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Review on shallow geothermal promoting energy efficiency of existing buildings in Europe

Zhengxuan Liu[a,b*], Queena K.Qian[a*], Henk Visscher[a*], Guoqiang Zhang[b*]
[a]Faculty of Architecture and The Built Environment, Delft University of Technology, Julianalaan 134, 2628, BL, Delft, the Netherlands
[b]College of Civil Engineering, National Center for International Research Collaboration in Building Safety and Environment, Hunan University, Changsha, Hunan, 410082, China
Corresponding author: Z.liu-12@tudelft.nl; K.Qian@tudelft.nl; H.J.Visscher@tudelft.nl; gqzhang@hnu.edu.cn

Abstract: The energy-saving renovation of existing buildings has been attracted sufficient attention to reduce fossil fuels and mitigate global warming in Europe. The shallow geothermal for building cooling and heating, as an environmentally-friendly and cost-effective alternative, has been widely explored to promote energy efficiency of existing buildings. However, few studies conduct the comprehensive overview on the applications, developments, and existing issues of shallow geothermal promoting energy efficiency of existing buildings (SGPEEEB) in Europe. The objective of this paper is to review the current application status and future trends of SGPEEEB in Europe. First, the common utilization forms and classifications of used shallow geothermal technologies are introduced to further clarify the investigated subject. Then, the research and application status of SGPEEEB has also analyzed and discussed. At last, this study proposes the future trends and comments of SGPEEEB in Europe.

Keywords: Shallow geothermal; Energy efficiency; Existing buildings; Application and development; European countries

1. Introduction

Approximately 40% of energy consumption in Europe is related to buildings [1, 2]. Thus, the building sectors are crucial for achieving the energy and environmental goals of carbon-neutral by 2050 in Europe [3, 4]. However, the majority of buildings in Europe are currently built more than 20 years with low energy efficiency standards designed at the time of construction, resulting in many existing buildings with significant energy consumption [5]. In recent years, a plenty of studies and practices on the energy-saving renovation of existing buildings have been conducted to properly address the above-mentioned issues in Europe. For example, at the end of 2020, the European Commission presented its Renovation Wave Strategy as part of the European Green Deal [6]. The Renovation Wave Strategy contains an action plan with specific regulatory, financing and enabling measures to promote the building renovation using the renewable energy technologies [7].

Shallow geothermal (SG), as one of the most common renewable energy technologies, has been widely used and explored for building heating/cooling and carbon-neutrality transitions in the practical application [8, 9]. SG refers to underground heat resources that are generally less than 200 m depth, and is also defined as near-surface geothermal energy [10, 11]. SG is not geographically restricted, and it can continuously and reliably supply energy anywhere in the world [12, 13]. However, most European countries are looking to significantly expand the SG utilization as they pursue heating and cooling decarbonization policies. To achieve this objective, the "European Geothermal Market Report 2020" reaffirms that SG requires supportive policies, carbon pricing and fair competition to end fossil fuel subsidies, a smooth licensing and permitting framework, as well as investment in innovation what could play a decisive role in energy transition. SG can be used in a rational manner to directly and effectively reduce building energy consumption and CO_2 emissions. However, SG technology is different from the common energy-saving retrofit technologies (e.g., wall insulation, and window updates), and its promotion and implementation processes not only need to take into account the impact of economic factors and the recognition of different energy-saving retrofit entities, but also the application potential and applicability of SG in different regions, so they often have more complicated implementation conditions and influencing factors [14].

The literature review suggests that there is still a wide research gap and thus a strong need to systematically investigate and analyze the current research and application situation of shallow geothermal promoting energy efficiency of existing buildings (SGPEEEB) in Europe. The objectives and contributions of this paper include: i) summarizing the common utilization forms of appropriate SG technologies in Europe; ii) investigating the implementation and development status of SGPEEEB in Europe based on the literature and policy documents from the official website; iii) analyzing the faced multiple barriers and existing issues for SGPEEEB in Europe; iv) proposing rationalized addressing suggestions and future recommendations for SGPEEEB in Europe.

