eNergetics 2018

Proceedings of the 4th Virtual International Conference on Science, Technology and Management in Energy

Editors: Janjić, A., Stajić, Z.

Publishers: Research and Development Center "ALFATEC", Niš, Serbia
Complex System Research Center, Niš, Serbia

Serbia, Niš, October 25-26, 2018

Proceedings of **4th Virtual International Conference on Science, Technology and Management in Energy**

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Editors: Prof. Dr. Aleksandar Janjić and Prof. Dr. Zoran Stajić

Technical Editor: Dr. Lazar Z. Velimirović

Published by: Research and Development Center "ALFATEC", Niš, Serbia, and Complex System Research Centre, Niš, Serbia

Printed by: Blue Copy, Niš, Serbia

Number of copies printed: 100

The publishing year: 2018

Printing of this edition has been financially supported by Serbian Ministry of Education, Science and Technological Development

ISBN 978-86-80616-03-2

CIP - Каталогизација у публикацији - Народна библиотека Србије, Београд

620.9(082)(0.034.2)

VIRTUAL International Conference on Science Technology and Management in Energy (4 ; 2018 ; Niš)
Energetics 2018 [Elektronski izvor] : proceedings / 4th Virtual International Conference on Science Technology and Management in Energy, Niš, October 25-26, 2018 ; editors Janjić A.[Aleksandar], Stajić Z.[Zoran]. - Niš : Research and Development Centar "Alfatec" : Complex System Research Centre, 2018 (Niš : Blue Copy). - 1 elektronski optički disk (DVD) ; 12 cm

Sistemski zahtevi: Nisu navedeni. - Nasl. sa naslovne strane dokumenta. - Tiraž 100. - Bibliografija uz svaki rad.

ISBN 978-86-80616-03-2 (RDCA)

a) Енергетика - Зборници
COBISS.SR-ID 271975436

4th Virtual International Conference on Science, Technology and Management in Energy

Organizer:

- **Research and Development Center "ALFATEC"**

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Supported by:

- **Serbian Ministry of Education, Science and Technological Development**

Benchmarking of Heat Energy Consumption in Public Buildings in the City of Kragujevac

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Abstract— **Final energy consumption in buildings has the highest share in final energy consumption on a global level. Heat has the highest share in final energy consumption in European buildings. Also, public buildings consume more final energy than residential buildings in general. Specific heat consumption is an important parameter that indicates the state of energy efficiency of the building sector. In this paper, specific heat consumption of public buildings in the city of Kragujevac is analyzed. Part of the data collected for the Energy Efficiency Program for the City of Kragujevac is presented and compared with similar results from other countries and cities. Authors conclude that specific heat consumption in municipal buildings of Kragujevac is relatively high compared to other countries and that its values also vary depending on building purpose and building built year.**

Keywords - energy consumption, energy efficiency, public buildings, specific heat consumption

I. INTRODUCTION

Lower values of specific heat consumptions are becoming imperative in a modern world as because of a decrease in costs of operational utilities in industry and buildings, as because of the necessity for gradual decrease of the energy dependence of local, regional and national, private and public services. According to energy balances for 2015, 39% of final energy consumption in EU went on buildings (residential and service sector), that is 13.5% higher than the share of final energy used in industry [1]. Shares of final energy consumption differ from country to country, for example, the share of final energy consumption in buildings, in total share of final energy consumption in Germany is around 41.4%, in Croatia 48%, Hungary 47% [1], while in Serbia the share is 45.5% [2]. Although final energy consumption in public buildings and service sector is lower than in residential, for 11.8% in total share [1], these sectors record constant growth in final energy consumption. Between 1990 and 2010 service sector (both public and private) in the EU recorded 41% of growth, while the growth between 2005 and 2010 was 12.2% [3].

Around 47% of final energy consumption on a global level went on heat (2009) [4]. In Serbia, 57.6% of heat energy consumption went on buildings [5]. Although consumption of heat, as well as final energy in general in public buildings, is lower than the consumption in residential buildings its share is not insignificant, 20.8% of total share of heat consumption in the EU [6] and 11.5% of total share in heat consumption in Serbia [2]. It is important to mention that specific heat consumption in public buildings in Serbia is for a half a value higher than in residential buildings [7].

