EXPERIMENTAL STUDIES AND ECONOMIC CONSIDERATIONS ON A THERMOSOLAR PILOT SYSTEM DESTINED FOR HOUSE TEMPERATURE MAINTENANCE

by

Ioan V. LUMINOSU

Original scientific paper
UDC: 620.91:662.997
BIBLID: 0354–9836, 7 (2003), 1, 47-61

The "Politehnica" University of Timisoara has built a thermo solar system implemented on the ground floor and first floor of a building. The system is made up of solar water collectors, an air-water heat exchanger, a bedrock heat accumulator and a minimal thermal loss enclosure. The statistical processing of the measurements performed during spring and autumn 2000 resulted in determining the average features of the system and in the evaluation of its efficiency in maintaining the enclosure's temperature, enclosure assimilated to a living space. The efficiency of the system is 30%. During spring and autumn, the enclosure's temperature is maintained at a level of 20 °C by solar and electrical gain, with a 60% solar energy ratio. With the help of the state in promoting solar energy, the investment's writing-off period would be 18.5 years, and the user's benefit, B = 2117€.

Key words: solar energy, solar collectors, demo solar house, return investment's period

Introduction

The thermo solar systems that equip solar houses are meant to maintain the indoor temperature at a comfortable level and also to supply domestic hot water.

The incongruity in time between sun effect and energy needs has led to different types of thermosolar systems complementary to classic installations.

Some of the achievements described in the specialized literature are:

– the hybrid solar system with heat pump, flat collectors and $CaCl_2$ $6H_2O$ storage tank [1],
– the solar system with heat pump using the heat released by the building's roof [5],
– the thermosolar system with flat collectors, complementary to the methane gas installation [7], and
– the thermosolar system complementary to gasoline installations [10].

The thermo solar pilot system built at "Politehnica" University Timisoara (45° N, 22° E) is meant to study the possibility of maintaining the indoor temperature through solar and electrical gain. The energy system includes water flat collectors, a water-air heat exchanger, a bedrock heat accumulator and a minimal thermal loss enclosure. The purpose of the minimal thermal loss enclosure is to disperse the thermal energy from the sun (stored in the bedrock) in the surrounding environment, at a very slow rate. The temperature inside the minimal thermal loss enclosure was maintained at 20 °C all throughout the non-insolation periods – when the environment's temperature was 4-15 °C. This was carried out by means of the heat extracted from the accumulator, as well as that supplied by an electric heater 6, 8 .

The measurements were carried out throughout March, April, May, September, October, and November 2000.

The systems described in the specialized literature show that the heat-transfer fluid is set into motion if the intensity of the solar radiation in the collectors' plan overpasses 300 W/m^2.

The thermo solar system detailed in this paper has a thermostat placed on the hot water pipe, which is ensuring the motion of the heat-transfer fluid provided that the temperature of the hot water exceeds 50 °C.

The experimental results provided by this system prove useful to solar equipment designers in the Euro-region bordered by western Romania, east part of Yugoslavia and southern Hungary, as settlements in these areas present similar climate conditions.

The description of the thermosolar system

The solar house

The building shown in fig. 1 has brick walls insulated with mineral wool. The ledged roof is made of double reinforced concrete plates, and it is insulated with bitumen. The building has two rooms, a lobby and an access hall. The minimal thermal loss enclosure is at the first floor, and it has double doors and triple windows. The enclosure's floor is made of ash-insulated reinforced concrete, covered in wooden planks. The room's dimensions are 3.5 × 3.5 × 2.8 m, the volume is V_r = 34.3 m^3 and the total thermal exchange area of the enclosure is A_r = 63.7 m^2. The technical room is at the ground floor. The basement shelters the bedrock thermal accumulator in the shape of a parallelepiped measuring 1.5 × 1.5 × 4 m and filled with river stone, C = 16.6 MJ/K. The concrete walls are 40 cm thick and they are insulated with mineral wool. The main side of the building is south orientated.

Figure 1. Photo of the solar house

Figure 2. Photo of the solar collectors

The access way into the building is through a lobby and hall protected by glass panels. The flat solar collectors are shown in fig. 2.

The energy system

The energy system shown in fig. 3 includes the flat solar collectors (1), the heat exchanger (2), the thermal accumulator (3), the heated room (4), and the technical room (5).

