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Utilizing Energy Piles as Cold Storages

Rauli Lautkankare*, Nikolas Salomaa** and Birgitta Martinkauppi***

*Turku University of Applied Sciences, Joukahaisenkatu 3, 20520 Turku, Finland

rauli.lautkankare@turkuamk.fi

**nollaE Oy, Tykistönkatu 4, 20520 Turku, Finland

***University of Vaasa, Wolffintie 34, 65200 Vaasa, Finland

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ABSTRACT

Energy piles are load-bearing structures that can be utilized as a part of thermal storage. They are used for both storing and collecting phases of storage operations. These piles have been recently used in underground parking hall in Turku, Finland as a part of thermal heat storage. The energy stored is renewable heat as it is obtained from solar collectors. However, energy pile systems have been mainly used for storing and utilizing heat. They have been sometimes used for natural indoor cooling because comfortable living temperature is just below or around 20 °C and ground temperature is low enough to be utilized for this purpose. Demand for cool has, however, increased in recent years due to heat waves and to growing need for cool and cold. Thus, the natural cooling may not be enough. As fossil fuel usage for producing cool and cold should be reduced, one solution is to make a storage for them. Thus, the goal of this paper is to study utilization of energy piles for low temperature storages integrated with renewable sources as to provide increased amount of cool and coldness and reduce use of fossil fuels.

1. INTRODUCTION

Energy piles can be used for providing support for residual, public or commercial buildings as well as for forming a thermal energy storage under a building (see e.g., Lautkankare et al. 2018, Lautkankare et al. 2014). The idea is to use the ground under a structure for storing thermal energy for later usage. The optimization of ground use is very important in city environments where the land is expensive and with limited availability. This also minimizes the construction work needed for ground as there is no need to build a separate storage.

Energy piles have been already subjected for both theoretical studies as well as real implementations. One of the recent implementations has been made in an underground parking hall in Turku, Finland (Lautkankare 2020). In this case, a renewable source (solar collectors) is used to provide renewable thermal energy to be stored for later use. There are also studies in other countries (Sani et al. 2019). Theoretical evaluations include analysis of soil (Sani and Singh 2020), use with solar energy (Ma and Wang 2020), use of cement (Nordbeck et al. 2020) and heat transfer (Kong et al. 2019). The studied and implemented energy pile storages are typically made for storing heat.

In addition of heating, residual, public or commercial buildings may also need cooling or cold to provide, for example, comfortable living (Comodi et al. 2016), food preservation (Carson & East 2018) or industrial processes (Mands et al. 2013). Some studies are already made for using certain aspects of energy piles for cooling and cold. The energy pile storages have been already suggested for both heating and natural cooling of a building with living comfort (e.g., Dupray et al. 2014, Kong et al. 2019, Hamada et al. 2007) and environments (e.g. He and Lam 2017 studied heating and cooling in China). Enhancing the performance of energy piles with PCM have been also researched, for example, by Olawoore 2020.

When the natural cooling is not enough, there are available several methods to cover the difference: cool or cold can be produced via electricity which can be from renewable sources like solar panels (Rad & Fung 2016). Collectors' surfaces can be used to radiate heat from the ground to the sky (Lhendup, Aye & Fuller 2012). There are already district cooling networks, but they require installation of long pipelines, cooling production plan and available land area (Inayat & Mohsin 2019). Instead of producing the cool or cold produced on the spot, storing is a possible solution. A storage can be natural or artificial and can provide a viable option e.g. to reduce use of electricity.. Natural cool storages include ground or aquifer systems in which the temperature is typically less than 12 ºC (Hendriks, Snijders & Boido 2008). If natural are not available, boreholes, bedrocks and other manmade storages can be utilized. Borehole, energy pile and bedrock cold storages are relatively little studied, e.g. by Nordell 2000, Hellström et al. 1997 or Martinkauppi et al. 2019.

