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COMBINING PERMEABLE PAVING WITH RENEWABLE ENERGY DEVICES: INSTALLATION, PERFORMANCE AND FUTURE PROSPECTS

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Note: The following is the notation used in this paper: (.) for decimals and ( ) for thousands.

Summary

Sustainable drainage apparatus can be combined with other sustainable infrastructure to maximise the benefits to consumers, the companies providing those technologies and the natural and the built environment. A combination of permeable paving, featuring rainwater recycling apparatus, with ground source heat pump (GSHP) technology has the potential to improve the environmental performance of new domestic building developments. The feasibility of this combination of sustainable technologies was tested onsite within a prototype sustainable home, the Ecohouse based at the BRE (Building Research Establishment), Watford UK, during 2007 and 2008. It was shown that it is possible to construct permeable paving with extra benefits, in addition to their well known performance in improving water quantity and quality attenuation.

The high efficiency rating of the GSHP was shown by a Coefficient of performance (COP) of 4 and the ability of the system to function well during the UK winter. Water was not readily lost due to evaporation from the GSHP reservoir in summer or winter. Regulatory and market forces are clear drivers for the future of this technology as shown by the significant impact of GSHP paving on the Code for Sustainable Homes environmental rating and the potential savings from combining drainage and energy infrastructure.

1. INTRODUCTION

The aim of creating a more environmentally sustainable future for the UK has recently been aided by several key pieces of draft and implemented legislation, by mandatory standards imposed on new developments and also new powers to prevent flooding. The draft climate change bill has committed the UK to a 60% reduction in CO_2 by the year 2050 relative to 1990 levels. The production of 20% of the country's energy by renewable sources by the year 2020 [Wolfe, 2007] will be a difficult target to reach, but demonstrates that significant changes to the UK's infrastructure will be necessary if such targets are to be met. The Merton Rule, introduced in 2003 in the London borough of Merton has been an example of how local renewable energy targets can be successfully introduced. This planning policy requires a building of 1 000 m^2 or 10 or more houses to generate at least 10 % of their energy by the use of on-site renewables. The Merton rule has been adopted by over 150 UK councils and has shown the benefit of local minimum standards that can be adopted depending on local needs [NHBC Foundation, 2009].

1.1 The Code for Sustainable Homes and BREEAM

Probably the most significant recent development for new housing in the UK has been the Code for Sustainable Homes (CSH). Launched in December 2006, the CSH is a single national standard to be used in the design and construction of new houses in England, and it is hoped that continual improvements in environmental standards will be achieved by the construction industry over the next few years (Department for Communities and Local Government, 2007).

The CSH is based on a scoring system that awards the building points for the effectiveness of its environmental solutions. A home can achieve a sustainability rating from one to six stars depending upon the extent to which it has achieved code standards. One star is the entry level and six stars is the highest, level, i.e. a ‘zero carbon home’. BREEAM (the BRE Environmental Assessment Method) is the equivalent of CSH for non-domestic buildings and is used to assess these buildings in a way similar to CSH.

Since the forthcoming environmental challenges such as climate change, flooding and degraded ecosystems cannot be met by scientific or technological disciplines that work in isolation, there is an urgent requirement, where possible, to combine sustainable building elements in order to reduce the real or perceived extra costs of capital investment and installation. There is a need for further evidence for the theory that sustainable building can be achieved in a more holistic way. An attempt was made by the UK National House Building Council (NHBC) between 2008 and 2009 to rank the relative importance of house insulation and different renewable energy strategies in meeting Merton rule targets. The conclusion reached was that although house fabric and air tightness are to be considered first, the carbon saving from this can only achieve a limited result. For more stringent energy targets such as those in the CSH, which demands a minimum 10 % CO_2 reduction of the DER (dwelling emission rate) against those allowable by building regulations, renewable energy schemes would need to be used. The NHBC study also concluded that “Viewing the site holistically will allow for the most cost-effective solution to achieving the greatest CO_2 emissions reductions” [NHBC Foundation, 2009]. This view reinforces the legislative changes that are already encouraging sustainable technology and opening up the market for novel combined solutions.

