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HEAT ACCUMULATION TO UNDERGROUND HEAT STORAGE FACILITIES

AKUMULACE TEPLA DO PODZEMNÍHO ZÁSOBNÍKU TEPLA

Abstract

At present, the research team of the Department of Building Environments and HVAC is intensely engaged in long-term heat storage in ground tanks for long-term, strategic, development options. This research area is primarily addressed in Germany and Canada, where ground heat storages are always applied to large buildings that act as both the main source and consumer of heat. The aim of this research is to create alternative heat ground storage options for a complex of 3 houses using easily recyclable materials.

Keywords

Underground heat storage, heat gain, recycled concrete chippings.

Abstrakt

V současné době se výzkumný tým katedry Prostředí staveb a TZB v rámci Institucionální podpory na dlouhodobý koncepční rozvoj intenzivně zabývá možnostmi dlouhodobé akumulace tepla v zemních zásobnících. Tato oblast výzkumu je řešena zejména v Německu a také v Kanadě, kde zemní zásobníky jsou využívány vždy na rozsáhlé objekty, které jsou zdrojem tepla a současně spotřebičem. Směr výzkumu, je vytvořit alternativu zemního zásobníku s modelovou strukturou pro komplex max. 3 rodinných domů a přitom využívat materiály, které lze lehce recyklovat.

Klíčová slova

Podzemní zásobník tepla, tepelný zisk, recyklovaná betonová drť.

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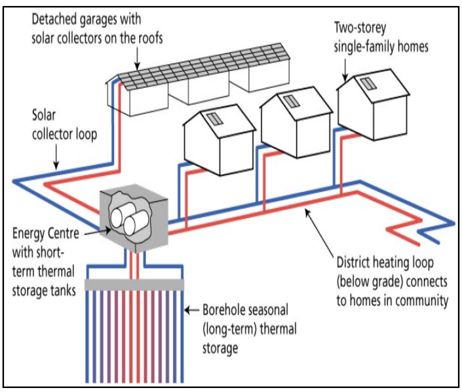
1 INTRODUCTION

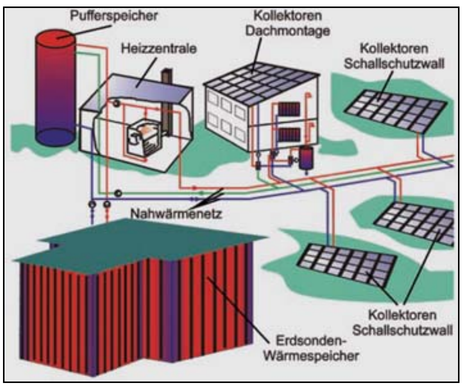
With the recent developments in a rapidly spreading global economic crisis, it is important to direct our attention towards options for inexpensive and efficient solutions in terms of energy provision. It is possible to reach this goal by using "zero energy balance". In practice, this means that a building would consume energy in the winter and then reproduce the expended energy with solar energy in the summer. This principle, however, does not entirely resolve the issue of decreasing energy consumption in real time. The cost of electric power has a tendency of rising while the fluctuation of the supply of electrical grid energy, during sunny days in the summer, is declining. Other options for reaching the required goal are to utilize heat storage from ground tanks. There is a system in place which is inexpensive, efficient and seasonal. The suggested solution involves using a system of solar collectors as a source of energy. Solar systems use solar energy as the most available, pure, and practically infinite, source of heat and light.

These objectives are in full compliance with a directive set forth by the European Parliament and Council 2010/31/EU, on building energy performance, titled EPBD II or EPBD recast [4], which was ratified in May 2010. Member countries of the European Union are obliged to implement this new requirement into their national regulations. Referring to a new version of the European Union directive on EPBD building energy performance, it is necessary to design buildings with significantly lower energy consumption by 2020. In article #9 [4], it states that member states will be responsible for ensuring that all new buildings have "nearly zero energy consumption" by December 31, 2020. As for the implementation of this norm into Czech legislation, there are discussions taking place in the professional community about alternate options for achieving these objectives. Steps are being taken with emphasis on the following: reducing greenhouse gas emissions by up to 20% by the year 2020 (compared to the year 1990); increasing the percentage of renewable energy in the EU by 20%; and increasing energy efficiency in Europe by 20%.

2 CURRENT STATE OF THE SITUATION

There are several similar ground tanks operating in the world. Some of them are based on storing heat in water (ATES storage), others into the ground (BTES - Drake landing solar community, Okotoks - Canada, Project Solaranlage stadtwerke Crailsheim - Germany, GreenGas Paskov – Czech republic) see figures 1 and 2. In cooperation with VSB-Technical University Ostrava, we have been dealing with an existing storage possessed by the company GreenGas Paskov, which is at the moment the only one of its kind in the Czech Republic [2]. Its concept is focused on larger, similar compounds in Germany and Canada.





