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CHARACTERIZATION OF SENSIBLE HEAT STORAGE

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ABSTRACT: *It is needed to know the application properties of solid heat storage when we want to calculate the optimal size of heat storage building and its heat insulation. The major application properties are the charge and discharge during the period of operation. This paper determines the different properties of heat storage and shows a calculation algorithm for the determination of these parameters. Finally, we present an example for the calculation of application properties.*
KEYWORDS: *characterization of heat storage, size of heat storage, thickness of heat insulation, charge, discharge, heat loss, exploitation of solar energy, energy balance of heat storage, calculation algorithm*

INTRODUCTION

Background: The calculations of publication [1] showed that, it is possible to store the thermal energy of solar radiation in the long term (all the year round) with low heat loss. The thermal energy storage takes places in solid materials e.g. magnesia bricks (MgO). The specific heat loss equals to the total heat loss is divided by the total thermal energy content of the storage building (storage tank) during operational period. The specific heat loss can be reduced by application of heat insulation material and by enlargement of storage building's size. It is necessary to consider both ways of decrease in the specific heat loss in the design of thermal energy storage building (TESB).

If we intend to calculate the optimal size of heat storage and its heat insulation then we have to be capable of characterizing the TESB. When we already know these characteristic parameters then we are able to choose among different TESBs on the basis of the characteristic heat storage parameters. In general, the TESB is charged and discharged continuously or fractionally during its period of operation. The most important parameters from the point of view of use are the charge, the discharge and the difference between them called as heat loss.

DESIGN VARIABLES AND FUNCTIONAL/OPERATIONAL PARAMETERS

From technical point of view, each TESB built in the same construction and from same materials can be distinguished from each other by only design variables:

- *size of the heat storage (x_1) and*
- *thickness of heat insulation (x_2).*

These design variables (x_1, x_2) are called basic properties. There is also a third property, the price by which each TESB can be distinguished from each other; however, price is not regarded as technical parameter. Beyond the design variables there are other properties as well. Let us call these properties functional/operational parameters. A part of functional/operational parameters is determined by the requirements of use or application. If we intend to, we may modify these parameters. The other part of functional/operational parameters is determined by ambient circumstances and conditions. We cannot influence the following ambient parameters: number of sunshine hours, ambient air temperature, and so on. Some functional/operational properties:

- *minimum temperature of heat storage T_{min},*
- *maximum temperature of heat storage T_{max},*
- *ambient temperature,*
- *properties of charge:*
  - *number of sunshine hours,*
  - *distribution of sunshine hours,*
- *properties of discharge:*
  - *distribution of discharge,*
- *period (cycle time).*

The functional/operational properties are those by which we want to use the TESB. The goal of application plays an important part in determining the values of functional properties.

APPLICATION PROPERTIES

The application properties are the most important properties. If we have a TESB with a given size (x_1) and on it heat insulation with a given thickness (x_2) then only two parameters characterize the storage during the application:

- *how much energy can we charge in it and*
- *how much energy can we discharge from it.*

The difference is the energy loss (heat loss) of storage. We call these properties (charge, discharge and loss) as application properties. The problem arises however how is it possible to determine, how to calculate the charge, the loss and the discharge.

PRESENTATION OF THE CASE STUDY – PARAMETERS TAKEN INTO CONSIDERATION

Exploitation of the maximum temperature range: It is easy to see, the TESB shall be operated with the exploitation of its full energy capacity during operation period. It means that, we exploit the maximum temperature range. The maximum temperature range is between the feasible minimum temperature and the feasible maximum temperature in the TESB.

The thermal conductivity of the insulating material depends on the temperature – $\lambda(T)$. Thermal resistance of the heat insulation decreases with the increase of the storage's internal temperature. We would like to mention here: it may occur that such internal temperature prevails that the bigger part of charge will be the energy loss and the smaller part of charge will be stored energy. Therefore, a characteristic curve can be established for the heat storage as well. This characteristic curve shows how efficiently the storage works at the given temperature level. Certainly, we have to cope with this problem and we are capable of doing so. The key to the solution is making cost-sensitive optimum calculations.

The value of x_1 is also a variable parameter. Well, two design variables of the TESB (x_1 and x_2), which are determined at beginning, and the operational parameters are known. The values of charge, discharge and loss have to be calculated from these data.

