PARAMETARSKO GENERISANJE I PRORAČUN EFIKASNOSTI SOLARNIH PRIJEMNIKA UPOTREBOM NAPREDNIH CAD ALATA

USAGE OF ADVANCED CAD TOOLS FOR PARAMETRIC MODELING AND EFFICIENCY CALCULATON OF SOLAR COLLECTORS

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U ovom radu izvršena je implementacija proračuna efikasnosti solarnih prijemnika u automatsko generisanje solarnih prijemnika korišćenjem naprednih CAD alata. Korišćen je matematički model koji je razvijen od strane autora prilikom prethodnih istraživanja. U okviru ovog istraživanja napravljen je algoritam za generisanje i proračun solarnih prijemnika koji je odgovarajuć za geometrijske karakteristike absorbera sa cevima kružnog poprečnog preseka, absorbera sa cevima pravougaonog poprečnog preseka i absorbera sa cevima kvadratnog poprečnog preseka. Rezultatima ovog istraživanja predstavljen je značaj primene upotrebe naprednih CAD alata u projektovanju solarnih prijemnika. Upotreba ovih rešenjaa vodi ka značajnom skraćenju vremena proračuna i projektovanja solarnih prijemnika. Primena ovakvog pristupa je vrlo lako moguća i u praktične svrhe.

Ključne reči: *solarni prijemnici; efikasnost; parametrasko generisanje; napredni CAD alati.*

In this paper, the implementation of the solar collectors efficiency calculation in the automatic generation of solar collectors was carried out using advanced CAD tools. The mathematical model, developed by the authors in previous research, was used. Within this research an algorithm for generating and calculating solar collectors has been developed that is suitable for the geometrical characteristics of the: absorber with circular cross-sectional pipes, absorber with rectangular cross-sectional pipes and absorbers with square cross-section pipes. The results of this research show the importance of using advanced CAD tools in the design of solar collectors. The use of these solutions leads to a significant reduction in the design of solar collectors. The application of this approach is very easy for practical purposes.

Key words*: solar collectors; efficiency; parametric generating; advanced CAD tools.*

1 Introduction

Efficiency of the solar energy usage always presents an attractive research topic. The usage of solar radiation energy is done through its transformation into various types of energy: heat, electric, or chemical. Due to cost effectiveness of solar radiation exploitation solar collectors for water heating are the most widespread. Solar collectors are divides which by absorbing solar rays convert radiation energy into heat energy of the fluid which circulates through the collector. Depending on the desired work fluid temperature there are two types of solar collectors: flat solar collectors which can achieve a temperature of over 100^0C, and focusing solar collectors which can achieve temperatures of over 3000^0C.

Design and technology development of flat solar collectors, done in order to increase their efficiency, decrease design time, decrease price of production, and other unwanted effects are a current research topic. These effects can be achieved through automation of solar collector calculation and design, which is the topic of this paper.

Farhat et al. [1] optimized solar collectors in order to increase their performances. Their research covered a large number of parameters: absorber area, gross dimensions, pipe diameters, input and output temperatures, temperature losses, and many others. Authors in paper [2] concluded how to choose optimal performance in order to increase efficiency of solar collectors. In paper [3] Vargas et al. have maximized the performance of a solar collector according to their use in realistic weather conditions. Authors of paper [4] have optimized solar collectors from a thermos-ecological standpoint. Optimization of collector type according to climate conditions was done by authors in paper [5]. Paper [6] gave the authors research on optimal performances of collectors from an interior parts standpoint for collectors with square cells set in a honeycomb formation. This research included an analogy with natural solutions as an alternative in solar collector development.

This paper presents an approach of connecting solar collector calculation and CAD modeling. Design is directed towards geometrical values with a large number of variables, which are significant in efficiency calculation. The mathematical model is created for various absorber pipes cross-sections in the authors previous research, [7].

