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COMPARATIVE ANALYSIS OF CONVENTIONAL AND SPLITTED SOLAR DOMESTIC HOT WATER SYSTEMS

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Abstract. For the impulse consumption model, the dependence of the specific yield of a domestic hot water (DHW) system on solar collector parameters and on the behaviour of a storage vessel was established by a simplified simulation model. Some recommendations for the design of a nearly optimal system were suggested. For both a mixed and a stratified storage mode, splitting the DHW system produced an energy yield gain with the solar collector parameters specified for both sections of the splitted system. An estimated energy gain of 20–40% was achieved over a conventional DHW system.

Key words: solar domestic hot water, simulation, mixed storage, stratified storage, specific yield, energy production gain.

1. INTRODUCTION

This study compares a traditional DHW and splitted DHW (SDHW) solar hot water system with a stratified and mixed storage. An analogous comparison for the mixed storage was discussed in [1]. It seems reasonable to compare the impact of storage behaviour also. Since essentially we do not have to distinguish between a one-loop or double-loop system, we shall consider the examples of an one-loop system, which consists of a flat-plate solar collector (panel) and a hot water storage (installed higher) (Fig.1 *A*). The reciprocal positioning of the collector and storage is of major importance to provide preferably natural (thermal) low-flow circulation (0.02–0.05 kg/m × m^2) of heat carriers (water, antifreeze), which provides the highest yield. Thermal circulation stops automatically if the radiation level drops below the critical value and the heat carrier is cooled rather than heated. Further, we presume that the systems operate with thermal circulation. Thermal circulation is observed within the temperature of 10–60 °C on the constant temperature rise step ΔT_C along the collector at the value of ca 10 K [2].

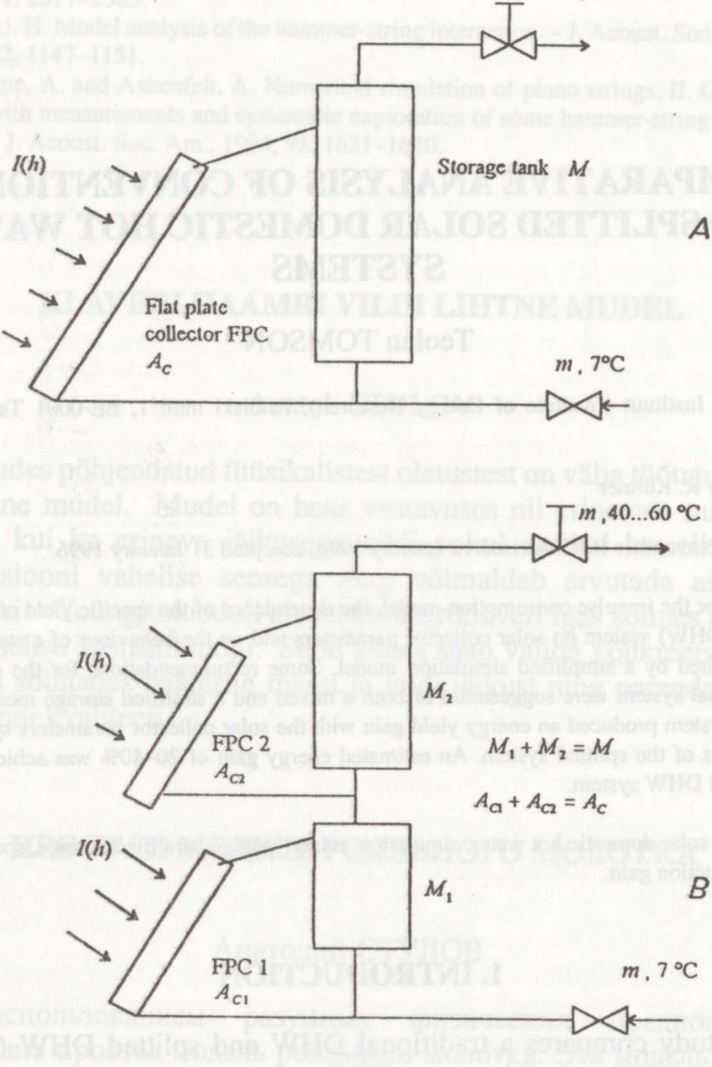

Fig. 1. A conventional DHW system (*A*) and a splitted DHW system (*B*) structure.

Figure 1 *B* illustrates the stucture of a SDHW system. This structure contains a series connection of two (different) DHW systems where the first "cold" section is a preheater for the "hot" section. In the latter, most of the water is storaged and heated to the required temperature T_{i2} (*16*). In the splitted system, the characteristics of any solar collector can be selected according to the temperature in that section. This provides technical advantages.

Due to the periodic and random solar radiation, the availability of a storage facility is indispensable. At lower latitudes and in regions with abundant solar radiation, DHW systems were designed to ensure a 2/3 daytime consumption of the storage capacity $m = 2M/3$. In the cyclonic climate of Estonia, the storage capacity must be increased and in the examples below, the storage capacity is three times daytime demand $M = 3m$. The technical advantage is provided by a smaller panel surface area for the same yield (capacity) and in densely inhabited cities it is of major importance. The system containing two storage facilities and additional piping is complicated, but both storage elements can be installed in a common vessel (separated by insulation). This construction does not add to the cost. However, additional piping is obligatory. In terms of the total cost, a pipeline is an inexpensive component. Thus, economical benefits can be expected. Since in a DHW system, the most important cost component is the panel price, we anticipate a decrease of the production costs on energy with an increase of the specific yield.

