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Operational data of the Star City rainwater harvesting system and its role as a climate change adaptation and a social influence

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ABSTRACT

The Star City rainwater harvesting system (RWHS) was featured in the December, 2008, issue of Water 21. The article highlighted that the RWHS has a 3,000 m³ rainwater tank used in water saving, flood mitigation, and emergency response. Since then, many news media, public officials, and people from both South Korea and abroad have visited the RWHS. In this paper, two years of the system’s operational data are presented and its role in short- and long-term climate change adaptation is investigated. The downstream sewer system has become safe for a 50-year rainfall without upgrading the existing sewer system, which was designed for a 10-year period. The 26,000 m³ of water saved has reduced the energy requirement of transferring water from a distant area. The success of the Star City RWHS has influenced 47 cities across South Korea, including Seoul, to enact regulations on rainwater management. It has shown that decentralized rainwater management can supplement the existing centralized system to ensure its safety.

Key words | climate change adaptation, decentralized rainwater management, rainwater harvesting, star city

INTRODUCTION

Decentralized rainwater management (DRM), which is mainly realized by onsite rainwater harvesting and infiltration, is likely to play an important role in complementing existing centralized urban water infrastructure in terms of water saving, flood mitigation, and groundwater recharge (Niemczynowicz 1999; Coombes et al. 2002; Han 2006). There have been several reports on rainwater quality and the design of rainwater harvesting systems (RWHS) in buildings (Han et al. 2004; Meera & Ahammed 2006; Han & Mun 2008; Amin & Han 2009; Karim 2010). Kim (2008) showed that runoff control can be achieved by installing a rainwater retention tank in a building. Rainwater quality and the design of the system in a RWHS of a building or complex have mostly been investigated, but there is little published research in terms of climate change adaptation (CCA) or a multipurpose role including water saving, flood control, energy saving, and social aspects based on the operational data of an individual RWHS.

Star City – located in an eastern suburb of Seoul, South Korea – is a major real-estate development project of more than 1,300 apartments. It comprises four 37–58 story buildings on an ~5 ha site. The Star City RWHS has been operating since 2007 and is receiving worldwide attention as a model water management system that supplements the existing centralized water infrastructure as a CCA strategy (IWA 2008).

Several innovative concepts have been applied in implementing the Star City RWHS. The first is the concept of a multipurpose system: the system is used in flood mitigation, water conservation, and emergency response. The second is the proactive management of flooding: the Star City RWHS has a remote control system for monitoring and controlling tank water level. The three different tanks also store water separately according to water quality. The risk of flooding is mitigated with a remote control system by emptying or filling the tanks appropriately. The third innovative concept applied in this project is the city government’s incentive program for the developer to alleviate fear of any economic disadvantage. The developer was permitted to construct three percent more floor space above what would normally be allowed. Considering the price of real estate in Seoul, that is a significant incentive.

This paper introduces the Star City RWHS, and analyzes its operational data from various viewpoints, such as
those of water saving, rainwater quality and runoff control for short-term CCA, and energy saving potential for long-term CCA. The social effect of the project on DRM promotion is also discussed. Finally, we suggest that DRM is a simple and efficient measure for addressing climate change issues and is applicable to most cities around the world.

MATERIALS AND METHODS

System configurations

Figure 1 is a schematic diagram of the Star City RWHS. The catchment area comprises 6,200 m² of rooftop and 45,000 m² of terrace. The entire fourth below-ground floor in Building B is used as a water storage area. Altogether, 3,000 m³ of water is stored in three separate tanks with a total floor area of 1,500 m². The capacity of each tank is 1,000 m³. Two of the tanks are used to store rainwater from the rooftops and the ground. Garden irrigation is achieved efficiently by ground infiltration, which is recycled to the tank for multiple uses. The third tank stores emergency tap water. Fresh tap water is maintained by regular replenishment after decanting half of the old water to the rainwater tank.

