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Research Paper

Combined Building-Energy Systems/Ground Heat Storage/Basic Calculations for Dimensioning

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ABSTRACT: *Heat accumulation addresses disparity between energy intake and consumption of thermal energy. Significance of heat accumulation is especially notable in case of heat sources, whose performance changes when the external climate conditions change. One example is the use of solar energy or the use of energy from the air by a heat pump. Different types of storage systems can be used for long-term heat accumulation, which differ mainly in the working medium used, but also for example in location and shape of the storage. In addition to the traditional working medium, such as water accumulated in conventional water storage tanks, ground heat storage (soil, a combination of soil and water, or gravel with water), aquifers, storage in ground boreholes, substances using phase change may be utilized, or they can use chemical - thermal reactions. A suitable heat accumulator should have a small volume, small heat losses, and a low price. Research focused on evaluation of the application of ground heat storage was the subject of the dissertation of Ing. Peter Janík, PhD. under the title: "Optimization of energy systems with long-term heat accumulation." (supervisor: Kalús), and at the same time of the research project HZ PG 73/2011 titled: "Experimental measurements, analysis, and determination of the optimal rate of use of renewable energy sources on a prototype of a family house EB2020 with nearly zero energy demand "(responsible researcher: Kalús). This paper is focused on basic calculations in the design of ground heat storage.*
KEYWORDS: *Heat accumulation, combined building-energy systems, active thermal protection (ATP), ground heat storage, losses of storage heat, soil properties*

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I. INTRODUCTION

The idea of storing heat in the soil is to improve natural storage processes by technical means so that a sufficient amount of heat with a sufficient temperature is available, for example to heat buildings, [48]. The following principles are recommended when designing heat storage:

- the soil must have suitable properties for long-term accumulation,
- the storage should have a suitable shape factor - the ratio of area to volume should be as small as possible,
- the groundwater level must not interfere with ground heat storage,
- appropriate location of the storage should be considered, it may be advantageous under the building,
- storage should have thermal insulation on the sides, consider also insulating the bottom of ground storage,
- the flow rate of the working medium in the exchanger into the storage should be low,
- the temperature gradient of the heating system should be as low as possible.

It is necessary to pay attention to the physical properties of soils. Compared to water as a traditional working medium, soil has a lower heat capacity, which does not mean that it is not suitable for long-term heat accumulation. Thermal-technical properties of selected soils under the conditions of the Slovak Republic (the city of Žilina) were measured, for example, in the project [47]. They were examined in dry state, in wet state and in frozen state. Thermal conductivity of the measured soils is shown in Table 1 and specific heat capacity and density in Table 2.

Table 1: Thermal conductivity of measured soils [37]

Soil type	Thermal conductivity λ (W/(m.K))			Humidity (%)
	dry	moist	frozen	
clay with medium plasticity	0.63	1.93	1.63	22.5
gravel clay	0.58	1.13	0.64	16.0
sand with clay	0.37	1.48	1.39	15.6

Table 2: Specific heat capacity and density of measured soils [37]

Soil type	Specific heat capacity c (J/(kg.K))			max. ρ (kg/m^3)
	dry	moist	frozen	
clay with medium plasticity	1756	2104	1485	1670
gravel clay	1710	1936	1464	1710
sand with clay	1107	1468	1372	1780

More detailed thermal properties of soils are described in the German guideline VDI 4640 (Use of underground for thermal purposes. Underground heat storage) and in several other publications [38], [39], [29]. Thermal conductivity is a function of soil bulk density, soil porosity, mass moisture, soil temperature and soil granularity. As the porosity decreases and the soil density increases, its thermal conductivity coefficient increases. With the moisture content of the soil, its coefficient of thermal conductivity increases, and this increase is sharper at lower humidity. As the grain size increases, the thermal conductivity coefficient increases slightly. The higher the value of the thermal conductivity of the soil, the faster the soil temperature rises or falls, [40]. In general, it can be said that gravelly and sandy soils are less suitable for building ground heat storage. Soil with higher clay content is suitable, while moisture has a significant effect on the accumulation capacity.

II. CLASSIFICATION OF GROUND HEAT STORAGE

One of the criteria based on which we can classify ground heat storage is according to temperatures [29]:

- **deep low-temperature heat storage <10°C,** also called cold storage, these are used in heating systems where heat demand to be covered is not high. They are operated without external heat supply.
- **low-temperature heat storage 10 to 30°C**, in contrast to the system of deep low-temperature heat storage, heat is supplied. Solar collectors, plastic absorbers, energy roofs, or waste heat can be used as heat sources,
- **medium temperature heat storage 30 to 50°C**, solar collectors, energy roof, or waste heat can be used as heat sources,
- **high temperature heat storage > 50°C**, which can use all aforementioned heat sources, but also heat from fireplaces, boilers, and others.

Another criterion according to which ground heat storage can be classified is according to the method of supplying and removing stored heat. The methods are used in the same way as for ground heat exchangers with ground-to-water heat pumps. Ground heat exchangers can be placed horizontally or vertically. Attention will be further paid to horizontal storage. Figure 1 and Figure 3 show ground storage formed by a plastic pipe. In this case, the heat storage is located under a family house or in the foundation slab.

Horizontal storage, which will be given more attention in this paper, and which is used in the system with active thermal protection ATP, can be divided into several temperature ranges. The warmest zone is situated in the middle. Figure 3 shows a view of ground heat storage located under a family house, which is divided into three areas. A valve is shown here to ensure that the flow of working medium is directed to the appropriate area. At low solar radiation, heat flux is supplied to the peripheral zone; if the working medium is heated to a temperature higher than 35°C due to high solar radiation, the center of the heat storage - the storage core - is heated.

