

Unit Energy Consumption of Water Supply Options and Energy Saving Potential by Rainwater Harvesting

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ABSTRACT: The energy required to supply one cubic meter of tap water in a conventional water supply system comprises of the energy required to water intake, transmission, purification and distribution.

In a conventional water supply system, the energy requirement depends on the quality of raw water, distance to the user, and elevation difference between the source and the user. In this paper, the unit energy requirement for water supply system (energy required to supply one m³ tap water) is calculated using the average value considering an arbitrary city. The distance of distribution is assumed from 100 m to 10,000 m. The average elevation is also assumed from 0 m to 100 m.

Alternative water supply systems such as rainwater harvesting system and grey water system are calculated and evaluated. These data can be used by the decision makes and policy makers to decide the optimum water supply solution for the sustainable growth in preparation for the climate change. Especially, it is noted that the energy saving by using rainwater harvesting is tremendous, which will be discussed with modelling and calculation results.

Keywords: Unit energy, water supply system, Rainwater Harvesting, energy consumption, energy saving

1. Introduction

Safe and sustainable water supply system has been the most important goal for all countries and cities throughout the history. Therefore, each city and country has to develop and maintain sustainable water supply system. In Korea, in order to achieve this object, several wide area water supply systems (WAWSS) are developed and operated. It takes raw water from dams or

supply treated water to consumers of more than two municipalities.

Although this system played a very important role in water supply system in Korea as a typical centralized water supply system, this system faced limited situation. To cover the increase of water demand, new big dam or big structure is needed in the WAWSS. But because of the growth of civil society and community awareness, it is almost impossible to build water supply system from new big dams.

In this situation, to supply water to new demand, alternative water resources are suggested as solution. Rainwater harvesting, gray water system and desalination of sea water are involved in alternative water resources.

Typical method to evaluate efficiency among these alternatives was to compare new water resources from the economic point of view. Engineering economy is simple and easy method to decide one solution in many alternatives.

However, because of the concern of CO₂ reduction and oil crisis, the dramatic effect of the rising costs of energy has contributed to a dizzying world-wide inflation [1].

So, in this paper, we investigated the energy consumption of each water supply alternatives, such as WAWSS, rainwater harvesting system and gray water system. An arbitrary city with different distance and elevation is considered for possible application to other cities. From this result, we can suggest a method to develop and maintain energy efficient water supply system.

2. Methods and Materials

2.1 Methods

The energy required for a water supply system can be calculated as the sum of water transmission and treatment.

The energy for water transmission by pump can be calculated from total head which is the sum of static head and friction head. Static head is the elevation difference between water purification plant and user). Friction head is a function of the distance and in this study, Darcy-Weisbach equation is used as shown in Eq. 1.

$$h_L = f \frac{L}{D} \frac{v^2}{2g} \quad (\text{Eq. 1.})$$

where, h_L : head loss [m]
 f : friction coefficient
 L : length of pipe [m]

D : diameter of pipe [m]
 v : velocity [m/s]
 g : acceleration of gravity [m/s²]

And the energy requirement to run pump and motor is calculated following Eq. 2.

$$P = 9.8 \frac{rQH}{\eta} \quad (\text{Eq. 2.})$$

where, P : The energy to run pump [kW]
 r : Density of fluid [kg/l]
 Q : Quantity of pump [m³/sec]
 H : Total head of pump [m]
 η : Efficiency of pump

The energy that is required in water purification is a function of the raw water quality and the water treatment goal, however, a data from an operating Gwangam water purification plant is used.

Also, energy required at alternative water resource is evaluated from operating rainwater harvesting systems and gray water systems.

2.2 Materials

To evaluate energy consumption of a typical water supply system in Korea, an arbitrary city is assumed. Schematic diagram is shown as in Fig. 1.

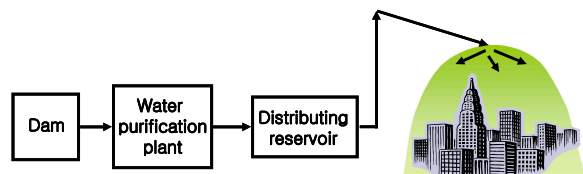


Figure 1: Schematic diagram of water supply for an arbitrary city.