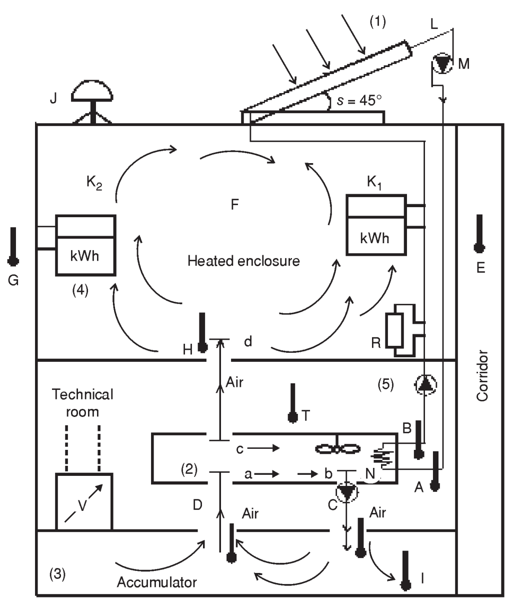

Figure 3. Simplified chart of the energy system
1 – Collectors, 2 – Heat exchanger, 3 – Stone-filled tank, 4 – Heated room, 5 – Technical room

Twelve "Sadu 1" solar collectors in parallel connection form the collectors' field. Each collector is a channel plate with aluminum pipes of a 20 mm inner diameter, facing south at an s = 45 deg angle from the horizontal. The distance between pipes is 150 mm. A 4 cm thick pane creates the greenhouse effect. The collector's dimensions are 2.0 × 1.0 × × 0.12 m, and its 50 mm insulation is made of mineral wool. The case is made of 0.8 mm steel plates. The heat-transfer fluid is water, activated by a Riello TF108 pump with P = = 40 W, and a flow of m_w = 300 kg/h. The collectors' area is A_c = 24 m^2. The thermal and optical features are U_c = 3.7 W/m^{2}K and $(\tau\alpha)_{eff}$ = 0.81.

The heat exchanger is an air-water type with copper coil, P = 60 W, m_a = = 1154 kg/h. The heat of the hot water flowing through the collectors and through the heat exchanger's coil is taken by the airflow and thus carried to the bedrock.

The physical properties of the storage environment, calculated according to [2], are given in tab. 1.

Table 1. The thermal accumulator's features

Parameter	Value	Parameter	Value	Parameter	Value
A_f m^2	2.25	d^* m	$9.9\cdot10^{2}$	ε	0.52
G kg/h·m^2	512.9	h_w W/ m^{3}K	837.7	τ^* h	14.7
U_{st} W/m^{2}K	1.74	NTU	37.3	Bi	0.24
v m^3	$5.2\cdot10^{4}$	Pe	$9.4\cdot10^{2}$		

The slide dampers in points a, b, c, and d (fig. 3) ensure the desired airflow direction, *i. e.* from the heat exchanger to the tank or from the tank to the heated room, through nozzles C, D, and H. The enclosure (4) may be heated either through solar gain, by the hot airflow coming from the accumulator through nozzle H, or through electrical gain, from radiator R equipped with a thermostat.

Measuring and automation instruments

The temperature in points A, B, C, D, H (heat transfer fluid), F (living room), E (hall), I (tank), G (exterior), and T (technical room) is read on the electrical thermometer (fig. 3), with an error of Δt = 0.5 °C. The thermometer's sensors are the 1N4148 diodes.

The intensity of solar radiation is read on the pyrheliometer J (Solaris 2) (fig. 3), with an error of ΔI = 1 W/m^2.

The amount of the water in motion is read on the AEM BN2.5 water gauge, in point M, with an error of ΔV = 25 cm^3. The water flow is determined through the ratio given by the volume recorded on the water gauge per water motion period.

The air speed is read in the point N on the FEET anemometer, with an error of $\Delta v_a = 5.0$ m/s. The airflow is given by the expression $V_a = A_a v_a = 895$ m^3/h.

The electrical energy used by radiator R is read on the AEM 1CM4A meter in point K_1 with an error of $\Delta Q_{el} = 5 \cdot 10^{-3}$ kWh. The energy used by the pumps is read on the supply meter in point K_2.

The automation element includes the temperature detector βM135 adjusted in point L, and a leading circuit. The leading circuit sets the pumps into motion only if the water emerging from the collectors has a temperature over 50 °C. This operating solution to the collectors' field has led to an increase of 5% in the collector's efficiency, as compared to the other solution that makes the pumps stop if the intensity of the solar radiation decreases below a certain level, usually set by the user around 300 W/m^2.

