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Energy Benchmarking in Educational Buildings in the City of Kragujevac – Possibilities for Energy Efficiency Improvement

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Abstract: The implementation of energy efficiency measures and use of renewable energy sources in educational buildings can significantly contribute to reducing energy consumption, but also to CO_2 emissions in the entire public sector. The paper shows the comparison of energy consumption indicators for 61 elementary school buildings which have previously been divided in 12 groups, according to the period of construction and size, based on the national typology called TABULA, as the first step of further study on how to use the renewable energy sources.

The aim of this paper is to use the energy benchmarking process to select representative facilities which are suitable for applying renewable energy sources, for their further energy efficiency improvement.

Indicators of annual specific electricity consumption and CO_2 emissions per unit area [kWh/m^2] and per user [kWh/user] were calculated. After that, from two groups (in which the highest electricity consumption and CO_2 emissions are 68.37% and 74.53% of the total consumption/ emissions), one representative facility was selected.

Keywords: Energy benchmarking, Educational buildings, Electrical energy consumption, CO_2 emission.

1 Introduction

The role of local governments is not only to manage energy consumption in public buildings, but also to promote energy efficiency and renewable energy sources. That is why it is important to encourage the use of renewable energy sources in public buildings, as a good example for all citizens. Using solar energy by installing photovoltaic panels on school buildings, for example, can be a good way to raise citizens' awareness of the importance of using renewable energy sources.

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On the other hand, school buildings are not only significant consumers of energy for the public sector, but also for all buildings. When examining electricity consumption in the United States, school buildings were ranked third and accounted for 10.8% of the total building electricity consumption, behind office buildings (20.4%) and retail and department stores (20.4%) [1].

In China, school buildings rank fourth in the total area of all buildings, after office facilities, retail business space and hospitals. That is why, a series of construction standards for public and residential buildings in various climate zones have been adopted, in which the thermal features of envelopes and the design of HVAC are mandatory for energy efficiency. Here are some of the examples of these Chinese standards and regulations, among others GB 50189-2005: Design Standard for Energy Efficiency of Public Buildings [2]. Since 1989, China has designed and applied over 40 energy efficiency (EE) standards and over 20 mandatory energy labels for a number of domestic, commercial and selected industrial equipment [3]. Similar to other countries, energy efficiency standards have key role in reducing the energy consumption of room air conditioners (RACs). Chinese RACs standards have been redefined according to the American and Japanese standards [4]. It is believed that building energy efficiency standards (BEES) are one of the most effective policies to reduce energy consumption, especially when the rapid urbanization is taking place, as in China [5].

The electric power consumption of Finland schools has increased by 49% in the last 40 years. The electric power consumption was higher in newer school facilities than in older ones, but this was not the case with the daycare centers. This is because newer schools are equipped with more of electrical equipment compared to older schools, whereas the amount of electrical equipment has relatively stayed the same in the daycare centers regardless of the construction year. This issue would require more detailed research, but if it would prove to be the case, then it would be more beneficial to install PV panels to newer schools than in older ones [6].

The aim of this paper is to select representative school facilities on which to further analyze the possibility of using the renewable energy sources.

Indicators of annual specific electricity consumption and CO_2 emissions per unit area [kWh/m^2] and per user [kWh/user] were calculated. After that, from two groups (in which the highest electricity consumption and CO_2 emissions are 68.37% and 74.53% of the total consumption/ emissions), one representative facility was selected.

Only electric energy consumption was analyzed, because the goal of the study was to select facilities which would be the best for using renewable energy sources. CO_2 emissions are also included in the study, because in the public sector of the city of Kragujevac, one half of the total CO_2 emissions from all public buildings come from educational institutions and out of all emissions from educational institutions, 73% come from elementary schools. Thus, energy rehabilitation of these facilities and the use of renewable energy sources on them become one of the tools in the fight against climate change.

Comparing buildings by consumption can be a criterion for determining on which building we should first implement energy efficiency measures. After that decision, we can prioritize energy efficiency measures using the criteria of primary energy consumption and initial investment cost [7].

Data on energy consumption and school buildings have been analyzed for years and there are numerous data available in the literature.

Data on global energy consumption in schools can be easily found in the literature. These are uncategorized data, e.g. energy type is not specified (primary or final energy), or data that does not specify the building type (primary school, secondary school, schools with/without pool or canteen, etc.). Although some authors have been showing that Display Energy Certificates (DEC) can be used to quantify school′s energy consumption, and therefore allow a fair benchmark, only a minority of the EU countries have this category of buildings fully addressed on their national Energy Performance Certification legislation [8].

Furthermore, as can be concluded from the survey, there exists great difference in per unit energy consumption between different types of universities classified by schools' discipline, nature and level, which would be taken into account when the energy consumption evaluation indexes system is established [9].

Research conducted in Italy has shown that it is possible to analyze representatives of individual groups of schools and do extrapolation that will help decision makers. The results could be extrapolated to each corresponding cluster and this could help the Public Administration in decision-making and prioritizing the energy retrofit of the buildings' stock with the lowest cost-efficiency ratio. Future developments will therefore analyze more in detail the two reference buildings in order to evaluate the persistence over time of the energy savings, the cost-effectiveness of further retrofit interventions, and the effect of management measures [10].

Research of the indicators in elementary and high schools in Taiwan has shown that, in 67 senior high schools, 62 junior high schools and 102 elementary schools, the values of their energy usage per person (kWh/person/year) were 1163, 469, and 465, respectively [11].

