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Possibility of Thermal Storage System Use with Different Accumulating Material in SPbSTU

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Abstract. In this article the possibility of heat accumulator use in one of the buildings of SPBSTU was analyzed. The use of this accumulator could lower the hot water demand. To complete the goal it was assumed that there is an additional café with defined working hours.
Different kinds of heat collecting materials were studied: water, red brick, concrete and granite. Depending on charging time of the heat accumulator, the results of the heat gaining abilities of different materials were made.
As a result it was calculated that single-phased accumulating materials should not be used as heat collectors in public buildings.

1 Introduction

Nowadays, energy efficiency is a leading topic in civil engineering. It saves money, resources so in the long run it helps economics and ecology.

To achieve high energy efficiency the heating system distribution should be modernized. One of the variants is to install heat accumulators for hot water and heating systems. In Russia it is popular in small houses outside cities.

In this article one of SPBSTU campuses is studied when it is assumed that there is an additional heating source along with higher hot water demand.

2 Literature review

Energy efficiency has become world tendency and now is going to be the first thing to consider during the designing process of all constructional elements [2-4]. In many countries there is legislation for energy efficiency, in Russian Federation it is Federal Law No. 261-FZ of November 23, 2009 “On Energy Saving and Increase of Energy Efficiency and Introduction of Changes into Separate Legislative Acts of the Russian Federation” [5].

During the design development designers in the first place try to apply energy saving space-planning concepts - construction of wide-bodied houses [6, 7] allows to reduce specific area of enclosing structures. They also use energy saving construction systems like

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heat insulation of exterior walls and hinged ventilated facades [8, 9]. Projects of "Green houses", partly or fully isolated from energy sources, appear [10-12]. As practice shows, energy saving can be highly increased by implementing new building services systems or by renovating them, for example, by installing automated heating unit [13-15]. Lately the appliance of heat accumulators became a very popular approach. They can store some amount of heat energy to use it during day periods when charges are higher or during the hot water consumption peaks to reduce the load on the heating unit [16-17].

3 Purposes and tasks

The purpose of this article and our research was to choose the most suitable type of heat accumulator for help to smooth the peak of hot water consumption or to define that under existing conditions it is inappropriately.

Following problems were solved:

- Calculation of hot water demand after the reconstruction of café;
- Calculation of possible amount of accumulated heat for different types of single-phased accumulating material (SPAM) in the accumulator;
- Analysis of the results and conclusion about possibility of application of different types of heat accumulators for smoothing the hot water consumption peak in considered problem.

4 Research description

Nowadays, there is a serious problem with cafes in SPBSTU because there is not enough place for all the people. Let us assume that to solve the task an additional café was working during peak loads on the existing café. Changes of the number of water-supply points can be seen in Table 1.

Table 1. Comparison of number of water-supply points in existing café and in designing café.

		Existing café	**Additional café**
1	Number of seats	18	50
2	Number of was-basins for clients	0	2
3	Number of sinks	1	3
4	Number of was-basins for stuff	0	1

There are two ways to lower the maximal hot water use:

- Recalculation of the substation and an expensive modernization afterwards;
- Installation of the heat collector as an additional equipment.

The heat collector will be used during when occupation of the café is maximal. From 12.00 to 16.00 there is the highest use of hot water. Outside this period an additional café is not needed.

These changes will highly increase the load on hot water supply system and the existing heat unit will not be able to bear it. Nominal capacity of the heat unit is 200 W and maximum hot water flow is 0.96 l/s. In order to smooth the consumption peak it was decided to install heat accumulator in series, when the accumulator is connected into power circuit after the energy source.

Main element of every heat accumulator is accumulating material. Hot water in hot water supply system transfers the heat to the SPAM, which, due to its high heat capacity, can accumulate a huge amount of heat during the charging time. Due to good quality of thermal insulation the heat energy may be stored for a long time and be used when needed – in our case during the consumption peak since 12 a.m. to 4 p.m.

In order to find the most profitable accumulator we considered several types of relatively cheap and non-toxical SPAMs (Fig.1):

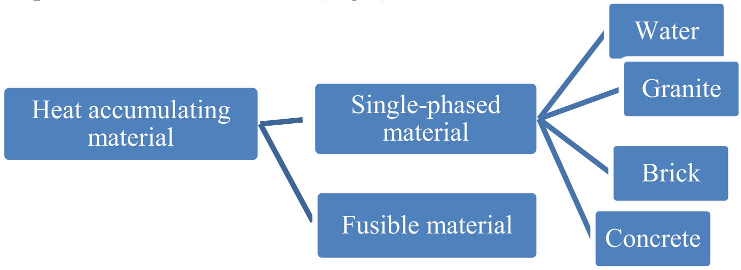

Fig. 1. Types of heat accumulating materials.

In this article we considered heat accumulators with single-phased SPAM.

Let's have a closer look to the working process of heat accumulator.