In the case of permeable paving, holistic site considerations could yield several technical and market opportunities. One of the opportunities available for exploitation, to reduce energy use, is the huge heat reserve in the storage area beneath a membrane bound paving system. The water storage volume of 1 m^3 per 10 m^2 of paving is not just a rainwater harvesting resource but, if combined with suitable heat recovery infrastructure and linked to a GSHP (ground source heat pump), could make available a large energy reserve from ground heat. This reserve could be connected to the nearby building as part of an integrated building programme for heating and cooling.

A large potential saving on installation costs is available if permeable paving is already specified for the landscaping as heat recovery pipes are simply laid in the base of the paving tank. This compares favourably with the costs inherent in installing separate a bore hole geothermal system, rainwater harvesting tank and SUDS apparatus as in a combined system heating and hot water, rainwater harvesting and drainage infrastructure are placed within one excavated area and installed together. The cost of installation of geothermal paving and an analysis of potential savings will be addressed elsewhere within this paper.

Therefore the questions that this paper will attempt to answer include:

- Is it technically possible to physically combine SUDS elements and renewable energy components (in this case permeable paving and ground source heating) within one site?
- Is it possible to obtain long term data on the performance of these combined technologies?
- What are the advantages of these combined solutions to the user or consumer?
- How well do these arrangements meet government targets for good practice and sustainability in construction, resource use and energy provision?

Attention will now turn to the first attempt to combine permeable paving with GSHP and the installation of a purpose built environmentally sustainable house which has served as a prototype building in which to test this innovation.

1.2 The OFFSITE 2007 exhibition

Between late 2006 and June 2007 several companies constructed their version of a sustainable home at the Building Research Establishment (BRE) innovation park in Watford, UK; this included the Ecohouse. The idea of the Offsite exhibition was to exhibit the latest in sustainable building technology. This was done in a way that allowed the companies involved in the build to trial new or modern, methods of construction, build prototype sustainable houses and allow an exchange of ideas with one another and the public.

The use of onsite renewable energy features was very much encouraged at Offsite 2007 and within the build, permeable paving was to provide a solution. The Ecohouse is shown in Fgure 1.

1.3 Permeable paving and geothermal energy

It has long been recognised that permeable paving can provide several environmental benefits within a single area of paving. Flow control, minimised runoff, significant water quality improvements and groundwater recharge are just some of the known benefits [Newman *et al*, 2005, Grabiowiecki *et al*, 2008].

The temperature of subsoil at 500 mm below ground is typically thought to be around 10°C to 12°C throughout the year, and this assumption was to be tested as part of this work (the temperature monitoring stack and pavement is shown in Figure 3). In a GSHP system the heat is harnessed in a similar way as a refrigerator keeps the interior chamber cool by removing the warm air inside using a coolant and then dispersing it at an exhaust point. In a GSHP, coolant is circulated around a piped system buried in the soil or aggregate which draws in heat from the surrounding soil water (shown in Fgure 2, below). This heat is then moved via a heat pump into the building and may be terminated in underfloor heating or a radiator system. As long as the heat extraction pipes buried in the soil are wet, a good efficiency of removal of the ground heat is experienced. It was estimated that 10 m^2 of paving could provide approximately 1 kW of power for the heating and cooling system. Up to 80% of domestic heating and cooling costs can be removed by the use of GSHP technology and payback on the system is usually achieved within 10 years [Geothermal International Ltd, 2007].

In practical terms, the installation of geothermal permeable paving requires only minor modifications to the standard pavement installation procedure.

These include:

- Ensuring that the membrane for the tanking is adequately constructed. A loss of the water due to leaks may lead to an efficiency decrease of up 90%.

- Placing of the GSHP heat recovery pipes onto a bed of gravel or sand to prevent them contacting the membrane beneath at high or low temperatures.
- Some consideration of the loss of water from the tank by evaporation. As the pipes must be in water, a geotextile that allows water to infiltrate but not escape too readily may be deployed, although this has tested and shown to not always be necessary [Coupe *et al*, 2009b]. Discharging roof water into the pavement is another way to ensure that the system is full.


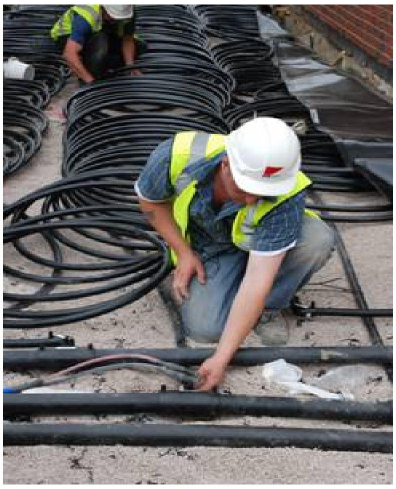


Figure 1. The Ecohouse; Figure 2.GSHP heat welding; Figure 3. Monitoring stack.