The quantity of rainwater flowing into the tanks is measured by pipe- and weir-type flowmeters (Figures 2(a) and 2(b)). The shock absorber in Figure 2(c) is used to relieve the high flow velocity of rainwater from the top of the building. A screen and a filter, as shown in Figures 2(d) and 2(e), are used for pretreatment. The calm inlet in Figure 2(f) and floating suction in Figure 2(g) are installed to mitigate the resuspension of bottom sludge and draw out high-quality subsurface rainwater, respectively.

Analysis of operational data

Rainwater supply was monitored using the flowmeter shown in Figures 2(a) and 2(b) from June 2007 to May 2008. Turbidity and pH were measured from May to August 2007 and compared with the Korean Gray Water Standard (KGWS) and the Korean Drinking Water Standard (KDWS). A rainfall, storage, and discharge (RSD) model was used for evaluation of runoff control during the RWH operation in the Star City complex. The RSD model was developed by Kim & Han (2008) for the design of flood control rainwater tanks (Figure 3). Kim and Han showed that by using the RSD system with a tank volume–catchment area ratio of 10 m³/100 m², a 100-year-frequency peak flow event in Seoul can be reduced to almost the same value as that of a 5-year-frequency rainfall occurrence.

The energy consumed for water supply from the existing Seoul-wide water supply system (WWS) and the Star City RWHS was also calculated, and the energy saving by DRM was evaluated from the results. A WWS consists of a water intake, an intake pipeline, water treatment plants (WTP), a transmission pipeline, distribution reservoirs (DR), and water supply facilities from the DRs. The energy demand of a WWS is mainly consumed in water treatment and conveyance. We assume that the water intake is adjacent to the WTP and water is supplied through gravity from a DR that usually stands on a rise close to end users. The energy required for water treatment and conveyance from the WTP to the DR was thus considered to represent
the energy demand of a WWS. The amount of energy consumed for producing 1 m$^3$ of potable water is derived from water service statistics (Ministry of Environment 2010), and the amount of energy for water conveyance by pumping was calculated as the sum of the static and friction heads. Static head is the elevation difference between a WTP and the DR. The friction head was calculated using the Darcy–Weisbach equation. The energy requirement for operating the Star City RWHS was calculated based on the hours of operation of the rainwater supply pump. The energy requirement for water treatment in the RWHS is assumed to be zero, because simple particle separation by screening and sedimentation are the only treatment methods used for non-potable purposes such as irrigation and toilet flushing.

RESULTS AND DISCUSSION

Water saving and flood mitigation potential

Monthly rainfall and rainwater supply from June 2007 to May 2008 are presented in Figures 4(a) and 4(b). Most rainfall was concentrated from summer to early autumn as shown in Figure 4(a). Rainwater was mostly used for gardening in summer and autumn, not in winter due to low temperature and freezing. Based on operating the system for a year, we found the volume of water conserved to be approximately 26,000 cubic meters per year, which is $\sim$47% of the annual amount of rainfall over the Star City complex. The ratios of the volume of water conserved per month to monthly amount of rainfall, ranged widely from 18% in July to over 200% in November. Over 200% could be achieved by supplying stored rainwater left from the previous month and by irrigation, which is recycled to the rainwater tank.

The turbidity of stored rainwater was maintained below 1.5 NTU, as shown in Figure 5. The dotted line in the figure represents the KGWS. The pH of the rainwater ranged from 6 to 8.4, which meets the KDWS (Figure 6). The red dotted line in Figure 6 represents the KDWS.

The total area of the Star City complex is $\sim$51,200 m$^2$, comprising 6,200 m$^3$ of rooftop and 45,000 m$^3$ of terrace and garden. The RSD model was developed to evaluate runoff control from the roof area. When considering the infiltration capacity of the garden, the runoff coefficient of the terrace was assumed to be 60% that of the roof. The total equivalent area thus becomes $\sim$34,550 m$^3$. The tank volume–catchment area ratio is 5.8 m$^3$/100 m$^2$. This ratio was plotted on the graph reported by Kim (2010), and the runoff control potential was evaluated. As can be seen in Figure 7, a 50-year-frequency peak flow of 27 m$^3$/h can be reduced to 20 m$^3$/h through a rainwater tank installation with a tank volume to catchment area ratio of 5.8 m$^3$/100 m$^2$. The peak flow of 20 m$^3$/h indicates a 10-year-frequency peak flow. Therefore, the Star City complex, which has a storage array with a 10-year design period, would provide protection from a 50-year flood.