Water supply flow can be divided in four steps. First step is transmission from dam to water purification plant. In this cases, the treatment plant is assumed to be located near the dam, and the energy consumption for the transmission is zero. Second step is the energy for water purification. Based on the annual operation report in Gwangam

water purification plant, the required energy to make one ton of tap water is used. Third step is transmission from water purification to distributing reservoir that is located in a higher elevation at a city. Forth step is supply water from distributing reservoir to city. We assume that this step also used gravity force. Therefore, this step is ignored in calculation.

To calculate energy consumption in whole step, we assumed a range of values as in Table 1.

Table 1: Factors that are considered in calculation.

Factor	Value
Elevation difference between water purification and distributing reservoir	0 ~ 100 m
Distance between water purification and distributing reservoir	100 m ~ 10,000 m
Pipe diameter	0.5 ~ 2.5 m
Electric cost per ton in purification	2.8 won
Friction coefficient	0.2
Water velocity	0.5 m/s

The energy that is required at rainwater harvesting system and gray water system, are calculated from published reports [2, 3]. Average cost of electricity is assumed to be 72.34 won per 1 kWh.

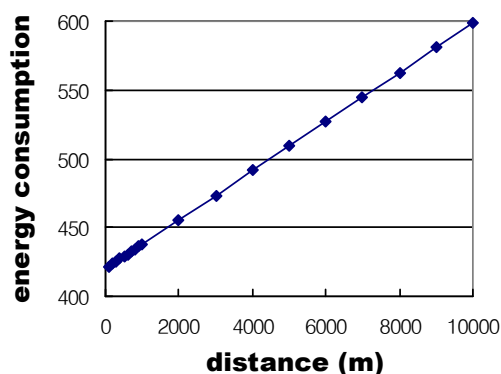
3. Results and discussion

3.1 Required electric power in transmission

Fig. 2 shows the consumed electric power to supply 1 ton tap water to a city at different distance. To supply 1 ton tap water to virtual city, 421.8 kWh is needed at the distance is 100 m. And, distance and energy consumption has linear relationship.

Figure 2: Energy consumption in cities located at different distances (m) at the elevation difference of 30 m and pipe diameter is 2 m.

(unit: kWh)



Relation between pipe diameter and energy consumption is shown in Fig. 3. Energy consumption is decreased while pipe diameter is increased. But the effect of pipe diameter is smaller than distance between distributing reservoir and virtual city. It's the reason that, distance is more effective factor than pipe diameter in Darcy-Weisbach equation.

Fig. 4 show that the relationship between elevation of virtual city and energy consumption. As elevation of virtual city is increased, energy consumption is increased sharply. The effect of headloss to total head is much smaller than the effect of elevation difference. Therefore, geological condition like distance or elevation difference is more important than pipe diameter. So, when water supply system is designed, nearest water resource should be used for energy saving.

Figure 3: Energy consumption according to the selection of pipe diameter at the distance of 100 m and elevation difference is 30 m.

(unit: kWh)

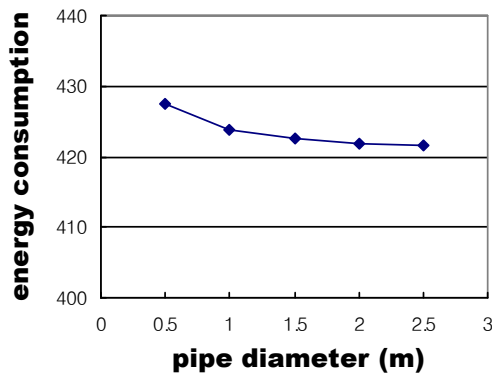
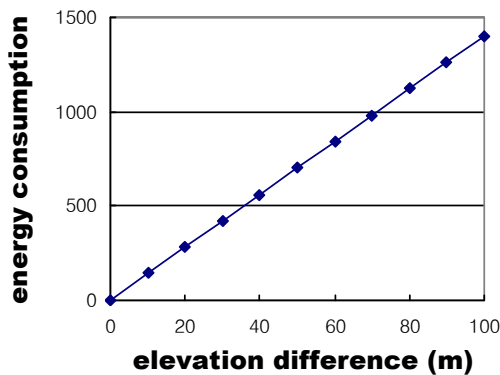


Figure 4: Energy consumption in wide area tap water system following elevation difference at the distance is 100 m and pipe diameter is 2 m.