2. OUTPUT CHARACTERISTICS OF A FLAT-PLATE SOLAR COLLECTOR

The output characteristics of a flat-plate solar collector (panel) are close to linear, which allows us to use the linear approximation of a characteristic. The conversion factor descends linearly, depending on the correlated parameter $p(h) = (T_i(h) - T_a(h))/I(h)$

$$\eta(p) = F_R(\tau\alpha) - F_R U_L p\,. \tag{1}$$

The term h refers to a current hour (in special cases, to a smaller time discrete), since the data on $I(h)$ are mostly given as hourly radiation, while the ambient temperature $T_a(h)$ and water temperature at the input to the panel $T_i(h)$ shows the average of the current hour. Besides the certain time point, $I(h)$ and $T_a(h)$ depend on the calendar day (via their maximum values). The examples below are given for the 90th summer day (because of the vernal equinox, regarded as the beginning of the season).

The input water temperature $T_i(h)$ depends on the initial conditions and integral impact of earlier factors and will be considered below. If $T_i(h) = T_a(h)$, $\eta(p) = \eta_{\max}$. This "maximum" is still a provisional characteristic of the panel and does not restrict the actual $\eta(p)$ from above, since with $T_a(h) > T_i(h)$, the panel becomes a heat exchanger consuming heat from the environment. If $\eta(p) = 0$, the panel will not produce any heat. The thermal circulation is stopped and the panel cools down to the ambient temperature. Thus, the balance equations are derived from (1):

$$I(h)\, F_R(\tau\alpha) = F_R U_L (T_i(h) - T_a(h))\,, \tag{2}$$

which defines the boundary conditions for the panel operation.

The technical characteristics of the panels vary essentially. Thus, we shall use artificial parameters, typical of a the certain quality of the product:

a simple inexpensive panel: $F_R(\tau\alpha) = 0.8$; $F_R U_L = 0.01$ kWh/m^{2}K;
an average panel: $F_R(\tau\alpha) = 0.7$; $F_R U_L = 0.007$ kWh/m^{2}K;
an improved ("expensive")
panel: $F_R(\tau\alpha) = 0.65$; $F_R U_L = 0.004$ kWh/m^{2}K.

3. DEFINITION AND MEANING OF SPECIFIC YIELD

To prove the advantage of one technical solution over another (conventional) tehnology, we need some kind of "scales". The decisive factor will be the cost of solar energy. However, our solutions cannot be based on it, since solar equipment sales are conducted on agreed prices rather than wholesale basis. These prices are inaccessible, and in addition, the physical basis of a novel technical solution should be explained first. Thus, to compare different systems, we need (at least temporarily) some technical, rather general parameters. Let it be *the specific yield of the panel* Q_{us} *(at a certain temperature)*.

$$Q_{us} = Q_{ud} / \Sigma A_C ,$$

where Q_{ud} is the daily amount of heat extracted from the system and ΣA_C the total panel area. It is evident that the system with the highest specific yield has technical advantages over others. The temperature should be selected in the DHW performance range of 40 to 60 °C. Below 40 °C, water is not suitable for the household use and it is unreasonable to warm it to above 60 °C, since according to (1), the efficiency of a panel will decrease at higher temperatures.

The daily energy extracted from the system in the impulse consumption model is

$$Q_{ud} = C_p\, m\, ((T_i(16) - T_i(8)),$$

where

m – the mass of water consumed in impulse;
$T_i(16)$ – the final temperature of the heated water;
$T_i(8)$ – the temperature of replacement water from the water supply system, which begins to warm up at 8 o'clock;
C_p – the specific heat of water.

In the examples below, we consider $T_i(8) = 7$ °C.

4. MODEL OF SOLAR RADIATION AND ITS VALIDITY

From the balance equation (2), because $I(h) = \text{var}$, the beginning and the end of the daytime operation period of a panel is limited. $T_i(h)$ in the balance equation has memorising properties, i.e., it depends on the state of the storage on the previous day and on its operation model (mixed or stratified water mode). Proceeding from (2), we calculated the starting and termination time for 45° tilted and south faced panels in three quality categories for the whole session. It may be concluded from these calculations, not presented here that the impulse model for the constant pulse width of $8h$ may be used without any essential error for simplification. Accordingly, for a daily use, we can define

$$I(h) = I_{\max} \cos(15\,h - 180), \tag{3}$$

where $I_{\max} = I_{\max}\,(d)$ is expressed by the following empirical formula

$$I_{\max}\,(d) = 0.73 \cos(d/5)\,. \tag{4}$$

Here 0.73 $\mathrm{kWh/m^2}$ is the value of total solar radiation in Estonia for a 45° tilted south oriented panel surface at the vernal equinox [3]. This is close to the optimal position of the panel and will be considered in our further analysis. We shall proceed from the total radiation indices applying diffused radiation to the direction of direct (apparent) radiation. This approach is reasonable in the conditions of homogeneous overclouding [4], which is prevailing in Estonia. The formula (3) is valid for the region of $h \in \{8...16\}$ and $I(h) = 0$ outside the region.

