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DISTRIBUTION OF SOLAR ENERGY OUTPUT IN ESTONIA

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Abstract. Seasonal solar energy yields for domestic hot water production are calculated across Estonia, based on the monthly distribution of temperatures and yearly distribution of global solar irradiation. A simplified pulse-mode simulation model was used to describe the processes in a stratified solar system.

Key words: domestic hot water, seasonal energy yield.

1. INTRODUCTION

Solar energy output here means the seasonal energy yield of a solar collector per square metre, produced in a Domestic Hot Water (DHW) system with the natural thermosiphone circulation from April to September. In Estonian conditions, summer season contains 82% of solar energy and will be highly favourable for its practical implementation.

This output depends on several circumstances:

1. Global solar irradiation in a particular location described in [1].

2. Average ambient temperature in a particular location described in [2].

3. Properties of the DHW produced, its volume and temperature as well as its consumption patterns.

4. Data describing the used collector, its positioning, and the regime of the heat carrier (water, antifreeze) in the collector.

5. Specific capacity (volume) of the storage tank and the regime of the heat carrier in the tank.

Because of numerous arguments, we had to introduce some limitations in our evaluation of the distribution of solar energy output in Estonia. The distribution of solar energy was calculated by a simplified simulation programme created in EXCEL-5.

2. LIMITATIONS

Our analysis was based on the following simplifications.

1. The temperature of the water consumed was considered to be constant at 60 °C and that of fresh water from the waterline was assumed constant at 10 °C. The pulse-mode consumption model was used: the daily consumption was concentrated on one single procedure after a "sunny" day (16.00). The water storage tank was regarded as ideal without thermal losses and as ideally stratified.

2. Daily solar irradiation was described by the cosine-pulse model [3] from 8 to 16 (solar time) and assumed zero outside that interval. The basic value of global irradiation in the simulation model was taken from [4], then recalculated for a 45° tilted south-facing surface.

3. To assess the real solar irradiation in a particular location, the values above were multiplied by a coefficient according to the yearly distribution of global irradiation [1]. Check-up in some control points of the monthly distribution of global irradiation gave the same result.

4. A "particular location" means an elementary square of 625 km^2 (25 × 25 km). In fact, the territory of Estonia consists of 95 elementary squares.

5. The daily ambient temperature was described by the cosine-pulse model [3] from 8 to 16 (solar time).

6. The efficiency of the 45° tilted south-facing collector was described by

$$\eta = \eta_0 - U_L\,(T_m - T_a)/Q\,,$$

where $\eta_0 = 0.722$ is the initial value of efficiency (if $T_m = T_a$) for several types of collectors produced in Scandinavian countries; $U_L = 0.00462$ kW/m^{2}K is average thermal losses for several types of collectors produced in Scandinavian countries; $T_m \sim 35$ °C is the approximate average temperature of the heat carrier in the collector with the snake-mode piping and thermosiphone circulation, producing hot water at the temperature of 60 °C; T_a, °C, is the temperature of ambient air; Q, kW/m^2, is the value of global irradiation.

7. The volume of daily consumed water was considered to be 50 kg [5] and the specific volume of the storage tank 100 kg (two-day storage). The standard value of 100 kg for daily water consumption recommended for western countries seems to be too high for Estonian consumption patterns.

3. SIMULATION MODEL

Simulation for daily energy output is described by a block diagram (Fig. 1). We can imagine the process as follows. By the end of each (statistical !) day, the top section of the storage tank will have filled the volume of 50 kg of hot water (60 °C) and another 50 kg of cold (10 °C) water will have filled the bottom section of the tank. The next day, the cold volume will be warmed up layer by layer. First, the upper layer $z = 1$ of cold water will warm up to 60 °C, then the next layer $z = 2$ will warm up, and it continues until the last layer $z = 5$ in the bottom will reach 60 °C by the end of the day. "z" is the sequence number of (five) layers used in the model. Depending on the conditions, maximum temperature can be reached earlier than the instant time $h = 16$. Therefore we have to control the maximum water output temperature $\max T_o(16)$ to be $h = 16$. By the end of the day, this warmed up water will flow up into the top section and so on. We can introduce such a value of the collector area A_C in the model, which will provide the final temperature at a predetermined accuracy. In our model, five layers and the accuracy of 60 °C ± 5K was used. The daily energy

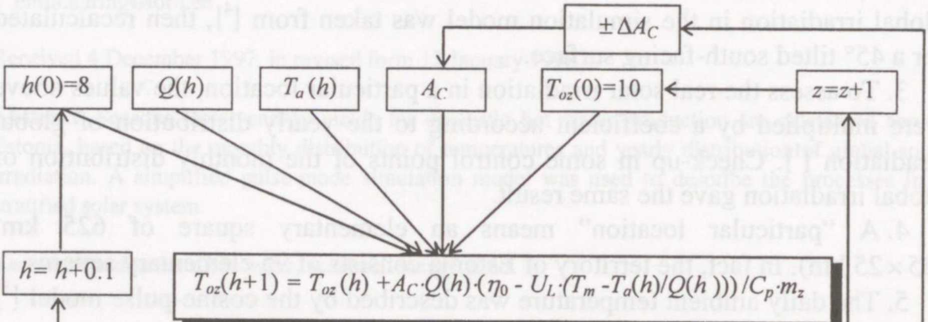

Fig. 1. Block diagram of the simulation model for daily energy yield calculations in a domestic hot water system with stratified water in the storage tank.

