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Research on heat accumulation possibilities of heating systems on the premises

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Abstract. The research has been developed with regard to some private living houses in Latvia. In order to provide a house with periodical stoking, its heating system has been equipped with a heat accumulator. The capacity of the hot water accumulator is about $10m^3$ and it is placed into the ground. The heating system has already been successfully used for several years. The researchers from the agency of the Latvia University of Agriculture Research Institute of Agricultural Machinery are developing experience and skills on the installation of such a simple and cheap type of periodical heating system in areas where central heating is not available. The types of heat accumulators, the more widely used heat accumulation stuff (HAS), mathematical expressions for the calculation of the charged heat energy, and the classification of buildings according to thermo energetic parameters will be looked at in this research.

As a result of the investigation it was stated that for low energy consumption in a house with $120m^2$ floor area and 4 inhabitants, and with a hot water accumulator of $5m^3$ volume implemented in the heating system, one stoking per week is enough. In order to decrease heat losses from the accumulator, its shape has to be chosen so that the ratio between its surface and volume is minimal. For cylindrical accumulators, the ratio will be its diameter being equal to its height. With the growth of the diameter (increase of volume), the ratio of the surface to volume will decrease.

Key words: Low energy house, heat accumulator, periodical heating.

INTRODUCTION

The research concerns mainly low energy consumption house heating, when wood for the stoking and radiators or heated floors for the heat distribution are used. As the heat capacity of such a system is small, stroking has to be performed continuously. In order to reduce a person's involvement in the stoking process, permanently burning boilers are used with wooden granules or chips as fuel gas. In places where natural gas is not available, permanently burning boilers charged by firewood are usually installed. One charge usually burns for 10–15 hours and the wood intake depends on the temperature of the room (Building.lv[1]). For most of the time the boiler works on smoldering regime which has a destructive impact on the furnace of the boiler. In order to get the boiler work at full capacity, which is more economic, heat accumulation has to be used. The main acquisition of the use of heat accumulation is comfort, because stoking can be performed in several days, for instance, once a week. During the stoking breaks, heat is taken from the heat accumulator and delivered to the heating elements, which can be easy performed by automatic control units

(Videszinatne.lv). In order to widen the working temperatures of the heat accumulator, for example, 35 85°C and to decrease the mass of the HAS, heated floors are recommended.

MATERIALS AND METHODS

Presuming that a more important parameter of a heat accumulator is the volume of the HAS, it follows from Table 1 that in comparison with a water accumulator, the volume of a stone chip accumulator is 4.2 times higher, but paraffin and sodium sulphate accumulators have 2.5 and 5.26 times smaller volume of the HAS, respectively.

In a house heating system, water is usually used as the HAS. A perspective HAS would be a certain concentration solution of sodium sulphate (Glauber's salts $Na_2SO_4 \cdot H_2O$) in water. Then, in comparison with water, the volume of the HAS could be decreased approximately five times (Hasnain S.M., 1998). The sodium sulphate accumulator has a characteristic feature (Dom.delaisam.ru) to keep the heat energy in cool conditions lastingly without any losses, and to give it back, when the process of crystallization is initiated.

The diversity of heat accumulation methods and ways cause a variety of possible technical and constructive solutions of the problem. Depending on physical and chemical processes going on in the HAS (Harchenko, 1991), heat accumulators can be divided as follows (Table 1):

A. Capacitive heat accumulators, where heat energy accumulation in the HAS is taking place (water, stone, metal, etc.).
B. Heat accumulators, where the heat from the change of the state of aggregation of the HAS is used (paraffin, sodium sulphate, etc.).
C. Heat accumulators, where the heat from the reflexive chemical and photochemical reactions is obtained.

Accepting the A type heat accumulator, the amount of the accumulated heat energy can be calculated as (Harcenko, 1991):

$$Q = m \cdot C_w \cdot \Delta T \quad , \qquad (1)$$

where: Q – amount of accumulated heat energy, kJ;

m – HAS mass, kg;
C_w – heat capacity (water C_w = 4.19kJ (kg·°C)$^{-1}$;
ΔT – water temperature difference in the heat accumulator before and after heating, °C.

For calculation the accumulated heat energy in large volume water accumulators, formula (2) is recommended

$$Q = 1{,}163 \cdot V \cdot \Delta T \, , \qquad (2)$$

where: Q – amount of accumulated heat energy, kWh;
V – volume of water in the accumulator, m^3.

The necessary mass of the HAS for the accumulation of certain amount of heat energy Q, can be calculated by formula (3)

$$m = \frac{3{,}600 \cdot Q}{C_w \cdot \Delta T}, \quad (3)$$

where: Q – amount of accumulated heat energy, kW.

The heat capacity of the heat storage accumulator depends on the thermal capacity of HAS, on the consumption of heat energy for rooms and water heating, and on the duration as well. According to the classification for a ‘low energy consumption house’ (Building.lv[2]), accepted by the European Union, it does not exceed 40kWh per $1m^2$ of floor area during a year and the total heat energy consumption for heating and home equipment operation does not exceed 70kWh.

Table 1. Characteristics of the heat accumulation stuff.