According to all above mentioned it can be concluded that:

- Final energy consumption in buildings has the highest share in final energy consumption in total,
- Public buildings consume more final energy than residential buildings,

ISBN: 978-86-80616-03-2

• Public buildings record constant growth in its energy demands and

• Heating energy has the highest share in final energy consumption in buildings.

In order to achieve global goals dealing with the reduction of carbon dioxide emissions as well as lowering anthropogenic influence on climate change and environment, international agreements are adopted. Therefore, governments of countries and regions adopt regulative and limitations dealing with greenhouse gases emissions in accordance with their possibilities, so every party can contribute to global goals.

The government of the Republic of Serbia adopted a series of regulations and strategic documents in order to promote and improve the state of energy efficiency in public and residential buildings:

• Rulebook on the energy efficiency of buildings in 2011

• Rulebook on the conditions, content, and manner of issuance of certificates of energy performance of buildings in 2012

• Law on efficient energy use in 2013

• Energy sector development strategy in the Republic of Serbia by 2030

• Program for the implementation of energy strategy for the period from 2017 until 2023

In order to achieve the goals of national strategies, several energy efficiency action plans were adopted. 1st National action plan for energy efficiency (2010) predicted that public buildings can contribute in 9% of savings in total share of final energy consumption of public buildings up to 2018 [8]. Renovation conducted in a number of public buildings included in SEEP1 and SEEP2 (SEEP - Serbian Energy Efficiency Project) (2005 - 2012) resulted in 47% of savings in final energy consumption in the renovated buildings. 3rd National action plan for energy efficiency (2016) predicts annual energy savings of 1% in the public sector. This goal is related to all municipalities with more than 20000 residents. Complying with this, city assembly of Kragujevac adopted Energy efficiency program for the period of 2018 – 2020. The Energy efficiency program contains all the elements envisaged by article 10, Law on efficient energy use.

One of the results of the Energy efficiency program of the city of Kragujevac is benchmarking analysis of energy consumption in different public sectors. The results of benchmarking of heat energy consumption in public buildings are presented in this paper.

II. RESEARCH AREA

The city of Kragujevac is administrative, industrial, cultural, educational and health care center of central Serbia. It is located in Šumadija region that contains six more municipalities: Batočina, Lapovo, Knić, Rača, and Topola. City land area creates 35% of the land area of the region and 1% of the land area of the Republic of Serbia. According to the National census from 2011 Kragujevac has 179417 residents (2.49% of the population of the Republic of Serbia). Urban city area has 150835 residents (84% of total count). This makes Kragujevac the fourth largest city in Serbia and the first referring to the share of the city residents living in the urban area [9].

Public building in Kragujevac can be classified in 6 categories:

• Educational buildings – preschools and kindergartens (15 buildings), elementary and high schools (75),

• Buildings of cultural institutions – museums (2), libraries (6+), houses of culture (2+), theatres (2) and other (3)

• Administrative buildings (93)

• Community health centers' buildings (26),

• Sport and recreation buildings (3).

• Buildings of public utility services and companies (7)

A certain number of analyzed buildings has mixed purposes. Building purpose is determined according to the main activity of services conducted in its office space.

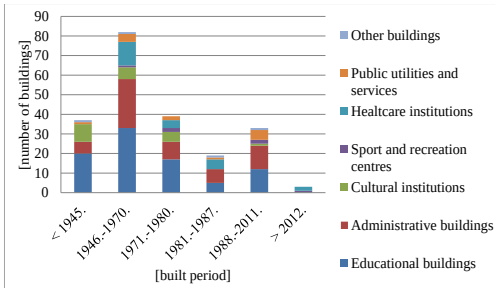

Figure 1. Overview of public buildings according to built year

According to a year of built, type of building construction and different legislation periods, public buildings in the city of Kragujevac can be classified into 6 categories:

- Buildings built before 1945,
- Buildings built between 1946 and 1970,
- Buildings built between 1971 and 1980,
- Buildings built between 1981 and 1987,
- Buildings built between 1988 and 2011,
- Buildings built after 2012.