2 Mathematical model used for parametric modeling and calculation

For the development of the mathematical model pipes with a circular, rectangular and square cross-section were considered. Independent mathematical models were developed for these cross-sections, where for all cases as a goal function the efficiency factor for flat solar panels *F'* was taken into consideration.

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In order to make a comparison between using collectors of various cross-sections, the following factors were considered: 1) inner area of the cross-section through which the fluid flows must be equal for all pipes regardless of cross-section shape, 2) total heat loss coefficient U_L must be the same, 3) absorber plate thickness δ must be the same, 4) wall thickness *t* must be the same, 5) distance between collector pipes W_f must be the same.

The equation for the efficiency factor of the solar collector *F'* for collectors with circular cross-section pipes is taken from [7]:

$$F' = \frac{\frac{1}{U_L}}{W_f\left[\frac{1}{U_L\left[(W_f - D_o)F + D_o\right]} + \frac{1}{C_b} + \frac{1}{\pi D_i H_{fi}}\right]} \tag{1}$$

Variables are: C_b, conductivity of the connection between the circular pipe and absorber (W/mK), D_i, inner diameter of circular pipe (m), D_o, outer diameter of circular pipe (m), *F*, standard rib efficiency (-), *F'*, solar collector efficiency factor (-), H_{fi}, heat conductivity coefficient in the ribs(W/m^2 K), U_L, total heat loss coefficient (W/m^2 K) and W_f, rib width (m).

The equation for solar collector rib efficiency factor *F* for collectors with circular cross-section pipes is taken from [7]:

$$F = \frac{\tanh\left[M\frac{W_f - D_o}{2}\right]}{M\frac{W_f - D_o}{2}} \tag{2}$$

Equation (2) uses the variable *M* which is defined as:

$$M = \sqrt{\frac{U_L}{k\delta}} \tag{3}$$

Variables are: *k*, heat conductivity of absorber plate (W/mK), δ, absorber plate thickness (m).

The cross-section of the collector rib with circular pipes is shown in figure 1.

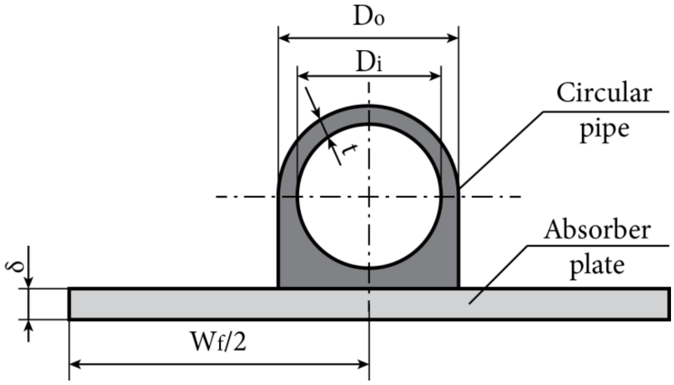


Figure 1 –Cross-section of circular pipe rib

A similar equation is used for determining the solar collector rib efficiency factor for pipes with rectangular cross-section:

$$F' = \frac{\frac{1}{U_L}}{W_f\left[\frac{1}{U_L\left[(W_f - W_o)F + W_o\right]} + \frac{1}{C_b} + \frac{1}{2(W_i + H_i)H_{fi}}\right]} \tag{4}$$

Variables are: W_i, inner width of rectangular pipe (m),W_o, outer width of rectangular pipe (m).

The equation for solar collector rib efficiency factor *F* for collectors with rectangular cross-section pipes is taken from [7]:

$$F = \frac{\tanh\left[M\frac{W_f - W_o}{2}\right]}{M\frac{W_f - W_o}{2}} \tag{5}$$

Variable *M,* for the collector with rectangular pipes is also calculated using equation (3). The cross-section of the collector rib with rectangular pipes is shown in figure 2.