The geothermal paving took approximately two full days longer to install than an equivalent area of membrane bound paving. Most of the extra time expended was associated with heat fusing the heat recovery pipes together, pressurising and testing the heat fused pipes. Although this would appear to be a significant extension to the total build time, it is a small commitment when considering that the expected lifetime of the heat pump unit is 20 years and for the pipework is a minimum of 50 years.

When the paving system was completed, the structural and geothermal properties of the system were as shown in Table 1 below:

Table 1. Some Structural and Geothermal properties of GSHP paving

Pavement structural properties	
Depth mm	300
Area m^2	50
Water storage depth mm (max)	150
Paving colour	Light grey
Geothermal properties	
Energy from the ground kW	9
Power consumption kW	2.4
House heating strategy	Underfloor heating
Coefficient of performance (COP)	4

2. GSHP SYSTEM PERFORMANCE

COP or Coefficient of Performance is a way of determining the efficiency of a GSHP and is calculated by the following formula:

$$\text{kWh (load)} = \frac{\text{flow(l/s)} \times \Delta T \times Cp \times 3600}{\text{Current (amps)} \times \text{Voltage}}$$

Where:

ΔT = the difference between input and output temperatures from the ground

Cp = a property of the coolant used within the geothermal heat loops

The efficiency of GSHP systems always exceeds that of an ordinary gas fired boiler, and in the case of the Ecohouse GSHP, a COP of 4 means that for every unit of energy used to run the heat pump, 4 units of energy are supplied by the ground.

2.1 Longer term GSHP performance

To the end user of space heating, a chief concern is the ability of the system to heat the building effectively. The initial COP results were very promising, and showed that the shallow depth of the pavement, imposed by challenging site conditions, was not a barrier to a good short term efficiency rating. However, only a longer term test would reveal whether or not a potential consumer would experience a comfortable house temperature when using geothermal paving.

The Ecohouse was equipped with a number of thermistors, calibrated to take a temperature reading every 10 minutes that were placed in the walls of the house at a depth of 50 mm into the brickwork outside and 50 mm into the plasterwork inside the house on all four walls. This had the effect of giving an outdoor reference temperature to verify whether or not whether the house was at a comfortable user temperature, but also to demonstrate whether or not changes in outdoor temperature were followed by the indoor readings.

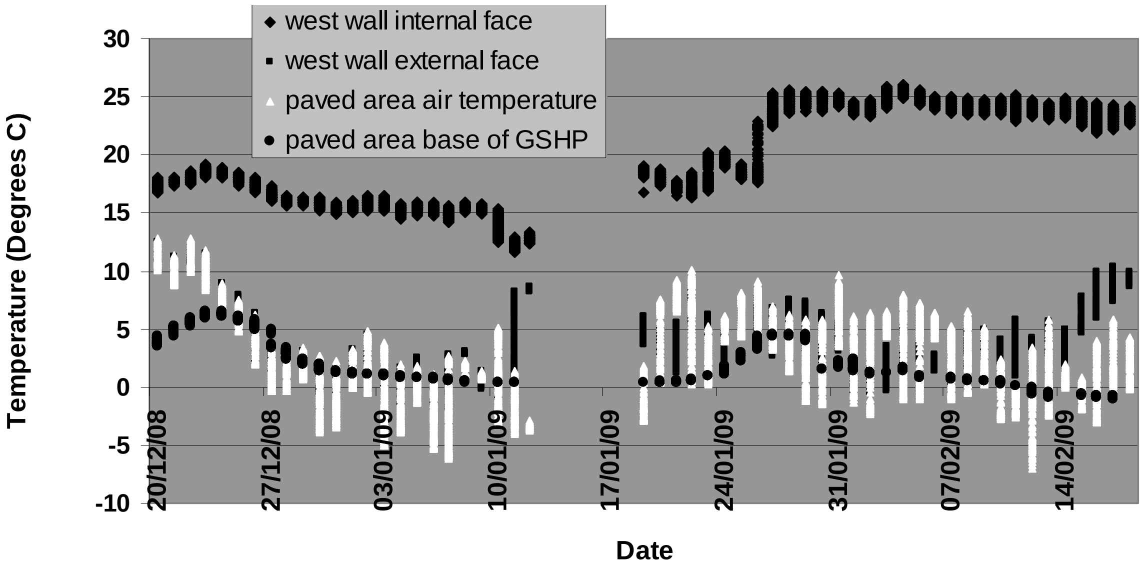

Figure 4. Temperatures in the Ecohouse, the exterior walls, air temperature and at the GSHP tank.