Figure 1: Construction of horizontal ground heat storage, which consists of exchangers formed by plastic pipes [60]

Figure 2: Construction of vertical boreholes that can be used to store and remove heat from the ground. Pictured on the right used for a heat pump [58]

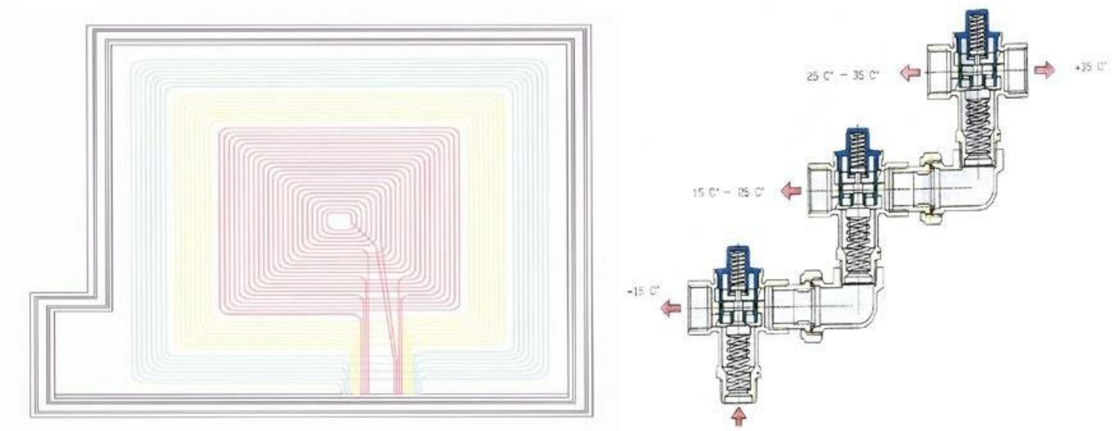

Figure 3: Ground heat storage located under a family house a control valve, divided according to temperature zones [63]

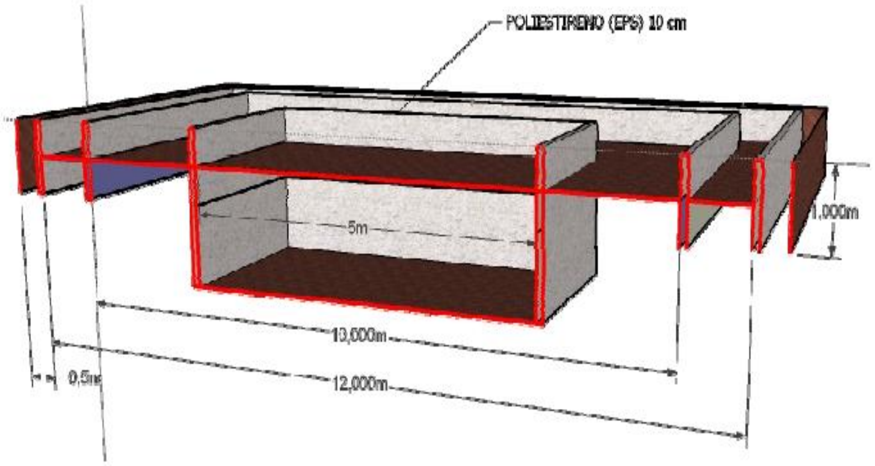

Figure 4: Cross section of ground heat storage divided into three temperature regions [63]

III. DESIGN OF THE VOLUME, ENERGY BALANCE, AND EFFICIENCY OF GROUND HEAT STORAGE

The volume of ground heat storage for heating buildings is recommended to be approximately as large as the volume of the heated building, or for flat horizontal storage the storage area should be approximately twice as large as the heated area of the building, [29]. It is necessary to know the temperature in the subsoil at the initial state. The soil temperature at a certain depth is almost constant during the year. FIG. 5 shows the course of temperature changes in the soil in selected months.

From a depth of 15 meters in the ground in our climatic conditions, the temperature does not change depending on the seasons and with the amount of sunlight falling on the earth's surface, [40]. It is possible to determine the temperature in the subsoil either by measurement or estimation. It would be necessary to measure temperatures over a longer period of time, e.g. over a year, which still may not be representative. It is easier to estimate the subsoil temperature, standards STN 06 0210 [50] and a combination of standards STN EN 12831 [51] and STN EN ISO 10 211-1 [52] can be helpful. STN 06 0210, which is no longer valid, states a temperature at a depth of 3 m below the earth's surface of 5°C, regardless of the temperature area and altitude. STN EN 12831 defines, in addition to the outdoor calculated temperature, also the average annual outdoor air temperature (minimum: Liptovský Mikuláš and Poprad 5.9°C, maximum: Bratislava 9.9°C), STN EN ISO 10 211-1 assigns a temperature boundary condition of the earth's surface at a depth of 3 m below the surface equal to the annual average outdoor air temperature, [149]. Relative to Bratislava, according to STN 06 0210, 5°C could be considered in calculations; according to the valid STN EN ISO 10 211-1 temperature of 9.9°C could be considered. Ground storage can be located under a building or next to a building.

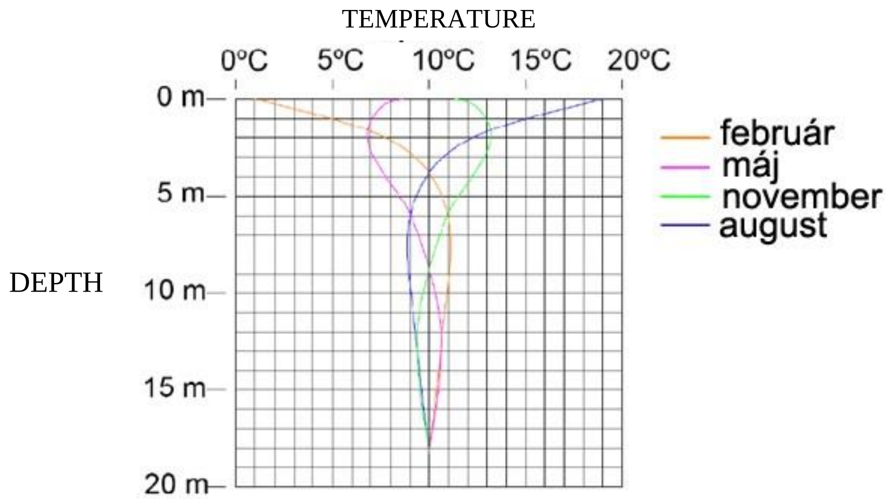

Figure 5: Temperature changes in the soil depending on depth [49]

The energy balance of heat storage can be expressed by the balance equation of a plot:

$E = A_{intake} + B_{release}$ (kWh) [42] (1)

Under natural conditions, heat release includes terrestrial radiation, cooling of the soil by the atmosphere, cooling by evaporation of atmospheric precipitation and groundwater evaporation, rock heat dissipation by seeping gravity water, heat dissipation to less warm horizons, heat consumption in various reactions, and heat consumption for melting of snow and ice. Heat intake includes solar radiation, soil heating by the atmosphere, heat generated by gas and water vapor adsorption and condensation, rock heating by artesian water, heat flow from warmer to colder horizons, heat generated by chemical and biological processes, heat of water during ice formation and terrestrial heat flux, [42], [38]. With soil under a building, the intake by direct sunlight decreases, on the other hand, it increases with the transfer of heat through the floor of the building. The value of the earth's heat flux is 500 to 700 W per hectare. When using a heat pump, this device consumes more heat than the earth can supply, which is reflected in an increase in electricity and thermal effects on the surrounding land, [42]. When using an ATO system, it is also not possible to supply the system with a constant temperature in the long run.

