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Calculation of Solar Energy Use as a Part of Determination of the Energy Performance of Building

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Abstract

The paper presents an actual national methodology in Croatia for the calculation of used solar energy in solar systems. It is based on Directive on the energy performance of buildings (2010/31/EU) and EN 15316-4-3 standard. The method has been successfully used in the calculation and proposing measures for increase energy efficiency in buildings. This contributes to increase the share of renewable energy sources, and thus reduces the consumption of primary energy. This paper presents a comparison of the calculation performed according EN 15316-4-3 which is based on monthly values and detailed hourly calculation based on hourly meteorological data of the test reference year. Comparison of the data is given for domestic hot water solar system of a family house located in the Mediterranean coastal region.

Keywords: solar thermal system, solar energy use, energy performance of building.

1. Introduction

Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings (EPBD) encourages the reduction of primary energy consumption in buildings, which can especially be achieved by using of renewable energy sources, in particular solar energy. Accordingly, when proposing measures to increase the energy efficiency of buildings in the Croatian coastal region, the installation of solar thermal system for domestic hot water (DHW) preparation represents a cost-effective measure. The simple payback period of such systems is around about 7-9 years. When analyzing the economic and energy impacts of the solar system, calculation of used solar energy is essential (Sartori and Hestnes, 2007). For the calculation of used solar energy, Croatian legislation stipulates method B - monthly calculation by using system's component data, according to the European standard EN 15316-4-3 (Ministry of Construction and Physical Planning of Republic of Croatia, 2014).

This paper presents a comparison between prescribed method of calculation performed according to EN 15316-4-3, which is based on monthly values, and hourly detailed calculation based on hourly meteorological data from the test reference year.

2. Description of the case system on which the comparison is performed

The comparison of two calculation methodology is performed on the case solar system for DHW preparation for a family house situated in the Croatian coastal climate zone. The system is designed to suit the needs of the family house with annual energy need for DHW equal to 5500 kWh/a. Solar thermal system consists of two heat storage tanks filled with sanitary water: solar tank and high-temperature tank. The high-temperature tank has been heated by auxiliary heat generator (gas boiler or electrical heater). The main characteristics of the system have been listed in Tab. 1, and basic outline of the case system has been given on Fig. 1.

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Tab. 1: The main characteristic of the solar thermal system used for comparison of the two methods

Annual thermal energy need for DHW	5500 kWh/a
Temperature of DHW	45 °C
Solar collector area, *A*	4 and 6 m^2
Type of solar collectors	Flat plate glazed collector
Inclination of solar collector to the horizontal plane.	45 °
Orientation of the collector	south
Volume of solar DHW tank	500 l
Volume of high-temperature DHW tank	200 l

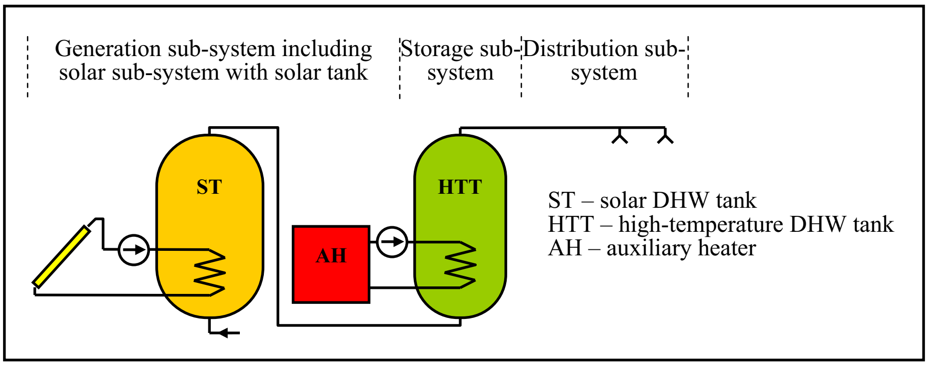


Fig. 1: Configuration of solar thermal system used for comparison of the two calculation methods

3. Calculation according monthly method given in EN 15316-4-3

According to the actual national regulations in Croatia, in the framework of determining the energy performance of buildings and energy certification, the calculations are carried out based on EN 15316-4-3 standard (Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 4-3: Heat generation systems, thermal solar systems). For determining the solar output of the thermal solar sub-system, the method B is applied which uses component data, i.e. input data from component tests (or default component input values given in the European standard). This calculation technique is based on the f-chart method.