The heat required for heating the enclosure

The temperature inside the technical room at the ground floor is kept at 20 ± 1 °C by means of electrical heaters equipped with a thermostat. As a consequence, the construction elements that determine the enclosure's temperature loss are: the southern, eastern and western walls, the ceiling, the window opening towards the exterior and the northern wall towards the corridor. The cool air coming from the exterior enters the room through the louvers of the triple window, and the air from the corridor comes through the louvers of the double door.

According to 9 , the heat loss per time unit through the walls, the ceiling, the window and the door openings is given by eq. (1):

$$\dot{Q}_1 \qquad m_i A_i \frac{\Delta T_i}{R_i} \tag{1}$$

where: $\Delta T_1 = T_F - T_G$, and $\Delta T_2 = T_F - T_E$.

According to 9 , the heat required to warm up the air infiltrated through the louvers of the window and the door is:

$$\dot{Q}_2 \quad E \quad (iL)u^{4/3}\Delta T_i \quad \dot{Q}_{door} \tag{2}$$

The double door, when opened, doesn't allow cold air into the room, thus $\dot{Q}_{door}$ 0.

The global resistance to thermal permeability is given by eq. (3):

$$R \quad \frac{1}{\alpha_{int}} \quad {}^{3}_{1} \; \frac{d_j}{k_j} \quad \frac{1}{\alpha_{ext}} \tag{3}$$

The heat loss of the room is the sum:

$$\dot{Q}_L \quad \dot{Q}_1 \quad \dot{Q}_2 \tag{4}$$

The expression found for parameter $\dot{Q}_L$, when taking into account the geometrical and thermal features of the construction elements, is:

$$\dot{Q}_L \quad 183(T_F \quad T_G) \quad 71(T_F \quad T_E) \qquad \text{W} \qquad (5)$$

The hourly heat loss of the room is:

$$Q_{h,L} \quad 3600\,\dot{Q}_L \qquad \text{J} \qquad (6)$$

The daily (12 h) heat loss of the room is:

$$Q_{d,L,room} \quad \overset{n}{\underset{1}{}} Q_{h,L}, \quad n\text{ – number of hours} \qquad \text{J} \qquad (7)$$

The average heat dissipated by the room throughout one day is $\overline{Q}_{d,L,room}$ 62 MJ, with an amplitude of 8 MJ/day. The heat lost by the room is compensated through solar and electrical gain:

$$\overline{Q}_{d,L,room} \quad \overline{Q}_{H \quad F} \quad \overline{Q}_{el,heat} \qquad \text{J} \qquad (8)$$

The processing module for experimental data

The hourly measurements were carried out over several series of 3-4 days, during spring (March, April, May) and autumn (September, October, November), 2000. In order to obtain the average insolation characteristics the experimental data were statistically processed, as follows:

- the measurement period was split into 12 h intervals, successively numbered 1, 2, ..., n; $n = n_1 + n_2$; n_1 – the number of insolation intervals, n_2 – the number of non insolation intervals (during night-time, somber days);
- the hourly and daily average energy were calculated using eqs. (9, 10, and 11):

$$H_h \quad 3600\, I_{h,c}\, A_c \qquad \text{J} \qquad (9)$$

$$\overline{H}_h \quad \frac{1}{n_1} \underset{(n_1)}{} H_h \qquad \text{J} \qquad (10)$$

$$\overline{H}_d \quad \overset{p}{\underset{1}{}} \overline{H}_h, \quad p = 1\text{-}8 \text{ – number of 1 h intervals in an insolation day} \qquad (11)$$

- the hourly average temperatures, in the points shown in fig. 3, were calculated using eq. (12):

$$\bar{t}_{h,q} \quad \frac{1}{n_{1,2}} \overset{n_{1,2}}{\underset{1}{}} t_{h,q}, \quad q \quad A, B, C, D, E, F, G, H, I \qquad (12)$$

- the energy system links were marked with j: $j = 0$ (collection area), $j = 1$ (collectors, bordered by A and B), $j = 2$ (heat exchanger, bordered by C and D), $j = 3$ (accumulator, bordered by I and H), $j = 4$ (room, bordered by H and F); the hourly and daily average heat were calculated afterwards, for each segment, using eq. (13 and 14):

$$\overline{Q}_{h,j} \quad 3600\, m_x C_x \Delta\bar{t}_{h,j} \tag{13}$$

$$\overline{Q}_{d,j} \quad {}_{(p)}\overline{Q}_{h,j} \tag{14}$$

$$(e.\,g.: \;\; \Delta t_{h,1} \quad \bar{t}_{h,A} \quad \bar{t}_{h,B})$$

The subscript index x shows the fluid's chemical nature: x a (air), x w (water).