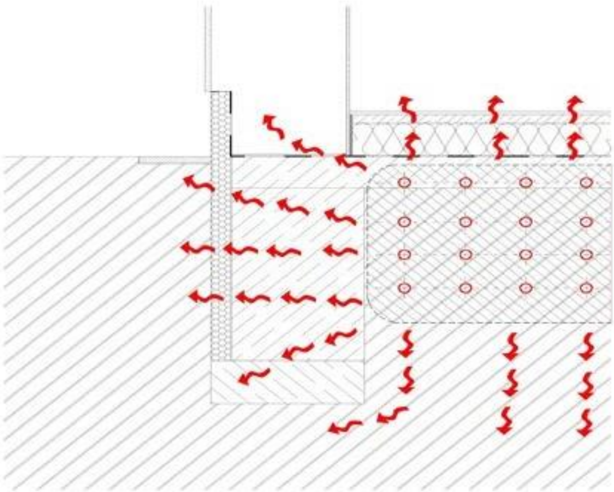

Figure 6: Illustration of heat losses from heat storage located under a house [42]

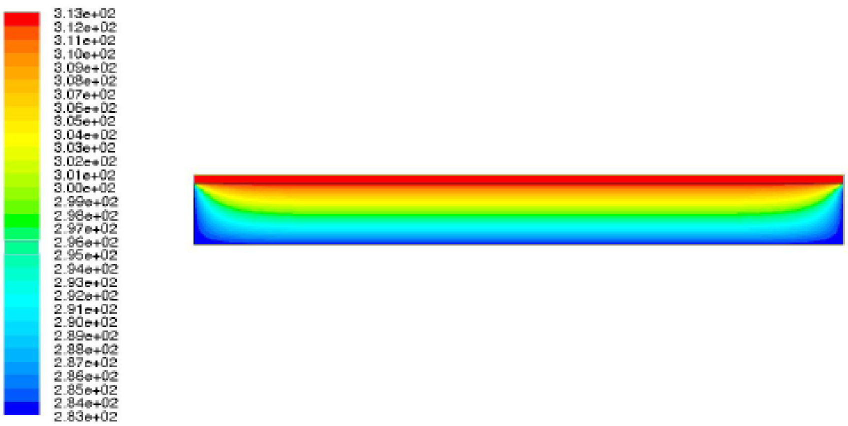

Figure 7: Simulation of ground heat storage located under a building at the temperature of the working medium in the pipe 40 °C, v = 1 m/s [42]

Ground heat storage should be thermally insulated to minimize heat loss. From the upper side, the storage is bordered by a reinforced concrete foundation slab with thermal insulation, which in this case also serves against overheating of the building. On the sides, the storage has thermal insulation, which can be (as in FIG. 6) situated along the foundation strips. It is recommended that the thermal insulation reaches at least 2 m below the ground surface. However, there are several ways to build buildings, several ways to thermally insulate the storage from the sides, several ways to place the storage (under a building, next to a building) and several ways to divide the storage into to temperature zones.

Heat losses of storage bordered by six sides are expressed as (2):

$$Q_{loss} = \sum_{i=1}^{n} U.A.(\theta_s - \theta_a) \quad (W)$$ [43] (2)

U heat transfer coefficient of the i-th part of the storage surface (W/(m^2.K)), A - i-th part of the storage (m^2),
Θ_s average temperature in the ground storage (°C),
Θ_a ambient temperature around the storage (°C).

Energy efficiency of heat storage (3) can then be expressed as:

$$\eta = \frac{Q_{ext}}{Q_{inj}} \quad (-)$$ [43] (3)

If it is considered that after one cycle (year) it returns to its original temperature, then efficiency can be expressed as follows (4):

$$\eta = \frac{Q_{ext}}{Q_{iext} + Q_{loss}} \quad (-)$$ [44] (4)

Q_{ext} thermal energy taken into storage during the year (W),
Q_{inj} thermal energy stored in the storage tank during the year (W).

Heat transfer in pipes can be expressed by the basic relationship (5):

$$\frac{q}{H} = \frac{\theta_i - \theta_E}{R_r} \quad (W/m)$$ [32], [44] (5)

q heat flux density in the pipe (W/m^2),
H distribution length (m),
Θ_i temperature of the working medium in the pipe (°C),
Θ_E ambient temperature of the pipe - in the ground heat storage (°C),
R_r thermal resistance including pipe resistance and soil resistance ((m².K)/W).

The thermal resistance, including pipe resistance and soil resistance, is expressed as (6):

$$R_r = \frac{1}{2.\pi.r_i.h_{conv,i}} + \sum_{i=1}^{n} \frac{\ln\left(\frac{r_i + 1}{r_i}\right)}{2.\pi.\lambda_i} + R_E \quad ((m^2.K)/W)$$ [32], [44] (6)

r_i pipe wall thickness (m),
λ_i coefficient of thermal conductivity of the pipe wall (W/(m.K)),
R_E thermal resistance of soil ((m².K)/W),
$h_{conv,i}$ heat flow coefficient in the pipe ((m².K)/W).

Heat flow coefficient in a pipe can be expressed under given conditions at a velocity of about 1 m/s and in water, as the working medium (7):

$$h_{conv,i} = \frac{1057.(1{,}352+0{,}019.\theta_i).v^{0,8}}{D_i^{0,2}} \quad (W/(m^2.K)$$ [32], [44] (7)

v flow rate of the working medium in the pipe (m/s),
D_i pipe diameter (m),
Θ_i temperature of the working medium in the pipe (°C).

There are several methods to calculate the thermal resistance of the soil. According to STN EN ISO 12241, thermal resistance of homogeneous soil is calculated according to the equation (8):

$$R_E = \frac{1}{2.\pi.\lambda_E}.arccos\frac{2.H_E}{D_i} \qquad ((m^2.K)/W) \qquad [45]\ (8)$$

λ_E thermal conductivity coefficient of the surrounding soil (W/(m.K)),
H_E distance between the center of the pipe and the ground surface (m).

Equation (8) can be simplified for HE/Di> 2 as follows (9):

$$R_E = \frac{1}{2.\pi.\lambda_E}.ln\frac{4.H_E}{D_i} \qquad ((m^2.K)/W) \qquad [45]\ (9)$$

Other methods for calculating soil thermal resistance are described in [32], [42], [43].

