Perspectives of Geothermal Climatization in Brazil: Benefits and Challenges

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RESUMO: A climatização geotérmica é destacada globalmente como uma alternativa sustentável e eficaz para o condicionamento térmico de edificações. Estudos recentes têm se dedicado a explorar a viabilidade de sua implementação em larga escala no Brasil. Por isso, o objetivo desta pesquisa foi realizar uma revisão de literatura abordando características, benefícios e desafios da climatização geotérmica no contexto brasileiro. A metodologia incluiu uma pesquisa bibliográfica minuciosa, selecionando estudos relevantes publicados nos últimos dez anos, seguida de uma análise crítica dos dados obtidos. Os resultados destacaram a redução significativa no consumo de energia, na poluição sonora e nas emissões de Gases de Efeito Estufa. No entanto, foram evidenciados desafios como custos de instalação elevados, a falta de incentivos financeiros, a escassez de conhecimento sobre seus benefícios e o contexto regulatório incipiente representando barreiras significativas para sua adoção. O reconhecimento dessa tecnologia no país é crucial para orientar decisões informadas que promovam o conforto térmico e contribuam para os Objetivos de Desenvolvimento Sustentável da Organização das Nações Unidas que devem ser alcançados até 2030 e com as metas estabelecidas pelo Brasil no Acordo de Paris, visando a transição para uma economia de baixo carbono.

PALAVRAS-CHAVE: Climatização geotérmica, caracterização, benefícios, desafios, eficiência energética.

ABSTRACT: Geothermal climatization stands out globally as a sustainable and effective alternative for thermal conditioning of buildings. Recent studies have been dedicated to exploring the feasibility of its large-scale implementation in Brazil. Therefore, the aim of this research was to conduct a literature review addressing the characteristics, benefits, and challenges of geothermal air conditioning in the Brazilian context. The methodology involved meticulous bibliographic research, selecting relevant studies published in the last decade, followed by a critical analysis of the obtained data. The results highlighted a significant reduction in energy consumption, noise pollution, and greenhouse gas emissions. However, challenges such as high installation costs, lack of financial incentives, scarcity of knowledge about its benefits, and an incipient regulatory framework were evidenced, representing significant barriers to its adoption. The recognition of this technology in the country is crucial to guide informed decisions that promote thermal comfort and contribute to the United Nations Sustainable Development Goals to be achieved by 2030, as well as the targets established by Brazil in the Paris Agreement, aiming at the transition to a low-carbon economy.

KEYWORDS: Geothermal climatization, characterization, benefits, challenges, energy efficiency.

1 INTRODUCTION

The construction sector exerts a significant impact on the environment, accounting for approximately 40% of global greenhouse gas emissions (International Energy Agency; United Nations Environment Programme, 2018) and 35% of worldwide final energy use (United Nations Environment Programme, 2020). With population growth (United Nations, 2019) and the increasing purchasing power of emerging economies, a 50% increase in global energy demand is projected by 2060 (International Energy Agency, 2017). This demand is largely attributed to the operational phase of buildings, which includes activities such as cooling, heating, ventilation, lighting, and appliance use, as reported by the United Nations Environment Programme (2009).

It is important to note that in tropical climates like that of Brazil, energy consumption for HVAC (Heating, Ventilating and Air Conditioning) can exceed 50% of a building's total energy consumption (Chua *et al.*, 2013). Data from 2017 revealed that electricity consumption by this system represented 17% of the total consumption in Brazilian households (Empresa de Pesquisa Energética, 2018).

Moreover, in recent years, the issue of renewable energy has become crucial to ensuring a sustainable future, given concerns about global warming and the energy crisis. In response, in the Paris Agreement, ratified by Brazil in 2015, the country committed to reducing its greenhouse gas emissions by 37% by 2025, based on 2005 levels, and by 43% by 2030; and to achieve 45% renewable energy use by 2030 (Federative Republic of Brazil, 2015).