Heat accumulator charge

Single-phased SPAM (Fig. 2a) is located around the pipe in which heat-transfer medium flows. Tci — input medium temperature, Tco — output medium temperature. Passing through the channel heat-tranfer medium is getting colder (Tci < Tco), transferring heat to the SPAM, thus the temperature of accumulating material Tn is increasing.

Heat accumulator discharge

The most common system is used: cold heat-transfer medium with input temperature Tdi flows through the channel and warms up to output temperature Tdo (Fig.2b).

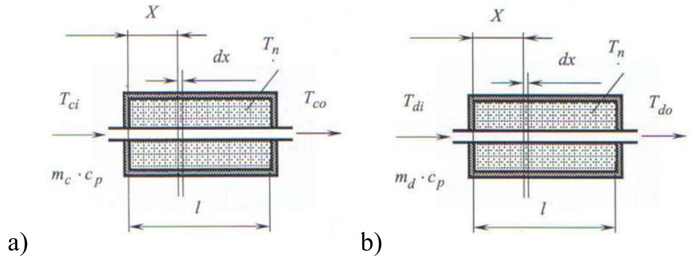

Fig. 2. Heat accumulator with single-phased SPAM: a. Charge b. Discharge.

By changing charging time we can choose the most profitable variant of using the heat accumulator for every type of SPAM.

5 Calculations

Firstly, we calculate the number of conditional dishes consumed per hour and per one working shift. Café is designed for 50 seats.

Number of dishes consumed per hour can be calculated with the formula (1):

$$u = n \cdot m \cdot u_o = 50 \cdot 3 \cdot 2.2 = 330 \quad (1)$$

Where

n — number of seats, n=50;

m — number of different customers seating at one seat per hour, m=3 (for students' café);

u_o — number of conditional dishes consumed by one customer ($u_o = 2.2$).

Café is open for 4 hours in a day. Daily quantity of dishes consumed can be calculated with the formula (2):

$$U = \frac{u \cdot T}{K} = \frac{330 \cdot 4}{1.5} = 880 \qquad (2)$$

Where
u — calculated number of conditional dishes consumed per hour;
T — working time of café;
K — hourly non-uniformity coefficient (K=1.5).
Therefore, for the calculated number of conditional dishes hot water flows were calculated (using SNiP 2.04.01-85 «Domestic water supply and plumbing system”):
q_h = 0.65 l/s — maximal design flow;
q_{hhr} = 1.28 m3/h — maximal hourly flow.
Heat flow during the hour of maximal water consumption Q_{hr} = 76800(ccal/h) = 321 546.240 (kJ/h) = 89.3 kW.
So, we can calculate how much heat is needed to be stored in the heat accumulator, if we multiply heat flow per hour by working time.
Then, amount of required heat is Q=1 286 184.96 kJ.
Physical characteristics of materials, calculated on the base of parameters found, are presented on the Table 2.

Table 2. Physical characteristics of different types of SPAM

SPAM	Spec.heat capacity [J/kg·K];	Density [kg/ m3] liquid/solid	Mass flow [m3/h].	Time of discharge [h]	Mass [t]
Water	4200	998,2	1277,7	4	9.34
Granite	750	2800	3200		14,3
Brick	840	1100	1408		5,6
Concrete	1000	2500	3584		12,8

As a result of modeling of heat accumulators with single-phased SPAM in series we have following functional connections:
For the temperature of SPAM (3),(4):
Charge:

$$T_{nc}(t) = T_o + (T_{ci} - T_o) \cdot (1 - e^{-y_c \cdot \theta_c}) \qquad (3)$$

T_o — initial temperature of SPAM (To = 283 K);
T_{ci} — input temperature of heat-transfer media entering the accumulator during charge (T_{ci} = 338 K).
Discharge:

$$T_{nd}(t) = T_{nc} - (T_{nc} - T_{di}) \cdot (1 - e^{-y_d \cdot \theta_d}) \qquad (4)$$

T_{di} — input temperature of heat-transfer media entering the accumulator during discharge (T_{di} = 283 K – in summertime, T_{di} = 278 K – in wintertime)
For the temperature of heat-transfer media in channel as it leaves heat accumulator (5), (6):
Charge:

$$T_{co}(t) = T_o + (T_{ci} - T_o) \cdot (1 - y_c \cdot e^{-y_c \cdot \theta_c}) \qquad (5)$$

Discharge:

$$T_{do}(t) = T_{co} - (T_{co} - T_{di}) \cdot (1 - y_d \cdot e^{-y_d \cdot \theta_d}) \qquad (6)$$

To find the temperature difference for the beginning and the end of charge and discharge it's needed to calculate coefficients with formulas (7)-(9):
a) Non-dimensional transfer numbers

$$N_c = \frac{K_c \cdot F(x)}{m_c \cdot c_p} \qquad N_d = \frac{K_d \cdot F(x)}{m_d \cdot c_d} \qquad (7)$$

b) Non-dimensional process times:

$$\theta_c = \frac{m_c \cdot c_p \cdot \eta_c}{M_\Sigma \cdot c_n} \cdot t_c \qquad \theta_d = \frac{m_d \cdot c_p}{M_\Sigma \cdot c_n \cdot \eta_d} \cdot t_d \qquad (8)$$

c) Ratios

$$y_c = 1 - e^{-\frac{N_c}{\eta_c}} \qquad y_d = 1 - e^{-N_d \cdot \eta_d} \qquad (9)$$

As soon as we've calculated these coefficients as a function of charging time tc, we can calculate temperatures for charge and discharge with formulas (3)–(6). Let's assume that charging time vary between 1 and 20 hours. Calculation results for single-phased SPAM can be presented in table form (Table 3).