A change of temperature of the working medium in the pipe - in a heat exchanger, which is placed in ground storage, can be expressed by the following relations (10), (11), (12):

$$\theta_{fm} - \theta_E = (\theta_{im} - \theta_E).e^{-\alpha.l} \qquad (°C) \qquad [42], [43]\ (10)$$

Where:

$$\alpha = \frac{q_L}{(\theta_{im} - \theta_E).m.c_p} \qquad (-) \qquad [42], [43]\ (11)$$

$$q_L = \frac{\theta_{im} - \theta_E}{R_r} \qquad (°C) \qquad [42], [43]\ (12)$$

Θ_{fm} final temperature of the working medium in the pipe (°C),
Θ_{im} initial temperature of the working medium in the pipe (°C),
Θ_E ambient temperature around the pipe - in the ground heat storage (°C),
l pipe length (m).
q_L heat flux density (°C).

Table 3: Temperatures of the working medium in a heat exchanger at the outlet of the storage at the given inlet temperatures, storage temperature, and pipe length [43]

Pile length l (m)	Θ_{im} = 35 °C Θ_E = 25 °C	Θ_{im} = 40 °C Θ_E = 10 °C	Θ_{im} = 50 °C Θ_E = 15 °C	Θ_{im} = 60 °C Θ_E = 17 °C	Θ_{im} = 60 °C Θ_E = 35 °C
10	34.7	39.1	48.9	58.7	59.2
30	34.1	37.4	47.0	56.3	57.9
50	33.6	35.9	45.2	54.1	56.5
70	33.1	34.4	43.4	51.9	55.3
150	31.4	29.3	37.5	44.6	51.1
190	30.7	27.1	35.0	41.5	49.3
250	29.8	24.4	31.8	37.6	47.0

The equations can be used to calculate the temperature of the working medium at the outlet of the heat storage, at a given inlet temperature to the storage and the average storage temperature (around the heat exchanger). By knowing the difference between the incoming and outgoing temperature of the working medium and at a given flow rate, it is then possible to calculate the heat transferred to the heat storage. Table 3 shows the results of calculations of the outlet temperatures from the heat storage at the inlet temperatures Θ_{im} and at the given temperatures in the ground heat storage Θ_E at different lengths of the plastic exchanger. Input values: exchanger material: PP (20x1 mm), working fluid flow rate 1 m/s, soil thermal resistance 1.01 (m².K)/W, working medium - water, soil heat capacity 1481 J/(kg.K). The calculation was made in 5 cm increments.

Based on these calculations, it is possible to calculate the heat that can be stored in the heat storage. It is recommended that the difference between the inlet temperature of the working medium and the ambient temperature in the storage be at least 2 K [61] and 6 K [62], respectively. Otherwise, the heat transfer process is not efficient.

The heat that can accumulate in the foundation slab can be expressed as:

$$Q = m \cdot c \cdot \Delta\theta \quad \text{(J)} \qquad [42]\ [43]\ \textbf{(}13\textbf{)}$$

m weight (kg),
c specific heat capacity (J/kg.K),
$\Delta\theta$ temperature difference (K).

In the theoretical calculation, storage will be considered, which is formed by reinforced concrete foundation slab, with the following properties: area = 100 m^2, thickness = 0.2 m, bulk density = 2400 kg/m^3, weight = 100 * 0.2 * 2400 = 48000 kg, heat capacity = 1020 J/kg.K. The temperature below the surface of the foundations in accordance with STN 730540/2002 was considered to be 5°C. If polystyrene 100 mm thick is considered above the reinforced concrete foundation slab, then at indoor air temperature of 20°C, the temperature in the middle of the foundation slab will be 5.5°C according to the calculations in the program Heat. The average temperature at the inlet into the heat storage from the energy roof or another heat source is selected at 30 and 50°C.

Heat that can accumulate in a given heat storage at a working medium temperature at the inlet to the storage of 30°C represents: Q = 48000 * 1020 * (30 - 5.5) = 1199520000 J = 333.2 kWh, at a working medium temperature of 50°C = 2178720000 J = 605.2 kWh

It is important to determine the time during which the ATP can be supplied. In the theoretical calculations, heat losses of the storage tank will not be considered. The calculation will be performed for ATP output of 0.5 kW, 1.0 kW, 1.5 kW and 2.0 kW. For example, at the temperature of the working medium at the inlet to the ground storage of 30°C, at the ATP output 0.5 kW, the theoretical time for supplying the ATP = 333.2/0.5 = 666.4 hours = 27.8 days. Theoretical calculations are summarized in Table 4.

Table 4: Theoretical duration of operation of ATP supplied from ground heat storage (GHS)

Temperature on inlet to GHS (°C)	Heat that can be accumulated in GHS (kWh)	Output of ATP (kW)			
		0.5	1.0	1.5	2.0
		Time ATP can be supplied (days)			
30	333,2	27.8	13.9	9.3	6.9
50	605,2	50.4	25.2	16.8	12.6

In theoretical calculations, foundation slab of a family house (area 100 m2, thickness 0.2 m) does not come out as optimal heat storage. Without taking into account heat losses, considering 30°C in the storage (foundation slab), a 1 kW ATP could only be supplied for less than 14 days, at 50°C in the tank for 25 days.

IV. EXPERIMENTAL MEASUREMENTS OF THE GROUND HEAT STORAGE

Experimental measurements were performed on the EB2020 experimental house. The source of heat is an energy roof formed by a plastic pipe placed under the roof tiles in circuits: 3 x 100 m, a fireplace insert and a gas boiler, Figure 8. In addition to the combined storage tank (V = 575 l for central heating and 180 l for DHW), the heat is stored in the ground storage, which is formed by a plastic pipe in the foundation slab in circuits: 5 x 100 m, Figure 9.

Figure 8: Energy roof consisting of plastic pipes under roof tiles, a low-temperature gas boiler and a fireplace with a hot water heat exchanger (Photo archive: Kalús) [10, 13]

Figure 9: View of the storage tank (V = 575 l for CH and 180 l for DHW), implementation and insulation of the ground heat storage with integrated pipes in the foundation slab (Photo archive: Kalús) [10, 13]

The connection diagram of the energy systems of the experimental house EB2020 is shown in Figure 10. It is clear from the diagram that the heat obtained from solar energy (energy roof) is stored in the ground storage, while under suitable conditions it can also be stored in the storage tank. A heat exchanger is installed between the primary side (in which a glycol-based antifreeze mixture circulates) and the secondary side. Heat to the ground storage can also be supplied by a fireplace insert, which is also a source of heat for the storage tank. A peak heat source for the storage tank is a low-temperature gas boiler. Low-temperature radiant floor heating is supplied from the storage tank. The m active thermal protection ATP can be supplied from the storage tank or directly from the ground heat storage.

