Energy tunnels: A sustainable future for Australia

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Australia embraces green innovation through the application of energy geostructures. The Melbourne Metro showcases a pioneering example of this sustainable technology, paving the way for nationwide adoption.

Shallow geothermal systems offer renewable solutions for space heating, cooling, and hot water production by leveraging stable ground temperatures found at depths of 10 to 200 meters. At these depths, the ground temperature typically mirrors the mean atmospheric temperature of the location. During summer, the ground acts as a heat sink: warm water pumped into the ground releases its heat and returns to the surface cooler, thus cooling the building above. In winter, the process reverses, the soil becomes a heat source, where cold water pumped through the pipes absorbs heat from the ground and returns warmer, heating the building. Figure 1 illustrates this process, showing how the system adapts to seasonal changes to regulate building temperatures.

These systems reduce reliance on traditional energy sources, which is crucial given that the heating and cooling sector accounts for nearly 50% of total energy consumption and 40% of greenhouse gas emissions (Gibb et al., 2022). However, the widespread adoption of these systems has been hindered by the high initial capital costs associated with traditional ground heat exchangers (GHEs), which involved drilling as it is traditionally applied using boreholes. Recognizing this barrier, the integration of geostructures as GHEs is emerging as a more cost-effective alternative, effectively overcoming this drawback and paving the way for broader implementation.

Energy geostructures

Piles, pavements, walls, and tunnels are some of the structures utilized as GHEs, with energy piles emerging as the most popular among them. Globally, nearly 200 energy geostructure projects are operational, with energy piles accounting for over 80% of these projects (Laloui & Loria, 2019). In Australia, although the adoption of this technology remains limited, a few notable projects have been implemented. A significant project is located in the Melbourne Metro, where an experimental energy piled wall was installed and monitored in one of the underground station's shafts (see Figure 2). This project demonstrated the promising energy potential of such structures and confirmed that the thermally induced stresses remained within acceptable design limits (Villegas et al., 2023; Zhong et al., 2022). Additionally, a 2019 field study in an Adelaide parking lot explored a geothermal pavement system. This project innovatively embedded horizontal ground heat exchangers within the pavement structure instead of traditional trenches, which effectively reduced capital costs. Despite being influenced by ambient temperatures, the study demonstrated that geothermal pavements are a viable solution for heating and cooling, achieving a heat exchange rate of 50.2 W/m²(Gu et al., 2022; Motamedi et al., 2021)

