Combining Sustainable Drainage to manage stormwater with renewable heat from the ground; monitoring of the Hanson Ecohouse, Watford, UK

Combiner la gestion durable des eaux pluviales et l'utilisation de la chaleur du sol ; suivi de la maison écologique Hanson, Watford, UK

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RÉSUMÉ

La recherche de la durabilité implique de considérer des technologies à bénéfices multiples et flexibles dans leur application. Les Systèmes de Drainage Durable remplissent ces critères et cet article traite de la possibilité de combiner le pavage perméable à réservoir permettant la récupération des eaux de pluie et un système de géothermie superficielle pour chauffer la Maison Ecologique Hanson, à Watford (GB). Ces deux techniques ne sont pas nouvelles, mais leur association est relativement récente. Le suivi des températures dans la maison, dans le réservoir du pavage perméable et dans l'air ambiant a montré que l'eau drainée gelait à certaines périodes, que l'air ambiant avait un impact sur les températures jusqu'en profondeur du réservoir et que la récupération de la chaleur menait à un déficit thermique qui perdurait jusqu'à la saison suivante, et que ce déficit pouvait s'accumuler dans le temps. Cependant, nos résultats indiquent que le système de pavage perméable a permis une gestion efficace des eaux de pluie, sans observation d'inondation, et que la qualité de l'eau était excellente. Les leçons tirées de cette étude innovante recommandent de restituer de la chaleur au sol pendant les mois les plus chauds et de construire le réservoir du pavage perméable plus profond. Ce système combiné a depuis été installé dans un bâtiment de bureau de 3 étages, dont le suivi est en cours.

ABSTRACT

Achieving sustainability requires multiple benefits and flexibility in application. Sustainable Drainage Systems have such credentials and this paper reports on the potential for a combination of tanked pervious paving and rainwater harvesting with ground source heat to heat the Hanson Ecohouse, Watford, UK. These techniques are not new, but the blend of energy and water is relatively recent. Monitoring temperatures in the house, the porous paving tank and ambient air found that, at times, the harvested water froze, ambient air influenced temperatures even at depth in the tank and there were indications that harvesting heat led to a heat deficit carried over into the following season, with the possibility of this accumulating with time. However, it was found that the porous paving performed efficiently in terms of water management, with no flooding reported, and water quality was excellent. Lessons learnt from this first-of-its-kind study included recommendations to replace harvested heat in the warmer months and construct a deeper porous paving tank. The combined system has since been installed into a 3-floor office development, monitoring for which is ongoing.

KEYWORDS

Sustainable Drainage Systems, Ground Source Heat, Rainwater Harvesting, Pervious Paving

1 INTRODUCTION

Achieving sustainability needs there to be multiple benefits from the technology used and also flexibility in its application. Whilst neither the harvesting of heat from the ground (Ground Source Heat, GSH) nor Sustainable Drainage systems (SUDs) are new, both having been used successfully for decades (Coupe *et al*., 2013), the blending of these 2 techniques to provide heat to domestic, or industrial buildings, is fairly new and innovative (Charlesworth et al., 2016). They would also provide the multiple benefits associated with both of their technologies in providing a clean and renewable source of heat, flood resilience and water quality improvements in one combined system. Laboratory-scale testing has been undertaken by Tota-Maharaj *et al*., 2010, which showed the potential of this blend, but a true insight into its performance could only be gained by monitoring at the building scale. This paper highlights some of the lessons learnt from a 3-year study of combining GSH extraction and a tanked, or sealed, block paver Pervious Paving System (PPS) at the Hanson Ecohouse, Watford, UK, and a critical appraisal of its potential to provide heat to a domestic dwelling.

2 METHODOLOGY

Built on the Building Research Establishment (BRE) site at Watford, UK, the Hanson Ecohouse is a 3-bedroom, detached, domestic dwelling completed in 2007 to demonstrate innovative construction techniques including the combined PPS/GSH extraction system. As such, therefore, it was not a true domestic dwelling since a family did not live there; the environment was therefore a challenging one to test new technologies in which groups of visitors were shown around the house with attendant problems associated with doors and windows being left open, equipment tampered with, including the thermostat and also siting of the building having to fit with other demonstrators. The PPS was sealed with an impervious membrane to provide a “tank” in which rainwater was allowed to collect. At 350mm, it was about 150 mm shallower than usual, with the coils for GSH extraction located at the bottom of the tank. Further details of the Ecohouse, the PPS/GSH combined system and the monitoring carried out can be found in Charlesworth *et al*., 2015. Whilst the combined system could potentially be used for both heating and cooling, only the former setting was used since it was considered that under the temperate UK climate it was likely that it would mainly be used for heating, unlike elsewhere where the ground may be used for both heat extraction (space heating) and rejection (space cooling). It was also an aim of this study to monitor the impacts on the ground temperatures of harvesting heat over a 3-year period since previous studies found that if the heat absorbed from the ground annually is not equal to the heat rejected to it, reduction in the ground heat may result over time (Xi *et al*., 2011; Ooka *et al*., 2011; Yu *et al*., 2011).

