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Simulation Application for Optimization of Solar Collector Array

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ABSTRACT
Solar systems offer a comparatively low output density , so increasing the output always means a corresponding increase in the size of the collector area. Thus collector arrays are occasionally constructed (i.e. with different azimuth angles and/or slopes, which be imposed by the location and structure available to mount the collector.
In this paper is developed simulation application for optimization for the solar collector array position and number of collectors in regard of maximum annual energy gain and thermal efficiency. It is analyzed solar collector array which has parallel and serial connected solar collectors with different tilt, orientation and thermal characteristics. Measurements are performed for determine the thermal performance of the system.
Using the programming language INSEL it is developed simulation program for the analyzed system where optimization is done through parametric runs in the simulation program. Accent is given on the SE orientated collectors regarding their tilt and number, comparing two solutions-scenarios and the current system set situation of the in means of efficiency and total annual energy gain. The first scenario envisages a change of angle from 35 to 25 solar panels on the SE orientation, while the second scenario envisages retaining the existing angle of 35 and adding additional solar collector. Scenario 1 accounts for more than 13% energy gain on annual basis while Scenario 2 has 2% bigger thermal efficiency.
Keywords–solar collector, array, tilt angle, efficiency, energy

I. INTRODUCTION

According the IEA(International Energy Agency) buildings represents 32% of the total final energy consumption and converted in terms of primary energy this will be around 40%. Inspected deeper, the heating energy consumption represents over 60% of the total energy demand in the building. Space heating and hot water heating account for over 75% of the energy used in single and multi-family homes. Solar energy can meet up to 100% of this demand. [1]

Solar technologies can supply the energy for all of the building's needs—heating, cooling, hot water, light and electricity—without the harmful effects of greenhouse gas emissions created by fossil fuels thus solar applications can be used almost anywhere in the world and are appropriate for all building types. The heat energy demand for heating the buildingand /or DHW determines the solar collectors area which often can exceed the available optimal area for installation of the collectors. Thus collectors are connected in arrays which open a variety of combinations regarding the number of collectors hydraulics and layout. It is obvious that high output can be provided in a relatively small space by boiler systems and heat pumps. This is not possible with solar thermal systems. Solar systems offer a comparatively low output density ; increasing the output therefore always means a corresponding increase in the size of the collector area.

Thus collector arrays are occasionally constructed (i.e. with different azimuth angles and/or slopes). These arrangements may be imposed by the location and structure available to mount the collector.

If the output is to be doubled, also double the collector area. Collectors cannot be built in any size, since the installation options, installation area and static set natural limits.

Consequently, large solar thermal systems are composed of many individual collectors linked together. This requires careful planning of the collector orientation, layout and hydraulics.
One of the biggest, most common, problems with solar thermal systems in the past has been incorrectly laid out collector arrays.

The building usually dictates that collector arrays are installed with different orientation. In that case it must be decided whether the system is operated as a whole or in separate parts (with individual pumps or a completely separate solar circuit). The optimization and recommendations concerns for flat plate solar collectors. [2]

Flat-plate solar collectors have potential applications in HVAC system, industrial thermal process, and solar engineering. They are the most economical and popular in solar domestic heating water system since they are permanently fixed in positions, have simple construction, and require little maintenance. The design of a solar energy system is generally concerned with obtaining maximum efficiency at minimum cost.

The major share of the energy, which is needed in commercial and industrial companies for production, processes and for heating production halls, is below 250°C. The low temperature level (< 80°C) complies with the temperature level, which can easily be reached with flat plate solar thermal collectors.

Owing to the many parameters affecting the solar collector performance, attempting to make a detailed analysis of a solar collector is a very complicated problem. Fortunately, a relatively simple analysis will yield very useful results, Duffie Beckmann [1991]. Mainly there are two general test methods have been followed in analysing the flat-plat solar collector performance: the stationery test and the dynamic solar collector model. Dynamic models were initially based on a one-node model. This kind model attempts to include the effects of thermal capacitance in a simple fashion. The one-node model was then upgraded to multi-node model was introduced, considering the collector consists of multiple nodes each with a single temperature and capacitance. The solar collectors stationary models presented by Hottel and Woertz [1942], Hottel and Whillier [1985] and Bliss [1959] were based on a zero-capacitance model, the effects of thermal capacitance on the collector performance are neglected. In an effort to include the capacitance effects on the collector performance, Close [1967] developed the one-node capacitance model. In which he assumes that the capacitance is all lumped within the collector plate itself. The limitations of this model are the assumptions that the temperature distribution along the flow direction is linear, and the fluid and tube base are at the same temperature. This model has been shown to be useful in predicting the performance of the collector including the collector storage effect due to the thermal capacitance. The working conditions of the solar collector are unavoidably transient and non-uniformity flow is present; therefore the need for a transient and multidimensional model arises. However, a detailed modelanalysis considers these aspects gives complicated governing equations that are difficult to solve. Therefore different models with simplified assumptions were developed in an attempt to predict the solar collector performance under transient conditions. [3]

