THE SIMPLIFIED CALCULUS OF THE FLAT PLATE SOLAR COLLECTOR

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***Abstract* - The utilization of solar energy covers a large area of multiple applications. The solar installations for house water heating are the most frequently used. These installations have as primary component the flat plate solar collector, that makes the conversion of solar radiation into thermal energy. The paper presents a simplified methodology that allows to design the flat plate solar collector. Also, a program in Visual Basic v6.0 was created with the possibility of a report generating in Microsoft Excel, with the unit values calculated.**

Keywords: *solar flat plate collector, solar radiation, collector efficiency*

1. INTRODUCTION

The energy radiation conversion into thermal energy is done with the help of solar collectors. The solar collector is the essential element of a thermal-solar installation [1]. The solar installations are often used for house water heating.

The solar energy offer could be combined with the necessary hot water, approximately constant along the year. In the summer months, installation could fully cover the adequate quantity of energy [5]. The conventional heating installation must be kept as a back up, because even the summer has bad weather periods.

All over the year, the solar installation delivers up to 70% of the necessary of energy for house water heating. In the future, the value of a building will be evaluated based on the energy costs. Considerably savings can be achieved using these installations, and the cost amortization is being done based on the input, in 2÷5 years. In case of a large hot water input (hotels, motels, houses) the installation amortization can be achieved in maximum one year.

Nowadays, in the technical field of solar heating installations of buildings and house water preparing, they use a great diversity of solar collectors.

At the falling of the solar radiation on a certain surface, this radiation could be absorbed, transferred through the matter or reflected. Defining the following notions:

a. absorption (absorption factor) α, - the proportion between solar power radiation absorbed and that of the incident;

b. transmittance (transmission factor) τ, - the proportion between the radiant power transferred through the matter and the radiant incident power;

c. reflectance (reflection factor) ρ, - the proportion between the reflected radiant power and incident radiant power.

Figure 1 shows a schematic flat plate collector with the following component factors [1]:

- the collector transparent surface which plays a double role in achieving the greenhouse effect and as thermal isolation (the isolation is obtained by reducing the losses from energy convection caught by the absorption surface dictated by the transparent surface);
- the absorption surface is the primary element of the collector (the surface requirement is a maximum absorption at a smaller emittance);
- the heat exchanger is the factor that converts the solar energy radiation, which drops on an absorption surface, into thermal energy;
- the absorption surface thermal isolation is designed to obtain the heat reduction by conduction;
- the case - can be made out of wood (board, lamina of wood), plastic material or metal (steel, aluminum)-painted, so that it won't be degraded (also combinations of these materials can be used).

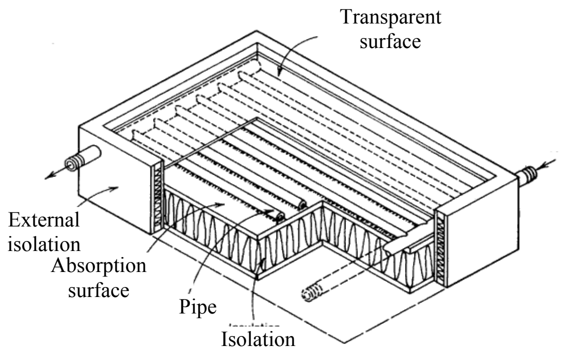

Figure 1. Flat plate solar collector [4]

2. THE FLAT PLATE COLLECTOR EFFICIENCY

The flat plate collector functioning principle is based on the absorption surface heating under the action of the solar radiation (direct or diffuse) [1].

The heat passes to the fluid that comes in thermal contact with the absorption surface, and then the

circulation of this fluid transfers the heat transferred to other elements of the installation that integrates the solar collector.
The performance of any solar collector is described by its own energy balance. This has the role to point out the way in which solar incident energy is distributed in useful energy and different losses.

