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The implementation of biofiltration systems, rainwater tanks and urban irrigation in a single-layer urban canopy model

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ABSTRACT

Urban vegetation is generally considered as a key tool to modify the urban energy balance through enhanced evapotranspiration (ET). Given that vegetation is most effective when it is healthy, stormwater harvesting and retention strategies (such as water sensitive urban design) could be used to support vegetation and promote ET. This study presents the implementation of a vegetated lined bio-filtration system (BFS) combined with a rainwater tank (RWT) and urban irrigation system in the single-layer urban canopy model Community Land Model-Urban. Runoff from roof and impervious road surface fractions is harvested and used to support an adequate soil moisture level for vegetation in the BFS. In a first stage, modelled soil moisture dynamics are evaluated and found reliable compared to observed soil moisture levels from biofiltration pits in Smith Street, Melbourne (Australia). Secondly, the impact of BFS, RWT and urban irrigation on ET is illustrated for a two-month period in 2012 using varying characteristics for all components. Results indicate that (i) a large amount of stormwater is potentially available for indoor and outdoor water demands, including irrigation of urban vegetation, (ii) ET from the BFS is an order of magnitude larger compared to the contributions from the impervious surfaces, even though the former only covers 10%

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of the surface fraction and (iii) attention should be paid to the cover fraction and soil texture of the BFS, size of the RWT and the surface fractions contributing to the collection of water in the RWT. Overall, this study reveals that this model development can effectuate future research with state-of-the-art urban climate models to further explore the benefits of vegetated biofiltration systems as a water sensitive urban design tool optimised with an urban irrigation system to maintain healthy vegetation.

1. Introduction

Significant research has been undertaken on biophysical processes governing the urban climate, but often this research does not take into account the knowledge and needs of urban planners and policy makers. Urban planning strategies target issues such as housing, transport and infrastructure but very few strategies comprehensively consider the urban climate and its interaction with the built environment (Coutts et al., 2010). As a way forward, Climate-Sensitive Urban Design (CSUD) is often mentioned as a comprehensive way of designing cities by skilfully combining measures in the areas of urban form, ventilation, solar radiation, natural water cycle and vegetation to mitigate urban heat and create thermally comfortable, attractive and more sustainable urban environments (e.g. Emmanuel, 2005).

Within the framework of CSUD, vegetation is regarded as a key tool as it can provide shade and evaporative cooling, enhance thermal comfort, improve air and runoff water quality and reduce storm water runoff intensity (Grimmond et al., 2010; Bowler et al., 2010; Coutts et al., 2013; Demuzere et al., 2014). However, for vegetation to provide these benefits it must be healthy and well supplied with water. As such, water sensitive urban design (WSUD) should be considered to help support vegetation in urban areas. Impervious land cover in built-up areas typically prevents infiltration as stormwater drainage networks are designed to rapidly remove runoff away from the city. This results in a soil moisture deficit that is, especially in dry environments, balanced by imported potable water for irrigation. If potable water restrictions are enforced during periods of drought, vegetation health can be compromised. Implementing WSUD can support the restoration of the natural water balance promoting more healthy urban vegetation and purposefully modify the urban energy balance to support CSUD through enhanced evapotranspiration (Coutts et al., 2013). In this respect, biofiltration systems (also commonly referred to as biofilters, bioretention systems, tree-pits and rain gardens) are often mentioned as a WSUD strategy suited to improve water quality by filtering water through biologically influenced media and to reduce stormwater runoff flow rates and volumes aiming to restore a more natural water balance, protect downstream receiving waters and encourage water loss via subsurface flows and evapotranspiration (Walsh et al., 2005; Fletcher et al., 2013; Hamel and Fletcher, 2014). In vegetated biofiltration systems, plants are included to enhance the removal of moisture and pollutants from the soil to further improve water quality. It is anticipated that the increase in infiltration and evapotranspiration originating from biofiltration systems could have positive benefits for urban climate, due to an optimal soil moisture content for evapotranspiration as a function of vegetation type.

Although the evaporative term is key to this, coupling both the energy and water balances (Hamdi et al., 2009), the PILPS-urban international comparison of urban models (Grimmond et al., 2010, 2011) revealed that even complex models very poorly model or even neglect the evaporative term and generally model vegetated or pervious fractions as independent natural fractions outside the street canyon that do not interact with street canyon properties. In addition, they rarely take into account detailed urban hydrological processes such as runoff, infiltration, interception or irrigation of which the latter is stated as a critical process that needs to be taken into account by urban models (Best and Grimmond, 2014).