

DEVELOPMENT FOR CO₂ EMISSIONS REDUCTION BY THE USE OF SOLAR THERMAL COLLECTORS IN THE PROCESS OF URBAN PLANNING

by

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Using RES is one of the most important characteristics of the sustainable and resilient development. Nowadays, need to minimize CO₂ emissions is obligatory, especially in the sector of urban and architectural planning, since in Serbia approximately 50% of produced energy is spent in buildings. The CO₂ emission, in urban structures, can and must be reduced at the different levels: building level, block, and city level. For the city of Kragujevac, based on urban parameters defined in General Urban Plan, typical urban block was chosen and typical building structure developed. Calculation were made, based on recommendations developed by the Ministry of mining and energy and Serbian regulations, for the energy needed for domestic hot water preparation. In this paper, the influences of architectural and urban parameters on the use of solar thermal collectors at the typical building and urban block level is investigated. Recommendations are prepared for principles of urban and architectural design in order to enable the use of collectors for domestic hot water preparation and in that way CO₂ emission reduction. Developed methodology for the city of Kragujevac can be applied in defining design principles in whole the country and Balkans region, not only for the use of solar thermal collectors but also for the use of other RES.

Key words: solar thermal collectors, CO₂ emissions, sustainable architecture, sustainable urban development

Introduction

One of the key components of sustainable and resilient development is using RES [1]. Developed countries realized the importance of CO₂ as well as other GHG emission reduction in the process of non-renewable energy consumption and the necessity of seeking alternative resources of energy. In the process of joining the EU, Serbia has to harmonize its regulations with regulations of the EU, reducing the consumption of energy, and using RES. It is not only necessary because of the EU recommendation, but it can also solve the current problems of unreasonable energy consumption in the sector of buildings, together with the measures of energy efficiency improvement, and raise the ecological quality of built environment. The Government of the Republic of Serbia has accepted norms stated in the Directive 2009/28/EC [2] about RES and thus Serbia agreed to increase the percent of renewable energy in the total consumption of final energy from 21.2% (in 2009) to 27% before 2020. In 2011

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in order to support the process, The Ministry of Environment, Mining and Spatial Planning of the Republic of Serbia supported by the United Nations Development Programme published set of detailed guides, among which is Construction of the Solar Heating Systems in the Republic of Serbia – Guide for Investors [3].

The Republic of Serbia has proclaimed that 2011 is the year of energy efficiency and adopted a few legal documents, among which, when energy efficiency of the buildings is in question, the most important is the Rulebook on Energy Efficiency of Buildings [4]. It precisely prescribes the quality of new buildings as well as the existing in the process of energy efficiency improvement, concerning their thermal characteristics and defines their energy classes based on energy needed for heating. At the same time, the methodology for calculation of energy needed for preparation of domestic hot water (DHW) is defined, although this calculation is not mandatory and does not influence energy class of the building. In spite of the fact that in Serbia, building stock uses more than 50% of total produced energy, urban-architectural regulation, when determining parameters which define urban structure, do not take into account use of RES and adjusting the physical structure of buildings to use of RES, including solar thermal collectors.

The goal of this paper is to set up methodology for the assessment of CO₂ emission reduction using solar systems for the preparation of DHW.

The target of the present work is city of Kragujevac and its typical urban block and typical building structure developed.

Literature review

Duffie and Beckman [5] created fundamental methodology of analysis of solar thermal collectors and have been cited in numerous scientific papers. They presented the mathematical model to calculate collector efficiency and indicated the parameters of influence.

Szokolay [6] published works presented at Solar World Congress where was investigated application of flat plate solar collectors in architecture and its efficiency.

Kreider and Kreith [7] defined many principles of solar energy application and solar conversion systems.

Pucar [8] analyzed bioclimatic architecture and indicated to houses as thermodynamic, not only structural entities.

Incorporating energy efficiency and sustainable green design features into new and existing buildings has become a top priority in recent years for building owners, designers, contractors, and facility managers. Kim *et al.* [9] researched development of an energy efficient building design process using data mining technology which can help project teams discover important patterns to improve the building design.