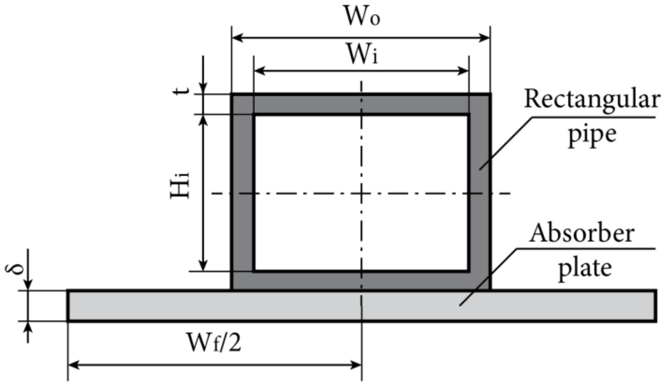


Figure2 – Cross-section of ribs with rectangular pipe

Ratio of inner pipe width W_i and inner height H_i is 1,5: 1. This ratio is frequent in cross-sections of rectangular pipes which are used for collectors.

A similar equation is used for determining the efficiency factor of solar collectors with square cross-section pipes:

$$F' = \frac{\frac{1}{U_L}}{W_f\left[\frac{1}{U_L\left[\left(W_f - B_o\right)F + B_o\right]} + \frac{1}{C_b} + \frac{1}{4B_iH_{fi}}\right]} \tag{6}$$

Variables are: B_i, inner side of the pipe with a square cross-section (m), B_o, outer side of the pipe (m).

The equation for the efficiency factor of the solar collector with a square pipe cross-section *F* is as follows:

$$F = \frac{\tanh\left[M\frac{W_f - B_o}{2}\right]}{M\frac{W_f - B_o}{2}} \tag{7}$$

The cross-section of the collector rib with square pipes is shown in figure 3.

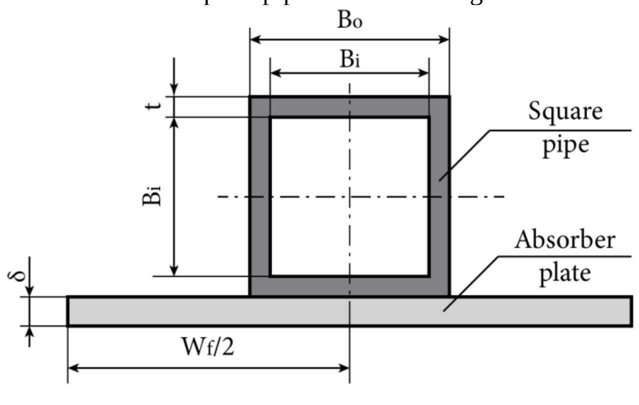


Figure 3 – Cross-section of square shaped pipe rib

3 Parametric modeling and efficiency calculation of solar collectors

The parametric modeling of the solar collector was done with the software package Autodesk Inventor. A technique of top-down assembly modeling was used to make the communication easier between parts of the assembly. All parameters of the solar collector are defined in the assembly file and connected to the individual parts of the collector. The method of defining the parameters in the assembly is given in Figure 4.

