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A SPLITTED SOLAR DOMESTIC HOT WATER SYSTEM

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Abstract. This paper analyses the performance of a splitted domestic hot water system with mixed (non-stratified) storage tank. We attempt to prove the expediency of splitting the system, based on the nearly 50% gain in energy generation for the same collector area. Physically, this effect provides reasoning for the implementation of used solar collectors in the suitable temperature range.

Key words: domestic hot water, mixed storage tank, gain in energy generation.

1. INTRODUCTION

A limited supply of solar resources in the Northern countries forces a search for the opportunities to increase the efficiency of domestic hot water (DHW) systems. One of the options seems to be dividing the low-flow-system (with low heat carrier velocity) into two (or more) series sections, which both implement a certain solar collector with the characteristics suitable to this section of the system at the applied conversion temperature different for each section. The aim is to analyse the expected effect comparing the generated specific energy yield for a summer day for a conventional and the equal-surface splitted systems, using some typical combinations of (most important) parameters of any solar collector – $F_R * (\tau\alpha)$ and $F_R * U_L$.

2. METHOD OF THE ANALYSIS

To prove the expected effect, we have to show that at the same quality of heated water, the specific yield of the splitted DHW (SDHW) system is greater than that in the conventional DHW system.

The water quality is considered here as water temperature, which should remain in the range $T_i = 40...60\,°C$. Water temperature below 40 °C (in the morning) is not efficient to use, to raise the water temperature above 60°C (to the evening) is not beneficial while higher conversion temperature of the collector makes it less efficient.

In the present paper, we use a simulated example which is most descriptive (for setting up the problem). In our numerical example, we use data on the Estonian climate [1, 2] and the pulse simulation model of water consumption: water is consumed in the evening beyond the collector operation period (or in the morning, which changes nothing while for simplification, an ideal model of a mixed storage tank without thermal losses in the storage regime is used). For both systems, wind influence is equal and may be neglected.

Figure 1*A* shows the layout of a conventional solar system with natural circulation (thermosiphone). Let the collector area in our example be $A_C = 4\ m^2$ and water mass in the single storage tank be $M = 300$ kg. Let the daily consumed water mass be $m = 100$ kg, which complies with the recommended consumption and reserve ratio $m \approx M/3$ under the Estonian climate conditions.

Figure 1*B* shows the layout of a SDHW system with the natural circulation. We used index "1" for the "cold" section and index "2" for the "hot" one. Provisionally (before optimizing the system), we split the system in sections optionally. Let the "cold" section area be equal to the "hot" section area $A_{C1} = A_{C2}$ (one exception outlined later), water mass in the "cold" section of the storage tank equal to the amount of consumed water $M_1 = m = 100$ kg and the latter in the "hot" section $M_2 = 200$ kg. Under these conditions, the whole water mass of both systems remains unchanged $M_1 + M_2 = M$. According to the pulse simulation model, the morning inlet temperature at $h = 8$ in the "cold" water section $T_{i1}(8) = 7\,°C$, which is the temperature of water supplied additionally from the water supply system. The argument in brackets $h \in \{8...16\}$ shows the hour (solar time). The starting temperature in the "hot" section $T_{i2}(8)$ is formed by mixing water from the "cold" and "hot" sections according to the volume of mixed water:

$$T_{i2}(8) = T_{i2}(16) - m * (T_{i2}(16) - T_{i1}(16))/M_2 - \mu * (T_{i2}(16) - T_{i1}(8))/M_2,$$

where $\mu = m - M_1 > 0$ is "surplus consumption" in the splitted system.

For the hourly irradiance $I(h)$ on the sloped collector surface, we apply the pulse simulation model too, where $I(h)$ is described by Eq. (1) in the argument range $h \in \{8...16\}$ and $I(h) = 0$ outside this range. The application of this simplified method results from the energy balance calculation which assesses the start and end of the solar collector operation under certain conditions of radiation. In Eq. (1) we still used statistical data on total solar radiation because under the conditions of isotropic clouds (typical of Estonia), most of diffused radiation is concentrated at a solid angle close to the sun direction [3].