The public building's structure according to the built period is presented in Figure 1.

Typical characteristics of the buildings in Serbia according to the period of construction are presented in table I [5].

TABLE I. CHARACTERISTICS OF BUILDINGS IN SERBIA ACCORDING TO THE PERIOD OF CONSTRUCTION

Period of construction	Basic characteristics
Before 1945	- construction without thermal regulations - traditional building techniques and full brick or stone materials - the thickness of external walls varies from 25 cm to 50 cm (U=1.33 – 1.05 W/m^{2}K). - ceilings are mostly wooden or massive (brick, stone or concrete elements) - floors often made on the layer of rammed earth - wooden doors and wooden double frame, double sash with single glazing windows (U=3.5 W/m^{2}K) - the buildings have lower thermal losses as newer lightweight concrete structures.
1946–1970	- period of intensive construction but without thermal regulations - lighter full brick or clay block structures without thermal insulation (U=1.61–1.74 W/m^{2}K)
	- wooden doors and wooden double frame, double sash with single glazing windows (U=3.5 W/m^{2}K)
1971–1980	- the first national regulation on thermal insulation of residential buildings - period of intensive construction – usage of light reinforced concrete structures without thermal insulation or with modest thermal insulation - wooden doors and wooden double frame, double sash with single glazing windows - no thermal regulations for windows and increase of glass surfaces on the facades
1981–1987	- standard JUS U.J5.600 – Thermal Engineering in Construction – Technical conditions for the design and construction of buildings (1980) - reinforced concrete walls are performed in minimal static thicknesses of 16 cm – 20 cm. Masonry structures are mainly made of a hollow block of bricks of 19 cm (or full bricks 25 cm) - roofs are often performed as flat roofs with a concrete slab and minimal isolation - large glass surfaces – windows with ISO glass, but very poor profiles, without an interrupted thermal bridge, and with bad sealing. - no thermal regulations for windows and increase of glass surfaces on the facades - almost no attention paid to solving the details of characteristic thermal bridges.
1987–2011	- standard JUS U.J5.600 – Thermal Engineering in Construction – Technical conditions for the design and construction of buildings (1987) - external walls with all available materials on the market and applied thermal insulation is such that it meets the existing regulations - most common insulation materials are rock wool and polystyrene, in the thickness of 4 cm, 6 cm and 8 cm for the external wall and 8 cm to 12 cm for a pitched roof.
2011	- according to Rulebook on the conditions, content, and manner of issuance of certificates of energy performance of buildings ("Official Gazette of RS", No. 69/12)

The most of the analyzed buildings (more than 120) were built in between 1946 – 1980. Considering that measures for the increase of energy efficiency have been applied on just a few of them, it can be concluded that potential for energy savings in public buildings in the city of Kragujevac is significant.

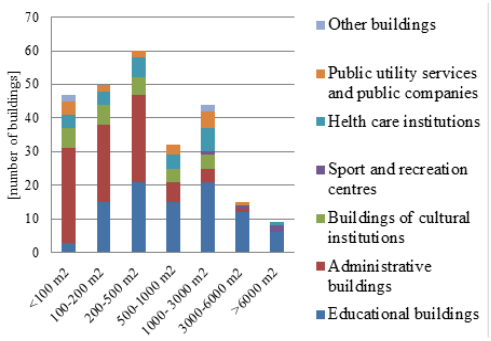

Figure 2. Overview of public buildings according to surface area

The highest share of public buildings in the city of Kragujevac has surfaces of 200 m^2 – 500 m^2. These groups contain the significant number of local community buildings and offices and the highest share of schools buildings in villages. Among the buildings with the useful surface higher than 1000 m^2 the highest share has educational buildings (Figure 2.).