Kamminga [1985] derived analytic approximations of the temperatures within a flat-plate solar collector under transient conditions. Oliva et al. [1991] introduced a numerical method to determine the thermal behaviour of a solar collector where distributed-character model considers the multidimensional and transient heat transfer properties that characterize the solar collector, while the flux of heat transfer by free convection at the air gap zone has been evaluated using empirical expressions and the solar irradiance was integrated to be constant hourly. Scnieders [1997] analyzed one stationary and five different dynamic models of solar collectors in different ways. Articles analyzing the possibilities of utilizing Artificial Neural Networks (ANN) to predict the operating parameters of flat-plate solar collector have been published. Molero et al. [2009] presented a 3-D numerical model for flat-plate solar collector considers the multidimensional and transient character of the problem. The effect of the non-uniform flow on the collector efficiency was quantified and the degree of deterioration of collector efficiency was defined. Cadaflach [2009] has presented a detailed numerical model for flat-plate solar collector. He noticed that the heat transfer through the collector is essentially 1-D; some bi-dimensional and three-dimensional effects always occur due to the influence of the edges and the non-uniform effects, for example, there are temperature gradients in both the longitudinal and transversal directions. However, the main heat transfer flow remains one-dimensional. The model was an extension of the model of Duffie and Beckman [1991]. The model was verified by an experiment data of single and double glazed collectors under steady-state conditions.

II. ANALYZED SYSTEM DESCRIPTION

The considered system of solar thermal collectors are used for preparation of domestic hot water for hotel located in Ohrid with position defined with latitude 41.12 N and longitude 20.8 E. Solar collectors mounted on the roof which has a northeast - southwest orientation . The total area of flat solar collectors is defined to meet the needs of domestic hot water (DHW) . However the optimum available roofs arehassouthwest orientation which has insufficient area for setting all collectors. Accordingly collectors are placed with different orientations and slopes..

Thus in this paper is developed a model that takes into account the position and hydraulic connection between solar collectors and verified by the measurements. In the simulation of the operation of solar collectors utilising multi node model. Simulation of the solar collector performance is used the graphical programing language INSEL.

Optimization is performed with the developed simulation application introducing parametric analysis. It is performed to optimize the position of find solution for the collector array connection and position having maximal annual energy gain and thermal efficiencyThe energy yield and efficiency of both partial arrays is calculated and then compared with the different proposed solutions. The results of the paper actually represent directions and recommendations for optimal connections and installation of solar arrays in regard of their position and hydraulic connections . The proposed solutionfor the collectors will enable a flexible response to the most diverse requirements made of collector array, resulting from the required size and the preconditions of the roof.

III. MATHEMATICAL MODEL FOR SOLAR FLAT PLATE COLLECTOR

In this part will be derived the mathematical model describing the thermal performance of the solar collector over time.

As an input parameters for the mathematical model are the geometric, thermal and optical characteristics of the each component of the solar collector also the climatic and working conditions under which the collector will operate.

The detailed configurations of the solar collectors may be different from one collector to the other, but in general the basic geometry is similar for almost all of the flat plate collectors. The output results from the derived model are the useful transformed heat energy, thermal efficiency in regard the aperture area and the outlet temperature. The mathematical model in general consist two parts: outside absorber energy balance (heat transfer between the absorber and the environment) and inside absorber energy balance (heat transfer between absorber plate and working fluid). In the outside energy balance is considered the radiation and natural convection heat transfer which arises between the absorber plate and the cover i.e. radiation from the absorber plate to the cover, conduction through the cover and radiation and convection from the cover to the outside atmosphere. The inside energy balances considers the heat transfer from the absorber surface to the working fluid through conduction of the welded pipe and convection between the inside pipe surface and the working fluid.

Deriving the mathematical model of the solar flat plate collector requires number of simplifying assumptions but without obscuring the basic physical situation: These assumptions are as follows:

- Construction is of sheet and parallel tube type
- Temperature gradient through the covers is negligible
- There is one dimensional heat flow through the back and side insulation and through the cover system
- The temperature gradient around and through the tubes is negligible
- Properties are independent of temperature
- In calculating instantaneous efficiency the radiation is incident on the solar collector with fixed incident angle

The performance of the solar collector in steady state is described through the energy balance of the distribution of incident solar energy as useful gain, thermal losses and optical losses.

In steady state the performance of the solar flat plate collector can be describe with the useful gain Q_uEquation (1), which is defined as the difference between the absorbed solar radiation and the thermal loss:

$$Q_u = A_c[S - U_L(T_{as} - T_a)] \quad (1)$$

where A_c is the gross aperture area of the collector, S is the absorbed solar radiation per collector aperture area which value represents the incident solar radiation decrease for the value of the optical efficiency of collector . The second term in the brackets represents the collector thermal losses i.e. the U_L is the overall heat loss coefficient, T_{as} is the mean absorber temperature and T_a is the ambient temperature. The mathematical model is described through two modes i.e. as optical properties-efficiency and thermal properties of the solar flat plate collector.

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3.1 Solar radiation absorption

The incident solar energy on a tilted collector consists of three different distributions: beam, diffuse and ground reflected solar radiation. In this mathematical model the absorbed radiation on the absorber plate will be calculated using the isotropic sky-model:

$$S = I_b R_b (\tau\alpha)_b + I_d (\tau\alpha)_d \left(\frac{1 + \cos\beta}{2}\right) + \rho_g (I_b + I_d) + (\tau\alpha)_g \left(\frac{1 - \cos\beta}{2}\right) \quad (2)$$

where the subscripts b, d, g represents beam, diffuse and ground-reflected radiation respectively, I the intensity radiation on horizontal surface, $(\tau\alpha)$ the transmittance-absorbance product that represents the effective absortance of the cover plate system, β the collector slope, $\rho_g$diffuse reflectance of ground and the geometric factor R_b is the ratio of beam radiation on tilted surfaces to that on horizontal surface. The transmittance absorptance product is the main leading performance characteristic factor which determines the optical properties of the glazed solar flat plate collectors.

