Symposium on Energy Geotechnics
Accelerating the energy transition
3-5 October 2023, Delft, the Netherlands

Peer-reviewed Conference Contribution

Thermal and structural response of a pavement solar collector prototype

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The last two decades have seen a growing trend toward energy harvesting technologies from asphalt pavements, mainly to discover a suitable replacement for fossil fuels to tackle the high demand for energy due to global population rise, urbanization, and environmental problems. Energy extraction from asphalt pavements, using Pavement Solar Collector (PSC) systems, is one of the most highly promising technologies. This is due to their extensive availability including in roads, cycle lanes, parking lots, airports, in addition to their great potential to absorb solar radiation. PSCs (also called hydronic asphalt pavement) circulate water or other liquid, through the pipe network that is embedded in the asphalt pavement. The primary aim of PSCs is to extract heat from the asphalt pavement in the summertime and use the harvested heat to provide snow/ice-free asphalt surface and prevent black ice formation. The PSC systems could potentially improve road safety, reduce the need for de-icing chemicals, and provide energy-efficient outdoor heating [2]. The heat source for PSCs can be from a central boiler or a renewable energy source such as solar thermal or geothermal. As a result, the system can be designed to be energy-efficient, reducing the overall energy consumption and carbon footprint of the roads.

The large-scale research prototype of the Heat Exchanging Asphalt Layer (HEAL) was designed and constructed on a bicycle path at the University of Antwerp's Groenenborger Campus to investigate the thermal and structural performance of the PSC systems. The total area of HEAL is nearly 65 m^2 (14 m x 4.6 m) with four heat exchange sections (8.5 m x 1 m each) and two reference sections of 30 m^2 (i.e. without the heat exchange layer). The HEAL system has four main parts: the heat exchanger section, technical unit, borehole thermal energy storage, and control system (see **Figure 1**). The heat exchanger section was designed and configured into four interconnected sections in order to provide different scenarios, including series, parallel, full power, partially activated, depending on the project settings and purpose (e.g. harsh snow or freezing temperatures) [1].

The energy harvesting efficiency of PSCs has been estimated to be mainly between 20%-30%, reaching to a maximum of 50% [3; 4]. The results of the experimental tests on the HEAL prototype indicated that the series configuration achieved around 20% efficiency, while it was 25% for the parallel configuration, and could theoretically reach a maximum of 34%. With respect to annual energy gain, recent studies reported that the PSC efficiency has a wide range between 0.6 and 1.21 GJ/m^2/year [5; 7]. Finally, it was concluded that the energy harvesting capability of large-scale PSCs is not only determined by the geometrical properties and geographical location of the installed systems, but also by the operational conditions such as fluid flow and weather parameters [1]. The required heat energy for snow-melting asphalt surfaces strongly depends on the weather parameters of the cold season. Hence, PSC systems use 100 to 900 W/m^2 of collected heat to provide ice/snow-free surfaces. In a recent study, a set of systematic experiments were designed and performed in the HEAL prototype to assess its seasonal energy balance. The output results demonstrated that the maximum hourly heat extraction rate was 91 W/m^2, compared to the average hourly power consumption of 15.2 W/m^2 to provide ice-/snow free road surface. Although the experiments of the study took place over a limited number of days, a comparison between average heat gain and power consumption showed that applying a low-temperature supply in wintertime could save above 80% of the collected heat in the summertime for the same number of operational days [1]. As a result, the remaining excess low-temperature

DOI: https://doi.org/10.59490/seg23.2023.511

heat in the storage can be used for various applications, such as providing (preheated) domestic hot water and heating to nearby buildings.

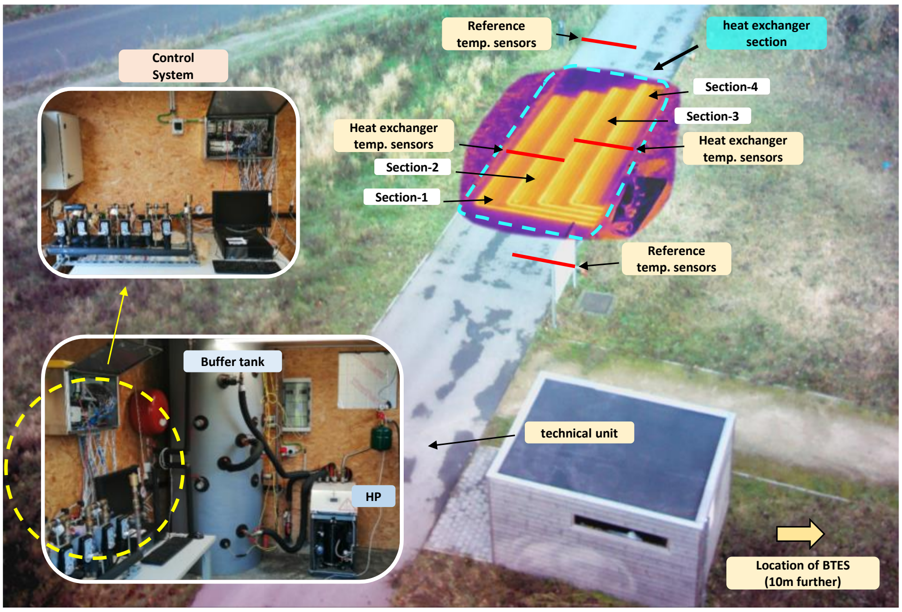

Figure 1: The layout of the HEAL prototype, showing the heat exchanger sections, location of temperature sensors, details of the technical unit, and control system.

In terms of the structural performance, the application of PSCs can reduce the temperature gradient of the asphalt pavement, thus increasing the service life of the pavement. Mallick et al. [6] claimed that the service life of the pavement could be extended between 3-5 years by using PSC systems. Furthermore, controlling the temperature profile of the asphalt pavement could potentially reduce pavement distresses, such as top-down cracking, rutting and fatigue cracking [1]. One of the main challenges in the design of PSC systems is related to the appropriate structural and geometrical designs to ensure that the potential structural damages are in an acceptable range for roads. The pipe depth is a key design parameter to fulfill a balanced trade-off between harvesting maximum heat (pipes closer to the surface) and minimum structural damage (pipes deeper in the asphalt layer). The ongoing and future research on the structural performance of the HEAL system includes: i) comprehensive assessment of the asphalt pavement service life, using field data and multi-layer elastic models ii) evaluation of the asphalt pavement's rutting and shear failure in the laboratory for samples with and without HEAL.

Contributor statement

Taher Ghalandari: Conceptualization, Methodology, Writing- Original draft preparation. Alalea Kia: Supervision, Writing - Review & Editing, David Taborda: Methodology, Writing - Review & Editing. Cedric Vuye: Writing - Review & Editing, Project administration.

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