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Scientific achievements and regulation of shallow geothermal systems in six European countries – A review

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ABSTRACT

The aim of this paper is to review the recent scientific literature concerning geothermal heat pumps and the existing regulations and/or technical guidelines in selected European countries. Focus was put on the environmental effects caused by open- and closed-loop vertical systems. Research was narrowed down to authors with affiliations in the European Union and scientific results of five countries were discussed in detail. Legislation is viewed in perspective of the scientific findings.

Numerous articles were found that may provide valuable information for improving the existing regulations and recommendations. Performance issues correlate with negative environmental effects therefore solutions for efficient operation support sustainability, too. However, licensing procedures are versatile and new research results seem not to be implemented in the rules.

A legislative framework is suggested on a European Union level that gives a unified definition of shallow geothermal systems, preferably on enthalpy basis, and lays down the principles of permitting process and criteria for sustainable GHP systems based on scientific results tolerating differences due to local geological and hydrogeological properties. A clear distinction of low-risk systems is desirable to aid the simplification of administrative procedure.

1. Introduction

Direct use of geothermal energy is increasing worldwide. In this article the focus is on the utilization of shallow geothermal energy, the type where heat pumps are required to transform the lower, directly not usable ambient temperature to a suitable, higher temperature for the internal heating circuit by investing energy. In case of floor and wall heating this temperature is around 35 °C [1], while in case of radiator heating it is between 55–65 °C [2], the latter being close to the maximum that can be provided by a heat pump.

Based on the report of the World Geothermal Congress in 2010 [3] the overall capacity had increased by 1.72 times between 2000 and 2009 while the capacity of geothermal heat pumps had boosted by 6.28 times. By 2014 these numbers are 4.64 and 9.46 for total and GHP capacities respectively (2000 being the base) [4]. It has to be mentioned though that these numbers were based on estimates since in several countries (e.g. Germany [5], Denmark [6], Slovenia [7] and Hungary [8]) no national statistics were available. It is possible that the number of installed systems was even higher.

The various heat pump systems can be categorized according to the phases of the heat transfer media (GHPs belong to the water-to-water category, other solutions would be air-to-water, water-to-air and air-to-air heat pumps,) [9] or to the connection with the ambient heat source, i.e. open- and closed loop systems.

Open-loop geothermal heat pumps (Table 1) are those systems, where the utilization of the ambient heat source goes together with the displacement of the original medium (that is, the ambient heat source is circulating) [10]. Usually, the required quantity of fluid is produced by the help of a well; then utilized energetically in the heat exchanger of heat pump and at the end of the process it is injected back into the preselected reservoir. For the terms of long-term operation safety the produced water should be introduced back to the original reservoir [11].

In practice, the most commonly used systems are well-doublets, because groundwater is available in most places. Nonetheless from a hydro-geological point of view the extraction and the reinjection raise several operational safety issues [12]. The one well system presented in Table 1 is not a widespread solution; Rode et al. [13] made a feasibility study.

In case of closed-loop geothermal heat pump systems (Table 2) the utilization of the ambient heat source goes directly without the displacement of the original medium. The heat is transferred by a fluid circulating in the loop deployed in the ambient heat source [14]. The different types may have many geometric designs

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Nomenclature

ASHP	Air Source Heat Pump
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers founded in 1959
BHE	Borehole Heat Exchanger
BTES	Borehole Thermal Energy Storage
CaRM	Computational Capacity Resistance Model
CFD	Computational Fluid Dynamics
CHP	Combined Heat and Power
COP	Coefficient of Performance
EGS	Enhanced Geothermal System
FEFLOW	Finite Element subsurface FLOW system
Fo	Fourier number
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GHP	Geothermal Heat Pump
GIS	Geographic Information System
GSHP	Ground Source Heat Pump
GWHP	Ground Water Heat Pump
HDR	Hot Dry Rock
HDPE	High-density polyethylene
HVAC	Heating, Ventilation, Air Conditioning
LCA	Life Cycle Analysis
MLAA	Multiple Aggregation Algorithm
nZEB	Nearly Zero-Energy Buildings
ORC	Organic Rankine Cycle
Pe	Péclet number
Re	Reynolds number
RSME	Root Mean Square Error
SGE	Shallow Geothermal Energy
SPF	Seasonal Performance Factor
TAZ	Thermally affected zone
TRT	Thermal Response Test
UNI	Ente Nazionale Italiano di Unificazione - Italian Organization for Standardization
UTES	Underground Thermal Energy Storage
VDI	Verein Deutscher Ingenieure - Association of German Engineers – standards association

(with U-, S-, helix- etc. shape); however, in terms of their operation they are the same.

