Multiple Benefits Derived from the Installation of Permeable Pavement Systems

Les bénéfices multiples dérivés de l'installation de systèmes de chaussées poreuses

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RÉSUMÉ

Les chaussées perméables offrent un avantage supplémentaire dans les zones de collecte et de stockage d'eau de pluie. Le recyclage de l'eau de pluie obtenue au moyen de chaussées perméables réduirait le besoin d'adduction d'une eau de qualité supérieure pour un usage nécessitant de l'eau de moindre qualité comme les chasses d'eau, le lavage de voitures, l'irrigation, etc. Cet article traite de divers projets de recherche au Royaume-Uni, réunissant des aspects multiples tels que la quantité et la qualité de l'eau et des considérations sur l'utilisation de la ressource en eau pour aboutir à la solution du système unique de chaussées perméables. Cette étude a été réalisée au moyen de plusieurs études de cas, afin de montrer comment de tels projets ont été exécutés en parallèle avec des systèmes déjà installés comme décrits ci-dessus, et comment ces systèmes répondent aux objectifs fixés par la législation britannique en termes d'impact sur l'environnement.

ABSTRACT

The pervious pavement system (PPS) has the potential to offer additional benefit in the areas of rainwater harvesting and storage. Recycling rainwater using the PPS would reduce over dependence on high quality mains water for low grade uses such as flushing of toilet, car washing, irrigation, etc. This paper focused on diverse but complimentary UK research projects that have brought together water quantity, quality and resource use considerations to provide a solution within a single permeable pavement system. A selection of case studies was used in this study to demonstrate how these projects have run alongside the installation of schemes that have put the theories outlined above into practice and how these schemes fulfill UK legislative targets on Environmental Impact.

KEYWORDS

Permeable Pavement System, Irrigation, Water Recycling, Ground Source Heat Pump (GSHP), Water Storage

1.1 Introduction

Permeable Pavement Systems (PPS) are tried and tested solutions for managing large volumes of urban runoff and they also address the problem of diffuse pollution from vehicles and other human activities (Newman et al, 2005).

Recent research has shown that there are environmental and economic benefits in using PPS as a secondary water resource based on rainwater harvesting, (Nnadi et al, 2009, Gomez Ullate et al, 2009) and PPS can even be used to provide a solution for the heating strategy in a building, (Coupe at al, 2009).

This paper will focus on diverse but complimentary UK research projects that have brought together water quantity, quality and resource use considerations to provide a solution within a single permeable pavement system. A selection of case studies will demonstrate how these projects have run alongside the installation of schemes that have put the theories outlined above into practice and how these schemes fulfil UK legislative targets on Environmental Impact.

1.2 Water provision by Tanked PPS

The reservoir structure beneath an impermeably lined PPS, is an area that is ideal for providing void storage to attenuate flow from a development, but also to trap the water for rainwater harvesting. As a general rule, a total pavement depth of 500 mm can provide 1000 litres of water within 10 m^2 of paving. In practice, this resource is often used in both domestic and commercial schemes to provide the non-potable water for a building. When using rainwater and not grey water, the quality of this water, stored within the tanked area is of very good quality, and is as safe to drink statistically as treated tap water as shown in a very recent study by Monash University in Australia (Science Daily, 2009).When assessing the volume of water that can be saved by PPS storage, this is highly dependent on the time of year, particularly where the PPS is linked to an outside tap for watering gardens and washing cars. As these uses for the water are unpredictable in terms of the volumes required and the regularity of demand for them compared with interior uses such as toilet flushing and the feed for washing machines, the savings to the user of a rainwater harvesting system vary, but some guidelines are presented below.

The table is based on summer average water use as defined by the Water Research Council UK for standard and best practice houses by a family of four. In this example, the toilet and washing machines and the outside tap are linked to the PPS reservoir. The volumes for interior and exterior use display the water that can be provided by the PPS reservoir.

