Water Budget Deviation's Control at Commercial Buildings

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Abstract

This paper focuses on an engineering approach for facilities managers/ users in Saudi Arabia to determine water budget deviation in commercial buildings. The approach has two parts; the first one converts As-Built drawing of water network area into a simple created template. The template gives a clear and a simple view to track target consumptions in cubic meters within the water network. Also, a formula has been created to distribute the target(s) through the same network. The second part utilizes statistical tools to check the deviation and thereby providing facility managers with the latest financial situation about the buildings' water network. The College of Business building at Alfaisal University has been chosen to be a case study for implementing the research methodology. It has been found that the inner ring and the outer ring zones of potable system as well as the outer ring zone of non-potable system are not within the budget and therefore, the user had a clear picture about his network and advised to make further investigation.

Keywords
Water Network, Budget Deviation, Data Analytics and Commercial Buildings.

1. Introduction

One statement, however, needs no qualification: human existence depends on water and water is a scarce and valuable resource. There is much talk of a water crisis, of which the most obvious manifestation is that 1.2 billion people lack access to safe and affordable water for their domestic use, less well documented is that a large part of the 900 million people in rural areas that have an income below the one-dollar-per-day poverty line lack access to water for their livelihoods (F. R. Rijsberman, 2004). Furthermore, about 348 million more people face severe economic water scarcity. They live in regions where the potential water resources are sufficient to meet reasonable water needs by 2025, but they will have to embark on massive water development projects, at enormous cost and possibly severe environmental damage, to achieve this objective (D. Seckler et al, 1999). In addition, in Mediterranean countries, there are high levels of inefficiency in the water use in some of these countries. In Portugal, for example, the overall global waste in water amounts at over 3 x 109 m3/year, which is around 39% of the country's total water requirement (A. Silva-Afonso and C. Pimentel-Rodrigues, 2011). They used 5R principles for water efficiency in buildings, which are reduce consumption, reduce loss & waste, re-use water, recycle water and resort to alternative sources. One of the water systems is irrigation, it is becoming an increasingly scarce resource for the agricultural sector in many regions and countries, its efficiency was measured with a stochastic production frontier (G. Karagiannis et al., 2003).

Apparently, controlling water consumption is important. The University of North Carolina did a conceptual model for water and waste water filtration process (K. Yao et al., 1971). Another way for controlling this source optimally was done by its distribution network through SCADA (Supervisory Control and Data Acquisition) in a supervisory control system (G. Cembrano et al., 2000). Also, at the same mirror for water consumption, monitoring it through information and communication technologies (ICTs) has a great potential for improved user awareness in Italy (G. Lanzarone and A. Zanzi, 2010).

There was a case study to evaluate a water savings measures in hotels of Spain (R. Barberán et al., 2013). The authors chose Zaragoza city for their implementation. They used a regression model to see which factor(s) has/ have a significant effect on water consumption. It was a good idea as they found the factors and as a result of their case, the total water consumption was reduced by 21.5%. Another research had described the factors influencing the water consumption but in buildings of southern Brazil (T. Dias et al., 2018). The authors used statistical tools such as multiple leaner regression as well as multiple determination coefficient (R^2) and verified that by using the student's t-test. Having said that, controlling the water consumption and accordingly saving the budget is too important approach in Brazil as one of the research did comparative life-cycle assessment of ordinary and water-saving taps (A. Kalbusch & E. Ghisi, 2016). As hotels are critical from water consumption point of view, a study was conducted on sewage system of 28 hotels in Hong Kong; to save the said consumption (W. Chan et al., 2009).

This paper proposes a methodology to help users/ facilities monitoring their water usage at a regular interval and thereby keep their budget always in control. Unfortunately, it has been observed that the current facility management systems have no tracking system to know whether water consumption from a real usage or there are unwanted elements in the water network that are contributing to the high consumption. This is not only mandating users/facilities to pay for what they have not used but also putting a lot of pressure on the water source such as the city water supply board to generate and supply more water to meet the community demand. The focus is to present a methodology to determine the water budget deviation within the commercial building's water network. A framework plan, which contains two main parts with their related proposed guidelines, is presented. The first part proposed a methodology to convert the As-Built drawing to a simple view for the user. The second part includes statistical analysis, which is used to identify whether the consumption at a specific location is within the budget limits.

2. Methodology

As stated in the introduction, the commercial buildings, which are feeding by city water, will be addressed and therefore, the user, who is working on water system either at operation and maintenance department, owner or higher management, will be focused on. A framework has been built for the user to determine the main goal of this study and it has two main parts, first one is called documentation tools and the second one is statistical tools. Each parts has detailed steps to be carried-out.

2.1 Documentation Tools

First thing here is arranging the As-Built drawings (ABD) of the understudy location/ area. This drawings are normally complicated, so a proposed template has been made (Fig. 1) to have an easier view. This template is understanding the ABD and make it simple. It contains legends and groups the water systems, buildings and the related zones. Secondly, the allotted budget for that understudy area has to be provided by the concern department, for example in Saudi Arabia, Saudi Riyals per period of time. Then, this budget has to be converted to the unit of water consumption, which is cubic meter (m3) and this can be done by considering the relevant tariffs, the allotted budget for the whole understudy area is named as main target (MT). After that, MT has to be distributed within the understudy network to know the sub-targets and therefore, the user will have a clear picture of his/ her network. To do so, the following formula has been created.

$$Ti = T * \frac{Di}{\sum_{i=1}^{n} Dn} \tag{1}$$

Where:
Ti: Target consumption for pipeline at location i (m^3).
T: Derived upstream target consumption (m^3).
Di: Diameter of pipeline at location i (mm, cm, inch or m).
Dn: Diameter of pipeline at the last location in the group (mm, cm, inch or m).