Results for the temperature monitoring work are shown for the period December to February in Figure 4. Also displayed here are the results from analysis of the paved area that supplied the GSHP, both the air temperature above the paving and also the base of the GSHP tank from where the heat is taken. The temperature in the house was always 10°C warmer than 500 mm deep within the exterior walls and was at a minimum of 15ºC, except for a 2 week period where a leak in the underfloor heating developed. This reduced the pressure in the system and led to a failure of the

GSHP to adequately circulate the heated water. Once this fault was repaired towards the end of January 2009, the heat from the ground was once again efficiently pumped into the house and raised the temperature to a consistent 22ºC to 25ºC. This should be compared with both the outdoor wall surface of 6ºC to 11ºC and an outside air temperature of minus 7°C to 11°C. When the GSHP was working correctly, there was at times a difference of 30°C between outside air temperature and the house, a habitable temperature for most individuals.

A minimum temperature of -1°C at the base of the GSHP tank demonstrates how much energy even 50 m^2 of permeable paving may contain. This was despite the shallow depth of both paving and water stored within the tank (300 and 150 mm respectively) and the demand for heating during one of the coldest winters in the UK for several years, where the provisional mean winter temperature value was 3.2°C, 0.5°C below the 1971-2000 average [Meteorological Office, 2009]. Indeed, even where the temperature of the base of the GSHP tank was below freezing, quite clearly this was not associated with a radical change in house temperature. It is quite possible to extract a large quantity of energy from a frozen medium as is demonstrated in domestic freezer apparatus. However, despite the success in maintaining a comfortable temperature indoors, prolonged freezing of the ground may lead to pavement surface instability due to frost heave of the aggregates. In practice this has never been observed in the Ecohouse GSHP pavement, but under commercial conditions this would be mitigated against by:

- Optimum spacing of the heat recovery loops. The Ecohouse paving loops are deliberately at a spacing of 10 % of their recommended spacing of 1 m to test the ‘worst case scenario’.
- A deeper overall excavation to 500 mm.
- A deeper water storage area.
- A larger total paved GSHP area.

The total energy available from the 50 m^2 of paving was 9 kW during early system testing and this is far beyond the estimated total of 1 kW per 10 m^2. This result is encouraging, but the fact that the Ecohouse represents a prototype system with no installed safety factor means that this value should be treated with caution. Despite the site compromises, it is clear that the GSHP at the Ecohouse can work effectively in very cold conditions.

3. GSHP TANK WATER LEVELS

The record of water depths shown in Figure 5 demonstrates that the maximum sustainable depth of 150 mm was sustained in the system for most of the duration of the test period. Indeed at times the depth of water was greater than this figure, and was probably due to a reading being taken when the paving was receiving water from the two adjoining roofs and inflow was exceeding discharge from the overflow. Sufficient water for normal operations was present in the GSHP tank in Watford during summer months, in one of the driest parts of the UK, the South East.

The 150 mm depth of water covers all the GSHP pipes with around 100 mm of water and evaporation seems not to have seriously reduced this volume. During the planning stage of the Ecohouse project, a conscious effort was made to ask the adjoining house builders to discharge water from their roofs into the GSHP tank. This resulted in at least three times the volume of water flowing through the GSHP than would occur without the roof water. This was advantageous to all parties in several ways:

- The GSHP tank received extra water to prevent evaporation becoming a problem.
- Adjoining house builders could adhere to sustainable drainage principles without the need for any extra cost.

- Any metals in the water from roofing materials would be attenuated to some degree when flowing through the permeable paving.
- The excess water leaving the GSHP tank would flow through a swale on exit to receive further flow and water quality improvement.
- It is possible that turbulent flow from roof water contributes to the high energy value associated with the paving GSHP. By periodically introducing new warmer water from roofs and flushing away colder areas near to the GSHP pipes, it may be possible to reduce the risk of excess heat take from a paved area, improving system performance.

