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SOLAR WATER HEATING FOR A SWIMMING POOL

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Abstract: The paper presents the theoretical elements that led to the elaboration of the technical project of a solar hot water preparation plant for a swimming pool. The thermal calculation of the solar plant, as well as the simulation of its operation, based on the climatic parameters in Cluj-Napoca provided by the typical meteorological year is analysed. The results of the study indicate the amount of the domestic hot water produced by the solar collectors and its share from the daily requirements.

Key words: renewable energy, solar energy, solar panel, domestic hot water, building services.

1. INTRODUCTION

The paper presents the theoretical elements of the designing of a solar hot water preparation plant intended for an existing swimming complex owned by Babeş Bolyai University Cluj-Napoca, as well as the design elements of the solar installation. In order to reduce the energy consumption, the efficiency of the domestic hot water (DHW) preparation, during the warm season, using flat plate solar collectors is analyzed. The DHW heated by the flat plate solar collectors is used by the showers of the swimming complex.

2. PRESENT STAGE

The swimming pool's heating plant consists of 3 boilers (3x1,200 kW). These boilers are used in the production of thermal agent that supplies the HVAC system as well as the preparation of the DHW used in the swimming pool and sanitary groups. At present, the preparation and accumulation of hot water is achieved by means of a 130 kW flat plate heat exchanger and a 2,000 liter storage tank.

In order to design the solar hot water preparation system, the calculation of the existing solution was performed during the academic year (October – June, cold period) and during the vacation (July – September, hot period). Atypically, considering the periods

when solar energy is available, the daily number of users during the cold season: 1,360 swimmers is much higher than in the summer 720 swimmers.

Table 1 presents the specific DHW requirements according to [1], as well as the mean values adopted for the preliminary calculations of existing equipment. Based on the data provided by the Babeş Bolyai University we were able to determine: the hot water consumption chart, the schedule of the thermal energies necessary for the DHW preparation, as well as the heat supplied by the flat plate heat exchanger and the amount of DHW that can be stored. It was concluded that the existing equipment of the heating plant can assure the demand DHW requirements.

Table 1
DHW - the specific requirements and daily consumption

Building type	Specific requirement [l/pers./day]		Daily consumption [l/day]		
	DHW 60°C	DHW 45°C	DHW 60°C winter	DHW 60°C summer	DHW 45°C* summer
Public showers	30	43	40800	21600	30960
Sports facilities	20	28	27200	14400	20160
Mean value	25	35.5	34000	18000	25560

* - solar produced according to [2]

In the case of solar DHW preparation the considered temperature is: 45 °C and the specific demand 35.5 l/pers./day [2], resulting the values presented in table 1.

3. THE SOLAR GEOMETRY

In order to determine the value of the total solar radiation on a random surface, as well as the distance between the flat plate solar collectors the hourly coordinates of the sun must be calculated.

3.1 The angle of incidence of the solar rays

The apparent movement of the sun towards a steady observer located on the surface of the earth and characterized by its latitude: φ and longitude: λ , is necessary in order to calculate the following angles:

- solar declination angle [3]:

$$\delta = 23,45^\circ \cdot \cos(30 \cdot m + d - 202); \quad [^\circ] \quad (1)$$

$$\delta = 23,45^\circ \cdot \sin(360 \cdot \frac{284 + n}{365}); \quad [^\circ] \quad (2)$$

where: m – the number of the month;
 d – day of the month;
 n – number of the day starting with the 1th January;

- elevation angle of the sun:

$$\sin(h) = \sin \varphi \cdot \sin \delta + \cos \varphi \cdot \cos \delta \cdot \cos(\omega \cdot \tau^*);$$

$$\omega \cdot \tau^* = 15^\circ \cdot (\tau - 12); \quad [^\circ] \quad (3)$$

where: τ – hour of the day;

- angle of solar azimuth [3]:

$$a = 180^\circ + A;$$

$$A = \frac{\sin(\omega \cdot \tau^*)}{\sin \varphi \cdot \cos(\omega \cdot \tau^*) - \cos \varphi \cdot \text{tg} \delta} \rightarrow$$

$$\sin A = - \frac{\cos \delta \cdot \sin(\omega \cdot \tau^*)}{\cos(h)}; \quad [^\circ] \quad (4)$$

