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# Field evaluation of the effects of air convection in energy harvesting asphalt pavements

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ABSTRACT

In this article, the performance of a convection-powered air flow through an asphalt prototype pavement is investigated in a field test. An asphalt prototype pavement with pipes buried in its aggregate layer was connected to a constant temperature heat source and installed at the University of Nottingham, UK. In the experimental configuration chosen, air at 15 °C was free to flow through the prototype pavement by natural convection and exit through a vertical chimney. The natural convection flow was meant to cool down or heat up the pavement based on the temperature gradient between the pavement surface and the air in the pipes. The experimental setup included a weather station and aimed to analyse the effect of the heat fluxes from and to the air in the pipes on the development of the surface temperature.

The experimental results produced a large dataset, which was analysed based on physical and statistical principles to provide guidance for future studies in the field. The system designed was able to provide pavement heating and cooling effectively in a real life environment. The maximum extent of the heating and cooling effects was quantified as ±5 °C.



## 1. Introduction

The durability and reliability of the road infrastructure is influenced by the variation of its surface temperature, as high or low values of this parameter are responsible for softening or embrittlement of the asphalt wearing course. When the surface temperature of asphalt pavements is high they become susceptible to rutting [1] and the ageing process is faster [2]. On the other hand, when the temperature is very low, the formation of ice on the pavement constitutes a hazard for vehicles [3,4] and the risk of fatigue failure is increased [5]. In the scientific literature, many ways have been considered to fight these issues. If the surface temperature of an asphalt pavement is expected to become too high the properties of the chosen mix may be changed, e.g., thermal conductivity, specific heat capacity, albedo, or emissivity (see for example [6–8]). In the case of low pavement temperatures, the focus is usually on trying to prevent ice formation, thus, chemical substances are spread on the asphalt surface [3,4]. A less common option, though occasionally used, is to install piping systems under the pavement surface and to circulate hot fluids through them, thus, aiming at increasing the material's temperature [9,10].

The authors have recently tried the use of convection-powered air flows to manage the temperature of pavements [11–13], both experimentally and computationally. The use of air as the operating fluid in the place of liquids comes with advantages, i.e., the independence from electric machinery for the circulation of the fluid and the safety in the case of the rupture of pipes [14]. However, air is known to have worse heat transfer properties than water or other operating fluids, thus, its effectiveness is usually lower for pavement heating and cooling [11]. Nonetheless, the authors showed that the use of convection-powered systems allows to both cool down a hot pavement [11–14] and to warm up a cold pavement [12]. Based on the previous experimental results obtained, the authors used the equipment called the ground source heat simulator introduced in [12] to generate a convective air flow through an asphalt pavement in the attempt to manage its temperature with varying weather conditions.

Therefore, the aims of this paper are (i) to assess the reliability and the potential of this thermal pavement evaluation equipment when installed in the environment, (ii) to verify the representativeness of the previous experimental observations through a field test, and (iii) to assess the influence of actual weather conditions on the performance of the system.

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## 2. Methodology

### 2.1. Experimental setup

In this paper, the experimental setup known as the ground source heat simulator and introduced in [12] was used (see Fig. 1). Such an experimental layout is meant to simplify the shape that an air-powered energy harvesting system could have in a real-life installation. In [12], the authors hypothesised that an inlet pipe could enter the soft shoulder of an asphalt pavement at a certain depth, then rise closer to the asphalt wearing course, and, finally, exit the pavement through an updraft chimney. The chimney could be, e.g., a traffic sign post or any other component of the road infrastructure with a similar shape and position relative to the pavement.

The ground source heat simulator comprises two main parts, i.e., an energy harvesting prototype pavement and a steel cabinet. The size of the pavement prototype represented in Figs. 1 and 2 is 470 mm × 700 mm × 180 mm [12]. The pavement prototype consists of two layers, i.e., a 50 mm-thick asphalt wearing course (limestone, maximum size 11 mm) and a 130 mm-thick aggregate layer (coarse limestone gravel), where the pipes allowing the air flow are installed.

In the steel cabinet, a vertical pipe called the inlet pipe was installed to connect the environment to the inlet air box (see Fig. 2). In order to simulate the presence of a geothermal source, ceramic heat emitters were pointed at the inlet pipe and connected to a thermostat to provide air at a controlled temperature of 15 °C inside the inlet air box. This temperature was chosen because it is representative of a typical geothermal source [15]. It is worth pointing out that such an inlet temperature is based on the assumption that the inlet air would be at thermal equilibrium with the surrounding soil. While this is not very likely for a dynamic and convection-powered system, no data on real inlet temperatures was available for this type of energy harvesting pavement (due to its novelty) and an approximation was required. Consequently, we recommend that this aspect is addressed in the future, when data availability will be higher and more accurate hypotheses will have been formulated.

