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IEA ES Task 38: Ground Source De-Icing and Snow Melting Systems for Infrastructure

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ABSTRACT

Thermal de-icing and snow melting systems are alternatives to mechanical and chemical de-icing and snow removal e.g. for roads, bridge decks, ramps, and other transport infrastructure. Snow melting and de-icing systems with a hydronic heated pavement (HHP) are used in several countries in various applications, for infrastructure or other purposes, commonly using district heating return flow, electric heating, or gas boilers as heat sources. As an alternative, the ground can be used as a heat source for HHP systems, with or without the aid of heat pumps. Such HHP systems may also use the pavement as a solar heat collector in the summer. This will cool the road surface, prolonging the life span of asphalt roads by preventing rutting. In 2021, the International Energy Agency (IEA), technology collaboration program (TCP) for energy storage (ES), initiated the international collaboration project Task 38 - Ground Source De-Icing and Snow Melting Systems for Infrastructure. Sweden, Türkiye, Italy, Germany, France and Belgium are part of the collaboration project. This paper gives an overview of the work within Task 38, and the current state-of-the-art of ground source de-icing and snow melting systems for infrastructure.

INTRODUCTION

The use of geothermal energy worldwide has been steadily increasing over the last three decades, and according to data presented by the International Geothermal Association (IGA) at the World Geothermal Congress 2020, the amount of geothermal energy direct utilization in 2019 amounted to 284 TWh, of which ground source heat pump (GSHP) applications account for 165 TWh (58%) with an installed total capacity of 108 GW (Lund and Toth, 2020). A small fraction (415 MW, 660 GWh) of the geothermal energy utilization is used for snow-melting and de-icing, where typically a hydronic heated pavement (HHP) is used. In the world geothermal overview by Lund and Toth (2020) Iceland, Japan, Argentina, the United States, Slovenia, Poland, and Norway are listed as reporting countries with such applications installed e.g. streets and sidewalks. The estimated area of heated pavement worldwide at the end of 2019 was 2.5 million square meters, of which 74% is installed in Iceland. Many of these systems do not use heat pumps but utilize geothermal water at temperatures sufficient for snow melting without the aid of heat pumps. In most countries around the world, high-temperature geothermal resources are not available. Ground source de-icing then requires heat pumps and/or underground thermal energy storage, such as borehole thermal energy storage (BTES) or aquifer thermal energy storage (ATES), to provide sufficient temperatures and energy for de-icing. De-icing and snow-melting with ground source heat date back to the mid-1900s, with the oldest known documented bridge deck de-icing with high-temperature geothermal

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resources in Klamath Falls in Oregon (Lund 1999). In the late 1980s and the 1990s, several examples of ground source de-icing and snow melting systems were built in Japan (Iwamoto et al., 1998). Ground source de-icing and snow-melting are now used in several other countries.

IEA ES TASK 38

In June 2021, the International Energy Agency (IEA), through the technology collaboration program for energy storage (ES), initiated the international collaboration project Task 38 - Ground Source De-Icing and Snow Melting Systems for Infrastructure (https://iea-es.org/annex-38/). The project goal is to increase the use of the ground, with or without the aid of heat pumps, as a heat source for de-icing and snow melting systems for infrastructure (Adl-Zarrabi et al. 2022), primarily as a replacement for thermal de-icing using electric heating or heat from fossil fuels. Sweden, Türkiye, Italy, Germany, France, and Belgium are active members of the collaboration project. The project ends in December 2024.

Task 38 activities are divided into four subtasks: 1) Market potential and State-of-the-Art, 2) Modelling of geothermal energy storage and de-icing systems, 3) Development of system components for selected applications, 4) Planning, construction, and monitoring.

In the spring of 2024 national state-of-the-art reports for Germany, Belgium, Italy, Türkiye, France and Sweden (Andersson et al. 2023) have been compiled within Task 38 and an overall state-of-the-art and a market overview report is being prepared with additional input from countries outside of the Task 38 collaboration project, e.g. the Netherlands, the USA and Japan. Results from two field tests, a test road in Östersund in Sweden and a bicycle path in Antwerp in Belgium, are analyzed and reported. An overview of modeling tools, and a guide for design, modeling, construction and components of ground source de-icing and snow melting will be compiled before the closing of the project at the end of 2024.

SYSTEM COMPONENTS AND CONSTRUCTION

In its basic form a ground source heated HHP system consists of a piping network embedded in the pavement, the ground source heating system (usually groundwater or boreholes with or without the aid of heat pumps), and a control system, which could include a weather station (Figure 1).

