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Ground Source De-Icing and Snow Melting Systems for Infrastructure

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Abstract

Thermal de-icing and snow melting methods to control winter conditions on surfaces of transport infrastructure offer several advantages compared to conventional techniques. These include the automated control of safe surface conditions, avoidance of chemicals and their environmental impact and prolongation of the life span of the infrastructure. Hydronic heat transfer systems can take advantage of collection of solar energy mainly during summertime and seasonal storage of thermal energy by geothermal heat exchange. Making use of these renewable resources in combination with energy storage enables savings in primary energy. In June 2021, the International Energy Agency (IEA), initiated a project related to utilization of ground thermal energy sources for de-icing of surfaces in transport infrastructures. The present paper gives a first overview of the project goals and methods.

Keywords: De-icing; Snow melting system;Ground source; Infrastructure

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1. Introduction

Thermal de-icing and snow melting methods to control winter conditions on surfaces of transport infrastructure offer several advantages compared to conventional techniques. These include an automated control of the surface conditions, avoidance of chemicals and their environmental impact and prolongation of the life span of the infrastructures. Generally, snow melting, and de-icing systems are conventionally heated by electrical energy. According to a study by the Ministry of Transport, Energy and Regional Planning of the State of North Rhine-Westphalia, Würtele et al. (2005), in Germany, electricity in combination with electrical resistance heaters is the most common form of energy source. The remaining systems are operated by a hydraulic circuit that is heated with either gas, oil, or district heating.

Melting snow/ice via embedded pipes is not a new method. In 1948, the earliest system was installed in Klamath Falls, Oregon, USA by Oregon Highway Department which used geothermal energy, Pan et al. (2015). Hydronic heat transfer systems, using pavement as solar energy collector, can take advantage of collection of solar energy mainly during summertime and seasonal storage of thermal energy by geothermal heat exchange. Making use of these renewable resources in combination with energy storage enables savings in primary energy. In 1994 a hydronic pavement system that utilized solar energy was installed on a bridge near Därlingen in Switzerland, Eugster (2002), Eugster(2007). The project, SERSO, proved the feasibility of such a system, Pahud (2007). They overcame the obvious problem associated with using solar energy in the winter by merging a seasonal thermal energy storage with a heat pump system. The working principle of the system used in the SERSO project can be divided in three parts: (I) During summer the solar radiation heats the pavement and by the embedded pipe network the heat is harvested and transferred to a seasonal thermal energy storage. (II) The system is dormant when no more heat could be gained from the pavements surface. (III) When there is a need for anti-icing or friction control, the pumps are started, and the stored heat is transferred to the pavement thereby mitigating the slippery conditions, see Fig. 1.

Fig. 1. A hydronic system, utilizing pavement as solar energy collector and seasonal storage by boreholes (Karin Holmgren)

Feasibility studies for north America has been performed based on using the ASHRAE method for designing hydronic pavements Han C et al., (2017). The idea to use renewable energies for safe and ice-free road infrastructures in cold climate was introduced in the papers related to sustainability assessment of infrastructure elements with integrated energy harvesting technologies Bijan Adl-Zarrabi et al. (2016). In 2017 a field station for hydronic heated pavements (HHP) was constructed outside Östersund (63.18 N, 14.5 E) in Sweden. The field station is part of a Nordfou project named HERO (Heating Road with Stored Solar Energy) and the major founders are the Swedish and Norwegian public road administrations. The aim of the field station is to investigate and prove the concept of using hydronic heated pavements in Nordic climate conditions with stored solar energy. The hydronic heated pavement will be used for preventing slippery road conditions in the winter and as an asphalt solar collector in the summer. The results of the measurements obtained from the field station and further analyses indicated that it is possible to utilize a low temperature HHP in Nordic climate Johnsson, J.& Adl-Zarrabi B (2019).