The calculation is not simple. The case is not that, we calculate the maximum heat capacity of the storage building and the heat loss of the maximally charged TESB (by T_{max}) with one of the determined thickness values of the heat insulation and we vary the thickness of the insulation and at the same time take into consideration the price of insulating materials and the price of the heat loss. Where the two price curves intersect each other, there is the optimum thickness of insulation. In this case, the value of x_1 is constant and only the value of x_2 is altering, which is a simple optimization for the heat insulations thickness [2, 3]. This optimization takes place on a given sized surface of the storage building. In this case is that, we omit the variation of x_1 from the calculation.

The specific surface of heat storage building depends on the value of x_1. The specific surface [m^2/m^3] equals to the surface of the storage building [m^2] which is divided by the volume of the storage building [m^3]. Because of that, we omit the change of the value of the specific surface in order to solve the problem. Based on the omit, we know already that up to a certain size, the increase of size or the decrease of specific surface is the best heat insulation method [1]. On the one hand we simplified the complex problem to the optimum calculation of the heat insulation material thickness and on the other hand we did not consider the changes of the operational parameters during the operational cycle time. In the present design of the TESB, not only the value of x_2 is a variable parameter but also the value of x_1. If also the value of x_1 is a variable parameter, we have to consider the change of specific surface as well.

Functional/operational parameters: In the design calculations we take into consideration the different functional/operational parameters during the operational period. Certainly, the inside temperature of the TESB depends also on the time.

SIMPLIFYING CONDITIONS

In the first step, in order to realise the major tendencies, we have to take the following simplifications for calculating the application properties:

- *The TESB is cube-shaped.*
- *The sides of the TESB are the same from the point of view of thermal resistance. It means that the values of heat currents are equal on each side of the TESB (the heat current depends on the T_{inside}, $T_{ambient\ air}$ and heat insulation). The heat losses on the bottom and the top of TESB are equal to the heat losses on the sides.*
- *The value of the heat transfer coefficient (α) between the external side of the insulation and the ambient air is constant.*
- *The value of volume heat capacity [MJ/m^3] of thermal storage material is constant within the whole temperature range.*
- *The inside temperature of the TESB is even everywhere.*

The thermal conductivity (λ) of the heat insulating material depends on the temperature. We consider a mean value of thermal conductivity for every 100 °C range, which means that the values are constant in every single temperature range. Well, we calculate with $\lambda_{<100°C}$, $\lambda_{100\text{-}200°C}$, $\lambda_{201\text{-}300°C}$ and $\lambda_{301\text{-}400°C}$.

DETERMINATION OF THE APPLICATION PROPERTIES

If we intend to calculate the heat loss, it is necessary to know the outside temperature of the heat insulation coat. This value can only be determined by using the numerical method (Figure 1).

The value of internal temperature of the TESB should be known for this computational algorithm (Figure 1), but it is unknown. The internal temperature of the TESB can be calculated from the charge and discharge values. The charge and discharge values are application properties of the TESB but these values are unknown as well. The application properties depend on the basic and operational properties. This calculation can be made by using the numerical method and its computational algorithm shows in Figure 2.

