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CALCULATION AND DEVELOPMENT OF DESIGN FOR THERMAL SALINE BATTERY

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The method of calculating the thermal battery with electrolyte phase transition accumulating material. The calculation of battery heat for heating building spaces. Certain size and weight of the battery accumulating material for daily heat consumption. Calculated heat loss to the environment and time period to "charge" and "discharge" thermal battery.

Heat salt battery, accumulating material, heat loss, phase transition.

Accumulation of heat is appropriate and can be widely used in cases where there is excess heat or other forms of energy that can be converted into heat at regular intervals. Of excess heat energy after its accumulation can be used in other periods of time for which the demand for it increases. Accumulation of heat in the heat accumulator (HA) can be performed either by a heat transfer medium, or additional use of the melting phase transition from solid to liquid heat accumulating material (HAM) [1¬8].

As the heat accumulating material selected salts and eutectic with a total power consumption 2001¬900 MJ/m^3. These materials are low cost and available in large quantities.

Heat accumulating is promising area for low-grade heat storage environment

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using, for example, heat pumps and (or) solar collectors [9¬10]. Another source of heat can be electricity at night by using multirate meters. The value of heat significantly reduced. Maybe the battery is designed for heat daily or seasonal heat storage battery that accumulates heat environment during the spring-summer-autumn period of time and uses the accumulated heat in the winter and autumn. In developing diurnal or seasonal use batteries HAM with low melting point such as Glauber's salt $CaCl \cdot 6H_2O$, sodium hyposulphite $Na_2S_2O_3 \cdot 5H_2O$, bishofit $MgCl_2 \cdot 6H_2O$ and more.

The purpose of the study. Development of methodology for calculation of daily salt thermal battery on phase transformations of HAM. Calculation of HA with low melting temperature of HAM, allowing heat to accumulate solar radiation, soil heat, water and other alternative sources of low energy use and heat pumps heliosystems and cheap electricity at night time.

Materials and methods of research. *Thermal design of HA.* Given that the coolant temperature in the space heating using such radiant floor heating, is 30¬50 °C, as there is selected salt $Na_2HPO_4 \cdot 12H_2O$, and insulating materials for household and used polyurethane.

Thermophysical properties of HAM and polyurethane:

melting point (crystallization) t_{kr} = 35 °C;

density of solid alloy HAM ρ_{tv} = 1.52 kg/m^3;

massive heat HAM C_f = 1.22 kJ/kg.^{0}C;

latent heat of melting (crystallization) r_f = 275 kJ/kg;

insulation - foam plates:

thermal conductivity λ_0= 0.04 W/m ^{0}C;

thickness of insulation δ_{iz} = 0.05¬0.1 m;

core temperature: maximum t_{max} = 60 ^{0}C, the minimum t_{min} = 25 °C;

room temperature t_0 = 18 ^{0}C;

soil temperature t_{zov}= 10 °C;

temperature of the coolant in the reservoir or heat pump, t_{vh} = 60¬100 °C;

water temperature in the underfloor heating system t_{vo}= 20¬50 °C.

By limiting the operating temperature range battery core values t_{max} and t_{min} and neglecting heat losses and heat capacity of the device in its design, the heat balance of the unit can be expressed by the relation:

$$Q_{ak} = V_f \rho_f (C_f (t_{kr} - t_{\min}) + r_f), \tag{1}$$

where V_f – volume occupied there that is phase transformation, m^3;

ρ_f – density HAM (in the single-phase state in which it is less), kg/m^3;

C_f – mass heat soothes (in the temperature t_{max} – t_{min}) kJ/ kg ^{0}C;

r_f – heat of phase transition quenches, kJ/kg.

Calculating the volume of HAM. To calculate the heat accumulator is necessary to determine the amount of heat required for heating and hot water facilities. Set the amount of space that is necessary to ensure warmth is 85 m^3. According to the rules for heating 1 m^3 living space to spend 22 watts of heat. This amount of heat needed to heat selected rooms – 145.9 MJ per 1 day.