3.1.1 Reflection, transmission and absorption by glazing

The reflection of polarized radiation passing from medium 1 with refractive index $n_1$to medium 2 with refractive index n_2 is evaluated using the Fresnel equation:

$$r = \frac{I_r}{I_i} = \frac{1}{2}(r_\perp + r_\parallel) \quad (3)$$

where the $r_\perp$ and $r_\parallel$ represent the normal and parallel component respectively of the reflection which are calculated:

$$r_\perp = \frac{sin^2(\theta_2 - \theta_2)}{sin^2(\theta_2 + \theta_1)} \quad (3.1)$$

$$r_\parallel = \frac{tan^2(\theta_2 - \theta_2)}{tan^2(\theta_2 + \theta_1)} \quad (3.2)$$

$\theta_2$andθ_1 are the incident and refraction angles which are related to the refraction indices by Snell's law:

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{sin\theta_1} \quad (3.3)$$

he absorption of radiation in a partially transparent medium is described by Bouger's law [3] and the transmittance of the medium can be represented as:

$$\tau_{\alpha} = exp\left(-\frac{KL}{cos\theta_2}\right) \quad (3.4)$$

where K is the extinction coefficient and L thickness of the medium i.e. of the cover glass. The subscript notes that only absorption has been considered.

At and off-normal incident radiation, reflection is different for each component of polarization so the transmitted and reflected radiation will be polarized. The transmittance τ, reflectance ρ , and the absorptanceα of a single cover for incident unpolarised radiation can be found by average of the perpendicular and parallel components of polarization:

$$\tau = \frac{1}{2}(\tau_\perp + \tau_\parallel) \quad (3.5)$$

$$\rho = \frac{1}{2}(\rho_\perp + \rho_\parallel) \quad (3.5.1)$$

$$\alpha = \frac{1}{2}(\alpha_\perp + \alpha_\parallel) \quad (3.5.2)$$

The radiation incident on a collector consist of beam radiation form the sun, diffuse solar radiation that is scattered from the sky and ground-reflected radiation that is diffusely reflected from the ground.

The integration of the transmittance over the appropriate incident angle with an isotropic sky model has been performed by Brandemuehl and Beckman [2] who suggested and equivalent angle of incidence of diffuse radiation:

$$\theta_{d,e} = 59.7 - 0.1388\beta + 0.001497\beta^2 \quad (3.6)$$

where β is the tilt angle of solar collector. For ground-reflected radiation, the equivalent angle of incidence is given by:

$$\theta_{g,e} = 90 - 0.5788\beta + 0.002693\beta^2 \quad (3.7)$$

The fraction of the incident energy ultimately absorbed on the collector plate becomes:

$$(\tau\alpha) = \tau\alpha \sum_{n=0}^{\propto}[(1-\alpha)\rho_d]^n = \frac{\tau\alpha}{1-(1-\alpha)\rho_d} \quad (3.8)$$

where$\rho_d$can be estimated from equation 3.5.1. For angles of incidence between 0° and 180° the angular dependence relation has been employed from Duffie and Beckman [3]:

$$\frac{\alpha}{\alpha_n} = 1 - 1.5879\times10^{-3}\,\theta + 2.7314\times10^{-4}\,\theta^2 - 2.3026\times10^{-5}\,\theta^3 + 9.0244\times10^{-7}\,\theta^4 - 1.8\times10^{-8}\,\theta^5 + 1.7734\times10^{-10}\,\theta^6 - 6.9934\times10^{-13}\,\theta^7 \quad (3.9)$$

Where the subscript n refers to the normal incidence and θ is in degrees.

1.1.2 Thermal properties and heat loss coefficient of the solar flat plate thermal collector

Part of the absorbed solar energy in the solar collector is transferred to the working fluid-useful energy and the rest are the thermal losses quantified by the heat loss coefficient.

Useful energy transferred to the working fluid can be calculated with the following equation:

$$\dot{Q}_k = IA_a(\tau\alpha) - U_TA_b(T_{pm} - T_o) - U_bA_b(T_{pm} - T_o) - U_eA_b(T_{pm} - T_o) \quad (3.10)$$

Where I is the horizontal solar radiation, A_a, $A_b$collector aperture and backside area, U_T, U_b, U_e are the top, back and edge heat loss coefficients respectively of the collector [6]. Assuming that all of the losses are based on a common mean plate temperature $T_{pm}$the overall heat loss from the collector can be represented as:

$$Q_{loss} = U_LA_C(T_{pm} - T_a) \quad (3.11)$$

whereU_L is the overall loss coefficient represented as a sum of the top, back and edge heat loss coefficient.