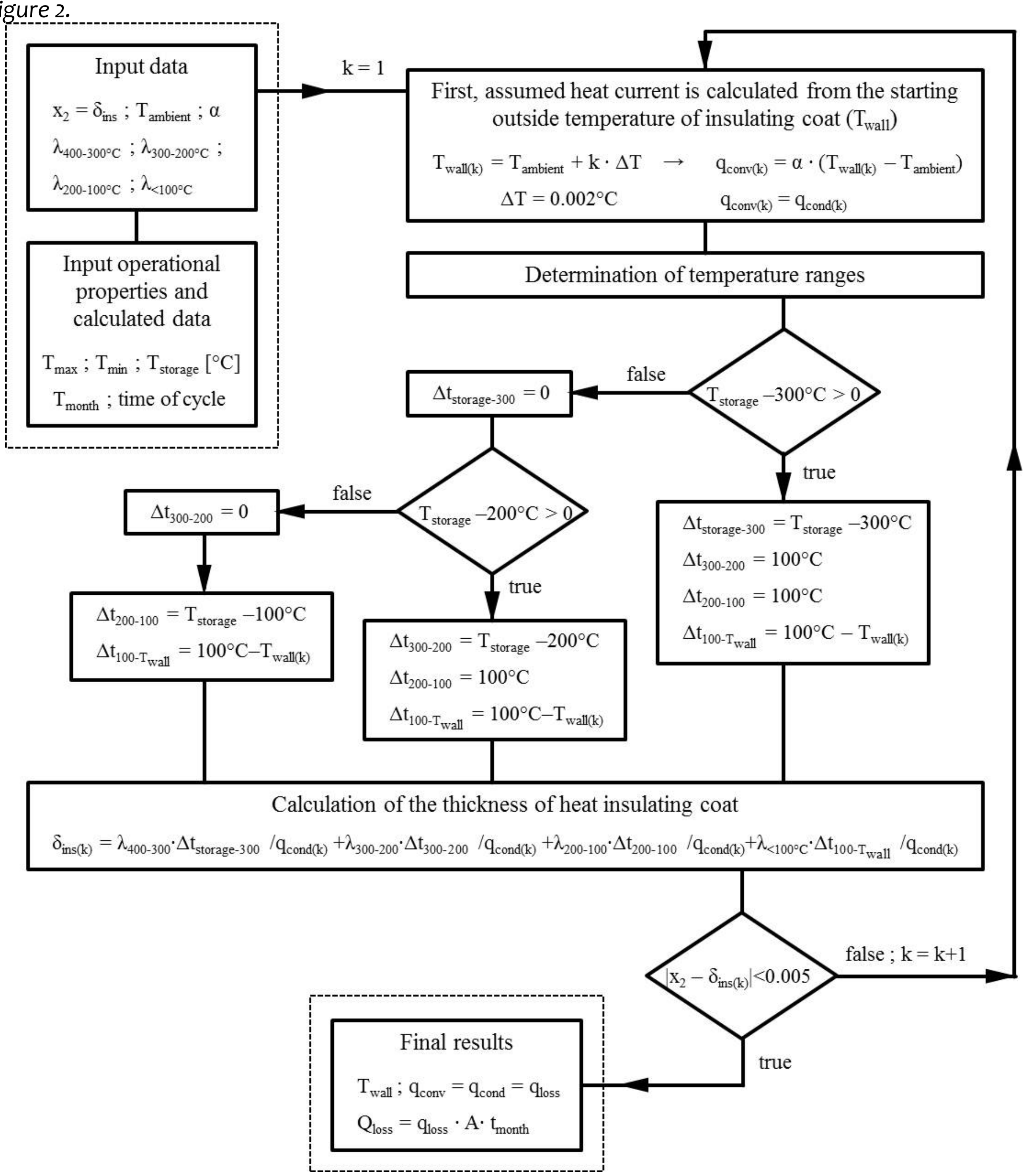

Figure 1. Determination of external wall temperature and of heat loss current

The starting value of charge is equal to the capacity of the TESB. The starting value of discharge is equal to zero. The heat loss has already been calculated from these starting values. If the value of heat loss becomes higher than the value of charge, the TESB cannot be used for storage purposes. If the value of heat loss becomes lower than the value of charge, we can discharge from the TESB. If we discharge the TESB, the internal temperature will be lower. If the internal temperature is lower, the heat loss will also be lower. Therefore, the heat loss depends on the internal temperature as well. We can raise the discharge up to the balance of zero (charge – discharge – loss = 0). When the balance becomes zero, then we can raise the value of charge. The cycle restarts again. The process continues until we reach the permissible maximum temperature of the TESB. As a result of the calculation we get the application properties.