Given this scenario, researchers have been focusing their efforts on the development and enhancement of more efficient technologies to reduce the environmental impact of the operational phase. In Brazil, geothermal climatization has emerged as a promising solution to address this challenge. Recent studies have explored its implementation in the country as a strategy to mitigate excessive energy consumption and greenhouse gas emissions associated with conventional heating and cooling systems (Mazzutti; Faro; Klamt, 2023).

This technique is already a reality in European and North American countries, harnessing shallow geothermal energy as a source and/or reservoir, where buildings can be heated and/or cooled with minimal effort and cost on the part of the builders. The only restrictive elements for the adoption of horizontal or vertical systems are the available contact area and the associated costs (Mazzutti; Faro; Klamt, 2023; Morais, 2019).

Based on the characteristics of the Brazilian context, where the demand for energy for climate control is substantial, geothermal climatization emerges as a promising alternative. However, the lack of knowledge and awareness among engineers and the general population about this technology represents an additional obstacle to its widespread adoption. Therefore, the aim of the research was to detail the characteristics, potential benefits, and associated obstacles of geothermal air conditioning systems in Brazil, providing valuable insights for engineers, policymakers, and consumers interested in promoting sustainable solutions for building thermal conditioning. In doing so, the goal is to catalyze the development and adoption of this technology, contributing to the country's transition to a low-carbon economy and a more sustainable future.

2 METHODOLOGY

To fulfill the objectives of this study, an extensive bibliographic investigation was conducted across several scientific databases, including Scopus, Web of Science, ScienceDirect, and Google Scholar, among others. The search utilized keywords such as "geothermal climatization", "geothermal energy", "energy pile", "horizontal ground heat exchanger", "vertical ground heat exchanger", "ground source heat pump", "geothermal foundations", and terms related to the benefits and challenges of geothermal climatization, both in Portuguese and English.

Initially, attention was focused on studies published within the last decade. Subsequently, titles and abstracts were scrutinized to determine their relevance to the study's objectives. Selected research was thoroughly examined, with pertinent data extracted and systematically organized for comprehensive analysis.

In the final phase, the collected data was analyzed and discussed in alignment with the pre-defined objectives. This process led to the identification of key insights and considerations, which are presented herein.

3 CHARACTERIZATION OF GEOTHERMAL CLIMATIZATION

Heat is a form of energy and the heat stored on Earth is called geothermal energy (Dickson; Fanelli, 2004). There is currently no universal classification, but, in general, they can be categorized into three main types of geothermal energy systems depending on temperature: electricity generation (above 150°C), direct use systems (below 150°C) and air conditioning using geothermal heat pumps (generally below 32°C) (American Society of Heating, Refrigerating and Air Conditioning Engineers, 2011).

The viability of geothermal air conditioning is due, in part, to the constancy of soil temperature throughout the year, as explained by Omer (2008). From a depth of 10 to 15 meters, the soil temperature remains practically stable, with values above 20°C in tropical regions. This is affected by different factors, including regional climate, surface and average annual air temperatures, humidity, vegetation cover, soil type, depth, thermal inertia, and seasonal changes (Vilela, 2004).

As pointed out by Haj Assad *et al.* (2022), geothermal systems are essentially composed of three elements (Figure 1): the primary circuit, responsible for transferring heat through heat exchanger tubes in direct contact with water, concrete or ground; the heat pump, a component that connects the two circuits, enabling thermal transfer; and the secondary circuit, where heat is extracted or stored to heat or cool the environment, commonly consisting of radiant floors, walls or ceilings, radiators or fan coil units (Lopes, 2014).

