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INVESTIGATION OF THE SENSIBLE HEAT STORAGE AND THE HEAT INSULATION IN THE EXPLOITATION OF SOLAR ENERGY

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ABSTRACT: 100% Solar Heating of Home in Hungary. This study investigates the exploitation of solar energy for 100% heating of home in Hungary. It determines the necessary amount of heat and the heat storage capacity. It considers the disharmony between charge and discharge in time. It submits a feasible technology to the sensible heat storage then it determines the size of heat store-building and the thickness of heat insulation and calculates the heat losses of heat storage. The paper gives proposals on the basis of results for the manner of heat storage and what technical parameters shall be considered at heat insulation. It submits the application of this heat storage method for the district heating and for the electric current generation.
KEYWORDS: solar energy, sensible heat storage, heat insulation, 100% solar heating of home, electric current generation

❖ INTRODUCTION

Our old endeavour is to reach that we could ingather the energy of solar radiation and to store it. Then we should be capable to use this ingathered and stored energy for 100% heating of home all the year round or to generate electrical current through several months with this energy. There are also certainly several problems to reach the goal:

- The flux of energy is low.
- Generation and consumption of energy are disharmonious and incalculable as a function of time. Because of that big energy storage is needed.
- The solution of efficient and economic energy storage is unsolved problem so far.

Efforts of last year decades on area of concentrated solar powers developments and the use or adaptation of the novel technologies executed here can be efficient in the thermal energy supply and in the district heating.

This paper investigates this issue and presents a feasible technological solution of that, how can the buildings continuously be supplied with heat energy from the solar direct radiation. How must store the energy as sensible heat storage and how must plan the heat insulation of the heat storage facilities [1].

❖ CALCULATION OF THE SIZE OF SOLAR RADIATION'S FIELD AND OF THE HEAT STORAGE CAPACITY

THE SOLAR RADIATION, what comes direct through the atmosphere is referred as direct radiation. That period, when the direct radiation is more than 210 W/ m^2, is referred sunny hours. In Hungary the number of sunny hours is between 1900-2200 per year that means quite a large number in the world. These data are founded on statistics of several years [2, 3, 4]. The direct radiation is approx 1000 W/m^2 on the surface of the ground in fair weather. This value is relieved by clouds and air pollution. We use in the following calculations on the average 400 W/m^2 for sunny hours (Figure 1).

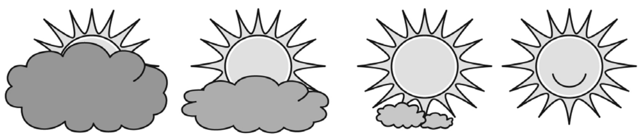


Figure 1. The intensities of the direct solar radiation

In a year's time period, perpendicularly to direction of solar radiation, we can estimate the amount of the gatherable direct solar energy as below

$$2000\frac{h}{year}\cdot 3600\,{}^{s}/_{h}\cdot 400\,{}^{W}/_{m^2} = 2880\,{}^{MJ}/_{(m^2\cdot year)}\,.$$

HEAT ENERGY CONSUMPTION OF A FAMILY HOUSE. In a dwelling-house there are two kinds of use of heat energy: the heating and the hot water production. Without explanation of the detailed calculating we have estimated all together 80.000 MJ per year heat energy consumption for five persons and an average house cc. 100 m^2. That number is equivalent to approx 2350 m^3 natural gas (34 MJ/m^3). Table 1 shows the energy consumption (heating and hot water generation) in every singly month of a year.

These data are equivalent to approx 220 kWh/m^2/year for the house. This is a realistic value. The new houses have lower energy requirements and the block houses have lower energy consumption as well. We have to gather this 80.000 MJ heat energy and the heat losses of heat storage "tank".

SIZE OF THE SOLAR FIELD. Well, we can gather energy approx 400 W on 1 m^2 surface. This energy can be gathered by a surface right-angle to solar radiation in sunny hours and there are approx 2000 sunny hours/year in Hungary. We can calculate this surface of solar radiation with that we can meet the claim of 80.000 MJ energy. This 28 m^2 doesn't include the heat losses.

