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Rainwater Harvesting, a Solution to Reduce Drinking Water Consumption for Buildings

Assoc. Prof. Dr. Eng. **Adriana TOKAR[1],** Dipl. Eng. **Paul FRASIE[2],**
Res. Asst. PhD. student Eng. **Dănuț TOKAR[1]**

[1] Politehnica University Timisoara, Faculty of Civil Engineering, adriana.tokar@upt.ro

[2] Pinchin Ltd., Canada, paul.frasie@yahoo.com

[*] adriana.tokar@upt.ro

Abstract: *Water consumption worldwide has increased considerably in recent decades and has a growing trend due to population growth in the coming years. Migration of the population from rural areas to urban areas will lead to problems arising from water insufficiency in crowded areas. Urban areas are oftentimes up to 8°F warmer than the surrounding rural area, creating "urban heat islands". In densely populated areas where more water is consumed, an important consideration would be whether a part of the urban water requirement can be covered by rainwater harvesting. First, rainwater harvesting helps to conserve water by reducing the amount of water needed for toilet (and urinal) flushing, and outdoor watering. The article analyzes the water consumption averaged between years 2015 and 2017 (thermal power plants, humidifiers, and plumbing) for a 25- stories building located in Canada. Based on the analysis, it was found that the combined seasonal average for the spring and summer was 62% higher than the winter and fall seasons. By using rainwater instead of potable (drinking) water for these applications, homeowners can reduce their daily water use by approximately 30%.*

Keywords: *Rainwater Harvesting, Reducing Water Consumption, High Buildings, Measures and Recommendations*

1. Introduction

"Humanity has the ability to make development sustainable to ensure that meets the needs of the present without compromising the ability of future generations to meet their own needs", is definition from Brundland Commission's report "Our Common Future (WCED), 1987.
Increased of world population in the next years will affect natural resources consumption. As a result, water consumption will increase with the same pace with the demographic increased and shall create problems like water scarcity in the urban areas. Meanwhile, water supply systems face water loss caused by both the age of pipes and system optimization issues such as pressure loss in the water network.
The study of economic profitability and various pressure control are required to establish the ways to take for the water network upgrades in the urban areas. This will meet the safety water consumption and protect the natural resources.
Natural resources management is a global concern and a priority for the lasting development. The population are in the center of this development. The understanding of population global trends and the next demographic changes are crucial to establish the objectives of lasting development for 2030. The right projections and forecast for the population water consumption will allow the government to anticipate future demographic trends and to include that information in their planning policies for 2030 [1]. Table 1 shows important data related to world population trend from EU and Romania [1]. The probabilities forecast was conducted on 80% and 90% samples.

Table 1: Total population by world, EU and Romania, annually for 1950-2100 [1]

No.	Total population (thousands)							
	Standard Projections (Estimates and Projection variants) 2015-2020 reported to the year							
	Area	1995	2015	2016	2017	2018	2019	2020
1	World	2.536.43	7.379.79	7.464.02	7.547.85	7.631.09	7.713.46	7.794.79
2	Europe	549.32	743.05	744.26	745.41	746.41	747.18	747.63

3	Romania	16.236	19.925	19.796	19.654	19.506	19.36	19.23	
	Probabilistic Projections (including prediction intervals)								
	Area	2030	2040	2050	2060	2070	2080	2090	2100
1	World	8.548.48	9.198.84	9.735.03	10.151.47	10.459.24	10.673.90	10.809.89	10.875.39
2	Europe	741.30	727.81	710.48	688.79	666.59	649.58	638.36	629.56
3	Romania	18.30	17.30	16.26	15.17	14.12	13.25	12.53	11.87

Table 1 shows that from 1995 to 2018 the population increase in all analyzed areas (i.e., Worldwide, Europe, Romania); after 2018 the forecasts show a Worldwide population increase, a slow population decrease in Europe and a concerning decrease population in Romania. If you look at 1995 forecast only, the population increased trend is the same in EU and Worldwide, meanwhile in Romania the concern stays the same. One of the most concerning issue is the fact the next decades will have the highest urban increase rate in human history, with 2.6 billion additional inhabitants until 2050. All the addition inhabitants will need water, but more importantly, there is not too much information about big cities water management and how the infrastructure affects global hydrologic cycle [2]. The adaptability to the recent challenges regarding the environment and water systems associated with the buildings is crucial. Rainwater harvesting plays a major role [3, 4, 5].