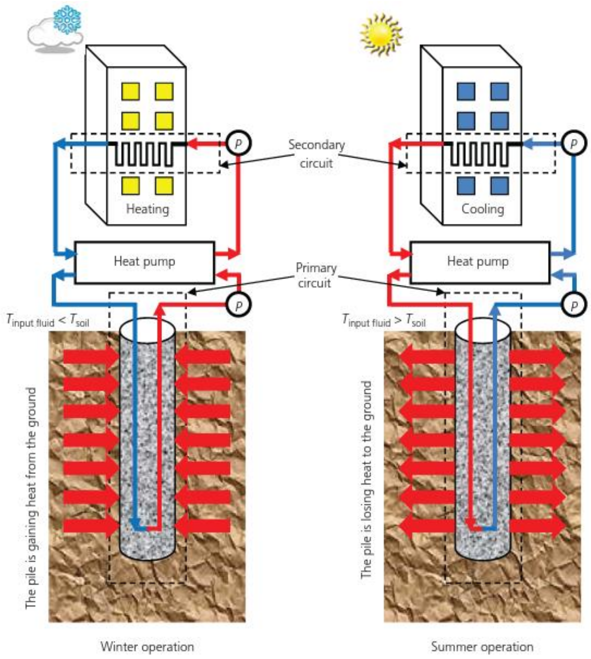

Figure 1. Depiction of a geothermal cooling and heating system (Abuel-Naga *et al.*, 2014).

In this technology, heat exchanger tubes perform thermal transfer between the building and soil layers or aquifer systems, using a working fluid, which is normally water. This circulates through pipes, generally made of High-Density Polyethylene, and can follow an open or closed circuit (Kuosa *et al.*, 2014).

In open circuit systems, heat or cold is extracted from groundwater (wells and aquifers) or surface sources (lakes and dams) and directed to a heat pump, where it is used and then returned to the original environment or a secondary one (Suryatriyastuti *et al.*, 2012). On the other hand, in the closed-loop approach, the fluid circulates in sealed pipes, which are installed inside the foundations, in contact with the ground or even water (Kuosa *et al.*, 2014).

3.1 Vertical ground heat exchangers

Geothermal piles are more economical as they perform a double function, acting as structural elements to support buildings and as heat exchangers in geothermal air conditioning systems. Taking advantage of the high thermal conductivity of concrete and the thermal stability of the soil, piles enable greater energy efficiency than geothermal trenches (Pahud, 2002; Brandl, 2006; Gao *et al.*, 2008; Moel *et al.*, 2010; Olgun; McCartiney, 2014).

Within this context, bored piles appear as the most common form of geothermal piles, following a specific installation process: drilling the ground, inserting heat exchanger tubes pre-fixed to the reinforcement, and concreting the foundation. The tubes are positioned along the armature in predefined positions, with different possibilities for arrangements designed to minimize thermal interaction between them and optimize the system's efficiency, some of the most common are U-shaped, S-shaped and Spiral, and the piping configuration can be simple, double, triple, in series or parallel, as illustrated in Figure 2 (Brandl, 2006; Hehrad; Soheil; Abbasali, 2015; Sani *et al.*, 2019).

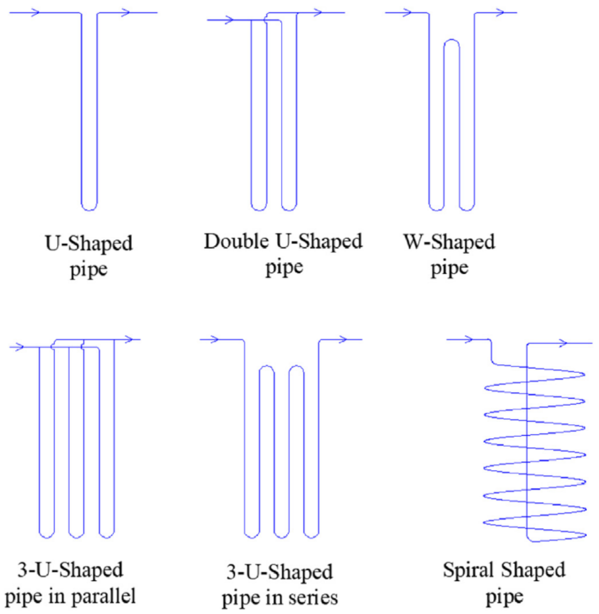

Figure 2. Different arrangements of vertical heat exchanger tube loops (adapted from Sani *et al.*, 2019).

It is important to highlight the preference for reinforced concrete piles due to their excellent properties in terms of conductivity and thermal storage capacity. However, it should be noted that there is also the option of metal piles, although they are less used due to their lower thermal storage capacity (Sani *et al.*, 2019).

