Thermal response of multifunctional wet swales for stormwater management and energy saving

Réponse thermique de baissières multifonctionnelles pour la gestion des eaux pluviales et les économies d'énergie

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RÉSUMÉ

Les villes sont de nos jours confrontées à des problèmes d´espace du fait de l´urbanisation intense. Des approches multifonctionnelles sont ainsi requises en vue de créer des cadres de vie attrayants, tout en améliorant la biodiversité, l´économie d´énergie, la fixation de carbone et la gestion adéquate des eaux pluviales. Des études antérieures ont démontré la possibilité d´associer des éléments de pompe à chaleur géothermique (GSHP) aux systèmes de drainage urbains durables (SUDS). Cette approche comble le manque de ressources dans la conception des baissières, contribuant ainsi à l´amélioration des indicateurs de planification durable. Dans le but de déterminer les performances thermiques des baissières, des modèles de laboratoire à l'échelle 1:2 ont été développés pour une plage de température de GSHP (20-50°C). Les baissières assurent de bonnes performances d'isolation tout en offrant une meilleure résistance aux processus de chauffage, retrouvant leur état initial dans les 16 heures suivant la phase de chauffage de l'expérience. La dissipation thermique verticale est également décrite avec grande précision grâce à des modèles comportementaux.

ABSTRACT

Cities are subjected to intense urbanization processes, leaving limited space available. Multifunctional approaches are demanded by society in order to create attractive spaces to live whilst improving biodiversity, enhancing energy saving, sequestering carbon and managing stormwater related problems. Previous research has stressed the possibility of developing Ground Source Heat Pump (GSHP) elements housed by Sustainable Urban Drainage Systems (SUDS). This contribution fills the gap for swales, helping to improve indicators of sustainability for planning development. With the aim of determining the thermal performance of wet swales when working under a range of GSHP temperatures (20-50ºC), laboratory models at a 1:2 scale were developed. Wet swales provide good isolation performance whilst increasing resilience to heating processes, recovering their initial thermal state within 16 hours after the heating stage of the experiment. Behavioural models were also obtained, describing with high accuracy the vertical thermal dissipation.

KEYWORDS

GSHP, heating and cooling, performance models, SUDS, WSUD.

1 INTRODUCTION

Sustainable Urban Drainage Systems (SUDS) have been designed in combination with Ground Source Heat Pump (GSHP) systems in the past, especially focused on Permeable Pavements (PP) as described by Tota-Maharaj et al. (2011) and del Castillo-García et al. (2013), amongst others. Gupta and Irving (2008) also highlighted the importance of applying GSHP in order to help dwellings to adapt to climate change by reducing carbon consumption. Supporting this path towards domestic and urban resilience, Charlesworth et al. (2017) identified future prospects for GSHP+PPS, emphasising the application of horizontal heat pump technology in greener SUDS such as wetlands (Tota-Maharaj et al. 2012). Andrés-Valeri et al. (2018) transferred these principles to swales, stressing the need to produce more research in order to fill this gap. Furthermore, Abrahams et al. (2017) demonstrated the key multifunctional role of swales applied in rural settings in the UK under a new scheme of biological design, providing flood resilience, biomass production, sewage purification and biodiversity enhancement. Besides, Nathanail and Banks (2009) gave special importance to further develop GSHP, carbon sequestration measures and SUDS in order to achieve sustainability in cities. New methodologies for planning development use GSHP and SUDS as indicators (Price et al. 2018). Thus, the literature has highlighted the need for a multifunctional approach.

This research encompasses all these concepts in a comprehensive laboratory research which aims to investigate whether wet swales could contribute to energy saving, as part of the ecosystem services inherently provided by them, when designed housing GSHP elements.

2 METHODS

The experiment consisted in three replicates based on the same wet swale design as per indicated in Table 1. Laboratory models were developed at a 1:2 scale. Temperature sensors (RTD1, RTD2, RTD3 and RTD4) were placed at 100, 200, 300 and 400 mm, respectively, from the bottom of the sub-base layer-2 (Figure 1).

Table 1. Materials used to build the wet swale models.