When choosing how HAM there salt Na_2 HPO_4. $12H_2O$ (ρ_f = 1520 kg/m^3, r_f = 275 kJ/kg) and taking values t_{kr} = 35 °C, t_{min} = 25 °C, we get:

$$V_f = \frac{Q_{ak}}{\rho_f C_f (t_{kr} - t_{\min}) + \rho_f r_f} \quad . \tag{2}$$

If heat loss is 15 % from size Q_{ac} and given them by factor ψ= 1,15, we find the necessary volume HAM accumulating in the nucleus: $V_{ham1} = \psi V_{fo} = 0{,}36\ m^3$. Accordingly, the mass of the core components: $M_{ham1} = \rho_f V_f = 549{,}236\ kg.$

Determination of the mass of HAM. Shell of HA is a steel building, which is located there HAM. When heated core battery heat accumulated in both HAM and the material of the case amount of heat accumulated body is given by:

$$H_к = M_к C_к (t_{мax} - t_{мin}), \text{ kJ},$$

where M_k ¬ body weight, kg; C_k ¬ mass specific heat of the material body, kJ/kg ^{0}C.

For HAM volume, which is 0.36 m^3, metal case design with geometric dimensions 1,1x1,1x0,3 m or 2,2 x0,55x0,3 m. As core body material for use sheet steel grade AISI439 (12x18H10T) thickness of 1 mm. Specific heat of steel C_k = 0.5 kJ/kg ^{0}C.

Body weight is determined by the formula kg: $M_k = F_c m_{st}$, $M_к = 19{,}8\ kg$,

where F_c ¬surface area of the walls kernel, F_c = 3.74 m2.

Heat, accumulated body, $H_k = 345{,}25\ kJ$.

Geometric dimensions of HA are shown in Fig. 1.

Calculation of heater power during charge of HA. Heat accumulator is a unit of continuous action. Ask ourselves the following parameters:

daily charge time − 8¬13 hours;

daily discharge time ¬ 24 hours;

playing modes of work for HA during a day, s:

first stage:

charge ¬ 14400 s;

level ¬ 14400 s;

Second stage:

Level ¬ 28800 s.

In the case of the daily value of accumulated thermal energy based on solar collectors, the value of the latter is, W:

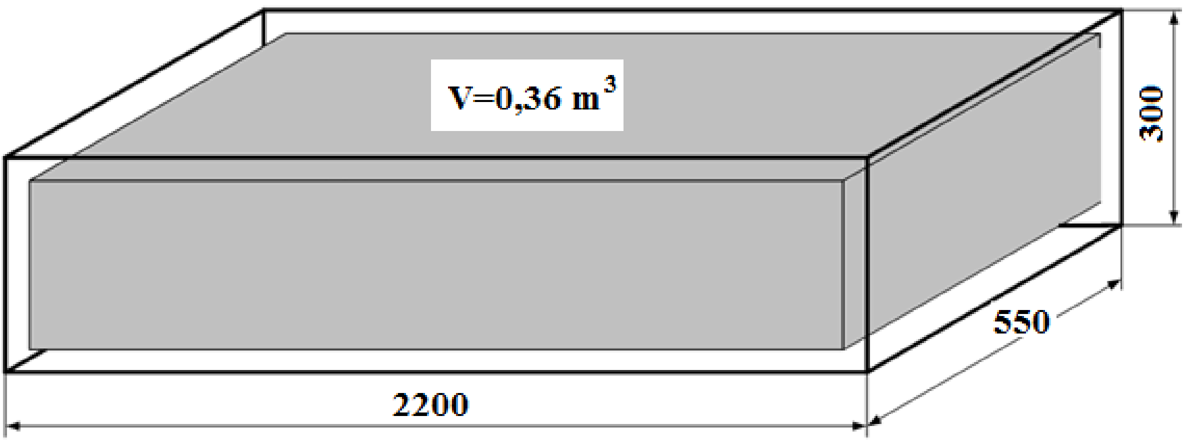

Figure. 1. Geometric dimensions of the insulated body of HA with HAM

$$Q_{k.c.o} = A_{k.c.o}\eta_{an}q_i, \tag{3}$$

where $A_{k.c.o.}$ ¬ area of solar absorbing surface, m^2; thing η_{an} ¬ the annual (seasonal) installation efficiency, q_i ¬ the intensity of solar radiation incident on the collector plane, W/m^2.

Substituting the relevant data, we obtain: $Q_{\kappa.c.o} = 37641{,}98\ W$.

When using a heat pump to heat capacity should have the same value.

Determination of heat losses through the insulation. To calculate the theoretical values of time charge heat during charging, time of discharge and heat during the discharge to determine the heat transfer coefficient for the wall battery with insulation.