Character of HAS	Stone chip	Water	Sodium sulphate	Paraffin
HAS mass for accumulation of 1 GJ heat energy at ΔT=20°C, kg	60,000	11,900	3,300	3,750
HAS mass as the ratio to water mass, $kg\ kg^{-1}$	5	1	0.28	0.32
HAS volume for accumulation of 1 GJ heat energy at ΔT=20°C, m^3	49.6	11.9	2.26	4.77
HAS volume as the ratio to water volume, $m^3 \cdot m^{-3}$	4.2	1	0.19	0.4

For a passive house in Germany these figures are 15 and $42kWh\ m^{-2}$, respectively. On calculating the total heat energy consumption of a house, the heat energy for rooms and water heating, home equipment operation and lighting have to be summarized. On average it does not exceed $60\text{-}80kWh\ m^{-2}$. The consumption of heat energy for house heating and hot water production can be expressed as

$$Q_d = \frac{Q_h \cdot S}{N} + n \cdot Q_w \quad (4)$$

where: Q_d – total energy consumption for house heating and hot water production, kWh/daily;
Q_h – consumption of hot water for room heating, $kWh\ m^{-2} \cdot year$;
S – floor surface area of the house, m^2;
N – length of heating in a year, days;
n – number of inhabitants in the house;
Q_w – daily consumption of hot water per inhabitant (Q_w = 2kWh).

With formula (2) it is possible to calculate the volume of the accumulator

$$V = \frac{Q_d \cdot T_h}{1.163 \cdot \Delta T} \cdot K_l \, , \tag{5}$$

where: T_h – period of heating, days;
K_l – heat loss coefficient.

In practice cylindrical heat accumulators are more popular.

RESULTS AND DISCUSSION

Using formulas (4) and (5), the volume of a water accumulator has been calculated at the following conditions:

- length of heating period – 6 months;
- during 6 summer months the water is heated by solar collectors or air heat pumps;
- the house of 120m^2 living area is inhabited by 4 people;
- the water temperature in the accumulator is 35-85°C ($\Delta T = 50°C$);
- heat losses 20% (K_l=1.2);
- periodicity of stoking 7 days.

The calculation results in daily need for heat energy Q_d =35kWh, and the necessary volume of the heat accumulator is 5m^3. The price of such a multifunctional boiler-accumulator E-5000 (Altenergo.lv) of 5,000 litres volume and offered without value added tax is about €4,300. It is possible to connect different energetic devices to the boiler, such as a solar collector, a hot water boiler, a water heating fireplace and an electric water heater, as well as hot water consuming equipment for room heating and other.

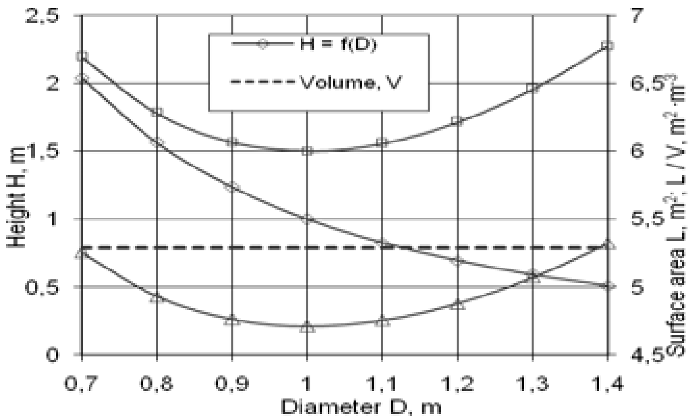

Figure 1. The ratio of the surface area L to volume V, depending on the diameter D and height H for the cylindrical water accumulator.

Fig. 1 depicts graphically the ratio of the accumulator's surface area to its volume, depending on its diameter and height in case of a cylindrical water accumulator.

The ratio between the surface area and the volume, depending on the diameter and height for a cylindrical water accumulator, and the accumulated amount of heat energy at the temperature difference 50°C has been calculated and numerically given in Table 2.

Table 2. Cylindrical hot water accumulator volume V, accumulated amount of heat energy Q at the temperature difference 50°C, and the ratio of the accumulator's surface area L to its volume V, depending on the diameter D and the height H of the accumulator.

