945 and 1988 there are 162 schools, or 87.6% of the sample.

A proportion of 74.2% of schools in the sample have a useful surface area ( $A_k$ ) in the range of 1500.00 to 3000.00 m<sup>2</sup>, the average value is 2332.00 m<sup>2</sup>. The average value of the building shape factor ( $f_o$ ) is 0.55 and in the range from 0.40 to 0.60 there are 128 schools, or 69.2% of the sample.



**Figure 3.** The number of school buildings from the sample by heating degree days.

### 3.3. Envelope Characteristics Analysis of School Buildings

Heat losses through the building envelope occur due to the temperature difference between the warm air in the room and the cold outside air in the direction of the lower temperature. Transfer of heat through a structure depends on the installed materials, their thermal conductivity and the thickness of their layers. Data on the thermal permeability of the building envelope are necessary to quantify losses through it. U value of the building envelope plays a key role in assessing the thermal performance of the structure [43]. Heat loss cannot be stopped; however, it can be reduced by improving the thermal insulation of the building's outer envelope.

Of all the parameters, the most important indicator used to describe the thermal properties of buildings, and thereby the overall energy efficiency of a building, is the heat transfer or thermal transmittance coefficient (U value) [44]. The building form is one of the most important parameters with respect to total heat loss of the whole building and the heat transfer coefficient (U value) determines the heat loss through unit area of opaque or transparent components of the building envelope [45].

In this research, the elements of the building envelope were classified into 4 categories, namely walls, floors, ceilings, and transparent (nontransparent) parts of facade (windows, doors, etc.). The average values of the areas of the building elements of the envelope and the average values of the U value are shown in Table 5. The results of the statistical analysis are shown in Table 6.

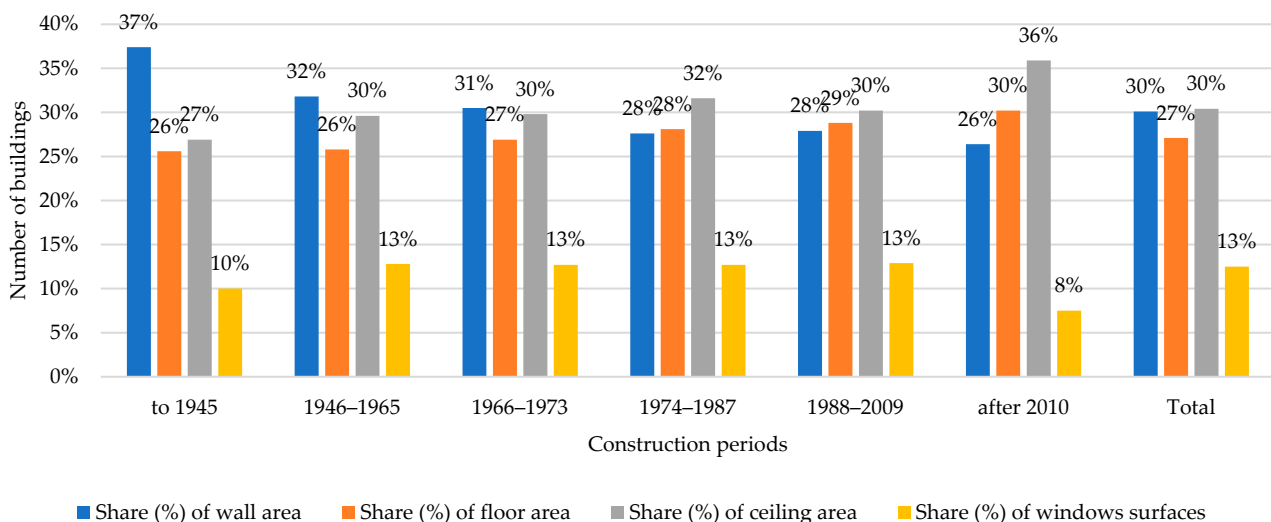
**Table 5.** The average values of the areas and the U value of building envelopes from the sample in relation to construction periods.