Capozzoli, *et al.* [10] discussed about an integrated whole building process throughout the entire project development process and about generating a large amount of data during energy simulations which was done by building designers. They noticed an importance of the analysis of these data in order to provide useful information for designers and authority planners, aimed at identifying the major causes of high energy consumptions and reference values to drive a building sustainability design approach.

Vasov *et al.* [11] noticed the fact that Serbia emitted around 80 million tons of CO₂ and was among ten countries with the highest emission of CO₂ per capita in the world. The specific review conducted in this paper indicates the environmental importance of improvement of energy efficiency by valorizing the quantitative reduction of CO₂ emission as a benefit of implementation of energy revitalization of buildings. They conducted the specific re-

view and indicated the environmental importance of improvement of energy efficiency by valorizing the quantitative reduction of CO₂ emission as a benefit of implementation of energy revitalization of buildings.

The analysis of the literature reveals the lack of methodology concerning principles and recommendations for urban and architectural design in order to enable the use of collectors for DHW preparation and in that way CO₂ emission reduction. Therefore, this research was planned with the aim of deepening the knowledge and understanding of this topic.

Materials and methods

In the paper the methodology for sustainability improvement of residential new building stock is presented. The influences of architectural and urban parameters on the use of solar thermal collectors at the average buildings and urban block level is investigated.

The research was conducted on a typical urban block in the city of Kragujevac, using planning parameters of the General urban plan as floor area (FA) ratio, plot ratio, number of floors, and average building was created. Depending on the façade and roof orientation four types of average buildings are defined and it was the base for formulation of the methodology. Based on the average building structure and using recommendations developed by the Ministry of Mining and Energy of the Republic of Serbia, and Serbian regulations were made calculations for the energy needed for DHW preparation. Further calculations were conducted based on the procedure from [3] and their purpose was to calculate the needed solar collector area. Since the previously defined average building differ in their position on the parcel and orientation of the collectors, solar collector area and the number of collectors was calculated for every type of building. The dimension of the collectors was assumed, and number of needed collectors was calculated for four defined types of building. Afterwards, using the obtained results it was calculated amount of the CO₂ emission which would be reduced using solar energy source for DHW.

The presented procedure is a simplified one, but considered precise enough for the purpose of average building methodology. The method of calculation does not take into account possible heating losses and they should be analyzed afterwards. Described methodology, based on the case studies of urban blocks in Kragujevac, should to establish principles for further implementation on other urban areas in the country and the region, not only for the use of solar thermal collectors but also for the use of other RES.

Urban planning regulations

Spatial and town-planning of the Republic of Serbia is defined by different regulations, from state level to local, municipal level and town-planning plans, general and detailed, are the important part of these documents. The General Plan is a strategic developing plan with common elements of spatial development [12]. The Plans of General Regulation (PGR) elaborate populated areas individually while the Plans of detailed regulation are done on the levels of parts of urban areas. These regulations define corridors, boundaries of the areas, parcelling, parcel purpose, building rules, and a lot of other parameters important for defining urban structure.

Case study of Kragujevac

For the purpose of this analysis Kragujevac city was chosen, mainly because it possesses urban matrix typical for a lot of towns in Serbia and surrounding countries and it also has geographical characteristics similar to other towns. Thus, the principle of methodology would easily be applicable to similar towns and the given results could be used for the rough

assessment of conditions of other urban areas. The research in this paper is based on the Plan of General Regulation *Center-Old Town* [13], and it is based on the block which was chosen as a typical for a town because of its purpose, parcelling and size. The definition of the block architectural structure was done according to the parameters defined in the PGR: area and dimensions of the parcel, the building zone, the parcel purpose, the building height, the position of the building, FA ratio, lot coverage (LC), etc. At the same time, those parameters are used in methodology development and definition of average building.