The performance of a hydronic heated pavement system depends on several parameters e.g., climate condition, fluid temperature, pipe distance, thermal properties of the pavement and available amount of energy. The control strategies (fluid temperature) have a large impact on the energy usage as well as on the surface condition of the heated pavement. High energy usage can provide safer surface conditions e.g., in the highway 41, Jönköping, Sweden, where the needed energy is covered by a nearby district heating system. Thus, the performance of the heated pavement system is almost 100%. Performance of a hydronic system based on renewable energy sources without a backup system, as in the field station in Östersund, will depend on available energy, fluid temperature and climate condition. The performance of the Östersund field station was calculated and measured for different controlling scenario, e.g., the system performance was 85%, by using a supply temperature of 4 °C and when the snow cover is 1 cm thick.

1.1 IEA ES Task 38

In June 2021, the International Energy Agency (IEA), technology collaboration program related to thermal storge (ES), initiated a three year long international collaboration project related to the utilization of ground thermal energy sources for de-icing of surfaces in transport infrastructures. The full project name is IEA ES Task 38 - Ground Source De-Icing and Snow Melting Systems for Infrastructure. The goal of the project is to expand the utilization of direct geothermal heating systems or ground source heat pumps in de-icing and snow melting systems for infrastructure. From the experience gained from the construction and operation of the demonstration plants in various climatic conditions, as well as from the experience of existing plants, recommendations are to be drawn up which summarize the essential aspects regarding the planning, construction, operation, and maintenance of geothermal snow melting and de-icing systems. These recommendations will then be the input to national guideline committees.

To achieve the goal of the project the existing knowledge of the experts working in this area will be summarized and further developed by the planned research activities in four work packages. An overview of the state of the art of these systems for different applications in various climate will be worked out, and a study of the market potential for the technology will be carried out by each of the participating countries, in which the market volume of as many relevant applications as possible will be determined.

2. Working plan for-Task 38

The participating countries in the IEA ES Annex 38 are Belgium, Finland, Germany, Italy, Turkey, and Sweden. The activities of Task 38 are divided into four subtasks. The subtasks and their goals are presented in Fig. 2.

De-icing systems with different energy source have been used for many different applications. The outcomes of Subtask1, 'Market potential and State-of-the-Art', is essential for the activities in subtasks 3 and 4 which deal with development of system components and 'design, construction and monitoring' of de-icing systems. Modelling of geothermal energy storage and de-icing systems (subtask 2) is challenging. There is several software for design of geothermal energy storage and usually a software which used for design for a floor heating system can be used for the design of de-icing system. The challenge is to combine the different software and furthermore adding a control system for optimization of the storage during de charging.

More information about the workplan, objectives and activities of Task 38 can be found in the following link: https://iea-es.org/annex-38/.

3. Current status of the subtasks

Annex 38 is still in an early project state, which means that the work within all four subtasks is on-going. The results of Subtask 1, 'Market potential and State-of-the-Art' is the backbone for activities in subtask 3 and 4, while subtask 2 is running in parallel with the other three subtasks.

