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Smart design of a sustainable building with zero water demand: Rainwater harvesting, in situ water and wastewater treatment

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Abstract

In this research, a smart sustainable building with zero water demand has been designed based on rainwater harvesting and in situ water and water treatment. Rainwater has been collected from all roof tops and basements. Additionally, two membrane bio-reactors (MBR) were used in the building to in situ treat the gray water. According to the results, total annual rainwater harvested (W_R) was 10,000 m³/Y which includes 2,507 m³/Y from roof tops and 7,604 m³/Y from basement. Total treated gray water (W_T) through the two MBRs was 25,000 m³/Y. While, the annual total water demand (W_D) of the building was estimated as 36,500 m³/Y. Therefore, the needs of supplying city water (W_C) from outside was less than 1,500 m³/Y. The results of economic analysis revealed that by the new smart design building in this study, approximately 1,840,695,000 IRR cost can be saved per year.

Key words: Smart design; Sustainable management; Zero water; Rainwater



1. Introduction

Today, the continuous increase in population has made the countries of the world face the problem of clean water availability more and more, the excessive consumption of water and the pollution caused by human activities threaten nature and human life and push them towards destruction [1-3]. Generally, 99% of the world water such as seawater and polar ice-water is not available for human being. The rest 1% includes river water, underground water and rainwater [2]. Rainwater as a free clean water source can be directly harvested from building roof top and urban residential catchments [4-6]. Sustainable architecture can be considered as promising approach for rainwater harvesting and re-use [6,7]. In the perspective of sustainable building design, the use of technology and intelligence in building components (building frame, materials, facade, etc.) leads the building to save water and be more environmentally friendly and increase its useful life.

Considering, number of building increases along with population growth and they are centers of toxic emissions, the needs of sustainable building design are necessary. Sustainable architecture and its solutions to deal with water demand problems have been accepted day by day by the market and sustainable clients, which include official and office customers, but the marketing and initial construction costs of a green office building are a difficult path for designers to encourage employers [8]. Rainwater harvesting from smart building roof tops, terraces and landfilled together with an in situ treatment after usage eliminate the need of water supply from outside: means zero water building (ZWB).

In the literature, different ZWB's were described and evaluated. It can be said that Alandre Architecture building (1991) was one of the first in the United States to be certified as LEED Zero Water which has 500 m² structure, also home to Eco Builders, Inc. Rainwater is collected from the 350 m² roof area and directed to a 6 m³ underground storage tank. Any overflow rainwater flows into a vegetated infiltration area. In drought conditions, a float switch in the storage tank causes the rainwater valve to close and the municipal water line to open. Average annual rainfall landing on the roof of the building totals about 7000 m³ [9]. As another example of ZWB, Bullitt Center Building in Washington, USA with 4830 m² area is good example. In this project all of water demand including drinking water is collected from the rainwater which is storage in 211,938 lit [10]. However almost in every ZWB projects either was defined differently or no exact definition was used. The lack of common understanding and common definition for ZWB became noticeable, since this building concept is thought to be an effective solution for decreasing the water supply from outside and greenhouse gas emissions from the building sector.

In this research, we designed a new smart building for sustainable water management. The designed building with 16,500 m² area has been located in Nowshahr, Iran with 613 mm annual rainfall. The total net water has been calculated for one year. A brief economic analysis has been conducted to estimate cost saving.



2. Materials and methods

2.1. Project location and annual rainfall

The project has been located in Nowshahr city which is one of the cities of Mazandaran province in IRAN. This city is bounded by Caspian Sea from the north, Alborz mountain ridge from the south, Nur city from the east and Chalus city from the west. In terms of geographic location, Nowshahr is located at 36 degrees 39 minutes' north latitude and 51 degrees 33 minutes' east longitude, which is connected to the Caspian Sea from the north, Alborz mountain range from the south, Nur city from the east, and Chalus city from the west, generally the western part of the province. Mazandaran has a moderate and humid climate, and the mountainous regions of the western part of the province, including Nowshahr and Chalus, have a cold and humid climate. The amount of rainfall and air humidity in the west of the province is higher than in the east. The winds that blow to this region from the west and Gilan province make the air cold and cause snow to fall in the mountains. Nowshahr is one of the coastal, port and tourist cities of the province. Cumulative rainfall in the month of February in Mazandaran province shows that the highest amount of cumulative rainfall is from the west coast of Nowshahr to the east coast Tenkaben, it was between 105 and 180 mm. The city of Nowshahr has relatively high humidity, rain falls on the people of this region on most days of the year. The average annual rainfall of Nowshahr was recorded as 613 mm.