III. METHODOLOGY

Specific heat consumptions per heated area of the buildings is the ratio of total heating consumption in observed period (period without changes of facility purpose, heating surface, thermal envelope and heating source) and heating surface area. In order to reduce the influence of difference of actual (measured in the observed period) and average number of HDD, considered as constant in energy classes labeling process according to Rulebook on the energy efficiency of buildings, specific heat consumption per heated area is determined according to (1):

$$SHC = \frac{1}{A} \cdot \left[\sum_{i=1}^{n} \frac{Q_i}{HDD_i} \right] \cdot \frac{1}{n} \cdot HDD_a \cdot 10^3 \quad (1)$$

Where:

SHC [kWh/m^{2}a] – annual specific heat consumption per heated floor area

A [m^2] – heated floor area

n [–] –number of heating seasons in analysis

Q_i [MWh] – consumption of heat during i– heating season

HDD_i [Kday] – the number of real (measured) HDD during i– heating season

HDD_a [Kday] – average number of HDD adopted by the (Rulebook on the energy efficiency of buildings, 2011).

The values of heating degree days (HDD) for the city of Kragujevac for the period 2014-2016 are shown in Table II. The values were calculated using data from the national hydro-meteorological service company (Republic Hydrometeorological Service of Serbia). The average value presents the value from the Rulebook on the conditions, content and manner of issuance of certificates of energy performance of buildings.

TABLE II. HEATING DEGREE DAYS FOR THE CITY OF KRAGUJEVAC

Average number of HDD	**2014**	**2015**	**2016**
2.610	2.133	2.510	2.349

Energy classes of building with different purposes were defined by the mentioned Rulebook on conditions, content and manner of issuing energy performance certificate of buildings. List of energy classes with its SHC thresholds for existing buildings is presented in Table III. In the case of reconstruction, modernization and revitalization, the renewed building has to improve its energy class for at least one level.

TABLE III. ENERGY CLASS THRESHOLDS FOR EXISTING BUILDINGS

En. class	**Administr. and offices**	**Education. and cultural institutions**	**Health care institutions**	**Sport and recreation facilities**
	[kWh/m^{2}a]	**[kWh/m^{2}a]**	**[kWh/m^{2}a]**	**[kWh/m^{2}a]**
A+	≤ 10	≤ 12	≤ 18	≤ 14
A	≤ 17	≤ 20	≤ 30	≤ 23
B	≤ 33	≤ 38	≤ 60	≤ 45
C	≤ 65	≤ 75	≤ 120	≤ 90
D	≤ 98	≤ 113	≤ 180	≤ 135
E	≤ 130	≤ 150	≤ 240	≤ 180
F	≤ 163	≤ 188	≤ 300	≤ 225
G	> 163	> 188	> 300	> 225

IV. RESULTS AND DISCUSSION

Specific heat consumption of public buildings in Kragujevac was calculated just for those buildings that are directly or indirectly financed by the city government. The share of heating energy consumed by each of the categories mentioned in chapter 2 is presented in figure 3.

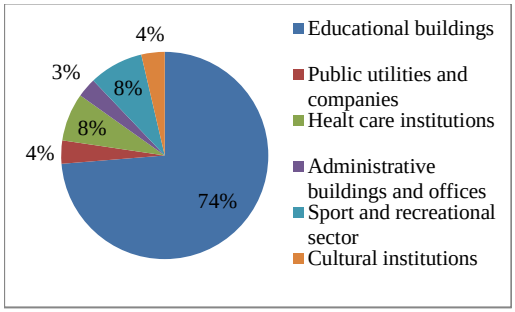

Figure 4. Heat consumption of different categories of public buildings in Kragujevac

A. *Educational buildings*

Because of their purpose, educational buildings have special social importance. They are responsible for the highest share in final energy consumption in the analyzed public buildings. There are 15 preschool and 75 elementary and high school buildings which energy costs are paid by local government. Among the analyzed public schools, there are also joint elementary and high schools, schools for the education of adults and schools for the students with special needs. Specific heat consumption of the schools classified according to built period, as well as average specific heat consumption of all the schools of the same built period is presented in figure 4.