The formula (4) is valid in the region of $d \in \{1...180\}$, where $d = 1$ at the vernal equinox and $d = 180$ at the autumnal equinox. Thus, the duration of the year has been taken 360 days, which includes a negligible error but gives a good overview.

By specifying the length of a constant $8h$ radiation impulse, we introduced an error to the stratified storage system (where it would be proper to consider the effective region of $h \in \{6...16\}$) for $I(h)$, but a precalculation showed a very low contribution of supplementary energy from the two morning hours, which influenced the results simulated by the radiation impulse of $8h$ width (splitting for providing success) less than 1%.

5. MODEL OF AMBIENT TEMPERATURE

The model of ambient temperature corresponds to the empirical approximation of [5]. Let us consider the daytime temperature change sinuous. As a result, we can eliminate a small component of the second harmonic in the daytime temperature fluctuation [6]

$$T_a\,(h) = T_{am} + T_{aa} \cos\,(15\,h - 225)\;, \tag{5}$$

where the daily amplitude of temperature fluctuation $T_{aa} = 3.4$ K is constant for the whole session under Estonian conditions. But daytime average temperature is a changing value and can be expressed empirically

$$T_{am}(d) = 5 + 11.6 \sin(d - 40). \tag{6}$$

In the formulae (5) and (6), *h* and *d* are valid within the same range as above.

6. WIND MODEL

In the simulation below, the wind impact was considered to be the same as the characteristics of the panels defined for the corresponding wind velocity (5 m/s). It means that we compare the systems operating under the same ambient conditions. Since the result is the different specific yield of the systems compared, the actual benefits of the system with higher specific yield appear to be higher than the calculated value. The system with a lower specific yield has a larger area, and for the equal capacity, it is more cooled in the wind. For the summer period, the wind (in Tallinn) could be considered constant at an average velocity of $v = 5$ m/s, which accidentally coincides with the standard wind velocity.

7. CONSUMPTION CURVE AND ITS APPROXIMATIONS

The consumption curve influences the specific yield, but it will not be discussed in this paper. The actual statistical consumption curve shows a morning and an evening peak, a lower consumption in the daytime and a zero consumption at night. Presuming an ideal heat insulation of the storage and no consumption at night, we add the morning and evening peak in one pulse and assume that all the consumption is concentrated in one (delta) pulse. It means that the consumed water is extracted from the system in a short term by replacing it with the water from the water supply system at T_i (8) temperature. Let us take this consumption impulse at 4 p.m. immediately after the panel has stopped to operate. (For an ideal storage, the time for the impulse is insignificant.)

8. MODEL OF A MIXED STORAGE

Let us assume an ideal situation with the water temperature constant throughout the storage volume. For that model, the inlet water temperature T_i (*h*) and the outlet water temperature T_o (*h*) are assumed to be equal ($\Delta T_C = 0$). Naturally, the water temperature at the extraction from the system is also equal to the temperature T_i (*h*). If additional cold water is supplied from the water supply system (in Estonia +7 °C), it will mix within the total volume of the storage and reduce the level of T_i (*h*) according to the volumes of mixing waters, as explained in [1].

9. MODEL OF A STRATIFIED STORAGE

In this ideal situation, we assume that volumes of water heated to different temperatures do not blend and heat conductivity between these volumes is absent. Figure 2 shows the behaviour of an ideally stratified storage, based on the plug-flow approach. Since the storage volume exceeds the volume of the water consumed per day $m < M$, there will always be some mass of heated water in the amount of $M - m$ in the upper part of the storage at the temperature T_i *(16)*, not involved in the heating process the next day. Replacement water at T_i *(8)*, which will not mix, intrudes in the lower part and (the next day) starts heating up within the cold volume layer, by layers downwards.

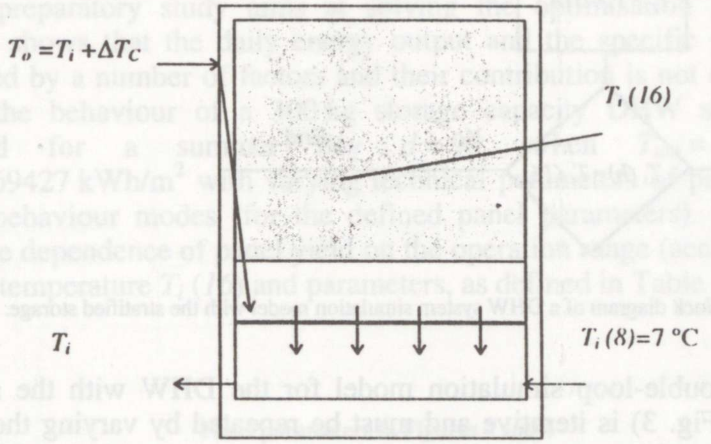

Fig. 2. Ideally stratified storage model based on the plug-flow approach.

