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Ground Source Hydronic Heated Pavement Systems for De-Icing and Snow Melting: Opportunities and Challenges in Sustainable Infrastructure

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Summary

Thermal de-icing and snow melting systems heat surfaces to prevent snow and ice buildup. They provide benefits compared to conventional winter maintenance methods such as salting and plowing, including improved safety, reduced environmental impact, and automated operation. Hydronic Heated Pavement Systems (HHPS) achieve this by circulating heated fluid through embedded pipes. These systems enhance sustainability by using shallow geothermal energy and storing solar heat collected during summer for use in winter. HHPS can provide a reliable, renewable alternative to energy-intensive electrical resistance heating, particularly in critical infrastructure areas that require continuous operation. This paper presents findings from the International Energy Agency (IEA-TCP) Task 38, which focused on advancing ground source de-icing and snow-melting systems. Drawing from over 50 documented cases across several countries, the study highlights technical, operational, and design considerations for HHPS. It examines both thermal performance and mechanical integration, identifying key design parameters such as pipe configuration, embedment depth, and material compatibility. It also explores how these parameters influence energy efficiency and snow melting performance. The results show that HHPS can significantly reduce winter energy demand and environmental impact, particularly when integrated with solar harvesting and seasonal thermal storage. However, challenges remain related to thermal performance under varying climatic conditions, long-term mechanical durability, and system scalability. To support broader adoption, the paper suggests practical design strategies. These include energy zoning, i.e., dividing pavements into independently controlled heating sections, and optimized integration with low-carbon energy sources, aimed at enabling more sustainable and resilient infrastructure in cold climates.

1 Introduction

Hydronic Heated Pavement Systems (HHPS) prevent snow and ice accumulation by circulating heated fluid through a heat exchange, typically consisting of embedded pipes or porous pavement, enhancing road safety and infrastructure durability (Figure 1). They reduce reliance on de-icers, lower maintenance costs, and allow integration with renewable energy sources for sustainable operation.

HHP technology demonstrates versatile applications in various infrastructural elements. It aids in snow melting and de-icing for roads, parking lots, walking/biking paths, ramps, stairs, and entrances, ensuring enhanced safety and accessibility during winter. Tunnel entrances, bridge decks, and road parts between tunnels benefit from HHPs by maintaining optimal temperature conditions and minimizing the impact of temperature fluctuations. Railway switches experience smoother operations as HHP technology prevents ice formation. Platforms, sensitive slopes, parking lots, and aircraft parking areas utilize HHPs to efficiently address weather-induced challenges, contributing to improved functionality and safety. The adaptability of HHPs extends even to sports fields, ensuring playability in diverse weather conditions.

Globally, interest in large-scale HHP projects has grown, with notable examples like the Solar Energy Pilot Project in Switzerland and Road Engineering Systems in the Netherlands. Commercial projects have been implemented to showcase the potential of HHP systems on a larger scale with differences in the technical specifications [1].

This paper presents a structured analysis of the thermal performance of HHPS, along with the mechanical requirements and structural responses of pavements incorporating such systems. The goal is to identify the key opportunities and challenges involved in implementing HHPS as part of a sustainable and resilient infrastructure strategy.

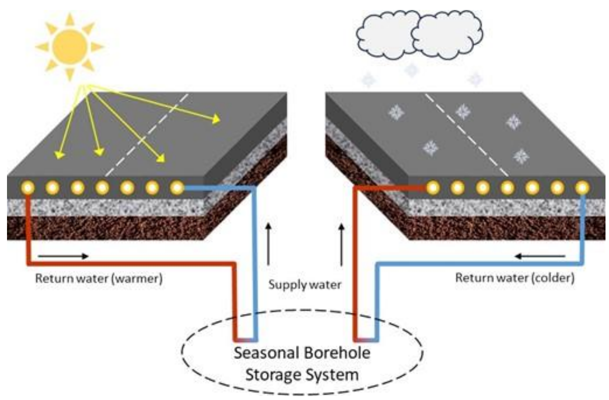

Figure 1: Schematic of a geothermally coupled HHP for (left) harvesting heat (right) snow melting

2 Thermal development of the heating surfaces

In recent years, significant attention has been directed towards exploring the feasibility and performance optimization of HHPs for de-icing and snow melting. Large-scale HHPs are constructed in various sizes depending on the application and area to be covered, and with varying geometrical specifications across projects such as pipe spacing, pipe configuration, and embedment depth.

Task 38 compiled over 50 case studies from member countries including Sweden, Türkiye, Italy, Germany, France, Belgium, and others. These reports documented key aspects of HHPS such as system components, thermal behavior, the influence of geometric design, material properties. Furthermore, they also included suggestions to facilitate system development across a range of applications and configurations. Although the effectiveness of HHPS for snow melting is well-established, the objective of Task 38 was to promote the use of the ground, either with or without the assistance of heat pumps, as a primary heat source for de-icing and snow melting systems in infrastructure [2]. This approach aims to replace conventional thermal de-icing methods that rely on electric heating or fossil fuels. However, transitioning from electrically powered systems to geothermal-based solutions introduces certain boundary conditions, particularly when considering broader applications in severe weather conditions or at critical locations where maintaining snow-free surfaces is essential. Since climate varies significantly by region, key factors such as ground temperature (especially in geothermally coupled projects), ambient air temperature, and precipitation patterns must be carefully considered during the design and implementation phases. Large-scale HHP installations must be designed to function effectively in high-priority areas such as emergency entrances, helipads, and other critical locations.