Table 1. The Contribution of PPS Reservoirs to UK Interior and Exterior Daily Water Use

Quantity	Standard practice house (212 L/person/day)	Best practice house (90 L/person/day)
Interior water use from PPS (Litres/person/day)	52	30
Water saved by PPS (%)	25	33
Exterior water use from PPS* (Litres/person/day)	90	90
Water saved by PPS (%)	100	100

*This value is based on 30 minutes of irrigation per day at a tap flow rate of 12 litres per minute

As can be seen in table 1, the PPS can play an important part in limiting the demand for mains water, throughout the year in the case of interior use and during the months of peak demand during the summer. The financial incentive for rainwater harvesting is also variable and payback on any investment is most efficient where metering is in place. However, the extra cost to the user of a PPS in installing electric pumps and in-line filters, when already committed to using PPS as a driveway is minimal and may be less than £1000.

1.3 The safety and water quality of recycled rainwater for irrigation

There is increase in the installation of the PPS in car parks, and sidewalks in the UK and other countries in Europe. This has also resulted in an increase in the potential of harvesting and recycling stormwater for other benefits especially irrigation. At the same time, there is an apparent overuse of potable water for both domestic and hospitality based irrigation. The impact of demands for watering landscaped areas can be particularly problematic, especially where the supply from rainfall is highly variable. In certain countries of the world, there are conflicting demands for water especially during dry seasons, and particularly for agricultural irrigation purposes.This would make irrigation for aesthetic reasons at best socially unattractive and at worst could initiate regulatory action by the authorities if precious potable waters are used for such purposes. This is also the case even in temperate countries during summer seasons for example, during the summer of 2006, most water companies in the UK imposed hosepipe bans and restrictions on their customers due to dry a winter and low rainfall recorded in the previous year in the country (Water Guide 2007). With the potential impact of global warming likely to push water shortage problems ever further in the developed world, the demand for cost effective local water storage and re-use systems can only increase. This highlights the importance of any SUDS technique that would harness and store stormwater during the wet season of abundance and make them available for reuse during the dry season of scarcity and at the same time would not increase the demand for land in a development

Successful irrigation projects involve not only the supplying of irrigation water to the land, but also the control of the salinity and alkali of the soil. If the amount of water applied to the soil is not in excess of the amount needed by plants, there will be no downward percolation below the root zone, and mineral matter will accumulate at that level. It is obvious that stormwater treated and stored in pervious pavement system has to meet various quality standards in order to be considered for reuse as credible irrigation water. These standards will differ from the standards applicable to both simple disposals to a watercourse and for drinking water use. Irrigation water quality is determined based on the measurement of various parameters. Some of these include: Electrical Conductivity (EC), pH, Total dissolved solids (TDS), Elements in water (Heavy or trace metals in water, Sodium adsorption ratio (SAR), Carbonate (CO_3) and Hydrogen Carbonate (HCO_3), Microbial water quality and Total oil or/mineral oil in water. However, the characteristics of an irrigation water that seem to be most important in determining its suitability for irrigation include the total concentration of soluble salts, the relative proportion of sodium to other cations (usually expressed as the sodium absorption ratio) and the concentration of boron or other elements that may be toxic. (Ashraf and Harris, 2004; Nnadi et al 2008).

Since Pratt (1999) recognized that the pervious pavement system has the capability to store water for reuse, the first attempt to holistically investigate the possibility of using the SUDS device simultaneously in source control and water recycling applications was conducted by Nnadi 2009. Table 2 shows the comparison of chemical water quality results obtained from experiments where water from geotextile incorporated pervious pavement system models on which 24ml per m^2 of hydrocarbon was applied as a pollutant; and a single dose of 17g of NPK slow release nutrients (applied to encourage biodegradation) was administered to the surface of PPS (simulating a worst case scenario of stormwater pollution for 10 weeks) to FAO wastewater reuse standards, WHO drinking water and irrigation water quality standards. The treated water stored underneath PPS models was used to irrigate tomato plants *(Lycopersicon esculentum (fantasio hybrid))* and rye grass *(Lolium Perenne)* for 10 weeks. The table shows that the concentrations of the selected elements were below irrigation, FAO irrigation water standards as well as the WHO heavy metals in drinking water standards. A mean oil retention efficiency of 95.59% was observed after 10 weeks of this study confirming earlier results obtained by Coupe (2004).