According to the above plug-flow approach, the circulation takes place only in the "cold volume" of the storage at the constant water temperature for one cycle. For each given time discrete h_i, water is heated at the temperature discrete ΔT_C for the mass discrete $m(h_i)$. By summing up the mass discretes calculated from the energy balance equation, we shall find the water mass heated up for ΔT_C at the current instant

$$m\,(h_i) = m\,(h_{i-1}) + A_C\,(I(h)F_R\,(\tau\alpha) - F_R\,U_L\,(T_i\,(h_i) - T_a\,(h_i)))/C_p\,\Delta T_C\,. \quad (7)$$

If $m(h_i) = m$, one circulation cycle at the temperature T_i is completed and will be repeated at the temperature higher by ΔT_C until the water has reached the temperature $T_i(16)$ given at the instant during the checking time of $h = 16$. At the instant means in the range of the given time error. The calculations were more precise with $h_i = 0.1$ h selected and the allowed mass error below 5 kg. $T_i\,(16) \in \{36.34;\ 46.12 \text{ or } 55.9\}$. In a rough calculation $h_i = 0.25$ h. For subjective reasons, the examples below were selected close to the Swedish standards 55 °C: $T_i\,(16) = 55.9$ °C and the temperature rise step $\Delta T_C = 9.78$ K, which corresponds to the five cycles of $m = 100$ kg.

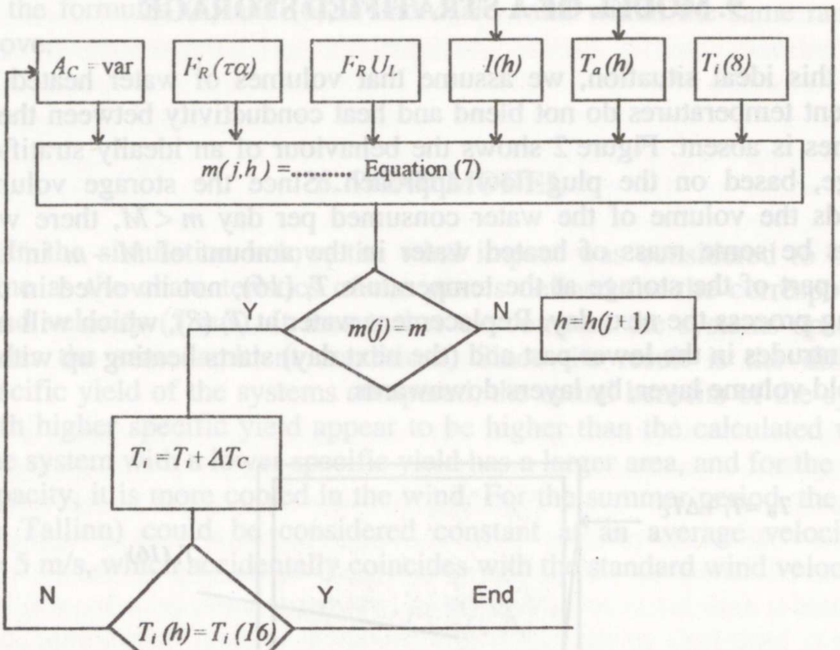

Fig. 3. Block diagram of a DHW system simulation model with the stratified storage.

The double-loop simulation model for the DHW with the stratified storage (Fig. 3) is iterative and must be repeated by varying the surface area of the given panel until the required temperature during $8h$ and for the mass m is obtained. The first loop shows the time instant for one (given) temperature discrete (with a given mass error) in the potential series of time discretes when the total heated mass m has been heated up for one (sequent) temperature rise step ΔT_C. Then, the procedure is repeated to the next temperature discrete. The second loop shows that by varying the surface area of the solar collector A_C (for the constant quality of the collector), we must reach $h = 16$, the mass m at the instant (i.e., with the given temperature error) has completed the given number j of temperature rise cycles. In the examples below $j = 5$. The SDHW system is split into two DHW systems with the same procedures applied for both sections. Here we take into account that the additional water to the "hot" section is the output water of the "cold" section

$$T_{i2}(8) = T_{i1}(16).$$

Since according to the model, circulation occurs only in the lower "cold volume" and does not reach the "hot" section, in a stratified system, the ratio m/M is negligible.

The temperature of the transferred water in the SDHW system (Fig. 1*B*) has also been studied, where we always get a combination $j_1 + j_2 = 5$. If the water temperature from the "cold" section

$T_{i1}\ (16) = 36.34$ °C, then $j_1 = 3$ and $j_2 = 2$. If $T_{i1}\ (16) = 46.12$ °C, then $j_1 = 4$ and $j_2 = 1$. In the model, the temperature of the transferred water shows a temperature rise in the series
$T_i\ (h) \in \{7;16.78;26.56;36.34;46.12;55.9...\}$, defined by the temperature rise step $\Delta T_C = 9.78$ K.
$T_i\ (8) = 7$ °C for DHW and SDHW in the "cold" section.
$T_i\ (8) = T_{i2}\ (8) = T_{i1}\ (16)$ for SDHW in the "hot" section.
The formula (7) is valid for the pulse-model consumption.