Layer	Depth (mm)	Thickness (mm)	Material
Surface	0-50	50	Grass
Base	50-150	100	Supporting media for grass growing
Sub-base layer-1	150-400	300	Limestone aggregates 18-35 mm particle size
GSHP looping	330-350	20	5 m polypropylene flexible pipe 20 mm diameter
Bottom platform	400-450	50	Plastic cells covered by non-woven polypropylene geotextile

Figure 1. Experimental test scheme.

Water was recirculated at 20, 30, 40 and 50ºC through the GSHP simulated looping (Table 1). The upper temperature limit was selected based on the usual operating temperature limit for the majority of the heat pumps (Energy Saving Trust 2007). In addition, temperature readings were taken at the inlet and outlet points of the laboratory models (Figure 1) as well as ambient temperatures.

Pre-tests were run in order to identify patterns of a certain degree of stationary behaviour under heating conditions. With this aim, heating experiments were conducted for a duration range of 73-95 hours, resulting 8 hours, the time after which the models reach a higher level of fit (Figure 2). Thus, the duration selected for the heating stage was 8 hours.

Therefore, tests were run over 24 hours in the experimental phase, being divided into two main stages: heating (8 hours) and cooling (16 hours). Statistical analyses were developed in order to construct mathematical models of performance for the heating stage based on regression models by using the least-squares method in MATLAB.

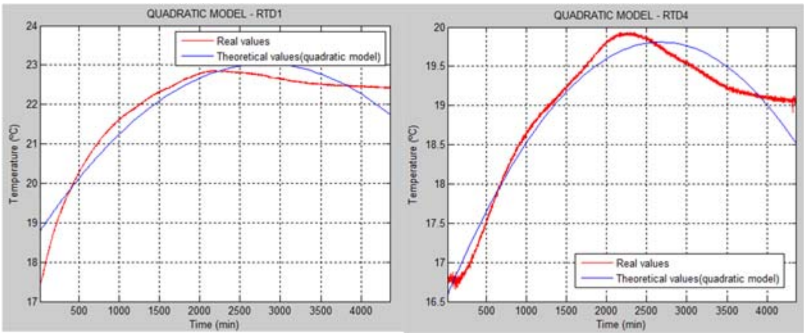


Figure 2. Quadratic models for the RTD1 and RTD4 for the pre-tests.

3 RESULTS AND DISCUSSION

The results obtained from this experimental research were divided into the two main stages, with the heating stage analysed from different views as follows: (1) vertical and (2) horizontal thermal dissipation. The first one contributes toward the potential of this combined approach to provide good isolation capacity, whilst the second aims to validate the experiment by testing whether the thermal dissipation is within an acceptable margin.

The statistical analyses applied to the temperature values (T measured in ºC) registered by the sensors during the experiments produced the following quadratic models depending on the time (t registered in minutes) for the vertical thermal dissipation during the heating stage (Table 2).

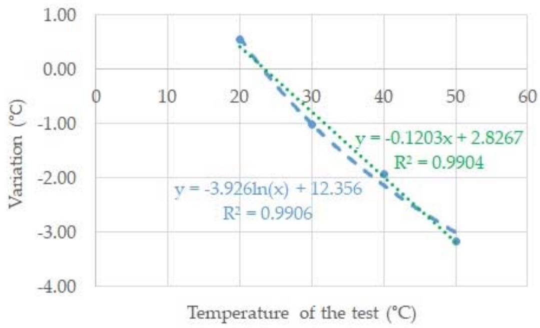
Table 2. Regression quadratic models ($T=a_0t^2+a_1t+a_2$) for the vertical dissipation during the heating stage.

Sensor	Temperature (ºC)	a_0	a_1	a_2	R^2
RTD1	20ºC	-2.9079E-06	0.0038	15.2110	0.9845
	30ºC	-6.3338E-06	0.0095	15.9646	0.9996
	40ºC	-1.0367E-05	0.0152	15.9599	0.9954
	50ºC	-1.7541E-05	0.0239	15.4303	0.9989
RTD2	20ºC	-3.5333E-06	0.0038	15.5638	0.9842
	30ºC	-5.0091E-06	0.0083	16.8260	0.9981
	40ºC	-1.4382E-05	0.0177	16.5443	0.9969
	50ºC	-1.9195E-05	0.0250	16.5089	0.9981
RTD3	20ºC	-3.3094E-06	0.0038	15.2652	0.9919
	30ºC	-2.8594E-06	0.0066	16.3455	0.9986
	40ºC	-9.6683E-06	0.0143	15.8760	0.9991
	50ºC	-1.3551E-05	0.0206	16.5089	0.9981
RTD4	20ºC	9.7249E-07	-0.0002	15.0351	0.9025
	30ºC	-2.8594E-06	0.0066	16.3455	0.9986
	40ºC	6.8632E-06	0.0143	15.8760	0.9991
	50ºC	8.4280E-06	0.0005	15.1394	0.9914

The horizontal thermal dissipation within the looping system was observed to range between 2.15 for 20ºC tests up to 4.60 for 50ºC which falls into low variability margins.