Table 2. Comparison of the Concentration of Some Elements in Water Stored in PPS to International Standards in mg/l. Where BLD = Below the Limits of Detection

Elements	Water Stored in Polluted PPS	Water Stored in Non-Polluted PPS	WHO (2008) Drinking Water Guideline for Heavy metals	FAO	Short-Term Irrigation Standard (Rowe and Abdel-Magid 1995)	Long-Term Irrigation Standard (Rowe and Abdel-Magid 1995)
Al	0.03	0.1		5.0	20	5.0
As	0.04	0.002		0.1	2.0	0.1
Mg	3.01	1.72		-	-	-
Cu	0.005	0.007	2	0.2	0.5	0.2
Cd	BLD	BLD	0.003	0.01	0.05	0.01
Fe	0.02	0.072		-	5.0	
K	15.02	6.21		-	-	
Pb	0.003	0.001	0.01	-	10	5
Ni	0.002	0.002	0.07	0.2	0.2	0.2
Zn	0.02	0.007	3	2.0	10	0.002

pH values of the water recycled using the PPS shown in table 3 was within acceptable limits for irrigation water. deHayr and Gordon (2006), presented a chart which indicated how the relationship between Electrical Conductivity (EC) and SAR of water can be used to predict the potential of soil structure problems caused by irrigation water. Application of this chart using the EC and SAR values shown in table 3 clearly shows that the use of water recycled in PPS will not pose soil salinity and structure problems.

Table 3: Potential Effects of Average EC and SAR of Water from PPS on Soil Structure

Parameter	Polluted PPS	Non-Polluted PPS	Standard
SAR	1.3 - 1.09	1.64 - 1.75	Effects on soil structure depends on EC values
EC	0.34 (dS/m)	0.23 (dS/m)	< 0.25 - 2.0 (dS/m) (Bauder et al. 2008). Effects on soil structure depends on EC values
Soil Structure	Stable	Depends on soil Type	Stable
pH	6.58 - 8.26	6.29 - 8.33	6.0 - 8.5 (Peterson, 1999) Depends on type of plant

Concentrations of heavy metals obtained after the analysis the soil after 10 weeks were below international limits. Analysis of plants after 10 weeks of irrigation indicated that the concentrations of heavy metals were within the normal ranges in Plants. Furthermore, there was no significant difference between concentrations of heavy metals in tomato fruits irrigated with waters from PPS and tomato fruits obtained from a local supermarket (ANOVA $p>0.05$). Figure1 below shows the ryegrass and tomato plants after 10 weeks of irrigation with water recycled by PPS.

Figure 1: Ryegrass and Tomato after 10 Weeks of Irrigation with Water stored in PPS

1.4 The Pervious Pavement System as a Reservoir and Source for Heat

Ground Source Heat Pumps are an established technology to provide low CO_2 source heating for buildings. A set of double tube ground loops filled with ethylene glycol and water are placed in the soil and the liquids in the pipe are pumped around the loop extracting heat from water. The only energy required to power the GSHP is electricity for the heat pump. The system extracts heat energy from the wet ground and moves the heat via a pump to the building where, following contact with a compressor (which increases the temperature of the water) is moved around the building, typically via underfloor heating. When the lined tank in the open graded crushed rock in the PPS is full with water, it is a considerable source for ground heat. If ground collector loops are placed in the bottom of the sub base as shown in the pictures later in the paper, the total surface area of the paving provides sufficient space to provide heat for buildings.

The energy available in the sub base of the PPS has been calculated to provide 1 kW of energy per 12-15 m^2 of paving. The reason for the relative precision of this estimate compared with GSHP technology placed in soil or where bores are drilled into rock, is that the hydraulic design criteria for the pavement tightly control the environmental variables and the system is designed with the heating system in mind, rather than fitting the GSHP into the ground.