3.2 Horizontal ground heat exchangers

In environments where there is flexibility in the use of space, horizontal heat exchangers emerge as a more economical option compared to vertical exchangers, due to the lower costs associated with trench excavation. However, it is important to note that these have a lower thermal performance than piles, due to their proximity to the surface and are more subject to daily and seasonal variations in air temperature and soil humidity (Narsilio; Aye, 2018; Beier; Holloway, 2015).

Although piles can be deployed in almost any soil condition and location, trenches are most common in suburban and rural areas, typically at a depth of between one and two meters (Zhou *et al.*, 2021). In these systems, the pipes are placed at the bottom of the trenches, maintaining a standard distance between two bends on the same vertical line generally varying between 0.6 and 1.2 meters. The trenches have a width that varies from 0.8 to 1.8 meters and a spacing of 2 to 4 meters between them (Cui *et al.*, 2019).

Additionally, as shown in Figure 3, the tubes can adopt three different configurations: Snail (a), Slinky (b) and Spiral (c). The Snail configuration has the pipes positioned horizontally under the soil surface inside the trench. The Slinky, on the other hand, is typically installed vertically to maximize trench utilization, although the additional pipe length increases the workload of the heat pump, reducing the system's coefficient of performance (COP). The spiral configuration employs piping oriented in circular loops in the trench, resulting in a reduction in demand in the horizontal direction (Cui *et al.*, 2019).

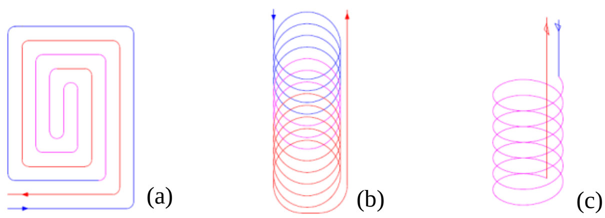

Figure 3. Configurations of geothermal trench systems (adapted from Aydin, 2015).

4 BENEFITS OF GEOTHERMAL AIR CONDITIONING

Geothermal air conditioning emerges as a promising and sustainable solution to the growing demands for thermal comfort in buildings, promoting a series of significant benefits. The technology offers superior energy efficiency compared to conventional HVAC systems. The geothermal heat pump is used to reduce the energy consumption required for heating and cooling buildings. Comparative studies revealed that geothermal climatization generally has higher COP values compared to conventional systems, indicating greater energy efficiency (Mattinen *et al.*, 2015). This superiority can be more than three times greater, as indicated by Park *et al.* (2019), requiring less electrical energy for operation and, consequently, reducing operational costs (Bakirci, 2010). Furthermore, the use of renewable energy sources, such as photovoltaic systems, in conjunction with geothermal pumps can further improve their cost-benefit ratio (Emmi *et al.*, 2020; Varney; Vahdati, 2015).

Another of its main benefits is its contribution to reducing GHG emissions. A study carried out in cold climates, which compared emissions between geothermal and HVAC systems, concluded that the former recorded emissions around 70% lower than those of conventional systems (Mattinen *et al.*, 2015). This result is attributed to the dependence of geothermal on stable ground temperature, which reduces the need for auxiliary heating and results in lower energy consumption and, consequently, lower emissions (Baglivo; Bonuso; Congedo, 2018).

Unlike conventional air conditioning systems, which are often noisy and can cause noise pollution, geothermal climatization systems operate silently and discreetly, contributing to a more peaceful and healthy environment (Dunsky Energy Consulting, 2020). Furthermore, the technology can be applied in a variety of environments and types of buildings, including residential, commercial, industrial, and institutional. This installation flexibility allows adaptation to different thermal needs, making it a versatile option. Finally, installing geothermal climatization systems can increase the market value of a property, as they are seen as a high-quality and sustainable feature that can attract environmentally conscious buyers interested in energy savings.