Based on input data, the following output data are calculated: heat delivered by the thermal solar system; thermal losses of the solar storage tank, collector loop and primary circulation; auxiliary energy consumption of pump and control equipment in the collector loop; recoverable and recovered auxiliary energy; recoverable and recovered thermal losses. In this paper for the comparison of two methods, kWh has been used as a unit of thermal energy, as in the corresponding norms.

The general equation for calculation of monthly values of used solar energy by the thermal solar system for DHW preparation, $Q_{\mathrm{W,sol,out,m}}$ is calculated as follows:

$$Q_{\mathrm{W,sol,out,m}} = Q_{\mathrm{W,nd,m}} \cdot \left(aY_{\mathrm{W}} + bX_{\mathrm{W}} + cY_{\mathrm{W}}^{2} + dX_{\mathrm{W}}^{2} + eY_{\mathrm{W}}^{3} + fX_{\mathrm{W}}^{3} \right) \quad [\mathrm{kWh}] \qquad \text{(eq. 1)}$$

where $Q_{\mathrm{W,nd,m}}$ denotes monthly energy need of for the DHW preparation in kWh; *a*, *b*, *c*, *d*, *e*, denote correlation factors depending on storage tank type, *f* denotes correlation factor specific to direct solar floor. X_{W} is dimensionless factor (similar to a ratio of loss to heat use applied) and it depends on the collector loop heat loss coefficient and the temperature difference, but also on the storage tank. Y_{W} denotes dimensionless factor (similar to a ratio of solar output to heat use applied) and it depends on the collector data (zero-loss collector efficiency) and the solar irradiance on the collector plane.

4. Calculation according detailed hourly physical method

Detailed physical calculation method takes into account, in addition to all the characteristics of the system, also the dynamic change of temperatures in the main components of the system (solar collectors and heat storage tanks). When using this method it is necessary to spend more mathematical effort. Temperatures are calculated by solving the heat balance for each component of the system (Franković et al., 1998; Viličić et al., 1998a, 1998b). Temperatures affect the current efficiency of the collector and consequently determine currently used solar energy which is calculated for each time step. As input meteorological parameters test reference year data for Croatian coastal region have been used, such as hourly air temperature and hourly global solar energy irradiation to the inclined surface.

The energy used in solar collector for every time step has been calculated taking into account the actual water temperature entering from solar DHW tank to the collector. Actual solar irradiation, air temperature and water temperature inside the collector affects the current collector efficiency which has been calculated by

$$\eta_{\mathrm{col}} = 0.8 - 0.0395 \cdot \frac{\vartheta_{\mathrm{col}} - \vartheta_{\mathrm{air}}}{G} \quad [-] \qquad \text{(eq. 2)}$$

where:

G global irradiance or solar flux density, W/m^2

ϑ_{col} water temperature inside solar collector, °C

ϑ_{air} surrounding air temperature, °C.

Accordingly, solar energy heat flux for each time step has been calculated using following equation:

$$\dot{Q}_{\mathrm{sol}} = G \cdot A \cdot \eta_{\mathrm{HE}} \cdot \eta_{\mathrm{col}} = G \cdot A \cdot 0.9 \cdot \left(0.8 - 0.0395 \cdot \frac{\vartheta_{\mathrm{col}} - \vartheta_{\mathrm{air}}}{G}\right) \quad [\mathrm{W}] \qquad \text{(eq. 3)}$$

where:

G global irradiance or solar flux density, W/m^2

A net solar collector area, m^2

η_{HE} heat exchanger efficiency (η_{HE} =0.9), -

η_{col} heat collector efficiency, -.

For the calculation of solar collector efficiency in each time step, it has been assumed that water temperature inside collector (ϑ_{col}) is equal to water temperature of solar storage tank from previous time step ($\vartheta_{\mathrm{ST,0}}$).

The value of solar energy heat flux in each time step represents the main input parameter for the calculation of next parameters, such as water tanks temperatures and energy provided by additional heater.