2. Influence of using stormwater

Stormwater contains pollutants and nutrients which can endanger soils, groundwater and slowly flowing receiving water when it is discharged.
The natural groundwater regeneration is influenced by the high degree of sealed surfaces and therefore, water bodies are considerably burdened as a result of the direct rainwater discharges. [6]
Paved surfaces (such as highways, roads, runways, parking areas, sidewalks, and driveways) typically constitute about 30 to 40% of developed urban areas. In the past few decades, the bane of urban cities has been the increased heating of the city by sunlight due to dark, heat-absorbing materials used in the construction of pavements and buildings. Urban areas are oftentimes up to 8°F warmer than the surrounding rural area, creating "urban heat islands" [7]. In densely populated areas where more water is consumed, an important consideration would be whether a part of the urban water requirement can be covered by rainwater harvesting, and whether traffic and other surfaces, in addition to roof surfaces, can be used for rainwater catchment. In this case, rainwater need not be drained into the sewer. This will result in an upgrading of the water quality, since urban surface water bodies are increasingly negatively affected by rainwater discharges and overflows mainly from the combined sewer. [6]
Rainwater harvesting has several benefits. First, rainwater harvesting helps to conserve water by reducing the amount of water needed for toilet (and urinal) flushing and outdoor watering. A new approach for the plumbing design to integrate and use the rainwater harvesting will drive to drinking water reduction and also to natural resources preservation. Studies show that using rainwater will reduce the drinking water consumption. [8,9,10]. Using this concept, the plumbing design will take into consideration plumbing fixtures that require potable water and those that don't require drinking conditions [3, 4, 5, 11]. By using rainwater instead of potable (drinking) water for these applications, homeowners can reduce their daily water use by approximately 30%. Secondly, rainwater harvesting can improve ecosystem health and reduce river and stream erosion by means of managing stormwater runoff. For instance, in Province of Ontario Canada, the approved uses for rainwater are for toilet flushing, urinal flushing, and outdoor use (hose taps and irrigation system). In contrast, uses rainwater for washing machine, shower and baths, cooking and drinking, lavatory faucets, et cetera are prohibited [12]. The article analyzes the water consumption averaged between years 2015 and 2017 (thermal power plants, humidifiers, and plumbing) for 25 stories building, located in Canada.

- ***Water Conservation***

The water-using systems in use for the multi stories building consist of the following: kitchen faucets, bathroom faucets, toilets, and urinals. The following tables (Table 2) quantifies domestic water fixtures in place.

Table 2: Conventional Domestic Water Systems Inventory for the 25 stories Building

Floor	Toilets	LPF	Urinals	LPF	Faucet	LPM	Custodial Sink	LPM	Kitchen Faucets	LPM
Typical Floor (14 Floors)	6	6	2	3.8	4	8.3	1	8.3	1	8.3

Table 3: Upgraded Domestic Water Systems Inventory for the 25 stories Building

Floor	Toilets with Sensors	LPF	Urinals with Sensors	LPF	Faucets with Sensors	LPM
Typical Floor (10 Floors)	6	4.8	2	1.9	4	1.9
Lobby	6	4.8	1	1.9	3	1.9

Figure 1 illustrates the estimated water consumption breakdown of a multi-tenant building based on the following sources and assumptions:

- Normalized sub-metered water data provided by the client July to November 2018 for the cooling tower, humidification, irrigation and DHW supply systems;
- Plumbing fixtures found on site;
- Typical water use patterns and typical distribution of office building water consumption.