Figures 1, 2: underground tanks designs in Drake landing and Crailsheimu [4,6]

The ground storage mentioned above, BTES (Borehole Thermal Energy Storage), utilizes the heat accumulation found in a rock massif. Currently, this massif is made up of various materials/rocks. This implies that the storage can basically be made from materials commonly available on our planet. However, it is necessary to divide them according to their specific heat capacity *c* [J/kg.K], which expresses the amount of heat absorbed by 1kg of a substance, when heated to 1 °C. (see tab. 1 for the specific heat capacity of some sample materials). These values show that the ideal material for heat accumulation is water. For this reason, there is a demand for such a material that would approximately resemble the specific heat capacity of water. Research done in the accumulation area revealed that an optimal solution would be to store heat into a prefabricated, underground storage tank filled with recycled concrete (see figure 3). This is due to the fact that concrete generally possesses better specific heat capacity than the Earth; a direct result of its ever changing and non-compact material composition.

Tab. 1: Examples of specific heat capacity of different materials

Material	Specific heat capacity [J/kg.K]
Water	4,180
Dry air	1,010
Bricks	920
Concrete	1,020

Fig. 3: Recycled concrete

3 BTES VS. STES STORAGE – BASIC COMPARISON

Differing from water tanks, heat tanks labeled BTES are made by a set of tens to hundreds of boreholes similar to those made for ground-source heat pumps (max. depth 30m). These boreholes are spread out within a regular network enabling heat to be distributed and stored throughout the rock. BTES storages are still in the research phase. The goal of this work is to gain more than a 90% share of solar energy, of the entire heat consumption in buildings, during winter months. There is also an ongoing effort to make those storages economically acceptable in the Czech Republic for heating and hot water warming in residential areas. The storage design was based on data gained from the system, which has been operating for several years in the city of Okotoks in Alberta, Canada. Currently, this installation is technically the most sophisticated in the world in terms of mutual interconnection of long term BTES storage, buffer tanks, solar panels and heating systems [2]. This tank is based on the principle of ground heat storage.

The intention of the Canadian tank was to design the dimensions as an energy unit within buildings. It was not divided into any particular phases. There are 52 family houses connected to a local power grid in Okotosk. These are timber houses compatible with higher standard requirements according to R-2000 (regulation #268/2009 – Basic requirements for constructions). Total heat consumption for heating and water warming is around 20-30 MWh per year, depending on the size of the home [3].

STES (Synthetic Thermal Energy Storage) is based on a similar principle to the one in Canada, where climate and weather conditions are similar to that of the Czech Republic, aside from the fact that there are more sunny days in Canada than in the Czech Republic. The difference between STES and BTES storages is that the energy is stored in layers filled by recycled concrete. The decisive factors are the effective distance from the accumulator being charged, and the secondary heat energy being consumed. Another distinguishing factor is its shape, which will copy the most suitable ground plan and structure of neighboring buildings (see figure 4 - structure of 3 family houses). The entire complex is situated facing south.

3.1 STES system description

Large, seasonal storages require a large amount of energy. Thus, accumulator charging time, and reaching the desired affectivity, can take up to several years. Unlike the examples in Okotoks or Crailsheim, this system solution consists of only two parts:

- Solar energy collectors
- Energy center including STES storages

STES storage uses about 1,020 m^3 of recycled concrete and stratified heat exchangers. The storage system is designed to maintain the highest temperatures in its center, with the outer edges maintaining cooler temperatures [1]. In this way, it is possible to minimize distribution loss and maximize transported heat potential. STES is hexagon-shaped and flexible in size to enable random changes and adjustments for given conditions.

The storage is divided into several stratified layers. These layers store energy unevenly along the entire height of the ground tank. Heat energy from solar collectors is spread in short distributions to stratified STES blocks (see figure 5), where they transfer the energy to filling material. Since this is an underground tank, the entire STES surface is insulated and prevents unwanted heat loss. Houses that use this kind of energy must be designed with low-energy and in accordance with passive standards. These houses are called underground houses (covered on three sides, roof covered by soil and window openings facing south). Their effective energy consumption is lower when compared with ordinary, free-standing buildings in open spaces.