As the need for cold and cool is increasing, so the storages under zero-degree temperatures have becoming more interesting. In this paper, we study elements of cold storage with energy piles. The goal is to provide a framework in which renewable energies are utilized as a source of electricity and cold. Novelty aspects of this paper are related to use of energy piles for creating an active cooling or cold storage.

2. GEOENERGY AND GEOTHERMAL ENERGY

In this article cold is mentioned as a meaning for thermal energy that has a temperature clearly below 20 °C which is the usual comfortable indoor living temperature. Utilizing cold ground for cooling purposes lower than 10 °C ground temperature would be reasonable enough to cool down buildings and keep the desired temperature efficiently at indoors.

It is well known that geoenergy can be used for cooling. Also, geoenergy can be enhanced or boosted as a source of cooling by charging the ground using significantly lower temperatures than the basic ground temperature is. Low temperature heat ie. cold can be charged into the ground using energy piles or boreholes. In other words, the same principle and technology is applied both in heating and cooling applications. Borehole thermal energy storage (BTES) system

Definitions and descriptions of geoenergy and geothermal energy varies in different parts of globe. In Nordic countries term geothermal is widely used to describe the deep geothermal systems and term geoenergy to describe shallow geothermal systems. According to Geological Survey of Finland geoenergy is thermal energy stored into a shallow ground, into earth's crust and its main source is solar energy. Shallow geothermal system's operational temperature is much lower than in deep geothermal energy systems. (Arola & all 2018) Basically, almost all the systems in Finland are shallow energy systems (depth < 400 m) and categorized as geoenergy.

Cold ie. low temperature thermal energy can be charged and stored into ground as well as higher temperatures. The purpose for storing heat or cold is basically the same: to boost or upscale the ground source heat pump (GSHP) efficiency in energy system. As the basic GSHP installation in a borehole system starts to operate close to ground temperature, upscaled systems ie. underground energy storages utilize hotter or colder energy sources to raise or decrease the basic ground temperature. Thus, upscaled systems have already a temperature closer to temperature demand.

Upscaling is typical in various seasonal thermal energy storage systems categorized as A-, B-, C- and D-TES. Upscaling and storing cold into ground are not as typical, but the principle stays the same respectively: colder resource supports the efficiency for cooling.

3. ELEMENTS OF ENERGY PILE STORAGE

Energy piles are naturally used in the storage. Fig. 1 displays an example of concrete pile as well as general image of the location of piles. The piles typically are from materials which are resistant to freezing. The other elements (cold source, storage material and circulating fluid) need to be selected suitably for the application.

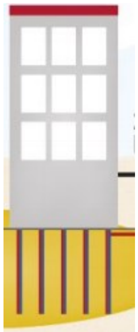

Figure 1. Left image: Energy pile made from concrete. Right image: energy piles are put under a building. (Source of the images: Rauli Lautkankare, presentation in Finnish, Link to presentation (tem.fi))

3.1. Storage material

Several materials can be used in cold storage. These materials can be water, clay, sand, wet and dry soil, and rock. They have different specific heat capacity which indicates varying potential of storing certain amount of cold. The specific heat capacity values are shown in Table 1 (The Engineering Toolbox).

Table 1. Specific heat capacity for certain substances (source: The Engineering Toolbox)

Substance	Specific heat capacity
Clay, sandy	1381
Ice (0°C)	2093
Granite	790
Sand, quartz	830
Soil, dry	800
Soil, wet	1480

All the materials in Table 1 are relatively cheap, abundant, and safe. Water is, of course, very cheap and useful material. It is well known that volume of water increases during freezing. This naturally happen to soil when it contains some water. The soil structure is affected by freezing and thawing (Gabrielsson et al. 1997). Whether the soil has been frozen before or not, may produce different results. For example, about 25 % deformation has been reported when testing previously unfrozen clay (Vähäaho 1989). Gabrielsson et al. 1997 tested freezing and thawing of clay up to -1 °C. This caused a deformation in the storage area. The pipes inserted in the clay should take some increase in pressure. Martinkauppi et al. cooled a dry borehole under zero-degree temperatures. As there was only a little water, the surrounding rock seems to be resistant to freezing.