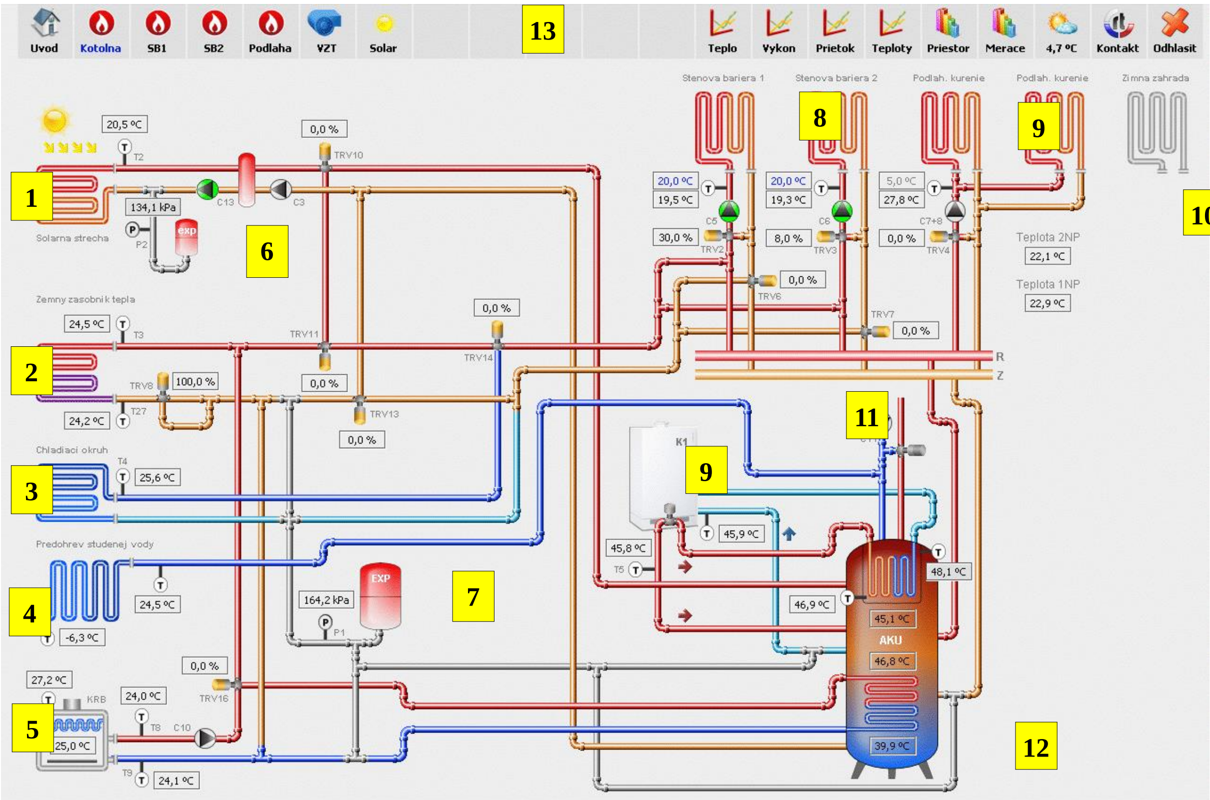

Figure 10: Connection diagram of energy systems in the experimental house EB2020 with the possibility of remote control via the Internet [10, 13]

1 - solar energy roof circuits, 2 - ground heat storage circuits, 3 - cooling circuit, 4 - hot water preheating circuit, 5 - fireplace with hot water heat exchanger, 6 - expansion vessel for solar roof, 7 - expansion vessel for heating system, 8 - active thermal protection circuits, 9 - low temperature gas boiler, 10 - preparation of heating for a winter garden, 11 - hot water circuit with a circulation pump, 12 - storage tank, 13 - output from the building control system to the computer, control via the Internet

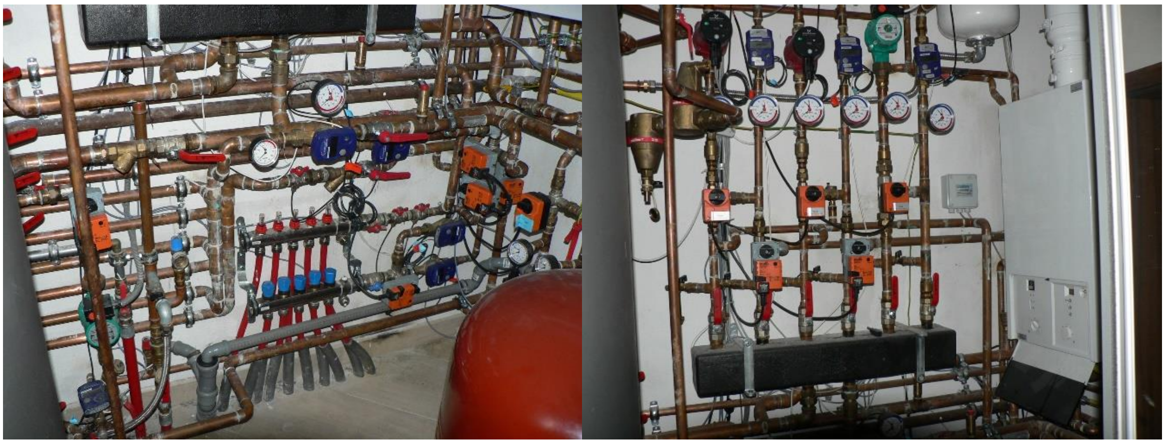

Figure 11: A view of the connection of energy systems in the experimental house EB2020 (Photo archive: Kalús) [10, 13]

In December 2011, the operation was started of the energy system with the use of active thermal protection and underfloor heating, while temporarily used from the heat sources were the low-temperature gas boiler and the hot-water fireplace insert. Different input temperatures to the active thermal protection ATP (wall barrier) and into the underfloor heating were set in order to find the optimal use of the energy system and evaluate the parameters of individual modes of operation. The measurement of the energy system with active thermal protection in the function of large-area wall cooling and thermal barrier and underfloor heating took place over two heating periods. Measurement of active thermal protection in the function of large-area wall cooling took place over one summer period (July to October 2012). The energy roof was put into operation in July 2012. The measurement of the energy roof and the charging of the ground heat storage in the charging cycle lasted one summer period.