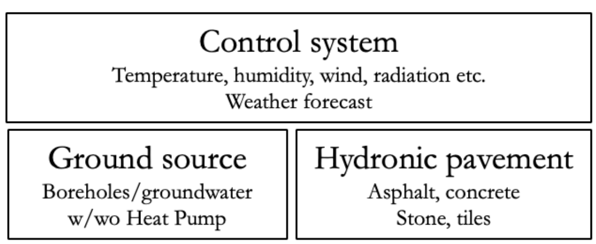

Figure 1 Ground source heated HHP system in its basic form.

The primary component of a HHP system is the heat exchanger, consisting of a pavement layer integrated with an embedded pipe network and circulating fluid. The hydronic pavement section may utilize bituminous asphalt or concrete as its primary material, while the pipes themselves can be composed of copper or polyethylene (PE). Additionally, various projects have adopted innovative approaches such as using grid support, laying pipes within grooves in previously installed layers, or connecting the pipe network to a square steel mesh using metal pins to ensure the precise positioning of pipes during construction. The ground-source heating system serving the HHPs may include various

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components, including a heat pump, buffer tank, circulation pump, expansion tanks, a control computer, flow meters, temperature and pressure sensors, control valves and regulating valves. The measurement devices record supply and return temperatures, flow rates, pavement temperatures, etc., all connected to a system for real-time monitoring and control. The control system receives data from a weather station that measures air temperature, relative humidity, wind velocity and direction, solar irradiation, and barometric pressure. By continuously monitoring weather conditions, the control system can dynamically adjust operational parameters in response to changing environmental factors. Heat storage becomes crucial for projects relying on harvested solar energy, with options for various types of seasonal heat storage systems based on available space.

MODELLING

Modeling the process of snow melting on a heated surface is complicated due to various factors, including the complex heat and mass transfer mechanisms involved in the snow melting process, as well as the temporal and spatial variability of surface and weather conditions. This leads to a wide variety of approaches to modeling i) climatic conditions representative of the cold season, ii) thermal load on the heated surface, and iii) utilized geothermal resources.

Within the framework of Task-38 activities, a collection of about 30 case studies have been considered, which exhibit differences in system components, configuration type, heated surface type, and heat source. Referring to this database, over the last 20 years, various modeling approaches to the problem have been proposed, ranging from simplified models (e.g., Ismail, 2013, Umas, 2014, Dupray et al., 2014), to more accurate and integrated methods (Liu et al., 2007a, Liu et al., 2007b, Mirzanamadi, 2017). Nevertheless, there is significant divergence in their ability to effectively handle the problem, and in reliability and practicality in their application. In this context, the challenge lies in integrating various software components and additionally implementing a control system to optimize storage during charging and discharging processes. Moreover, the effectiveness of a model largely hinges on its capacity to accommodate the array of surface conditions and precipitation encountered during storm events. Of primary importance is the modeling of the required heat flux on the heated surface, which needs to be defined based on the desired outcomes. Additionally, this heat flux depends on various aspects, such as (a) climatic conditions and environmental heat transfer mechanisms, (b) infrastructure construction aspects (materials, thickness, area, and orientation), (c) hydronic tubing construction (material, diameter, spacing, and burial depth), (d) system flow rates, (e) heat transfer fluid properties (density and thermal properties), and (f) the fluid supply temperature (Han & Yu, 2017). The design heat flux also depends on the extent to which it is acceptable to allow snow and ice to remain on the surface at critical conditions. There is a vast difference between preventing condensation or sublimation on a surface, keeping a surface free of ice, and melting any amount of falling snow. It is usually impractical to design a system that keeps a surface free of snow and ice at any extreme weather condition. Considerations in this initial phase, in turn, influence the modeling of the geothermal components of the system.

TASK 38 NATIONAL OVERVIEWS

This section gives a brief overview of the current state of the art in ground source de-icing and snow melting in the six European countries involved in Task 38. There are a couple of research test sites built in Sweden, Belgium, and Germany (Table 1). Germany is by far the most developed user of ground-source heated thermal de-icing and snow-melting systems, with several operational pilot and full-scale applications (Table 2).