– the average efficiencies of the links were calculated using eq. (15):

$$\overline{\eta}_j \quad \frac{\overline{Q}_{d,j\ 1}}{\overline{Q}_{d,j}} \tag{15}$$

$$(e.\,g.: \;\; \text{for the collectors, } \overline{Q}_{d,0} \quad \overline{H}_d$$

$$\eta \quad \frac{\overline{Q}_{d,1}}{\overline{H}_d} \quad \frac{\overset{8}{\underset{1}{}} 3600 m_w C_w (\bar{t}_{h,A} \quad \bar{t}_{h,B})}{\overline{H}_d}$$

– the average efficiency of the solar system is given by eq. (16):

$$\overline{\eta}_{syst} \quad \overset{3}{\underset{1}{}}\, \overline{\eta}_j \tag{16}$$

The daily average radiant energy on the collectors

The hourly variation of the parameter $\overline{H}_h$, considering the hour of the average day, is shown in fig. 4.

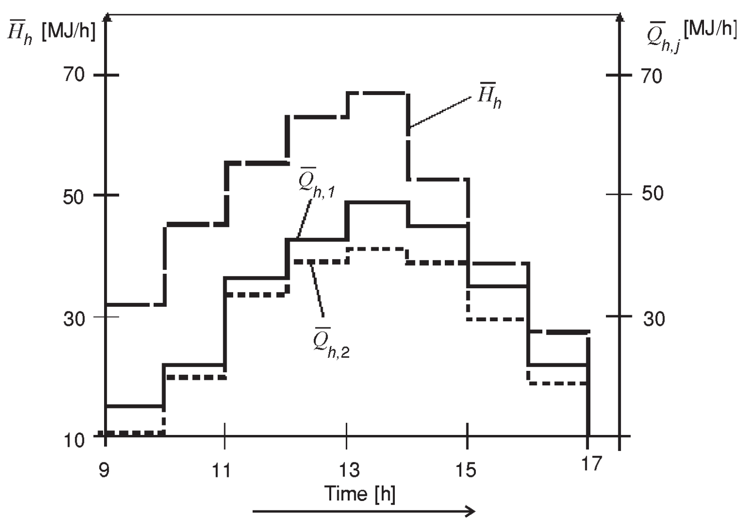

Figure 4. Hourly average variations of parameters $\overline{H}_h$, $\overline{Q}_{h,1}$, and $\overline{Q}_{h,2}$

The diurnal average value of the radiant energy, given by eq. (11), is:

$$\overline{H}_d \quad 389.8 \ \text{MJ/day}$$

Average thermal levels

The average hourly temperatures in points A, B, C, D, and I, depending on the hour of the day, are shown in fig. 5.

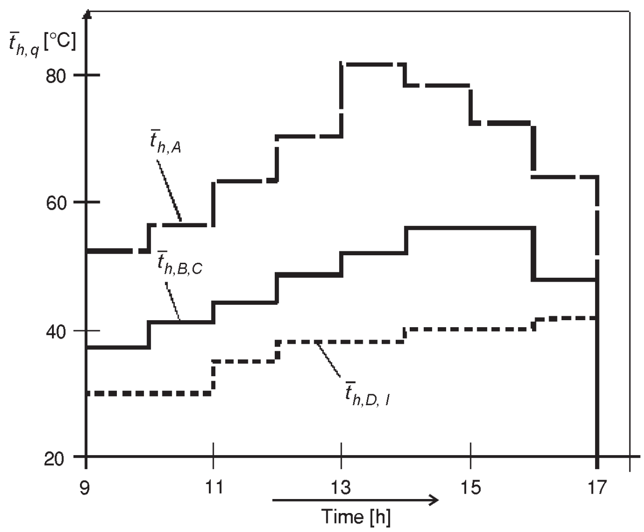

Figure 5. Hourly average temperatures in points A, B, C, D, and I

The average temperature in A, at noon, is 83 °C. The highest temperature in A, *i. e*. 87 °C, is reached during May and September. During March and November the same point reaches the lowest temperature, *i. e*. 61 °C.

The maximum average temperature of the air in the heat exchanger is 52 °C.

The temperature of the accumulator was carefully maintained over 30 °C all throughout the measurement period ($t_{\text{min,st.}}$ = 30 °C).

The average increase in temperature of the tank during the daily loading period is Δt = 11 °C/day.

The average decrease in temperature of the tank during the storage period is 0.3 °C/day.