The heat flux transferred from the core wall insulation, where part of it is lost (due to thermal conduction) into the environment, W:

$$Q_{iz} = K_{iz}F_{st.iz}(t_{st.iz} - t_{\min}), \tag{4}$$

where $F_{st,iz}$ ¬ surface area of wall insulation $F_{st,iz}$ = 3.8 m2 $t_{st,iz}$ ¬ wall temperature insulation, ^{0}C.

Heat transfer coefficient of wall insulation K_{iz}, W/m^2 ^{0}C, is given by:

$$K_{iz} = \frac{1}{\frac{1}{\alpha_{ham}} + \frac{\delta_{st}}{\lambda_{st}} + \frac{\delta_{iz}}{\lambda_{iz}} + \frac{1}{\alpha_{iz}}}, \quad (5)$$

where α_{ham}, α_{iz} ¬ respectively the coefficient of heat transfer from HAM to the wall soothes the body core and the insulation of the walls in the environment, for the sodium salt have α_{ham} = 2,32-11,63 W/m^2 ^{0}C, respectively, for the foam – α_{iz} = 10¬12 W/m^2 ^{0}C; δ_{st}, δ_{iz} - wall thickness of shell and core layer of insulation, m; λ_{st}, λ_{iz} ¬ thermal conductivity of steel grade AISI439 (12x18H10T) and foam, λ_{st} = 16.88 W/m ^{0}C, λ_{iz} = 0,0416 W/m ^{0}C.

Heat transfer coefficient according to (5) has the value $K_{iz} = 0{,}491 \frac{W}{m^2 \cdot {}^o C}$. Heat flux transmitted through the wall insulation in the environment (consider that the battery in the soil) at different temperatures and jobs (in the temperature range 25-60 °C) in the range: $Q_{iz} = 27{,}98 - 93{,}27\ W$.

Calculation of operating parameters of HAM during the heat soothes.

Withdrawal of heat and a heating core from 25 ^{0}C to 35 ^{0}C. Given the geometric size of the HA shell core and value of calculated above amount of heat, wonder parameters such heat exchange surface of the beam pipe, located in HA:

pipe material – stainless steel SUS304;

outer diameter – d_z = 0.034 m;

distance between the heating pipes – 0,11x0,11 m;

amount of heat process pipes – n_{tr} = 5 pcs.

Carts heat by heating core from 25 ^{0}C to 35 ^{0}C. The time required for heating the core from 25 ^{0}C to 35 ^{0}C is determined by the heat required for heating of HAM and heat flux, which is consumed for heating, s:

$$\tau_{z1} = \frac{H_{z1}}{Q_{z1}'}, \quad (6)$$

where Q'_{z1} – thermal energy that we get from solar collectors or heat pump (in view of the value of the heat flux, which is removed from the heat process pipe during heating core of HA and as well as heat losses through the insulation layer, W:

$$Q_{z1}' = Q_{z1} - Q_{iz} \quad , \qquad (7)$$

where Q_{iz} – heat loss through the insulation layer of polyurethane foam (with an average temperature between 25 ^{0}C to 35 ^{0}C), W; Q_{z1} – heat flow, which is removed from the tube, W.

The value of the latter is found from the expression:

$$Q_{z1} = K_{st} F_{tr} (t_v - t_c), \qquad (8)$$

and K_{st} – coefficient of heat transfer from the steel pipe to HAM, W/m^{2} ^{0}C; which is determined how:

$$K_{st} = \frac{1}{\frac{1}{\alpha_v} + \frac{\delta_{st,r}}{\lambda_{st}} + \frac{1}{\alpha_{st}}}, \qquad (9)$$

where α_v – coefficient of heat transfer from the water to the wall steel pipe, according to the calculations of α_v = 2560 W/m^{2}. ^{0}C; α_{st} – coefficient of heat transfer from the pipe wall to heat accumulating material (for steel grade SUS304 – α_{st} = 15 W/m^{2} ^{0}C) $\delta_{st,tr}$ – pipe wall thickness, $\delta_{st,tr}$ = 0.002 m; λ_{st} – thermal conductivity: for steel grade SUS304, λ_{st} = 16.88 W / m. ^{0}C : F_{tr} – the total surface area of the pipe wall, m^{2}: Where L_{tr} – the total length of all tubes heat process, m Substituting values, we obtain: t_v – the water temperature in the system in the initial period charge and, t_v = 30 ^{0}C.