The block 3.6, which was chosen for the analysis, is in the town center. Its main purpose is habitation and its area is 13.850 m². The block consists of 18 parcels, whose number can be reduced to 16 parcels by grouping four smaller parcels, because of the prescribed minimal area of parcels, defined in the plan with 200 m², on which the buildings can be built.

The maximal allowed total gross FA (GFA), of the building is defined by three parameters:

- The FA ratio, the values in the PGR, for the block 3.6 are 1.6-3, multiplied with the LA gives the GFA.
- The LC, the values in the PGR, for the block 3.6 are 60-70%, multiplied with the LA gives the GFA of the biggest floor of the building including balconies and overhangs.
- Height of the building defined through the number of floors above the ground floor (GF), the values in the PGR, for the block 3.6, are GF+3 and GF+4.

The maximal allowed GFA of the building must comply with smaller value. The total FA or the total heated area is defined as 75% of the calculated GFA. Using these parameters, the possible, calculated maximal GFA for all the parcels were calculated enabling definition of average building area, FA, height of the building and definition of façade area.

When the type of roof is in question, according to the urban plan, it is possible to design both, flat and pitched roof. For the purpose of this paper and definition of average building, pitched roof is used. Pitched roof is typical for Serbian architecture because of the climate conditions and the applied slope is usually, because of the used brick tiles, approximately 30°.

Based on adopted parameters and characteristics of Serbian architecture, the definition of the typical building, or average building, is created. For block 3.6. in Center-Old Town in the city of Kragujevac, the average building is – free standing building, average LA 451 m², GFA is 902 m², and net heated area is 676 m². The maximal average FA is 270 m², and the building is 4 floors (GF+3) high. As limiting factor in the case of block 3.6 is GFA, maximal average FA and horizontal projection of the roof must be reduced to 225 m² giving the pitched roof area of 260 m². Taking into account that the block 3.6 is situated near the town center, it is expected that the GF can be used for shops and other public purposes, while other floors are used for flats, thus the average net heated residential FA of 507 m². According to Serbian standard, which defines that 40 m² of residential FA is needed per person on higher residential standards, number of residents can be calculate for average building and the whole block. It can be expected that 13 persons live in the average building, giving the 208 as the total expected number of residents in the block.

Position of the block 3.6 is defined by the street regulation and the orientation of the buildings must follow this matrix. Four types of average buildings are defined, depending on the façade and roof orientation:

- type A – orientation south-north;
- type B – orientation east-west;
- type C – orientation north-south, and
- type D – orientation west-east, fig. 1.

Energy needed for DHW calculation

Four defined types of buildings, typical for analyzed urban block, were the base for formulation of the methodology.

Pitched roofs with the angle of roof planes $\alpha = 30^\circ$, were analyzed in this paper, although solar thermal collectors can be also installed on flat roofs and facades. In accordance with the economic status in Serbia, the type of collector which was chosen for the analysis is flat plate solar collector [14]. Nowadays, flat plate collectors are the most common type of solar thermal collector and they have been investigated since long time [15]. Using vacuum solar collectors, with much higher prices, the percent of solar energy in preparation of DHW would be higher, but in order to form realistic methodology and get realistic results, they are not analyzed in this paper.

There are two possible ways of installation of flat plate collectors on pitched roofs:

- installation on roof cover using special supporting system and
- integration into the roof cover.

Integrating collectors into the roof is the solution that is more acceptable from the architectural aspect, it can be more economical since it replaces the part of the roof covering, but it also requires high-quality insulation and construction. Also, the angle of the collectors is the same as the roof and cannot be adjusted to the optimal angle for the location in question. On the other hand, when installing on the roof, over the covering, collectors are put without any changes on the existing roof, with the help of certain type of anchors. In this case, the angle of collector can be modified with supporting spacer to the optimal one from the energy point. Because of these reasons as well as the fact that attached collectors can be used also in the process of building renovation, in this paper, only the installation of collectors over the covering of the pitched roof is taken into account.

The next data whose influence is important for the calculation is optimal tilt angle of solar collector and which could be defined in a different way. It is the parameter that affects the performance of a solar collector and this is due to the fact that the variation of tilt angle changes the amount of solar radiation reaching the collector surface [16].