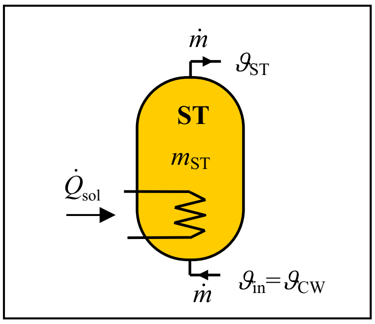


Fig. 2: Heat balance for solar DHW tank

Storage tank heat balance according to Fig. 2 can be expressed as follows:

$$m_{\mathrm{ST}} \cdot c_{\mathrm{w}} \cdot \frac{\mathrm{d}\,\vartheta}{\mathrm{d}\,t} = \dot{m} \cdot c_{\mathrm{w}} \cdot \vartheta_{\mathrm{in}} + \dot{Q}_{\mathrm{sol}} - \dot{m} \cdot c_{\mathrm{w}} \cdot \vartheta_{\mathrm{ST}} \quad [\mathrm{W}] \qquad \text{(eq. 4)}$$

Using an explicit method for discretisation over time it can be obtained:

$$m_{ST} \cdot c_w \cdot \frac{\vartheta_{ST} - \vartheta_{ST,0}}{\Delta t} = \dot{m} \cdot c_w \cdot \vartheta_{in,0} + \dot{Q}_{sol} - \dot{m} \cdot c_w \cdot \vartheta_{ST,0} \quad [W] \qquad \text{(eq. 5)}$$

From which it is obtained an expression for the temperature in the tank at each time step:

$$\vartheta_{ST} = \frac{\left(\dot{m} \cdot c_w \cdot \vartheta_{in,0} + \dot{Q}_{sol} - \dot{m} \cdot c_w \cdot \vartheta_{ST,0}\right) \cdot \Delta t + m_{ST} \cdot c_w \cdot \vartheta_{ST,0}}{m_{ST} \cdot c_w} \quad [°C] \qquad \text{(eq. 6)}$$

For the above equations applies:

ϑ_{ST} water temperature in solar DHW tank during current time step, °C
$\vartheta_{ST,0}$ water temperature in solar DHW tank during previous time step, °C
m_{ST} mass of water inside solar DHW tank, kg
$\dot{m}$ mass flow of DHW (equal to currently DHW consumption), kg/s
c_w specific heat of water, J/(kg K)
$\dot{Q}_{sol}$ solar energy heat flux during current time step, W
Δt time step, s

The accuracy of this method depends on the size of the time step. The higher accuracy can be achieved using smaller time steps. For this analysis, a time step Δt = 360 s has been used. Detailed hourly physical method requires a distribution of daily DHW consumption as input parameter. Total daily DHW consumption is assumed as 370 l, which suits the need of the reference family house. This corresponds to annual energy need for DHW equal to 5500 kWh/a (calculated with the assumption that the temperature of the tap water is 10 °C and DHW temperature is 45 °C). Daily distribution of this daily consumption is assumed as shown in Fig. 3.

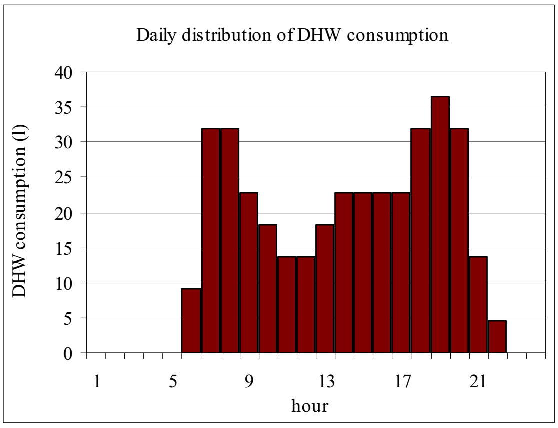


Fig. 3: Daily distribution of DHW consumption

The heat required for DHW preparation in each time step is determined by the expression:

$$Q_{W,nd} = \dot{m} \cdot c_w \cdot \left(\vartheta_{DHW} - \vartheta_{tap}\right) \cdot \Delta t \quad [J] \qquad \text{(eq. 7)}$$

where:

$\dot{m}$ mass flow of DHW (equal to currently DHW consumption), kg/s
c_w specific heat of water, J/(kg K)
ϑ_{DHW} required temperature of DHW, ϑ_{DHW} = 45 °C
ϑ_{tap} tap water temperature in, ϑ_{tap} =10 °C
Δt time step, s.