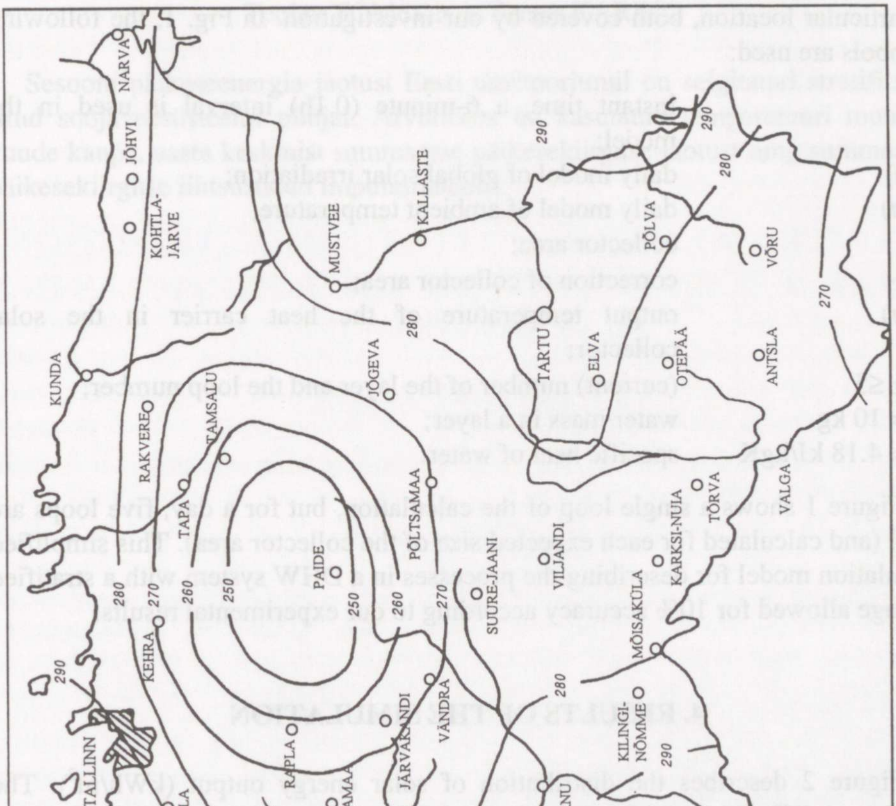

Fig. 2. Summer solar energy yield in Estonia.

output was constant in this approach, but due to the varying collector area A_C, the **specific energy** (per m^2) will be different, characterizing a particular day and a particular location, both covered by our investigation. In Fig. 1, the following symbols are used:

h	instant time, a 6-minute (0.1h) interval is used in the model;
$Q(h)$	daily model of global solar irradiation;
$T_a(h)$	daily model of ambient temperature;
A_C	collector area;
ΔA_C	correction of collector area;
$T_o(h)$	output temperature of the heat carrier in the solar collector;
$1 \leq z \leq 5$	(current) number of the layer and the loop number;
$m_z = 10$ kg	water mass in a layer;
$C_p = 4.18$ kJ/kgK	specific heat of water.

Figure 1 shows a single loop of the calculation, but for a day, five loops are used (and calculated for each expected size of the collector area). This simplified simulation model for describing the processes in a DHW system with a stratified storage allowed for 10% accuracy according to our experimental results.

4. RESULTS OF THE SIMULATION

Figure 2 describes the distribution of solar energy output (kWh/m^2). The maximum difference of 1.22 times in the DHW productivity was found between the results from the island of Ruhnu (maximum) and the Järvamaa County (minimum). This is twice higher than the difference of global solar irradiation (1.1 times). In the nature, a positive feedback exists: local ambient temperature is higher in the areas with good solar conditions, while at higher ambient temperature, the DHW system will be more efficient.

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SESOONNE PÄIKESEENERGIA JAOTUS EESTIS

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Sesooni päikeseenergia jaotust Eesti territooriumil on selgitatud stratifitseeritud soojaveesüsteemi põhjal. Arvutustes on kasutatud temperatuuri muutust kuude kaupa, aasta keskmist summaarse päikesekiirguse jaotust ning summaarse päikesekiirguse lihtsustatud impulssmudelit.