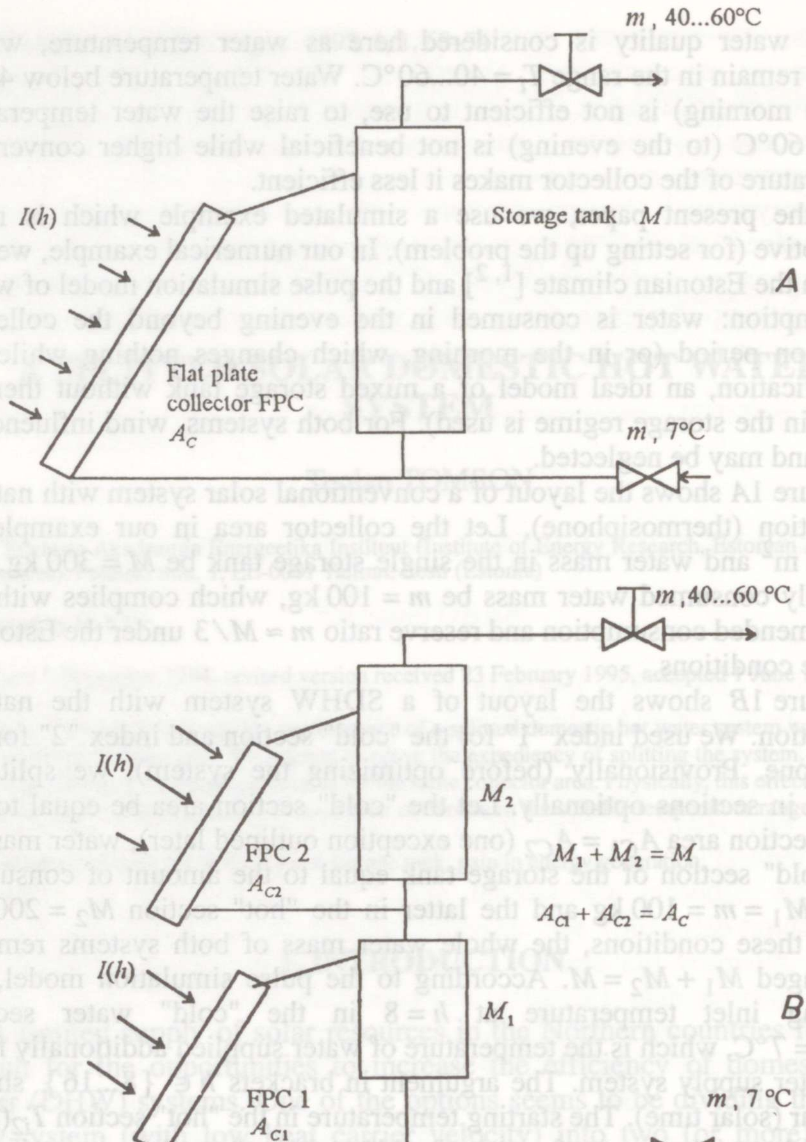

Fig. 1. The layout of a conventional DHW and modified SDHW system.

The calculation model is valid for the collector inlet water temperature $T_i(h)$. Let us recall that according to the mixed storage tank model, this is also the temperature of the consumed water: $T_i(16)$ for the DHW system and $T_{i2}(16)$ for the SDHW. The model includes the following parts:

Hourly solar (total) irradiance

$$I(h) = I_{\max} * \cos(h * 15 - 180). \qquad (1)$$

For the selected example $I_{\max} = 0.72\ \mathrm{kWh/m^2}$. The value of ambient temperature (its daily behaviour can be well defined by the cosinus function)

$$T_a(h) = T_{am} + T_{aa} * \cos(h * 15 - 225). \quad (2)$$

For the selected example, the average value of daily temperature $T_{am} = 14.2\,°C$ can be considered a constant and its fluctuation amplitude is $T_{aa} = 3.4\,°C$.

The water inlet temperature (step) to the end of the hour h

$$\Delta T_i(h) = (Q_u(h) * 860)/(M * C_p), \quad (3)$$

where $M \in \{M, M_1, M_2\}$ is the heated water mass according to the investigated modification, C_p is specific heat of water and "860" is a transformation coefficient 1 kWh = 860 kcal.

So the daily current value of the searched water temperature is

$$T_i(h) = \sum \Delta T_i(h). \quad (4)$$

The amount of solar energy converted in the hour h according to the principal formula [4, (6.7.6.)] is

$$Q_u(h) = A_C * (F_R * (\tau\alpha) * I(h) - F_R * U_L * (T_i(h-1) - T_a(h))). \quad (5)$$

In this formula, the temperature value for the previous hour is used to avoid a transcendence in formula (3).