To ensure continuous availability of domestic hot water and given the inconstancy of solar energy, the system contains also the auxiliary heater with the aim to heat up the water to the required temperature when needed. The energy of the auxiliary heater for each time step has been calculated using:

$$Q_{aux} = \dot{m} \cdot c_w \cdot \left(\vartheta_{DHW} - \vartheta_{ST}\right) \cdot \Delta t \quad [J] \qquad \text{(eq. 8)}$$

where:

$\dot{m}$ mass flow of DHW (equal to currently DHW consumption), kg/s

c_w specific heat of water, J/(kg K)
ϑ_{DHW} required temperature of DHW, $\vartheta_{DHW} = 45$ °C
ϑ_{ST} water temperature in solar DHW tank during current time step, °C
Δt time step, s.

Actually utilized solar energy that belongs to each time step is calculated as the difference between required energy for DHW preparation and those provided by the auxiliary heater, according to the formula:

$$Q_{sol} = Q_{W,nd} - Q_{aux} \quad [J] \qquad \text{(eq. 9)}$$

where:
$Q_{W,nd}$ heat required for DHW preparation in each time step, J
Q_{aux} energy from auxiliary heater in each time step, J.

The heat required for DHW preparation $Q_{W,nd}$, energy from auxiliary heater Q_{aux} and actually utilized solar energy Q_{sol} has been summarize on a monthly and annual basis. The calculations have been performed using commercial table calculator software (MS Excel).

5. Results and comparison

The analysis has been carried out according to both methods for the same input parameters. Moreover, in order to investigate the influence of the size of installed solar collector area, the analysis has been performed for two different collector areas, maintaining all other parameters unchanged. A comparative analysis of the two methods has been conducted based on a comparison of monthly and annual values of solar fraction.

Solar fraction on monthly and annual level has been calculated using the following equation:

$$SF = \frac{Q_{sol}}{Q_{W,nd}} \quad [-] \qquad \text{(eq. 10)}$$

where:
Q_{sol} actually utilized solar energy (monthly or annual value), J
$Q_{W,nd}$ heat required for DHW preparation (monthly or annual value), J

Used solar energy and energy provided by auxiliary heater calculated using monthly method given in EN 15316-4-3 for two different solar collector areas (4 m^2 and 6 m^2) have been presented on Fig. 4. The analogue values calculated using detailed hourly physical method have been presented on Fig. 5. It is evident that the monthly method underestimates the value of used solar energy in comparison with the hourly physical method, using previously selected input parameters.