CAPACITY OF HEAT STORAGE. A heat storage "tank" is needed because of disharmony between charge and discharge. Table 1 shows the calculating of the capacity of heat storage "tank". The heat capacity depends on the charge and the discharge. The total capacity of heat storage "tank" has come to 52.000 MJ. This size of heat storage "tank" can insure the supply of heat energy all the year round for a house.

Table 1. Energy consumption of a dwelling-house per year

period (days)	sunny hours	ingatherable direct solar energy per m^2 [MJ/m^2]	Charge [MJ] gathered solar energy on 27,75m^2	heating [MJ]	hot water production [MJ]	Discharge [MJ] total claim of heat energy	Amount of energy to store [MJ]
April (30)	187	269	7470	1840	1200	3040	4430
May (31)	253	364	10110	900	1240	2140	12400
June (30)	267	384	10670	0	1200	1200	21870
July (31)	297	428	11870	0	1240	1240	32500
August (31)	278	400	11110	0	1240	1240	42370
September (30)	202	291	8070	260	1200	1460	48980
October (31)	139	200	5550	1900	1240	3140	51390 ≈52000 MJ
November (30)	63	91	2520	9470	1200	10670	43240
December (31)	40	58	1600	14730	1240	15970	28870
January (31)	57	82	2280	16830	1240	18070	13080
February (28)	83	120	3320	12100	1120	13220	3180
March (31)	136	196	5430	7360	1240	8600	10
all year (365)	2002	2883	80000	65390	14600	79990	

❖ MANNER OF HEAT STORAGE AND THE SIZE OF THE HEAT STORAGE "TANK"

The sensible heat storage has been chosen for heat storage. We have surveyed many heat storage materials and have chosen the magnesite brick. The calculation with the magnesite brick showed the best results. Table 2 shows the properties of the magnesite brick.

Table 2.Properties of the magnesite brick [5, 6]

Content	Application range of temperature ΔT	Specific heat J/(kgK)	Density kg/m^3	Density of energy MJ/(m^3K)	Heat conductivity W/(mK)	Prise $/ton
37-98 % MgO 1-60 % CaO and/or Cr_2O_3	65 -500 °C (melting point 2852 °C)	1172	3020	3,54	8,4 (on 500°C)	100-500

The corundum (95% Al_2O_3) brick is also a very good heat storage material: its density of energy 3,3 MJ/(m^3K) and its melting point 2020^{0}C.

We can calculate the mass and volume of magnesite brick from the energy capacity of heat storage "tank" (≈52.000 MJ) and from the planned range of temperature (*ΔT = 500 ^{0}C - 65 ^{0}C = 435 ^{0}C*) and from its specific heat and from its density. The calculation is as below:

$$Q = c \cdot m \cdot \Delta T \rightarrow m = \frac{Q}{c \cdot \Delta T}; \quad m = \frac{52 \cdot 10^9 J}{1172 \frac{J}{kgK} \cdot 435K} = 101997\ kg \approx 102\ ton;$$

$$V = \frac{m}{\rho} = \frac{102\ tonna}{3{,}02 \frac{tonna}{m^3}} = 33{,}7\ m^3 \approx 34\ m^3.$$

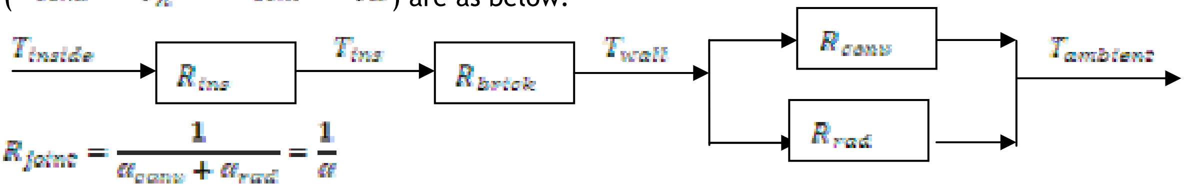
This size seems to be normal value, normal scale. The size is realisable, even if the range of temperature were smaller. If the end point of maximum temperature were just 430 ^{0}C, the size of heat receiver would be 40 m^3. But the 500 ^{0}C of maximum temperature is real too, scilicet the thermooils (heat transfer fluids) work on 580^{0}C (1060^{0}C) in the existing concentrated solar power plants. The temperature difference, what is needed to heat exchange is ensured.

