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Editorial: Recent progress and advanced technologies in geothermal energy utilization for building heating and cooling

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Editorial on the Research Topic

Recent progress and advanced technologies in geothermal energy utilization for building heating and cooling

Geothermal energy, as a renewable resource derived from subsurface heat, has garnered considerable interest for its potential in sustainable building heating and cooling applications. Owing to its inherent stability, low carbon emissions, and abundant reserves, geothermal energy represents a compelling alternative to fossil fuels across residential, commercial, and industrial sectors. In light of escalating global energy demands and the pressing need to mitigate greenhouse gas emissions, it is imperative to develop rational strategies for expanding the adoption of geothermal technologies. Thus, our Research Topic is focused on addressing these challenges through innovative extraction techniques, advanced materials, and hybrid energy systems, while also highlighting the existing economic and regulatory constraints.

In the work of [Val Hyginus Udoka Eze et al.](#) it points out a future direction of geothermal energy utilization where cooperation, innovation, and policy will all work together to realize the full potential of this technology.

The distinct benefits of geothermal energy are indisputable, with its considerable operational energy efficiency, sustainability, and flexibility. The intermittency issues of solar and wind renewable energy sources are further addressed by their hybrid configurations with geothermal energy. Because of these qualities, geothermal energy is positioned as a flexible foundation of contemporary energy infrastructure rather than as a specialized actor. The convergence of cutting-edge engineering and technologies is what really sets apart the current trajectory of geothermal energy. Geothermal energy is becoming an intelligent energy asset that can adapt to changing climatic circumstances and grid needs. Yet, for all its promise, geothermal energy faces persistent hurdles. High initial installation costs, coupled with geological uncertainties and regulatory barriers, have slowed its widespread adoption. Three pillars need to be strengthened to speed up the transition towards a renewable

geothermal-based energy system: international cooperation to share best practices, funding, and knowledge, especially for developing countries with unrealized geothermal potential. With strong backing from governments, businesses, and academics, geothermal energy has the potential to advance beyond its current state and play a key role in creating a clean, resilient, and sustainable global energy future.

Zhang et al. conducted an innovative study to explore the utilization potentials and methods of geothermal energy in coal mines for sustainable heating and cooling. Where the heat transfer performance of a network of five tunnel borehole heat exchangers (BHEs) in active high-temperature coal mines were simulated and studied, with a coupled three-dimensional numerical model developed by OpenGeoSys. The model is rigorously benchmarked against an analytical line-source solution and a 1-D wellbore simulator, achieving errors below 3% and showing accuracy for further analysis. Subsequent studies reveal the influence of injecting water temperature, borehole distance and groundwater velocity on the heat extraction rate and the thermal interference of BHE arrays. These findings provide the quantitative design envelope for harnessing mine geothermal energy while simultaneously mitigating underground heat stress, thus building a solid foundation for coupling such arrays to nearby district-heating networks. Future work should extend the analysis range to the seasonal energy performance and conduct techno-economic optimization under varying market and geological conditions.

Olubayo Babatunde et al. conducted a mini review concerning the transdisciplinary approach towards hybrid renewable energy systems for its sustainable design. Three key perspectives are emphasized, including size optimization, multi-criteria decision-making (MCDM), and spatial optimization. The study addresses the multifaceted challenges inherent in planning and deploying sustainable HRES. Size optimization involves formulating objective functions under conflicting constraints that must be satisfied to arrive at viable solutions. Furthermore, the deployment of these systems requires optimal siting, which is typically accomplished through spatial optimization techniques. Additionally, this paper proposes an integrated framework that combines sustainable design principles with size optimization, MCDM, and spatial optimization strategies to support comprehensive HRES implementation.

Moreover, Bu et al. made a timely and forward-looking contribution by presenting a novel shallow-depth enhanced geothermal system (SDEGS) for high-temperature thermal energy storage. By coupling solar thermal Research Topic with subterranean storage in engineered shallow rock formations, the authors demonstrated a solution that is not only technically robust but also economically scalable. Through comprehensive numerical simulations, the study showed that SDEGS achieves thermal recovery efficiencies consistently above 90% over 20 years. Unlike conventional aquifer or mine energy storage, where heat losses and natural convection undermine performance, the SDEGS stores energy directly in tight rocks, ensuring long-term stability and resilience. Beyond the technical achievements, Bu et al.'s study carries broader implications for decarbonization strategies in regions like northern China. By offering a pathway to combine high solar potential with stable geothermal storage, the research highlights how innovation at the interface of technologies can

accelerate the transition toward sustainable, resilient, and affordable heating infrastructure worldwide.

The work of Samah Al Dwiek et al. considers machine learning (ML) and aims to reveal the revolutionary influence of artificial intelligence (AI) on the design of the built environment. The scientometric analysis to measure the progress of the scientific production of ML in interior design was summarized. In the process of investigating the application of machine learning in interior design, some aspects are explored. Accordingly, the incorporation of ML into the above elements of interior design leads to the potential to revolutionize the sector. However, the researchers are limited to specific applications or experimental circumstances. For future research, high-quality and diverse datasets for training ML models are required for successful ML-driven solutions adapted to the complexities of interior design.

Overall, this Research Topic is dedicated to presenting and examining the latest advances in geothermal energy technologies aimed explicitly at heating and cooling applications in the built environment. It seeks to provide a comprehensive survey of recent innovations, technological developments, and practical implementations that underscore the feasibility and efficacy of geothermal solutions. Furthermore, this Research Topic aims to forecast emerging trends and future research pathways that could facilitate the integration of geothermal systems into hybrid and multi-source building energy frameworks. It is intended that the related findings will assist policymakers, engineers, and researchers in promoting more efficient and sustainable utilization of geothermal energy.

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