2.2 Mathematical model of solar flat plate collectorused in the simulation

From the above defined equations can be concluded that it is very difficult to develop detailed dynamic simulation models for each available single collector type with product specific variations. Therefore, in this paper will be used a simplified dynamic simulation model, which is based on the parameters of the harmonized collector test procedure described in EN 12975-2:2001 – part 2. Since these parameters are available for nearly all collectors, the developed model can be easily adapted to different collector types of different producers.

$$\dot{q}_{col} = \eta_0 G_t - a_1(T_{col,m} - T_a) - a_2(T_{col,m} - T_a)^2$$

and the overall collector efficiency is:

$$\eta_{col} = \eta_0 - a_1\left(\frac{T_{col,m} - T_a}{G_t}\right) - a_2\frac{\left(T_{col,m} - T_a\right)^2}{G_t} \quad (3.12)$$

If the collector mean temperature $T_{col,m}$ is approximated by the mean temperature of the collector inlet $T_{col,in}$ and collector outlet $T_{col,out}$ and the overall collector efficiency is:

$$T_{col,m} = \frac{T_{col,in} + T_{col,out}}{2} \quad (3.13)$$

hen the useful heating power of the collector is given by

$$\dot{Q}_{col} = \eta_{col} \cdot G_t \cdot A = \dot{m}c_p\left(T_{col,out} - T_{col,in}\right) \quad (3.14)$$

where$\dot{m}$ is the mass flow rate and c_p is the specific heat capacity. The solution of equation 3.8 and 3.10 for the collector outlet temperature leads to a quadratic equation with the solutions:

$$T_{col,out\,1/2} = -\frac{p}{2} \pm \sqrt{\left(\frac{p}{2}\right)^2 - q} \quad (3.14)$$

and the coefficients:

$$p = 2\frac{a_1}{a_2} + 2T_{col,in} - 4T_a + \frac{2\dot{m}c_p}{Aa_2} \quad (3.15)$$

$$q = \left(2\frac{a_1}{a_2} + T_{col,in} - 4T_a - \frac{2\dot{m}c_p}{Aa_2}\right) \cdot T_{col,in} - 4 \cdot \left(\frac{G_t\eta_0}{a_2} + \frac{a_1T_a}{a_2} + {T_a}^2\right) \quad (3.16)$$

The advantage of this model is that requires only the efficiency parameters of the collector zero efficiency η_0, linear heat loss coefficient a1, and quadratic heat loss coefficient a2 together with the reference gross aperture or absorber area. These values are provided on the product datasheet of the collectors. This block in the software simulates a solar.

collector on the basis of the collector equation which doesn't take into consideration the heat capacity of the collector.[7]

IV. SOLAR COLLECTOR ARRAY

Connecting the collectors with one set of manifolds makes it difficult to ensure drainability and low pressure drop. It will be also difficult to balance the flow so as to have same flow rate through all collectors.

An array usually includes many individual groups of collectors, called modules, to provide the necessary flow characteristics. To maintain balanced flow, an array or field of collectors should be built from identical modules. A module is a group of collectors that can be grouped in parallel flow and combined series-parallel flow.

The choice of series or parallel arrangement depends on the temperature required from the system. Connecting collectors in parallel means that all collectors have input the same temperature, whereas when a series connection is used, the outlet temperature from one collector (or row of collectors) is the input to the next collector (or row of collectors).

4.1 Layout of single and multi-array systems

In single array systems, the collector assembly is connected directly with one return and one flow, respectively. Within the collector assembly there are various options for linking the collectors.

As partial arrays can assembled into multi array system. This is best achieved when all partial arrays (collector assemblies) are of the same size, are linked in the same way and consequently have the same pressure drop. Multi-array systems with unequal partial arrays (regarding size, shading or pressure drop) must be balanced.

Performance data for a single panel cannot be applied directly to a series of connected panels in the flow rate through the series is the same as for the single panel test data. If N panels of same type are connected in series and the flow is N times that of the single panel flow used during the testing then the single panel performance data can be applied. If two panels are considered connected in series and the flow rate is set to a single panel test flow, the performance will be less than if two the two panels were connected in parallel with the same flow rate through each collector. The useful energy output from the two collectors connected in series is given by: (Morrison, 2001) :[8]

$$Q_k = A_cF_R[(\tau\alpha)G_t - U_L(T_i - T_a) + (\tau\alpha)G_t - U_L(T_{o1} - T_a)] \quad (1)$$

Where T_{o1} is the outlet temperature from the first collector given by:

$$T_{o1} = \frac{F_R[(\tau\alpha)G_t - U_L(T_i - T_a)]}{mc_p} + T_i \quad (2)$$

Substituting T_{o1} in the previous equation

$$Q_k = F_{R1}\left(1 - \frac{K}{2}\right)[(\tau\alpha)_1G_t - U_{L1}(T_i - T_a)] \quad (3)$$

Where F_{R1}, U_{L1} and $(\tau\alpha)_1$ are factors for the single panel tested, and K is:

$$K = \frac{A_cF_{R1}U_{L1}}{mc_p} \quad (4)$$

For N identical collectors connected in series with the flow rate set to single panel flow rate, set to single panel flow rate,

$$F_R(\tau\alpha)_{series} = F_R(\tau\alpha)_1\left[\frac{1-(1-K)^n}{NK}\right] \quad (5)$$

$$F_RU_{L_{series}} = F_{R1}U_{L1}\left[\frac{1-(1-K)^n}{NK}\right] \quad (6)$$

If the collectors are connected in series and the flow rate per unit aperture area in each series line of collectors is equal to the test flow rate per unit aperture area in each series line of collectors is equal to the test flow rate per unit aperture area, then no penalty is associated with the flow rate other than an increased pressure drop from the circuit.[9]

4.2 Solar collector system and measurements description

Measurements and analyzes were performed on an existing system of solar collectors placed at hotel for heating DHW located in Ohrid, R.Macedonia. The complete system installation layout is given on Fig.1.