To determine the angle of incidence of the solar rays, on a surface tilted with the angle α from the horizontal plane, and oriented in southern direction indicated by the angle γ , the following relation as used [3]:

$$\cos \beta = \sin(h) \cdot \cos \alpha + \cos(h) \cdot \sin \alpha \cdot \cos(\gamma - A).$$

$$[^\circ] \quad (5)$$

3.2 Distance between the solar panels

Depending on the dimensions of the area, in this case the available terrace, the type of flat plate solar collector (horizontal or vertical) is adopted, so that the maximum number of solar panels (SP) is assured. In this case, because of the constraints of the available terraces, vertical solar collectors have been adopted. Solar collectors should be positioned so that they do not shade each other during the spring-autumn period.

The length of the shade in the vertical plane containing the sun and the centre of the earth is determined with:

$$l = \frac{l_{SP} \cdot \sin \alpha}{\text{tg}(h)} + l_{SP} \cdot \cos \alpha; \quad [\text{m}] \quad (6)$$

where: l_{SP} – length of the solar panel, [m].

Considering a southern orientation of the solar panel the length of the shade in the plane normal to the panel is obtained, using:

$$l_{shadow} = l \cdot \cos a. \quad [\text{m}] \quad (7)$$

In the designed solar plant the following values were adopted: the length of the panel: $l_{SP} = 2.38$ m, the angle of the collector from the horizontal plane: $\alpha = 45^\circ$, that allowed for the determination of the length of the shade during an entire year.

Figure 1, presents the variation of the shadow length of the collector at 12:00. Consequently the adopted distance between the solar collectors is: 3.5 m, in order to ensure that the collectors do not shade each other, for a period of 20th March – 25th September.

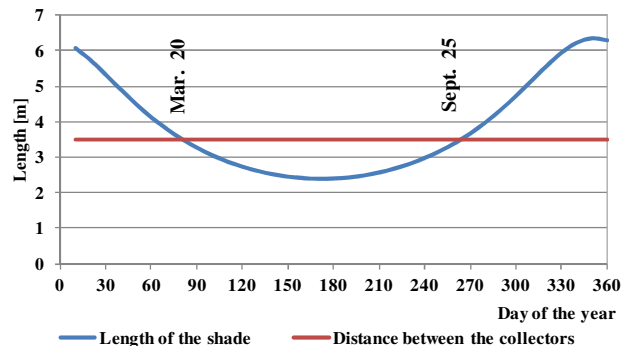


Fig. 1. Variation of shadow length

3.3 Calculation of solar irradiance

The calculation of the intensity of incident solar radiation on a tilted flat surface was performed based on the climatic data from the typical meteorological year (TMY), taking into account the orientation of the collectors and the elements of solar geometry.

The TMY indicates the values of the direct solar radiation on a horizontal plane I_{dirO} , in $[W/m^2]$ and diffuse solar radiation on a horizontal plane I_{difO} , in $[W/m^2]$.

The total intensity of incident solar radiation on the surface of the solar collectors, is determined by the direct and diffuse solar radiation, noted as I_{dir} , in $[W/m^2]$ and I_{dif} , in $[W/m^2]$ respectively, taking into account the location and orientation of the collectors:

$$I_t = I_{dirO} \cdot \frac{\cos \beta}{\sin(h)} + I_{difO} \cdot \frac{1 + \cos \alpha}{2} \quad [W/m^2]. \quad (8)$$

Figure 2 presents the ambient temperature variation and the variation of the incident solar radiation intensity according to the TMY, considering a southern orientation of the collector: $\gamma = 0^\circ$, and tilted at: $\alpha = 45^\circ$.