3. RESULTS OF SIMULATION

The Table and Fig. 2 illustrate the results of calculation for the DHW water temperature $T_i(h)$ and SDHW water temperature function $T_{i2}(h)$. Some different modifications of SDHW were investigated.

Comparison of DHW and SDHW versions

$I(h)$	$T_a(h)$	h	1. $T_i(h)$	2. $T_{i2}(h)$	3. $T_{i2}(h)$	4. $T_{i2}(h)$	5. $T_{i2}(h)$
		7	40.8	58.2	63.15	39.2	58.3
0.359998473	13.3231	8	41.484	57.6654	63.448	40.322	58.533
0.509115947	14.2027	9	43.38	58.114	64.6	42.269	59.193
0.62353785	15.0822	10	46.114	59.2767	66.382	44.82	60.177
0.695466481	15.9016	11	49.271	60.852	68.533	47.713	61.359
0.72	16.6051	12	52.428	62.523	70.772	50.667	62.602
0.695466481	17.1449	13	55.178	63.978	72.815	53.4	63.764
0.62353785	17.4843	14	57.158	64.933	74.397	55.652	64.711
0.509115947	17.6	15	58.069	65.148	75.289	57.189	65.323
0.359998473	17.4843	16	57.701	64.446	75.313	57.835	65.507
Q_{ud}, kWh			5.8954	6.6797	7.94186	9.451163	6.802326
Q_{us}, kWh/m^2			1.4739	1.67	1.985465	2.362791	2.267442
Q^*_{us}			1	1.133	1.347083	1.603088	1.538396

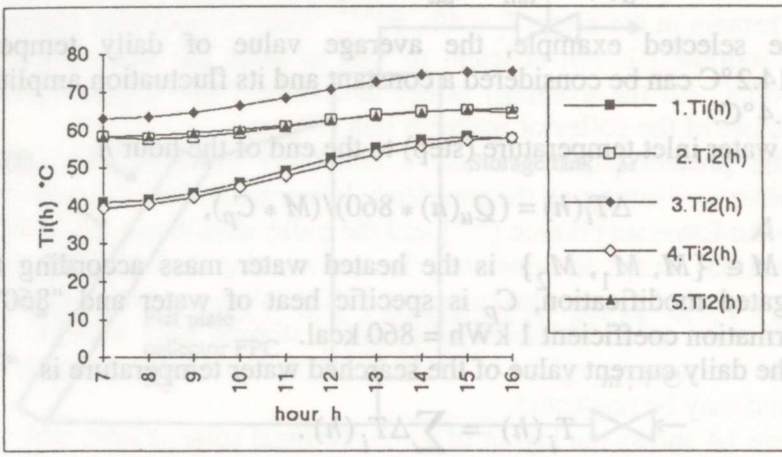

Fig. 2. Behaviour of a DHW and several modifications of the SDHW system during a summer day.

The lower rows of the Table have the following meaning:

Q_{ud} – the solar energy generated in the DHW (SDHW) system during the day;

Q_{us} – daily specific energy yield per unit of the collector area (1 m^2);

Q^*_{us} – the relative specific energy yield of the given modification (as related to the basic modification) and the parameter describing the efficiency of splitting.

1. The column in the Table and curve 1. $T_i(h)$ in the chart describe the conventional DHW system (basic modification) in Fig. 1*A* where $A_C = 4$ m^2; $F_R * (\tau\alpha) = 0.7$; $F_R * U_L = 0.007$ kWh/°C $*$ m^2. All other SDHW systems are shown in Fig. 1*B*.

2. The column and curve 2. $T_{i2}(h)$ describe the "hot" section of the SDHW system with two equal collectors $A_{C1} = A_{C2} = 2$ m^2. Both of them have $F_R * (\tau\alpha) = 0.7$ and $F_R * U_L = 0.007$ kWh/°C $*$ m^2.

3. The column and curve 3. $T_{i2}(h)$ describe a nonsymmetrical SDHW, where the "cold" section includes a collector with the area $A_{C1} = 2$ m^2; $F_R * (\tau\alpha) = 0.8$ and $F_R * U_L = 0.01$ kWh/°C $*$ m^2. These indices characterize the collectors with a light optical cover, which is inexpensive compared to the basic modification. The typical parameters of the "hot" section of this modification are $A_{C2} = 2$ m^2; $F_R * (\tau\alpha) = 0.65$ and $F_R * (\tau\alpha) = 0.004$ kWh/°C $*$ m^2.