Thermal Characteristics/Construction Periods	Avg. Wall Area (m <sup>2</sup> )	Avg. "U" Walls (W/m <sup>2</sup> K)	Avg. Floor Area (m <sup>2</sup> )	Avg. "U" Floors (W/m <sup>2</sup> K)	Avg. Ceiling Area (m <sup>2</sup> )	Avg. "U" Ceilings (W/m <sup>2</sup> K)	Avg. Windows (m <sup>2</sup> )	Avg. "U" Windows (W/m <sup>2</sup> K)	Avg. Envelope Area (m <sup>2</sup> )	Avg. "U" Envelope (W/m <sup>2</sup> K)
to 1945	1703	1.45	1166	1.81	1224	2.17	456	3.27	4567	1.91
1946–1965	1548	1.53	1254	2.10	1437	2.04	622	3.01	4862	2.02
1966–1973	1205	1.58	1062	2.34	1177	1.86	502	2.78	3948	1.99
1974–1987	1404	1.46	1431	1.72	1610	1.72	645	2.86	5094	1.77
1988–2009	934	1.13	964	1.53	1012	0.81	432	2.68	3342	1.38
after 2010	2236	0.33	2559	0.63	3038	0.34	631	1.46	8464	0.51
TOTAL	1414	1.48	1274	1.95	1429	1.82	587	2.90	4707	1.87

Looking at the overall sample (Figure 4), the surfaces of external walls and ceilings each represent 30% of the total envelope area, followed by the floor area with 27% and finally the opening area with 13%. The average envelope area is 4707.00 m<sup>2</sup>. In the range of the envelope area from 2000.00 to 6000.00 m<sup>2</sup>, there are 136 schools or 73.5%, and in the range from 3440.00 to 5706.00 m<sup>2</sup> there is 50% of the envelope area from the sample. The average U value for the total envelope is 1.87 W/m<sup>2</sup> K, and in the range of values from 1.00 to 2.50 W/m<sup>2</sup> K there are 154 schools or 83.2%, and the range of 1.44 to 2.26 W/m<sup>2</sup> K is found in 50% of the schools in the sample. The U value for the envelope area have a weak dispersion (coefficient of variation is up to 30%).

**Table 6.** Basic statistical parameters of the areas and the U value of building envelope data set.

Variable	$x_{min}$	$x_{max}$	$R_x$	$X$	$M_e$	$\sigma_x$	$V$
Avg. wall area (m <sup>2</sup> )	105.7	4065.5	3959.8	1413.6	1327.1	640.7	45.3%
Avg. "U" walls (W/m <sup>2</sup> K)	0.25	2.81	2.56	1.48	1.43	0.46	30.8%
Avg. floor area (m <sup>2</sup> )	100.1	3608.4	3508.3	1274.2	1158.1	606.7	47.6%
Avg. "U" floors (W/m <sup>2</sup> K)	0.34	4.37	4.03	1.95	1.65	1.14	58.8%
Avg. ceiling area (m <sup>2</sup> )	100.1	4251.5	4151.4	1428.7	1333.4	672.0	47.0%
Avg. "U" ceilings (W/m <sup>2</sup> K)	0.32	4.81	4.48	1.82	1.57	1.06	58.0%
Avg. windows (m <sup>2</sup> )	22.0	1635.2	1613.2	587.0	555.5	299.3	51.0%
Avg. "U" windows (W/m <sup>2</sup> K)	1.41	5.07	3.66	2.90	2.97	0.71	24.5%
Avg. envelope area (m <sup>2</sup> )	327.9	11,459.9	11,132.0	4707.0	4681.5	1942.5	41.3%
Avg. "U" envelope (W/m <sup>2</sup> K)	0.51	3.31	2.81	1.87	1.86	0.55	29.6%

**Figure 4.** Share (%) of the area of individual building elements in the total area of the building envelope from the sample.