According to the publicly available data and the software [17] optimal tilt angle of solar collector for the location of Kragujevac and urban block 3.6 is 34° . For exactly estimating the tilt angle it is necessary to have complex and precise set of data. Nevertheless, in a technical literature, there are some practical recommendations concerning the fixed optimum tilt angle. Duffie and Beckman [5] stated some general *rules of thumb*. For maximum annual energy availability, a surface slope equal to the latitude is best. For maximum summer availability, slope should be approximately 10° to 15° less than the latitude. For maximum winter energy availability, slope should be approximately 10° to 15° more than the latitude [18].

Since the optimal tilt angle of solar thermal collector could differ, for the purpose of the calculation in this paper it was been adopted the optimal tilt angle of solar collector which was proposed for maximum annual energy availability, 44° . It is equal to the latitude of city of Kragujevac and the urban block 3.6.

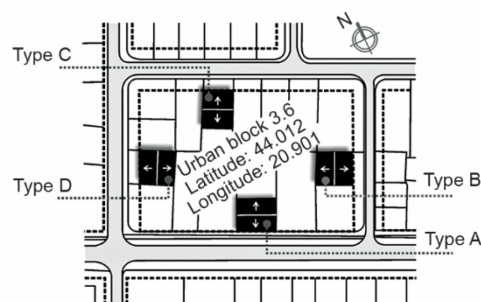


Figure 1. The scheme of urban block 3.6 with different position of the average building

Since the accepted slope of roof planes is 30° and the optimal angle of collectors is 44°, for the purpose of this analysis, characteristics of flat collectors installed on average building roof on spacers and with the angle of 44° were used. The orientation of roof planes and collectors is determined with the mentioned defined orientation of average buildings. The north orientation is excluded from further calculations because of the small neat gains in Kragujevac. Thus the remaining parameters which determine average building type are defined: type A (South), type B (West), type C (South) and type D (East), fig. 2.

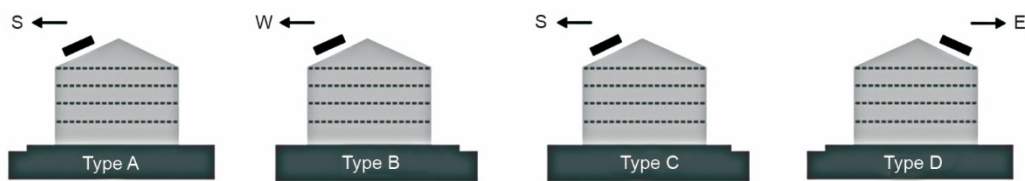


Figure 2. Definition of building types

Advantages and calculation procedures

The calculations were conducted based on the procedure [3]. The presented procedure is a simplified one, only a few information are needed, but considered precise enough for the purpose of average building methodology. The method of calculation does not take into account possible heating losses and they should be analyzed afterwards.

Yearly quantities of needed DHW for average building were calculated based on previous assumptions that:

- Average net heated (residential use) area of the building is 506 m².
- Based on Rulebook on Energy Efficiency of Buildings [4] in the multifamily apartment blocks the standard is 40 m² per person.
- 13 persons living in the average building.
- Daily need of DHW per person is 50 L for average needs according to VDI 2067-4 [19].

The needed daily volume of DHW is calculated in the following way:

$$V_o = 0.001v_o n_o \quad (1)$$

Using eq. (1), it is calculated that the daily needed amount of DHW for each average building is 0.65 m³. That value was used as input information for the further calculation of daily amount of energy needed for the preparation of DHW:

$$q_{uk} = \frac{\rho V_o (T_f - T_i) C_p}{3600} \quad (2)$$

Recommended final water temperature is 45 °C, according to VDI 2067-4 [19], initial water temperature is 10 °C. Based on the given data, the daily amount of energy needed for the preparation of DHW is 26.41 kWh per day for the model (average building).