❖ THE HEAT INSULATION AND THE HEAT LOSSES

CONSTRUCTION OF THE HEAT STORE-BUILDING FROM BRICKS. The heat storage "tank" will be named as heat store-building hereafter because there is no tank in the construction. We investigate only cubic shaped heat store-building therefore it is built from bricks. The construction is showed by Figure 2. We differentiate the bottom and the uppers of the store-building [7].

THE HEAT RESISTANCES OF THE HEAT STORE-BUILDING

The bottom touches to the soil, the uppers of the store-building touches to the ambient air. The uppers are built up from lateral-walls and the roof. We take account of these parts as alike. The thermal resistance of the upper and the thermal resistance of the bottom ($R_{cond} = \delta/\lambda$ ill. $R_{conv} = 1/\alpha$) are as below:



$$R_{joint} = \frac{1}{\alpha_{conv} + \alpha_{rad}} = \frac{1}{\alpha}$$

$$R_{uppers} = R_{cond} + R_{joint} = R_{ins} + R_{brick} + R_{joint}$$

$$R_{bottom} = R_{concret} + R_{gravel} + R_{soil}$$

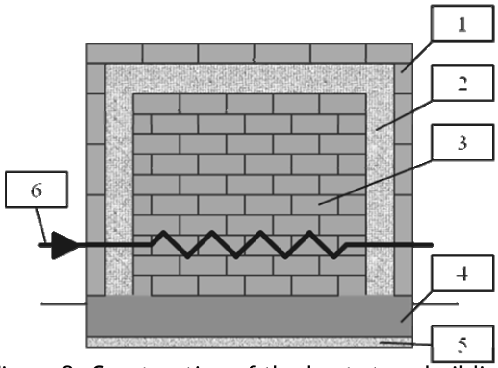


Figure 2. Construction of the heat store-building from bricks. 1 – external wall 2 – coat of heat insulation from rock wool 3 – magnesite bricks 4 – concrete pad 5 – gravel bed 6 – pipe of heat transfer oil

❖ THE DATA AND THE PROPERTIES WHAT WE HAVE USED DURING THE CALCULATIONS

Value of the heat transfer coefficient between the external side of wall and the ambient air is

$$\alpha = 24 \frac{W}{m^2 K}.$$

This value has been got from a Hungarian architectural standard (MSZ 04-140-02). The foundation of store-building would be made from cellular concrete: its density is 700 kg/m^3 and its bearing strength is more than 150 N/m^2. Table 3 shows the properties of the materials of store-building, what we have used in the calculation process [6, 7, 8,].

Table 3. Applied value of λ thermal conductivities and ∂ coating thickness

rock woll		brick/barge stone	cellular concrete	gravel	soil
500–400 ^{0}C	0,180 W/(mK)	0,64 W/(mK)	< 0,17 W/(mK)	0,35 W/(mK)	1,3 W/(mK)
400–300 ^{0}C	0,100 W/(mK)				
300–200 ^{0}C	0,070 W/(mK)				
200–100 ^{0}C	0,049 W/(mK)				
<100 ^{0}C	0,038 W/(mK)				
δ_{szig} = need to determine		$\delta_{brick} = 0.12$ m	$\delta_{concrete} = 0.6$ m	$\delta_{gravel} = 0.3$ m	$\delta_{soil} = 0.4$ m

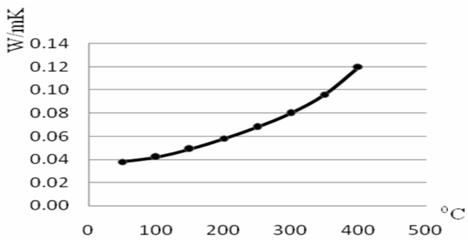


Figure 3. The thermal conductivity of rock wool versus temperature

The thermal conductivity of the heat insulation (rock wool) increases significantly with the rise of temperature $\lambda(T)$. The curve can be seen in Figure 3.