There are ten flat plate collectors each with area of 2 m^2 with characteristics given in Table 1 placed with SW orientation of the roof and same inclination like the roof 25°. Another four flat plate SE orientated solar collectors are tilted under 35° with characteristic given in Table 2.

The system is regulated by differential controller which controls the circulation in the system working heat transfer fluid i.e. switches on/off the circulating pumps in regard of the temperature difference between the boiler temperature and the solar collector outlet measured with temperatures probes marked on Fig.1 with "TS".

Regarding the hydraulics, collectors are grouped in two modules which are parallel connected. Each of the modules consists of two sub modules: first has five SW orientated solar collectors and second has two SE positioned solar collectors. The first and second submodule i.e. the SW and SE solar collectors are in serial connection.

Measurements are performed in order to determine the system thermal behavior and response during the day function. Thus the measuring points are marked on Fig.1: Temperatures data loggers using thermocouples are measuring: the main inlet collector temperature "3", serial collector's inlet temperature "2" and main outlet temperature "2".

Table 1. Solar collector technical data

Collector name	Aperture area (Aa)	Gross area (AG)	Power output per collector unit G=1000 W/m² Tm-Ta 0 K	10 K	30 K	50 K	70 K
	m²	mm	W	W	W	W	W
Sun Pan	1.83	2.02	1389	1324	1168	1000	820
Collector efficiency parameters related to aperture area (Aa)				ηoa	0.754		
				a1a	4.45		
				a2a	0.0041		

Table 2. Solar collector technical data

Collector name	Aperture area (Aa)	Gross area (AG)	Power output per collector unit G=1000 W/m² Tm-Ta 0 K	10 K	30 K	50 K	70 K
	m²	mm	W	W	W	W	W
ESK 2.5 SB	2.35	2.5	1771	1667	1449	1224	992
Collector efficiency parameters related to aperture area (Aa)				ηoa	0.754		
				a1a	4.45		
				a2a	0.0041		

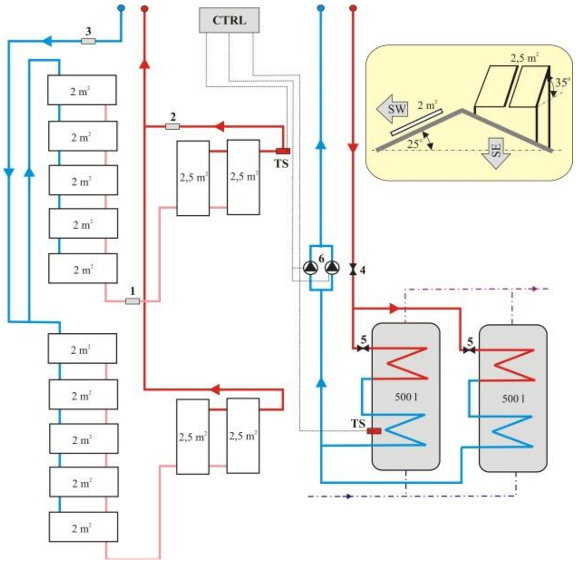

Figure 1. Connection scheme of the analyzed system

The valves "4", "5" and "6" are balancing valves used to regulate and measure the mass flow rate of the working fluid which was set during the measurements on 0.27 kg/s. Pumps frequency work is monitored through the data logger which records the supply voltage, which has value of 220 V when the pumps are on, and 0 V when they are off.

Recording frequencies are set: for the temperatures every 5 min, the pumps every 30 sec and for the horizontal global solar radiation every 30 min.. The measurement period is for one day i.e. for 02.08.2013.

On Fig.2 graphically is presented the hourly values W/m2 for the horizontal global solar radiation over the measuring period.

On Fig. 3 are presents the results from the temperature distribution over the time i.e. the main inlet marked as on Fig.1 with "3" and main outlet marked with "2".