Beyond their primary function of de-icing and snow melting, HHPS can also function as pavement solar collectors, extracting thermal energy from the pavement (Figure 1). The thermal performance of HHPs has been extensively studied with energy harvesting efficiency (i.e., a ratio of extracted heat to incident solar radiation) estimated to range between 20% and 50% [3, 4]. A recent feasibility study conducted on a large-scale HHP project in Utrecht province, Netherlands, estimated the total heat harvesting potential to range approximately between 0.6 and 1.15 GJ/m² per year, depending on system configuration [5]. A comparison of average hourly heat gain during summer with heat consumption for snow melting and de-icing in winter reveals that utilizing a low-temperature supply in winter can preserve over 80% of the heat harvested in summer. The remaining stored heat can be repurposed for applications such as supplying (preheated) domestic hot water or supporting heating systems in nearby buildings [3]. Nonetheless, the direct use of this low-temperature heat in district heating networks remains a significant challenge [6].

3 Mechanical requirements of the surface heating system

The heat exchange layer embedment in HHPs introduces distinct challenges related to structural integrity and performance such as stiffness of pavement structure and potential for cracking. The choice of pipe material and pavement material (e.g., bituminous mixture) affects both compaction quality and heat distribution across the pavement surface. Differences in stiffness between the pipe and surrounding materials can lead to cracking initiation, particularly around the pipe zone. Additionally, pipe placement plays a crucial role in pavement deformation, as it may contribute to rutting in asphalt pavement during warmer months. Addressing these factors is essential to ensure a balance between effective heat transfer and structural integrity, ultimately enhancing the durability and reliability of HHP systems.

The integration of HHP during pavement construction introduces specific challenges, particularly due to the high temperatures involved in the paving process. Asphalt mixtures can reach temperatures of up to 160 °C, which poses a risk to embedded PE pipes, which have melting points typically ranging between 100–130 °C. To protect the pipes, techniques such as using a warm mix asphalt or circulating cold water through the pipes during construction can be employed to diminish the thermal stress.

In rigid pavements, the integration of HHP systems presents specific design and construction challenges. When pipes are embedded within the concrete structure, careful attention must be paid to the geometrical layout to prevent interference with essential structural elements such as dowel bars and tie bars, which are critical for load transfer and block connectivity. For jointed reinforced concrete pavement and continuously reinforced concrete pavement, the primary challenge lies in coordinating pipe placement with the reinforcement layout.

4 Conclusion

Hydronic Heated Pavements (HHPs) have emerged as an innovative solution for improving winter road safety and infrastructure durability by integrating shallow geothermal energy to prevent snow and ice accumulation. As part of the IEA Task 38, participating countries documented a wide range of HHPS applications, sharing practical insights and experiences. The following sections outline market opportunities, essential design specifications, technical challenges, and operational practices associated with the application of HHPS:

- Most existing snow melting and de-icing systems are either electric or hydronic, with many relying on district heating as the main energy source. However, there is increasing potential to transition toward renewable alternatives such as ground source and solar energy, driven by the need for greater energy efficiency and reduced environmental impact. To support this shift, reliable thermal energy storage is essential to ensure consistent performance during winter. Key challenges to wider adoption include climate variability, energy storage efficiency, and the scalability of these systems for large-scale infrastructure such as urban roads or highways.

- Large-scale demonstration projects have shown that integrating ground source and solar energy (pavements as solar collectors in summer) can significantly reduce operational costs and environmental impact in de-icing systems. While these pilot initiatives have proven effective, key areas still require further development. These include coupling with thermal energy storage, enhancing system response times, and refining control strategies to better adapt to extreme and dynamic weather conditions.
- New market opportunities are emerging, especially in regions without access to district heating or where renewable systems present a more cost-effective alternative. Ground source systems show strong potential for applications such as railway switches, sports facilities, and remote or off-grid infrastructure, where low operational costs and high energy efficiency are critical.
- To optimize energy demand for de-icing and snow melting, it is essential to set appropriate surface temperature set points that regulate both the flow rate and supply temperature. Additionally, dividing the pavement into separate heating zones allows for targeted operation, enabling more efficient energy use by activating only the areas that require snow or ice removal. This zoning strategy significantly reduces overall energy consumption while maintaining effective system performance.
- The effectiveness of HHPs relies on balancing thermal performance with structural integrity for long-term durability. While thermal performance is influenced by both operational and design factors, mechanical response is primarily affected by geometrical aspects, particularly pipe spacing and embedment depth. Since operational parameters (e.g., flow rate or fluid temperature) do not directly impact structural behaviour, optimizing pipe placement is critical to ensuring both efficient heat transfer and pavement response.

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