The closed-loop systems may be divided into two main types: vertical and horizontal heat exchangers. The Borehole Heat Exchangers (BHE)-the most commonly used solutions - are placed into vertical holes and usually made of hard plastic (HDPE) loops of tubing [15]. The loops may be for example single U-type, double U-type, simple coaxial or complex coaxial versions with 50–150 m typical installation depth [16]. In case of energy piles the heat exchangers are placed in the load-bearing structure of the buildings. In exceptional cases they are installed separately in the ground if this solution is more economical [17]. The most widely used material is concrete [18], but research has shown that other materials are available for better performance, too [19]. Thermal response tests are commonly used for optimal borehole heat exchanger design [20]. If there is a lake with suitable size and depth near the heated object, the ambient side heat exchanger can be placed into the lake. In most cases, the heat exchanger is strengthened helically onto a support structure, which is placed down to 1.8–2.4 m under the surface of the lake [21]. Their advantage compared to BHE system that high drilling costs are saved [22].

The pipes of horizontal heat exchangers are laid out to a depth of 1.5–2 m [23]. Because of the horizontal design their space requirement is significantly higher than other technologies [24]. The tubes may be coiled up to save space. In this case the specific performance is more favourable because of the higher pipe length per unit area [25]. A similar solution is called flat panel where the pipe is organized into a series of loops like a labyrinth [26].

The shallow geothermal systems are suitable for active or passive cooling during summer. This solution is closely linked to the underground thermal energy storage (UTES) technique because this way excess heat is stored. In the case of vertical system with borehole thermal energy storage (BTES) the field can be regenerated [27], thereby increasing the value of the heating COP.

Fig. 1 shows the different types of geothermal heat exchanger technologies. On the left, in green frames, the open-loop technologies are shown, such as double well system, or production well with surface water discharge system or lake system. The closed-loop systems are marked with blue frames. Horizontal solutions include horizontal loop, slinky and coil heat exchanger. From the vertical design systems pond heat exchanger, energy pile, and borehole heat exchanger are illustrated. The heat pump of the heat exchanger shown in the figure; depending on local conditions; can be connected to any solution, coupling the system with solar panels may further improve the efficiency.

In the European Union the main driving force to propagate the spread of geothermal energy utilization is the Directive 2009/28/EC on the promotion of the use of energy from renewable sources [28]. It introduced the National Renewable Energy Action Plans that had to be prepared by each Member State describing the means of increasing the ratio of renewable energy compared to the overall energy consumption by 2020. The transition towards renewable energies is said to be advantageous from an economic point of view, too, by inducing GDP increase and improving energy security [29]. The report of the Joint Research Centre on the status of geothermal energy in 2014 [30] provided information on the progress in this area. Data show that though the 2012 target for shallow geothermal capacity was exceeded by 43%, the reported capacity is only 55% of the 2020 target value; thus, further installations are needed leading to more intense use of the shallow reservoirs. Nonetheless there are limitations for exploitation because the potential may vary by area for very shallow (up to 10 m below ground) [31] and also for geothermal resources in deeper regions [32]. Additionally, geothermal energy is renewable only if overexploitation does not occur. Ideally thermal response tests are carried out to assist the correct design of such systems [33] to avoid that. Recovery rate of different geothermal energy utilization schemes collected by Rybach [34] is shown in Table 3. Since the use of geothermal energy clearly has environmental side-effects even for shallow geothermal energy (changes of temperature [35] thus influencing microbial activities [36] and altering flow patterns [37]) it is regulated in numerous countries.

In 2010 Hähnlein et al. [38] prepared an overview of the legislation concerning geothermal heat pumps in 60 countries worldwide. Their results showed great diversity for minimum distances and temperature thresholds. European countries were among the more regulated countries but even in these cases the static limit values seemed to lack scientific background. Special care has to be taken in vulnerable areas such as the Alpine region to preserve the natural and cultural values while satisfying energy demands [39]. Additionally, the local climate defines whether the system in question is heating- or cooling-dominated [40] thus determines the optimal configuration of integrated systems.