

Geothermal Source Exploitation for Energy Saving and Environmental Energy Production

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Abstract: Many European and some other developed countries have addressed the use of geothermal energy systems as a renewable source of energy worthy of investment and development. Geothermal energy is a non-intermittent and potentially inexhaustible source that can be used for energy saving and environmental energy production, as well as to provide heating and cooling to buildings, by increasing the energy efficiency of conventional systems. This editorial paper collects the most significant and recent studies, dealing with geothermal source exploitation, the possible role of geothermal systems in the building retrofit measures, the use of shallow geothermal sources, and specific aspects of systems that exploit geothermal energy.

1. Introduction

The use of energy diversification and the implementation of systems that exploit renewable energy sources is very urgent. The use of geothermal energy is of considerable economic and environmental value due to the exploitation of the natural heat of the Earth. The main feature of systems that exploit geothermal energy is their use for space heating and cooling with the resulting relatively low CO₂ emissions in the environment [1]. A large number of studies focus on the use of geothermal energy in heat pumps for air conditioning (ground-source heat pumps, GSHPs), which have a higher efficiency than those that use air and are also suitable for installation in locations with colder climates [2]. In [3], Calise et al. highlight how geothermal systems can be used in district heating and district cooling in fifth generation systems in order to reduce the primary energy demand of about 64% and to reduce CO₂ emissions by 76% by applying this system in a neighborhood of 50 buildings in the city of Leganés (Madrid).

In addition to active systems, geothermal energy can be used in passive systems through the use of buried pipes in which there is a heat exchange between the ground and another fluid, generally air (i.e., earth-to-air heat exchangers). These systems can be very useful as a passive energy saving strategy in buildings. In [4], D'Agostino et al. show how the earth-to-air heat exchanger can be used in different worldwide climatic conditions, both as a single system and as a component of an all-air conditioning system, by reducing the consumption for heating and cooling by 60%. Other applications of geothermal systems are developed identifying a combination of geothermal energy and solar energy in hybrid systems in trigeneration plants for production of electricity, space heating and cooling [5] but also for DHW [6]. There are numerous applications of geothermal systems in high energy efficiency buildings with the drawback of still having high installation costs and space problems for large-scale applications [7,8]. In addition to the high cost in numerous geothermal applications, the thermal and geological risk due to geothermal systems such as the installation of high-depth probes can lead to thermal instability because the loading and unloading phases must be considered [9].



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2. Research Papers Selected for This Editorial

A total of seven papers were selected regarding the topic of “*Geothermal source exploitation for energy saving and environmental energy production*”. The main ideas and conclusions of these papers are briefly reviewed in the following subsections.

2.1. The Role of Geothermal Systems in Buildings Retrofit

Most of the energy efficiency strategies are focused on civil buildings. However, in some cases, acting on existing civil buildings can be a great challenge as not all energy saving strategies are able to adapt to an existing construction. The following works show how the use of systems that exploit geothermal energy is also widespread for energy retrofit interventions on the existing building stock. Piselli et al. [10] focus on low-enthalpy geothermal energy systems as a retrofit strategy on a historic building. The authors exploit a geothermal heat exchanger (GHEX) coupled with an absorption heat pump for a rural building of a medieval complex located in central Italy that currently houses university offices and laboratories (Figure 1). The decision to use these innovative GHEXs is dictated by the fact that often drilling for vertical probes can lead to difficult and expensive operations, all this taking into account a lower efficiency compared to the vertical ones. The authors adopt a historical building information modelling (HBIM) approach that integrates the design phase with those of management and maintenance. In this case, the solution with the innovative geothermal probes arranged horizontally allows to obtain not only an energy saving but also internal comfort conditions. The results highlighted how the HBIM approach is optimal for the energy retrofit of historic buildings through the refurbishment based on a user-focused approach also thanks to a new facility management tool. In addition, the FM system facilitates design assessments, monitoring, and control at the same time of the energy needs and thermal comfort of occupants.