The average U value for the walls is 1.48 W/m<sup>2</sup> K, and in the range of values from 1.00 to 2.00 W/m<sup>2</sup> K there are 139 schools or 75.1%, and in the range of 1.20 up to 1.77 W/m<sup>2</sup> K there are 50% of the schools in the sample. The U values for floors have a strong dispersion (coefficient of variation is over 50%), the average U value is 1.95 W/m<sup>2</sup> K, and in the range of 0.98 to 2.67 W/m<sup>2</sup> K there are 50% of schools from the sample. The U values for the ceilings also have a strong dispersion, the average U value is 1.82 W/m<sup>2</sup> K, and in the range of 1.02 to 2.53 W/m<sup>2</sup> K there are 50% of the schools in the sample. Analyzing the U values for windows, most schools have an average U value in the range from 3.00 to 3.50 W/m<sup>2</sup> K, in the range from 2.00 to 4.00 W/m<sup>2</sup> K there are 153 schools or 82.7%, and in the range of 2.38 to 3.38 W/m<sup>2</sup> K there are 50% of the schools in the sample. The average U value of the windows is 2.90 W/m<sup>2</sup> K.

Analyzing the change in U values by construction periods, the influence of the change in wall thickness can be noticed. Buildings built before 1945 have massive exterior walls made of solid brick 48 cm thick or of natural stone and plastered on both sides. After that period, there was a change in construction technologies and the introduction of reinforced concrete so that the walls became thinner and thinner, which led to an increase in the

U values for the walls. It was not until the 1970s and the entry into force of the regulations on minimum thermal insulation that walls with layers of thermal insulation began to be built, which had the effect of reducing the U values for the walls.

The impact of changes and improvements in construction technology and quality of external windows can be seen in the improvement of the U values. Until the 1970s, exterior windows were mostly made of wooden frames, double, with joined wings and single glass. With the introduction of double glazing or thermal glass and since the 1980s part of the PVC and aluminum frames, the thermal properties have been improved and the U value for the windows has been reduced.

The average U value of the envelope in the north region is  $1.87 \text{ W/m}^2 \text{ K}$ , and in the south region  $1.88 \text{ W/m}^2 \text{ K}$ . Therefore, it can be concluded that the analyzed buildings from the point of view of thermal characteristics of the envelope have similar characteristics regardless of the location and climatic regions in the FBiH.

The quality of thermal insulation of the building envelope is determined by the U value. According to the "Regulation on technical requirements for thermal insulation of buildings and rational use of energy", the allowable U of building elements of the envelope are defined in relation to the average monthly temperature ( $\Theta_{e,m}$ ) of the coldest month of the year. Table 7 shows the allowable U values of some building elements of envelope.

**Table 7.** The allowable U values according to climatic regions [31].

Building Elements of the Envelope	The Actual U Values ( $\text{W/m}^2 \text{ K}$ )	The Allowable U Values $\Theta_{e,m} \leq 3 \text{ }^\circ\text{C}$ (RN FBiH)	The Allowable U Values $\Theta_{e,m} > 3 \text{ }^\circ\text{C}$ (RS FBiH)
Exterior walls	1.48	0.45	0.60
Floors	1.95	0.50	0.50
Ceilings	1.82	0.30	0.40
Transparent openings	2.90	1.80	1.80

By comparing the actual U values with the allowable U values, the degree of fulfillment of these properties in relation to the requirements prescribed by regulations is determined. The actual average U values are many times higher than the allowable U values and indicates the lack of layers of thermal insulation and to the greatest extent affects the total heat transmission losses. Due to the above, the U values of the building elements of the envelope represent one of the basic characteristics or character variables that affect the energy needs for space heating.

Based on the known data on the surfaces and the U values of the building elements of the envelope for each individual building, the values of the transmission heat transfer coefficients ( $H_{Tr}$ ) were calculated. The transmission heat transfer coefficients ( $H_{Tr}$ ) ( $\text{W/K}$ ), according to EN 13789, are determined to the following expression [46]:

$$H_{Tr} = H_D + H_U + H_G + H_A \text{ [W/K]} \quad (1)$$

where are they:

$H_D$ —the direct heat transfer coefficient between the heated space and the exterior through the building envelope ( $\text{W/K}$ ),

$H_U$ —the transmission heat transfer coefficient through unconditioned spaces ( $\text{W/K}$ ),

$H_G$ —the steady-state ground heat transfer coefficient ( $\text{W/K}$ ),

$H_A$ —the transmission heat transfer coefficient to adjacent buildings ( $\text{W/K}$ ).