This function $\lambda(T)$ has been considered in the calculation process. In every single month we have various heat resistances in fact. Table 4 shows values of the ambient temperature and the soil temperature in 1 m depth.

❖ THE HEAT LOSSES OF HEAT STORE-BUILDING

We calculate the heat current as heat conduction through the flat wall. The heat transfer between the external surface of wall and the ambient air equals to the conductive heat current in the wall. As follows if we know the temperature of the external surface of the wall and the internal temperature ($\Delta T_{transfer} = T_{magnesite\ brick} - T_{outside\ wall} = T_{int} - T_{ext}$) or the thickness of heat insulating material (δ_{ins}) we can calculate the heat current ($\dot{q}$ $\left[\frac{W}{m^2}\right]$).

$$\dot{q} = \frac{\Delta T_{transfer}}{R_{transfer}} \quad és \quad \dot{q} = \frac{\Delta T_{cond}}{R_{cond}} \rightarrow R_{cond} = \frac{\Delta T_{cond} \cdot R_{transfer}}{\Delta T_{transfer}} \rightarrow \dot{q};\ \delta_{ins} \rightarrow Q = \dot{q} \cdot A.$$

We designed maximum internal temperature (T_{int}) 500^{0}C and maximum external temperature of wall's surface (T_{ext}) 16^{0}C. This responds to state of October. We calculated 35 cm of the thickness of insulating material (rock wool). This is also a realistic value. Table 4 shows the heat losses of every single month and all the year round. The calculations have been made for 1 house (the size of store-building is 34 m^3), for 50 houses (the size of store-building is 1700 m^3) and for 100 houses (the size of store-building is 3400 m^3).

Table 4. The heat losses of different sized heat store-building with thickness of rock wool 35 cm

							34 m^3	1700 m^3	3400 m^3
	T_{int} [^{0}C]	T_{ext} [^{0}C]	T_{amb} [^{0}C]	q_{uppers} [W/m^2]	T_{soil} [^{0}C]	q_{bottom} [W/m^2]	Q_{total} [GJ]	Q_{total} [GJ]	Q_{total} [GJ]
April (30)	102	12	12	10	10	20	1,9	26	41
May (31)	169	18	17	18	14	33	3,5	47	74
June (30)	248	21	20	31	18	49	5,5	75	120
July (31)	337	24	22	51	20	68	9,1	123	196
August (31)	419	24	21	78	21	85	13,4	181	288
September (30)	474	21	17	106	19	97	17,1	231	367
October (31)	495	16	11	117	14	102	19,3	262	416
November (30)	427	10	6	84	10	89	13,8	188	298
December (31)	307	4	2	45	7	64	8,1	110	175
January (31)	174	1	0	21	5	36	4,0	54	85
February (28)	92	2	2	9	4	19	1,6	22	35
March (31)	65	6	6	6	5	13	1,2	16	26
total heat losses of a year [GJ]							98,5	1337	2122
total heat consumption of a year [GJ]							80,0	4000	8000
heat losses versus heat consumption per cent [%]							123%	33%	27%

It is a tangible result, the specific heat losses fall with increasing size (m^3) of the store-building. It is incredible how much it has been decreased. The cause of that, the specific surface "A/V – surface/volume" decreased. We calculated further: the specific heat losses have come to 12% in the case of the store-building of 500 dwelling-houses (the size is 17000 m^3), 16% in the case of 1000 dwelling-houses (34000 m^3) and 11% in the case of 1500 dwelling-houses (34000 m^3)!