In order to investigate the characteristics of school building energy consumption, energy consumption of 17 schools in Tianjin have been counted and discussed. Based on the statistics, the results indicate that the average comprehensive energy consumption of school per unit area is 121.81 kWh/(m^2a), the average energy consumption per person is 36 kWh/(pa) and the average electricity consumption is 36.07 kWh/(m^2a) in 2007. It is found that the energy consumption per unit construction area is lower than the average energy consumption of public buildings, which is 257.61 kWh/(m^2a) in 2015.The main reason is that the quality of the thermal environment is poor and the running time of school is short. However, the school's total energy consumption is large and we should pay more attention to it. At the same time, we point out the problems of the school energy consumption in Tianjin based on the statistics and proposed energy-saving reforms [12].

The annual primary energy use in Cyprus schools is 116.22 kWh/m^2 year [13].

In the Brussels Capital Region the certificate "is based on consumption data for electricity and fossil fuels used for all purposes, based on meters or invoices", and "the EP indicator is calculated on the basis of the occupied floor area." An index of CO_2 emission is also foreseen. The mean value emissions and energy consumption anticipated for school and college buildings category is 40 kgCO_2/m^2yr and 230 kWh/m^2yr, respectively [14].

The average power consumption per unit area of the surveyed public buildings is 47.96 kWh/(m^2a). The average values of office, hospital and school building are 65.74 kWh/(m^2a), 86.00 kWh/(m^2a) and 24.31 kWh/(m^2a), respectively [15].

Similar to Korea, there are two problems in Serbia as well – schools in rural areas, small in size, attended by a few students, which are not worth investing in. The second problem is that there is no precise national statistics which would enable comparison of school facilities in Kragujevac and other cities in the same climate zone. There are only general data [16]. The other problem is that, for most small and medium-sized buildings, there is usually no room for sub-metering by end-uses owing to expensive installation and management costs. The end-use data for small and medium-sized buildings are actually a national blind spot. The third problem is that even if each end-use was sub-metered, there is no national benchmark (e.g. statistical distribution) of similar buildings, so it is difficult to determine whether the amount of energy used is appropriate [17].

2 Typology of Elementary School Buildings in Kragujevac

The typology of elementary school buildings includes the classification of school buildings by size and construction periods, with the aim of defining possible levels of energy renewal, whose ultimate goal is reducing energy consumption in the public sector of the City of Kragujevac, but also contributing to energy savings and combating climate change throughout Republic of Serbia. Improving energy efficiency and reducing CO_2 emissions would be achieved by implementing measures on the building envelope, on mechanical and electric power systems and by using renewable energy sources.

The importance of typological classification of school buildings is reflected in wide applicability in making strategic decisions for the renovation of all school buildings in the city of Kragujevac.

For defining the physical characteristics of the sample buildings, a research conducted in Serbia was used as part of the European project of creating typologies of buildings called TABULA. The national typology of school buildings [18] is a continuation of this research, within which 1,857 school buildings were processed. The national typology of school buildings implies their classification by size and periods of construction.

The basic matrix of of school buildings typology is defined through four time periods: till 1945, 1946 – 1970, 1971 – 1990 and 1991, and three types by size (gross floor area): smaller than 500 m^2, from 500 to 2000 m^2, and larger than 2000m^2.

Therefore, all schools in Kragujevac are divided into 12 groups, as shown in **Table 1**.

Table 1

Matrix of the typology of elementary school buildings in Kragujevac (based on the national typology of school buildings in Serbia).

Year	GROSS FLOOR AREA [m^2]		
	Smaller than 500	From 500 to 2000	Larger than 2000
Before 1945	Number of such schools 14 Share in total area 3.79%	Number of such schools 3 Share in total area 4.34%	Number of such schools 2 Share in total area 7.27%
1946–1970	Number of such schools 9 Share in total area 2.28%	Number of such schools 7 Share in total area 3.9%	Number of such schools 6 Share in total area 22.05%
1971–1990	Number of such schools 2 Share in total area 5.56%	Number of such schools 4 Share in total area 5.22%	Number of such schools 7 Share in total area 42.23%
After 1991	Number of such schools 3 Share in total area 0.72%	Number of such schools 4 Share in total area 5.22%	
NA	Number of such schools 2 Share in total area 0.37%		

The largest number of users have large schools, over 2.000 m^2, built in the periods 1971 – 1990 and 1946 – 1970: 44.2% and 29.39%, respectively (Fig. 1). In some school buildings in rural areas, in addition to the fact that all school buildings are smaller than 500 m^2, the number of users is often less than 10 (Fig. 2).

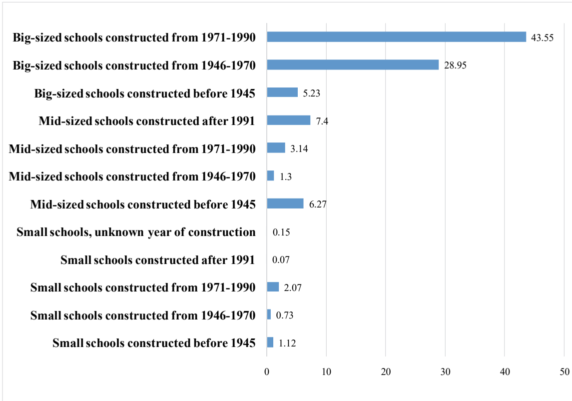

Fig. 1 – *Distribution of no. of users* [%].