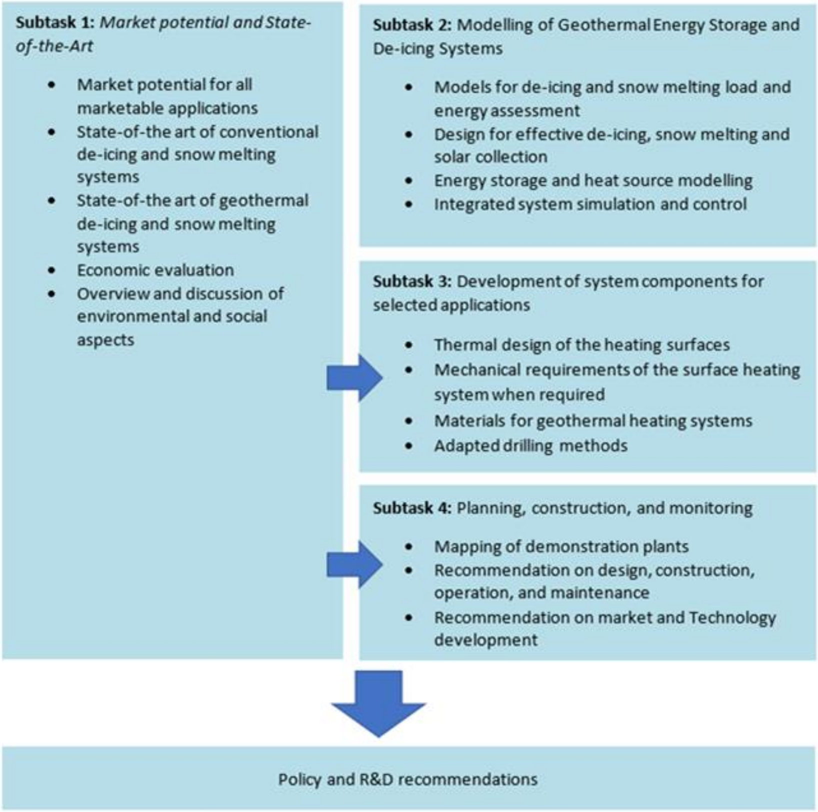

Fig. 2. Subtask and goals of each subtask

3.1 Market potential and State-of-the-Art

De-icing systems may be used in many types of infrastructural applications, including ramps, stairs, entrances, bridge decks, road parts (e.g., between tunnels and at sensitive slopes), biking paths, parking lots, aircraft parking areas, tunnel entrances and sport fields. In Japan geothermal snow-melting systems for pavements, railways and roofs, as well as frost prevention systems have been used for decades. Johnsson (2019) gives examples from hydronic heated pavement applications with a focus on Scandinavian climate. The energy source used for de-icing systems varies depending on available energy sources close to the de-icing system. In urban areas with existing district heating networks (DHN) the return flow from the DHN may be used as energy source for de-icing. In rural areas, however, the available energy sources are more limited and geothermal energy may be the only option. In many cases utilization of renewable heat, such as geothermal energy or surplus energy, provides a more environmentally benign de-icing alternative. Within the subtask 1 the participating country are currently composing national state-of-the-art and market overviews as input to the overall state-of-the art report. State of the art for existing technologies and applications that cover both conventional (using electricity or district heating as energy source) and geothermal de-icing systems will be covered. Also economic, environmental, and social aspects of a de-icing systems are reviewed.

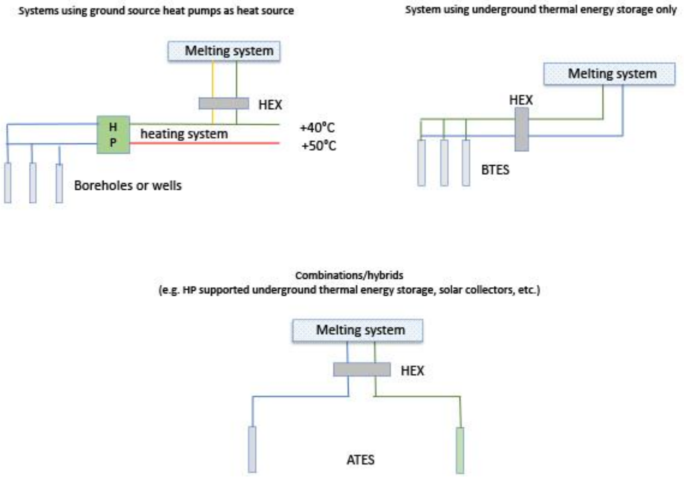

Fig. 3. Three generic examples of ground-coupled snow melting and de-icing systems that are used.

As for the geothermal energy applications, de-icing and snow melting systems using ground source heat pumps (GSHP) as well as borehole thermal energy storage (BTES) and aquifer thermal energy storage (ATES) will be included. The work within subtask 1 is on-going and a draft report is planned for August 2022. Figure 3 shows three examples of generic ground source de-icing and sow melting systems that are in use in various applications.