Figure 1 :Project location



2.2. Smart building design

Building form plays an important role in creating suitable conditions for water harvesting. The external horizontal surface of the building is in direct contact with the raindrops which can harvest rainwater as clean water source. Therefore, the design must ensure that the least possible amount of the external horizontal surface.

The height of the building also has a significant effect on the pressure head of harvested rainwater, because with the increase in height, the pressure head of water also increases. One wall of the building is dedicated to the green facade and the terrace, to capture the favorable view of the site and the beauty of the building.

The net area of the site after withdrawal is 16500 m². The land measures 95-138-142-141 meters. In the report of National Climate and Drought Crisis Management Center of Iran Meteorological Organization, the average rainfall in Mazandaran last year was 613 mm.

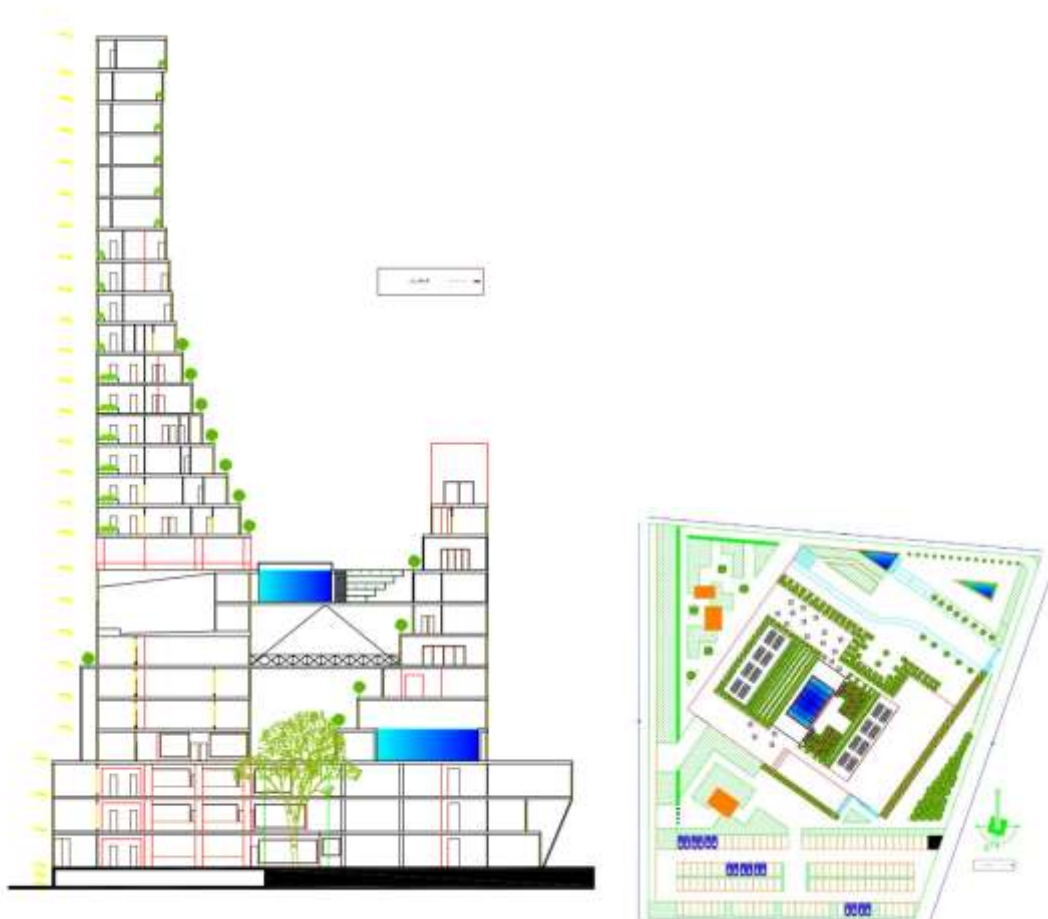


Figure 2 :New designed bulding



2.3. Water measurements

Total water use is the amount of water consumed within the boundaries of a building from all sources (potable and non-potable including freshwater and alternative water) over the course of a year. Total harvested rainwater (W_R) is estimated using Eq. (1):

$$W_R = P_t \times A_t \quad (1)$$

where, P_t is total annual rain fall which is approximately 0.6 mm in this case study and A_t is total surface area which can harvest rain water. Water returned is the amount of water collected from the building systems (green infrastructure and on-site treated wastewater) and returned back to the original water source over the course of a year. In a net zero building, the total annual water use should be offset by water returned to the original source in part or completely.

3. Results and discussion

3.1. Water net in the new designed ZWB:

An ideal net zero water building uses on-site alternative water sources to supply all of the building's water needs. All wastewater discharged from the building is treated on-site and returned to the original water source. Net zero water creates a water-neutral building where the amount of alternative water used and water returned to the original water source is equal to the building's total water consumption. In this project the water sources is divided and estimated as follows:

