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Renewable energy combined with sustainable drainage: Ground source heat and pervious paving

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ABSTRACT

Taken individually, Ground Source Heat (GSH) pervious paving systems (PPS) and rainwater harvesting are not new, but in combination, this energy–water blend is relatively recent. Sealed with impermeable geomembrane, PPS becomes a water harvesting tank and by installing GSH collectors in the base, there is the potential to sustainably heat and cool buildings, provide flood resilience and improve water quality.

A review of the literature found that Coefficients of Performance suggest that such systems could be considered viable, reaching the value of 2.875 required by the EU Renewable Energy Directive, 2009. Small-scale laboratory-based test rigs of the combined system were able to reduce pollutants by up to 99% for biological oxygen demand and 95% for ammonia-nitrogen, with rare occurrences of potentially pathogenic bacteria e.g. *Legionella*, and low survival rates of *Escherichia coli*.

Whilst test rigs provide valuable information, field monitoring at the building scale is the only way to validate the technology. Thus, this paper presents previously unpublished results of monitoring a combined system at the building scale which found that there is clear potential to use a clean, renewable and sustainable source of heat at the same time as providing flood resilience, water quality improvements and some amenity in a domestic setting. However, it was also found that seasonal changes and building use affected levels of comfort achievable. Lessons were learnt, such as construction strategies to optimise design, including depth of the heat collectors and the optimal surface area of the PPS available to infiltrate water.

1. Introduction

In order to provide resilience to the effects of change and for it to be sustainable in the long term, interventions need to have multiple benefits and be flexible. Simply addressing individual or relatively few outcomes is inefficient and restrictive in terms of the impacts. This paper has two principle foci: the provision of a renewable, sustainable source of energy coupled with resilience to flooding at the building scale.

Global demands for energy, a large proportion of which is used for electricity [1], are increasing and are likely to continue to do so. Factor in such concerns as the likely depletion of fossil fuels, upon which much of the world depends for its' energy, associated pollutant emissions such as the increase in Greenhouse Gas (GHG) emissions which Li and Lin [2] estimated to have increased by 80% between 1970 and 2004 and De Boeck et al. [3] predict will rise by a further 52% between 2005 and 2050, as well as the far-reaching impacts of global climate change, and a scenario is created whereby seeking alternative sources of energy becomes urgent [4,5]. Many governments are encouraging the use of renewable energy, and in February 2014, the European Parliament voted to increase the percentage of Member States' energy to come from renewable sources from 20% to 27% by 2020. Shafiei and Salim [5] suggest that investing in renewable sources of energy in general has the potential to reduce GHG emissions, CO_2 in particular. An abundant and constantly renewable source of energy is that from the ground, or Ground Source Heat (GSH), the extraction of which is said by Self et al. [1] to be relatively easy. In a review of the systems used for extracting and concentrating this heat (GSH Pumps, GSHP) Omer [4] states that it is: "highly efficient renewable energy technology" which can be used for both heating and cooling buildings. Whilst when extracted, the temperature of this heat is relatively low, once concentrated [1,4] the heating it provides is "environmentally and economically advantageous" [1]. Omer [4] also suggests that GSHPs are suitable for any kind of building worldwide, and are particularly suited to underfloor heating. Furthermore, specifically extracting GSH has the potential to reduce CO_2 emissions and hence mitigate the impacts of climate

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Abbreviations: GHG, Greenhouse Gas; GSH, Ground Source Heat; GSHP, Ground Source Heat Pump; PPS, Pervious Paving System; SuDS, Sustainable Drainage System; WWTW, Waste Water Treatment Works

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change [6]. Whilst using this technology has been predicted by Bayer et al. [6] to save up to 30% of GHG emissions in comparison with conventional heating methods across Europe, this is dependent on the efficiency of the pump, the electrical mix and the substituted heat. These potential savings are country-specific and depend on a saturated market for the technology and the use of renewables (e.g. solar or wind) to provide power for the pump. A problem with their use in dense urban settlements may be a lack of space; thus the ability to integrate it with other technologies to provide multiple benefits and flexibility in application needs to be explored.

Extraction of GSH is particularly flexible in that it can be harvested from the soil and also surface waters, such as rivers, streams, lakes and wetlands [7]. It can also be installed vertically using boreholes, or horizontally in the form of slinky coils laid in the bottom of a trench. However, vertical boreholes are expensive, and horizontal slinky coils require a reasonably large area to be excavated [4], which might limit their use, particularly in dense urban areas. If integrated with Sustainable Drainage Systems, or SuDS [8], there are opportunities for horizontal slinky coils to occupy the space already provided by a variety of individual devices and management trains. SuDS mimic nature in order to address the impacts of urbanisation on the storm hydrograph of short reaction times and “flashy” catchment responses, leading to flooding and pollution. They achieve this by allowing water to infiltrate or be stored and then conveyed slowly to the receiving watercourse [8,9] utilising hard infrastructure, such as Pervious Paving Systems (PPS) or vegetated devices, such as swales, filter strips, wetlands, green roofs and walls [10,11]. PPS are hard infiltrating structures which provide running or parking surfaces for vehicles as well as pedestrian pavements [12]. They are particularly well suited to hosting a GSHP as they require a trench in which the pump can be installed, and furthermore, if the PPS is used as a parking space to the front of a property, they will not use any extra space.