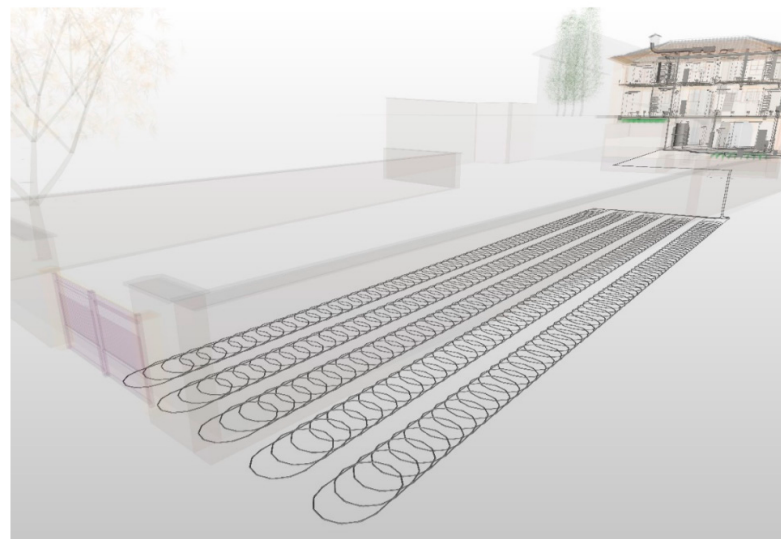


Figure 1. Designed location of the slinky ground source heat exchangers (GHEXs) with respect to the building [10].

A mapping of existing interventions on the heritage is instead made by Soutoulo et al. [11] through an innovative geographical information system (GIS) platform able to spatially map geographical, geothermal and solar characteristics to facilitate energy retrofit interventions carried out on the territory at the postal district level. In this research, starting from available cadastral data, buildings representative of energy consumption for air conditioning have been identified. An innovative aspect is the introduction in the mapping of buildings with particular characteristics that determine particular energy efficiency strategy interventions. Additionally, in this case, geothermal energy is a key point in the energy retrofit of existing buildings. In fact, the use of geothermal energy in the Asturias (Spain),

using a reference case study to test the GIS platform, is manifold. The results show how the mapping generated by GIS is useful in sustainable development strategies that combine geothermal energy with solar energy ensuring a beneficial action also on the economies of the countries since often a retrofit strategy is economically more convenient than a demolition and reconstruction.

2.2. Review on the Use of Shallow Geothermal Sources

Pająk et al. [12] present a review of the hydrogeological and geological data of the lower cretaceous aquifers in the Polish Lowlands. They examine the opportunities for the use of geothermal water resources both in new and existing district heating networks. In order to evaluate the potential use of the geothermal sources, the authors use several literature data about (i) the environmental and energy impacts of the adoption of low-enthalpy geothermal resources as heat sources for urban district heating networks and (ii) experience related to the use of thermal waters in existing geothermal systems. With this aim, they examine the characteristics of hydrogeothermal conditions in the area of Mszczonów, Uniejów and Poddebice. These areas are able to produce approximately 4 PJ of geothermal energy annually, useful to cover the heat requirements of local cities in a large part of Poland. However, to reach this aim, the authors also identify that the implementation of such solutions requires the improvement of specific aspects, such as: ensuring regulations and laws and financial support for the development and exploitation of geothermal resources; the public awareness through suitable education plans aimed at the youngest school children; and comprehensive and efficient energy management measures at the local, regional, and central levels.

Christodoulides et al. [13] present an overview describing the modeling characteristics of shallow geothermal energy systems (SGES) and the definition of the systematic guidelines related to their design, not well-defined in the literature. The authors highlight that SGES have recently garnered significant attention due to energy geo-structures (EGS), which result to be suitable for the heat exchange elements integration in geotechnical structures. In this work, the available modeling alternatives of SGES as well as their several practices and aspects are provided. The review also includes a quite lengthy subsection describing the most important software tools related to thermo-hydro-mechanical and thermal analysis of SGES that may be suitable for practical purposes. The authors describe both numerical models and analytical ones related to the SGES. The processes related to the thermal behavior of SGES were identified. Numerical models have the ability to achieve very high detail of modeling accountancy for phase change in soil due to freezing, variable boundary temperature conditions, pile internal components, and the thermal capacitance of pile inner materials. Analytical models that can be used for transient simulations were explained, describing in detail the infinite and finite line-source modelling and the cylindrical-source modelling. The authors also provide a list of the crucial factors affecting the modeling of SGES. In particular, the crucial factors that they identify are:

- the spatial dimensions, essential in case of infinite length assumption for short heat exchangers (see for example the case of energy piles);
- the boundary conditions, such as the heat flow or temperature variation temperature, affecting the predicted thermal behavior of SGES;
- the definition of specific parameters of SGES that may involve certain techniques to overcome practical problems;
- the comparison of a long- vs. short-term analysis depending on the thermal storage characteristics of ground heat exchange of different sizes;
- the groundwater effect, affecting the temperatures of fluid in both heating and cooling modes;
- the modelling of thermo-mechanical interactions in case of EGS considered both a heat exchanger and a structural element.