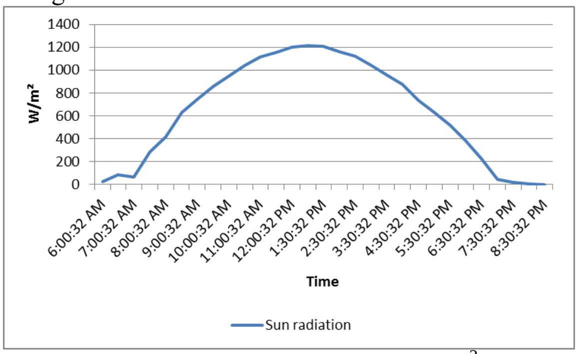

Figure 2. Horizontal global radiation W/m^2, Ohrid, Macedonia

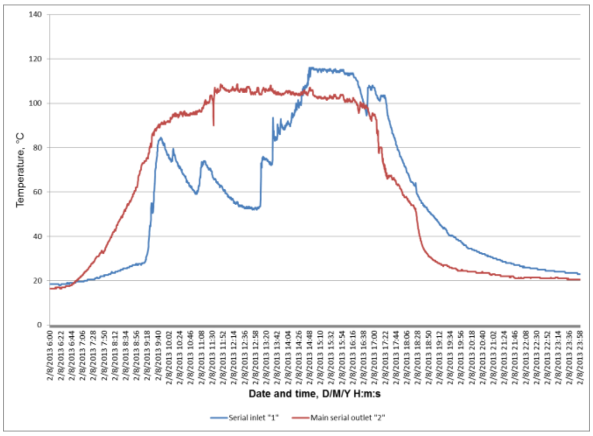

Figure 3. Temperature change at the solar collector serial inlet and outlet

From Fig.3 clearly can be noticed that at some period of the day the inlet temperature of working fluid is bigger from the outlet temperature i.e. in the collector occurs a reverse process of cooling instead of heating. The temperatures deviation begins around 14:30 and keeps its stream until the end of the day. This could be explained with the collector orientation i.e. the SW orientated collectors in the afternoonreceives more solar radiation resulting in bigger temperature gradient which can not be continued with the SE orientated collectors due to the lower solar intensity. Knowing that the position of the roof only allows to be changed the SE collectors tilt or to be added more collectors in order to keep the system efficiency on acceptable level and avoid working fluid cooling in the afternoons.
The next measurements are done between the days of 06.08 and 07.08 where are measured and recorded the same parameters: solar radiation, temperatures of the cold water entry into solar collectors "3", the output of five parallel "1" and the main outlet "2" as marked on Fig.1 and the pump work is presented on Fig.5

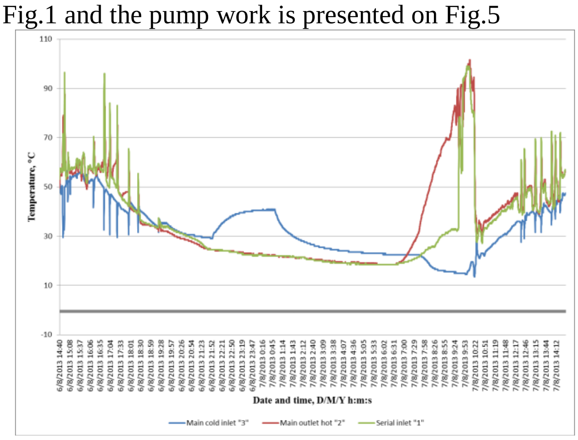

Figure 4. Hourly temperature distribution measured at points “1”, “2” and “3”according Fig.1

On the diagram there are certain peaks where the pump was suspended after beginning work at the initial circulation recorded temperatures. Is worthwhile noting here that the reverse process occurs in the afternoon hours which is marked when the working fluid serial inlet temperature “1” has bigger value compared to the main hot outlet “2”.

To be more convenient to observe the changes in the temperatures of the working fluids through the collectors, the diagram in Fig.4its divided into two intervals, i.e. morning and afternoon.

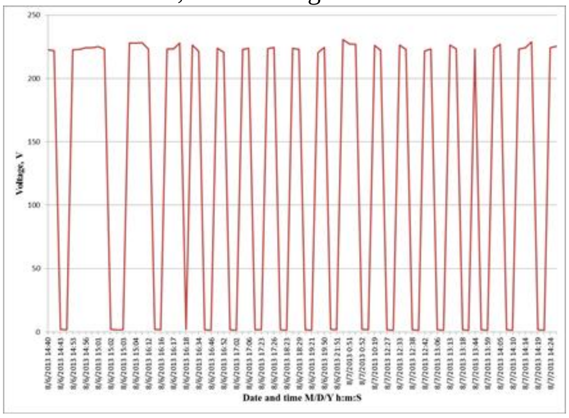

Figure.5 Frequency intervals of pump work

On Fig.5can be seen that the pump was working from 22:00 until 01:00 which was made by mistake of the controller, but it didn’t influenced on the analysis.
Based on the work of the pump it is carried out a selection on temperature measurements data i.e. selection is made only on the values when the pumps were operational.

Figure 4presents the changes in temperature in the serial connections “1” and “2” for the periodon 08.06.2013 between 10:20 huntil 13:16.

According the presented results from the diagram on Fig.4 and Fig.5 can be concluded that in the morning occurs the normal work of the collectors i.e. the working fluid temperature is increased, but in the afternoon begins the reverse process in the serial connected collectors.

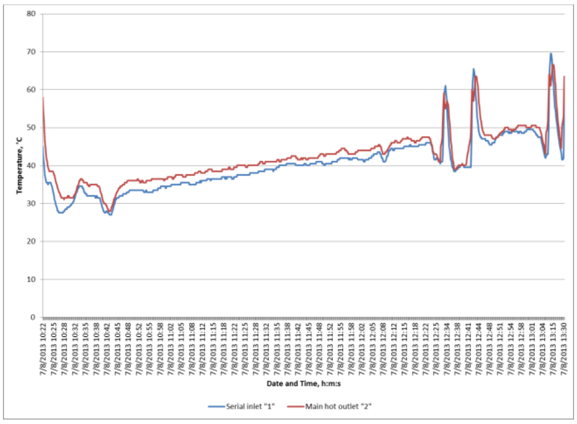

Figure.6 Hourly measured temperature distribution at the serial collectors water inlet/outlet-afternoon period

Reduction occurs in the afternoon part of the day as can be seen on Fig.6 i.e. Fig.7 as a consequence of the position of the serial collectors is SE where the incidence solar radiation on the surface of the collector is not sufficient to increase the temperature of the input fluid.