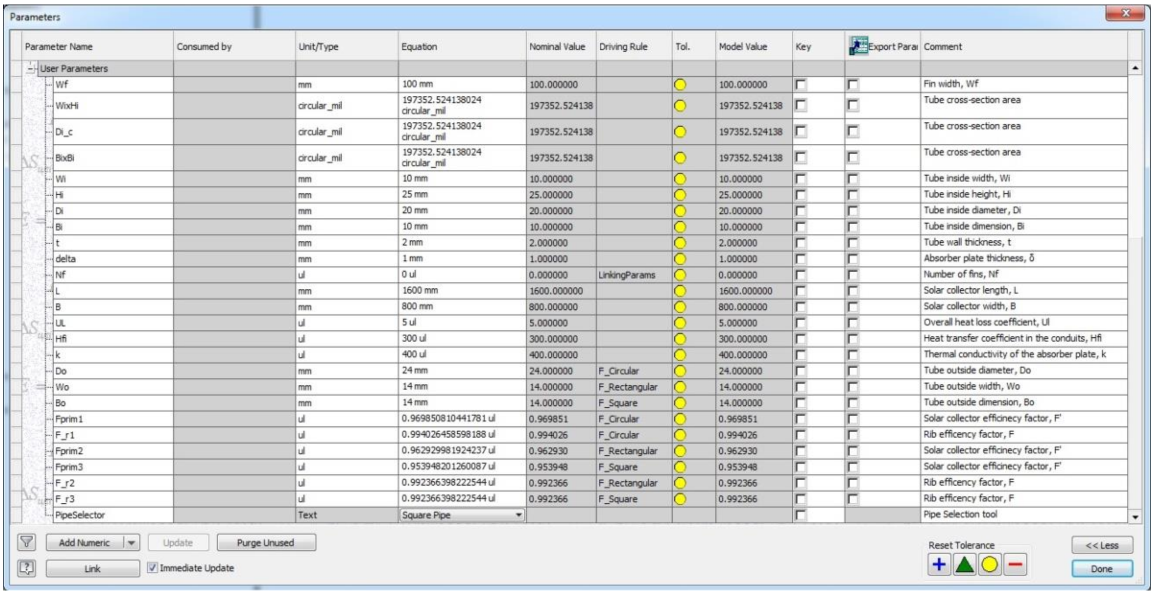


Figure 4 – Automation and calculation parameters definition

When defining the parameters, all the parameters that define the assembly and all the parameters that define the individual parts of the assembly are made in one single table. Parameters for collector efficiency calculation are also made. All mutually dependent parameters are also related with mathematical relations. After defining the parameters, the parts of the solar collector assembly are made: box, absorber with different types of pipes and cover glass.

When creating all individual parts, parameters that have the same name as the parameters in the assembly file are made. This action was necessary to make a script for linking part parameters with the parameters of the assembly.

The most difficult to create the CAD model of this assembly is certainly an absorber. Absorber had to be performed using three separate files. Each separate file is an absorber with pipes of the previously described cross sections.

After creating part files and naming the parameters as previously named in the assembly, connecting of parts parameters the assembly file is conducted. This step is done in the i-logic environment. Connection of part parameters and assembly parameters is performed by creating a script for equalizing the parameters. Script is created by the Add rule command. Figure 5 shows the code layout for linking part parameters with previously created assembly parameters.