Table 3. Dependence of the temperature of heat-transfer media on the charging time.

	T [K]	**t_c [h]**								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**20**
Water	$T_{co}(t)$	289.7	295.5	300.7	305.3	309.2	312.7	315.8	318.5	*333.9*
	$T_{do}(t)$	286.7	290.1	292.9	295.4	297.7	299.6	301.3	302.9	*311.5*
Granite	$T_{co}(t)$	303.5	316.4	324.4	329.5	332.7	334.6	335.9	336.6	*337.9*
	$T_{do}(t)$	285.5	287.0	288.0	288.6	289.0	289.3	289.4	289.5	*289.7*
Brick	$T_{co}(t)$	319.3	331.6	335.8	337.2	337.7	337.9	337.9	337.9	*338*
	$T_{do}(t)$	287.4	288.9	289.4	289.6	289.7	289.7	289.7	289.7	*289.7*
Concrete	$T_{co}(t)$	300.9	313.1	321.2	326.7	330.4	332.8	334.5	335.6	*337.9*
	$T_{do}(t)$	285.2	286.6	287.6	288.3	288.8	289.1	289.3	289.4	*289.7*

With the formula (10) we can calculate possible amount of heat we can accumulate in dependence of charging time of heat accumulator and can compare the results (Table 4) with the required amount of heat for café.

$$Q = M \cdot \Delta T \cdot C_n \qquad (10)$$

Table 4. Dependence of heat amount on the charging time

		t_c [h]								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**20**
Water	Q [MJ]	115.7	217.4	306.6	385.0	453.8	514.2	567.3	613.9	*879.1*
Granite		193.4	314.6	390.5	438.2	467.7	486.4	498.0	505.3	*517.5*
Brick		149.9	200.8	218.1	224.0	226.0	226.6	226.9	227.0	*227.0*
Concrete		202.0	337.9	429.4	491.0	532.4	560.3	579.1	591.7	*617.6*

Dependence of heat amount on the charging time is shown on the fig.3.

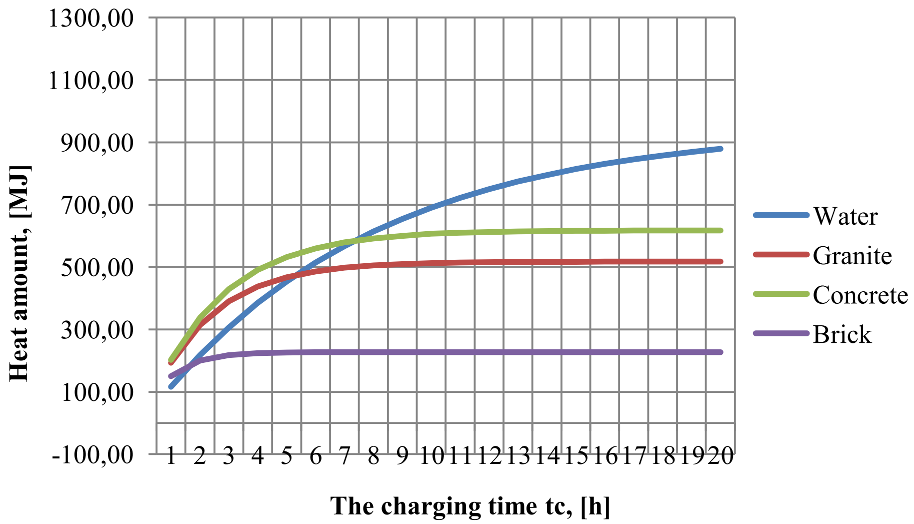

Fig.3. Dependence of heat amount on the charging time.

As it can be seen from the graph, even during the maximal charging time – 20 hours – SPAM can't accumulate the required amount of heat (1286 MJ).

6 Conclusions

1. Hot water flow in “Hydrotechnical building-2" of campus of SPbSTU during the working hours of designing café has increased almost in two times and became 1.61 l/s instead of 0.96 l/s
2. Applying of heat accumulator is unpractical for full and autonomous supply of café for 50 seats.
3. Heat accumulator with SPAM-water can be used as additional power source.

4. Heat accumulators with SPAM-granite/brick/concrete don't accumulate a lot of heat when charging time is increased maximally
5. Recalculation of heat unit with nominal capacity of 289.2 kW and hot water flow of 1.61 l/s is needed.

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