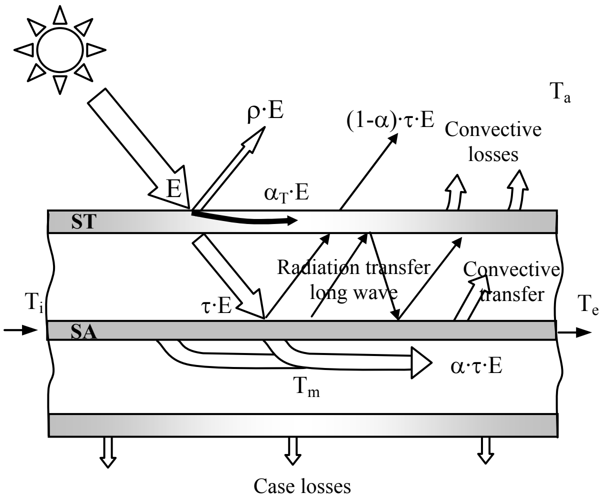

Figure 2. The heat losses of the flat plat solar collector ST – transparent surface; SA – absorption surface

Due to the solar radiation reflection on the transparent surface and also due to the solar radiation absorption in the transparent material, a part of the solar radiation doesn't reach the absorbing surface (optical losses) [2]. If the heat losses through solar radiation reflection are dependent on the angle on which the radiation drops (at angles higher than 45º the losses are highly increasing). The heat losses through transparent material absorption can be estimated by τ - transmission factor [5].

Type of material	Transmittance
Ordinary glass (for windowpane, 6 mm)	0,80
Floating glass (4 mm)	0,87
Low content of ferro oxide glass	0,91
Polycarbonates	0,70
Polyethylene membrane	0,82
Plexiglas (3 mm)	0,80
Tedlar	0,88

Table 1. Transmission factor values for different materials

Optical losses can be reduced by selecting certain selective collector surfaces (ferro oxide masking or special paint).
The quantity of heat caught by the absorption surface results in rising its temperature over the environment temperature.
The heat and thermal conduction losses are due to this difference of temperature (thermal losses) [2].

The heat losses unit (thermal losses) is closely connected with the solar collector constructive thermal characteristics and the temperature difference between the environment temperature and that of the absorption surface.
The efficiency of solar radiation transforming into heat is defined by the absorption surface factor α.

Type of material or absorption surface	Absorption α_{scurte}, short waves
Traditional materials	
Pure iron	0,44
Pure aluminum	0,10
Gilt copper	0,35
Oxide steel sheet	0,74
Black painted steel sheet	0,95
Graphite	0,78
Funingina	0,96
White paint	0,12÷0,18
Selective surfaces and materials	
Black chrome on a Nichel surface	0,95
Porosity ceramics on a steel surface	0,96
Black Nichel oxide on an aluminum surface	0,85÷0,93
Copper oxide Cu-O on a copper surface	0,90

Table 2. The absorption of certain materials and absorption surface

The thermal losses can be reduced by improving the isolation (increasing the number of transparent surfaces and using quality materials suitable for the isolation).
Only a part of the global solar radiation will be converted into heat. The global solar radiation E is defined by the properties of the transparent surface materials and those of the absorption surface, too [2].

$$Q_a = (\alpha\tau)\cdot E = A_0 \cdot E \quad \left[W/m^2\right] \qquad (1)$$

Q_a – the heat derived from the absorption surface, [W/m^2];
A_0 – optical factor – percentage from solar radiation intensity E that converts into heat on the absorption surface.
The solar collector optical losses represent the difference between solar radiation intensity and the absorbed solar radiation intensity by the absorption surface.

$$q_{opt} = E - Q_a \quad \left[W/m^2\right] \qquad (2)$$

The thermal losses are directly related to the temperatures difference T_m between the absorption surface and the environment T_a:

$$q_t = k\cdot(T_m - T_a) \quad \left[W/m^2\right] \qquad (3)$$

k – global losses factor, [W/m^2·°C], who varies from 1 to 30W/m^2·°C.
T_m – the average temperature of the absorption surface, [°C];