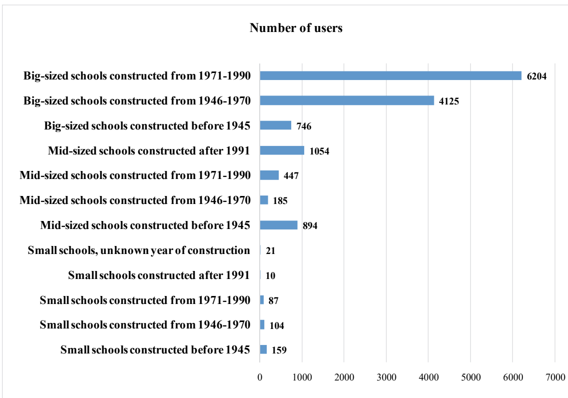

Fig. 2 – *Distribution of number of users.*

3 Overview of the Annual Specific Energy Consumption and CO_2 Emission per Unit Area [kWh/m^2] and Per User [kWh/user] Depending on the Period of Construction and Size of School Facilities

3.1 Annual specific electricity consumption per unit area [kWh/m^2] and per user [kWh/user]

In this paper, we used the data from the Energy Efficiency Program [19].

Average annual specific electricity consumption per unit area [kWh/m^2] for small schools, up to 500 m^2, amounts to 68.03 kWh/m^2.

Maximum and minimum annual specific electricity consumptions per unit area [kWh/m^2] for small schools, up to 500 m^2, amount to 356.65 kWh/m^2 and 0.42 kWh/m^2 respectively, as shown in Fig. 3.

Average annual specific electricity consumption per user [kWh/user] for small schools, up to 500 m2, amounts to 726.3 kWh/user.

Maximum and minimum annual specific electricity consumptions per user [kWh/user] for small schools, up to 500 m^2, amount to 9249.33 kWh/user and 13.87 kWh/user respectively, as shown in Fig. 4.

Average annual specific electricity consumption per unit area [kWh/m^2] for mid-sized schools, from 500 to 2000 m^2, amounts to 25.8 kWh/m^2.

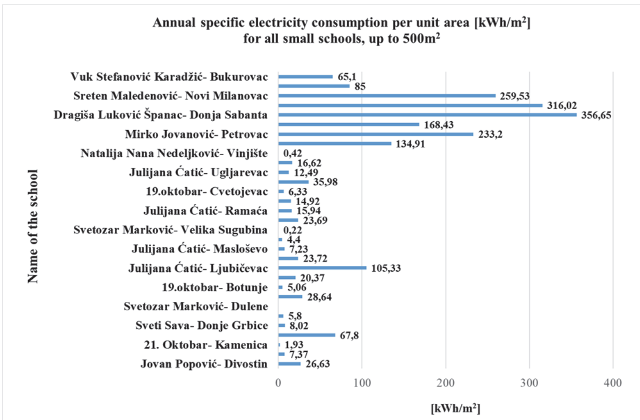

Fig. 3 - *Annual specific electricity consumption per unit area* [kWh/m^2] *for all small schools, up to* 500m^2.

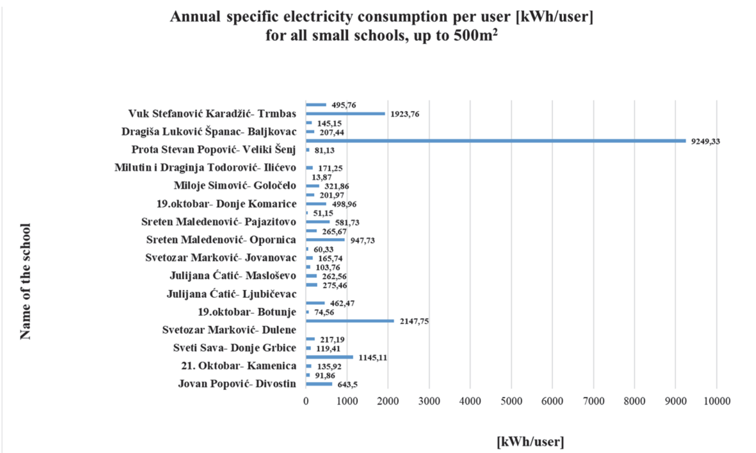

Fig. 4 – *Annual specific electricity consumption per user* [kWh/user] *for all small schools, up to* 500m^2.

Maximum and minimum annual specific electricity consumptions per unit area [kWh/m^2] for mid-sized schools, from 500 to 2000 m^2, amount to 39.41 and 10.19 kWh/m^2 respectively, as shown in Fig. 5.

Average annual specific electricity consumption per user [kWh/user] for mid-sized schools, from 500 to 2000 m^2, amounts to 289.9 kWh/user.

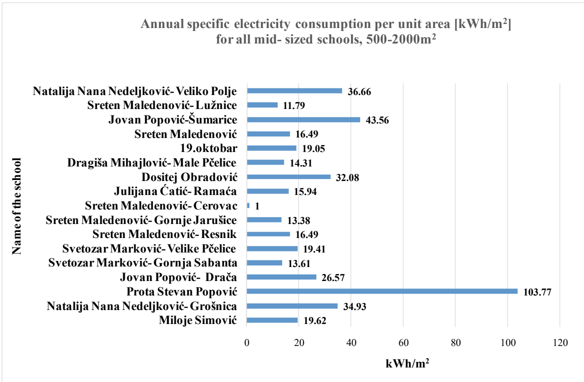

Fig. 5 – *Annual specific electricity consumption per unit area* [kWh/m2] *for all mid- sized schools,* 500–2000m^2.