The next step was to calculate the needed solar collector area for heating DHW using the given formula:

$$A_{PSE} = \frac{365 q_{uk}}{G_a \eta_{PSE}} \quad (3)$$

Collector efficiency is a complex parameter which influences the collectors production and it is strongly influenced by weather conditions. As the efficiency of flat plate solar thermal collectors has been increased by means of different measures (*e. g.* improving the structure of the system and the properties of its materials), the possibility to further upgrade its performance has become more and more limited, and more expensive [20]. Based on the Viessmann technical data and instructions, for the purpose of the calculation in this paper it was been adopted flat plate solar collector type Vitosol 100-FM and its efficiency factor 0,60 (60%). It must be said that this type of collector is recommended by the manufacturer (Viessmann) as adequate in relation to the location of the urban block where are not effects of salty environment on the collector. The other reason is its accessibility when its price is in question.

The average values for radiation on horizontal surface for the location of Kragujevac and the area of analyzed block 3.6 is taken from the online base Photovoltaic Geographical Information System [17], the average yearly global irradiation on horizontal surface is 1305,52 kWh/m², fig. 3.

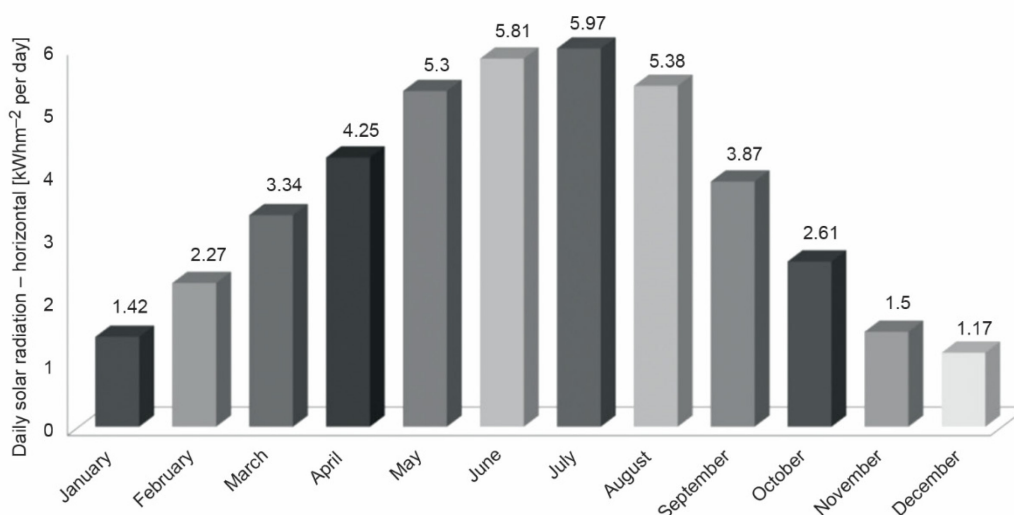


Figure 3. Diagram of average daily radiation on horizontal surface in Kragujevac city

Using the given expression, it is calculated that for the preparation of DHW for the average building, the needed solar collector area is 12.31 m². Since the previously defined type buildings A, B, C, and D differ in their position on the parcel and orientation of the collectors, solar collector area and the number of collectors was calculated for every type of building. The calculated parameters are shown in tab. 1. The factor of shade from the adjacent buildings did not have influence on calculation, since the block, which is analyzed in this paper, is far enough from the surrounding buildings. As the dimension of the collectors are 2.5 m² (dimensions 1.05 m × 2.38 m), number of needed collector can be easily calculated.

Results and discussion

According to the results presented in tab. 1, it is obvious that the area of the roof is far sufficient for installation of collectors. It means that average building is independent from the public power supply for DHW. Using solar energy source for DHW the consumption of

electric energy would be reduced for 9639.65 kWh per year, and thus the CO₂ emission would be also reduced. If we assume that the usual energy source for the preparation of DHW is electric energy, using calculations from The Rulebook on Energy Efficiency of Buildings [4] the reduction of CO₂ emission would be 5109.01 kg/kWh for an average house for a year.