Miranda et al. [14] present a first-order assessment of the geothermal energy source for the sustainable energy development of the Canadian off-grid northern communities. The authors state that deep geothermal energy sources can be significantly important for

these communities, which are based almost exclusively on fossil fuels. Nunavik is home to 14 communities that are independent of the southern provincial electrical grid and rely exclusively on diesel for electricity, space heating, and domestic hot water, such as the majority of communities in northern Canada of Kuujjuaq. In order to infer the deep geothermal potential beneath, the community data related to the shallow subsurface as well as outcrop samples were used. To simulate the subsurface temperature distribution, heat conduction models with time-varying upper boundary conditions reproducing climate events were utilized. The evaluation of the subsurface temperature distribution was imperative to determine the available thermal energy accordingly with the volume method. Thus, 2D transient heat conduction models were solved numerically with the finite-element method (FEM). In the work, the determination of the main geological and technical uncertainties on the deep geothermal potential was carried out by the Monte Carlo-based sensitivity analyses. A risk analysis is also presented to forecast the future energy production. The achieved results, even though theoretical, show that the old Canadian Shield beneath Kuujjuaq hosts the potential to fulfill the community's annual average heating demand of 37 GWh. In particular, the probability of meeting the estimated heating demand is higher than 98% at a depth of 4 km and below. Hence, deep geothermal energy may be a favorable solution to help the energy transition of isolated northern communities. The approach adopted in this work can be applied to other remote areas facing the same off-grid challenges, such as Svalbard, Faeroe Islands, Greenland, and other Arctic and non-Arctic communities.

2.3. Other Topics

Other works focus on more specific aspects of systems that exploit geothermal energy. Zhang et al. [15] focus on the high exploitation of geothermal energy in the deep mineral resources and its implication in local phenomena of energy decompensation with consequent high temperature and thermal risk in the ground. In their research, the authors resort to a thermal filling accumulation consisting of phase change materials (PCMs) (Figure 2). Through a heat-exchange model, the heat accumulation/release phases were analyzed, obtaining the temperature distribution in the filling carried out with PCMs. The result of this research is a guide for the exploitation of geothermal energy of deep mineral resources by quantifying the optimized filling content added with PCMs, which has excellent mechanical properties and good heat storage/heat release characteristics, also highlighting the temperature distribution of a backfill body for different conditions.

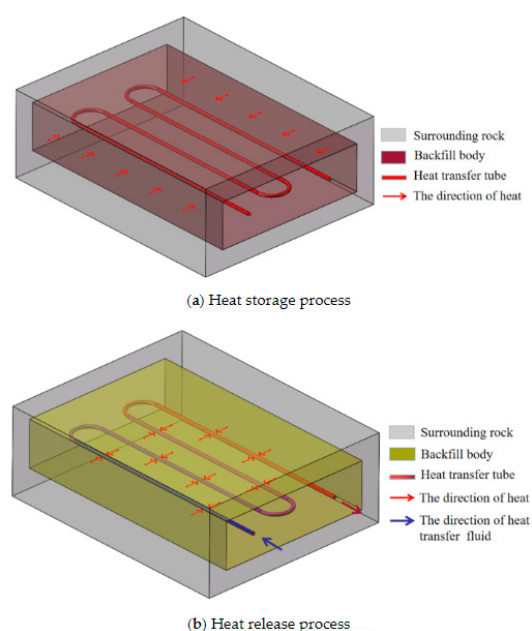


Figure 2. The working process of the phase-change heat storage backfill body.

Geothermal stress phenomena due to the presence of perforations for geothermal probes have been detected by Xing et al. [16] through a scientific injection campaign conducted at the site of the Utah Frontier Observatory for Geothermal Energy Research (FORGE). Numerous tests conducted on the well for different depths have shown that the closing stress increases with the speed/volume of pumping. It is also noted that the presence of natural fractures at the site can play a fundamental role in the closure stress and have important implications when moderate volumes of fluid at high temperature are injected into the already fractured reservoir.

In conclusion, both works highlight how the use of technologies that exploit geothermal energy requires an accurate assessment of all boundary conditions that can generate geothermal stress phenomena.

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