In Germany a surface heating system is developed using a two-phase-thermosiphon as borehole heat-exchanger. The basic concept of the surface heating system is illustrated in Fig. 4. The condenser section of a two-phase-thermosiphon is part of the first or second layer of the surface. It is connected to one or more boreholes through pipes that have to be installed at an inclination angle of at least 2 degrees towards the borehole so that the liquid phase can flow back to the heat source. The evaporator of the system is in a borehole with depths of 30 up to 100m. Up to 10 evaporator pipes are placed into one borehole. Depending on the size of the heated area, the thermo-physical properties of the ground and the depth several boreholes are necessary to supply the heating system.

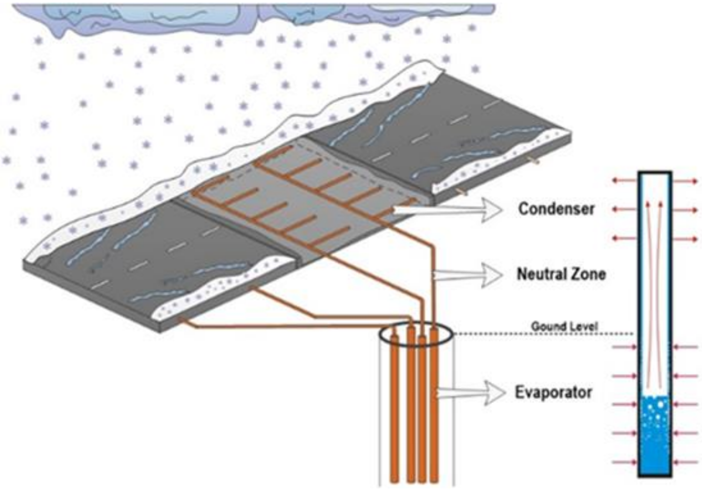

Figure 4 Concept of the surface heating system

The system starts to heat if the temperature in the condenser is getting colder than the refrigerant in the borehole. It stops to heat when the temperature in the condenser is equal or higher than the refrigerant in the borehole. The system is therefore completely self-controlled. There is neither need for an auxiliary energy supply nor for any controlling device.

3.2 Modelling of geothermal energy storage and de-icing systems

In a literature survey, models to simulate borehole storages, heat pumps, and system components like water storages, hydraulics and building loads are explored Persson and et.al. (2016). There is several software which can be used for design of a ground source heating systems, e.g., EED, TRNSYS, Polysun, Modelica, IDA ICE, and Matlab/Simulink+Carnot. The scopes and limitations of the software and models are evaluated and the advantages and disadvantages with the software are addressed. It was found that the user-friendliness is strongly linked to the level of flexibility in the models. Higher flexibility usually means less user-friendliness and more time to learn the tool. The models covering most of the aspects of borehole simulations are the TRNSBM-model in TRNSYS and the "INTERACT 2016" model for Modelica Persson and et.al. (2016).

Research on Hydronic Heated Pavements (HHP) has been performed since the introduction of the technology in 1948 in Oregon, USA Lund (2000); Panet al. (2015); Magnusson (1977); Adlam (1950). The hydronic heated pavement consists of a pipe network embedded in the pavement. A warm fluid is circulated in the pipes thereby facilitating the transport of thermal energy into the pavement. Frequently used energy sources are boilers or district heating, which reduces the environmental gains or restricts the sites suitable for hydronic pavement systems. Further reductions of the environmental impact can be achieved if HHP systems used renewable energy sources.Solar thermal energy is a renewable energy source that is available in abundance. In 1994 a hydronic pavement system that utilized solar energy was installed on a bridge near Därlingen in Switzerland Lund (2000); Eugster (2002); Eugster (2007). This project, SERSO, proved the feasibility of such a system Pahud (2007).

