Analysis of Asphalt Solar Collectors Using a Finite Element Approach

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Abstract

Current trends of research aims at the reduction of conventional fossil fuel consumption so as to mitigate anthropogenic global warming and thus to combat with the climate change. This can be done by shifting to more efficient, alternate, non-conventional and environmental friendly energy resources. This necessity encourages the research community to develop alternate and reliable sources of energy.
Every day asphalt concrete road surfaces absorb significant amounts of solar radiation, up to 40 MJ/m² over the course of a day during summer, which causes high temperatures in the pavement structure. This heat energy can be harvested using a heat exchanger system embedded in the pavement structure. The heat exchanger fluid cools down the pavement, thus extracting energy, which could potentially be used for different purposes: production of domestic hot water, building heating or even cooling of buildings via adsorption cycles, de-icing etc. Such a system is often referred to as a pavement solar collector (PSC). In this research, the use of a heat exchanging asphalt layer (HEAL), as a means to extract low temperature heat from the pavement, is studied in detail.

The main objective of this research is to develop a modeling framework for the PSC system using COMSOL Multiphysics® software and validate it with a self-instructed laboratory experiment. Such a model will allow for a detailed parametric study of the system and to optimize the design on the performance of the system. A long-term energy output of the system that is currently lacking is calculated based on results of the study on weather parameters.

In this study, the geometry of the PSC consists of a number of horizontal pavement layers, one of which contains at least one pipe loop that acts as a heat exchanger. The entire PSC is modeled in 3D using finite element techniques. In this model PSC is simulated using the Heat Transfer Module and the CFD Module in the COMSOL Multiphysics® software. Even though the CFD Module is used in 3D geometry, certain assumptions and simplifications regarding the fluid flow (laminar flow) through the pipe of heat exchanger are made to reduce the computation time. The input data are thickness of the layers, material properties and effective evolutions of climatic parameters (i.e. temperature and humidity of ambient air, solar radiation, sky temperature, wind speed). The outputs are the profiles of temperature fields along the depth of the slab ant its soil sub-base. Some evolutions are computed at particular depths corresponding to sensors positions, in order to be compared with the measure.

It was found that the experimental data and the modeling framework are in good agreement with respect to fluid outlet temperatures and pavement temperatures. The model can, therefore, be used to evaluate possible benefits of the system on pavement life and to help analyze the use of the generated heat energy. The goal of this study was to determine the potential output and efficiency of this technology as a function of location, weather and design parameters.

Figures used in the abstract

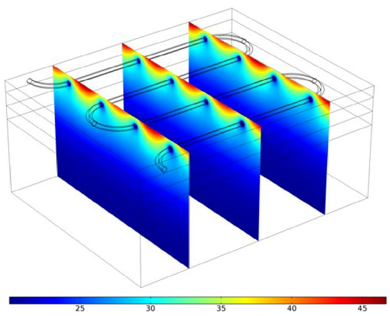

Figure 1: Example of temperature field during operation of the system.