The results of the research show that the average value of transmission heat losses ( $H_{Tr}$ ) of buildings from the sample is  $7137 \text{ W/K}$ . The largest heat losses in the average amount of  $6432 \text{ W/K}$  (approx. 90%) relate to losses to the external environment ( $H_D$ ) through walls, ceilings and openings. Losses of the floor on the ground ( $H_G$ ) average  $651 \text{ W/K}$  (approx. 9%). Losses over unheated spaces ( $H_U$  and  $H_A$ ) average  $54 \text{ W/K}$  (approx. 1%).

Regulation on technical requirements for thermal insulation of buildings and rational use of energy defined allowable values of the transmission heat transfer coefficients ( $H_{Tr}$ ) per unit area of the envelope ( $A$ ) marked  $H'_{Tr,adj}$  ( $W/m^2 K$ ) in relation to the building shape factor ( $f_o$ ) and the average monthly temperature of the coldest month of the year ( $\Theta_{e,m}$ ) [31]. The average value of the transmission heat transfer coefficients ( $H'_{Tr,adj}$ ) of the buildings in the sample is  $1.58 (W/m^2 K)$ , the average allowable value is  $0.72 (W/m^2 K)$ . Comparing the average actual and allowable values of the transmission heat transfer coefficients ( $H'_{Tr,adj}$ ), we come to the conclusion that the actual values are over 2 times higher than allowable, which shows very poor thermal characteristics of the current state of existing school buildings in FBiH.

### 3.4. Energy Consumption Analysis of School Buildings

An analysis of actual and calculated energy consumption for space heating was performed. The actual energy consumption for space heating, in addition to the characteristics of the building and its parts and equipment, also depends on the behavior of the users themselves, which can have a significant impact on energy consumption, which this research did not include. The analysis of actual heat consumption was performed based on a dataset from DEA documents.

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 use of space heating. Delivered energy can be calculated or it can be measured [47]. The actual specific delivered energy for space heating ( $Q'_{H,del}$ ) ( $kWh/m^2$  year) in relation to the useful surface area of building ( $A_k$ ) is determined according to the following expression:

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

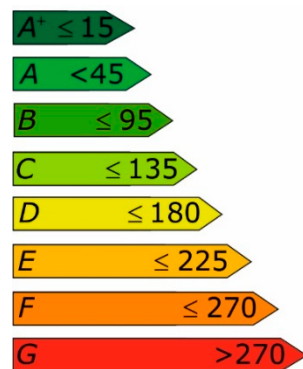
In the next step, it is necessary to determine whether the actual energy consumption for space heating corresponds to the needs. Therefore, the calculation or modeling energy for space heating is performed according to the applicable regulations or standards and the annual energy needs for space heating ( $Q_{H,nd}$ ) are calculated first. The annual energy needs for space heating ( $Q_{H,nd}$ ) represent the heat to be delivered to a conditioned space to maintain the intended temperature conditions during a given period. The energy needs are calculated and cannot easily be measured [47].

The calculation of the annual energy needs for space heating ( $Q_{H,nd,cal}$ ) for the existing condition were performed based on the known above-mentioned input data for each building from the sample. The internal design temperature for school buildings is  $\Theta_{int} = 20 \text{ }^\circ\text{C}$ . The annual energy needs for space heating ( $Q_{H,nd,cal}$ ) are calculated in accordance with the standard BAS EN ISO 13790 calculation method by months [34]. The calculation methodology is not presented in this paper.