Experimental measurements of the ground heat storage took place during one charging season (values taken into account from 10 July, i.e. from the beginning of the operation of the solar energy roof) and one discharging season (one heating period). The heat source is the energy roof and a hot water fireplace insert. The energy roof is also a source of heat for the combined water tank for heating and hot water. However, since the temperature in the said combined storage tank was always higher than the temperature obtained from the energy roof, the heat from it was accumulated in the ground heat storage during the entire charging season. The fireplace insert is equally a source for both ground and water heat storage. The control of the system is set for primary heating of the combined water storage tank, whereby after it is heated to the required temperature, the heat is further accumulated in the ground heat storage.

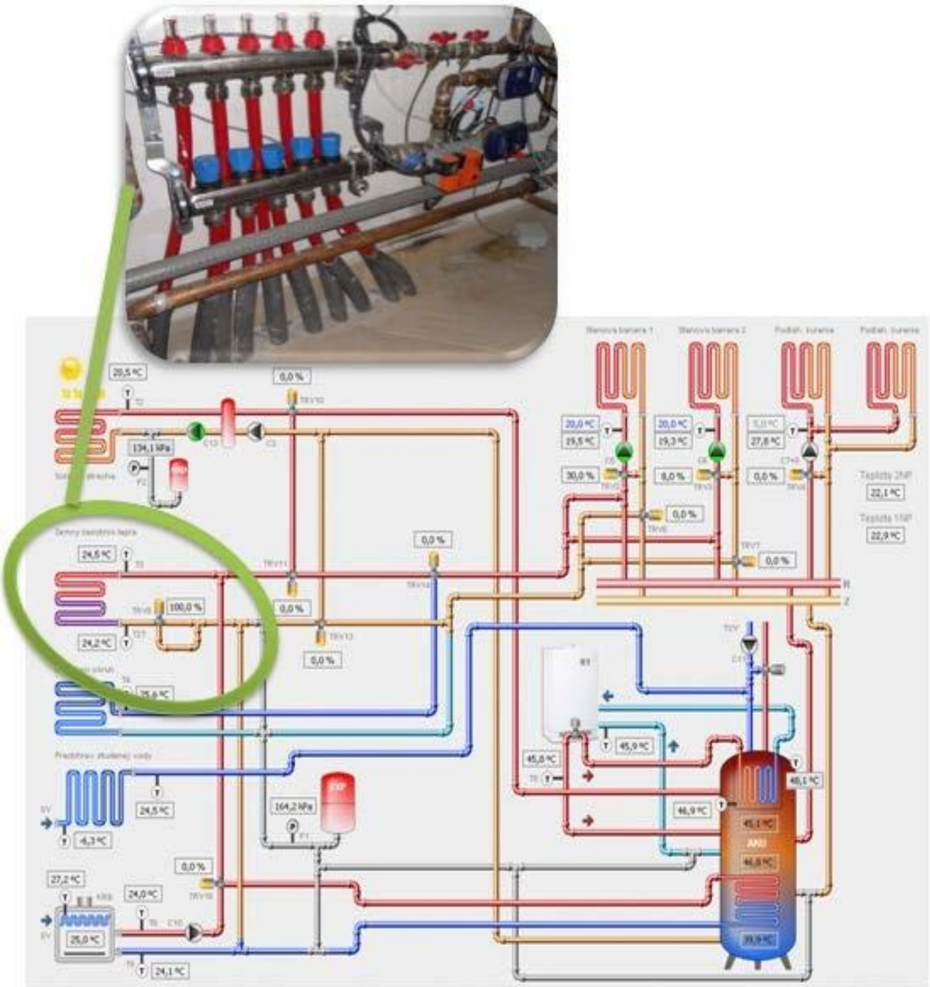

Figure 12: Diagram of the energy system in the family house and display of compact heat meters connected by a by-pass at the ground heat storage [10, 13]

A compact heat meter is fitted to the ground heat storage (heat, flow rate, total flow volume, temperatures and output are measured). A second compact heat meter is fitted via a by-pass. One meter is used for measuring when heating (charging) GHS, the other when taking heat from GHS (discharging). Heat meters with the bypass are shown in Figure 12.

Compact heat meters are also fitted to the energy roof and fireplace insert. Heat from the energy roof could be accumulated in the combined water heat storage as well as in the ground heat storage. At the time of measurements during the entire operation, it was accumulated only in the ground heat storage. Heat from the hot water fireplace insert was accumulated both in the combined water heat storage tank and in the ground heat storage. This means that it is possible to find out the values on the heat meter at the fireplace insert, but further, the values behind the three-way valve are not recorded - towards the combined water heat storage tank and towards the ground heat storage.

4.1 Experimental measurements when charging the ground heat storage

Figure 13 shows the heat stored in the ground heat storage in GJ for the period 10 June to 22 December 2012 with marked average flow rates and average temperatures of the working medium at the inlet to the ground heat storage and in the return pipe (at the outlet from the GHS). The chart is divided into two periods: "A" and "B". The limit is the time when the energy roof is no longer used. After 6 October 2012, the conditions for its use were no longer suitable.

- period "A" – 10 July to 6 October 2012 - heat to the GHS was stored mainly from the energy roof, only partially from the hot water fireplace insert,
- period "B" 7 October to 22 December 2012 - heat was stored in the GHS only from the hot water fireplace insert.