T_a – the average temperature of the environment, [°C].
The average temperature of the absorption surface (figure 3) is determinate with relation:

$$T_m = \frac{T_i + T_e}{2} \qquad (4)$$

T_i – thermal factor temperature at the collector entry, [ºC].
T_e - thermal factor temperature at the collector exit, [ºC].
The usable heat derived from the catcher Q_u is the heat transferred by the mentioned thermal factor and it actually represents the heat derived from the absorption surface and thermal losses from the collector (relation called Hottel-Whillier- Bliss):

$$Q_u = \alpha \cdot \tau \cdot E - k \cdot (T_m - T_a) \quad \left[\frac{W}{m^2}\right] \qquad (5)$$

In relation 5 the collector specific heat, the heat losses trough the transport of the thermal factor and the angle adjustment under which the solar radiation drops are being neglected.
The thermal efficiency is defined as the ratio between the resulted usable energy and the radiation intensity:

$$\eta = \frac{Q_u}{E} = \frac{\alpha \cdot \tau \cdot E - k \cdot (T_m - T_a)}{E} = \alpha \cdot \tau - k \cdot \frac{(T_m - T_a)}{E} \qquad (6)$$

The heat absorbed by the thermal factor is :

$$Q_t = \dot{m} \cdot c \cdot (T_e - T_i) \quad [W / m^2] \qquad (7)$$

$\dot{m}$ - thermal flow rate factor, [kg/s·m^2];
c - thermal capacity, [J/kg·ºC].
Because the heat absorbed by the thermal factor is equal to the usable heat derived from the solar collector we can write (figure 3):

$$\dot{m} \cdot c \cdot (T_e - T_i) = \tau \cdot \alpha \cdot E - k \cdot (T_m - T_a) \qquad (8)$$

as a result the flow rate factor becomes :

$$\dot{m} = \frac{Q_u}{c \cdot \Delta T} \quad \left[\frac{kg}{s \cdot m^2}\right] \qquad (9)$$

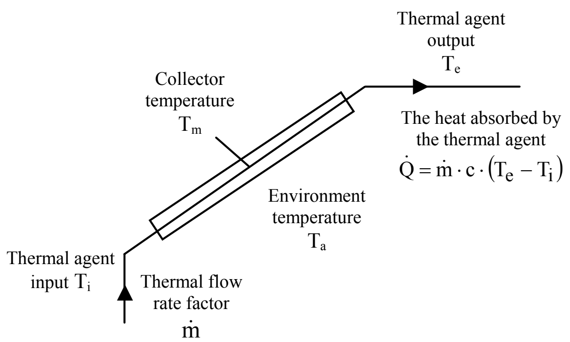

Figure 3. Energetically balance figure

Smaller temperature differences between the entry temperature and the exit temperature from collector implies high flow rate factor that runs through the collector. If the flow rate factor is low, then results a high temperature differences between the entry and the collector exit.
If the heat derived from the absorption surface is not absorbed by the thermal factor (the circulating pump is stopped or broke down), the temperature of the absorption surface rises to the value T_{max}, when the solar collector heat losses will be equal to the absorbed from the solar radiation. For a certain solar collector the temperature at null weight flow is determined by the relation:

$$T_{max} = \frac{E_{max} \cdot A_0}{k} \qquad (10)$$

These temperatures impose conditions upon materials used to build the solar catcher, but also the thermal factor selection and overpressure protection for thermal factor circuit.

3. NUMERICAL EXAMPLE

There is considered a flat solar collector for which it is determined the usable heat, the catcher efficiency, thermal factor weight flow and thermal factor maximum temperature.
Assuming that the solar radiation is perpendicular on the absorption surface, it will be consider that the intensity radiation value is E=1000W/m^2, transmission factor τ=0,85 and the absorption factor α=0,90.
According to presented methodology, there results:
- optical factor:

$$A_0 = \alpha \cdot \tau = 0{,}9 \cdot 0{,}85 = 0{,}765$$

- heat derived from the absorption surface:

$$Q_a = (\alpha\tau) \cdot E = A_0 \cdot E = 0{,}765 \cdot 1000 = 765 W / m^2$$

- optical losses:

$$q_{opt} = E - Q_a = 1000 - 765 = 235 W / m^2$$

Based on the following hypothesis:
k=3W/m^2°C;
T_a=22°C.
T_i= 18°C;
T_e=40°C.
There results:
- average temperature of the absorption surface:

$$T_m = \frac{T_i + T_e}{2} = \frac{18 + 40}{2} = 29^\circ C$$

- thermal losses:

$$q_t = k \cdot (T_m - T_a) = 3 \cdot (29 - 22) = 21 W / m^2$$

- usable heat derived from the collector:

$$Q_u = \alpha \cdot \tau \cdot E - k \cdot (T_m - T_a) = 765 - 21 = 744 W / m^2$$