Results from study in Santander, Northern Spain to examine the long term presence of water in a membrane bound paving system have shown that even without an extra contributing area such as roofs, water can be stored year-round in the system and that results from the Ecohouse site are not exceptional [Coupe *et al*, 2009].

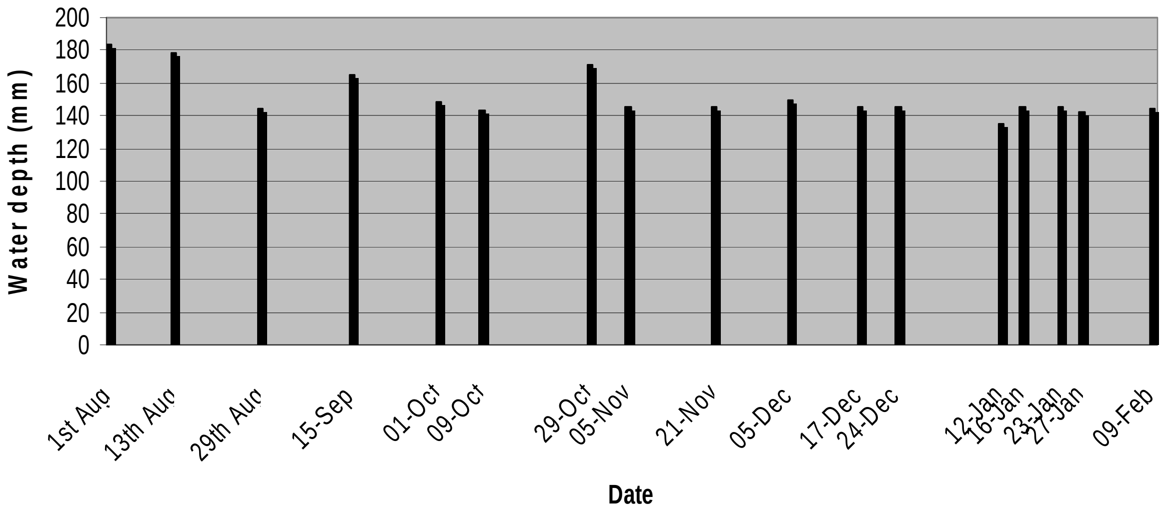

Figure 5. Recorded water depths in the GSHP.

4. ASSESSMENT AGAINST THE CODE FOR SUSTAINABLE HOMES

The Ecohouse was independently assessed against the Code for Sustainable Homes by Arup consultants at both the design and post construction stage. Unlike most kinds of landscaping, the geothermal paving was able to affect the house energy rating as well as the surface water runoff and mains water reduction categories. The GSHP paving contributed 18 credits to the Ecohouse code score of 63 from a possible total of 90, almost one third of the total. The house was awarded code 4 status where code 6 is a true 'zero carbon dwelling'. To put this into context, adherence to current best practice in building regulations would gain 36 credits and achieve code 1.

The results from the CSH assessment exercise also show that the GSHP would score heavily in BREEAM assessment or reach the Merton rule renewable energy target of 10%. Factoring up the size and scale of the paving, a similar performance with BREEAM would get a 'Very Good' energy rating. Geothermal paving at the Ecohouse uses mains electricity to power the heat pump which is why it would never be 100% carbon free. Despite this, when viewed holistically, the GSHP contributes to drainage and large mains water savings as well as energy, something that could not be achieved by alternative renewable energy scheme.

5. COST SAVINGS FROM PERMEABLE PAVING WITH GSHP

As stated previously, there is considerable potential for geothermal paving to produce cost savings for the end user when installing the GSHP. Any comparable system of providing energy, water harvesting and drainage benefits must be capable of producing comparable performance and have similar feature (e.g. a car port, drainage infrastructure and a borehole or separate GSHP loop system). In Table 3 below is a comparison of like for like costs.

Table 2. The contribution of Geothemal paving to the Hanson Ecohouse CSH score.