2. Common utilization forms of SG technologies

The essential characteristic of SG systems is to provide a relatively stable heating and cooling source, without being affected by seasonal climatic variations [15, 16]. In fact, at a depth of several meters, the ground temperature has the additional advantage of remaining almost constant throughout the year [17, 18]. The ground temperature is usually higher than the outside air in winter and lower in summer, so the energy efficiency index of SG systems is generally higher than that of air-source heat pumps [19]. Geothermal heat pumps have been demonstrated to decrease energy consumption by 30-70% in heating mode and by 20-50% in cooling mode compared to conventional solutions [20]. Nowadays, they have become the main renewable energy technologies to achieve zero carbon emission in the building sectors in Europe and even worldwide. Based on the characteristics of heat exchange medium (gas or liquid) in the buried pipes of SG systems, these systems can be divided into earth-to-air heat exchange (EAHE) systems using flowing air as the heat exchange medium and ground source heat pump (GSHP) systems using liquid as the heat exchange medium, such as water[13, 21, 22].

EAHE system is also called geothermal ventilation system, soil to air heat exchanger, air to soil heat exchanger and tunnel ventilation, etc., which is mainly composed of one or multiple subterranean buried pipes, through which the outdoor air is heat exchanged with the relatively stable soil temperature [23]. The cooled or preheated flowing air is sent to the building through the fan, thus realizing the building cooling in summer or preheating in winter to achieve thermal comfort of indoor environment [23-25]. According to the forms of buried pipes, the common used EAHE systems can be divided into horizontal-buried pipe and vertical-buried pipe systems [26, 27], as shown in Figure 1. The horizontal-buried EAHE system mainly refers to the one with buried pipe depth of 2-4 m, and the typical length of buried pipe is in the range of 30-100 m [28]. A large basement pit needs to be excavated first, and the buried pipe inside the pit is almost in a horizontal position. However, the minimum slope of buried pipe should not be less than 2.5% to eliminate the condensation that may form on the pipe wall during system's summer operation [11]. Vertical buried-pipe EAHE system is a newly proposed SG ventilation system, and its buried pipe generally adopts U-shape form [29]. The advantages of vertical-buried pipe EAHE compared with horizontal-buried pipe system include: 1) it has a smaller footprint (generally less than 1 m^2) and does not require larger foundation pits and construction sites, therefore it is more suitable for existing buildings in Europe [30]; 2) the depth of buried pipe is generally 15-30 m (considering the construction complexity), therefore it has a more stable soil temperature, relatively high heat transfer efficiency and less requirement for the topography of the construction site [31, 32]; 3) the slope of vertical-buried pipe EAHE system is 90 degrees, so the condensate generated during the system operation in summer could be quickly concentrated at the bottom, which can be discharged through the pump in real-time [33, 34]. Therefore, the wall of vertical-buried pipe EAHE system will not be adhered to the condensation for a long time, thereby avoiding the problems of germs caused by the condensation adhering to the pipe wall of traditional horizontal EAHE system for a long time [24]. As a result, vertical buried pipe EAHE system can provide more stable, comfortable and clean air supplying to building compared with traditional EAHE system. However, the existing practices also demonstrates that the vertical-buried pipe EAHE system, as a new type of SG utilization system, has relatively high construction cost due to the lack of mature construction and installation methods [33, 34].

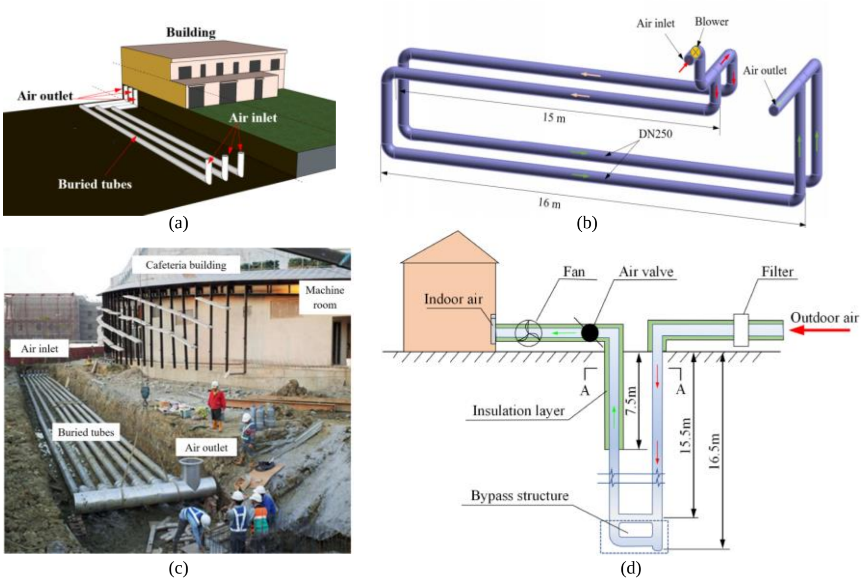

Figure 1. Common utilization forms of EAHE systems: (a) Multi-row horizontal-buried pipes; (b) Multi-layer horizontal-buried pipes (Modified from [35]); (c) Single inlet and outlet multi-row horizontal-buried pipes (Modified from [36]); (d) U-type vertical-buried pipes (Modified from [37]).