- *Total annual rainwater harvesting through the smart building (W_R):*

The total annual harvested rainwater (W_R) is equal to total annual harvested rainwater from roof tops (W_{RO}) and trace plus total annual harvested rainwater from lands (R_L):

$$W_R = W_{RO} + W_L \quad (2)$$

Total annual harvested rainwater from roof tops (W_{RO}) is estimated as total roof top areas (4090 m^2) \times total annual rainfall (0.613 m) = 2507.17 m^3 . Total annual harvested rainwater from land (W_L) is estimated as total roof top areas ($12,406 \text{ m}^2$) \times total annual rainfall (0.613 m) = 7604.88 m^3 . As a results, the total annual harvested rainwater (W_R) from our smart building has been estimated approximately as $10,000 \text{ m}^3$ per year.



- *Total annual water demand of the smart building (W_D):*

The total annual water demand of the smart building (W_D) has been estimated based on the commercial and residential demands per person. It has been reported that normally each person use approximately 200 lit/day water (equal to 73 m³/year). Considering that the building has been designed for almost 500 person, the total annual water demand of the smart building (W_D) has been estimated as 36,500 m³ per year.

- *Total in situ treated water in the smart building (W_T):*

Two in situ membrane bio-reactors (MBRs) system were used in the building which continually treat gray water to producer reuse water for non-drinking purposes. These MBR systems could potential produce ~ 25,000 m³ treated water per year.

- *Total annual water supply from city (W_C):*

The total annual water supply from city to the smart building (W_C) is equal to the difference between the total annual water demand of the smart building (W_D) and the total annual harvested rainwater (W_R) plus total treated gray water in the building (W_T).

$$W_C = W_D - W_R - W_T \quad (2)$$

According to the value estimated for W_D (36,500 per year), W_R (10,000 m³ per year) and W_T (25,000 m³ per year), the total annual water supply from city to the smart building (W_C) has been estimated as 1,500 m³ per year (Almost zero).

Figure 3 shows the net water in the new designed building. According to the figures data, only 1,500 m³ should be supply to the building from outside, annually. This amount can be reached to zero if more gray water be treated in the building