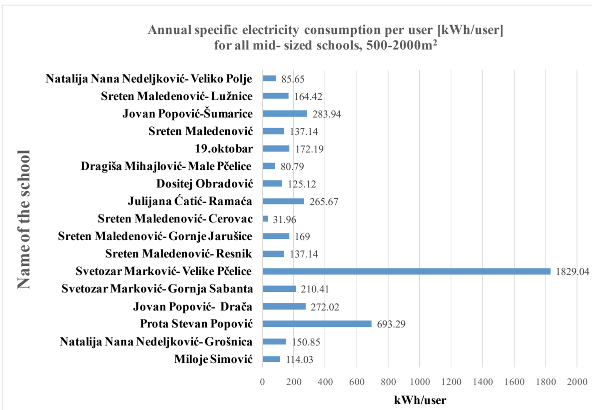

Fig. 6 – *Annual specific electricity consumption per user* [kWh/user] *for all mid- sized schools,* 500–2000m^2.

Maximum and minimum annual specific electricity consumptions per user [kWh/user] for mid-sized schools, from 500 to 2000 m^2, amount to 1829.04 and 31.96 kWh/user respectively, as shown in Fig. 6.

Average annual specific electricity consumption per unit area [kWh/m^2] for big-sized schools, over 2000 m^2, amounts to 21.78 kWh/m^2.

Maximum and minimum annual specific electricity consumptions per unit area [kWh/m^2] for big-sized schools, over 2000 m^2, amount to 39.41 and 10.19 kWh/m^2 respectively, as shown in Fig. 7.

Average annual specific electricity consumption per user [kWh/user] for big-sized schools, over 2000 m^2, amounts to 143.6 kWh/user maximum and minimum annual specific electricity consumptions per user [kWh/user] for big-sized schools, over 2000 m^2, amount to 300.07 and 57.82 kWh/user respectively, as shown in Fig. 8.

Indicators per user are extremely high for small area schools, less than 500m^2, for all periods of construction. These schools are located mainly in rural areas and the number of students is often ranging from one to several, usually with one teacher. So the total consumption of electricity and primary energy is divided by a small number. That is why it is impossible to compare the indicators in these schools with the indicators in the urban area schools that are attended by several hundred students.

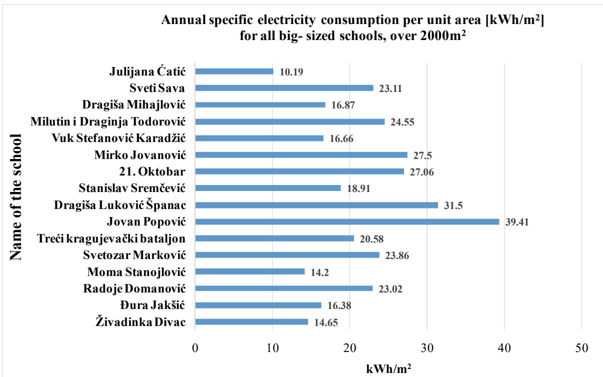

Fig. 7 – *Annual specific electricity consumption per unit area* [kWh/m2] *for all big-sized schools, over* 2000 m^2.

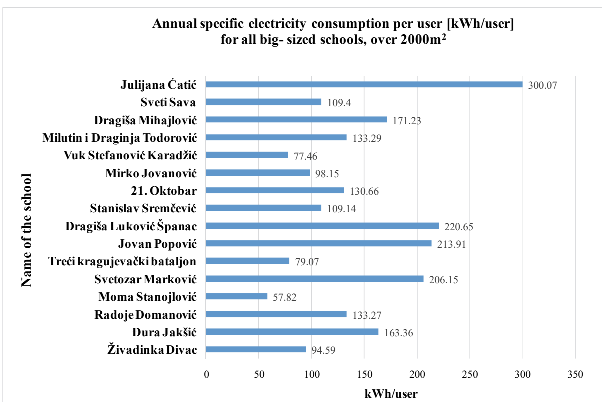

Fig. 8 – *Annual specific electricity consumption per user* [kWh/user] *for all big-sized schools, over* 2000 m^2.

3.2 Annual specific CO_2 emission per unit area [kWh/m^2] and per user [kWh/user]

Average annual specific CO_2 emission per unit area [kWh/m^2] for small schools, up to 500 m^2, amounts to 61.78 kWh/m^2.

Maximum and minimum annual specific CO_2 emissions per unit area [kWh/m^2] for small schools, up to 500 m^2, amount to 143.64 and 0.17 kWh/m^2 respectively, as shown in Fig. 9.

Average annual specific CO_2 emission per user [kWh/user] for small schools, up to 500 m^2, amounts to 2327.028 kWh/user.

Maximum and minimum annual specific CO_2 emissions per user [kWh/user] for small schools, up to 500 m^2, amount to 25315.45 and 48.27 kWh/user respectively, as shown in Fig. 10.

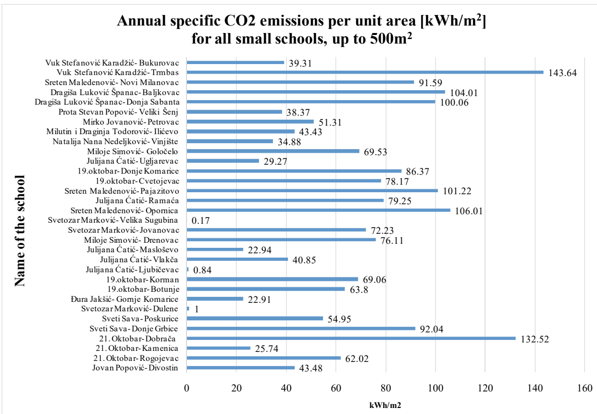

Fig. 9 – *Annual specific* CO_2 *emissions per unit area* [kWh/m2] *for all small schools, up to* 500 m^2.