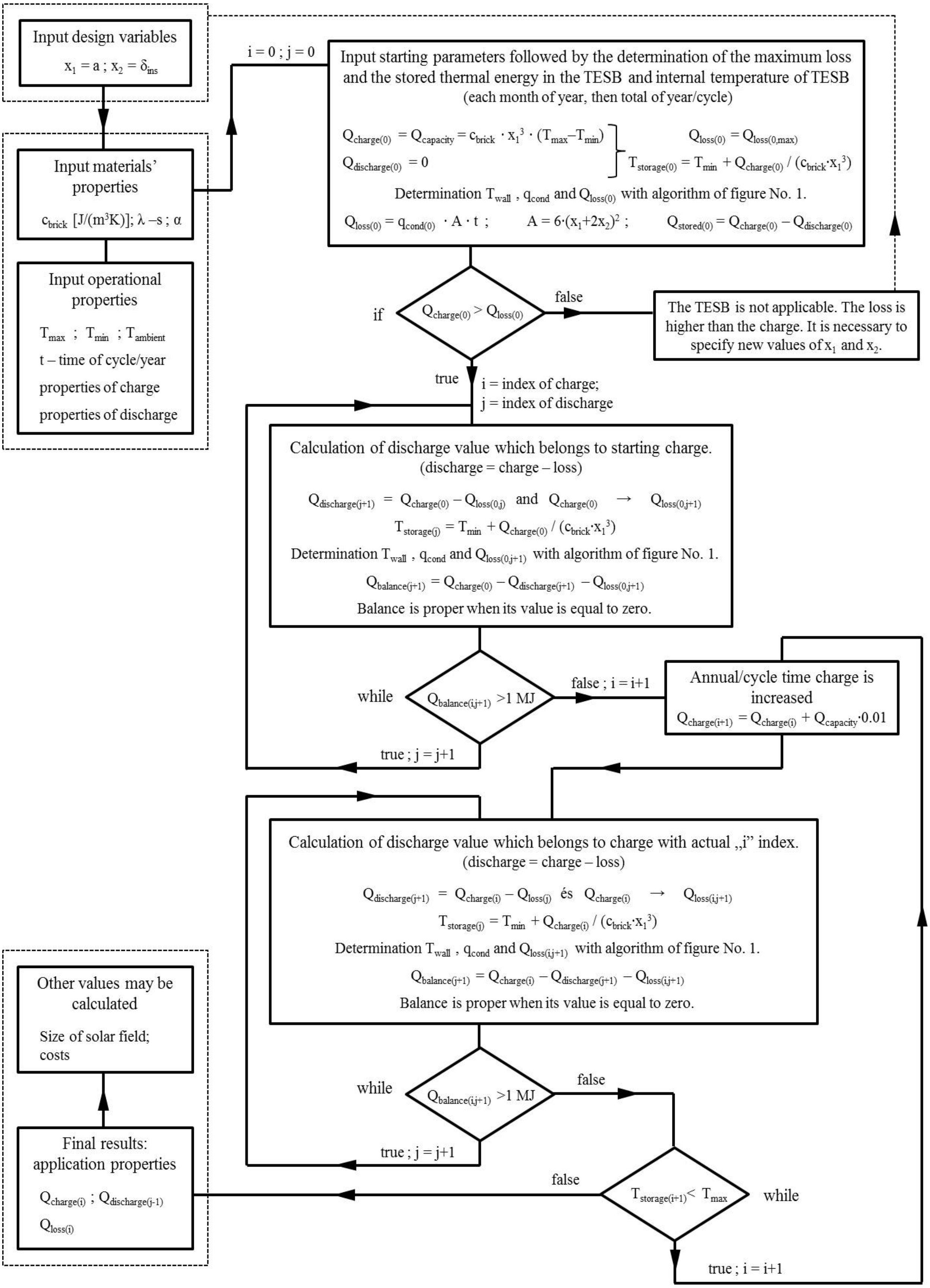

Figure 2. Determination of application properties of TESB

Very important! The TESBs with the same basic properties show other values of application properties if they have different operational properties.

We have made a MATLAB program for the above mentioned algorithms.

EXAMPLE OF ILLUSTRATION

Figure 3 shows the schematic sketch of the storage technology for the exploitation of concentrated solar radiation with thermo-chemical power plant (Kalina cycle). There is no harmony between the energy gathering and the consumption of the power plant. Therefore it is necessary to apply a TESB. The calculations apply to Hungarian circumstances.

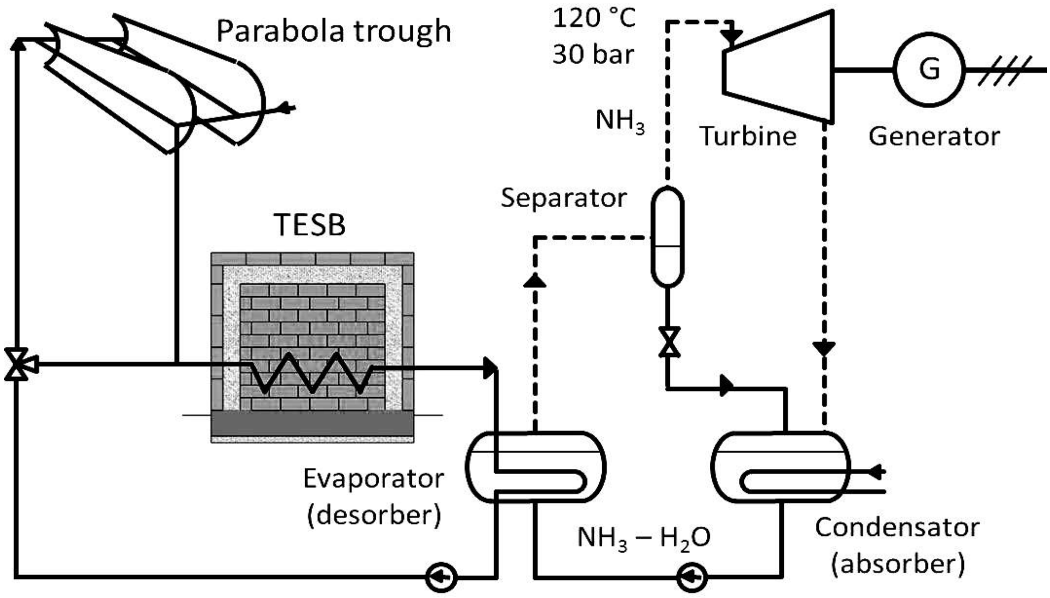

Figure 3. Proposed technology with thermal energy storage building (TESB) for the utilization of solar radiation heat energy