Ten schools were excluded from the analysis because they went through full or partial thermal envelope renovation. Four village schools were also excluded, as they have local electric heating systems which prevent exact distinction of final energy consumption for heating and for other purposes. Average specific heat consumption of analyzed educational buildings in the city of Kragujevac is 175.6 kWh/m^{2}a. This value can be considered as relatively high having in mind that specific heat consumption in educational buildings in Austria is 117 kWh/m^{2}a [10], in Poland 123 kWh/m2a [11], Hungary 110 kWh/m2a [12], Slovakia 85 – 112 kWh/m^{2}a [13]. The reasons for relatively high values of specific heat consumption are nonexistence of legislation refereeing to energy savings in between 1946 – 1988 and existence of relatively week legislations and rulebooks dealing with thermal insulation of building envelope.

B. *Community health centers*

Results of specific heat consumption in tertiary healthcare institutions i.e. community health centers and ambulances are presented in this chapter. Generally, final energy consumption of a health care center depends on the specific type of laboratory and services it provides so final energy consumption cannot be a comparable indicator of building energy efficiency. Nevertheless, specific heat consumption definitely has more comparable value than final energy consumption. Results for community health centers are presented in figure 5.

Two ambulances were excluded from the analysis as their heating energy consumption was not able to be separated from total final energy consumption (heating on electricity). Average specific heat consumption of analyzed healthcare institutions is 149 kWh/m^{2}a, that can be considered as relatively moderate consumption comparing to educational buildings. However, according to research dealing with final energy consumption in health care centers in the city of Kragujevac [14], almost all analyzed healthcare buildings have

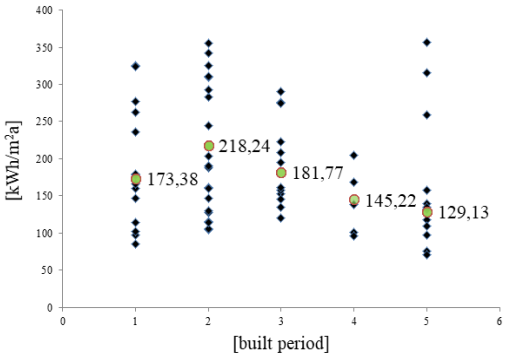

Figure 3. Specific heat consumption in educational buildings in Kragujevac classified according to built period

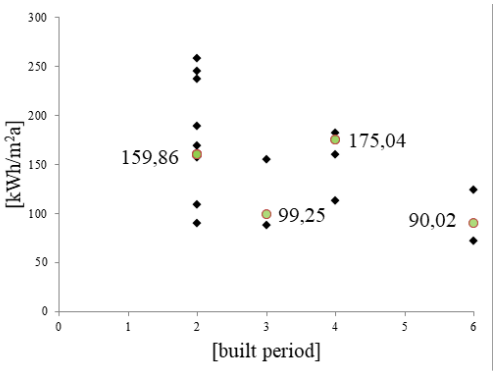

Figure 5. Specific heat consumption in health care institutions in Kragujevac classified according to built period

been reheated by some sort of individually installed electric heaters. Estimated share of electricity used for heating in total heating demand ranges from 6 – 60%, so average specific heat consumption in health care institutions calculated taking this into account is 195 kWh/m^{2}a. For comparison, specific heating consumption in health centers in Vojvodina (Northern Serbia) is 244 kWh/m^{2}a [15].

C. Administrative building

Many of 97 analyzed administrative buildings share building spaces with private entities through different types of private-public partnership. Majority of mentioned buildings have local heating systems that are used just occasionally during the heating season for infrequent meetings. For those local heating systems, electricity and fuelwood (provided from residents own funds) are used. Therefore, 89 municipal administrative buildings were excluded from the analysis and the results of the analysis are presented in figure 6.