In the PPS based system, the outflow for the paving is set higher than usual, typically at 300 mm up from the bottom of the sub base. This means that the benefits of flow attenuation and water quality improvements are retained, as well as the potential water harvesting benefits, provided that the system is correctly sized and the anticipated areas for collection are large enough to allow water to be used from the tank and without risking the loss of water over the collector loops. If the pipes are not covered by water, the thermal conductivity of the ground is reduced by a factor of ~24 because air is known to be much less efficient at thermal conductivity than water (Young, 1992), making the system inefficient and unable to provide the necessary heat to the building.

1.5 Case study: UK Office development with GSHP paving

In 2008, the GSHP PPS system was specified for a new 3 floor office development with around 7000 m^2 of total area in Bedford, UK.

The proposed design featured 6500 m^2 of car parking to go with the office and very quickly, the GSHP paving was analysed for its suitability for the heating system.

Following extensive consultation between stakeholders, the drainage and heating system design were combined and the suppliers of GSHP equipment calculated that the PPS would provide sufficient heat to completely heat and cool the building.

Installation phase photographs for the liner, heat recovery coils and paving are shown in figure 2 below.

Paving installation phase:

Figure 2. A: site excavation and ground preparation, B: installation of the heat welded impermeable membrane, C: The GSHP collector loops, D: The completed paving surface.

The design criteria followed during the planning phase included the mitigation of any additional runoff post development and this was done by:

- Infiltration of rainwater at the surface by the use of permeable block paving
- Storage and flow control of the infiltrated rainfall in the lined pavement sub base to a depth of 300 mm. This also covered the heating coils allowing with water allowing good thermal conductivity
- Recycling of roof water in non-potable uses within the office development. On this site the storage element was not the permeable pavement but roof based tanks.

Together, these criteria prevented rapid runoff from the site and reduced both the rate and the volume of water discharging into the stormwater network.

The energy demand for the building and the capacity of the permeable pavement to supply it were assessed and design needed to be integrated between surface water management, structural design criteria and energy needs. This required a high degree of cross-communication between designers suppliers and contractors. In many cases for members of the consortium, the scheme described here was the first time a permeable pavement and GSHP had been combined, meaning that design details and the capabilities of many innovative technologies needed to be explained, verified and demonstrated for many parties.

Following the completion of the landscaping, the plant room was established to hold the 5 heat pumps, which were 130 kW in capacity. The maximum of 650 kW capacity in the pumps was greater than the anticipated load to the building of 520 kW, but this allowed for potential future changes to the building infrastructure. The plant room photographs of the heat pumps and the completed offices are shown below in figure 3.

In addition to heating by the PPS, there was a load of 200 kW of cooling in the paving, this was concentrated primarily on the IT suite but the relatively low requirement for cooling reflected the passive cooling of the building for ventilation and the masonry construction which was able to resist external temperature changes.

Unlike most GSHP heated buildings, the Bedford office development featured state of the art radiators that were manufactured in order to provide the highest possible surface area to dissipate the relatively low temperature heat in a GSHP efficiently. The increased surface area is necessary due to the lower temperature of water in the heating system which is 55-60 °C rather than 80 °C from a gas fired boiler.