Heating pipes weight M_{tr}, kg is given by:

$$M_{tr} = L_{tr} m_{tr},$$

where m_{tr} – mass 1 m stainless steel grade SUS304, m_{tr} = 2.42 kg and after of culculation we have:

$$M_{tr} = 29{,}282\ kg. \tag{10}$$

The value of heat transfer coefficient is calculated using (9) from which we obtain K_{st} = 14.79 W/m^2 ^{0}C.

The value of heat flux, which is removed from the pipe (in start period of during storage at a temperature of core t_c = 25-35 0C is equal to: $Q_{z1} = 946{,}56\ W.$

The required amount of heat energy obtained from solar collectors or heat pump, which is consumed in heating the core of HA:

$$Q_{z1}^{'} = 909{,}25\, W. \tag{11}$$

The amount of heat required to heat the core from 25 ^{0}C to 35 ^{0}C, is:

$$H_{z1} = M_{ham}^{''} C_f (t_{kr} - t_{\min}) + M_k C_k (t_{kr} - t_{м\min}) + M_{tr} C_{st} (t_v - t_{\min}) =$$

$$= 7{,}605\, MJ \tag{12}$$

Warm-up time kernel from 25 ^{0}C to 35 ^{0}C:

$$\tau_{z1} = 8364\ s = 2{,}32\ hour.$$

<u>Carts heat for melting of HAM (35 °C)</u>. For the second stage of "charge" the battery on the surface of pipes is a natural convection of molten HAM. Estimates show that in this case the heat transfer coefficient on the surface of the pipe is equal α_{st} = 140 W/m^2 ^{0}C. In calculating the heat transfer coefficient by the formula (9) we obtain K_{st} = 130.6 W/m^2 • ^{0}C.

The value of heat flux, which is removed from the pipe:

$$Q_{z2} = Q_{z1} = K_{st} F_{tr} (t_{v,k} - t_c) = 7523{,}1\, W. \tag{13}$$

The amount of heat required to melt of HAM:

$$H_{z2} = M_{ham}'' r_f = 150{,}754\, MJ. \tag{14}$$

Thermal energy wasted during melting core of HAM:

$$Q_{z2}' = Q_{z2} - Q_{iz}.$$

The value of heat flux, which is removed from the tube (in the second period of storage at a temperature of core t_{va}= 35 ^{0}C) is equal to: $Q_{z1} = 7523{,}1\, W.$

The required amount of heat energy obtained from solar collectors or heat pump, which is consumed in heating the core of HA:

$$Q_{z2}' = 7476{,}4\, W.$$

Time for melting of HAM:

$$\tau_{z2} = \frac{H_{z2}}{Q_{z2}'} = 20164\, s = 5{,}6\, hour. \tag{15}$$

Carts heat by heating core from 35 ^{0}C to 60 ^{0}C. The heat that is removed from the pipe:

$$Q_{z3} = Q_{z1} = K_{st} F_{tr} (t_v - t_c) = 5432{,}96\, W. \tag{16}$$

The amount of heat required to heat the core from 35 ^{0}C to 60 ^{0}C, is:

$$H_{z3} = M_{ham}'' C_f (t_{\max} - t_{kr}) + M_{\kappa} C_{\kappa} (t_{\max} - t_{kr}) + M_{tr} C_{st} (t_{\max} - t_{kr}) =$$

$$= 17{,}361\, MJ. \tag{17}$$

Thermal energy wasted on heating the molten core of HA:

$$Q_{z3}' = 7460{,}6\, W.$$

Warm-up time kernel:

$$\tau_{z3} = \frac{H_{z3}}{Q_{z3}'} = 2327\, s = 0{,}65\, hour. \tag{18}$$

Calculation of operating parameters and during cooling and crystallization of HAM.

In calculating the cooling heat accumulator assume that the number of tubes in which water flows from the heating system is equal to n = 15 pcs. Surface area of the pipe is determined by the formula $F_{tr} = 3{,}84\ m^2.$ where L_{tr} – the total length of all heat process pipe, m:

$$L_{tr} = nl_1 = 33{,}0\ m.$$

Substituting the values, we get: F_{tr} = 3.84 m^2.