The daily average decrease in temperature during the extraction of the heat from the bedrock is 4.5 °C/day.

The average temperature inside the heated room is 20 ± 1 °C/day.

The outside temperature ranges between 4 and 15 °C.

The average efficiency of the energy system

The efficiency of the collectors

The daily average heat transferred by the collectors to the heat exchanger – fig. 4, and determined by eq. (13 and 14) is:

$$\overline{Q}_{d,A \quad B} \quad \overline{Q}_{d,1} \quad 291.6 \ \text{MJ/day} \tag{17}$$

The average efficiency of the collection field calculated by eq. (15) is:

$$\overline{\eta}_2 \quad 0.75 \tag{18}$$

The efficiency of the heat exchanger

The daily average heat – fig. 4, taken by the airflow from the AB coil is:

$$\overline{Q}_{d,D \quad C} \quad \overline{Q}_{d,2} \quad 239.4 \ \text{MJ/day} \tag{19}$$

The efficiency of the heat exchanger, determined by eq. (15) is:

$$\overline{\eta}_{2,ld} \quad 0.82 \tag{20}$$

The efficiency of the bedrock thermal accumulator

The daily average heat the rock takes over from the hot airflow presents the following value at thermal charge:

$$\overline{Q}_{d,I \quad H} \quad \overline{Q}_{d,3} \quad 183.7 \ \text{MJ/day} \tag{21}$$

The efficiency of the thermal charge is:

$$\overline{\eta}_{2,ld} \quad 0.77 \tag{22}$$

The heat from the accumulator can be transferred to the room at a daily average rate of $\overline{q}_{d,3} \quad 34$ MJ/day, over a period of three days. The room thus has a solar gain of:

$$\overline{Q}_{d,3} \quad \overline{Q}_{d,4} \quad \overline{Q}_{d,H \quad F} \quad 115.7 \ \text{MJ/day} \tag{23}$$

The efficiency of the heat extraction from the storage environment is:

$$\overline{\eta}_{3,ds} \quad 0.63 \tag{24}$$

The global efficiency of the accumulation and storage of the heat is:

$$\overline{\eta}_3 \quad \overline{\eta}_{3,ld}\overline{\eta}_{3,ds} \quad 0.49 \tag{25}$$

The efficiency of the system

The efficiency of the device, calculated by eq. (16), is:

$$\bar{\eta}_{syst} \quad 0.30 \tag{26}$$

The energy balance of the average day

The incident solar energy on the collectors is the primary source of energy. Each j link of the energy system receives energy from the $j-1$ link, converts a part of the energy according to its function and then transfers it to the $j+1$ link, while the rest of it is lost to the environment.

If we generically consider Φ as the energy forms flowing through the energy system, the written equation of the energy balance is:

$$\underset{(j)}{}\bar{\Phi}_{d,j}^{in} \quad \underset{(j)}{}\bar{\Phi}_{d,j}^{out} \quad \underset{(j)}{}\bar{\Phi}_{d,j}^{sp} \tag{27}$$

The elements Φ develop from one segment to another, as follows:

$$\begin{aligned} &\underset{(j)}{}\bar{\Phi}_{d,j}^{in} \quad \bar{H}_d \quad \bar{Q}_{d,1} \quad \bar{Q}_{d,2} \quad \bar{Q}_{d,3} \quad \bar{Q}_{d,el,heat} \\ &\underset{(j)}{}\bar{\Phi}_{d,j}^{out} \quad \bar{Q}_{d,1} \quad \bar{Q}_{d,2} \quad Q_{d,3} \\ &\underset{(j)}{}\bar{\Phi}_{d,j}^{sp} \quad \bar{Q}_{L,1} \quad \bar{Q}_{L,2} \quad \bar{Q}_{L,3} \quad \bar{Q}_{L,4} \end{aligned} \tag{28}$$

Adding the elements in group (28) to eq. (27) results in:

$$\bar{H}_d \quad \bar{Q}_{d,el} \quad \bar{Q}_{L,1} \quad \bar{Q}_{L,2} \quad \bar{Q}_{L,3} \quad \bar{Q}_{L,4} \tag{29}$$

That means that the sum of the amounts of energy entering the system through its ends equals the sum of the heat losses on the segments the system.

The above considerations are shown in fig. 6.