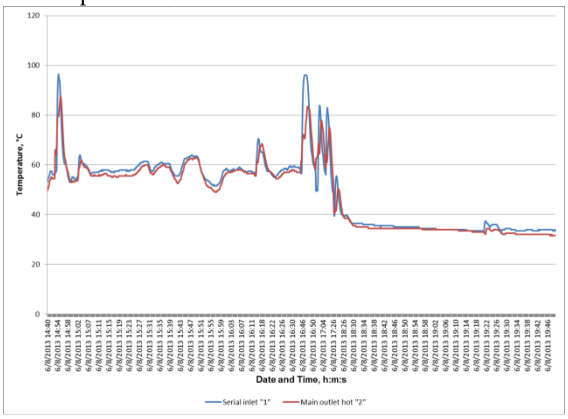

Figure.7 Hourly measured temperature distribution at the serial collectors water inlet/outlet-afternoon period

Therefore it is developed the simulation program aiming to find an optimal solution in regard of the slope and orientation of the collectors or supplemented the SE orientated solar collectors with another additional solar collector i.e. two in total for the whole system.

V. SIMULATION APPLICATION DEVELOPEMENT

The software that is used in the thermal analysis is called INSEL which is acronym for INtegratedSimulation Environment Language. INSEL it's not a simulation program but provides an integrated environment and a graphical programing language for the creation of simulation applications. The basic idea of the software is to connect blocks to blocks diagrams that express a solution for a certain simulation task.

In the graphical programming language the data flow plays the key role. This language provides graphical symbols which can be inter connected to build a larger structures. The graphical symbols represent mathematical functions and real components like: solar thermal collectors, photovoltaic modules, wind turbines and batteries, for example, or even complete technical systems of any kind.

Fundamental blocks, basic operations and mathematical functions of the environment are provided in a dynamic library. It contains tools like blocks for date and time handling, access to arbitrary files, blocks for performing mathematical calculations and statistics, blocks for data fitting, plotting routines etc.

Energy meteorology and data handling are available as library. This library contains algorithms, like the calculation of the position of the Sun, spectral distribution of sunlight, radiation outside atmosphere. A large data base provides monthly mean values of irradiance, temperature and other meteorological parameters. Generation of hourly radiation, temperature, wind speed, and humidity data from monthly means is possible. Further, diffuse radiation models, conversion of horizontal data to tilted are included.

Most of the measurements or available data for solar radiation are for horizontal surfaces which should be converted into values of solar radiation on the tilted surface. There are plenty of models which can be used to convert horizontal data to tilted.[?} Most of them use the same approach: in a first step the radiation data are split up into their beam and direct use fractions by some statistical correlation, and in a second step both components are converted to the tilted surface. Concerning the beam part Gbh the conversion can be done by pure geometry, in the case of the direct use radiation some assumption about its distribution over the sky dome must be made.

Since it is for tilted surfaces this portion depends on the ground reflectance, or albedo which having a minor role will be set constant to ρ=0,2.

The correlations which calculate the diffuse use fraction are based on the clearness index kt. defined as the ratio between the global radiation that arrives at the Earth`s surface on a horizontal plane Gh and its extraterrestrial pendant Goh.

The optimization procedure is an program assembly of several subprograms.

On the Fig.8 is presented the graphical appearance of the simulation application in which mathematically is described the analyzed system. The measured values such as: sun radiation, collectors orientation, tilt angles and hydraulic connections are used as inputs in thedeveloped simulation application.

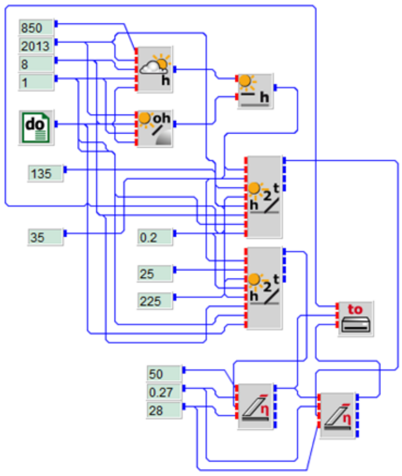

Figure 8. Graphical appearance of the simulation application

Multiple blocks are used such as the block "GENGH" is used to transform the value of daily average solar radiation (850 W/m2) in hourly values , while with the block G2GDH using the model ofHollandsis used to derive hourly values of diffuse radiation. The model of Hay i.e. with the block"GH2GT"are obtained as output valuesfor the incident solar radiation on the collectors surface. When calculating the values of solar radiation using Latitude 41.11 N and Longitude 21.8 E. For the mass flow is used the measured value of 0,27 kg / s. The solar collectors mathematical model uses as input parameters presented in Table 1 and Table 2.
In the simulation application the mathematical model for the solar collector's considers water inlet temperatures, where are considered only their average annual values. Thus the annual average inlet temperature is used as parameter in the simulations i.e. in determine the thermal efficiency and energy gain.