The total mass of pipes is $M_{tr} = 79{,}84\ kg.$

Determination of the number of dedicated heat and cooling time kernel with "discharge" of HA (60 ^{0}C to 35 ^{0}C). Quantity of dedicated heat:

$$H_{p1} = M_{ham}''C_f(t_{\max} - t_{kr}) + M_kC_k(t_{\max} - t_{kr}) + M_{tr}C_{st}(t_{\max} - t_{kr}) =$$

$$= 17{,}361\,MJ. \tag{19}$$

Time of cooling liquid quenches from 60 ^{0}C to 35 ^{0}C, s:

$$\tau_{p1} = \frac{H_{p1}}{K_{st}F_{tr}(t_{\max} - t_{kr}) + K_{iз}F_{iз}(t_{\max} - t_{kr})}, \tag{20}$$

where α_{iz} – heat transfer coefficient for heat insulation; K_{st} – coefficient of heat transfer through the wall, W/m^2 • ^{0}C.

According to calculations

$$\alpha_{iz} = 0{,}491 W/m^2\ ^0C;$$

$$K_{st} = 130.6\ W/m^2\ ^0C. \tag{21}$$

Substituting, we obtain:

$$\tau_{p1} = \frac{17361000}{2194{,}7} = 7910\ s = 2{,}2\ hour.$$

Core cooling during crystallization of HAM. Heat, committed during crystallization:

$$H_{p2} = M'_{ham}r_f = 150{,}754\ MJ. \tag{22}$$

The value assigned heat pipes (including heat losses through the insulation):

$$Q_{p2} = Q_{iz} + K_{st}F_{tr}(t_c - t_o) = 2554,4\,W. \qquad (23)$$

Cooling time of HAM:

$$\tau_{p2} = \frac{H_{p2}}{Q_{p2}} = \frac{150754000}{2554,4} = 59017\,s = 16,4\,hour. \qquad (24)$$

Core cooling from 35 ^{0}C to 25 ^{0}C. The amount of heat required to cool the core from 35 ^{0}C to 25 ^{0}C, will:

$$H_{P3} = M_{ham}{}^{''}C_f(t_{kr} - t_{\min}) + M_\kappa C_\kappa(t_{kr} - t_{\min}) + M_{tr}C_{st}(t_v - t_{\min}) =$$

$$= 7,01\,MJ \qquad (25)$$

The value assigned heat pipes (including heat losses through the insulation):

$$Q_{p3} = Q_{iz} + K_{st}F_{tr}(t_{c,mid} - t_o) = 305,76\,W. \qquad (26)$$

Cooling time of HAM:

$$\tau_{p3} = \frac{H_{p3}}{Q_{p3}} = \frac{7010000}{305,76} = 22927\,s = 6,4\,hour. \qquad (27)$$

Results of the studies. Results of calculation of heat during charge and discharge are shown in the table.

Estimate and set of time work for battery in various modes.

Mode of the work for HAM	Temperature, ^{o}C	|Operating time, hour.	
		Computed	Set
Charge	25 – 35 35 35–60	2,32 5,6 0,65	8,0–11,0
Discharge	60 – 35 35 35 – 25	2,2 16,4 6,4	24,0

Layout of the beam pipe in the heat accumulator is shown in Fig. 2.