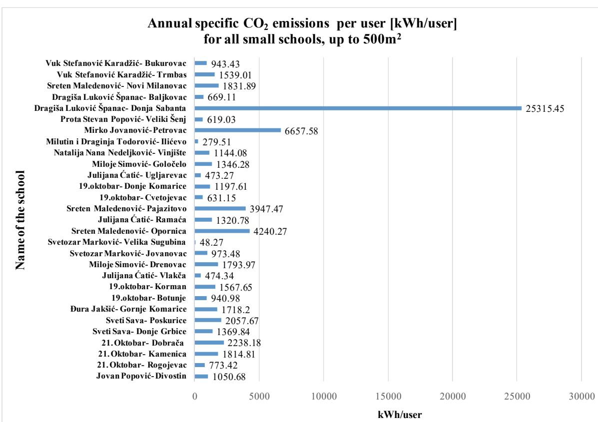

Fig. 10 – *Annual specific* CO_2 *emissions per user* [kWh/user] *for all small schools, up to* 500 m^2.

Average annual specific CO_2 emission per unit area [kWh/m^2] for mid-sized schools, from 500 to 2000 m^2, amounts to 58.9 kWh/m^2.

Maximum and minimum annual specific CO_2 emissions per unit area [kWh/m^2] for mid-sized schools, from 500 to 2000 m^2, amounts to 103.67 and 29.6 kWh/m^2 respectively, as shown in Fig. 11.

Average annual specific CO_2 emission per user [kWh/user] for mid-sized schools, from 500 to 2000 m^2, amounts to 665.1638 kWh/user.

Maximum and minimum annual specific CO_2 emissions per user [kWh/user] for mid-sized schools, from 500 to 2000 m^2, amount to 1463.23 and 139.9 kWh/user respectively, as shown in Fig. 12.

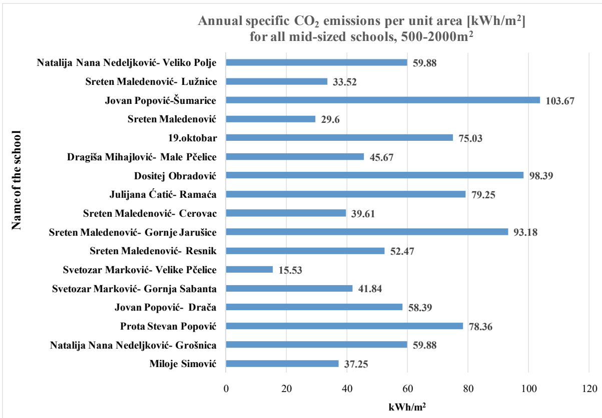

Fig. 11 – *Annual specific* CO_2 *emissions per unit area* [kWh/m^2] *for all mid-sized schools* 500–2000m^2.

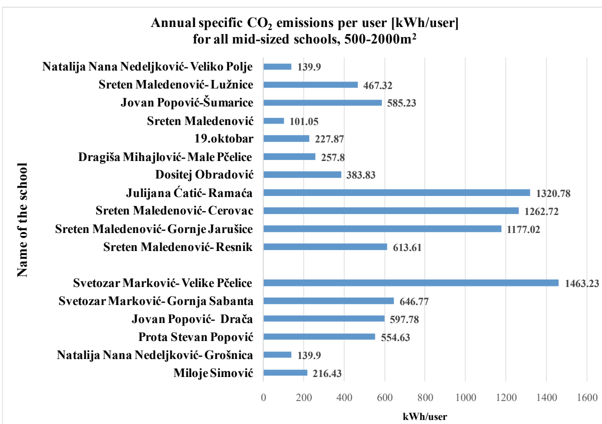

Fig. 12 – *Annual specific* CO_2 *emissions per user* [kWh/user] *for all mid- sized schools,* 500–2000m^2.

Average annual specific CO_2 emission per unit area [kWh/m^2] for big-sized schools, over 2000 m^2, amounts to 81.23 kWh/m^2.

Maximum and minimum annual specific CO_2 emissions per unit area [kWh/m^2] for big-sized schools, over 2000 m^2, amount to 187.57 and 38.3 kWh/m^2 respectively, as shown in Fig. 13.

Average annual specific CO_2 emission per user [kWh/user] for big-sized schools, over 2000 m^2, amounts to 692.82 kWh/user.

Maximum and minimum annual specific CO_2 emissions per user [kWh/user] for big-sized schools, over 2000 m^2, amount to 1018.15 and 197.8 kWh/user respectively, as shown in Fig. 14.

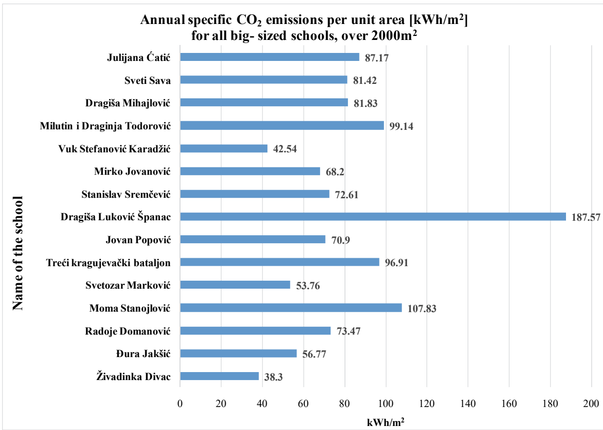

Fig. 13 – *Annual specific* CO_2 *emissions per unit area* [kWh/m^2] *for all big-sized schools sized, over* 2000 m^2.

