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Evaluating the potential of improving residential water balance at building scale

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ABSTRACT

Earlier results indicated that, for an average household, self-sufficiency in water supply can be achieved by following the Urban harvest Approach (UHA), in a combination of demand minimization, cascading and multi-sourcing. To achieve these results, it was assumed that all available local resources can be harvested. In reality, however, temporal, spatial and location-bound factors pose limitations to this harvest and, thus, to self-sufficiency. This article investigates potential spatial and temporal limitations to harvest local water resources at building level for the Netherlands, with a focus on indoor demand. Two building types were studied, a free standing house (one four-people household) and a mid-rise apartment flat (28 two-person households). To be able to model yearly water balances, daily patterns considering household occupancy and presence of water using appliances were defined per building type. Three strategies were defined. The strategies include demand minimization, light grey water (LGW) recycling, and rainwater harvesting (multi-sourcing). Recycling and multi-sourcing cater for toilet flushing and laundry machine. Results showed that water saving devices may reduce 30% of the conventional demand. Recycling of LGW can supply 100% of second quality water (D_{Q2}) which represents 36% of the conventional demand or up to 20% of the minimized demand. Rainwater harvesting may supply approximately 80% of the minimized demand in case of the apartment flat and 60% in case of the free standing house. To harvest these potentials, different system specifications, related to the household type, are required. Two constraints to recycle and multi-source were identified, namely *i*) limitations in the grey water production and available rainfall; and *ii*) the potential to harvest water as determined by the temporal pattern in water availability, water use, and storage and treatment capacities.

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1. Introduction

In the transition towards more sustainable urban water systems, increasing attention is given to self-sufficiency (Rygaard et al., 2011; Agudelo-Vera et al., 2011, 2012a), and to new planning and design approaches that incorporate resource recovery from wastewater (Guest et al., 2009). Within this transition the role of decentralized systems is considered important to address challenges faced by climate variability, population growth and urbanization (Makropoulos and Butler, 2010; Sharma et al., 2010). In addition, the importance of structural considerations such as the form of urban development, patterns of land use, types of land cover in the city, and the effect of lifestyles on water consumption are highlighted (Guhathakurta and Gober, 2010; Troy and Holloway, 2004).

1.1. *Residential water consumption*

Residential water consumption is related with type and number of water appliances, household size, and presence of a garden (Fox et al., 2009). Butler and Graham (1995) described the use of different water appliances as quasi-random, with frequency of use being related to the time of day, each with its own characteristics (e.g. quantity, quality, temperature). Water consumption has also been related to whether people are at home or not and if they are asleep, getting up or preparing for bed (Blokker et al., 2010). Several studies have found a bi-modal distribution for residential water consumption with a morning and an afternoon peak (Blokker, 2010; Butler, 1991; Memon et al., 2007). However, a standard residential water demand pattern is difficult to determine, given the large number of variables involved and the unpredictable nature of human behavior. Typically, the residential water demand patterns of individual households present high fluctuations due to the short duration of activities. At a larger spatial scale that includes multiple households, a dampening of the water use pattern occurs due to a scatter in time and magnitude of the individual water consumptions (de Moel et al., 2006).

1.2. *Decentralized water supply systems*

Grey water recycling and rainwater harvesting are nowadays widely accepted as feasible and as contributing to sustainable water management (Pidou et al., 2007; Dixon et al., 1999). Such treated urban wastewater provides a water supply relatively unaffected by periods of drought (EEA, 2009). The characteristics and treatments of grey water have been extensively studied by, among others, Eriksson et al. (2009); Li et al. (2009), and Pidou et al. (2007). As for non-potable use of recycled grey water the following treatment steps are recommended: *i*) pre-treatment, *ii*) chemical or biological treatment, *iii*) sand filtration or membranes and *iv*) disinfection.

Although technologies are available for on-site treatment and re-use of grey and rainwater (Jiménez and Asano, 2008), dimensioning guidelines taking into account variations in household occupancy and appliance types are lacking. It is important to consider the variations of both the supply and demand pattern for the dimensioning of decentralized systems, e.g. recycling of grey water or rainwater harvesting for non-potable use. Yearly averages can give an indication. However, it is important to investigate also the dynamic daily pattern for the different building types to evaluate the efficiency of the recycling and rainwater harvesting systems and to estimate the required storage capacity.

1.3. *Urban Harvest Approach*

The Urban Harvest Approach (UHA) proposes a hierarchy of measures to improve urban resources management. The UHA uses the metabolic profile to compare different strategies. The metabolic profile is calculated based on the inputs, outputs, re-use within the system and export of resources (Agudelo-Vera et al., 2012b). The UHA can be described in three steps: input minimization by implementation of more resource efficient technology; output minimization by cascading and recycling of flows[1]; and multi-sourcing of the remaining demand by harvesting local-renewable resources. Preliminary results for an average house in the Netherlands and Australia have shown that at household level, self-sufficiency can be achieved by following the UHA (Agudelo-Vera et al., 2012b). These results are, however, valid for an average household, assuming that all the available local resources can be harvested. In reality, there are limitations to harvest all the available local resources. The main limitations are (*i*) spatial variations depending on building typology, e.g. single houses or apartment blocks; (*ii*) seasonal and location-bound variations, e.g. yearly precipitation patterns; and (*iii*) temporal variations, e.g. demand and supply patterns that fluctuate through the day – day/night, within the week – working days/weekends, and within the year – seasons.

Our hypothesis is that urban areas are reservoirs of resources that can be harvested and used to supply urban demands (Agudelo-Vera et al., 2012b). To estimate and design urban systems, there are restrictions given by the urban typology, such as building type (Agudelo-Vera et al., 2011, 2012a). Therefore, to optimize urban resource cycles, development of increased understanding of process dynamics relevant for resources management at different scales is necessary. Although a lot of knowledge has already been gained over the last decades (Arbués et al., 2003; Burkhard et al., 2000), there is still a knowledge gap on how urban/building characteristics influence the system efficiency of decentralized urban water systems. Until now, only subsystems of the urban water system, like recycling grey water for toilet flushing, are being evaluated (e.g. Farreny et al., 2011; Fewkes and Butler, 2000). However, to evaluate the efficiency of subsystems, the effect on the complete system – in this case the building unit – also needs to be considered. Objectives of evaluating at building unit level are twofold: firstly to demonstrate that only results at subsystem level can be incomplete and secondly to show the applicability of the UHA for different scales.

[1] Cascading refers to direct reuse of waste flows, meanwhile recycling includes quality upgrading of the flow before reuse. In this paper, to secure quality standards, we will only consider recycling.