The calculated specific energy needs for space heating ( $Q'_{H,nd,cal}$ ) ( $kWh/m^2$  year) in relation to the useful surface area of building ( $A_k$ ) are determined according to the following expression:

$$Q'_{H,nd,cal} = \frac{Q_{H,nd,cal}}{A_k} \left[ kWh/m^2 \text{ year} \right], \quad (3)$$

According to the Regulation on energy certification of buildings, the energy ratings of buildings are determined in relation to the values of specific energy needs for space heating ( $Q'_{H,nd}$ ) according to reference climate data (energy classes are graphically shown in Figure 5) expressed in  $kWh/m^2$  year [32].



**Figure 5.** Energy rating of non-residential buildings in FBiH [32].

In this paper, approximate energy ratings are determined in relation to the actual climatic data and according to the average calculated specific energy needs for space heating ( $Q'_{H,nd,cal}$ ) (kWh/m<sup>2</sup> year) because no energy certification is performed in relation to the reference climatic data.

The calculation of the annual delivered energy for space heating ( $Q_{H,del,cal}$ ) represents the quotient of the calculated annual energy needs for space heating ( $Q_{H,nd,cal}$ ) and the degree of efficiency of the heating system ( $\eta_{H,sys}$ ) according to the following expression:

$$Q_{H,del,cal} = \frac{Q_{H,nd,cal}}{\eta_{H,sys}} \text{ [kWh/year]}, \quad (4)$$

The degree of efficiency of the heating system ( $\eta_{H,sys}$ ) represents a measure of efficiency of converting the delivered energy ( $Q_{H,del}$ ) into energy needs ( $Q_{H,nd}$ ) for space heating and depends on the condition of the heating system and its elements (boiler, distribution and regulation). According to the data from the DEA, the average value of the efficiency of the heating system ( $\eta_{H,sys}$ ) for school buildings in FBiH from the sample is 0.73 or approximately 73%, which means that an average of 27% of heat losses occur in the heating system. Due to the above, the improvement measures also envisage thermotechnical measures to improve the heating system in order to reduce heat losses.

The calculated specific delivered energy for space heating ( $Q'_{H,del,cal}$ ) (kWh/m<sup>2</sup> year) in relation to the useful surface area of the building ( $A_k$ ) are determined according to the following expression:

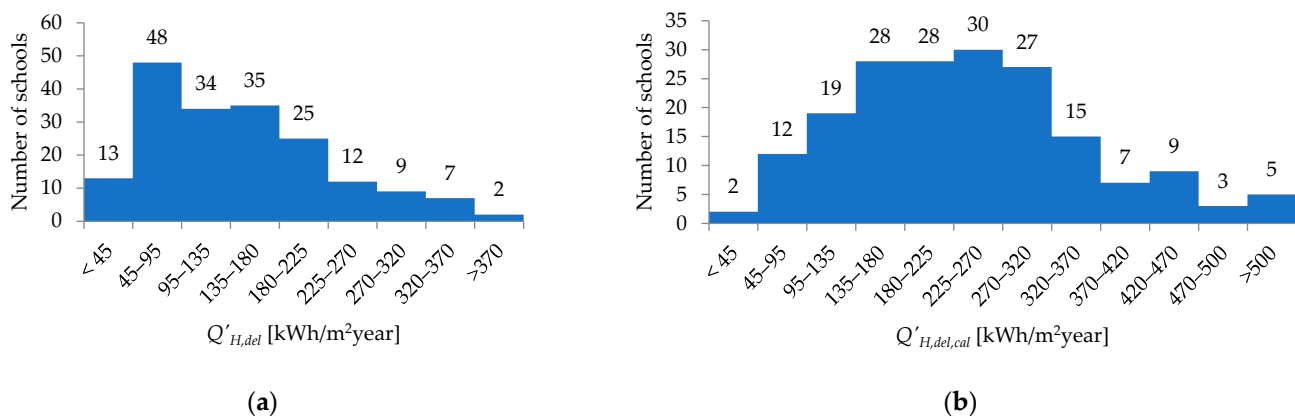
$$Q'_{H,del,cal} = \frac{Q_{H,del,cal}}{A_k} \text{ [kWh/m}^2 \text{ year]}, \quad (5)$$

The results of the statistical analysis of the actual specific delivered energy ( $Q'_{H,del}$ ) and the calculated specific delivered energy ( $Q'_{H,del,cal}$ ) for space heating of data set are shown in Table 8 and Figure 6.