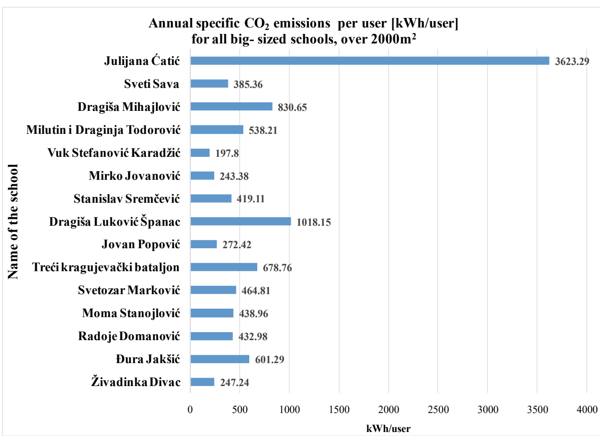

Fig. 14 – *Annual specific* CO_2 *emissions, per user* [kWh/user] *for all big-schools sized, over* 2000 m^2.

The highest CO2 emissions per user and per unit area in each school group are for coal-heated schools. Indicators for rural schools, less than 500 m^2 in area, are the largest because they have the fewest students - users and cannot be compared with other indicators.

Therefore, in the rest of the paper, only buildings with more than 500 m^2 and a larger number of users were observed. For school facilities that are in these groups, the indicators can be compared.

4 Selection of Representative Facilities

4.1 Selection of groups based on the highest energy consumption

Analysis of the indicators of the annual specific electricity consumption per unit area [kWh/m^2] and per user [kWh/user] was done with the aim of selecting the facility on which the simulation of energy efficiency measures and installation of photovoltaic panels will be carried out.

The energy consumption and CO_2 emission, depending on the period of construction and size of school facilities, was analyzed in order to select facilities on which energy efficiency measures would be implemented first. Analysis of the energy behavior of buildings under the city administration authority is necessary in order to form a city energy planning policy and make strategic decisions about which buildings need to be thermally improved and where there is a possibility of using renewable energy sources. After the initial analysis of the school buildings' stock, energy modeling of representative buildings would be initiated. The modeling would estimate the current energy consumption, compare the calculated and actual values and then simulate the effects of improving energy efficiency - by measures on the building envelope, on mechanical and electrical systems and the use of renewable energy sources (photovoltaic panels).

More than 60% of electric energy that is consumed in all schools with more than 500 m^2 area, is consumed in two groups of facilities. Over 70% of CO_2 emission derives from electricity that is consumed in these same two groups of facilities:

– big-sized schools, with over 2000 m^2, constructed between 1971 and 1990;

– big-sized schools, with over 2000 m^2, constructed between 1946 and 1970.

Most electricity (36.33%) is consumed in school buildings built in the period 1971-1990 and in the period 1946-1970: 32.04%, as shown in Fig. 15.

The highest CO_2 emissions (40.39%) come from energy consumed in school buildings built in the period 1971-1990, and in the period 1946-1970: 34.14%, as shown in Fig. 16.

Table 2
Matrix of typology of school buildings in Kragujevac
(based on the National typology of school buildings in Serbia).

Year	Gross floor area		
	Smaller than $500m^2$	from 500 to $2000m^2$	larger than 2000 m^2
Before 1945	Electricity consumption share – 2.42% Heat consumption share 3.45% CO_2 emission share 3.08%	Electricity consumption share – 8.45% Heat consumption share 2.32% CO_2 emission share 3.26%	Electricity consumption share – 3.3% Heat consumption share 9.03% CO_2 emission share 5.1%
1946–1970	Electricity consumption share – 1.44% Heat consumption share 2.43% CO_2 emission share 2.06%	Electricity consumption share – 2.32% Heat consumption share 2.63% CO2 emission share 2.3%	Electricity consumption share – 32.04% Heat consumption share 28.89% CO_2 emission share 34.14%
1971-1990	Electricity consumption share – 0.72% Heat consumption share 0.77% CO_2 emission share 0.59%	Electricity consumption share – 7.83% Heat consumption share 4.92% CO_2 emission share 2.6%	Electricity consumption share – 36.33% Heat consumption share 41.42% CO_2 emission share 40.39%
After 1991	Electricity consumption share – 0.72% Heat consumption share 1.2% CO_2 emission share 1.02%	Electricity consumption share – 7.83% Heat consumption share 4.92% CO_2 emission share 4.99%	
NA	Electricity consumption share – 1.65% Heat consumption share 0.09% CO_2 emission share - 0.47%		

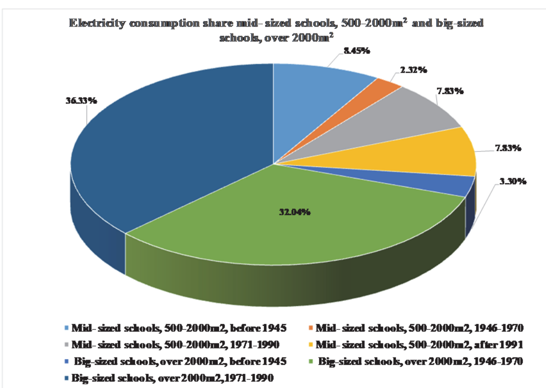

Fig. 15 – *Distribution of electricity consumption* [%].