The following data are used:

Design variables: We made the calculations by using several variations, with several values of design variables (x_1, x_2). Table 1 shows these design variables.

Operational properties

- *Number of sunny hours in each month: [57; 83; 136; 187; 253; 267; 297; 278; 202; 139; 63; 40].*
- *Mean power of solar radiation during sunny hours: 400 W/m^2.*
- *Number of days in each month: [31; 28; 31; 30; 31; 30; 31; 31; 30; 31; 30; 31].*
- *Discharge is even in March/Apr/May/Jun/Jul/Aug/Sept/Oct.*

Meaning: $Q_{discharge\_March} = Q_{discharge\_Apr} = Q_{discharge\_May} = \ldots = Q_{discharge\_Oct}$.

- *Discharge is zero in Nov/Dec/Jan/Feb.*

Meaning: $Q_{discharge\_Nov} = \ldots = Q_{discharge\_Feb} = 0$ J.

- *Cycle time: 1 year.*
- *Temperature range: T_{max} = 400 °C and T_{min} = 130 °C.*

The TESB becomes entirely empty at the end of October.

Volume heat capacity of magnesite-oxide brick (heat storage material): 3.54 MJ/(m^{3}K).

The thermal conductivity of mineral-wool (heat insulating material):

- *Range 301-400 °C, $\lambda_{301\text{-}400°C}$ = 0.100 W/(mK),*
- *Range 201-300 °C, $\lambda_{201\text{-}300°C}$ = 0.070 W/(mK),*
- *Range 101-200 °C, $\lambda_{101\text{-}200°C}$ = 0.049 W/(mK) and*
- *Range < 100 °C, $\lambda_{<100°C}$ = 0.038 W/(mK).*

The value of heat transfer coefficient is: α = 24 W/(m^{2}K). This value has been derived from a Hungarian architectural standard (MSZ 04-140-02).

The results of calculations are presented in Table 1.

Table 1. Calculated application properties and other results of TESB with different design variables and a given operational properties

x_1 [m]	25	25	30	30	40	40	50	50
x_2 [m]	0.3	0.6	0.3	0.6	0.3	0.6	0.3	0.6
$Q_{capacity}$ [PJ]	15	15	26	26	61	61	120	120
Q_{charge} [PJ]	118	143	239	240	600	551	1129	1057
$Q_{discharge}$ [PJ]	68	119	166	208	479	499	957	980
Q_{loss} [PJ]	50	24	73	32	121	52	172	78
energy efficiency [%]	57.7	83.3	69.6	86.7	79.9	90.6	84.8	92.7
heat power-output [MW]	3.2	5.6	7.8	9.8	22.6	23.6	45.2	46.3
size of solar field [m x m]	202 x 202	222 x 222	288 x 288	288 x 288	456 x 456	437 x 437	626 x 626	606 x 606

The energy efficiency is very high and it can even be improved in the following ways:

- *We enlarge the thickness of insulating material.*
- *We enlarge the size of TESB.*

We choose a differently shaped TESB. If the TESB is not cube-shaped but for example cylinder-shaped, where the diameter equals the height (H/D=1), the cylinder has smaller specific surface than the cube. The ball has the smallest specific surface but it is not practical to be implemented from bricks.

CONCLUSIONS

This paper investigates how much energy can be charged in the heat storage building and be discharged from it under determined operating conditions.

We determined the kinds of the storage building's properties. These clusters are:

- *design variables,*
- *functional/operational properties, and*
- *application properties.*

The next step was to calculate the application properties from the values of design variables and functional/operational properties. We made a computational (calculation) algorithm and, as a result of it, we are able to calculate the application properties (charge, discharge, loss) of different sized TESBs under different operating conditions.

If we are already familiar with these application properties, we have to make a decision which one of the different sized heat storage buildings will be suitable for our goal. Based on the above calculation it is possible to determine the optimum values of TESB design variables.

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