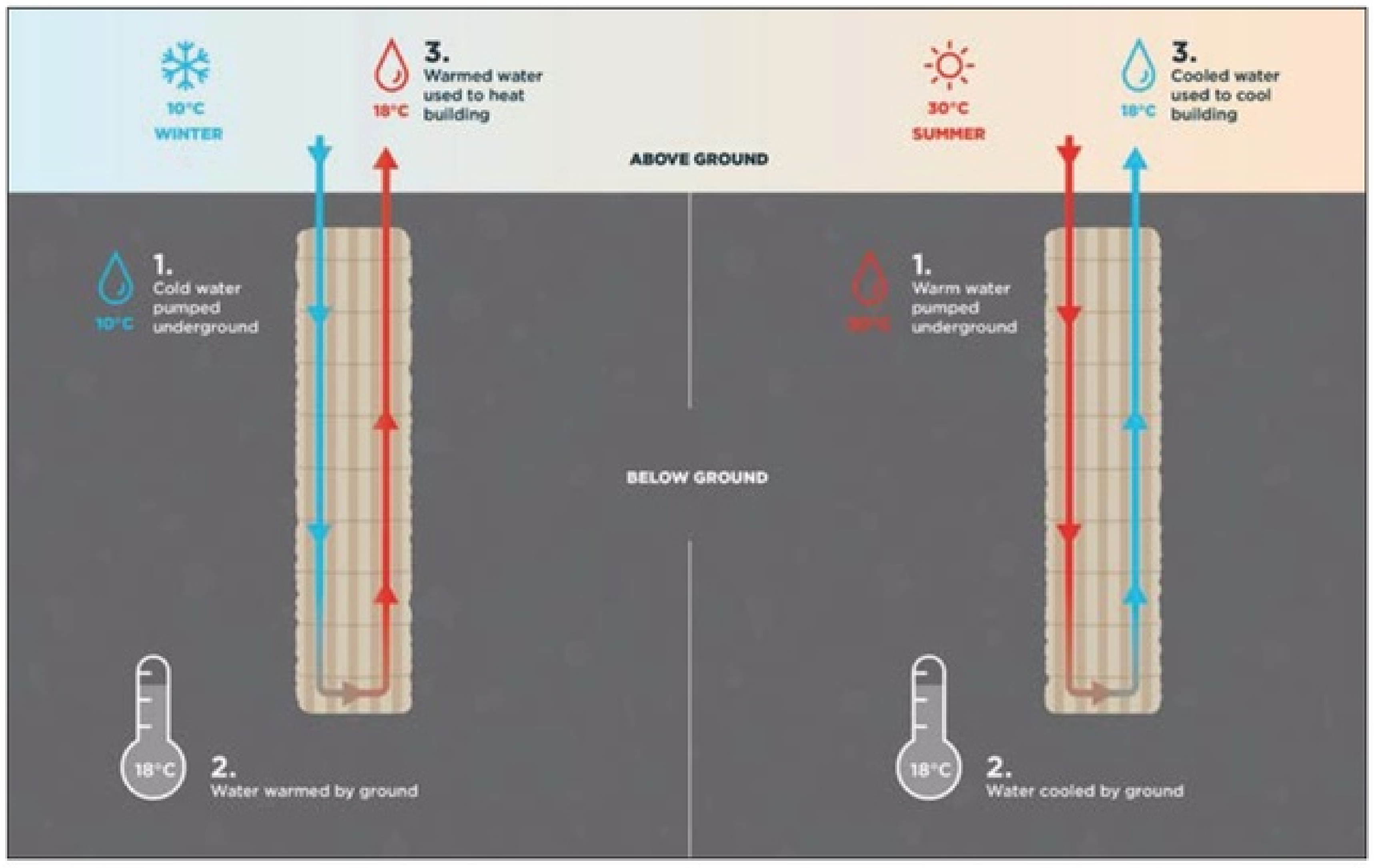

Figure 1- Geothermal heat exchange diagram (State Government of Victoria, 2024).

Figure 2- a) Thermally activated retaining wall b) Geothermal pipe installation (State Government of Victoria, 2024).

Energy tunnels

Following the success of other geothermal geostructures, energy tunnels are emerging as a pivotal innovation within the field. While still relatively uncommon, energy tunnels are gaining traction due to their alignment with sustainability goals and the increasing need for clean, renewable energy sources. Currently, there are 19 energy tunnel projects worldwide, encompassing operational, pilot, and evaluated initiatives which involve preliminary or feasibility studies to assess potential implementation (Dai et al., 2023). These projects are distributed across various countries in Europe and Asia, including Austria, China, France, Germany, Italy, Japan, Poland, South Korea, Switzerland, Turkey, and the UK. Specifically, in Australia, the projects remain in the evaluation phase, offering a strong foundation for future development and implementation (Bidarmaghz et al., 2017; Rottemberg et al., 2023).

As depicted in Figure 3, a typical energy tunnel system involves a tunnel lining fitted with heat absorber pipes, transforming traditional tunnels into energy extraction systems. An internal circulating fluid flows through these pipes, enabling effective heat exchange with both the surrounding ground and the air within the tunnel, which is often heated by vehicles and passengers during normal operations. The energy collected is then transferred to the surface through header pipes by heat pumps, and subsequently distributed to buildings.

Figure 3- Schematic of an energy tunnel providing space heating and cooling to a building (not to scale).

Regarding the design and analysis of energy tunnels, due to their dual functionality (structural and thermal) their behaviour is intricately influenced by multiple interconnected physical systems which impact the surrounding soil and soil-structure interfaces. Consequently, a comprehensive understanding of the integrated multiphysical processes involved is essential. These processes include thermal (T), hydraulic (H), and mechanical (M) interactions within the system. Specifically, the mechanical system addresses stress-strain behaviour, the hydraulic system accounting for pore fluid flow, and the thermal system involving the ground heat transfer.

Despite the complexity of these systems, existing studies suggest that the structural responses of tunnels due to thermal influences are relatively minor when compared to the impacts of tunnel excavation. However, as research in this area remains limited, a deeper understanding of the thermal, structural, and geotechnical performance of energy tunnels is crucial to encourage their broader adoption and optimize their efficacy.

In conclusion, energy tunnels represent a revolutionary innovation in subsurface engineering, offering a sustainable and decarbonized solution for meeting urban energy demands. With their ability to utilize a larger volume of ground and surface area for heat exchange, they surpass other underground structures like building foundations or retaining walls in effectiveness as heat exchangers (Bourne-Webb & da Costa Gonçalves, 2016; Gawecka et al., 2021). By leveraging this dual functionality, energy tunnels promote a forward-thinking approach to urban planning, fostering the development of greener and more resilient cities Their integration into urban infrastructures presents a tangible solution for reducing CO_2 emissions and addressing key challenges in combating climate change.

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