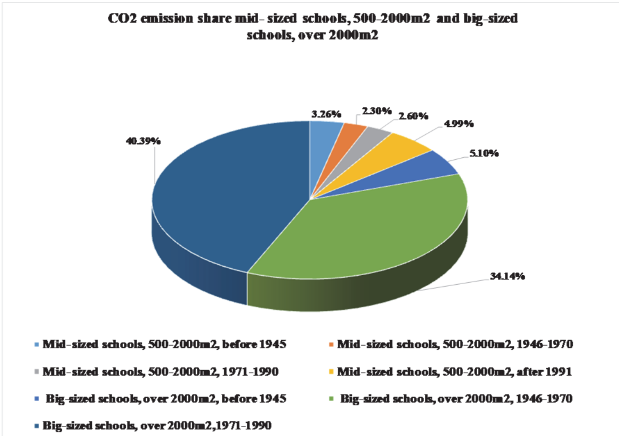

Fig. 16 – *Distribution of* CO_2 *emissions* [%].

Based on all the above, representative facilities from these two groups, that have the largest share in electricity consumption and CO_2 emissions, will be selected for the facilities on which the simulation of energy efficiency measures and installation of photovoltaic panels will be done.

4.2 Selection of representative facilities from selected groups

After this, representative facilities were selected from these groups using two criteria: indicators of annual specific electricity consumption per unit area [kWh/m^2] and per user [kWh/user] that are closest to average annual specific electricity consumption per unit area [kWh/m^2] and per user [kWh/user] for the analyzed group, and the buildings that have the largest area of flat roofs or roofs with the smallest slope, most favorable for the installation of photovoltaic panels. Mean electricity consumption indicators for each of the two groups are as shown in the Figs. 17 – 20.

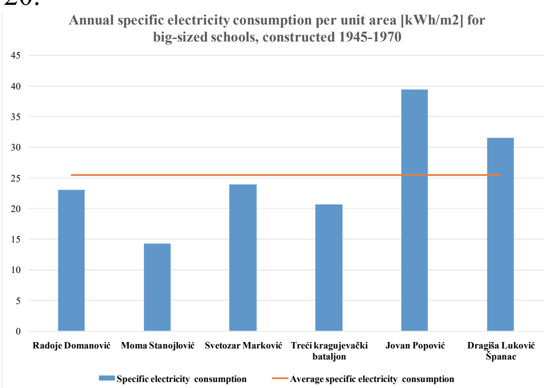

Fig. 17 – *Annual specific electricity consumption per unit area* [kWh/m^2] *for big-sized schools, constructed* 1945–1970.

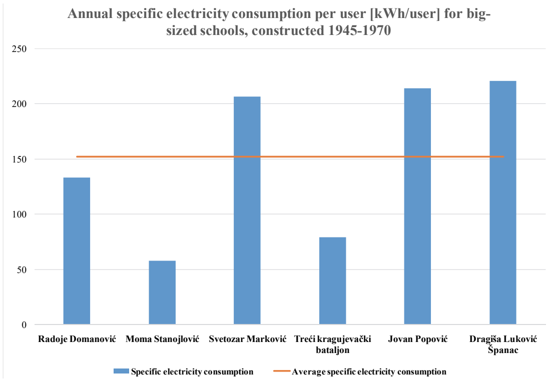

Fig. 18 – *Annual specific electricity consumption per user* [kWh/user] *for big-sized schools, constructed* 1945 – 1970.

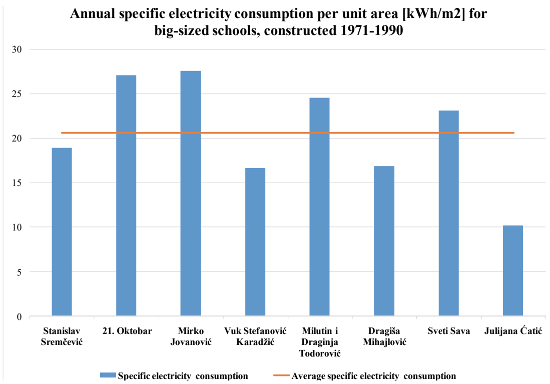

Fig. 19 – *Annual specific electricity consumption per unit area* [kWh/m^2] *for big-sized schools, constructed* 1971 – 1990.

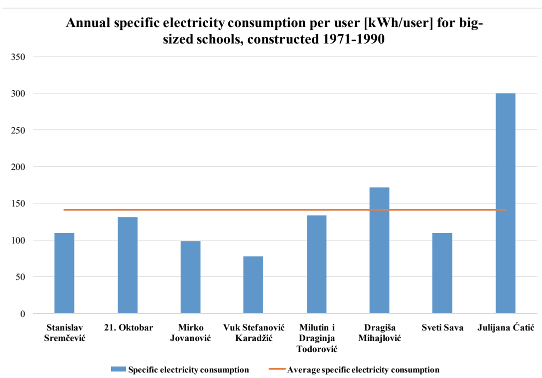

Fig. 20 – *Annual specific electricity consumption per user* [kWh/user] *for big-sized schools, constructed* 1971 – 1990.

Mean CO2 emission indicators for each of the two groups are as shown in the Figs. 21 – 24.