10. DEPENDENCE OF THE SPECIFIC YIELD OF PANELS ON THE OPERATION RANGE

This preparatory study aims at solving the optimisation problem. Figure 3 shows that the daily energy output and the specific yield are influenced by a number of factors and their contribution is not clear yet. Below, the behaviour of a 300 kg storage capacity DHW system is simulated for a summer day $d = 90$, when $T_{am} = 13.8861$; $I_{\max} = 0.69427$ kWh/m^2 with varying technical parameters of panels and storage behaviour modes (for the defined panel parameters). Figure 4 shows the dependence of panel yield on the operation range (according to the final temperature $T_i\ (16)$ and parameters, as defined in Table 1.

Table 1

Panel parameters in Figures 4 and 6

Symbol used in Fig. 4	Symbol used in Fig. 6	$F_R(\tau\alpha)$	$F_R U_L$
	I	0.9	0.02
	II	0.85	0.015
0.8	III	0.8	0.01
0.7	IV	0.7	0.007
0.65	V	0.65	0.004

The water temperature is raised by 30 K, but in a different temperature range, e.g., 5–35 °C, 10–40 °C, etc. Figure 4 shows that

a) the specific yield drops towards the higher end temperature; the negative dependence is linear;
b) the specific yield of the system with a stratified storage is always higher and the storage should be adjusted to such behaviour mode;
c) the lower value of $F_R U_L$ reduces the dependence of the specific yield both on the temperature and on the storage behaviour model;
d) the dependence of specific yield on the temperature is not related to the operation model of the storage. Its values were considered according to the separate panels:

“0.8” : $dQ_{us} = 0.083$ kWh/m^{2}K;
“0.7” : $dQ_{us} = 0.059$ kWh/m^{2}K;
“0.65” : $dQ_{us} = 0.033$ kWh/m^{2}K.

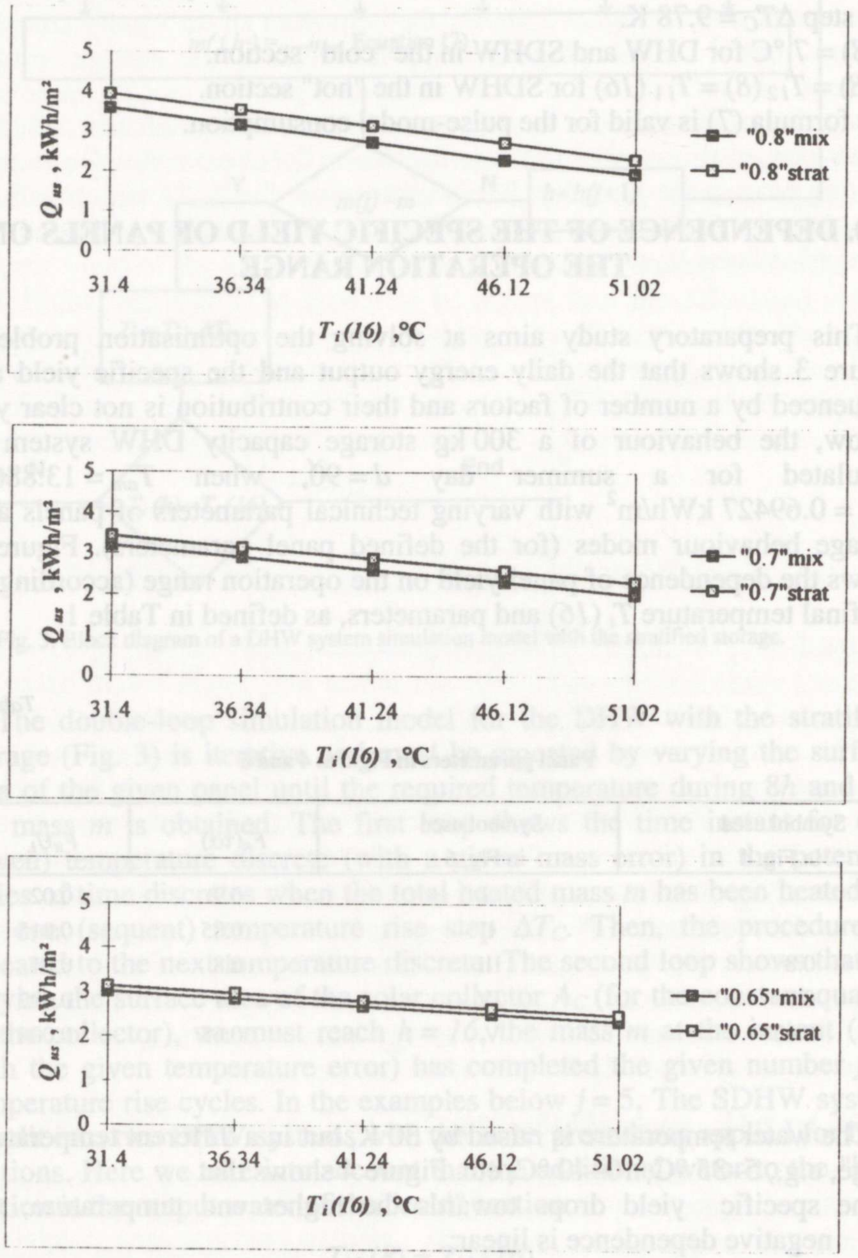

Fig. 4. The influence of collector characteristics to the daily energy yield according to the storage model and its final temperature (“mix” or “strat” show the used storage model).