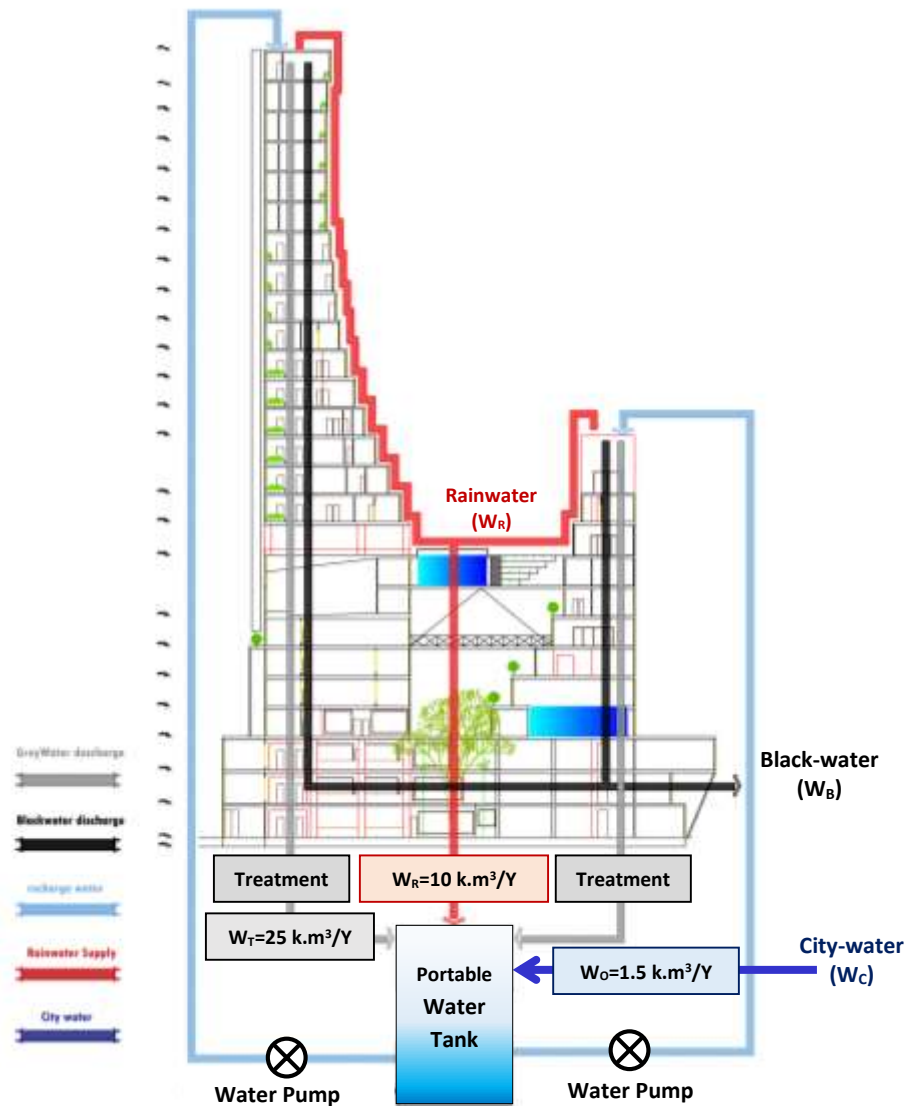


Figure 3 :Net water in the new designed building

3.2. Economic analysis

According to the results of section 3.1, in the new smart designed building without gray water treatment approximately 10,000 m³ water can be saved in a year through rainwater harvesting system. Considering the city water price of Iran for commercial buildings in 2022 (50,433 IRR/m³), in total 504,433,000 IRR can be saved. This amount can be increased to 1,765,050,000 IRR by gray water treatment inside the building. It should be noted that without any rainwater harvesting and in situ gray water treatment in the building, total water price for the new designed building would be 1,840,695,000 IRR. While, after smart design of the building the total water price of the building becomes 75,645,000 IRR.



4. Conclusion

A net zero water building completely offsets water use with alternative water plus water returned to the original water source. The smart sustainable building in this study has been designed based on rainwater harvesting and in situ gray water treatment. According to the results, total annual rainwater harvested (W_R) was 10,000 m³/Y which includes 2,507 m³/Y from roof tops and 7,604 m³/Y from basement. Total treated gray water (W_T) through the two MBRs was 25,000 m³/Y. The new designed building could not completely remove the needs of water supply from outside. However, the needs of city water (W_C) from outside was less than 1,500 m³/Y. The results of economic analysis revealed that by the new smart design building in this study, approximately 1,840,695,000 IRR cost can be saved per year.

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