A software, HyRoSim, developed by Josef Johnsson, Bijan Adl-Zarrabi (2020) which combines a numerical model for the HHP and a modified numerical borehole storage model Pygfunction. The finite difference model (HyRoSim) calculates the pavement and fluid temperatures for each time step, and Pygfunction updates the supply temperatures to the pavement based on the hourly heat load of the storage. It is therefore possible to predict the fluid and pavement temperatures as well as the surface conditions of the system. HyRoSim can be used for further developments to study the heat transfer and the surface condition of the selected application.

3.3 Development of system components for selected applications

Integrating an additional component, like a pipe network, into the pavement is a challenge since it introduces a new, unknown, feature from a structural point of view. However, the experience of ASC (Apshal Solar Collector) and HHP (Hydronic Heated Pavement) are increasing. There are several studies and installation from which experience can be gathered.

The structural aspects and maintainability of the road is of the most important challenges when designing an HHP system. The pipes should not put the road construction at risk. The depth of the pipes is governed by the possibility to replace the wearing layer as well as the structural durability of the pipes. It is recommended to have a wearing layer of 5 cm and to place the pipes in an intermediate layer of about 5 cm, with the pipes positioned in a plastic mesh that keeps the pipe in position but also acts as a reinforcement for the pavement (Vossebeld 2018).

There are different materials available for producing the pipes necessary for the HHP. Each material comes requires special considerations. However, the selection should be based on the durability, workability, thermal characteristics, and cost of material. The most common material that is used are plastics like PEX pipes. The main draw back for PEX is the low thermal conductivity, but this is compensated for by the durability (no corrosion), ease of installation and low cost.

Fig. 4. Using plastic mesh for positioning the pipe. (www.ooms.nl)

Structural response from emending pipes and cables in pavements were presented in Liu et al. (2018, 2019, 2021); van Vliet et al. (2005); Zhou et al. (2021). The recommended depth is 75 mm and spacing is 100 mm Basheer Sheeba and Krishnan Rohini (2014).

The report of this subtask describes the procedure, the main results and experience in the development of these components. The main questions are the structure of the heating elements on the surface, mechanical strength but also which materials can be used and which drilling methods should be used. The report of the subtask will include the following items, thermal design of the heating surfaces, mechanical requirements of the surface heating system when it is required materials for geothermal heating systems and, adapted drilling methods for sandy unconsolidated soils near railways or roads.

3.4 Planning, construction, and monitoring

Across the world there are several pilots and demonstration plants in operation. Each of these plants focus on different aspects and challenges. However, there is also an overlap in what is tested. To identify what should be further investigated, information from different demonstration plants will be gathered through interviews and meetings. The information will consist of e.g., design, construction, cost, performance, and challenges encountered. This will make it possible to compare different demonstration plants regarding functioning but also to learn from the development process of these plants.

4. Outlook and future work

The detailed results and the report related to ‘Market potential and State-of-the-Art’ will be presented in September 2022. Based on the report, several applications will be selected for further investigations in subtasks 2.4.

The selected application will be analyzed by existing numerical methods. If the existing models are not adequate for analyzing the select application, new/or modified will be developed in the frame of task ‘Modelling of geothermal energy storage and de-icing systems’

Materials and components needed for design and operation of the selected HPP applications will be identified. Thermal design of the heated surfaces, mechanical properties of the embedded pipes in the pavement, materials for geothermal heating system will be described.

Finally, the output from the Subtask 1-3 and gather information from demonstration plants across the world will be presented as recommendations on design, construction praxis, operation and maintenance of the current systems and future needs for further development of HPP technology development.

5. Discussion

The heated pavement systems have been used in many applications e.g., road infrastructure. The systems are conventionally heated by electrical energy. Replacing electricity as energy source to renewable energy such as geothermal energy will increase the sustainability of a heated pavement system. Several projects have used hydronic systems based on geothermal heat exchange. To expand utilization of hydronic systems, requires guidelines concerning, calculation procedures, components specifications and system optimization. The results of the Annex 38 can be the first step for creation of the guidelines.

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