Neither GSH nor SuDS are new approaches taken separately, however designing them together, making use of a renewable source of energy as well as finding a secondary use for excess surface water which would otherwise be directed to the storm sewer, is relatively new, and a timely development. In fact, Tota-Maharaj and Paul [13] call this infrastructure the “next generation” of PPS. Laboratory experiments with model test rigs have indicated the potential for this technology, but there has been very little information published at the building scale. Previously unpublished data from a combined GSHP and PPS system in a domestic setting are presented, which enables a thorough critique of these approaches to be achieved, with further recommendations made, based on their combined potential.

2. Pervious paving systems and ground source heat

PPS attenuate the storm peak by reducing water quantity and slowing water flow, but also improve water quality as well as providing some amenity benefits [14]. By reducing the volume of water needing to be managed by the storm sewer system and consequently passed through the Waste Water Treatment Works (WWTW) [8], there are positive changes in the hydraulics of the sewer; the frequencies of overflow and their durations are reduced, and ultimately the fraction of wet weather flow that arrives at the treatment plant [15]. Taken overall, these effects will reduce the energy required to treat this excess water and hence reduce GHG emissions [16].

The surface course of PPS can comprise permeable block pavers, porous asphalt, concrete or resin, generally with the underlying bedding layer divided from the coarse aggregates beneath by means of a geotextile (see Fig. 1). Further details of the various PPS structures and their functions in terms of water quantity reduction, water quality improvements and amenity provision can be found in [9,12,14].

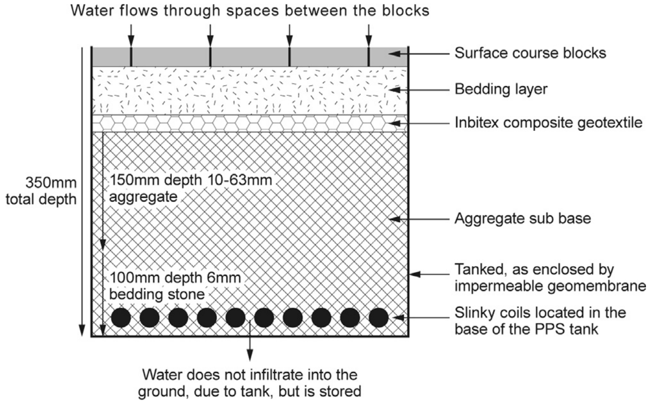

Fig. 1. Cross section through the combined GSHP+PPS at the Ecohouse, Building Research Establishment, including siting of the geotextile and geomembrane tank.

PPS are usually no more than 500 mm deep, and can be “tanked”, or sealed, by means of an impermeable membrane, enabling them to harvest incident rainfall, roof or surface water runoff, hence providing a suitable environment for the installation of heat collectors. Below 3 m depth in the ground, the temperature only varies between 6 and 13 °C throughout the year [17]; however, at approximately 500 mm below the surface, within the aggregate sub-base of the PPS, the temperature is affected by seasonal temperature changes, as was found by Novo et al. [18]. It is still perfectly possible to harvest this shallow heat by means of a liquid, usually an ethylene glycol mix (anti-freeze) or sometimes brine, contained in pipes which circulate the heat into the building via a pump into a radiator system or underfloor heating (heating cycle) [4]. It is also possible to return heat to the ground store in times of excess in a building (cooling cycle). By keeping the buried heat exchanger apparatus wet, by means of harvesting rainwater, heat removal or return is more efficient since heat is transferred from water more effectively than from either air or soil. The finding that relatively wetter conditions have a positive effect on the performance of a GSHP has been supported by results obtained in other studies such as Tarnawski et al. [19].

The distribution of heat in PPS at the field-scale suggested that evaporation of water within the sub base, and the thermal properties of the surface course were the most important factors in designing a combined GSHP+PPS [18,20,21]. Application of these properties has resulted in the development of “cool” or “wet” pavements (e.g. [8,22,23]) achieved by designing the surface of the PPS so that it more efficiently transferred solar energy down into the structure, thus enabling evaporation to occur e.g. by making the surface a lighter colour. By applying cool pavement technology to GSHP+PPS the transfer of heat from the overlying atmosphere could be made more efficient, improving the performance of the combined system overall. Modelling of temperature and energy balances in these paving systems by Tota-Maharaj et al. [24], further developed the ability to optimise the design of the heat extracting PPS by determining slinky coil size, tank volume and energy efficiency.

3. Water quality at the laboratory scale

The main focus for laboratory-based experiments of the combined system were concerns regarding the impact on water quality of harvesting heat in the sub-base of a PPS [13]. Standard water

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