CATEGORY	CREDITS FROM PAVING	CREDITS AVAILABLE	PERCENTAGE SCORE
Energy 1: Dwelling Emission Rate	8*	15	52
Energy 7: Low carbon solutions	2	2	100
Water 1: Internal water use	4**	5	83
Water 2: External water use	1	1	100
Surface Water Runoff	2	2	100
Flood risk	1***	2	50

* *This is a minimum value for Energy credits where mains electricity powers the ground source heat pump rather than another renewable energy source, e.g. wind.*
** *Water credits here relate to water provided by the paving for WC flushing only with a total house water use of ≤ 90 litres/person/day.*
*** *This credit is gained in areas where flood risk is moderate/severe and the paving offers flood attenuation.*

Table 3. A cost comparison of separate and combined GSHP and rainwater harvesting systems

RAINWATER TANK PLUS GSHP	COMBINED PAVING AND GSHP
Tank, Filter, Pump £ 5 000	Paving, sump, pump, aggregate **£8,000**
Excavation for rain tank and install £ 2 500	
Paved Drive £4 000	
Standard Slinky Loop and excavation £ 1 500	Geothermal Loop laid in sub base **£500**
TOTAL £ 13 000	TOTAL **£8,500**

The above estimate of costs is based on a paved area of 60 m^2 with a 6 kW heating requirement for a well insulated home. A separate rainwater tank to provide the same storage volume would need to provide 4 000 l of stored water. In the combined system, the overflow would be set to maintain at least 2 000 l of water to cover the GSHP pipes. This exercise, along with the CSH assessment demonstrates that a combined technology to meet sustainability targets can lead to considerable cost reductions.

6. DIFFICULTIES ASSOCIATED WITH, AND DISADVANTAGES OF, GEOTHERMAL PAVING

The introduction of a new innovation will inevitably be a time consuming and challenging task. During the installation, operation and assessment phases of the Ecohouse project, obstacles were encountered. These included:

6.1 Integrating the landscape and the dwelling.

In most cases, landscaping does not affect the timescales of a house building programme, nor do architects or engineers need to consider how to consider landscaping as a fundamental part of how a house will function.

6.2 Linking the GSHP pipework and house plumbing.

When a system with non-standard plumbing is to be installed, it can be more difficult to troubleshoot any faults as many of the components are buried underground. At the Ecohouse, poor underfloor heating installation led to sub optimal GSHP performance until a suitably qualified plumber with experience of renewable energy was found.

6.3 System design and site considerations.

At the Ecohouse, GSHP paving was installed for the first time. It was difficult to decide on how and where the system would be installed and how much energy would be available. To test the worst case scenario, an excess of GSHP coils were deployed and due to difficulties with excavation, these were placed in a tank that was shallower than usual.

6.4 GSHP system visibility

The BRE site is part of a nationally important research facility and exhibition. Many influential visitors pass through the area to view sustainable buildings. Unlike Photovoltaic panels and wind turbines, GSHP apparatus is not visible as it is underground. Although this is in some ways advantageous, it makes it harder for GSHP to make a visual impact on the observer.

7. CONCLUSIONS

Combining GSHP and permeable paving has been shown to be technically feasible, and despite compromises in the installation phase and operational difficulties, the Ecohouse project has been a success. The recoverable energy from paving and water has exceeded prior expectations and good levels of performance in some very cold prolonged weather conditions has shown that the heat is effectively and consistently distributed via underfloor heating. GSHP is now an option for new buildings provided that hydraulic and geothermal design considerations are integrated to include a safety factor and where contractors use the design guidance.

Work at the Ecohouse has been conducted alongside related projects to answer questions related to long term viability and safety that may have arisen from using GSHP paving. The presence of water all year within the PPS at Watford and at the University of Cantabria in northern Spain, has provided greater confidence in the ability of the system to allow consistent and efficient heat transfer [Coupe *et al*, 2009a].

The effect of running GSHP apparatus within a membrane bound permeable pavement system on the chemical and microbiological water quality of PPS has been examined during the last three years at Edinburgh University. This work has shown that heating PPS water to a temperature of around 18ºC when the heat pump is in 'cooling mode' does not risk increasing the growth of unfavourable microbes such as *Legionella pneumophila* or *E. coli* in PPS [Coupe *et al*, 2009b].

Regulatory and market drivers have been shown to favour geothermal paving as the CSH assessment exercise has shown. Although costing of such a system is subject to many variables, the Ecohouse project has indicated that a combination of sustainable drainage and renewable energy should be competitive.

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