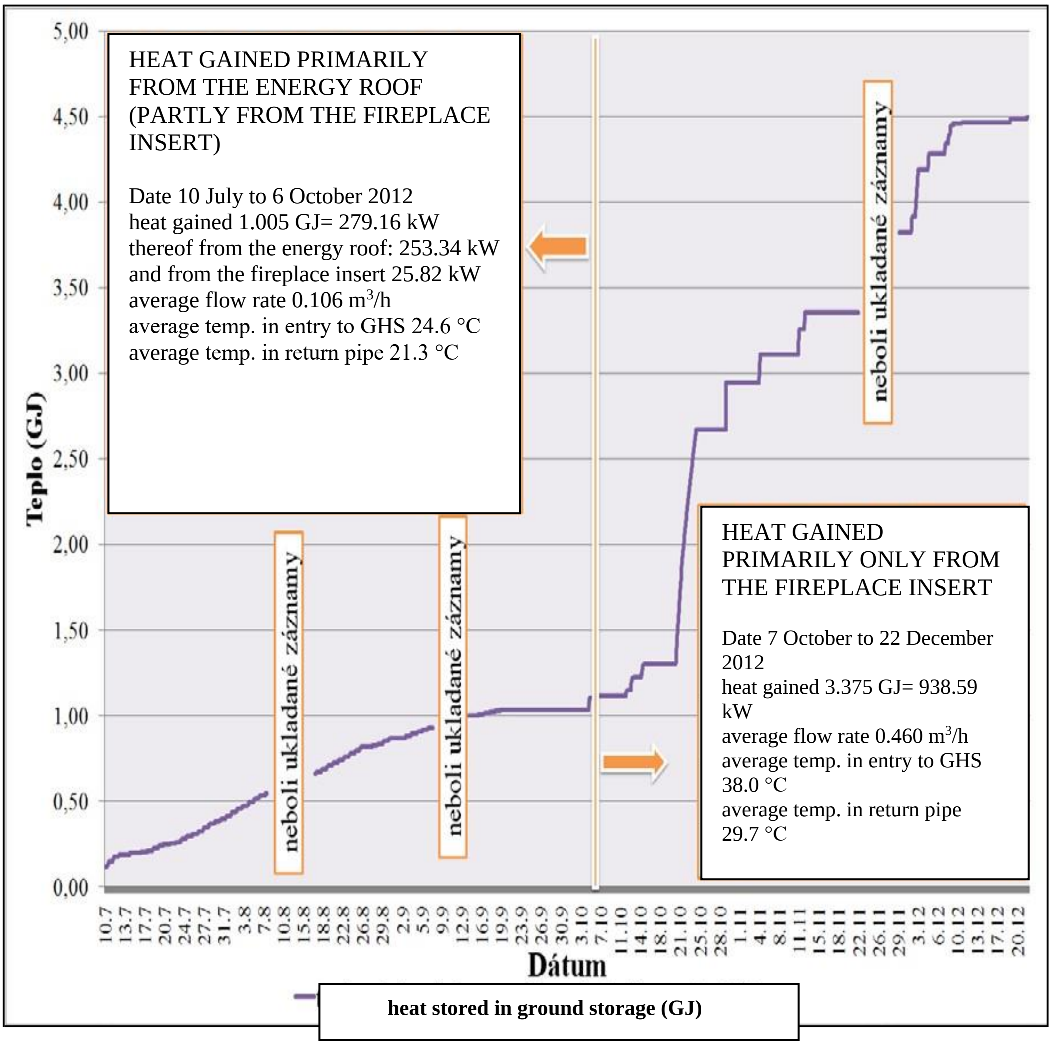

Figure 13: Heat stored in the ground heat storage (GJ), period: 10 July to 22 December 2012 with marked flow rates and temperatures [10, 13]

Figure 14 shows the flow rate during charging of the ground heat storage and at the same time the temperature difference at the inlet to the GHS and the outlet (in the return pipe). The boundary between periods "A" and "B", i.e. the time when the energy roof ceased to be used, is separated by an orange line. At the time of operation of the fireplace insert, the heat was primarily supplied to the combined water storage tank, and after it was heated, the heat was further used to supply the ground heat storage. The fireplace insert was used irregularly by the inhabitants. After 22 December 2012, in the heating season 2012/2013, the fireplace insert was no longer used to supply heat to the ground heat storage.

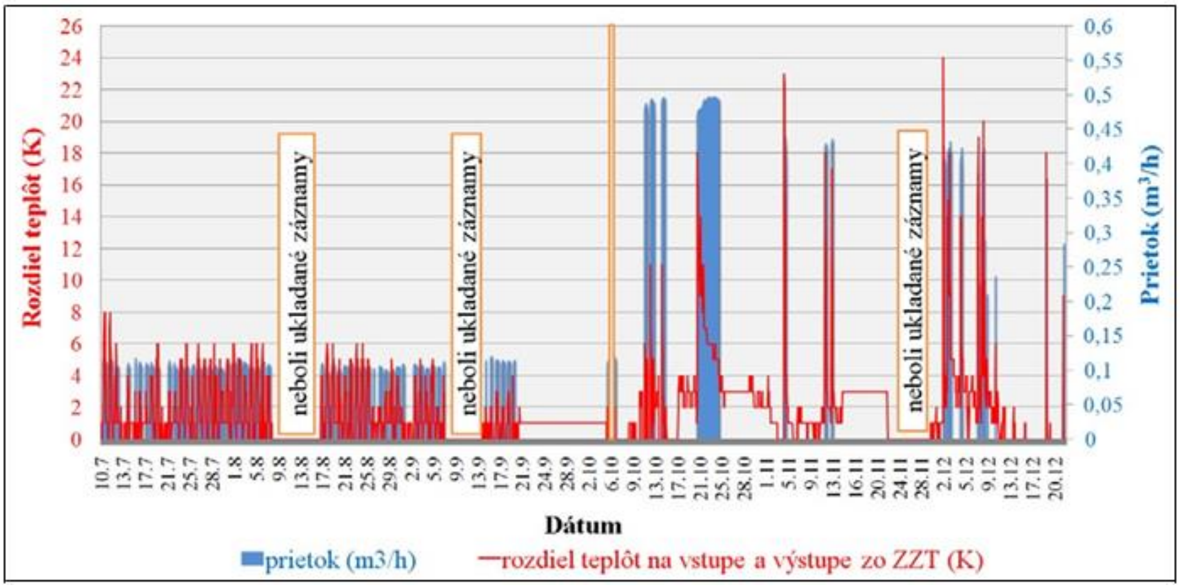

Figure 14: Flow rate during DHW charging (m3/h) and temperature difference at the inlet to the DHW and outlet (in the return pipe): 10 July to 22 December 2012 [10, 13]

During the period "A" (10 July to 6 October 2012) heat was stored in the GHS: 279.16 kW, of which a substantial part = 253.34 kWh was supplied from the energy roof. The hot water fireplace insert supplied heat to the GHS on 19 and 20 September and October 5 and 6. Total heat supplied to the GHS from the fireplace insert from this period = 25.82 kWh.

During the period "B" (7 October to 22 December 2012), a total of 938.59 kWh was stored in GHS. This heat was supplied only from the hot water fireplace insert. Heat from the period before July 10 2012 is obtained during testing of heat meters, pressure test of the system, and initial inspection of the system = 29.72 kWh. The heat obtained from the energy roof for the entire charging period is 253.34 kWh, the heat obtained from the hot water fireplace insert is 964.41 kWh.