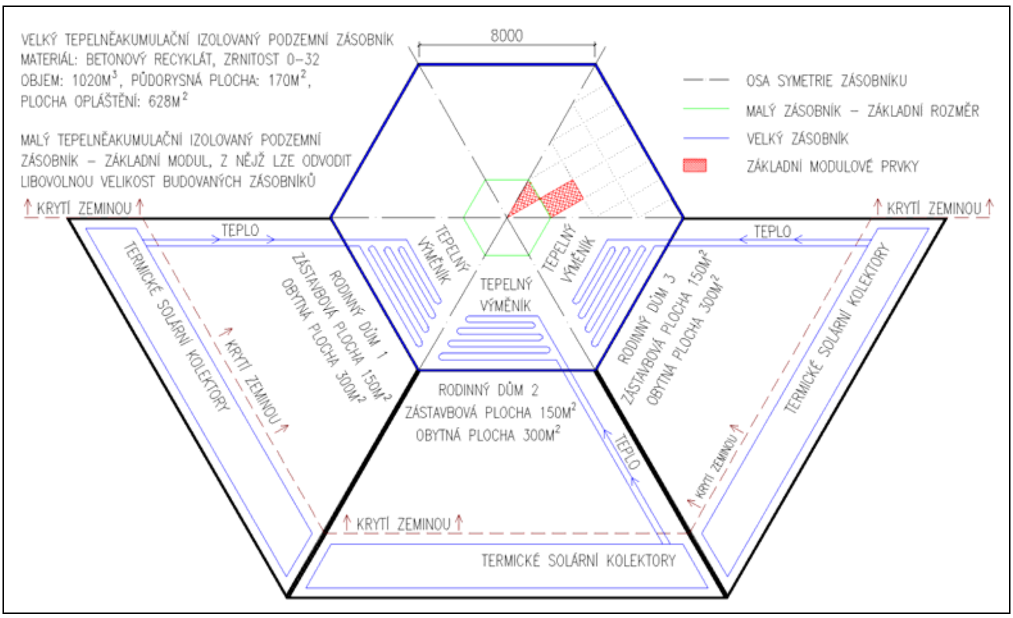


Figure 4: plan for STES storage and family home area

Solar collectors and their positions are shown in figure 4. Single collectors are strategically placed so as not to interfere with the building's character or architectural design, while meeting desired energy needs for hot water at 100% during the summer and 20% in the winter, or in cloudy weather conditions. The collectors transfer surplus heat capacity to STES underground heat storage tanks.

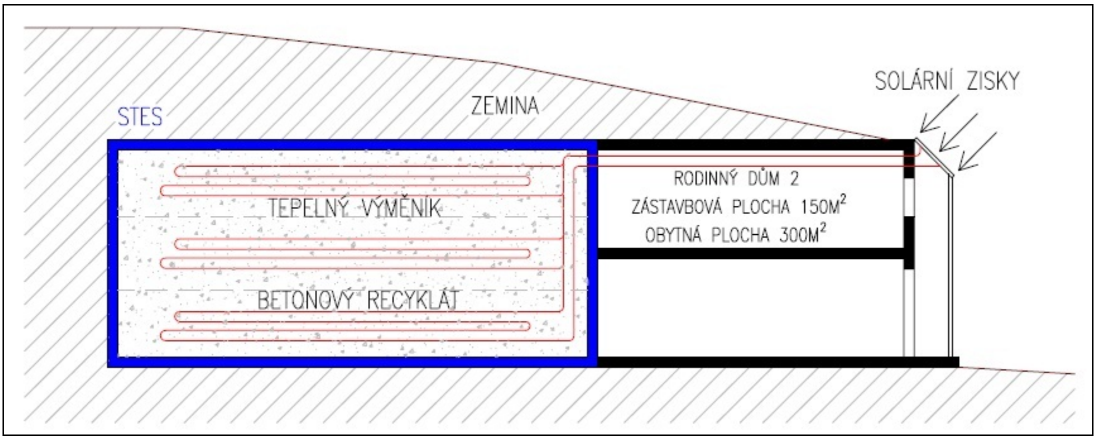
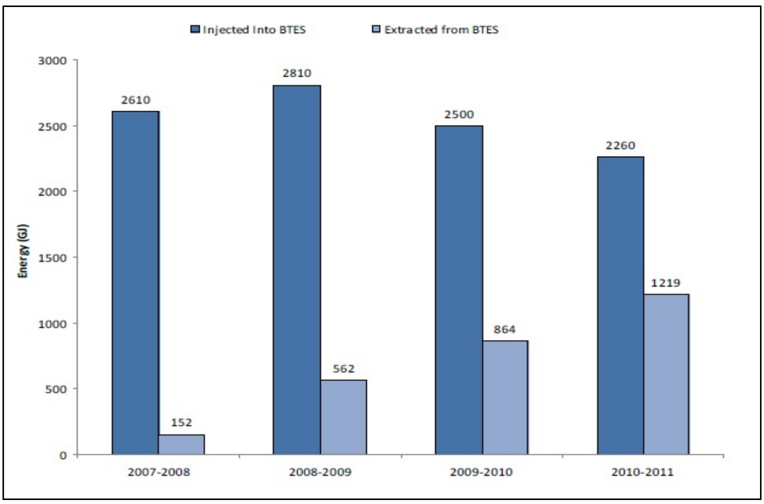