GSHP system is to use geotechnical body, stratum soil, groundwater or surface water as the heat/cooling source of heat pump system. It is a technology to realize the transformation of low-grade heat energy to high-grade heat energy by using a small amount of high level electrical power [38, 39]. The common GSHP system can be used for building heating and air conditioning, and also for domestic hot water. This one system can replace two units or systems of the original boiler plus air-conditioning. Especially for buildings with both heating and cooling requirements, GSHP systems have some obvious advantages. According to different cooling and heating sources, GSHP systems can be classified into water source heat pump (WSHP) systems and soil source heat pump systems (SSHP) [40, 41]. The common utilization types of GSHP systems are specifically shown in Figure 2.

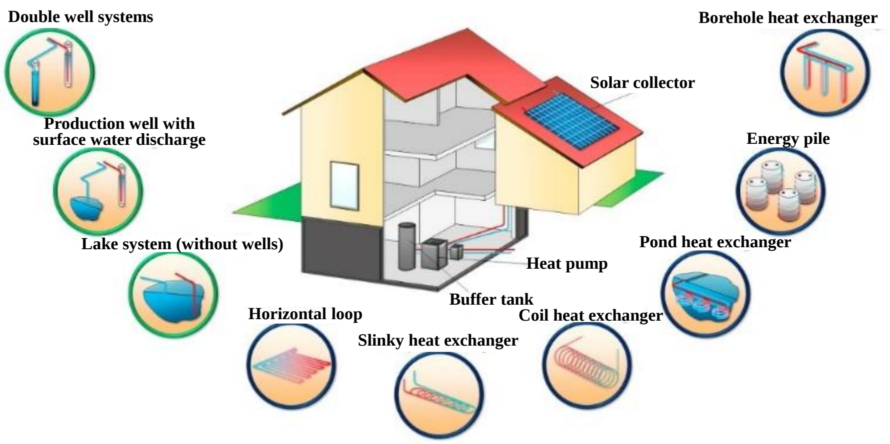

Figure 2. Common types of GSHP system (Reprinted from [42], Copyright with permission from Elsevier).

WSHP as one of the most geothermal utilizations, which utilizes low-grade thermal energy resources formed by solar and geothermal absorbed from shallow water sources (e.g., groundwater, rivers and lakes), and achieves the transformation of low-grade to high-grade thermal energy [43]. However, its application using groundwater or surface water as the heat (cold) source is limited by the hydrogeological conditions, especially in most European countries where the water resources policy requirements have become increasingly stringent in recent years, and therefore their application has been further restricted [44, 45]. SSHP system has been recognized as the most promising GSHP technology due to its energy efficiency and environmental friendliness independent of groundwater conditions [46]. Horizontal-buried pipe GSHP system mainly refers to placing plastic pipes at a depth of about 2 m, and generally has a large footprint, large excavation volume, and underground heat exchangers are affected by surface climate change [47, 48]. Compared to horizontal-buried pipe GSHP systems, the vertical-buried pipe GSHP systems are usually installed at a depth of 50-150 m. It mainly consists of one or more buried pipes connected to the heat pump unit. When the vertical SSHP system operates, it does not consume or pollute water, without boilers, without cooling towers, and without sites for stacking fuel waste, and thus it has remarkable environmental benefits [49]. Therefore, vertical-buried pipe GSHP systems have been the main form of geothermal systems, and well supported by government departments in many European countries.

3. Research and application status of SG technologies

SG is a prospective low carbon alternative to meet the heating and cooling requirements of buildings, which has been one of the most commonly installed renewable energy systems in many European countries [9]. Over the past decade, the main driving forces of promoting the utilization of SG are the Directive 2009/28/EC regarding the encouragement of renewable energy applications in Europe. It presents the National Renewable Energy Action Plan that is mandatory for each participating member state, which also delineates the methodology for increasing the ratio of renewable energy application to total energy consumption up to the year 2020 [42]. In 2021, the European Geothermal Council called on the European Commission to guarantee more funding to support innovative renewable energy applications, including SG technologies [50].