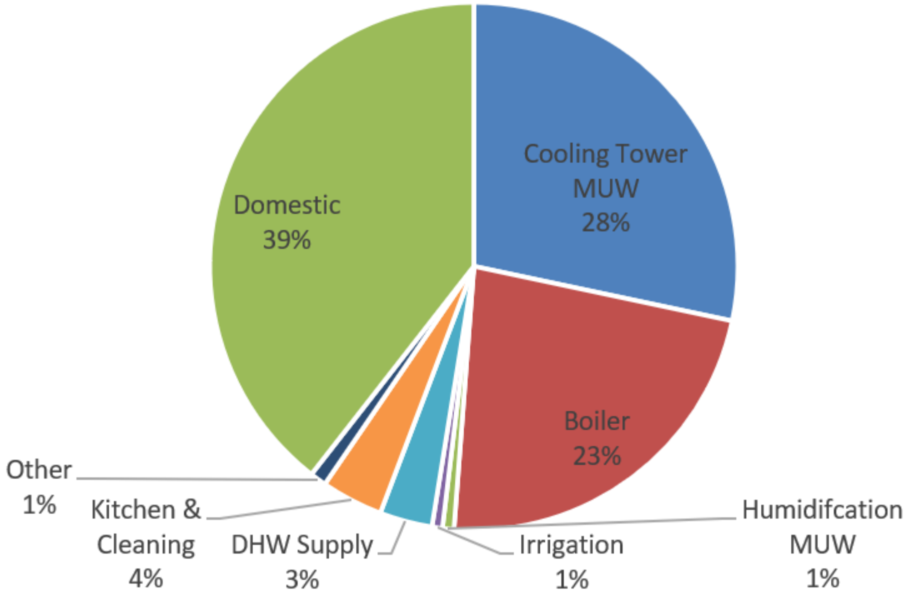

Fig. 1. Estimated Breakdown of Annual Water Consumption

Water conserving measures are expected to reduce water costs and wear and tear within water consuming systems. Table 4 lists water conservation recommendations for the building.

Table 4: Water Conservation Recommendations

Equipment Type	Issue	Recommendation	Section
Cooling Tower	Higher efficient cooling towers are now available that can possibly use rainwater harvesting.	Full cooling tower performance review and system design review at the end of their typical life prior to replacement.	3
Humidification	Humidifier may not be performing at optimal efficiency	Full humidifier performance review and system design review at the end of their typical life prior to replacement	3

- ***Water Consumption***

The data recorded for the period 2015-2017 regarding the annual and monthly consumptions are presented in figures 2 and 3, as follows: Figure 2 provides a summary of annual water data for the period from 2015 to 2017 and Figure 3 provides a monthly summary for the Site building over the same time period.

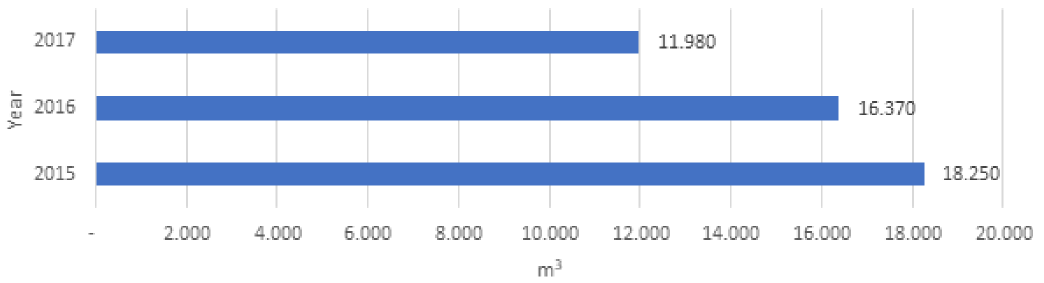

Fig. 2. Total Water Consumption

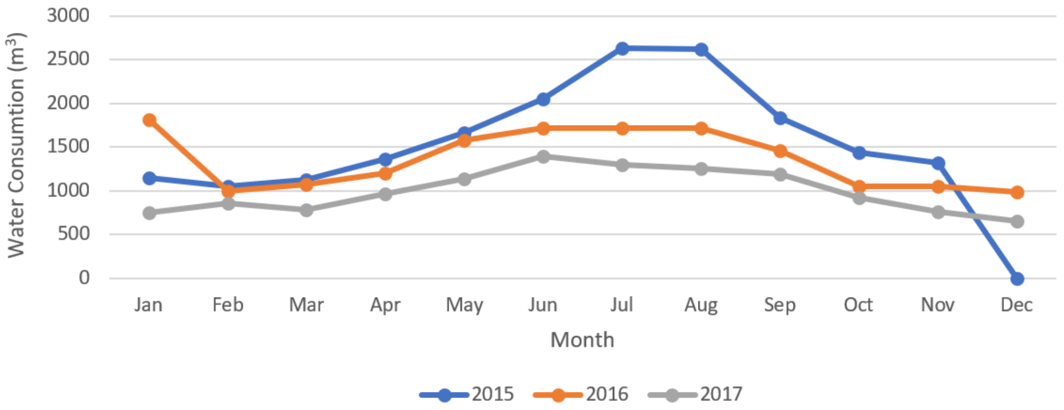

Fig. 3. Monthly Water Consumption

Water is used on Site for domestic hot water, boilers, humidification systems, and domestic systems. The average monthly consumption is 1.294 m^3. The seasonal averages were compared, with the fall and winter seasons having the lowest averages, 909 m^3 and 1067 m^3 respectively. The spring and autumn season averages were 1.453 m^3 and 1.749 m^3 respectively. The combined seasonal average for the spring and summer was 62% higher than the winter and fall seasons.