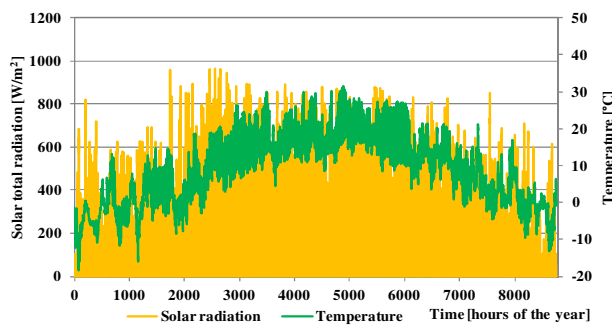


Fig. 2. The variation of the ambient temperature and total incident solar radiation on the solar collector

The efficiency of the flat plate solar panel is defined as the ratio between the density of thermal flux stored in the heat transfer fluid (HTF): \dot{q}_u , $[W/m^2]$ and the total intensity of solar radiation [3]:

$$\eta_{SP} = \frac{\dot{q}_u}{I_t} = \frac{I_t - \dot{q}_p}{I_t} = 1 - \frac{\dot{q}_p}{I_t} = \Phi_1 - \Phi_2 \frac{t_{mf} - t_{air}}{I_t} \quad [-, \cdot 100 \%] \quad (9)$$

where: \dot{q}_p - density of thermal flux released to the ambient air, $[W/m^2]$;

Φ_1 - characterizes the absorption capacity of the panel;

Φ_2 - characterizes the heat losses to the environment through the external surface of the panel.

Equation (9) yields the following form [4]:

$$\eta_{SP} = \eta_o - k \cdot \frac{t_{mf} - t_{air}}{I_t}; \quad [-, \cdot 100 \%]$$

or a more precise relation [4]:

$$\eta_{SP} = \eta_o - k_1 \cdot \frac{t_{mf} - t_{air}}{I_t} - k_2 \cdot \frac{(t_{mf} - t_{air})^2}{I_t}; \quad [-, \cdot 100 \%] \quad (10)$$

where: η_o - optical efficiency of the solar panel: $\eta_o = 77,5-84 \%$ [4], [5];

k - global heat transfer coefficient of the external surface per unit surface area, $[W/m^2 \cdot K]$, $k = 2 \div 4 W/m^2 \cdot K$ [4], [5];

k_1, k_2 - coefficients that take into account the heat losses to the external environment, $[W/m^2 \cdot K]$, $k_1 = 3.36 \div 4.16 W/m^2 \cdot K$, $k_2 = 0.0073 \div 0.013 W/m^2 \cdot K$, for flat thermal panels [4], [5];

t_{mf} - mean temperature of the HTF - water + ethylene/propylene glycol, $[^\circ C]$;

t_{air} - ambient air temperature, $[^\circ C]$.

Adopting the average heat transfer fluid temperature involves the analysis of the operation of solar hot water plants, taking into account the random nature of solar radiation as well as the unsteady heat transfer. Under normal operating conditions, the pump starts circulating heat transfer fluid if the temperature difference between the panel temperature and hot water temperature in the tank is within the range of: $8 \div 10^\circ C$.

The pump stops circulating heat transfer fluid when there is a difference in panel temperature and hot water temperature of $2^\circ C$.

Thus the efficiency of the collector is determined considering a mean value of the heat transfer fluid's temperature in the range of: $t_{mf} = 53 \div 55^\circ C$, a value which exceeds the DHW operating temperature with $8 \div 10^\circ C$ [2].

During the absence of solar radiation, or during periods when the intensity of solar radiation is reduced, the efficiency of the collector calculated with relation (10) assumes negative values. Therefore during these periods the efficiency is considered $\eta_{SP}=0$.

3.4 The effective HTF temperature

In the absence of solar radiation, the temperature of the solar collectors and of the **HTF** is considered equal to the ambient temperature, as thermal equilibrium is reached.

In the presence of solar radiation, but in the case where the intensity of solar radiation is reduced (logical test $\eta_{SP}=0$), the preheating of the **HTF** contained within the flat plate solar collector takes place. In this situation the circulation of the **HTF** stagnates.