Table 1. Ground Source De-icing System Test Sites

Location	Application	Ground Source	Reference
HERO, Östersund, Sweden	Road part	Boreholes, no heat pump	[Johnsson, 2019]
HEAL, Antwerp, Belgium	Bicycle path	Boreholes, heat pump	[Ghalandari et al. 2023]
Füssen, Germany	Tunnel	Groundwater, no heat pump	[Moorman and Buhmann, 2017]

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Germany

Germany is the second largest user of geothermal energy in Europe, and thermal de-icing and snow-melting systems are widely used in Germany for a range of applications such as driveways, parking areas and sports facilities. Most of the thermal de-icing systems are HHP systems heated by a gas or oil furnace, or electric resistance heating embedded in the paved surface, but there are several full-scale implementations of ground source de-icing in operation in Germany for various paved surfaces as well as for rail switches. The ground sources vary from groundwater to boreholes, with and without heat pumps, as well as two-phase thermosyphons (Table 2). A thermosyphon is a closed tube where heat from the ground is transferred to a heat sink, in this case the pavement, by a temperature driven evaporation-condensation process. No additional energy or control system is needed to operate the thermosyphon. Commercial systems and products for ground-source heated HHP are available in the German market.

Table 2. Ground Source De-icing Systems in Germany

Location	Application	Ground Source	Reference
Therese-Giehse-Allee, Munich	Metro station	Groundwater/two-phase thermosyphon	[Schenk, 2011]
Berkenthin	Canal Bridge	Groundwater heat pump	[Eilers et al., 2020]
Bergson strasse, Munich	Buslane	Groundwater heat pump	-
Audi, Ingolstadt	Garage Ramps	Unspec. Ground source	-
Fire department, Bad Waldsee	Exit Ramp	Boreholes/thermosyphon	[Zorn, 2015]
Grünberg	Railway switch	Boreholes/thermosyphon	-
Hamburg	Railway switch	Boreholes/thermosyphon	-
Sponholz	Railway switch	Boreholes/thermosyphon	-
Bad Lauterberg/Barbis	Platform heating	Boreholes + heat pump	-
Riegelplatz, Dresden	Tram platform and switch heating	Boreholes/thermosyphon	[Hamann et al., 2005]

A test site for a passive open-space ground source heating system at a service yard for a tunnel in Füssen (Germany) was constructed in 2019-2020 and operated in the winter of 2021-2022 and kept the surfaces free from snow and ice throughout the test winter (Moorman and Buhmann, 2017). Groundwater from the mountain was pumped directly through piping in the pavement without heat pumps and heat exchangers and is used both for de-icing in the winter and cooling the surface in the summer.

Sweden

Sweden is the third biggest geothermal energy user in the world after China and the USA (Lund and Toth, 2020). 20% of single-family houses use a GSHP. Despite this, geothermal energy is not yet used for de-icing and snow-melting to any significant extent. Arlanda International airport in Stockholm uses its large-scale ATES system partly for snow melting at airplane parking areas. Many commercial and institutional buildings that use GSHP systems for space heating and cooling, also include HHP systems at e.g. entrances and ramps. An experimental road section in Östersund (Johnsson, 2019) with an HHP supported by four boreholes (the Nordic HERO project) was set up in 2017-18. A 20 m long and 3.5 m wide heated concrete pavement surface with embedded 20 mm PEX pipes at a centre-to-centre distance of 50 mm was constructed next to an unheated reference surface. The paved surface is used as a solar collector in the summer and the heat is stored in the granitic rock surrounding the four boreholes. In the winter, the stored heat heats the test surface. Measurements were performed between the 14th of May and the 31st of August 2018, which was an exceptionally warm period. The total heat harvested was 17 200 kWh (245 kW h/m^2) with peak values of 20 kW. The calculated solar efficiency of the pavement was 42%. The de-icing operation was conducted between the 15th of October 2018 and the 10th of April 2019. Heat for the HHP system was provided partly from the boreholes and partly from an electric boiler. The total heat supplied to the road surface during the test period was 9175 kWh (132 kW h/m^2) of which 4401 kWh (63 kW h/m^2) came from the boreholes. The electric boiler used 4770 kWh (68kW h/m^2).