4.2 Experimental measurements of discharging the ground heat storage

The main idea in the design of projects with ground heat storage is the long-term accumulation of low-potential heat and its subsequent use in a low-temperature heating system, or active thermal protection. Figure 15 shows the heat taken from the ground heat storage in GJ from the period 29 November 2012 to 25 February 2013 with the marked average flow rates and average temperatures of the working medium at the outlet from the ground heat storage and in the return pipe. After February 25, 2013, no heat was removed. A total of 0.020 GJ = 5.56 kWh of heat was taken from the GHS for the ATP. The average flow rate was 0.021 m^3/h = 0.33 l/min. The average temperature at the outlet from the GHS was 20.2°C, the average temperature in the return pipe to the GHS was 18.4°C. In the chart it is possible to distinguish two main periods when heat from GHS was used. The first period is marked in green in the chart. This heat was removed during the charging cycle of the GHS.

Precisely half of the total heat taken, i.e. 0.010 GJ = 2.78 kWh, was taken from 7 February to 25 February 2013. This period is marked in burgundy in the chart. During this period, the input temperature to the ATP was set to 20°C, so the conditions for its supply from the ground heat storage were suitable. In this period from 7 February until 25 February 2013, the average flow rate was 0.021 m^3/h = 0.33 l/min, the average temperature at the outlet from the GHS was 19.2°C and the average temperature in the return pipe to the GHS was 17.6°C. Even after 25 February 2013, the ATO was supplied with inlet temperature of 20°C, but there was no longer enough heat in the GHS to supply it. As only 5.56 kWh of heat was taken in total, of which only 2.78 kWh after the end of the charging cycle, temperatures and flow rates will no longer be displayed graphically.

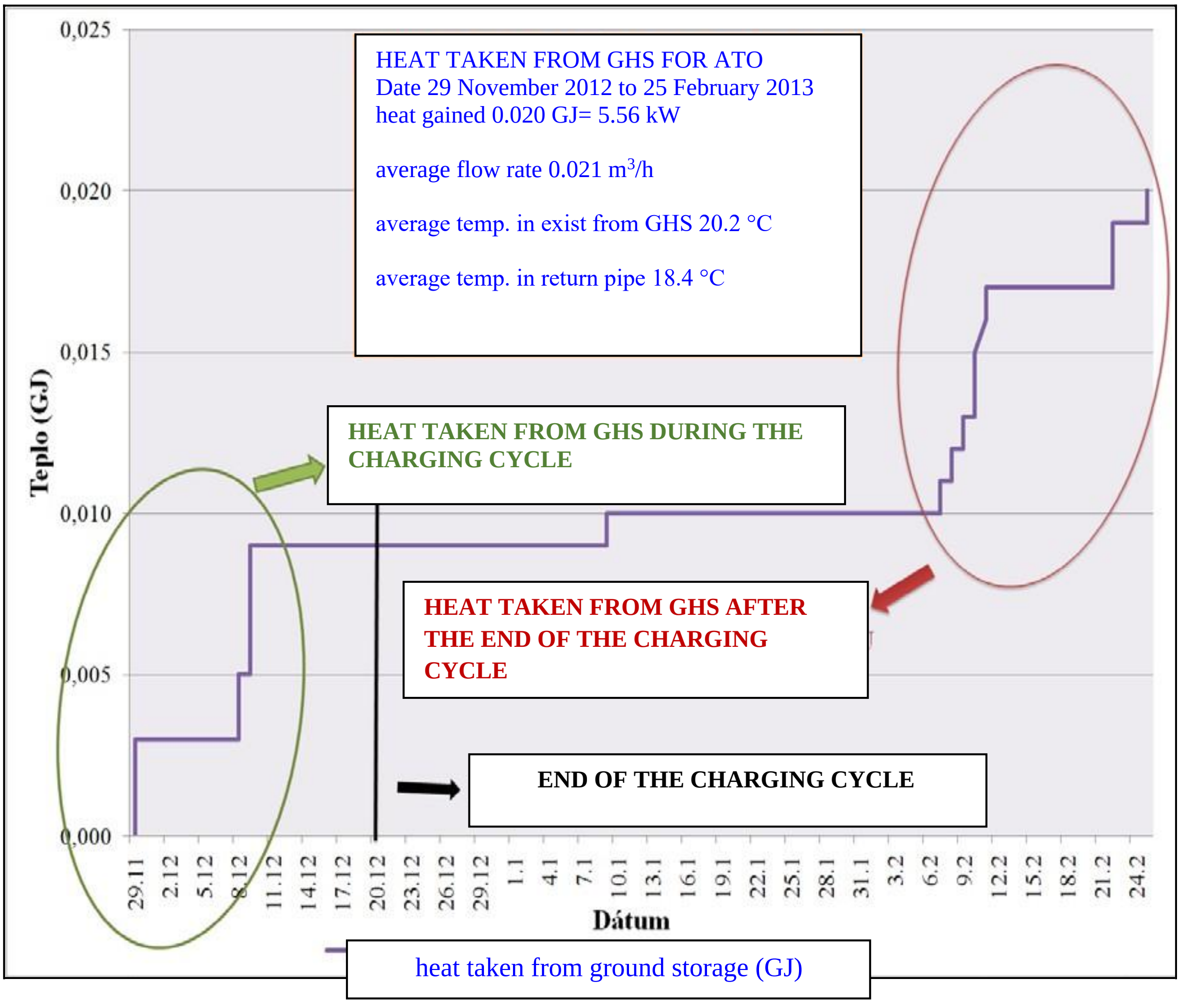

Figure 15: Heat taken from the ground heat storage (GJ), period: 7 February to 25 February 2013 with marked flow rates and temperatures [10, 13]

V. CONCLUSION

Calculation, design and assessment of ground heat storage require a comprehensive analysis of the input data, which can be summarized in the following recommendations:

- when designing heat storage, it is necessary to take into account the climate data of the area, heat sources, the heating system and hot water preparation system, possibly also the cooling system,
- to minimize heat losses, the storage should have a suitable shape factor, provided with a suitable thickness of thermal insulation and be suitably located - in the case of a water tank, consider placement in a heated space, technical room, outdoors or in the ground, in a ground tank under a building or on a plot next to the building, consider insulation also from below,
- consider simultaneous use of ground storage and a water reservoir, where they can be heated simultaneously in favorable sunlight,
- properly position heat exchangers,
- flow of the working medium in the exchanger should be at a suitable speed,
- the temperature gradient in the function of low-temperature heating should be as small as possible,
- in the case of ground storage, the soil must have suitable properties and groundwater cannot enter the ground storage - not every land plot is suitable for building ground storage.

Other recommendations:

- it is recommended to perform simulations of water reservoirs and ground storage, where it is possible to dynamically change external and internal conditions,
- perform measurements on real buildings in order to determine the amount of heat transferred and subsequently the amount of heat taken.

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