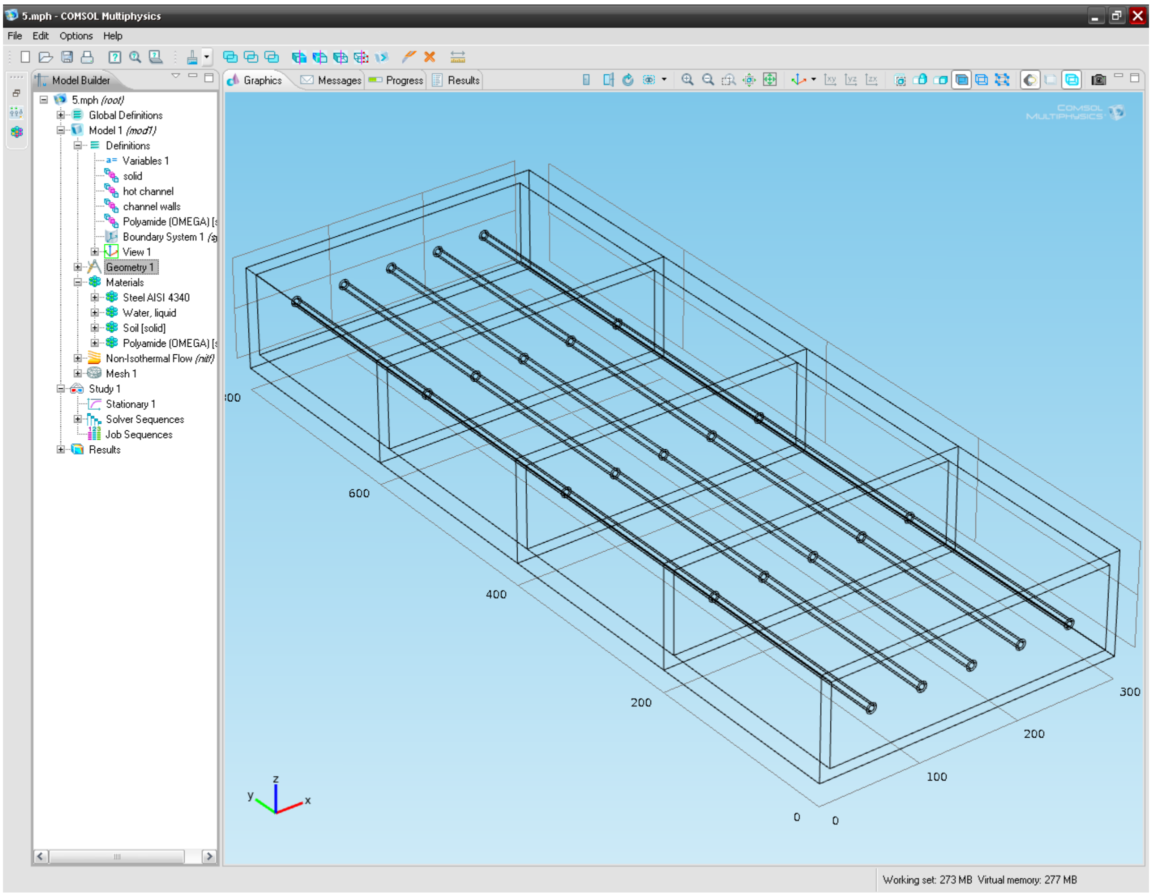

Figure. 2. Scheme of the thermal battery

Given that the real efficiency of flat solar collectors is within 22−40% (the value of efficiency obtained empirically) the nominal current value, which amounted to 64%, which is almost 2 times higher than the true, therefore it is suggested to leave the adopted parameters of heat exchange surface without changes.

For the duration of employment and the "charge" or as the table shows, the calculated value is less than specified, but given the real meaning of efficiency of flat solar collectors, as well as at work and in the "category", we believe that the parameters of heat exchange surface (number of heat process pipes and their diameter) is optimal for both modes of HA.

Conclusions

The calculations showed that the daily accumulation of heat, followed by its use in space heating capacity of 80 m^3, HA requires the following parameters:

pipe material − stainless steel SUS304;

outer diameter d_z = 0.034 m;

distance between the heating pipes 0,11 x0,11 m;

amount of heat process pipes n_{tr} = 5 pcs.,

amount of cooling pipes n_{tr} = 15 pcs.,

heat accumulating material − salt Na_2 HPO_4 $12H_2O$;

HAM weight 550 kg;¬

size battery 2,2 x0,55x0, 3 m.

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Розроблено методику розрахунку теплового сольового акумулятора з фазовим переходом акумулюючого матеріалу. Проведено розрахунок акумулятора теплоти для обігріву будівельних приміщень. Визначено розміри акумулятора та масу акумулюючого матеріалу для добового теплоспоживання. Розраховано теплові втрати в навколишнє середовище та часові проміжки для «зарядки» і «розрядки» теплового акумулятора.

Тепловий сольовий акумулятор, акумулюючий матеріал, теплові втрати, фазовий перехід.

Разработана методика расчета теплового солевого аккумулятора с фазовым переходом аккумулирующего материала. Проведен расчет аккумулятора теплоты для обогрева строительных помещений. Определены размеры аккумулятора и массу аккумулирующего материала для суточного теплопотребления. Рассчитаны тепловые потери в окружающую среду и временные промежутки для «зарядки» и «разрядки» теплового аккумулятора.

Тепловой солевой аккумулятор, аккумулирующий материал, тепловые потери, фазовый переход.