- ***Seasonal Water Consumption Analysis***

The water consumption of the Site building, averaged between 2015 and 2017, was determined to be 15.533 m^3 and hence can be used as the baseline benchmark. Figure 4 shows the trend correlation between water consumption compared against Heating Degree Days and Cooling Degree Days measured in degrees Celsius (°C) summed per month. Consumption peaks were observed in July and August of 2015 and January of 2016. General increases were observed in the spring and summer months of all years reviewed. Fluctuations of water consumption could have been attributed to many factors: the lack of a cooling tower system, office temperature preferences, potential shifts in occupancy of the Site building, installation of different fixtures, leaks, etc. Overall, the water consumption of the building correlates to the seasons.

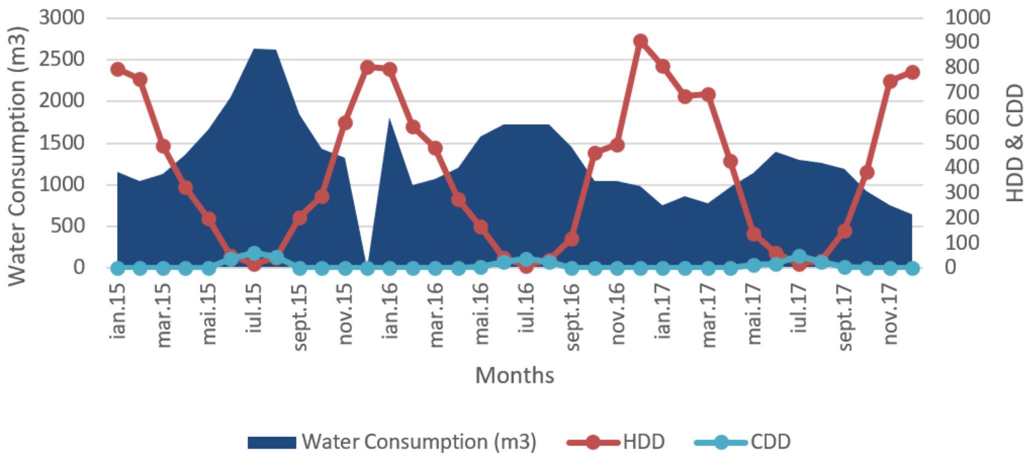

Fig. 4. Water consumption comparison of the building plotted against heating and cooling degree-days between 2015 and 2017

Figure 5, is a graphical representation of water consumption in relation to the increase in number of cooling degree days (CDD), at the Site building. From this graph, a slight decrease in measured water consumption can be seen to occur in relation to the measured number of cooling degree days. The correlation between consumption and CDD is expressed as the displayed value of R2 in Figure 5. Essentially, this represents the amount of water lost per increase in cooling degree day. The R2 value does not in any way represent how efficiently the system operates. On a scale of 0% to 100%, the relation between water consumption and CDD can be expressed as 47%, which indicates moderate correlation. The correlation is expected as the building does possess cooling towers.

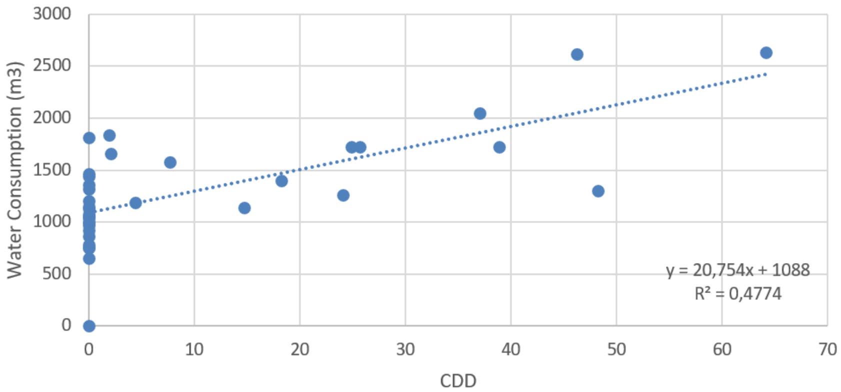

Fig. 5. Water Consumption and Cooling Degree Day Regression Analysis

3. Water Conservation Measures and Recommendations

- ***Cooling Tower Systems***

The cooling tower blower fan unit in use is using a VFD control system. The VFD control system significantly reduce the amount of energy consumed by this unit by reducing its operating speed and operating capacity in relation to the amount of measured cooling demand within the facility. This could be better accomplished using a slide scale algorithm to intercept the linear relationship