**Table 8.** Basic statistical parameters of the actual specific delivered energy ( $Q'_{H,del}$ ) and the calculated specific delivered energy ( $Q'_{H,del,cal}$ ) for space heating of data set.

Variable	$x_{min}$	$x_{max}$	$R_x$	$X$	$M_e$	$\sigma_x$	$V$
$Q'_{H,del}$ (kWh/m <sup>2</sup> year)—FBiH	13.66	397.75	384.08	145.59	131.25	82.80	56.9%
$Q'_{H,del,cal}$ (kWh/m <sup>2</sup> year)—FBiH	32.09	788.23	756.15	242.91	226.77	123.21	50.7%





**Figure 6.** (a) The number of school buildings in relation to the actual specific delivered energy ( $Q'_{H,del}$ ) for space heating in FBiH; (b) The number of school buildings in relation to the calculated specific delivered energy ( $Q'_{H,del,cal}$ ) for space heating in FBiH.

The following Table 9 summarizes the average values of the specific energy needs for space heating and energy class of school buildings in the FBiH from the sample in relation to the periods of construction.

**Table 9.** The average values of actual ( $Q'_{H,del}$ ) and calculated delivered energy ( $Q'_{H,del,cal}$ ) for space heating, energy needs ( $Q'_{H,nd,cal}$ ) for space heating and energy class of school buildings from the sample in relation to construction periods.

Energy for Space Heating/Construction Periods	Average Actual Delivered Energy $Q'_{H,del}$ (kWh/m <sup>2</sup> year)	Average Calculated Delivered Energy $Q'_{H,del,cal}$ (kWh/m <sup>2</sup> year)	Average Ratio [%] of Actual to Calculated $Q'_{H,del}$	Average Calculated Energy Needs $Q'_{H,nd,cal}$ (kWh/m <sup>2</sup> year)	Energy Class (Rating)
to 1945	148.8	294.4	0.53	233.5	F
1946–1965	142.2	296.3	0.52	207.9	E
1966–1973	158.7	223.8	0.75	156.1	D
1974–1987	150.8	220.4	0.72	152.3	D
1988–2009	66.4	116.7	0.69	93.0	B
after 2010	16.1	32.1	0.50	27.6	A
TOTAL	145.6	242.9	0.65	171.9	D

The calculated specific energy needs for heating ( $Q'_{H,nd,cal}$ ) school buildings in FBiH from the sample have an average value of 171.90 kWh/m<sup>2</sup> year (energy class D). The calculated specific energy needs for heating ( $Q'_{H,nd,cal}$ ) school buildings in north region (RN) FBiH have an average value of 197.05 kWh/m<sup>2</sup> year (energy class E) and the calculated specific energy needs for heating ( $Q'_{H,nd,cal}$ ) school buildings in the south region (RS) FBiH have an average value of 98.04 kWh/m<sup>2</sup> year (energy class C). It can be concluded that climatic conditions and the duration of the heating season have a significant impact on the energy for space heating, which in turn affects the total heating costs.

The actual specific delivered energy ( $Q'_{H,del}$ ) of school buildings in FBiH from the sample have an average value of 145.60 kWh/m<sup>2</sup> year, in the range of approximately 82.00 to 193.00 kWh/m<sup>2</sup> year there are 50% of schools in the sample. The average value of the calculated specific delivered energy for heating ( $Q'_{H,del,cal}$ ) school buildings in FBiH from the sample is 242.90 kWh/m<sup>2</sup> year, in the range from approximately 155.00 to 304.00 kWh/m<sup>2</sup> year there are 50% of schools in the sample. By comparing the actual and calculated values of the delivered energy for space heating ( $Q'_{H,del}$ ) of school buildings in FBiH, it can be concluded that the actual consumption is less than calculated and amounts to approximately 65%. There is a performance gap between predicted (calculated) and measured (actual) performance.