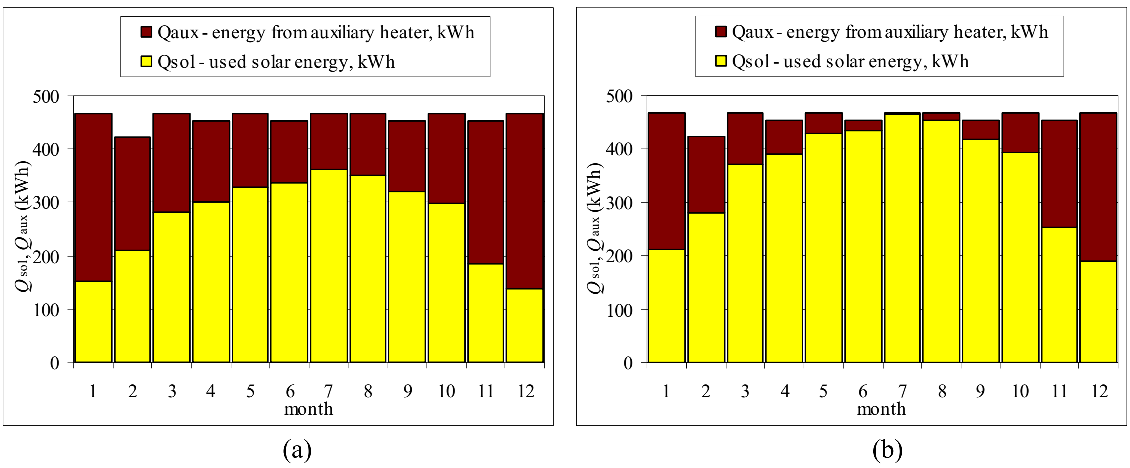
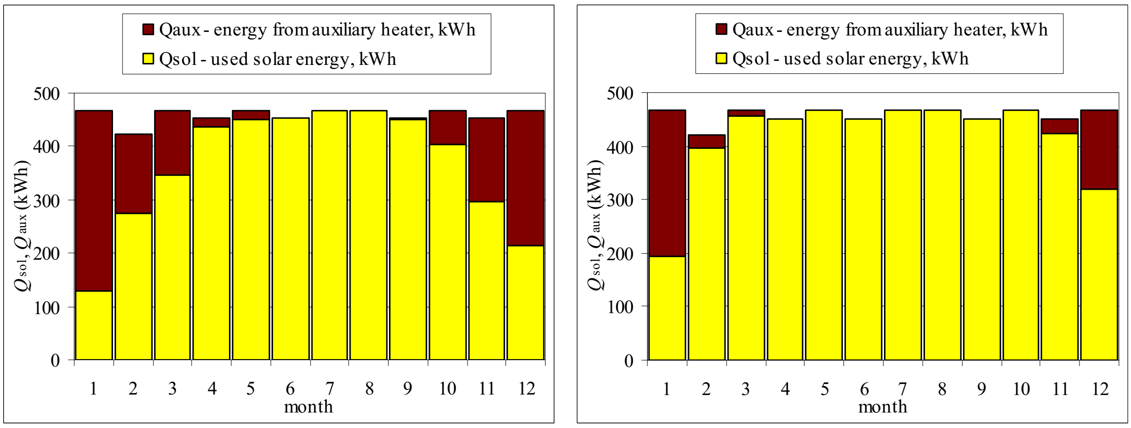


Fig. 4: Used solar energy and energy provided by auxiliary heater calculated using monthly method given in EN 15316-4-3 for different solar collector areas: (a) *A*=4 m^2; (b) *A*=6 m^2



(a) (b)

Fig. 5: Used solar energy and energy provided by auxiliary heater calculated using detailed hourly physical method for different solar collector areas: (a) A=4 m^2; (b) A=6 m^2

Annual solar fractions for different calculation methods and solar collector areas have been presented in Tab. 2. The distributions of monthly solar fraction values have been given on Fig. 6.

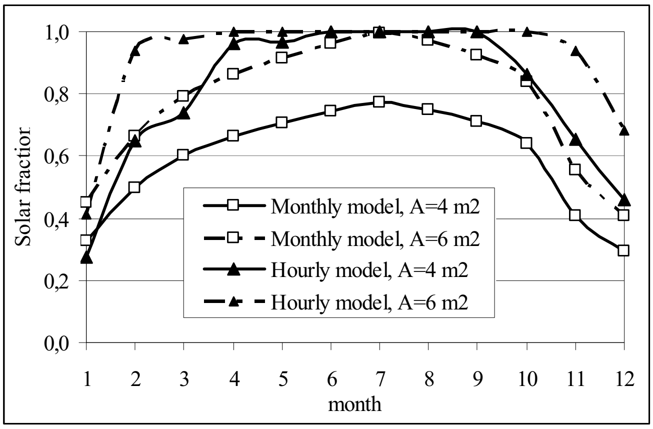


Fig. 6: Monthly solar fractions for different calculation methods and solar collector areas

Tab. 2: Annual solar fractions for different calculation methods and solar collector areas

	Monthly model, A=4 m^2	Monthly model, A=6 m^2	Hourly model, A=4 m^2	Hourly model, A=6 m^2
SF	**0,59**	**0,78**	**0,80**	**0,91**

6. Conclusion

Comparing the two different calculation methodologies for calculation of used solar energy, significant differences were observed. It was concluded that the methodology suggested by actual regulations and EN 15316-4-3 can be successfully applied for the preliminary economic analysis of cost-effective measures, i.e. for the calculation of simple payback period. However, for a more detailed analysis of solar energy contribution of solar systems it is necessary to carry out the calculation based on hourly physical method using real meteorological parameters from the test referent year.

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