Figure 5 demonstrates the dependence of the specific yield of a panel on the specifications at several end temperatures, showing that

a) the relationship $Q_{us} = f(T_i\,(16)$ if $F_R(\tau\alpha) = \text{const})$ is linear;

b) the relationship $Q_{us} = f(F_R(\tau\alpha)$ if $T_i\,(16) = \text{const})$ is linear;

c) the relationship $Q_{us} = f(F_R U_L$ if $T_i\,(16) =$ const) is nonlinear both for $T_i\,(16)$ and $F_R U_L$; the relationship is higher at higher temperatures and with poor insulation;

d) the highest impact on the specific yield is expressed by

$$dQ_{us}/dT_i\,(16) = 0.125\ \text{kWh/m}^2\text{K, if } F_R U_L = 0.01\ \text{kWh/m}^2\text{K}.$$

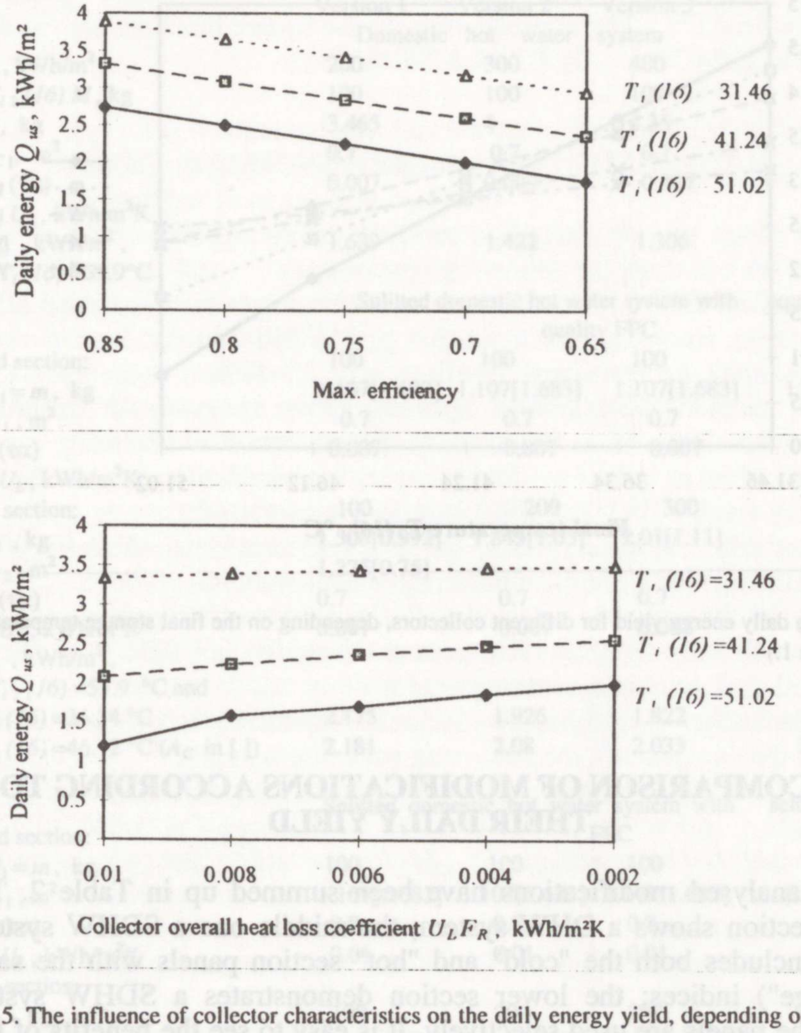

Fig. 5. The influence of collector characteristics on the daily energy yield, depending on the final storage temperature.

The lowest impact on the specific yield is expressed by

$$dQ_{us}/dT_i\,(16) = 0.0562\ \text{kWh/m}^2\text{K, if } F_R U_L = 0.002\ \text{kWh/m}^2\text{K}.$$

The diagram in Fig. 6 illustrates the field of expanded modifications (for a stratified storage model), showing the following:

a) if $T_i\,(16) <$ ca 35 °C, the panels with maximum $F_R(\tau\alpha)$ must be used, the insulation does not contribute significantly;

b) if T_i *(16)* > ca 45 °C, the panels with minimum F_RU_L must be used, $F_R(\tau\alpha)$ does not contribute significantly;
c) if T_i *(16)* ≈ ca 40 °C, panel selection is not critical.

The dependence of the system behaviour on the panel characteristics is practically identical to both mixed and stratified storages.