The authors of the detailed energy audit documents state that the poor thermal characteristics of the envelope and the high infiltration of outside air through the existing openings cause large heat losses. Moreover, the lack of funds that the analyzed schools receive from the founders (usually local government units) for the purchase of the necessary energy sources for heating is one of the main reasons for lower heat consumption. The consequences are reflected in lower room temperatures and non-heating of all parts of the building (especially hallways, school halls, and toilets) or some classrooms due to the smaller number of students, which is why the buildings do not provide a satisfactory level of thermal comfort, i.e., a pleasant and quality stay [48–54].

A review of the literature also indicates the existence of the performance gap between the predicted and observed (measured) performance. The review by van Dronkelaar et al. finds the magnitude of the performance gap to be +34% based on 62 buildings. This paper finds the dominant causes of deviation are specific uncertainty in modeling, occupant behavior, and poor operational practice [11].

A survey conducted in Slovenia on 24 school buildings in the period 1997 to 1999, based on energy audits, showed that these buildings are high energy consumers and have poor air quality, which was expressed by 60% of surveyed students. Heat losses have been shown to be 89% higher than the allowable values. The total annual energy consumption for space heating of the analyzed school buildings varied from less than 112 kWh/m<sup>2</sup> to 196 kWh/m<sup>2</sup>. It has also been found that actual energy needs or energy consumption are less than calculated energy needs [13].

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

### 3.5. Correlation Analysis

A correlation analysis was performed to determine which variables (building characteristics) were associated with actual energy consumption for heating and with what degree of correlation. First, the factors of simple correlation of all variables were calculated based on data from the entire sample. For further analysis, the values of the factors of simple correlation of individual independent variables ( $X_i$ ) in relation to the dependent variable ( $Y$ ) for which the actual delivered energy ( $Q_{H,del}$ ) for space heating were selected are particularly important.

Correlation coefficient values from 0 to 0.25 or from 0 to  $-0.25$  indicate the absence of correlation, while values from 0.25 to 0.50 or from  $-0.25$  to  $-0.50$  indicate poor correlation between variables. Values from 0.50 to 0.75 or from  $-0.50$  to  $-0.75$  indicate a moderate to good correlation, and values from 0.75 to 1 or from  $-0.75$  to  $-1$  indicate a very good to excellent correlation between variables [55].

The elimination of certain independent variables was performed in such a way that in the case of pairs of independent variables whose correlation coefficient exceeds the value of 0.50, the variable that has a lower correlation with the dependent variable is removed. By eliminating multicollinear independent variables, the following were ultimately adopted:

- The number of heating degree days (HDD) that characterizes climatic conditions and whose correlation coefficient with the dependent variable ( $Y$ ) is 0.5198, which represents a moderate to good correlation.
- The variable that best defines the geometric characteristics of a building is the usable area ( $A_k$ ). The correlation coefficient with the dependent variable ( $Y$ ) is 0.5576, which represents a moderate to good correlation.
- The correlation coefficient of the number of hours of work per day with the dependent variable ( $Y$ ) is 0.5167, which represents a moderate to good correlation.

The results for the selected variables are presented through the final correlation matrix in Table 10. Presented correlations are only those that are significant at  $p < 0.05$ . If the coefficient of correlation is statistically significant in regard to the set limit ( $p < 0.05$ ), we conclude that the coefficient of correlation is significant.

**Table 10.** The final correlation matrix.

Variables	1	2	3	4
1—The number of heating degrees days (HDD)	1.0000	0.2188	0.4104	0.5198
2—The usable area ( $A_k$ )	0.2188	1.0000	0.2488	0.5576
3—The number of hours of work per day	0.4104	0.2488	1.0000	0.5167
4—The actual delivered energy ( $Q_{H,del}$ ) for heating	0.5198	0.5576	0.5167	1.0000

Finally, multiple regression was performed for the selected variables to determine the strength of the interdependence of the dependent variable with all selected independent variables through the correlation index  $R$  of 0.7365, which represents a moderate to good correlation (values from 0.50 to 0.75 or from  $-0.50$  to  $-0.75$  indicate a moderate to good correlation between variables).