The effective temperature of the **HTF** from the solar collectors t_{eff} , is determined by solving equation (10), that yields a unique solution for $\eta_{SP}=0$:

$$t_{eff} = t_{air} + \frac{-k_1 + \sqrt{k_1^2 + 4 \cdot \eta_o \cdot I_t \cdot k_2}}{2 \cdot k_2} \cdot [^{\circ}\text{C}] \quad (11)$$

respecting the condition: $t_{eff} < t_{mf}$.

If the effective temperature of the **HTF** reaches or exceeds the value of the mean temperature of the **HTF**: $t_{eff} \geq t_{mf}$, the pump is turned on. This implies the calculation of the amount of solar heated **DHW**. In the case of a high intensity in solar radiation the efficiency of the collector is $\eta_{CSP} > 0$, and the calculation of the amount of produced **DHW** is carried out.

3.5 The amount of DHW

The determination of the amount of **DHW**: m_{DHW} [kg/h] that can be prepared over a period of time: $\Delta\tau = 3600$ s, is carried out on the basis of the energy conservation law, according to the relation:

$$\Delta\tau \cdot I_t \cdot S_{SP} \cdot n_{SP} \cdot \eta_{SP} \cdot \eta_{SPL} = m_{DHW} \cdot c_{DHW} \cdot (t_{DHW} - t_{CW}) \Rightarrow$$

$$m_{DHW} = \frac{\Delta\tau \cdot I_t \cdot S_{SP} \cdot n_{SP} \cdot \eta_{SP} \cdot \eta_{SPL}}{c_{DHW} \cdot (t_{DHW} - t_{CW})} \quad [\text{kg/h}] \quad (12)$$

where: S_{SP} – the surface area of a solar panel, [m²];

n_{SP} – number of solar panels: 3*19 constrained by the available space;

η_{SPL} – overall efficiency of the solar plant, considering the heat losses to the environment through thermal insulating layers of the pipe system and heat losses of the flat plate heat exchanger. The efficiency is estimated at: $\eta_{SPL} = 94 \div 96$ %;

c_{DHW} – specific heat capacity of **DHW**, [J/kg·K];

t_{CW} – temperature of cold water (**CW**), in [°C], adopted as $t_{CW} = 5,5$ °C and $t_{CW} = 12,5$ °C, during the cold season and hot season respectively.

4. SOLAR PLANT FOR DHW PREPARATION

The solar hot water plant designed for the swimming pool is shown in figure 3 and has the following components:

a. Plate solar panel

The solar panels are mounted on the terrace roof of the swimming pool in the area of the auxiliary spaces. The configuration of the roof allows the mounting of a total number of solar panels: 19 rows * 3 panels / row, oriented to the south.

The rows of solar panels are connected to the distribution by: elastic connections allowing free expansion, isolation valves, provided with manual air vent valves at the highest points, and drainage valves. The distribution of the **HTF** made from the copper pipe is in the Tichelmann loop, which ensures the hydraulic balancing of the solar plant. The ends of the distribution are equipped with: isolation valves, drainage valves, air vent valves.

The distribution pipes are equipped with expansion axial compensators. The copper pipes of the distribution are insulated with semirigid shells made of polyurethane or basalt mineral wool casted with aluminum foil and protected from the exterior with a barrier of polyethylene foil and galvanized steel sheet.

b. Solar DHW preparation

Solar preparation and storage of hot water is provided by means of indirect heating in a hot water tank (**HWT**) with the capacity of 2,000 l