Figure 5: plan of distribution in stratified layers of a family home

4 STES STORAGE WORKING EFFICIENCY

The total capacity of the collectors represents about 200% of the need for water warming and heating. With low-energy homes, the ratio between the need of heat for water warming and the need of heat for heating is 100:100. For passive houses the ratio is 100:50. The resulting heat capacity of STES underground storage should cover 100% of heat energy consumption for water warming and 80% of heat energy consumption for heating three houses. The remaining 20% surplus represents the basic need for battery charging and gradual expansion of heat in the tank, similar to the tank in Okotoks. According to Canadian data, it appears that such handling of heat energy is more efficient than discharging the storage to a level of new storage.



Graph 1: The development of charging and discharging BTES storage in Canada [3]

Graph 1 shows the amount of energy delivered to the BTES storage tank and the amount of energy used in each year of service. These figures clearly reveal the gradual efficiency improvement of the accumulator. The efficiency rates of ground storage illustrate a rising trend due to the increasing temperature of storage material.

The humidity locked inside the storage has significant influence on its efficiency. The temperature of the core depends on the humidity in particular stratified layers. With each ensuing year of service, constant values of humidity are expected to be related to the average core temperature.

$$T_{core} = \frac{T_t + 2 \times T_m + T_b}{4} \qquad [°C][3] \tag{1}$$

where:

T_t = temperature in the upper area of the BTES storage [°C],

T_m = temperature in the middle are of the BTES storage [°C],

T_b = temperature on the bottom of the BTES storage [°C],

T_{core} = core temperature of the BTES storage [°C].

Generally, it is surmised that the determination of energy storage efficiency is the most problematic area of research, as is the observation of those devices. The environment designed for this objective is not ideally created to ensure that the working efficiency is in balance with the increase of energy stored in the tank.

5 CONCLUSION

A new, coherent conception of heat energy storage from alternative sources of heat, i.e. solar collectors, is a significant contribution. The overall contribution is in the development of conception of thermally insulated energy storage (STES). The storage has provable, homogeneous thermophysical, properties. The homogeneous structure of the inner volume of the tank is made of recycled concrete with steep, nearly straight, grain-size curves, which seem to behave most like rock mass. By insulating this area we get storage with measurable heat capacity, thereby making it possible to calculate the amount of accumulated heat. This method is progressively useful and cost-effective due to the minimizing of its volume.

The main advantage in the potential of a synthetic storage construction (directly connected to an appliance - a family home in this case), lies within its very short distribution system, which maximizes the use of STES heating potential. Another "breakthrough" is the fact that this STES storage can be built on any space with maximal variability for increasing or decreasing thermal energy needs. Compared with BTES storage, which is dependent on the specific heat capacity of rock mass, it is possible to build the STES storage tank in any environment or area.

The development phase of this task is far from complete. It is necessary to design a mathematical model of STES storage that will set the heat flux in particular phases of stratified layers. Thus, storage technology can develop to a level that is necessary for the creation of a real model.

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REFERENCES

[1] NAKORCHEVSKII, A. I., Dynamics of discharging of a heat accumulator in an infinite grand massif. *Journal of Engineering Physics and Thermophysics*. 2005, roč. 78, č. 6. ISSN 1062-0125. Dostupné z: http://www.springerlink.com/index/10.1007/s10891-006-0042-0

[2] ROZEHNAL, Zdeněk. Sezónní zásobník tepla šetří energii. *Stavitel*: *Měsíčník Hospodářských novin*. Praha: Economia, a.s, 2011, č. 10, s. 16. ISSN 1210-4825. Dostupné z: http://www.dpb.cz/soubor/sezonni-zasobnik-tepla/sezonni-zasobnik-tepla.pdf

[3] SIBBITT, Bruce and all., Measured and simulated performance of a high solar fraction district heating system with seasonal storage. In: *Www.ises.org* [online]. [cit. 2012-09-20]. Dostupné z: http://www.dlsc.ca/reports/ISES_SWC_2011_final.pdf

[4] Směrnice 2010/31/EU of the european parlament and of the council of 19 May 2011 on the energy performance of buildings

[5] TYMOVÁ, P., *Solární systémy v architektuře.* Sborník vědeckých prací Vysoké školy báňské – Technické univerzity Ostrava, řada stavební, 2007, roč. 7, č. 1. Ostrava : VŠB-TUO, 207, s. 233-236. ISSN 1213-1962.

[6] Wohnen mit der sonne. In: [online]. [cit. 2012-09-20]. Dostupné z: http://www.stw-crailsheim.de/fileadmin/images/web-service/pdfs/Solarbroschuere.pdf

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