The benefits demonstrated by geothermal air conditioning highlight its importance and potential as a sustainable solution for heating and cooling demands in Brazil. Therefore, investing in the adoption and development of this technology can not only boost the transition to a cleaner energy matrix, but also contribute to mitigating the impacts of climate change and promoting a healthier and more sustainable environment for future generations.

5 CHALLENGES OF GEOTHERMAL CLIMATIZATION

Despite the benefits that geothermal air conditioning offers, its implementation faces challenges that demand attention and creative solutions to ensure its efficiency and large-scale implementation in Brazil. These systems generally have higher installation costs than conventional ones (Bottarelli; Gallero; 2020). This can pose a significant barrier to widespread adoption of the technology, especially for homeowners with limited budgets. This ends up getting worse with the lack of financial incentives, such as subsidies, tax credits or preferential financing, which discourages investments in technology (McClean; Pedersen, 2023).

The lack of knowledge about the benefits and functioning of this type of air conditioning can also lead to mistaken perceptions about its viability, efficiency, and safety. This can generate resistance and be an obstacle to its adoption (Mazzutti; Faro; Klamt, 2023), especially when considering the vast territorial extension of Brazil, the particularities of each region and the scarcity of studies that prove its viability in different climatic conditions and underground temperature variations (Tonus *et al.*, 2022).

It is noteworthy that, possibly due to the abundance of natural resources in Brazil, such as water, wind, sun and biomass, priority has been given to the installation of plants from these sources, relegating geothermal energy to a secondary level. However, with the growing demand for energy and the need to reduce Greenhouse Gas emissions, no alternative should be discarded (Omido; Barbosa; Moreira Júnior, 2017). It should also be noted that the lack of clear regulations and specific technical standards for geothermal climatization can make it difficult to incorporate it into building codes and make it difficult for engineers to understand its construction (McClean; Pedersen, 2023), which needs to be carefully designed so that thermal pollution of water from wells, lakes, dams, and aquifers does not occur.

By addressing these challenges in a comprehensive and collaborative way, Brazil can overcome barriers to the adoption of geothermal air conditioning and take advantage of the economic, environmental, and social benefits that the technology offers. These challenges highlight the importance of further studies for its implementation in different Brazilian regions, strategic investments, and cooperation between different stakeholders to promote the sustainable development of technology in the country.

6 FINAL CONSIDERATIONS

This study confirmed that geothermal climatization represents a promising alternative in the Brazilian panorama, providing important benefits. However, it urges the need for a careful analysis of the challenges to ensure the full implementation of this technology. Recognition of its implications, both positive and negative, are essential to guide informed decision-making within the scope of sustainable thermal conditioning in the country.

In short, the benefits highlighted highlight the importance of geothermal air conditioning as a sustainable solution for heating and cooling demands in Brazil. The significant reduction in energy consumption, noise pollution and greenhouse gas emissions highlight its environmental benefits. Therefore, investing in the adoption and development of this technology can not only boost the transition to a cleaner energy matrix, but also contribute to mitigating the impacts of climate change and promoting a healthier environment for future generations.

However, its implementation in Brazil faces significant challenges. High installation costs, lack of financial incentives, lack of knowledge about its benefits and the incipient regulatory context represent significant barriers to its large-scale adoption. Furthermore, the predominance of other renewable energy sources in the country may have diverted attention from geothermal energy. However, as demand for energy grows and the need to reduce emissions becomes more pressing, it is essential to consider all available alternatives. Overcoming these challenges requires more research to adapt the technology to Brazil's diverse climatic and geological conditions, strategic investments, and collaboration between various interested actors. Therefore, by facing these challenges in a proactive and cooperative manner, Brazil can not only take advantage of the economic, environmental, and social benefits of geothermal climatization, but also promote its sustainable development and contribute to the transition to a cleaner and more diverse energy matrix.

Recognizing the characteristics, benefits and challenges is essential to guide informed decision-making in the field of thermal conditioning in Brazil. By considering all these aspects, policymakers, engineers and building owners can make more informed decisions that not only promote thermal comfort but contribute to the United Nations Sustainable Development Goals that must be achieved by 2030, with the companies' Environmental, Social and Governance Agenda and with resilience in engineering.

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