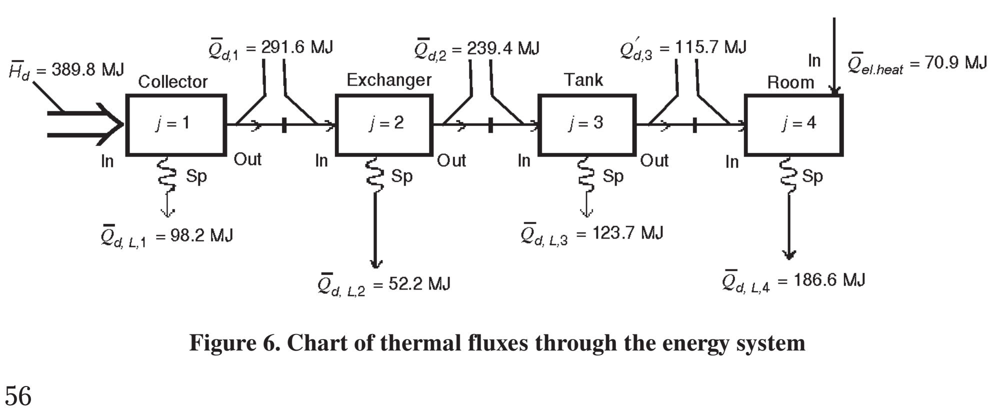

Figure 6. Chart of thermal fluxes through the energy system

Equation (29) is verified by fig. 6, as follows:

$$\begin{aligned} &\overline{H}_d \quad \overline{Q}_{d,el,heat} \quad 460.7 \ \text{MJ} \\ &\overline{Q}_{L,1} \quad \overline{Q}_{L,2} \quad \overline{Q}_{L,3} \quad \overline{Q}_{L,4} \quad 460.7 \ \text{MJ} \end{aligned} \tag{30}$$

The daily power consumption for the pumps is $\overline{Q}_{el,pump} \quad 5.2 \ \text{MJ/day}$.
The solar energy ratio for room heating is:

$$p[\%] \quad \frac{Q_{d,3} \quad Q_{el,pump}}{Q_{d,L,4}} \quad 59 \tag{31}$$

An example of device using

Figure 7 shows the variation of temperatures $\bar{t}_F$ (room), $\bar{t}_G$ (exterior), and $\bar{t}_I$ (tank) between the 13th and 17th of April 2000, depending on n (12 h).

During intervals 1, 3, and 7, traced with a dashed line, the temperature $\bar{t}_F$ was maintained at 20 °C through electrical gain only.

During intervals 2, 4-6, 8, and 9, traced with a double line, the constant level of $\bar{t}_F$ temperature was maintained through both solar and electrical gain.

As to the temperature of the bedrock, $\bar{t}_I$ the simple line segments show its increase during the thermal charge of the tank, while the thick line segments show a decrease in the tank's temperature during heat extraction.

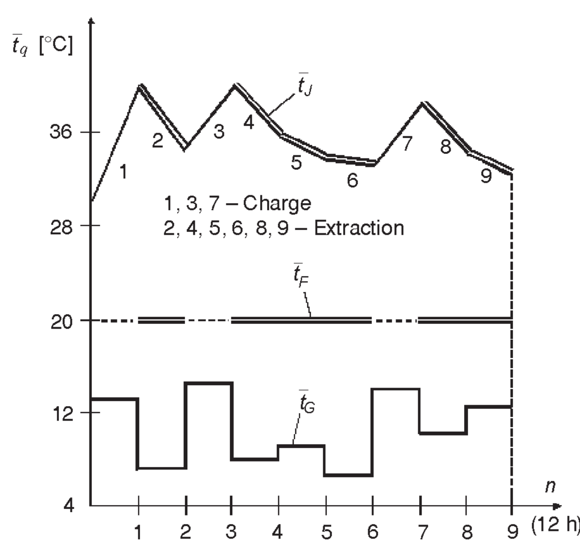

Figure 7. Temperature variation during consecutive 12 h ranges of room heating, in April 2000

The environment's average temperature ranged between 5 and 15 °C.

The energy balance for the room with constant temperature, as presented in fig. 7, includes the following heat values: $H = 1072$ MJ, $Q_{H\to F} = 322$ MJ, $Q_{L,r} = 531$ MJ, and $Q_{el,heat} = 209$ MJ.

The energy balance is $Q_{L,r} = Q_{H\to F} + Q_{el,heat} = 531$ MJ.

The power consumption of the pumps is $Q_{el,pump} = 20$ MJ.