- thermal efficiency:

$$\eta = \frac{Q_u}{E} = \frac{744}{1000} = 0{,}744 \rightarrow 74{,}4\%$$

- thermal flow rate factor:

$$\dot{m} = \frac{Q_u}{c \cdot \Delta T} = \frac{744}{4185{,}5 \cdot 7} = 0{,}025 kg / s \cdot m^2$$

- maximum temperature of the absorption plate:

$$T_{max} = \frac{E_{max} \cdot A_0}{k} = \frac{1000 \cdot 0{,}765}{3} = 255^\circ C$$

Based on presented methodology it has been conceived a software application under Visual Basic 6.0. The software application allows the evaluation of the collector efficiency for some different values of the radiation intensity, the absorption factor corresponding to the absorbent surface material and the gradient temperature between the output and input thermal agent temperatures that flow on the collector (figure 3). The calculated values are transferred to a Microsoft Excel application.

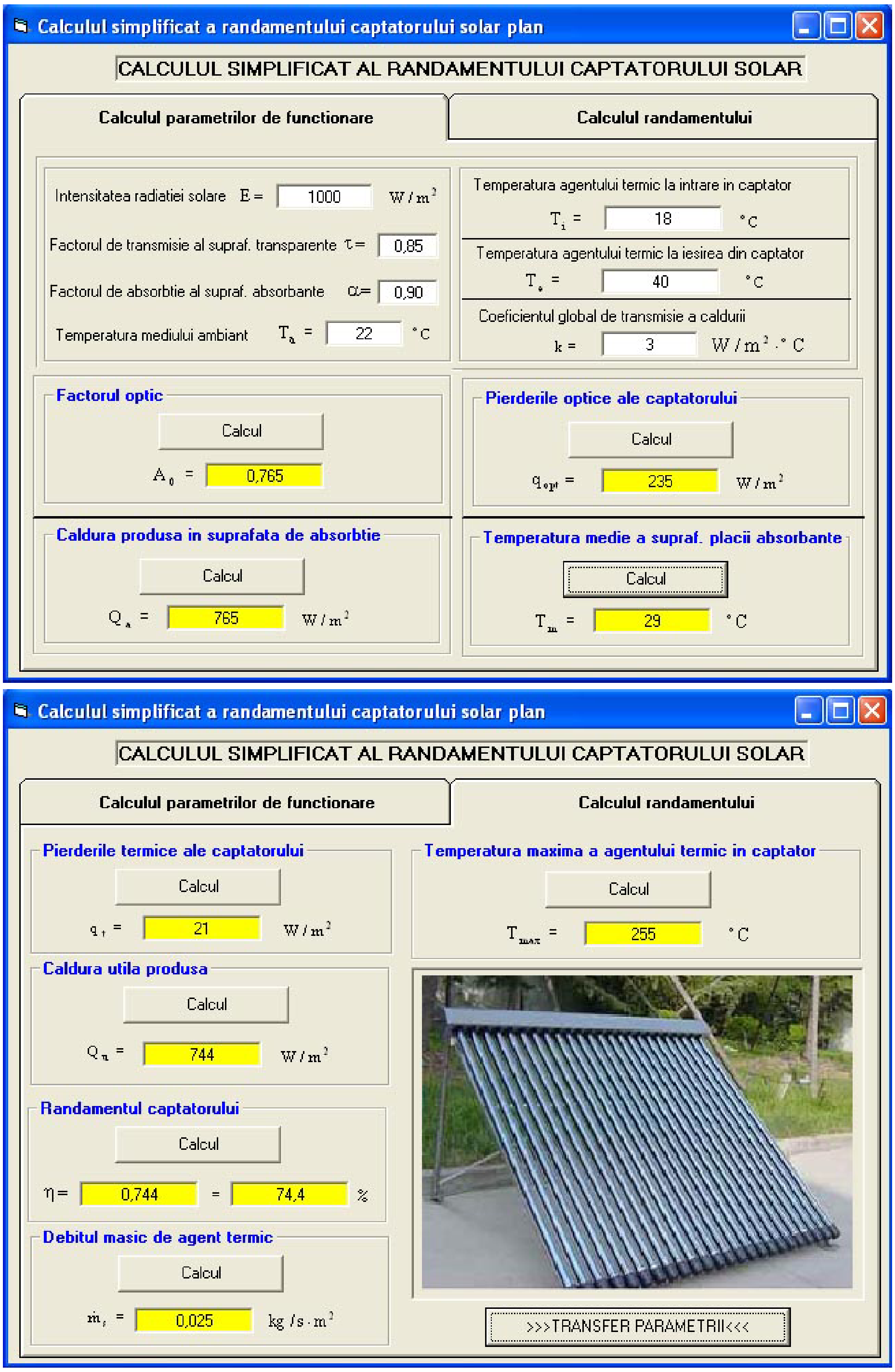

Figure 4. Energy efficiency for the flat plate collector indicators using a software application

Nr. crt.	Q_a [W/m^2]	q_{opt} [W/m^2]	q_t [W/m^2]	k [W/m^2·^{o}C]	Q_u [W/m^2]	$\dot{m}_s$ [kg/s·m^2]	T_{max} [^{o}C]	η_t [%]
α=0,35 (gilt copper); τ=0,8; E=400; T_a=20; T_i=18; T_e=55								
1.	112	288	49,5	3	62,5	0,001	37,34	15,62
α=0,74 (oxide steel sheet); τ=0,8; E=400; T_a=20; T_i=18; T_e=55								
2.	236,8	163,2	49,5	3	187,3	0,003	78,93	46,82
α=0,95 (black chrome); τ=0,8; E=400; T_a=20; T_i=18; T_e=55								
3.	304	96	49,5	3	254,5	0,004	101,34	63,62
α=0,35 (gilt copper); τ=0,8; E=800; T_a=20; T_i=18; T_e=55								