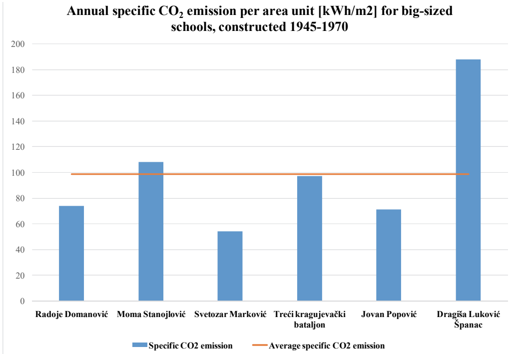

Fig. 21 – *Annual specific* CO_2 *emission per unit area* [kWh/m²] *for big-sized schools, constructed* 1945 – 1970.

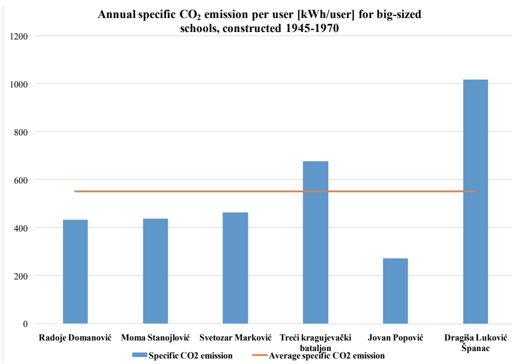

Fig. 22 – Annual specific CO_2 emission per user [kWh/user] for big-sized schools constructed 1945–1970.

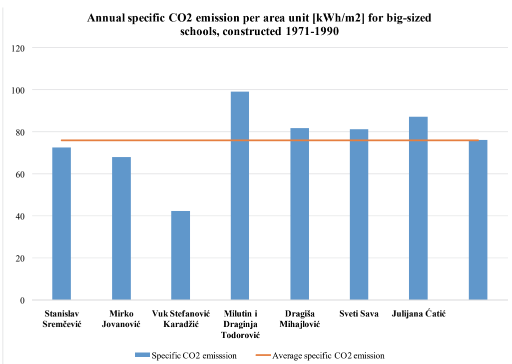

Fig. 23 – *Annual specific* CO_2 *emission per unit area* [kWh/m²] *for big-sized schools, constructed* 1971 – 1990.

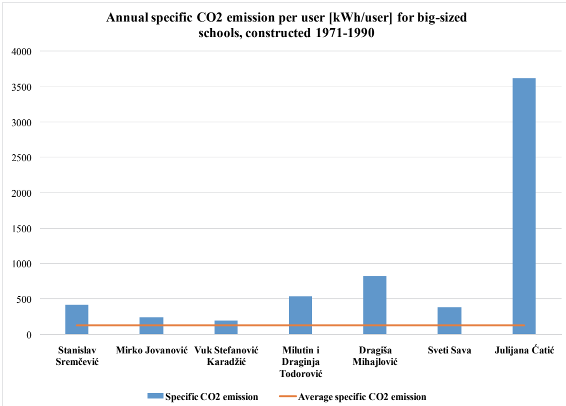

Fig. 24 – *Annual specific* CO_2 *emission per user* [kWh/user] *for big-sized schools, constructed* 1971–1990.

Thus, based on previously presented data, the following facilities were selected:

– From the group big-sized schools, over 2000 m^2, constructed between 1971 and 1990 – "Milutin i Draginja Todorović" Elementary School;

– From the group big-sized schools, over 2000 m^2, constructed between 1946 and 1970 – "Treći kragujevački bataljon" Elementary School.

5 Conclusion

The paper presents the process of benchmarking of energy consumption indicators for 61 Kragujevac elementary school buildings. These school buildings have previously been divided in 12 groups, according to the period of construction and size. This benchmarking process will produce data to be implemented in a subsequent study on how and where to use the energy efficiency measures and, especially, renewable energy sources. The implementation of energy efficiency measures and renewable energy sources in educational buildings, such as schools, can significantly contribute to reducing energy consumption, but also to reducing CO_2 emissions in the entire public sector of the city.

Indicators of annual specific electricity consumption and CO_2 emission per unit area [kWh/m^2] and per user [kWh/user]. After that, from two groups (in which the highest electricity consumption and CO_2 emissions are 68.37% and 74.53% of the total consumption/emissions), one representative facility was selected. Those two groups of facilities are:

– big-sized schools, over 2000 m^2, constructed between 1971 and 1990;

– big-sized schools, over 2000 m^2, constructed between 1946 and 1970.

Schools in these two groups participate with 36.33% and 32.04% in total electricity consumption and with 40.39% and 34.14% in total CO_2 emissions.

Then, the indicators in these two groups of facilities were analyzed and, based on the mean specific annual electricity consumption per user, two representative facilities were selected. In the further work, the possibilities for the installation of photovoltaic panels on these two facilities will be additionally analyzed.

The part of the paper analyzing which school buildings consume the most electricity is significant for other cities located in the same climate zone as well, because it is possible for them to implement the final results of the paper, stating that the most energy consuming school buildings are those larger than 2000 m^2 in area and constructed from 1971-1990 and from 1946-1970.

The paper shows that the comparison of energy indicators can play a significant role in the selection of facilities where energy efficiency measures will be implemented and renewable energy sources will be used.

The results of the paper can also benefit decision-makers when deciding which buildings will be the first to be energetically renovated, as they clearly show which schools consume the most electricity and as a result have the highest CO_2 emissions.

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