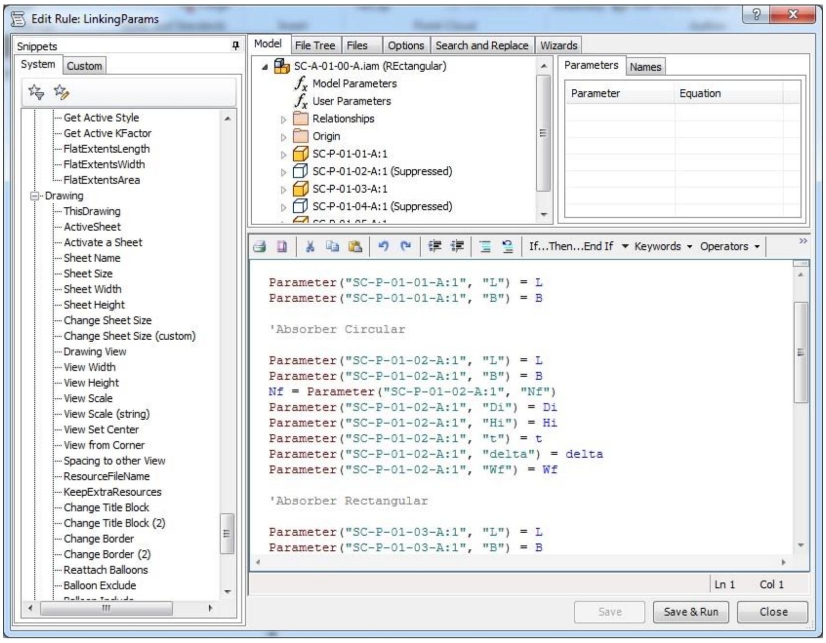
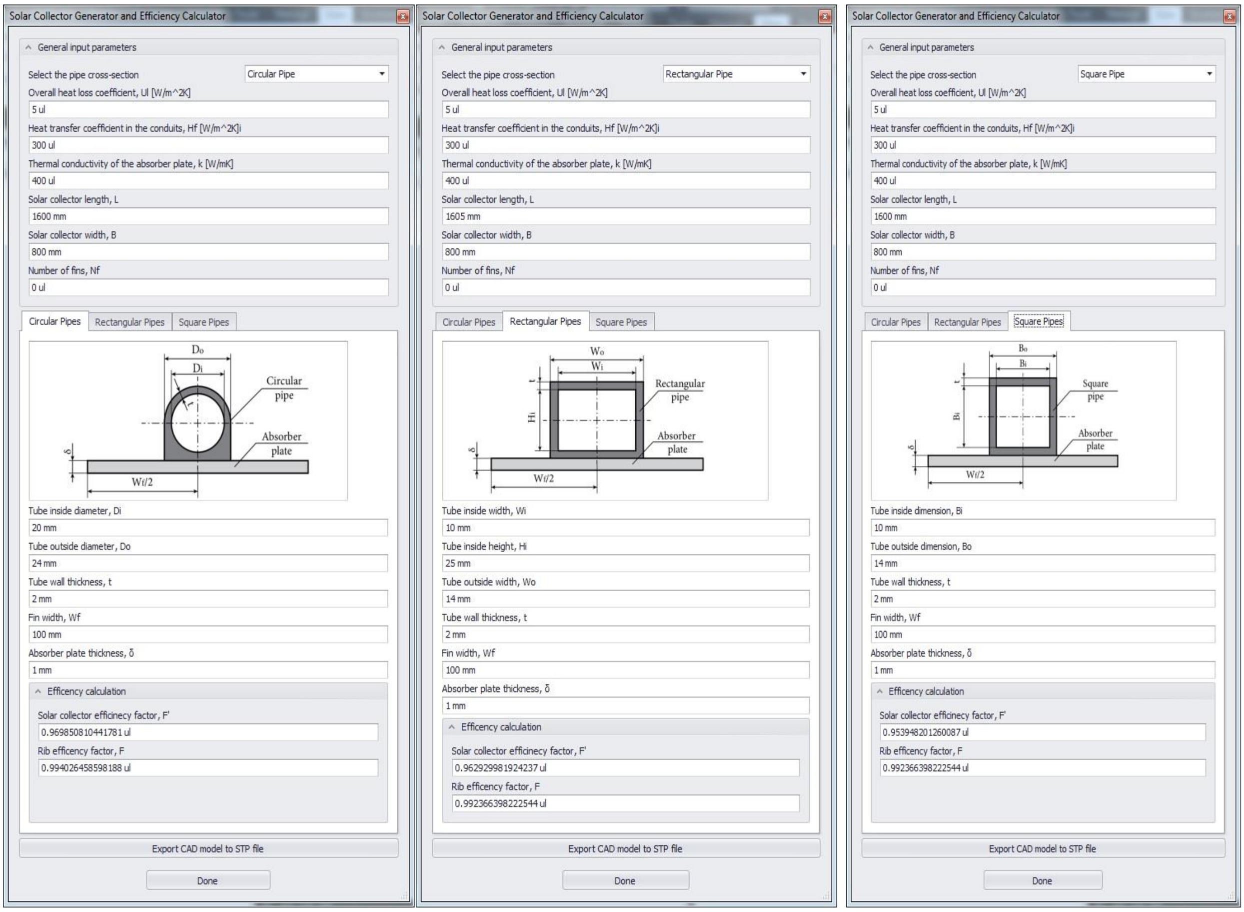