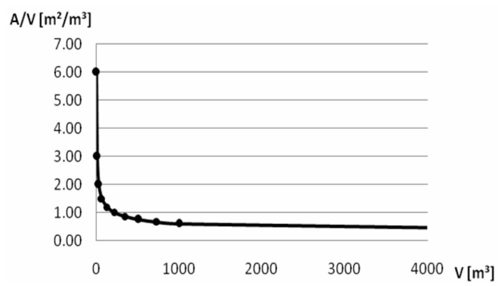


Figure 4. Specific surface versus volume of cube

We investigated how the specific surface "A/V" depends from the volume "V". We executed the investigation with cube. Table 5 shows the results of the volume (V [m^3]) and the specific surface (A/V [m^2/m^3]) with different lengths of edge of cube. Then we graphed them in Figure 4. The next algebraic formula describes the function of Figure 4: $y = 6/\sqrt[3]{x}$

Table 5. The specific surface of cube versus its size

a [m]	1	2	3	4	5	6	7	8	9	10	20	30	40	50
A [m^2]	6	24	54	96	150	216	294	384	486	600	2400	5400	9600	15000
V [m^3]	1	8	27	64	125	216	343	512	729	1000	8000	27000	64000	125000
A/V [m^2/m^3]	6,00	3,00	2,00	1,50	1,20	1,00	0,86	0,75	0,67	0,60	0,30	0,20	0,15	0,12

❖ CONCLUSIONS

The paper has said the storage of solar energy is possible all the year round or long period and this stored heat energy can supply the total heating of houses or generate electric current in Hungary as well. The heat losses can be kept at low level (< 20%). Certainly we must consider some technical facts. The heat energy shall be stored as below:

- on high temperature: the higher the better,
- in such materials which have high energy density [MJ/(m^{3}K)] (one of the solid materials, for example the magnesite brick) and
- in big size enough of store-building, because the heat losses shall be low.

The presented method is easy end safe. There isn't high pressure, steel tank and the brick isn't flammable and isn't explosive. According to my opinion this method should be used for district heating and the electric current generation. The Figure 4 and 5 show the principal schemes.

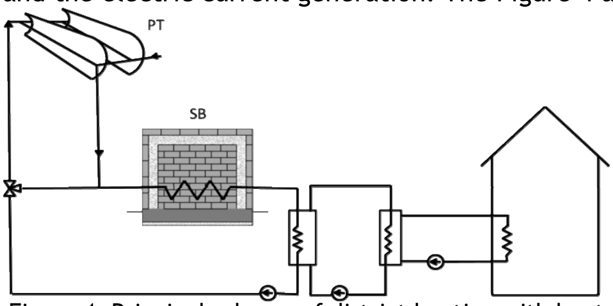


Figure 4. Principal scheme of district heating with heat store-building. PT - parabolic trough SB - heat store-building

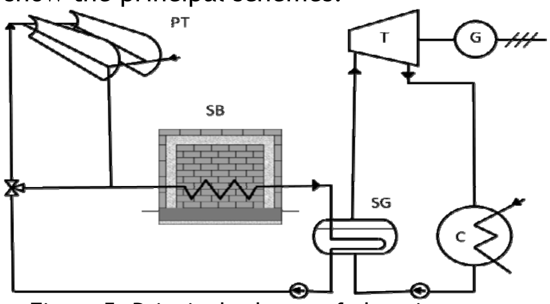


Figure 5. Principal scheme of electric current generation with heat store-building. PT - parabolic trough SB - heat store-building T - turbine G - generator C - condenser SG - steam generator

The thermal conductance in flat wall is a nonlinear function (Figure 7) at high temperatures and in wide temperature ranges. In the calculation of heat losses we have to consider these properties.

We can tell more as well, the rising of size is the best heat insulation to a determined size.

The next goal for us is to determine the optimum size of the heat store-building and the thickness of heat insulation coat [9, 10].

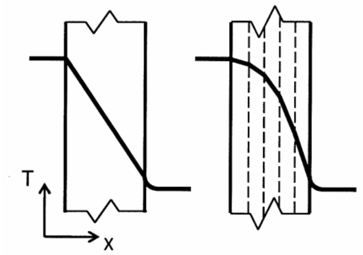


Figure 6. Temperature versus place linear and nonlinear function in a flat wall

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