Average specific heat consumption of analyzed administrative buildings in Kragujevac is 200 kWh/m^{2}a. Specific heat consumption in the buildings of the same type in AP Vojvodina is 254 kWh/m^{2}a [15], in Austria 251 kWh/m^{2}a, in the Czech Republic 294 kWh/m^{2}a, in Bulgaria 130 kWh/m^{2}a [16].

D. Buildings of cultural institutions

In this chapter, libraries, theatres, buildings of cultural and artistic societies, houses of culture and museums are considered as buildings of cultural institutions. Four buildings among all analyzed are not heated and for 5 other buildings it was not possible to separate heating from final energy consumption since the buildings use electricity for heating. Therefore, the analysis of specific heat consumption in

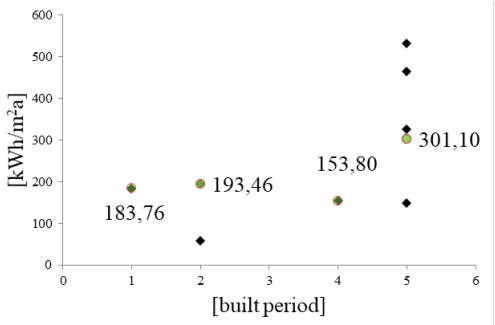

Figure 6. Specific heat consumption of administrative buildings in Kragujevac classified according to built period

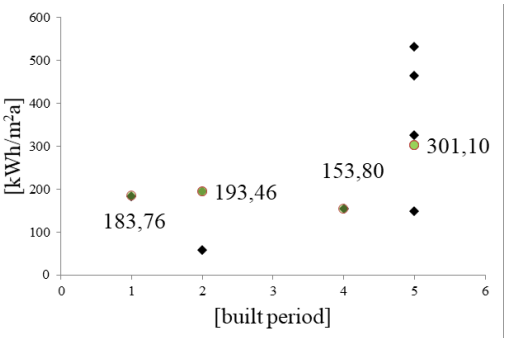

Figure 7. Specific heat consumption of cultural buildings in Kragujevac classified according to built period

buildings of cultural institutions was performed on the sample of 15 buildings (figure 7).

The lowest specific heat consumption has the building of cultural and artistic society "Abrašević" (58.7 kWh/m^{2}a) because its space is heated occasionally. Majority of the analyzed buildings have the status of cultural monuments and they are under direct jurisdiction and protection of the Ministry of Culture and Information of the Republic of Serbia. Preservation of cultural heritage is the primary goal to be achieved with these buildings; therefore their energy efficiency is not considered as a priority. In a case of potential reconstructions, the Ministry issues a special permit taking care that the visual identity of the building stays undisrupted.

E. Sport and recreation centers

Data for nine buildings for sport and recreation activities were collected and analyzed. Since four of the buildings do not have space heating and for two it was not possible to determine heat consumption, specific heat consumption for only two sport halls and indoor swimming pool were calculated. "G. Bogojevic" sport hall (89.7 kWh/m^{2}a) and indoor swimming pool (397.6 kWh/m^{2}a) are relatively new buildings, built in 2009 and 2011 respectively. "Jezero" Hall (267.8 kWh/m^{2}a) was built in 1978 and until now it has not been reconstructed while the building requires renovation. With 5320 seats "Jezero" is main city sports hall that hosts main sports events, while "G. Bogojevic" is used as concert and tournament hall. It has mounted seats and smaller useful space. Specific heat consumption of the sport halls in Stuttgart (Germany) is 140 kWh/m^{2}a [17].

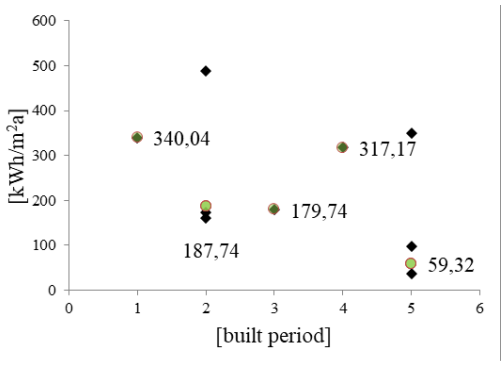

Figure 8. Specific heat consumption of the public services and companies in Kragujevac, classified according to the built period