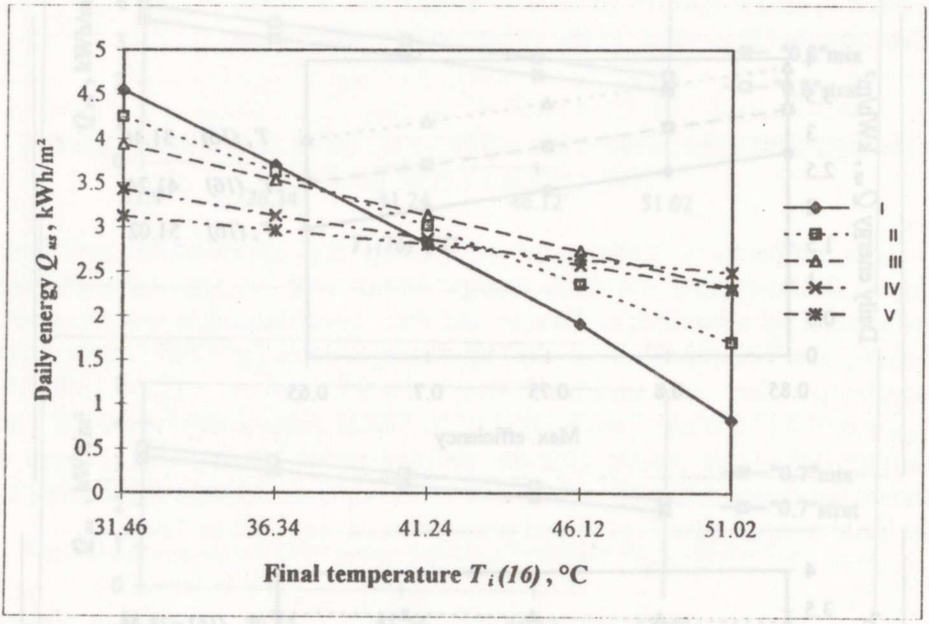

Fig. 6. The daily energy yield for different collectors, depending on the final storage temperature. (See Table 1.)

11. COMPARISON OF MODIFICATIONS ACCORDING TO THEIR DAILY YIELD

The analysed modifications have been summed up in Table 2. The upper section shows a DHW system; the middle one a SDHW system, which includes both the "cold" and "hot" section panels with the same ("average") indices; the lower section demonstrates a SDHW system where the panels are used selectively. It is easy to see the benefits of this technical solution over the previous DHW or SDHW systems.

The advantages of a system which includes the "average" panel $F_R(\tau\alpha) = 0.7$; $F_RU_L = 0.007$ kWh/m^2 K in the "hot" section and the panel $F_R(\tau\alpha) = 0.8$; $F_RU_L = 0.01$ kWh/m^2 K in the "cold" section were analysed. Evidently, this solution is less expensive and improves the specific yield. Table 2 does not contain data on this modification.

Table 2

Concentrated results of the analysis

FPC parameters and results Q_{us}	Mixed storage model			Stratified storage model
	Version 1	Version 2	Version 3	
	Domestic hot water system			
Q_{us} , kWh/m^2 ,	200	300	400	300
if $T_{i\,2}\,(16)$ M , kg	100	100	100	100
m , kg	3.465	4	4.35	2.4
A_C , m^2	0.7	0.7	0.7	0.7
$F_R\,(\tau\alpha)$	0.007	0.007	0.007	0.007
$F_R\,U_L$, kWh/m^{2}K				
Q_{us} , kWh/m^2 ,	1.639	1.422	1.306	2.369
if $T_i\,(16)$ =55.9°C				
	Splitted domestic hot water system with equal quality FPC			
Cold section:	100	100	100	100
$M_1 = m$, kg	1.107[1.683]	1.107[1.683]	1.107[1.683]	1.09[1.62]
$A_{C\,1}$, m^2	0.7	0.7	0.7	0.7
$F_R\,(\tau\alpha)$	0.007	0.007	0.007	0.007
$F_R\,U_L$, kWh/m^{2}K				
Hot section:	100	200	300	200
M_2 , kg	1.505[0.992]	1.845[1.05]	2.01[1.11]	
$A_{C\,2}$, m^2	1.275[0.75]			
$F_R\,(\tau\alpha)$	0.7	0.7	0.7	0.7
$F_R\,U_L$, kWh/m^{2}K	0.007	0.007	0.007	0.007
Q_{us} , kWh/m^2 ,				
if $T_{i\,2}\,(16)$ =55.9 °C and				
$T_{i\,1}\,(16)$ =36.34 °C	2.175	1.926	1.822	2.402
$T_{i\,1}\,(16)$ =46.12 °C (A_C in [ ])	2.181	2.08	2.033	2.397
	Splitted domestic hot water system with selective FPC			
Cold section:				
$M_1 = m$, kg	100	100	100	100
$A_{C\,1}$, m^2	1.107[1.683]	1.107[1.683]	1.107[1.683]	0.97[1.5]
$F_R\,(\tau\alpha)$	0.8	0.8	0.8	0.8
$F_R\,U_L$, kWh/m^{2}K	0.01	0.01	0.01	0.01
Hot section:				
M_2 , kg	100	200	300	200
$A_{C\,2}$, m^2	1.505[0.922]	1.845[1.05]	2.01[1.11]	1.04[0.56]
$F_R\,(\tau\alpha)$	0.65	0.65	0.65	0.65
$F_R\,U_L$, kWh/m^{2}K	0.004	0.004	0.004	0.004
Q_{us} , kWh/m^2 ,				
if $T_{i\,2}\,(16)$ =55.9 °C and				
$T_{i\,1}\,(16)$ =36.34 °C	2.73	2.608	2.562	2.977
$T_{i\,1}\,(16)$ =46.12 °C (A_C in [ ])	2.539	2.504	2.496	2.785

A DHW system with a mixed storage was analysed for different values of *m/M*. This ratio influences the specific yield and is not essential for a DHW system with an ideally stratified storage where only some constant water mass ($m = 100$ kg) is engaged in water exchange (under simulation conditions). Both theoretically and according to the simulation model, the specific yield remains invariant to the ratio *m/M* here.