2.1 Temperature monitoring

Temperature was monitored at 10-minute intervals over almost three years, at the 4 cardinal points around the house, both inside and out providing >1.3 million data points. For the combined PPS/GSH extraction system, temperature was measured at various depths in the tank: 60mm, 130mm, 200mm and 350mm, from 8th August, 2008 to 30th March, 2010. The ambient or overlying air temperature during this period was also measured at 1300mm above the surface of the PPS. There were a total of 15 thermistors installed in and around the house. Further specific details of the instrumentation are given in Charlesworth *et al*., 2015.

2.2 Water quality and incidence of flooding

Water in the PPS subbase was collected for 2 years at 2-3 weekly intervals, yielding a total of 36 samples. These were analysed for Zn, Cd, Cu, Ni, P, Na and Pb using ICP-AES. Incidence of flooding was by observation of the staff at the BRE site over the 3 year study.

3 RESULTS AND DISCUSSION

3.1 Temperature in the PPS and ambient air monitoring

Descriptive statistics for the temperatures of the ambient air and four PPS tank depths are given in Table 1 which shows that the minimum temperatures at all depths in the tank were below zero (i.e. any stored rainwater was probably frozen). During very cold conditions, it was found that the surface of the rainwater in the reservoir froze, whilst at the bottom the harvested rainwater remained liquid. This finding was in contrast to studies concluding that freezing started around the extractor coils, e.g. Eslami-nejad and Bernier (2012). These different observations are probably related to the medium surrounding the coil, since it was surrounded by rainwater not soil; therefore during the freezing process, ice forms on the surface of a body of water, in contrast with the coil buried in soil where freezing of the ground begins around the GSH extractors. The highest maximum and lowest minimum temperatures were recorded at 60mm in the PPS tank; these characteristics reduced with reservoir depth. Table 1 shows that there was very little difference between mean temperatures recorded for each depth and that they were not significantly different from that of the ambient air.

Depth (mm)	Ambient	60mm	130mm	200mm	350mm
Minimum	-3	-4.4	-3.1	-1.9	-1.1
Maximum	22.5	26.2	24.7	21.2	20.0
Average	10.0	9.7	9.5	8.8	9.6
Median	10.8	9.5	9.2	9.1	11.0
Standard Deviation	6.0	6.9	6.9	6.6	6.7
Significant difference between depths and ambient air ($p<0.001$).		3.931	4.718	8.074	10.541

Table 1 Ambient air and PPS tank temperatures (°C) throughout the monitoring period (n = 2,449)

Table 2 shows the mean annual monthly temperature characteristics of each PPS depth, together with those for the ambient air; temperature differences ranged between 0.8°C and 7.4°C. Table 2 also shows how closely the temperatures in the tank follow those of ambient air, and hence the influence that it had on thermal distribution in the PPS reservoir.

Depth	60 mm	130 mm	200 mm	350 mm	ambient
Jan	1.8	2.2	2.6	1.8	2.4
Feb	1.8	0.6	0.1	-0.3	3.8
Mar	5.2	3.5	0.3	0.4	7.7
Apr	10	8.8	6.5	6.1	10.8
May	14.9	14.6	13	12.4	13.6
Jun	18.6	18.3	16.4	15.7	16.3
Jul	19.2	19.1	17.9	17.5	17.4
Aug	18	17.9	17.1	16.8	17.5
Sep	14.5	14.6	14.4	14.5	14.3
Oct	10.4	9.4	9.4	9.7	11.6
Nov	8.3	8.6	9	9.5	9.1
Dec	3.7	4.8	5.3	4.9	4.1

Table 2 Mean monthly temperature measurements (^{o}C) of the ground at several depths and the ambient air throughout the monitoring period (n = 2,449)

During the period 27/01/2009 – 30/04/2009, heat was extracted more or less continuously. It was found that the temperature at the bottom of the reservoir was lower than both ambient air and the ground at 60mm and 130mm depth by an average of 5.5, 3.6, and 2.3°C respectively. The low temperature at 200mm and 350mm is, apart from the influence of the cold ambient air, most likely because of the GSH extracting coil removing heat (Gonzalez *et al*., 2012). In fact, Wu *et al*. (2010) concluded that the effect of heat extraction could be observed up to a distance of 900mm from the heat exchanger, and 250mm below the ground surface. The total depth of the PPS at the Ecohouse was 350mm, thus extraction of heat was likely to have contributed to the dropping of ground temperature - predominantly at the bottom of the reservoir but also in the top layers. Hence, extracting heat continuously from the ground could have contributed to an underground temperature drop. Also, given Britain's climate and environmental conditions it is likely that if temperatures near the GHS extractors decreased over time, the ground may not have been able to completely recharge for the following season during the summer; hence this could lead to a reduction in GSH performance over time. At 350mm, the PPS was shallow, with the stored rainwater therefore closer to the surface than is usual and overly influenced by ambient air temperatures. Other studies, eg Singh *et al*., 2010 and Gan *et al*., 2007 used horizontal heat extractors, but these were buried in soil 0.5 and 1.8 m deep respectively, leading to less influence of ambient conditions.

