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Possibility of Thermal Storage Systems Usage During Buildings Renovation in Saint-Petersburg

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Abstract

To increase energy efficiency of building it is to apply thermal storage systems. There are multiple successful examples of their use in countries of North Europe. The article reviewed method of thermal storage system installation in a building of SPbSTU campus for the purpose of heat supply renovation program.

There was solved the problem of comparing different types of heat accumulators and selection of the most suitable system for climate conditions of St.-Petersburg, which would meet the set requirements of the task.

A cafeteria for 50 seats working since 12 a.m. till 4 p.m. was considered as a benchmark data. For hot water flow calculation we had to calculate the number of conditional dishes consumed in cafeteria per hour and per day.

Several variants of heat accumulating were calculated:

Accumulator with single-phased accumulating material (SPAM):

- *SPAM is water;*
- *SPAM is granite;*
- *SPAM is brick;*
- *SPAM is concrete.*

The result shows that performance of using water as the heat storage material is better than that of others. Applying of accumulator with single-phased accumulating material is unpractical for full and autonomous supply of cafeteria. Calculation of phase-changing heat accumulator is needed, if this is not the case recalculation of heat unit with higher nominal capacity is needed.

Keywords - thermal storage system, energy efficiency, heat supply

1. Introduction

The topic of energy efficiency has become very popular and is being under discussion because of economical and ecological problems of many countries. So different actions in order to increase energy efficiency are being made often now as a part of the Russian Federation government program "Energy efficiency and energetic development". [1] In search of the most effective way of energy saving attention are often put on heating and water supply systems. In the following article we consider the possibility of appliance of heat accumulators in hot water supply system for public building and in particular – the possibility with the help of them to smooth the peak of hot water consumption, which is expected after reconstruction of cafeteria in on one of the SPbSTU buildings.

2. Literaturereview

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 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. Purposesandtasks

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 cafeteris;
- Calculation of possible amount of accumulated heat for different types of 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

Reconstruction project of cafeteria in one of the SPBSTU buildings is now under designing. Due to increasing amount of students it was decided to open another cafeteria (working hours 12 a.m. – 4 p.m.) in order to reduce the load on the existing one. Working hours have been chosen based on the condition of maximum visit of cafeteria. There is no separate lunch breaks in Russian universities. As long as, lectures starts at 10 am, most of the students prefer to take a lunch after 2-3 classes on a breaks 13:40-14:00 and 15:40-16:00 or during free time in the schedule 12:00-13:40 and 14-15:40.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 cafeteria and in designing cafeteria.

		Existing cafeteria	Additional cafeteria
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

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):

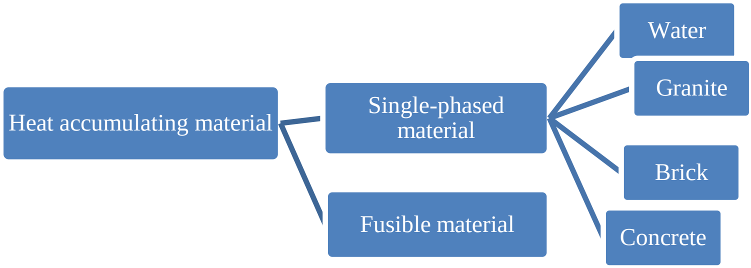


Fig. 1. Types of heat accumulating materials

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

The construction of heat accumulator is a boiler, installed into the section of heating network so that heat transfer medium flows through it. Heat transfer medium does not contact directly with heat accumulating material but flows inside in the pipes. Boilers with granite,brick or concrete are hard heat accumulators. To improving heat transfer and eliminate different level of heatup of accumulating material the last one is shattered.

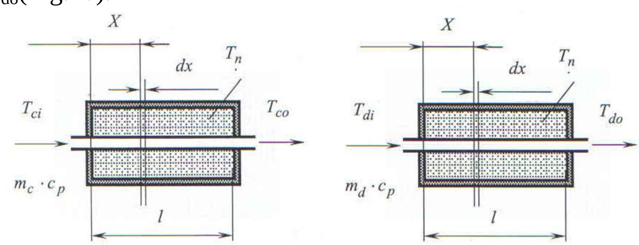
Let's have a closer look to the working process of heat accumulator.

Heat accumulator charge

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

Heat accumulator discharge

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



a) b)

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. Cafeteria is designed for 50 seats.

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

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

Where

n — number of seats, n=50:

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

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

Cafeteria 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 cafeteria;

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^h_{hr} = 1.28 m^3/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	Massflow [m3/h].	Timeofdischarge [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:

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

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:

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

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:

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

Discharge:

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

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

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

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 t_c, 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.Dependance of the temperature of heat-transfer media on the charging time

SPAM	**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 cafeteria.

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

Table 4. Dependence of heat amount on the charging time

SPAM		**t_c [h]**								
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	***20***
Water	**Q [MJ]**	115.76	217.40	306.65	385.02	453.83	514.28	567.32	613.92	*879.10*
Granite		193.47	314.62	390.50	438.02	467.78	486.41	498.08	505.39	*517.53*
Brick		149.94	200.86	218.15	224.02	226.01	226.69	226.92	227.00	*227.04*
Concrete		202.02	337.97	429.47	491.06	532.49	560.38	579.15	591.78	*617.60*

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

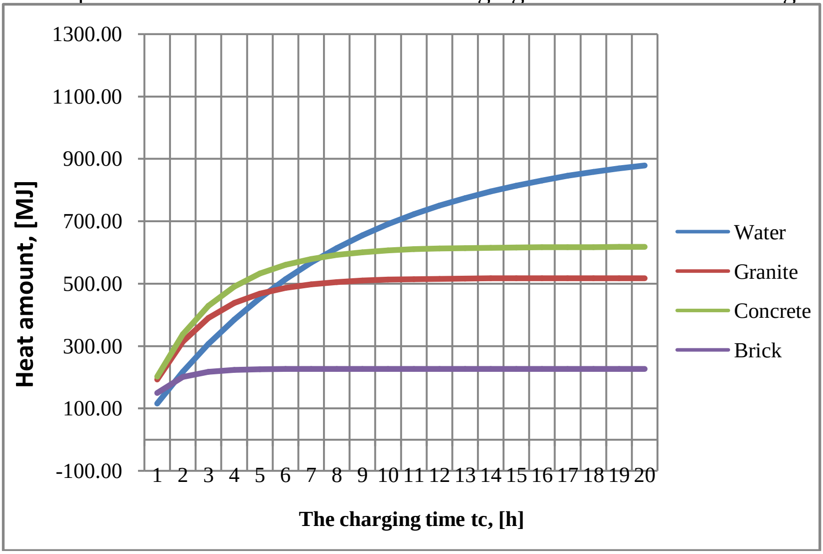


Figure 3. Dependence of heat amount on the charging time

As it can be seen from the graph, even during the maximal charging time – 20 hours – SPAM can not 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 cafeteria 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 cafeteria 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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