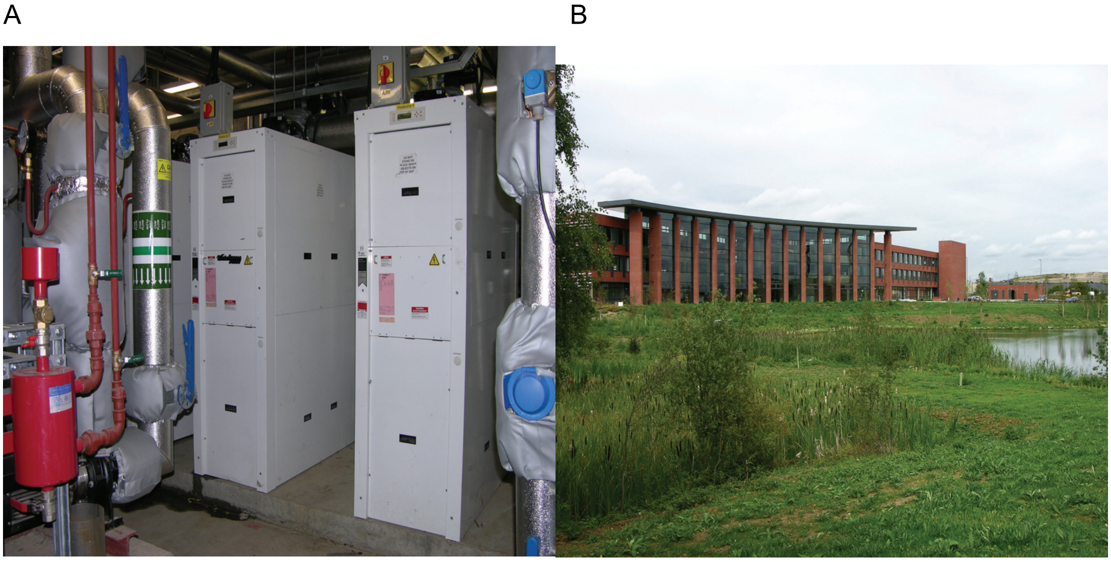

Figure 3: A: The plant room showing heat pumps, B: The exterior of the office development.

The benefits of the GSHP paving that are projected are summarised above. In addition to the benefits in ‘green energy’ provision are the hydrological benefits which include two stage treatment for water quality of all the rainfall that falls on the paving system, significant attenuation of the flow from the site into the nearby watercourse and the crucial contribution to the heating system. The onsite flood risk is also eliminated.

The summary data on the installation of the GSHP paving is shown below:

- Typical 70% reduction on overall building carbon emissions
- A reduction in utility bills of 50 %
- No local emissions or pollution
- Lower risk of fires and explosions than for gas boilers
- No external equipment & noise units exceed NR35
- Significant planning approval advantages

The total investment on the GSHP paving was £900,000m, giving a cost per kW of £1737 for heating and a cost per m^2 of £138 for this infrastructure from the 6500 m2 of paving. It must be remembered that the site must be viewed holistically from a point of view of energy and drainage as the PPS performs both roles simultaneously. Acknowledgement of the significance of this development was made by the UK Building Research Establishment (BRE), who used the BRE Environmental Assessment Method (BREEAM) to assess the office development and gave a rating of ‘Excellent’, the second highest rating from the lowest ‘Pass’ to the highest ‘Outstanding’.

1.6 Conclusion

Permeable Pavement Systems have enormous potential to provide added benefits to their role as a source control device without compromising efficiency in the long run. This paper has shown that there are added benefits to the customer for choosing to install this device. These benefits include provision of void spaces for storage, recycling of stormwater, serving as a source of irrigation water and a supply of renewable energy.

This paper is intended as a demonstration of how extra sustainability benefits can be made available to the built environment from sustainable drainage infrastructure. This benefit in the provision of rainwater for the reduction of mains water use and tapping into energy from beneath a permeable pavement needs to be researched carefully after deployment. In the case of the Stewartby offices, the operation of the GSHP has been shown to be encouraging, with a comfortable internal temperature above 20 °C and only 200 kW of the possible 520 kW of energy available to the heat pumps actually in use. A monitoring strategy is in place to determine the correlation between the anticipated CO_2 reductions and the reality over the long term.

It is equally important to determine the safety and appropriateness of rainwater stored in a paving system for the intended uses. In the case of the simulated paving systems described above, not only was the attenuation of pollution demonstrated to be extremely good, with low metal and oil concentrations, despite high initial loads, but the deployment of this water for irrigation was highly successful.

This study has shown the need for research on sustainability in drainage to proceed in a number of ways simultaneously but with clear goals in mind.

Small scale, affordable studies on water quality and water use can be a powerful tool in combination with larger studies with a strategic view for resource use.

The goals in mind are to lessen environmental impact, limit primary resource use and to make these solutions affordable by combining these benefits in a single solution.

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