Energy saved by using rainwater supply

The energy consumed in supplying potable water is mainly used in water purification and transmission. The energy requirement for water treatment depends on the degree of treatment, which in turn is based on the quality of the raw water and the desired quality of the potable water. The value of treatment energy used here is 0.0387 kWh/m$^3$ for potable water (Ministry of Environment 2010). The energy requirement of water transmission depends on the relative elevations and the transmission distance. For Seoul, it is calculated to be 0.34 kWh/m$^3$ assuming a 60 m elevation difference and an 8,000 m distance. Consequently, the total energy required to supply 1 m$^3$ of potable water is
estimated to be 0.38 kWh. This means that approximately 90% of the total energy requirement for supplying potable water is consumed in water conveyance. In this study, only water treatment and transport from WTPs to the DRs are considered in calculating the energy consumption of the WWS. The estimated energy requirement for water supply is therefore expected to be higher than 0.38 kWh/m³. However, the energy required for treatment of rainwater is zero, and with a 10 m elevation difference and less than 100 m transmission distance the total amount of energy required is calculated to be 0.039 kWh/m³, which is ~10% of the energy consumed in conventional means of supplying potable water. Based on the foregoing calculations, ~8.9 MWh of electricity is expected to be saved per year by rainwater use in the Star City project.

Social impact

The success of the Star City project served as a model for enacting regulations aimed at rainwater harvesting and management in Seoul. In December 2004, the city authority announced new rules to enforce the installation of RWHS, with the main purpose of mitigating urban flooding and a secondary purpose of conserving water and extending energy savings. These measures are expected to ensure the safety of the city from future flooding. A special feature of the new system is the provision of a network for monitoring water levels in all water tanks at the central disaster prevention agency in the City Office (Figure 8). Data are gathered from each gu or district office. Depending on the expected amount of rainfall, the central disaster prevention agency may issue an order to building owners to either fully or partially empty their rainwater tanks. An incentive program is planned to reward those who follow the order and penalize those who do not. After a storm event, the stored water can be used for fire fighting and non-potable purposes, such as toilet flushing and gardening.

The buildings included in the regulations are as follows:

- All public buildings. Compulsory for new buildings and recommended to the extent possible for existing buildings.
- New public facilities, such as parks, parking lots, and schools, to the extent possible.
- Private buildings. Recommended for new buildings subject to building permission (floor area larger than 3,000 m²).
Large development plans, such as new town projects. A rainwater management system is a first priority. By October 2010, 47 local authorities in South Korea had made regulations on rainwater management to promote DRM by providing financial incentives and subsidies, and by establishing operating rainwater committees. Several cities have proposed rules for the publication of comprehensive rainwater management reports every 10 years. Many other cities are planning to make rainwater regulations under the Green Growth Policy of the South Korean government.

CONCLUSIONS

The Star City RWHS is introduced here as a model water management system to address water-related problems and as a measure to respond to climate change. Its design and operational data are analyzed from various viewpoints, such as those of water saving, rainwater quality, runoff control for short-term CCA, and energy saving potential for long-term CCA.

About 26,000 m$^3$ of water was saved per year from rainwater supply. The turbidity of the rainwater in the tanks was below 1.5 NTU and their pH was between 6 and 8.4. The tank volume–catchment area ratio of 5.8 m$^3$/100 m$^2$ and 10 year design period for this building would provide protection from a 50 year rainfall flood event. It is also estimated that approximately 8.9 MWh of electricity was saved from June 2007 to May 2008 by using the 26,000 m$^3$ of rainwater.

The success of the Star City project has raised interest in rainwater management and has served as a model for the enactment of regulations concerning RWH and management in Seoul and 47 local authorities. The Star City approach shows that DRM can be a feasible supplement to the existing centralized system, and CCA in a newly constructed residential complex can be achieved by installing a proactive and multipurpose RWHS.

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