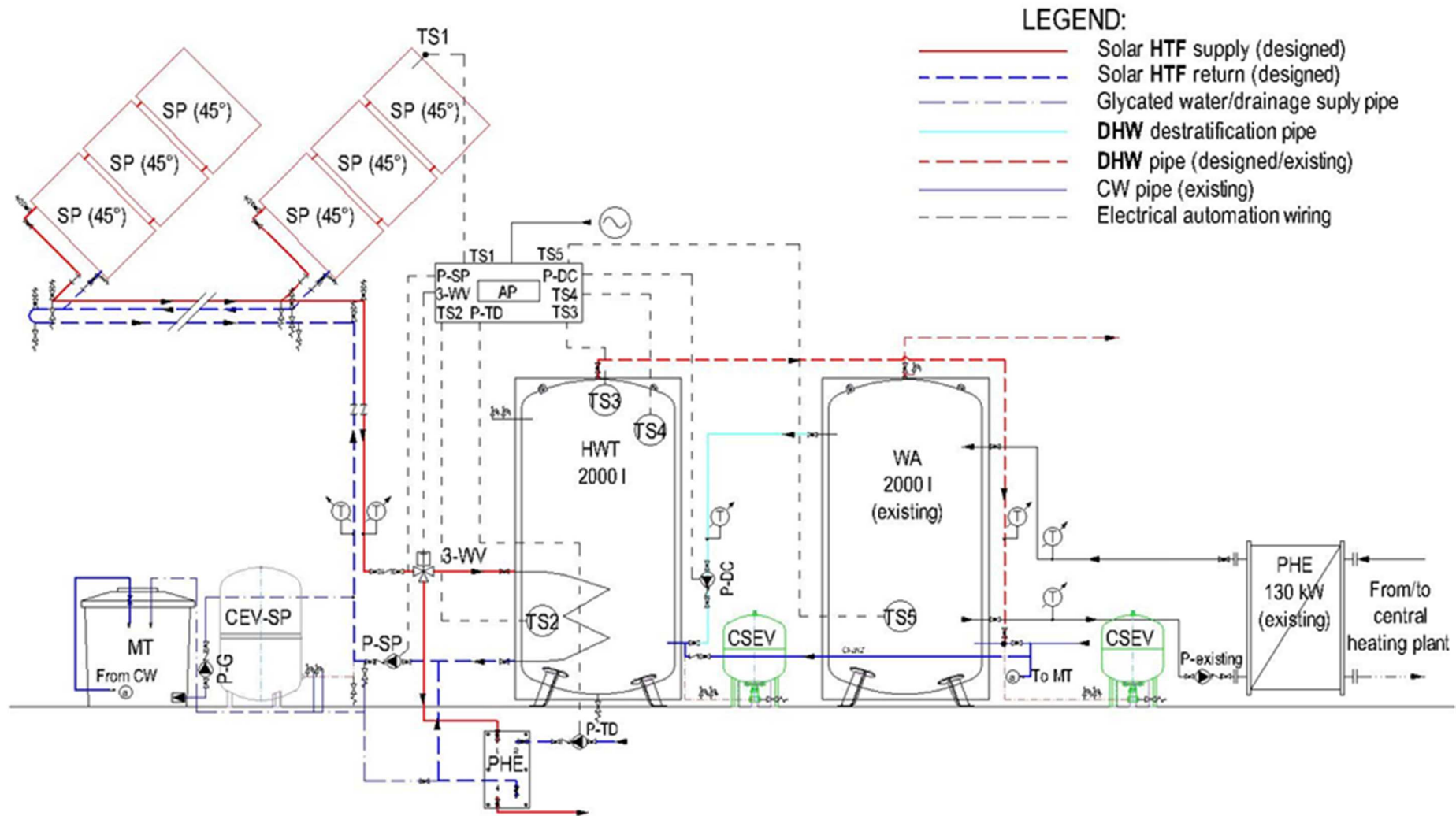


Fig. 4. Scheme of the solar plant for DHW preparation

based on the thermal energy supplied by the solar panels.

The solar **DHW** plant within the central heating system has the following circuits:

- Solar panels - **HWT**

The supply and return circuit made of copper pipes are equipped with:

- variable speed circulation pump of the solar plant (**P-SP**);
- 3-way motorized valve (**3WV**), with on/off system, which allows thermal discharge in case of overheating of **HTF**;
- closed expansion vessel for the solar plant (**CEV-SP**) with elastic membrane that allows the dilatation of glycated water from solar panels;
- closed sanitary expansion vessel (**CSEV**).

- **HWT** – existing water accumulator (**WA**) destratification circuit

The destratification circuit is equipped with a variable speed circulation pump of the destratification circuit (**P-DC**), to ensure the storage of hot water in both tanks.

- Glycated water supply circuit

The glycated water from the solar system is obtained by mixing: softened water (supplied by the thermal plant softening station): 60 % with ethylene/propylene glycol 40 % in the mixing tank (**MT**). A filling pump is used to supply the system with glycated water (**P-G**).