3.2 Efficiency of the PPS: water quality and quantity

Concentrations of Cd, Cu, Ni, P and Pb in the PPS tank were below the limits of detection, whilst the mean concentrations of Zn and Na were 2.01 and 7.69 mg $^{-1}$ respectively and were thus of no concern. There was no reported incidence of flooding associated with the Ecohouse PPS, and thus the combination of GSH extraction with the PPS did not appear to have compromised the performance of the pavement from the water quality or quantity point of view.

4. CONCLUSIONS

It was found that temperatures in the bottom of the PPS reservoir were less than both the layers above and also ambient, overlying air. This could be due to two factors: firstly, by not replacing the heat extracted during the colder months by heat in the warmer ones, the temperatures in the bottom of the tanked PPS could gradually cool such that ground temperature at 60mm and 130mm were higher than those at depth since the top of the reservoir was less affected by the heat being harvested. By submerging the extraction coils in rainwater, harvesting of heat is more efficient, and therefore the effect of cooling at depth may have been more than in studies where the coils were buried in soil. It is therefore recommended that even in a temperate climate such as the UK, if a combined system is used during the warmer months heat is rejected into the ground in a cooling cycle in order to replenish the heat at depth.

Secondly, temperatures with depth in the PPS reservoir were influenced by those of the overlying ambient air. This was likely due to the fact that the PPS tank was quite shallow and the coils were installed at a depth of 350mm. This was due to site conditions at BRE, but in future it would be recommended that the tank be at least 500mm in depth in order to reduce any effects of external environmental conditions. However, it is not possible to estimate the contribution of either of these factors to the heat loss found.

Both of these recommendations have been carried out in a new build office block at Stewartby, Bedford, UK whereby the PPS tank was excavated to 500mm and the cooling cycle engaged during the summer months. Whilst monitoring of this system is on-going, as the only source of heat to the building, the combined system has been very successful.

REFERENCES

Charlesworth, S.M., Faraj-Lloyd, A.S., Coupe, S. (2015) Renewable energy and sustainable surface runoff management: combining Ground Source Heat and Porous Paving to heat buildings. Proceedings of Water Efficiency Conference, Exeter University, UK. Pp 206-215. Available at: http://tinyurl.com/nufkbnf (accessed 14 October 2015).

Charlesworth, S. A. Faraj-Lloyd, S. Coupe (2016) Combining sustainable drainage devices and sources of renewable heat: pervious paving and ground source heat. Renewable & Sustainable Energy Reviews. DOI: 10.1016/j.rser.2016.02.019

Coupe S.J. AS Faraj, EO Nnadi, SM Charlesworth (2013) Integrated Sustainable Urban Drainage Systems Book title: Water Efficiency in Buildings: Theory and Practice. K. Adeyeye. Wiley Blackwell Chapter 9, 147-163

Eslami-nejad, P., Bernier, M. (2012). Freezing of geothermal borehole surroundings: A numerical and experimental assessment with applications. *Applied Energy* 98, pp. 333-345

Gan, G., Riffat, S., Chong, C. (2007). A novel rainwater–ground source heat pump – measurement and simulation. Applied Thermal Engineering 27(2–3), pp. 430–441

Gonzalez, R.G., Verhoef, A., Vidale, P.L., Main, B., Gan, G., Wu, Y. (2012). Interactions between the physical soil environment and a horizontal ground coupled heat pump, for a domestic site in the UK. Renewable Energy 44, pp. 141-153

Ooka R., Sekine K., Yokoi, M., Shiba, Y., Hwang, S. (2007). Development of a ground source heat pump system with ground heat exchanger utilizing the cast-in place concrete pile foundations of a building. EcoStock 2007. Stockton, NJ. ASHRAE Transactions 11p. [online] Available from: http://www.zeneral.co.jp/resarch_release/I-02.pdf Accessed 5/11/2015

Singh, H., Muetze, A., Eames, P.C. (2010). Factors influencing the uptake of heat pump technology by the UK domestic sector. Renewable Energy 35(4), pp. 873–878

Tota-Maharaj K., Scholz M., Ahmed T., French C. and E. Pagaling, (2010). The Synergy of Permeable Pavements and Geothermal Heat Pumps for Storm-water Treatment and Reuse, Environmental Technology. 31, 14, 1517 - 1531.

Wu, Y., Gan, G., Verhoef, A., Vidale, P.L., Gonzalez, R.G. (2010). Experimental measurement and numerical simulation of horizontal-coupled slinky ground source heat exchangers. Applied Thermal Engineering 30 (16), pp. 2574-2583

Xi, C., Lin, L., Hongxing, Y. (2011). Long term operation of a solar assisted ground coupled heat pump system for space heating and domestic hot water. Energy and Buildings 43(8), pp 1835-1844

Yu, X., Wang, R.Z., Zhai, X.Q. (2011). Year round experimental study on a constant temperature and humidity air-conditioning system driven by ground source heat pump. Energy 36(2), pp. 1309-1318