Figure 5 - Rule for parameters linking

With this approach, a general model of solar collector is created. Finding the desired dimensions of the collector is possible by changing the value of the independent parameters in the dialogue from Figure 4. However, in order to accelerate this process, a form was created for controlling the independent parameters of the solar collector generating and efficiency calculation. The advantage of introducing the form is that it cannot make mistakes in entering input data.

When changing the data in the dialogue from Figure 3, one of the dependent parameters can be modified and thus the parameterization concept can be distorted. Three different tabs for independent elements of solar collectors with different types of absorber were made during the design of the form. The data entry form is shown in Figure 6.



a) *b)* *c)*

Figure 6 – Communication form: a) for solar collector with circular pipes; b) for solar collector with rectangular pipes; c) for solar collector with square pipes

The first tab refers to a collector with round tubes of the absorber, while the second and third tabs relate to reservoirs with rectangular and square tubes of the absorber. The common input sizes for all three types of collectors are: dimensions, heat conductivity coefficient in the ribs, total heat loss coefficient and thermal conductivity of the absorber plate.

4 Results

Three examples with the same general input parameters were taken to test this parameter model and collector efficiency was calculated. The cross-sectional dimensions are calculated so that all three examples have the same cross-sectional area. In this way, it is possible to make a comparative analysis of the efficiency of all three types of collectors. The input data for the test cases is given in Table 1.

Table 1. Input values for a test example

Parameter name	*Des.*	*Value*	*Parameter name*	*Des.*	*Value*
Heat conductivity coefficient in the ribs (W/m^2 K)	H_{fi}	300	Fin width, (mm)	W_f	100
Total heat loss coefficient (W/m^2 K)	U_L	5	Inside pipe diameter, (mm)	D_i	20
Heat conductivity of absorber plate (W/mK)	k	400	Inside pipe width, (mm)	W_i	8
Solar collector length, (mm)	L	2044	Inside pipe height, (mm)	H_i	39,25
Solar collector width, (mm)	B	1050	Inside pipe dimension, (mm)	B_i	17,72

For the input parameters, the data from the literature [1] were used, while the standard dimensions of the solar collectors were adopted. The results obtained by the calculation from the input Form shown in Figure 6 are shown in Table 2.

Table 2. Efficiency from algorithm calculation

Absorber cross-section profile,	*F', solar collector efficiency factor*	*F, standard rib efficiency*
Circular	0,969	0,994
Rectangular	0,901	0,994
Square	0,972	0,993

Figure 7 shows the generated CAD model, which is derived from the input parameters entered in communication form. The model shown corresponds to a solar collector with an absorber with square cross-section pipes.

Figure 7 – Generated solar collector CAD model

5 Conclusion

In this paper an algorithm for automatic generation of CAD models and calculation of efficiency of solar collectors is presented. Collectors with three different types of absorbers are considered: absorber with circular pipes, absorber with rectangular pipes and square pipes absorber. Before the algorithm was made, a mathematical model for all three types of absorbers was defined.

From Table 2 it can be concluded that the efficiency of individual ribs of all three types of collectors is similar, while the values for total efficiency are slightly different. The highest efficiency for the given input parameters is with a square tube collector. In relation to it, the circular tube collector has an insignificantly lower efficiency of about 0.2%. The rectangular pipe collector has the lowest efficiency of all three types of collectors, and it is smaller by 7.5% of the collector with square pipes collector. As in practice, the most acceptable solution with circular pipes is the most commonly used.

Further research of this problem would require taking into account all types of materials used in the making of solar collectors. In order to achieve an optimal solution to this problem it is necessary to use multi-criteria optimization, with experimental verification of results.

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