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Electric surface heating systems (electric heating cables and mats) were once widely used in Sweden to keep paved areas free from snow and ice, but increasing electricity prices have led to a gradual decrease of such systems. Hydronic Heated Pavement systems, on the other hand, are widely used, covering a total area of some 600 000 m², mainly for pedestrian streets and sidewalks in city centers. These are typically heated with heat from the district heating (DH) return pipe, commonly at a temperature of some 35°C, and require a typical power capacity in the range of 250-350 W/m². Apart from heating pavements, hydronic heating systems are also used to heat artificial turf soccer fields. Approximately 8% of the fields have HHP systems, representing a heated surface area of some 500 000 m² (Andersson et al., 2023). The main heat source is also, in these cases, district heating, but several soccer fields use the ground as a heat source. Backadalen IP in Katrineholm, Täby football arena, Torvalla arena and Kungsängen sports center all use BTES systems and a football field in Hallsberg uses heat from groundwater (Andersson et al., 2023).

Belgium

Belgium has a mild winter climate, and thus the interest in thermal snow melting systems as an alternative to conventional snow removal has so far been limited. There are two pilot projects on hydronically heated asphalt pavement for snow melting in Belgium, both located in Antwerp, of which one research prototype site (heat exchanging asphalt layer - HEAL) at the University of Antwerp is operational and the other is a currently non-operational system in Zonnige kempen social housing complex in Westerlo. The HEAL test site is a 65 m² section of a bicycle path constructed in 2017. It has four heat exchange sections, each 8.5 m x 1 m, and two non-heated reference sections of 30 m². The test surface is connected to a heat pump and buffer tank. The heat pump heat source consists of two 100 meters deep boreholes with single U-tubes and a water-monopropylene glycol mixture. The asphalt HHP system collects solar heat in the summer and is used for de-icing and snow melting in the winter (Ghalandari et al. 2023).

France

The climate in France varies from mild winters in the southern and western parts to more severe winters in the central and eastern regions. Winter road maintenance is done with mechanical and chemical (salt) methods. Thermal de-icing and snow melting are not much used, although electric heating cables are sometimes used for rail infrastructures, football fields, and rarely for pavement. Pavement solar collectors with embedded piping and heat storage in the ground have been developed over the last decade and commercial systems and products are available on the French market. Research on porous layer systems is ongoing. The pavement solar collector systems with and without boreholes and heat pumps have so far been implemented for space and water heating but can be used for solar heat collection combined with de-cing and snow-melting. The cooling of the pavement in summertime increases the service life of the surface.

Italy

The Italian climate is largely characterized by Mediterranian climate conditions but ranges between Alpine climate in the northern and central mountainous regions to mild climate along the coastline and on islands. Snow-removal and de-icing systems in Italy rely on mechanical and chemical (salt) removal. Electric surface heating systems are limited to indoor heating and small-scale uses and are challenged by the high electricity cost and strain on the electrical grid. Italy has an extensive DH network and a promising development of geothermal energy, but there are so far no reported HHP installations for de-icing and snow-melting using either DH, or ground source heating in the country.

Türkiye

The geothermal potential in Türkiye is considerable, with both low-temperature ground sources, and high-temperature geothermal heat. Cetin (2020) estimates the geothermal heat potential in Türkiye as 35 500 MW_t and the geothermal power generation potential as 4500 MW_e. While surface heating is widely used for heating sports fields, using gas boilers or electric heating as heat sources, Türkiye has no examples of ground source de-icing systems so far. 22 football fields

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with an area of about 157 000 m² are heated with hydronic heating systems using fossil fuel as heat source and another ten arenas with a total area of about 71 400 m² are heated with electric cables. Electric heating is also used for keeping pedestrian streets, ramps, roofs, greenhouses, and hospital entrances free from ice. There have been academic studies and laboratory testing of ground-source heated pavements in Türkiye, but so far there are no actual installations. Using BTES or ATES for de-icing and snow melting would also allow for surface cooling in the summer, which would be a valuable service to prolong the lifetime of asphalt and concrete surfaces in the Turkish climate.