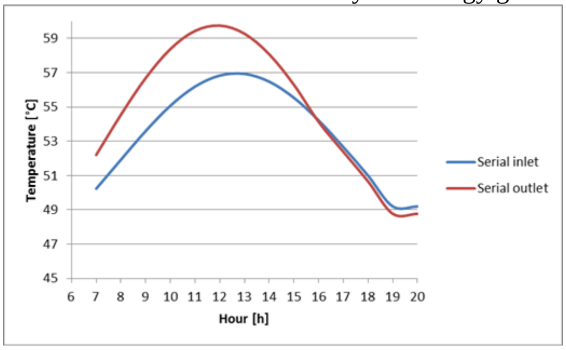

Figure 9. Inlet/outlet water hourly temperatures variations

On Fig.10 are presented results from the simulation of the hourly temperature distribution for the serial inlet "1" and main hot outlet "2".
Criteria for selection of the optimal solution considers between the maximum thermal efficiency and maximum useful annual energy gain.
Efficiency is determined in regard of the tilt angle of the SE orientated collectors.

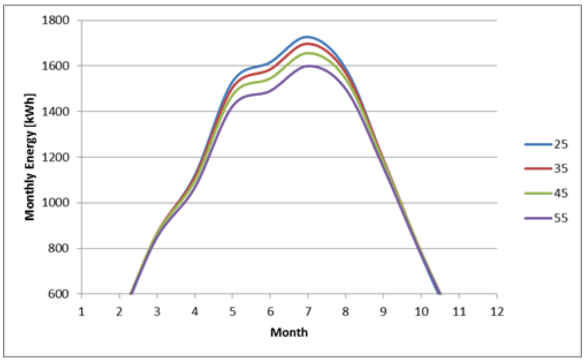

Figure 10. Collector array thermal efficiency in regard of tilt angle

According to the diagram on Fig.10 can be concluded that the maximum thermal efficiency will be achieved if the SE orientated collectors are tilted on 25°. The main difference appears in summer months while in winter it doesn't differs significant.
Further is performed analysis of the monthly values of the energy gain in regard of different tilt angles of the SE orientated collectors.

The diagramspresented on Fig. 9 and Fig. 10 indicates that the main differences between the efficiencies and monthly energy gains for the different tilt angles arise in the summer months i.e. between May and September. This means that the temperature at the collector inlet has significant influence on the system efficiency. Thus it is performed an analysis comparing two suggested scenarios for improving the system performances.

In Scenario 1 are considered same collectors but the SE orientated collectors are tilted on 25°, Scenario 2 considers increasing the number of SE orientated collectors i.e. three collectors with retaining the same tilt of 35°. The Scenarios are compared in regard of annual energy consumption and the thermal efficiency averaged on annual basis for the both set of collectors.

The results are presented on diagram on Fig.11 as a percentage difference between the annual energy gain using the the collectors tilt as parameter for angles between 25 – 55 in step of 10°, in regard of average annual inlet temperature.

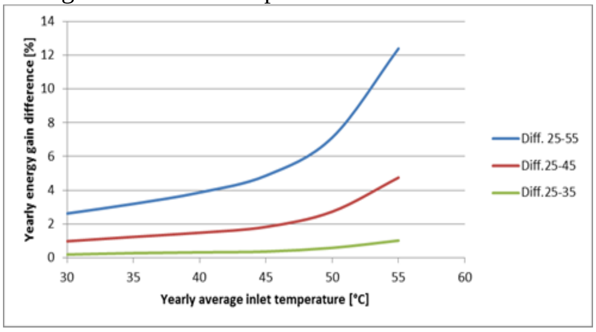

Figure 11. Difference of annual energy gain between collector tilted 25,35,45,55° in regard of temperature

The blue line indicates the biggest difference between collectors tilted 25° and 55° with nearly asymptotic growth as the average temperatures inlet values rises. Also the total annual energy gain is seriously affected by the value of the average inlet temperature.

VI. CONCLUSION

According the presented results the collectors optimal tilt angle would be 25° in regard of maximal thermal efficiency and energy gain.

Another examined possibility is retaining same tilt angle and adding additional solar collector to the SE oriented collector array having the same thermal performances as the array.

Simulation is performed between the current –base- situation, and the proposed Scenario 1 and Scenario 2 for different average inlet temperatures of the working fluid in regard of annual energy gain and efficiency. The simulation results are presented in Table 3.

In the first column are given annual average fluid inlet temperatures. In the next columns are presented the results for the Base case, Scenario 1 and Scenario 2 grouped in two main columns one for the annual

Table 3.Simulation results for energy gain and collector efficiency

Annaul average inlet temperature [°C]	Annual energy gain [kWh]			Annual average efficiency , η		
	Base	Scenario 1	Scenario 2	Base	Scenario 1	Scenario 2
30	35062.4	35157.6	40727.5	0.631	0.634	0.63
35	29707.9	29808.2	34435.6	0.399	0.404	0.398
40	24366.3	24455.4	28186.1	0.142	0.149	0.141
45	18703.6	18798.7	21556.6	-0.103	-0.093	-0.102
Averaged	26960.05	27054.975	31226.45	0.26725	0.2735	0.26675

energy gain and second for average thermal efficiency. It can be noticed that for temperatures of 45 °C and above the average thermal efficiency has “negative” values which are exactly due the fact that for higher main inlet temperatures the outlet temperatures from the SE orientated collectors decreases i.e. the working fluid is cooled.

The annual energy gain is biggest for the Scenario 2 but the annual average thermal efficiency has biggest value for Scenario 1. The explanation is logical because in the Scenario 2 we have one more collector which increase the useful energy gain but decreases the overall thermal efficiency because has higher inlet temperature value and thus lower temperature gradient.

Recommendations are toward Scenario 2 because it will have 14% increased energy gain compared to the current situation and only 2% efficiency decrease compared to Scenario 1.

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