- c. The thermal discharge installation

During periods when the consumption of domestic hot water is low, in order to avoid overheating of the glycated water from the solar plant, thermal discharge takes place through a plate heat exchanger using the water from the thermal plant of the swimming complex as secondary **HTF**.

During the summer, in the vacation period maintenance and reparations of the thermal plant and **HVAC** system are carried out. In order to avoid overheating of the solar panels during this period (15-20 days) the panels are protected with radiation resistant blinders.

- d. The automation panel (**AP**) of the **DHW**

For the efficient operation of the solar hot water preparation plant, its operation will be controlled by an automation board, which must satisfy the following functions:

- Automatic preparation of solar **DHW**

The automation controls the operation of the solar circuit pump **P-SP** based on the temperature difference between the temperature of the solar panel and the **HWT** temperature (Δt), as measured by the temperature sensors (**TS**) **TS1** and **TS2**. **P-SP** starts when $\Delta t = 8^\circ\text{C}$. Pump flow is modulated according to temperature difference:

- $\Delta t = 8^\circ\text{C} \rightarrow 30\%$ nominal flow rate;
- $\Delta t = 10^\circ\text{C} \rightarrow 40\%$ nominal flow rate;
- $\Delta t = 20^\circ\text{C} \rightarrow$ nominal flow rate.

P-SP stops when $\Delta t < 8^\circ\text{C}$.

- Charging of **WA**

Automation orders the charging of the **HWT** and the existing **WA** as follows:

- **P-DC** starts at $\Delta t = 15^\circ\text{C}$, the temperature difference between **TS4** and **TS5**;
- **P-DC** stops when $\Delta t < 5^\circ\text{C}$;

- Automation of thermal discharge of the solar installation

The automation controls the start of the thermal discharge at the maximum allowed temperature of the **HWT** determined by the temperature limiter **TS 3** - set at $90 (95)^\circ\text{C}$.

The automation orders:

- the position of the 3-way motorized valve in the direction to the plate heat exchanger (**PHE**);
- the operation of **P-SP** at nominal flow rate;
- the operation of the discharge pump **P-TD**.

Thermal discharge stops when the **HWT** water temperature drops below the maximum allowed temperature difference generally set at: $\Delta t = 10^\circ\text{C}$.

The automation orders:

- the position of the 3-way motorized valve in the direction to the **HWT**;
- the shutdown of **P-TD**;
- operation / shutdown of the pump in the solar circuit **P-SP**, controlled by the temperature

difference measured by temperature sensors **TS1** and **TS2**.

- Preparation of **DHW** without solar input

During the periods without solar radiation, the **DHW** is prepared by the existing boilers of the thermal plant, the operation being ensured by the existing automation.

In periods of moderate consumption, the **DHW** is prepared by the existing plate heat exchanger **PHE** (130 kW) and is accumulated in the **WA**. During these periods, the **HWT** and **P-DC** are not operating.

During peak periods, if the demand for hot water exceeds the existing capacity of the **PHE** (130 kW) and the existing capacity of the **WA**, it is possible to also accumulate **DHW** in the **HWT** by turning on the destratification pump.

In periods of low solar input, it is possible to preheat the hot water consumption on the basis of solar radiation. The operation of solar **DHW** preparation is controlled by the temperature difference Δt - between the solar panel temperature sensor **TS1** and the temperature sensor on the **HWT** **TS2** which controls the solar panel pump **P-SP**.

5. RESULTS AND CONCLUSION

Based on the theoretical elements presented above, a program has been developed to simulate the operation of the solar plant for **DHW** preparation. The climatic data for Cluj-Napoca was taken from the **TMY**.

The amount and share of solar prepared **DHW** during the hot period are resented in figures 4 and 5 respectively.