These indices are typical of the collector with an improved optical cover and thus of more expensive modification. We expect the cost of the total collector system be of the same level with that of the basic modification with double area and average indices.

4. The column and curve 4. $T_{i2}(h)$ demonstrate the characteristic of the last modification, where $m > M_1 = 160$ kg under the conditions of surplus consumption. This allows us to implement the same temperature regime as for the basic modification and these two results – the first and the forth – can be compared correctly.

5. The column and curve 5. $T_{i2}(h)$ show a methodical exception. Here, the characteristics of the "hot" and "cold" section correspond to those in the third case, but their area is different. Thus, the parameters of the "cold" section collector are $A_{C1} = 2\ m^2$; $F_R * (\tau\alpha) = 0.8$; $F_R * U_L = 0.01$ kWh/°C $*\ m^2$ and the data on the "hot" section collector $A_{C2} = 1\ m^2$; $F_R * (\tau\alpha) = 0.65$; $F_R * U_L = 0.004$ kWh/°C $*\ m^2$.

The last modification is presented to draw attention to the need of optimization of the function with several variables: the daily output was defined by the combination of $F_R * (\tau\alpha) : F_R * U_L$, ratio A_{C1}/A_{C2}; relative consumption m/M_1 and, perhaps, ratio M_1/M_2. But first of all, the modification of stratified storage tank, including the SDHW philosophy, should be checked.

4. CONCLUSION

The simulated example should attract the attention of specialists as an option to raise the efficiency of DHW systems with structural changes. The gain from splitting a mixed storage system is noticeable. Before drawing final conclusions, the behaviour of a stratified modification of SDHW system should be checked and experimental testing carried out.

NOMENCLATURE

A_C – solar collector area, m^2
A_{C1} – solar collector area in the "cold" section, m^2
A_{C2} – solar collector area in the "hot" section, m^2
C_p – specific heat (of water), kcal/kg
F_R – heat removal factor
h – hour (solar time)
$I(h)$ – hourly solar irradiance, kWh/m^2
I_{max} – the maximum of $I(h)$, kWh/m^2
M – (storage tank) water mass, kg
m – daily consumed water mass, kg
M_1 – water mass in the "cold" section storage tank, kg
M_2 – water mass in the "hot" section storage tank, kg
$Q_u(h)$ – useful energy converted during the analysed hour, kWh
Q_{ud} – daily useful energy, kWh
Q_{us} – specific daily useful energy, kWh/m^2
Q^*_{us} – relative daily useful energy
$T_a(h)$ – ambient air temperature, °C
T_{aa} – the amplitude value of daily temperature wave, °C
T_{am} – the average value of ambient air temperature, °C
$T_i(h)$ – water inlet temperature, °C
$T_{i1}(h)$ – water inlet temperature in the "cold" section, °C
$T_{i2}(h)$ – water inlet temperature in the "hot" section, °C

U_L – collector overall heat losses coefficient, kWh/m^2°C
$\Delta T_i(h)$ – temperature step during the analysed hour, °C
μ – water mass, daily consumed over M_1, kg
$(\tau\alpha)$ – transmittance-absorbance product

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SEKTSIONEERITUD HELIO-SOOJAVEESÜSTEEM

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Sektsioonideks lõhestatud helio-soojaveesüsteemi omadusi on käsitletud ja eelised on tõestatud juhtumil, kui soojaveesalvesti töötab mittestratifitseeritud anumana. Vastavalt arvutusnäitele võib lõhestamine anda päevas kuni 50% energiatoodangu juurdekasvu võrreldes tavasüsteemiga. Selle efekti füüsikaline alus on võimalus sektsioonidesse jagatud heliokollektoreid tööle rakendada neile sobivas temperatuurirežiimis.

СЕКЦИОНИРОВАННАЯ СИСТЕМА СОЛНЕЧНОГО ВОДОНАГРЕВА

Теолан ТОМСОН

Рассмотрены свойства расщепленной гелиоустановки для нагрева воды и показаны ее преимущества для случая, когда тепловой аккумулятор работает в нестратифицированном режиме. При этом положительный эффект достигает 50% в день против показателей обычной системы. Физической основой такого эффекта является возможность заставить каждую секцию солнечного коллектора работать в оптимальном для нее температурном режиме.