Table 1. The table of data according to the type of building

Building type	Roof area, [m ²]	Quantity of DHW, [m ³] (13 persons)	Amount of energy, [kWh per day] (13 persons)	Horizontal orientation of collectors	Correction coefficient	Solar collector area [m ²]	Number of collectors [pcs]
Type A	113	0.65	26.41	South	1	12.31	5
Type B	226	0.65	26.41	West	1.3	16	7
Type C	113	0.65	26.41	South	1	12.31	5
Type D	226	0.65	26.41	East	1.3	16	7

Comparing the same parameters, collector area and remaining roof area of a building, it is noticed that there is a great percentage of the roof that is not used, and it gives the opportunity for saving additional amount of energy by using other passive or active solar systems. The additional capacity of solar collectors could be also used for energy reduction that is used for heating. On the other hand, because of their performances the average buildings would be adequate for the use of photovoltaic panels, which have requirements that are similar to the requirements of solar thermal collectors.

Conclusions

The research was carried out on the chosen urban block 3.6, which is typical for the city of Kragujevac. The aim of the research was to set up methodology for the assessment of CO₂ emission reduction, when using solar systems for the preparation of DHW.

The subject of this paper can be considered important for the Republic of Serbia because of energy inefficient residential building sector, the habit to use almost exclusively electricity for preparation of DHW with high CO₂ emission, but also because of the Serbian obligations stated in National Energy Efficiency Action Plan to raise the use of renewable according to the obligations from Directive EU 2009/28/EC [2].

Having in mind available potentials of the Republic of Serbia, increasing energy efficiency using RES is very productive energy alternative. The analysis of this urban block is based on the use of urban- architectural parameters which are defined by the plan of general regulation Centar-Stara Varoš.

The very simple methodology was developed for the calculation of energy needed for DHW based on the model of average building. Model of average building was established based on urban parameters, Serbian regulations concerning living standards and use of DHW. For the model building, typical floor and roof areas were calculated. Number of residents and energy needed for the preparation of DHW were also calculated as well as the necessary number of solar collectors, depending on the orientation of the roof.

It can be concluded that the roof area needed for collectors is far smaller than the roof area, for east and west orientations, it is only 7%, while for south orientation 11% of the roof area is needed for installation of the collectors. The corresponding CO₂ emission reduction is

more than 5 tons per year for every average building, or approximately 80 tons for investigated block 3.6 in Kragujevac.

Very important conclusion, with the consequences on architectural design, is that the angle of the roof does not have to meet the requirement for optimal angle of 34° and those less optimal slopes of the roofs can be also used. The final decision must be made according to architectural design and economic parameters when type of collector and the way of installation is in question.

Small percentages of the roof area under the collectors needed for preparation of DHW leave enough space for application of other solar systems: solar collectors can be used for preheating of water in heating system, photovoltaic modules can be installed for electricity production, and green roofs can be applied for heat island effect reduction.

Presentation of solar thermal collectors investment budget methodology for the block and estimate the return period of the investment were not the part of the paper, but it would be included in a future research as a vital analysis.

As a final conclusion, it must be said that, developed methodology is very user friendly but gives enough data for the urban planning and architectural design process enabling and supporting architects in decision making. As such, it should be recommended or introduced in urban and architectural regulations as a corrective factor.

Nomenclature

AP_{SE}	– solar collector area, [m ²]	T_i	– initial water temperature, [°C]
C_p	– thermal capacity per unit mass, [kJkg ⁻¹ K ⁻¹]	V_o	– total daily quantity of DHW, [m ³]
G_a	– average yearly global irradiation on horizontal surface, [kWhm ⁻²]	v_o	– volume of DHW per person daily, [L]
n_o	– number of persons in the building	<i>Greek symbols</i>	
q_{uk}	– heat energy, [kWh per day]	η_{PSE}	– collector efficiency factor, [%]
T_f	– final water temperature, [°C]	ρ	– density, [kgm ⁻³]

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