The cooling stage showed that the wet swale design tested in this experiment was able to come back to the initial temperatures of the system, presenting good resilience to recover the initial state once the heating stage was over. Models were obtained to describe this resilient behaviour (Figure 3).

Figure 3. Resilience performance models depending on the work temperature of the system.



4 CONCLUSION

Wet swales provide good isolation properties for the combination of GSHP and SUDS, even when working under the highest temperatures of heat pump performance (50ºC). Their structure is also resilient to heating processes, recovering their initial state within 16 hours after the heating stage. Behavioural models obtained in this research describe with high accuracy the vertical thermal dissipation during the heating stage.

Future research based upon the findings from this research are highlighted towards the understanding of heat transfer, through the different materials used in wet swales. Field studies and long-term patterns of performance would be required to produce and validate robust models of performance.

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LIST OF REFERENCES

Abrahams, J.C., Coupe, S.J., Sañudo-Fontaneda, L.A., Schmutz, U. (2017). *The Brookside Farm Wetland Ecosystem Treatment (WET) System: A Low-Energy Methodology for Sewage Purification, Biomass Production (Yield), Flood Resilience and Biodiversity Enhancement*. Sustainability, *9*, 147.

Andrés-Valeri, V.C., Sañudo-Fontaneda, L.A., Rey-Mahía, C., Coupe, S.J., Alvarez-Rabanal, F.P. (2018). *Thermal Performance of Wet Swales Designed as Multifunctional Green Infrastructure Systems for Water Management and Energy Saving*. Proceedings, *2*, 1433.

Charlesworth, S.M., Faraj-Lloyd, A.S., Coupe, S.J. (2017). *Renewable energy combined with sustainable drainage: Ground source heat and pervious paving*. Renewable and Sustainable Energy Reviews, 68, 912-919.

del Castillo-García, G., Borinaga-Treviño, R., Sañudo-Fontaneda, L.A., Pascual-Muñoz, P. (2013). *Influence of pervious pavement systems on heat dissipation from a horizontal geothermal system*. European Journal of Environment and Civil Engineering, 17(10), 956-967.

Energy Saving Trust (2007). *CE82 Domestic ground source heat pumps: design and installation of closed-loop systems (2007 edition)*. London, Energy Saving Trust.

Gupta, R. and Irving, R. (2008). *Assessing the potential of ground source heat pumps to provide low-carbon heating and cooling in UK dwellings in a changing climate*. Proceedings of Conference: Air Conditioning and the Low Carbon Cooling Challenge, Cumberland Lodge, Windsor, UK.

Nathanail, J., Banks, V. (2009). *Climate change: Implications for engineering geology practice*. Geological Society, London, Engineering Geology Special Publications, 22, 65-82.

Price, S.J., Terrington, R.L., Busby, J., Bricker, S., Berry, T. (2018). *3D ground-use optimisation for sustainable urban development planning: A case-study from Earls Court, London, UK*. Tunnelling and Underground Space Technology 81, 144-164.

Tota-Maharaj, K., Scholz, M., Coupe, S.J. (2011). Modelling temperature and energy balances within geothermal paving systems. Road Materials and Pavement Design, 12(2), 315-344.

Tota-Mahara, K., Grabowiecki, P., Babatunde, A., Devi Tumula, P. (2012). Constructed wetlands incorporating surface water heat pumps (SWHPS) for concentrated urban stormwater runoff treatment and reuse. In: Proceedings of the sixteenth international water technology conference, IWTC 16; Istanbul, Turkey.

Woods Ballard, B., Wilson, S., Udale-Clark, H., Illman, S., Ashley, R., Kellagher, R. *The SuDS manual. CIRIA 753*. CIRIA, London, UK, pp. 968, 2015.