The solar energy ratio for room heating is:

$$p[\%] \quad \frac{Q_{H\quad F} \quad Q_{el,pump}}{Q_{L,r}} 100 \quad 60$$

Economic considerations

The daily average useful specific heat of the solar facility is $\bar{q}_{d,u} \quad 4.9 \ \mathrm{MJ/m^2}$. The number of clear days is $N = 73$. The annual average useful specific heat is $\bar{q}_{y,u} \quad N\bar{q}_{d,u} \quad 358 \ \mathrm{MJ/m^2} \quad 99.4 \ \mathrm{kWh/m^2}$.

Paper 4 shows that, considering the present conditions, the write-off period for solar equipment investments is very large. The paper in question also proves that an increase in unit price of the conventional energy supply will lead to a decrease in the write-off period for solar investments up to 16-23 years.

This paper suggests an involvement of the state in promoting solar energy through the following mechanisms:

- value added tax (VTA) exemption for the producing firm;
- the state should bear 10% of the firm's benefit;
- exemption from certain social expenses for the firm, *e. g.* health insurance, unemployment fund, *etc.*;
- the state should bear the inflation costs during the write-off period;
- the state should give limited credits with very low interest ($d = 4\%$).

Under these circumstances, considering the costs in Romania as well as the exchange rate in March 2002, the total investment is $I = 2800$ □.

The specific investment is $i = I/A_c = 116$ □/m². The annual specific expenses for installation maintenance are $c_1 = 0.6$ □/m²·year.

The electrical energy, used for comparison, has a unit price of $c_{el} = 0.07$ □/kWh.

The specific monetary saving is $e_m \quad \bar{q}_{y,u}\, c_{el} \quad c_1 \quad 6.8$ □/m²·year.

The initial investment's write-off period (n_1) is calculated using eq. (32), 9 :

$$i \quad n_1\, c_1 \quad n_1\, \bar{q}_{y,u}\, c_{el} \tag{32}$$

and the value obtained is $n_1 = 18.5$ years.

The installation's lifetime is $n_2 = 30$ years.

The annual average installment, Y, paid by the user until the investment's write-off, is calculated by eq. (33), 3 :

$$Y = Id \frac{(1+d)^{n_1}}{(1+d)^{n_1}-1} \tag{33}$$

and the value obtained is Y = 218.3 □/year.

The annual monetary average flux until the investment's write-off is:

$$F = e_m A_c - Y = -54.4 \text{ □/year.} \tag{34}$$

The user's net profit for the interval n_2 is:

$$B = n_2 e_m A_c - |\Phi n_1| = 2117.6 \text{ □} \tag{35}$$

The price of 1 kWh of comparable energy during the installation's running life is:

$$c_2 = \frac{I}{\bar{q}_{y,u} A_c n_2}; \quad c_2 = 0.04 \text{ □/kWh} \tag{36}$$

So, $c_2 < c_{el}$, $c_2 - c_{el}$ = 0.03 □/kWh.

The values F and c_2 will increase the consumers' interest in solar energy, thus producing a good effect both on the environment and on the energy resources.

Final remarks

The experimental study presented in this paper shows the economic and the energetically effectiveness of the thermo solar system, thus promoting the solar architecture in the Danube – Kris – Mures – Tisa Euro-region.

The first step in promoting solar energy requires the involvement of the riverside states to stir interest of the users.

The above idea might be well illustrated for the economical and climate conditions of Timisoara.

The southern average surface of a house's roof has an area of A' = 40 m^2. A collection field of an A' area would give each year a useful heat $Q_u = \bar{q}_{y,u} A' = 3977$ kWh. The annual monetary saving would be $E = (\bar{q}_{y,u} c_{el} - c_1) A' = 254.4$ □.

This study can also be extended to thermo solar systems, which do not contain a heat exchanger. In this case the water collectors would be replaced with air collectors. The hot air can be directed both towards the rooms and towards the thermal storage tank.

Acknowledgements

The author takes this opportunity to thank technician Mr. Attila Murvay for engineering the automation and electronic elements, and to certificated accountant Mr. Popa Lucian, from "Cont Control" firm, for his advice in financial matters.