Over the past few years, the increasing installation of SG systems throughout EU has demonstrated the necessity of establishing a specific and detailed legal framework. Tsagarakis et al. [51] conducted an in-depth investigation for fourteen European countries (i.e., Croatia, Cyprus, France, Greece, Italy, Latvia, Lithuania, Poland, Portugal, Serbia, Slovenia, Spain, Sweden, and Turkey) to provide an overview on the legislative aspects of SG applications within the European perspective. The results showed that legislative provisions, as well as regulations, standards and institutional support, were significantly different across the European countries. Somogyi et al. [42] also suggested a legislative framework at the EU level with a uniform definition of SG systems, preferably based on enthalpy. Also, the permitting process and criteria for sustainable SG systems should be developed based on scientific results to accommodate differences due to local geographical and environmental conditions. About the practical application of different geothermal system for the energy efficiency of existing buildings, D'Agostino et al. [11] compared and analyzed different retrofit strategies using two different geothermal systems (i.e., GSHP and EAHE systems) and common heating and cooling systems (e.g., air source heat pump systems). A comprehensive comparison was also carried out from the energy, environmental and economic perspectives. The statistics indicated that the utilization of the low-enthalpy geothermal system resulted in more primary energy savings relative to the pre-retrofit building, with specific energy savings of 61% using only EAHE system, 67% using only GSHP system and 71% using the combination of EAHE and GSHP systems.

In Europe, Finland is one of the northernmost countries to promote the implementations of geothermal system for energy efficiency of existing buildings, and the operating conditions for GSHP systems are characterized with an extremely cold climate and rock-hard crystalline bedrock. Therefore, the implementations of SG technology in Finland present more challenges, including environmental risks and technical issues. The similar situations also can be found in other northern European countries. Majuri [52] investigated the typologies and construction practices of underground heat exchangers in Finland, as well as the problems encountered by practitioners during the design and construction of underground heat exchangers. Results indicated that the borehole heat exchanger was the most preferred type of underground heat exchanger in Finland, accounting for 85% of SG utilizations.

4. Main barriers, future trends and recommendations

The existing studies have carried out a considerable amount of analysis and discussions on improving the performance of SG systems and promoting their application in buildings from different perspectives. However, the current application percentage of SG systems in the energy efficiency of existing buildings is still not high. The representative issues include: i) although governments of different countries have made significant improvements in promoting SG technologies, there are still relatively feeble policy support and financial subsidy policies [53, 54]; ii) in order to carry out projects or obtain government policy support for SG technology, and this technology has been exaggerated as an inexhaustible renewable energy system that can be used in any regions, without regard to its scientific and applicability conditions; iii) the policy uncertainty together with the lack of defined decarbonization pathways and technology uptake are considered to be a major barrier for SG application [55].

In addition, the issues of public acceptance and willingness also present significant challenges to SG technologies, which originate from unwarranted apprehensions, misconceptions, misinformation and previous experiences regarding the reliability of GSHP systems, i.e., previous perceptions of shortcomings for SG applications [56]. The awareness of geothermal technologies can also be increased through people's daily activities, such as energy saving and environmental protection, reusing and recycling, and energy conservation in their houses. The awareness-raising efforts should focus not only on public awareness but also on the awareness activities of those professionals who are actively involved in the field of building construction and the installation of heating/cooling systems. The government's support to strengthen the policies on SG should be intensified, as well as establishing perfect encouragement policies and technical approval, and supervision and management mechanisms of SG application for energy efficiency of existing buildings in different regions. SG applications should be promoted from various aspects, e.g., promotion mode, technology innovation, regulation development and government subsidies.

5. Conclusions

This paper provides an overview on current application status, challenges and future trends of SGPEEEB in Europe. First, this paper summarizes the common utilization forms of appropriate SG technologies, including the EAHE system using flowing air as the heat exchange medium, and GSHP system using liquid as the heat exchange medium. Second, this paper investigates the current status of SGPEEEB in Europe based on the literature. Third, this paper analyzes the faced multiple barriers and existing issues for SGPEEEB in Europe. Last but not least, this paper proposes some rationalized addressing suggestions and future recommendations for SG application in Europe, including strengthening related existing policies, establishing perfect encouragement measures and technical approval, and improving public participation awareness, etc. These findings could provide some fundamental references to effectively promote the application of SG for energy efficiency of existing buildings in Europe.

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