D, m	V, m^3 Q, kWh L/V, $m^2 \cdot m^{-3}$	H, m							
		0.25	0.5	1	1.5	2	3	4	8
0.25	V	0.01	0.02	0.05	0.07	0.10	0.15	0.20	0.39
	Q	0.71	1.43	2.85	4.28	5.71	8.56	11.42	22.84
	L/V	24.00	20.00	18.00	17.33	17.00	16.67	16.50	16.25
0.5	V	0.05	0.10	0.20	0.29	0.39	0.59	0.79	1.57
	Q	2.85	5.71	11.42	17.13	22.84	34.25	45.67	91.34
	L/V	16.00	12.00	10.00	9.33	9.00	8.67	8.50	8.25
1	V	0.20	0.39	0.79	1.18	1.57	2.36	3.14	6.28
	Q	11.42	22.84	45.67	68.51	91.34	137.01	182.68	365.37
	L/V	12.00	8.00	6.00	5.33	5.00	4.67	4.50	4.25
1.5	V	0.44	0.88	1.77	2.65	3.53	5.30	7.07	14.14
	Q	25.69	51.38	102.76	154.14	205.52	308.28	411.04	822.08
	L/V	10.67	6.67	4.67	4.00	3.67	3.33	3.17	2.92
2	V	0.79	1.57	3.14	4.71	6.28	9.42	12.57	25.13
	Q	45.67	91.34	182.68	274.03	365.37	548.05	730.73	1461.4
	L/V	10.00	6.00	4.00	3.33	3.00	2.67	2.50	2.25
4	V	3.14	6.28	12.57	18.85	25.13	37.70	50.27	100.53
	Q	182.68	365.37	730.73	1096.1	1461.4	2192.2	2922.9	5845.8
	L/V	9.00	5.00	3.00	2.33	2.00	1.67	1.50	1.25
8	V	12.57	25.13	50.27	75.40	100.53	150.80	201.06	402.12
	Q	730.73	1461.4	2922.9	4384.4	5845.8	8768.8	11691	23383
	L/V	8.50	4.50	2.50	1.83	1.50	1.17	1.00	0.75
10	V	19.63	39.27	78.54	117.81	157.08	235.62	314.16	628.32
	Q	1141.7	2283.5	4567.0	6850.6	9134.1	13701	18268	36536
	L/V	8.40	4.40	2.40	1.73	1.40	1.07	0.90	0.65

The principal scheme of a home heating system using the heat accumulator in Fig. 2 is given. The heat accumulator 2 is connected with a fire-wood furnace 1, expansion tank 3 and heated floors 5 in rooms A, B and C, using a piping system. The temperature in any of the rooms is controlled by a temperature control unit 4. At the start of the stoking, hot water is circulating through the loop 'a' by means of the pump S_1. When its temperature reaches a certain level, for example 70°**C,** the valve V_{T1} opens and the hot water is running along the loop 'b', heating the water in the accumulator barrel. Control of the temperature in the heat accumulator is performed by the thermometers T_1 and T_2.

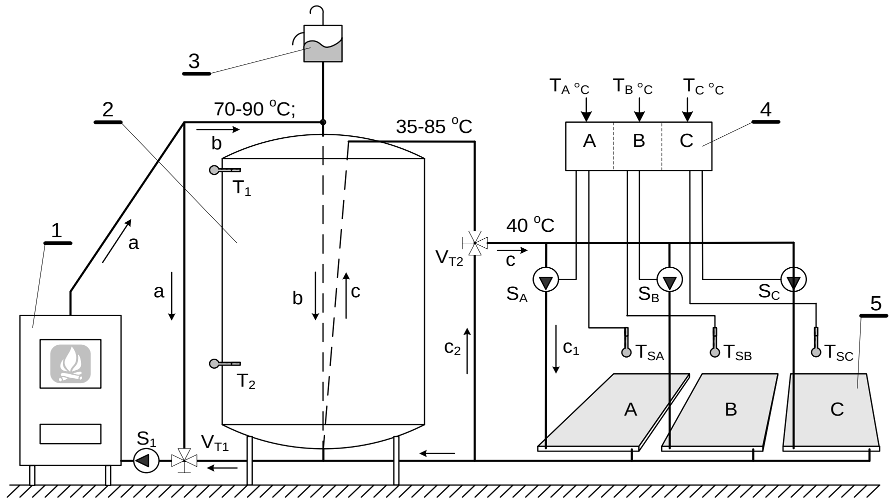

Figure 2. The heating system with heat accumulator: 1 – fire-wood furnace, 2 – hot water accumulator, 3 – expansion tank, 4 – temperature control unit, 5 – heated floor.

Room heating is carried out automatically by the control unit 4 in accordance with the adjusted temperature value in the separate rooms (A, B and C). The temperature control unit 4 receives information about the temperature level in the rooms from the temperature sensors T_{SA}, T_{SB} and T_{SC}, located in each of the rooms. According to the necessary temperature in the rooms ($T_{A^\circ C}$, $T_{B^\circ C}$ and $T_{C^\circ C}$), the temperature control unit 4 switches on or off the water pumps S_A, S_B and S_C. In the floor heating process the hot water is running along the loop 'c', 'c_1' and 'c_2'.

As our experimental investigation shows, in order to maintain comfortable room heating conditions with the furnace stoking only once a week and a rational heat consumption in the house, the volume of the hot water accumulator barrel has to be calculated equal to (0.15-0.25)m^3 per 1kWh of the medium heat consumption per 24 hours in the house during the heating season.

CONCLUSIONS

1. For low energy consumption house with a floor area of 120m^2 and 4 inhabitants, it is possible to insure the necessary heat supply installing a hot water accumulator of 5m^3 volume and performing one stoking a week.

2. In order to decrease the heat losses through the accumulator surface, its shape has to be chosen so that the ratio of the accumulator surface to its volume is at a minimum. For the cylindrical form of the water accumulator it will be at the diameter equal to the accumulator's height; the bigger the volume, the smaller the surface area.

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