The data on A_C (given in square brackets) are valid when water transfer from the "cold" to the "hot" section takes place at $T_{i1}\,(16) = 46.12$ °C. The numbers outside the square brackets are valid for $T_{i1}\,(16) = 36.34$ °C.

12. CONCLUSIONS AND RECOMMENDATIONS

As a result of our simplified analysis of the specific yield of solar systems, we can draw the following conclusions:

1) A stratified DHW system has several advantages over a mixed DHW system. Excluding the transition period (close to the days of vernal equinox), the estimated benefit may be 25–30%.
2) For a mixed DHW system, splitting gives a significant benefit. It reaches 30% when the same collectors are used. Splitting can be described as inducing (double-layer) forced stratification. Its benefit may reach 70% when suitable collectors are used.
3) In a stratified storage system, splitting will provide no benefits if the collectors with identical parameters are used.
4) But with the properly selected collectors, a stratified system can still benefit from splitting. The estimated benefit is ca 20% (e.g., for the collector used in our examples).
5) For the technical optimisation (which includes no economical indices of the equipment), the following parameters apply:
   surface area of both collectors A_{C1}, A_{C2} (or their ratio), $F_R(\tau\alpha)$, $F_R U_L$;
   capacity of both storages M_1 , M_2 (or the ratio of their capacities);
   volume of the consumed water *m* (or its ratio to the total stored water volume);
   the end temperature $T_{i1}(16)$ of the water preheated in the "cold" section.
6) The higher the temperature of water transferred from the "cold" section the less is the influence of the storage behaviour model on the specific yield, i.e., the properties of the mixed and stratified systems approach.
7) For a conventional (non-splitted) system, the difference of simulation models (for a mixed and a stratified storage) is significant.
8) The validity of the impulse model used should be checked either by comparing it with a known simulation program (e.g. TRNSYS) or experimentally.
9) Since the analysis covered a certain geographical location and climatic factors, it cannot be freely expanded for optional conditions.

In fact, no real system can be represented by an ideal mixed or a stratified type. Therefore, the values calculated above should be looked at as follows: for the mixed storage, the calculated effect should be considered as an estimation from above; for the stratified storage model, the calculated effect should be considered as an estimation from below. Thus, the actual effect is assumed to be between the numbers described.

NOMENCLATURE

A_C, A_{C1}, A_{C2} – collector area (according to the collector number), m^2
C_p – specific heat (of water), J/kgK
d – day number (since spring equinox)
F_R – collector's heat removal factor
h – hour number
h_j – time discrete, with number j
I – solar irradiance, kWh/m^2
j – sequence number
M, M_1, M_2 – storage mass (according to storage number), kg
m – water mass, warmed up daily, kg
m_j – water mass discrete, kg
$p(h)$ – characteristic parameter, Km^2/kW
Q_{ud} – daily useful energy, kWh
Q_{us} – specific daily useful energy, kWh/m^2
T_a – ambient temperature, °C
T_{am} – average value of ambient temperature, °C
T_{aa} – amplitude of the ambient temperature sine-wave, K
T_i, T_{i1}, T_{i2} – temperature of the input water (according to the collector number), °C
T_o – collector output temperature, °C
U_L – collector's overall heat loss coefficient, kWh/m^2K
v – wind-speed, m/s
η – collector efficiency
$(\tau\alpha)$ – transmittance-absorbance product
ΔT_C – temperature rise step on the collector, K

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HARILIKU JA LÕHESTATUD HELIO-SOOJAVEESÜSTEEMI VÕRDLEV ANALÜÜS

Teolan TOMSON

Lähtudes impulsstarbimise mudelist on määratud lõhestatud konfiguratsiooniga helio-soojaveesüsteemi eritootlikkuse sõltuvus süsteemi elementide parameetritest ja salvesti töörežiimist. Simulatsiooni meetodil on tehtud soovitused optimaalsele lähedase süsteemi koostamiseks. Süsteemi lõhestamine tagab selektiivselt valitud heliokollektorite puhul energiatoodangu juurdekasvu nii salvesti segistatud kui ka stratifitseeritud töörežiimi korral. Arvutatud toodangu kasvu suurust võiks hinnata 20–40%-le võrreldes hariliku süsteemiga.

СРАВНИТЕЛЬНЫЙ АНАЛИЗ ТРАДИЦИОННОЙ И СЕКЦИОНИРОВАННОЙ СИСТЕМ СОЛНЕЧНОГО ПОДОГРЕВА ВОДЫ

Теолан ТОМСОН

Для модели импульсного потребления нагреваемой воды рассчитана зависимость удельной производительности расщепленной (секционированной) гелиосистемы водоподогрева от свойств и режима работы ее элементов. Методом математического моделирования выработаны рекомендации для создания системы, близкой к оптимальной. Расщепленная гелиосистема водоподогрева обеспечивает при селективно выбранных коллекторах увеличение ее производительности как в случае смешанного, так и в случае стратифицированного режима работы резервуара нагреваемой воды. Расчетный прирост производительности такой системы может быть оценен в 20–40% по сравнению с показателями традиционной установки.