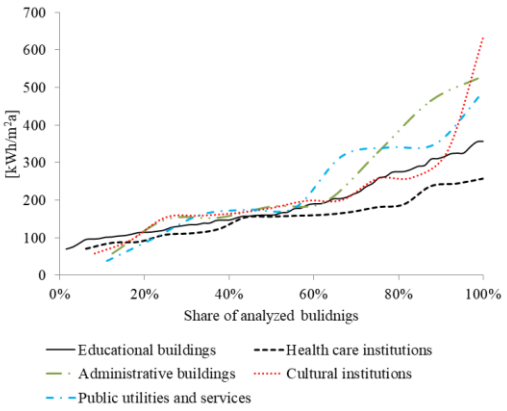

Figure 9. Share of the building of the same sector inside total heat energy consumption of the sector

F. Public services and companies

This group of buildings consists of city market halls, buildings of water supply and sewerage utility company, buildings of the waste management company, buildings of city greenery services, city sanitation and zoo-hygiene services and buildings of city cemetery services. Ten buildings do not have or have just occasional heat consumption (buildings of city cemeteries and inactive utility services) and the consumption of just nine buildings is presented in figure 8.

Average specific heat consumption in analyzed buildings is 130 kWh/m^{2}a, which is the lowest value of all types of public buildings in Kragujevac. City market halls have great influence on relatively low average specific heat consumption as they have useful space of 4828 m^2 and 1490 m^2 and consume in average 37.6 kWh/m^{2}a and 98.1 kWh/m^{2}a, respectively. Other buildings consume in average 227 kWh/m^{2}a of specific heat.

G. Overall analysis

The share of the building of the same sector inside total heating energy consumption of the sector is presented in picture 9. The sport facilities were excluded since the number of the buildings is small.

More than 90% of educational buildings consume more 100 kWh/m^{2}a. Around 40% of analyzed buildings have specific heat consumption in between 100 and 200 kWh/m^{2}a, while 35% of the analyzed buildings have consumption greater than 200 kWh/m^{2}a, and 20% of analyzed public utility services and administrative buildings have consumption greater than 300 kWh/m^{2}a as well as 10% of analyzed cultural institutions.

V. CONCLUSION

This paper analyzes specific heat consumption in public buildings calculated for the creation of the Energy Efficiency Program for the City of Kragujevac 2018 - 2020. All the buildings have been classified in groups according to their type and built period and the consumption of heat inside every group has been presented separately. Average specific heat consumption in public buildings in the city of Kragujevac is 216.6 kWh/m^{2}a. Sport and recreation facilities (influenced with high consumption of indoor swimming pool) and buildings of cultural institutions have bigger than this value. According to data from table III, higher than the calculated average value (149 kWh/m^{2}a) should be expected in health care institution. The lower than expected value is due to the fact that the clinical center is not included in the analyses (only municipal health centers were included). Although educational buildings do not have the highest average specific heat consumption, they consume the highest share of heating energy in public buildings 74%.

Comparing the calculated data of specific heat consumption of municipal public buildings in Kragujevac with data from table III it can be concluded that only 7,8 % of buildings have heat consumption that corresponds to “C” energy class, 19,1% to “E”, 33 % to “F” and 40 % to “G” energy class. The biggest number of energy inefficient buildings belongs to educational buildings, cultural institutions and

administrative buildings and offices and those buildings are the priority for defining energy efficiency measures. Energy efficiency measures in the buildings can be divided into two groups. The first group - technical measures are: improving building envelope thermal insulation, installation of new and more efficient doors and windows, improvement of heating system efficiency, automatic regulation of the heating system, fuel substitutions, etc. Another group of measures refers to introducing energy management system techniques of monitoring and targeting heat energy consumption in buildings.

ACKNOWLEDGMENT

This paper presents a result of research on III42013 project that has been financed by the Ministry of Education, Science and Technological Development of the Republic of Serbia.

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