4.	224	576	49,5	3	174,5	0,003	74,67	21,81
α=0,74 (oxide steel sheet); τ=0,8; E=800; T_a=20; T_i=18; T_e=55								
5.	473,6	326,4	49,5	3	424,1	0,006	157,87	53,01
α=0,95 (black chrome); τ=0,8; E=800; T_a=20; T_i=18; T_e=55								
6.	608	192	49,5	3	558,5	0,008	202,67	69,81
α=0,35 (gilt copper); τ=0,8; E=1000; T_a=20; T_i=18; T_e=55								
7.	280	720	49,5	3	230,5	0,003	93,34	23,05
α=0,74 (oxide steel sheet); τ=0,8; E=1000; T_a=20; T_i=18; T_e=55								
8.	592	408	49,5	3	542,5	0,008	197,34	54,25
α=0,95 (black chrome); τ=0,8; E=1000; T_a=20; T_i=18; T_e=55								
9.	760	240	49,5	3	710,5	0,01	253,34	71,05
α=0,95 (black chrome); τ=0,8; E=1000; T_a=24; T_i=18; T_e=55								
10.	760	240	37,5	3	722,5	0,014	253,33	72,25
α=0,95 (black chrome); τ=0,8; E=1000; T_a=24; T_i=20; T_e=55								
11.	760	240	40,5	3	719,5	0,013	253,34	71,95

Table 3. Computed values according to software application

4. CONCLUSIONS

The fate plate collector is a technical installation characterized by a global efficiency that is used in way to choose and dimensioned for the thermal-solar installation. Using the computed values as given in Table 3 it can be observed a better influence upon the efficiency based on the radiation intensity, the absorption factor corresponding to the absorbent surface material and the gradient temperature between the output and input thermal agent temperatures.

The equipment producers offers the methodology according with the technical principles and the equipment constructive characteristics.

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