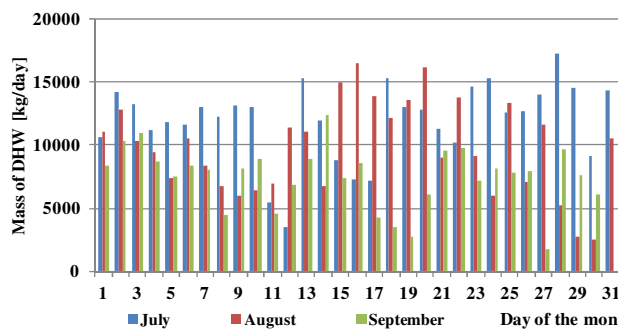


Fig. 4. Amount of **DHW** produced by the solar collector during the hot season

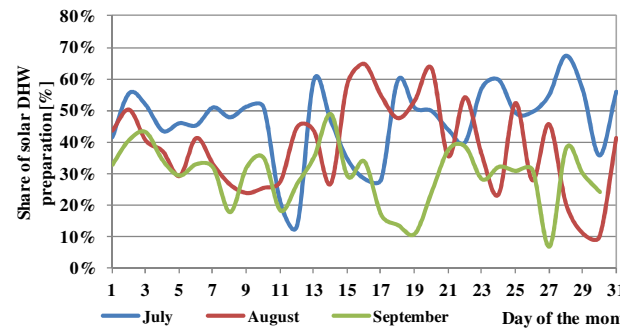


Fig. 5. Share of solar prepared **DHW** from the total amount of **DHW** demand during the hot season

The amount and share of solar prepared **DHW** during the cold period are resented in figures 6 and 7 respectively.

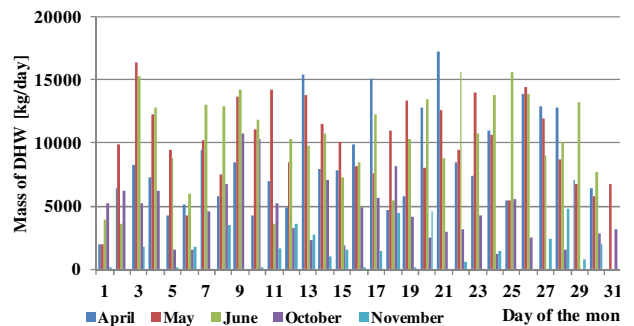


Fig. 6. amount of **DHW** produced by the solar collector during the cold season

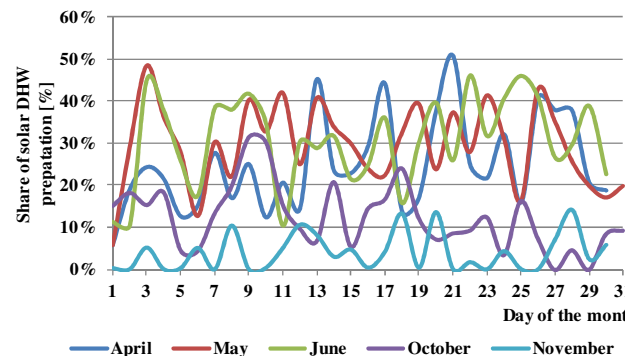


Fig. 7 share of solar prepared **DHW** from the total amount of **DHW** demand during the cold season

The results of the simulation indicated a reduction in energy consumption for the production of **DHW** as follows:

- during the spring: 25.03 ÷ 30.68 % (April – June);
- during the summer: 38.32 ÷ 46.89 % (July and August);
- during autumn: 12.46 ÷ 29.32 % (September and October).

The maximum amount and share of solar prepared **DHW** is limited by the surface area of the roof which determines the number of solar panels.

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Prepararea solara a apei calde pentru un complex de natație

Rezumat: *Lucrarea prezintă elementele teoretice care au stat la baza elaborării proiectului tehnic al unei instalații solare de preparare a apei calde de consum pentru un Complex de natație. În lucrare este sintetizat calculul termic de dimensionare a instalației solare, precum și simularea funcționării acesteia pe baza parametrilor climatici din Cluj-Napoca furnizați de anul climatic standard. Rezultatele studiului indică cantitatea de apă caldă de consum preparată solar și ponderea acesteia din necesarul zilnic, ceea ce indică economia de combustibili convenționali.*

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