(unit: kWh)

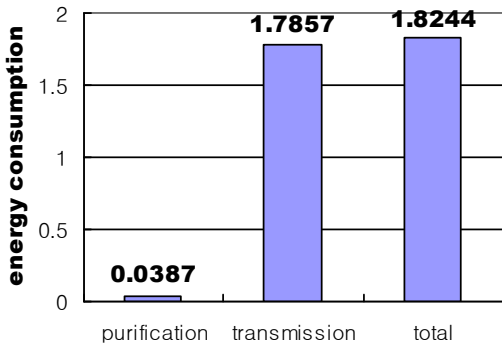


3.2 Required electric power in purification

Energy consumption in water purification step is calculated in operating data of Gwangam water purification plant. Energy consumption of water purification step is shown in Fig. 5 with minimum energy consumption of transmission and minimum total energy consumption. It is shown that transmission is main consumer in wide area tap water system. Transmission occupies 97.9 % of total energy consumption. Therefore, in consideration of energy cost at WAWSS transmission should be considered carefully than purification step.

Figure 5: Energy consumption comparison between transmission and purification.

(unit: kWh)

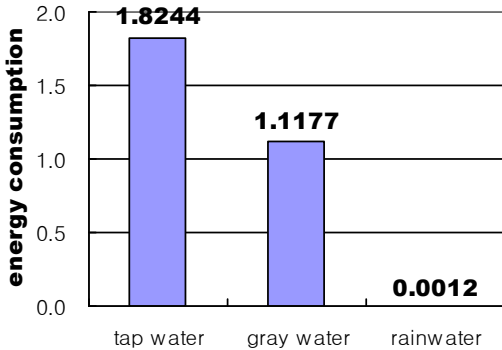


3.3 Alternative water supply systems

Required energy for each water supply system is shown in Fig .6. Assuming minimum energy consumption value in WAWSS (elevation: 0 m, distance: 100 m). Both alternative systems require less energy than WAWSS, because they do not require the long distance transmission. In Rainwater Harvesting system, the energy requirement for purification is minimum, because it can be used for non-drinking purpose. Thus, when water supply system is designed, rainwater harvesting system should be considered as first option to supply water. And gray water system also can be included as the second option.

Figure 6: Required energy for each water supply system.

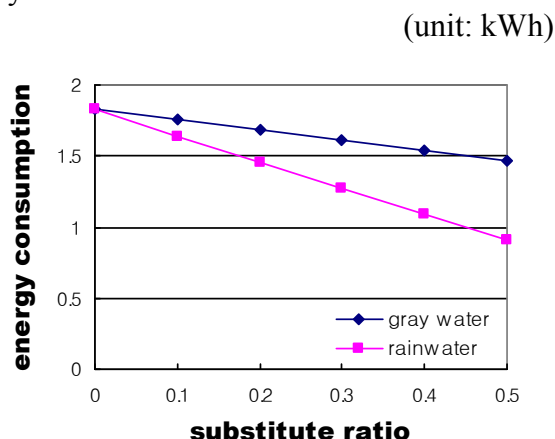
(unit: kWh)



Based on the above result, energy reduction potential is calculated on the assumption that the city adapts the energy saving by introducing the alternative water supply system from 0% to 50%. As shown

in Fig. 7. The potential of rainwater harvesting system in the energy reduction is tremendous. If we substitute 50 % of tap water as rainwater, we can reduce 50 % of energy that is required for WAWSS. Gray water system also, can be used to save energy. But this system is not as effective like rainwater harvesting system.

Figure 7: Energy consumption as gray water system and rainwater harvesting system substitute ratio.



4. Conclusion

In this paper, several water supply systems such as WAWSS, rainwater harvesting and graywater systems are compared in the viewpoint of energy.

The energy required for a water supply system consists of water transmission and purification. WAWSS system which supplies water for a far city requires most of its energy for transmission.

The rainwater harvesting system has a very high potential to save energy because it does not require transmission and purification. Therefore, in the design and operation of city water supply system, rainwater harvesting system should be considered as the first priority for saving energy.

REFERENCES

- [1]David, G, Argo. 1976. Energy and water supply, Orange county, California. Desalination. Vol 25. pp135-149. Netherland.
- [2]Sang-Hean Park & Jong-Il Park. 2003. A study on the economic evaluation of grey water system in hotels. Proceedings of the 2003 Summer Conference on Air-Conditioning and Refrigeration Engineering. 2th-4th July. South Korea.
- [3]Han, Moo-young & Kim, Young-wan. 2004. Outline and economical valuation of rainwater utilization facility in SNU dormitory. Journal of the Korean society of water and wastewater. Vol 18. No 5. pp547-557. South Korea