As seen in Fig. 2, the air flows from the inlet air box to the energy harvesting prototype pavement, which is placed right next to it. The energy harvesting prototype consists of an asphalt wearing course, under which a set of 13 steel pipes are installed along with limestone gravel [11]. The pipes outlet into a second mixing box, which, in turn, is connected to the environment via a 1 m long vertical chimney. At the chimney outlet a small cowl was installed to allow air to exit the system but also to prevent water infiltration.

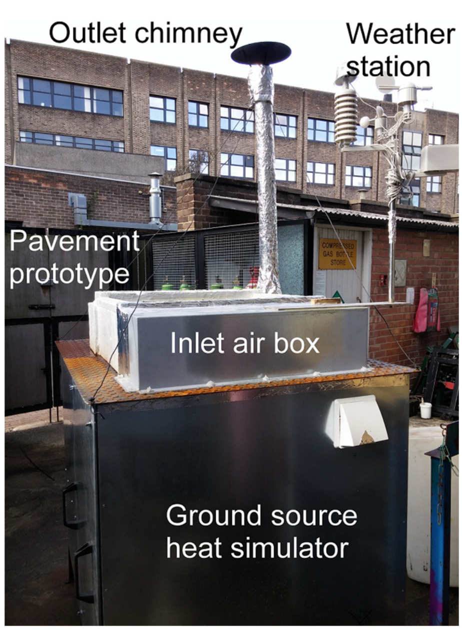


**Fig. 1.** Photograph of the experimental setup.

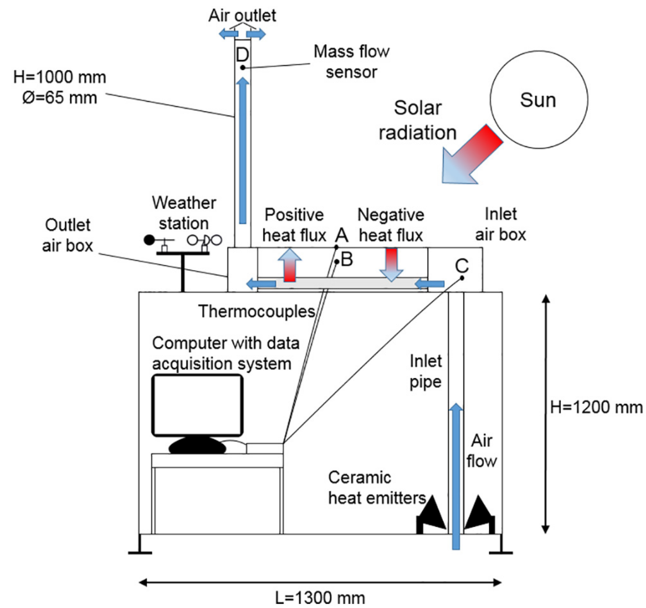


**Fig. 2.** Scheme of the experimental setup used with position of the thermocouples and the mass flow sensor, adapted from [12].

The steel cabinet was highly insulated, so that the environmental conditions (e.g., weather, precipitation, etc.) could not influence the operation of the ceramic heat emitters. A control asphalt slab with no energy harvesting pipes was monitored along with the prototype pavement to show the effect of the experimental setup chosen.

The ground source heat simulator was installed in the University Park campus at the University of Nottingham, UK. As a result, it was exposed to varying weather conditions and day/night cycles. In particular, during the day the combined effect of the sun's radiation and thermal radiation from surrounding buildings was expected to heat up the prototype pavement, thus, causing an energy flux from the pavement to the air in the pipes (negative heat flux for the pavement). In contrast, during the night or cold periods the pavement temperature was expected to decrease and, in this case, the pavement would receive energy from the warmer air flowing through the pipes (positive heat flux for the pavement). The presence of these heat fluxes was verifiable by comparing the surface temperature of the prototype pavement to that of the control slab installed next to it.

### 2.2. Measuring equipment

In order to monitor the behaviour of the system a number of measuring tools were used. To begin with, K-type thermocouples (see Fig. 2) were used to record the temperature evolution on the prototype pavement surface (point A), at 50 mm from the surface (point B), in the inlet air box (point C), and on the surface of the control asphalt slab (not shown in Fig. 2). In addition, an IST FS5 thermal mass flow sensor was used to monitor the wind speed at the chimney outlet (point D in Fig. A). The sensor was connected to an electronic board to enable datalogging through an OMEGA OMB-DAQ-54 datalogger.