The determination index  $R^2$  was also determined and it shows what percentage of the variability of the dependent variable is explained through the variability of the independent variables. The value of the adjusted determination index  $R^2$  is 0.5348 and according to the Chaddock scale, the relationship between the dependent variable and the independent variables can be characterized as salient (values from 0.50 to 0.70). This can be interpreted as 53% of the variability of the dependent variable (the actual delivered energy ( $Q_{H,del}$ ) for space heating) explained through the commonly combined 3 independent variables (the number of heating degree days (HDD), the usable area ( $A_k$ ) and the number of hours of work per day).

The results of statistical tests show that the regression coefficients are statistically significant and so is the correlation index  $R$  ( $p < 0.0000$ ). This indicates that the independent variables have a real relationship with the dependent variable.

#### 4. Conclusions

This is the first such study conducted in the FBiH. The paper presents an analysis of the energy performance of schools buildings in the FBiH according to construction periods based on data collected from detailed energy audit documents. Evaluation of the energy performance was performed by comparing the calculated results and measured results with the allowable values according to the regulations.

The study shows that the analyzed schools built in periods when thermal insulation was not applied have very poor energy performance. The results indicate that there is a very high potential in reducing energy consumption (and thus reducing environmental impact) by applying energy efficient measures when renovating buildings.

In order to implement the planned strategic measures and carry out the renovation of existing public buildings, it is necessary to determine energy performance and energy consumption. The results of energy performance of school buildings in FBiH can be the basis for defining energy measures for renovation. The analyzed data on the characteristics of school buildings in FBiH according to the periods of construction from this research can be used in all surrounding countries that have a similar architectural heritage.

Statistical analysis and multiple correlation identified independent variables the number of heating degree days (HDD), the usable area ( $A_k$ ) and the number of hours of work per day that, in combination, best show variation of the dependent variable (the actual delivered energy ( $Q_{H,del}$ ) for space heating). Correlation analysis showed that the Pearson correlation coefficient between the variables,  $U$  value of the envelope, and the actual specific delivered energy ( $Q'_{H,del}$ ) is only 0.16, which indicates a slight correlation. This confirms the performance gap between calculated and actual delivered energy ( $Q_{H,del}$ ) for space heating.

In future research, an analysis of the energy costs (a part of the operation and maintenance cost of using) of school buildings in the FBiH will be performed. The aim is to

determine the relationship between energy performance (characteristics or variables of buildings) with energy costs and to develop a mathematical model for estimating energy costs.

The energy cost prediction model can be used for several purposes:

- forming a ranking list of school rehabilitation priorities based on energy costs;
- in engineering practice to estimate and calculate operating and maintenance costs;
- and to investigate and verify prediction models on similar buildings in surrounding countries.

**Author Contributions:** Conceptualization, D.K. and H.K.; Formal analysis, D.K.; Investigation, D.K.; Methodology, D.K.; Project administration, D.K.; Resources, D.K.; Software, D.K.; Supervision, H.K.; Validation, D.K., H.K. and S.M.; Visualization, D.K.; Writing—original draft, D.K.; Writing—review and editing, H.K. and S.M. All authors have read and agreed to the published version of the manuscript.

**Funding:** This research received no external funding.

**Informed Consent Statement:** Not applicable.

**Data Availability Statement:** The data presented in this study are available on request from the Environmental Fund of Federation of Bosnia and Herzegovina. The data are not publicly available due to ethical restrictions.

**Acknowledgments:** We would like to thank the Environmental Fund of Federation of Bosnia and Herzegovina for providing documents of detailed energy audits for school buildings in FBiH for this research.

**Conflicts of Interest:** The authors declare no conflict of interest.

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