Global outlook

Several countries outside of the IEA ES Task 38 collaboration project use thermal de-icing and snow-melting with ground source heating. The use of geothermal water for heating sidewalks and pavements to melt snow during the winter in Iceland has increased over the years and the total area in 2019 covered 1 200 000 square meters, mostly in the Reykjavik area. The total installed capacity was 260 MW and the geothermal energy use was 525 GWh for snow melting in 2019, which is 3.2% of the total geothermal direct use in Iceland (Ragnarsson et al., 2020). According to Yasukawa et al. (2020), geothermal snow melting systems with an installed capacity of 150 MW in total and a heat delivery of 12 GWh were installed in Japan by the end of 2019. They counted 103 geothermal snow melting systems for roads and one for a parking lot in 2019 and this had increased to a total of 106 systems for roads and parking lots in 2022 (Yasukawa et al. 2023). Groundwater, seawater, geothermal water, and boreholes are used as ground source heating for de-icing and snow-melting, with and without heat pumps in Japan. Most applications use HHP but there are also examples of warm water sprinkling systems (Ochifuji, 2000). Chiodi et al. (2020) estimated the installed capacity for geothermal snow melting systems in Argentina to 1.36 MW installed capacity and 8 GWh. Since 1998 the Copahue-Caviahue thermal field has been used for heating streets and roads in the Copahue Village, southwest of Buenos Aires (Pesce, 2000). Geothermal steam at 8 bar pressure and 178°C is used to heat radiant panels that keep the streets free from snow. In Slovenia, there was 1 MW installed capacity providing 4.43 GWh geothermal heat for snow melting by the end of 2019. These systems are installed in three localities in Slovenia: In Lendava a sidewalk heating system uses excess geothermal heat from a thermal water doublet system, at Hotel Vivat in Moravske Toplice there are two geothermally heated football pitches and in Čatež there are another three geothermally football pitches (Rajver et al., 2020). Kepinska (2020) mentions geothermal snow melting systems in two locations in Poland - a heated football pitch and walking paths in Uniejów and a snow melting system for a parking area in the Podhale region. The total installed capacity is 0.5 MW and the heat provided is 550 MWh. In the USA there are several large-scale snow melting systems using the ground as a heat source. Lund et al. (2020) estimate the total installed capacity as 2.1 MW at the end of 2019. Already in 1948 ground source snow melting systems were installed in Oregon in Klamath Falls for a bridge deck (Lund, 1999) and have since been expanded for sidewalks and on a bridge deck leading up to the high school, altogether accounting for some 1.17 MW installed capacity and 1 GWh heating. Additional systems are installed for stairs at the Oregon Institute of Technology camps (0.06 MW) and a steeply inclined state highway section at a traffic signal on a state highway steep hill (0.26 MW) which prevents vehicles from sliding when they stop at the signal. Lund et al. (2020) also list bridge deck snow melting in Laramie (0.06 MW, 300 MWh) and in Cheyenne (0.26 MW, 1.5 GWh) where ammonia heated from a ground temperature of 8°C is circulated in the pipes. Minsk (1999) describes ten bridge deck de-icing systems in the USA, of which two in Oregon and one in Texas use the ground as heat source. Later research efforts on thermal de-icing with ground sources include a heated bridge deck in Oklahoma (Spitler and Ramamoorthy, 2000, Liu et al., 2007a, Liu et al., 2007b). Several airports in the USA have installed ground source de-icing systems, e.g. Greater Binghamton Airport in New York, which has a ground source de-icing system for the airport pavement using BTES (Ziegler and Nixon, 2023). In january 2024 the cAnother example of ground source heated de-icing systems for transport infrastructure, installed in 1994, is the SERSO project near Därlingen in Switzerland (Eugster, 2002, Eugster, 2007, Lund, 2000 and Pahud,

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2007). Solar heat is collected from the road surface, and the heat is stored in a borehole storage in rock, to be used with heat pumps to keep the road free from ice in the winter. In Norway, two examples of geothermal snow melting systems for helicopter landing areas are installed at Gardermoen International airport in Olso and at Taraldrud ski municipality. The boreholes are 1500 m deep and fitted with borehole heat exchangers (BHE). At Gardermoen International airport in Olso, Norway, an ATES system is also used for snow melting at airplane parking areas.

CONCLUSION

Snow melting and de-icing systems with hydronic heated pavements (HHP) have been used in several countries worldwide over the past half-century, mostly utilizing heat sources such as district heating return flow or gas boilers. Examples of geothermal energy sources for HHP systems are fewer but are found for several different applications in Asia, Europe, and the Americas. The IEA ES Task 38 international collaboration project, running 2021-2024, involves six countries and aims to survey the market for ground source heated de-icing and snow-melting systems and provide guidance on design, components, construction, and operation. Ground source heated de-icing and snow-melting systems consist of three parts: the heated surface, the ground source heating, and the control system. While all three parts are individually developed and commercially available techniques, the challenge is to find an energy-efficient, cost-effective, and robust combination of the three.

Two test sites for ground source de-icing and snow melting are used within the Task 38 project. One is a test road surface in Östersund in Sweden (Johnsson, 2019) and the other is a part of a foot and biking path in Antwerp in Belgium (Ghalandari 2021, 2023).

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