between two plotted points and determine the required fan operating capacity. Note: BAS contractor shall confirm the cooling tower operation.
Cooling towers require continuous make-up water to account for losses due to evaporation and drift. A key parameter used to evaluate cooling tower operation is "cycles of concentration" (sometimes referred to as cycles or concentration ratio). This is calculated as the ratio of the concentration of dissolved solids (or conductivity) in the blowdown water compared to the make-up water. Since dissolved solids enter the system in the make-up water and exit the system in the blowdown water, the cycles of concentration are also approximately equal to the ratio of volume of make-up to blowdown water. Many systems operate at two to four cycles of concentration, while six cycles or more may be possible. Increasing cycles from three to six can reduce cooling tower make-up water by 20% and cooling tower blowdown by 50%.
The use of rainwater harvesting as the main or partial source of make-up water has become increasingly common for industrial and commercial cooling tower applications. Rainwater, however, must be properly assessed and tested for nutrient presence.

- ***Humidification Systems***

The Gas Steam Humidifier will periodically "blowdown" or skim water from the tank to reduce the concentration of total dissolved solids that accumulate during long-term operation. An important parameter used to evaluate humidifiers operation is "hardness of the water". Due to the wide range of water conditions, it is important that the blowdown is set according to the local water conditions. By water conditions we are referring to the hardness of the water supplied to the humidifier.

- ***Domestic Systems***

Based on the information gathered from the domestic water system audit, the majority of urinals, toilets, and lavatory faucets are conventional ones.
The Site buildings can reduce water if they update the remaining domestic toilets, urinals, and faucets to highly efficient/low flow options (<4.8 LPF, <1.5 LPF, and <1.9 LPM respectively).

- ***High Efficiency Bathroom Faucets***

High efficiency bathroom faucets consume 1.9 LPM of use, significantly lower than that of conventional faucets. As shown in Table 2 and Table 3, the Site building currently makes use of conventional and 2.39 lpm bathroom faucet fixtures. Converting all the conventional and 2.39 LPM faucets to high efficiency faucets would reduce the associated water consumption.

- ***High Efficiency Kitchen Faucets***

High efficiency kitchen faucets consume 5.7 lpm and conventional kitchen faucets consume 8.3 lpm. As shown in Table 2, the Site building currently makes use of 6.76 lpm kitchen faucet fixtures. Converting the 6.76 LPM kitchen faucets to high efficiency faucets would reduce the associated water consumption.

- ***Low Flow Regulators in Urinals***

High performance low water urinals, complete with a pressure compensating internal flow regulator, consume 1.5 liters of water per flush (LPF), which is lower than the current 3.8 liters of water per flush (LPF) for the urinals on floors 11-25. Converting the conventional urinals to high efficiency would reduce the associated water consumption.

- ***High Efficiency Toilets***

High efficiency toilets consume 4.8 LPF of use, significantly lower than that of conventional toilets. As shown in Table 2 and Table 3, the Site building currently makes use conventional toilets with an assumed flow rate of 13.2 LPF on floors 11-25. Converting all the conventional toilets to low flow/high efficiency faucets would reduce the associated water consumption.

4. Conclusion

In the new urban setting, Rainwater harvesting can be considered a viable solution. This technology has the advantage of flexibility and simplicity of construction.
Stormwater recycling is likely to be of significant environmental benefit through the reduction of non-point source pollutant loads and the minimization of the requirement to build additional water supply infrastructure with increasing population densities. [1]
The paradigm of those rainwater harvesting systems refers to the stormwater quality, which is connected with the roofs, gutters, downspouts, water tanks and to the actual drinking water cost.

Regarding rainwater quality, the studies show that the correct design of the stormwater collection and storage will guarantee the use of water for nondrinking purposes (e.g., toilets, irrigation, etc.); however, a correct stormwater treatment will assure the use for drinkable purposes. Considering the price increase of drinking water and also the water scarcity in some areas, the implementation of government programs subsidies for both existing and new buildings will be a solution for rainwater harvesting. It is important to understand that the advantages of this technology will be beneficial for both the end user and the society.

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