Cold storage material should be selected in such a way that either there is little change in volume, or the design considers the volume change. Dry materials seem a possible choice for minimal volume change. Another option is to keep the storage in freezing condition all the time.

3.2. Circulating fluids

The minimum temperature which the storage material can be cooled is limited by the circulating fluid. Several different fluids are commercially available. One of the commonly used in Finland is bioethanol-water mixture. Other possibilities are betaine, ethylene glycol, methanol, potassium formate, and propylene glycol, potassium formate, and methanol. Methanol is generally not recommended because it is poisonous.

The fluids have varying freezing point (Table 2). The freezing point depends not only on the selected fluid but also on the mixture ratio, e.g., with 30 % of bioethanol, a freezing point of -17 ^{o}C can be reached. So, the choice must be made based on the targeted minimum temperature. There are also further limiting factors: needed viscosity, conductivity, and specific heat capacity of the fluid.

Table 2. Melting points of fluids. Some melting (freezing) points are shown for available mixture.

Substance	Melting point
Betaine (50 %)	-40 °C (Source: Fortum Ltd)
Bioethanol (90 %)	-114 °C (Source: Altia Ltd)
Ethylene glycol	−12.9 °C (Source: Wikipedia)
Methanol	−97.6 °C (Source: Wikipedia)
Potassium formate (50 %)	-60 °C (Source: Vesitekno Ltd)
Propylene glycol (50 %)	- 34 °C (Source: Telko ltd)

3.3 Sources of cold

In the Nordic areas, the winters are typically cold with several days under zero-degree temperatures. Thus, cold air cold as well as ice and snow are possible choices for natural cold source. The other possibilities are compressors, Peltier-phenomena, adsorption chillers, magnetic cooling (viuf 2018).

4. GENERAL STRUCTURE OF COLD STORAGE

The possible diagram for renewable cold storage is shown in Fig. 2. Renewable sources provides both cold and needed electricity. The cold to be put on the storage can be natural (e.g. cold air in Nordic countries) or made using renewable electricity like from PV. The control devices like pumps are used with renewable electricity. The renewable electricity can be from PV, wind turbine or hydroelectric power plant.

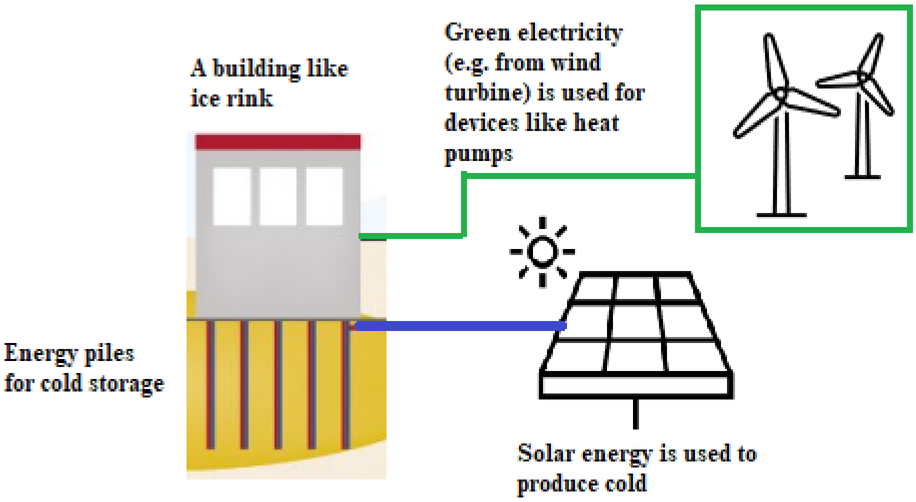

Figure 2. A possible diagram for a cold storage with energy piles and renewable sources.

5. CONCLUSIONS

The need for cooling and cold will be increasing in the future. They can be used for providing living comfort as well as cooling down commercial and public buildings, and in industrial application. This cold can be got via renewable sources and cold storages. Cold storages are needed to provide cool when it is not available or during peak consumption.

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