Nomenclature

A – area, m^2
B – financial profit
c – financial costs
C – specific heat, J/kgK
d – daily interest
– the widths of the layers which form the walls
*d** – equivalent diameter, m
e – specific financial saving, □/m^2
E – financial saving, □
– correction factor, *E* = 1 (first floor)
F – monetary flux
G – weight rate per frontal area, kg/m^2s
h – thermal transfer coefficient, W/m^2K
H – radiant energy, MJ/h , MJ/day
i – the air infiltration coefficient, $i = 0.081$, $W(s/m)^{4/3}/mK$
– specific investment, □/m^2
I – solar radiation intensity, W/m^2
– financial investment, □
k – thermal conductivity, W/mK
L – the louvers' length, $L_{door} = 5.4$ m, $L_{window} = 4.4$ m
m – fluid weight rate, kg/h
– the thermal massiveness coefficient, $m_1 = 0.90$ for the walls, and $m_2 = 1.2$ for the window and the door
n – number of 12 h intervals
– number of years
N – number of days
p – number of insolation hours
– weight
P – power, W
q – heat transfer rate, MJ/day
– heat through area unit, MJ/m^2
Q – heat quantity, MJ
– power consumption, kWh
$\dot{Q}$ – heat quantity per unit time
R – the global thermal resistance, m^2K/W
s – angle from the horizontal level
t, T – temperature, °C , K
u – the wind's speed, *u* = 3.4 m/s
U – thermal transfer coefficient, $Wm^{2}K^{1}$
v – fluid speed through the flow-tube, ms^{1} ,
– volume, m^3
V – fluid volume, m^3 ,
– flow, m^3/h

Greek letters

$\alpha_{int, ext}$ – the surface thermal exchange coefficients, $\alpha_{int} = 8$ W/m^2K, $\alpha_{ext} = 22.8$ W/m^2K
Δ – finite difference
ε – filling coefficient
η – efficiency
Π – product
τ – time
τ^* – specific time
Y – monetary rate, □/year
Φ – generic parameter denomination

Subscripts

a – air
c – collector
calc – calculated
d – daily
ds – thermal discharge
el – electric
ext – exterior
f – frontal
h – hourly
heat – heating
in – enclosure
int – interior
j – energy system link number, bordered by the points A, B (j = 1); B, A (j = 2); C, D (j = 3); H, F (j = 4)
L – losses
ld – thermal charge
q – one of the energy system points: A, B, C, D, E, F, G, H, I
r – heated room
– tank
st – storage
syst – thermo solar system
u – useful
w – water
– cubical

Superscripts

in – entering the segment *j*, following the thermal flux sense
out – quitting the segment *j*, following the thermal flux sense
sp – towards the environment

Dimensionless groups

Bi – Biot number
NTU – number of thermal transfer units
Pe – Peclet number
$(\tau\alpha)_{eff}$ – absorption – transmission equivalent absorption
VTA – value added tax

References

1 Çomakli, Ö., Kaygusuz, K., Ayhan, T., Solar-Assisted Heat Pump and Energy Storage for Residential Heating, *Solar Energy, 51* (1993), 5, pp. 357–366
2 Duffie, J. A., Beckman, W. A., Solar Energy Thermal Processes, John Wiley et Sons, New York, 1974, pp. 237–241
3 Fara, V., Grigorescu, R., Popovici, A., Technical and Economical Analysis of a Solar Energy Facility (in Romanian), *Proceedings,* Physics Congress, Pitesti, 1978, pp. 174-178
4 Lo, S. N. G., Deal, C. R., Norton, B., A School Building Reclad with Thermosyphoning Air Panels, *Solar Energy, 52* (1994), 1, pp. 49-58
5 Loveday, D. L., Craggs, C., Stochastic Modeling of Temperatures Affecting the in Situ Performance of a Solar-Assisted Heat Pump: The Univariate Approach, *Solar Energy, 49* (1992), 4, pp. 279-287
6 Luminosu, I., Constant Temperature Maintenance within an Enclosure with Small Losses, *Solar Energy in Romania, 2* (1993), 1-2, pp. 113-114
7 Pedersen, P.V., Experience with a Large Solar DHW System in Denmark – The Nordic Solar Heating Demonstration Project, *Solar Energy, 50* (1993), 30, pp. 259–266
8 De Sabata, C., Luminosu I., Complex Experimental Base for the Study of Heat Conversion and Solar Energy Storage, *Solar Energy in Romania, 2* (1993), 1–2, pp. 115–116
9 Savulescu, T. D., Heating and Ventilation Installations (in Romanian), Tehnica, Bucharest, 1984, pp. 384–396
10 ***, Thermal Solar Energy Manual (in Spanish), IDEA, Madrid, 1996, pp. 131-135

Author's address:

I. V. Luminosu
Department of Physics, Universitatea "Politehnica"
P-ta Regina Maria nr. 1
1900 Timisoara, Romania
E-mail: ioan.luminosu@europe.com

Paper submited: June 13, 2002
Paper revised: February 2, 2003
Paper accepted: March 5, 2003