Once all the targets are calculated, Fig. 1 has to be updated with the equation outcome, so every location has its own target and the general view will be clear for the user to move forward to the next step.

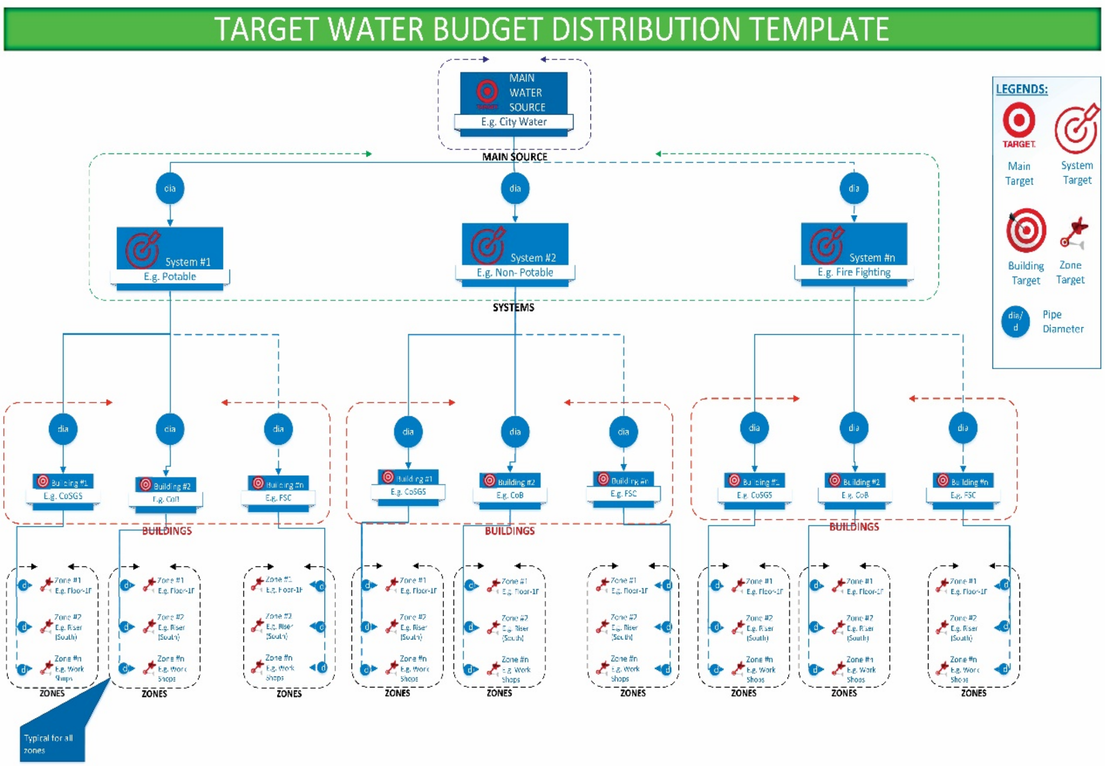

Figure 1: Template for Target Water Budget Distribution

Fig. 1: Template converts ABD to a schematic diagram

2.2 Statistical Tools

Now, a clear picture of the user's understudy location has been made. So, to determine the deviation on each location, the user has to make sure there are proper reading tools have been placed/ implemented such as building management system (BMS) for real time data. It is recommended to refer to the case study was done on IQRA University for more details about BMS (W. Tariq et al., 2012). The theme for collecting the data in this study is based on convenient, it is advisable to be more than or equal 30. For the said goal, one sided t-test is adopted and its hypothesis tests are as follows:

H_0: $\mu \leq \mu_0$
H_1: $\mu > \mu_0$

Where:

H_0: Null Hypothesis, this is a claim that is initially assumed to be true (D. C. Montgomery & G. C. Runger, 2014).
H_1: Alternative Hypothesis.
μ: Mean value of the collected data (m^3).
μ_0: Ti, (m^3) which was defined in documentation tools part.

One of the many ways to run/ do this test is through R language, it is freely open source platform. R & Rstudio can be downloaded through Comprehensive R Archive Network (CRAN) mirror site http://cran.r-project.org/bin/windows/base/ (J. Schmuller, 2017). The following steps are recommended to go through for running the said test through R:

- Data of each location i, where 'i' refers to the understudy location number, has to be collected and tabulated in the following format (Table 1) and then to be copied it in Excel. The x's are the water consumptions during the study period.

Table 1. Data Format

Location.i
X_1
X_2
. .
X_n

- Once the tabulated data is copied in Excel, a file for each location, has to be named as "Li" and saved as type of "CSV" in "Documents" folder of the computer. For example if i = 1, then the file name will be "L1.csv".
- The user then needs to open RStudio and go to "Session" in toolbar, press "Set Working Directory" and then select "To Source File Location".
- After that, he/ she needs to writ the following arguments in R Script for each location i:

```
# Testing of location i
read.csv("Li.csv")
install.packages("DAAG")
require(DAAG)
location.i <- read.csv("Li.csv")
location.i
t.test(location.i, mu = μ0, alternative = "greater")
```

- Finally, the user has to select/ highlight all the above arguments/ expressions and then press "Run" on the toolbar of R Script.

The result of the test will appear automatically in Console, the important one is probability value (P-Value), which is the smallest level of significance that would lead to rejection of the null hypothesis H0 with the given data (C. Aschwanden, 2015). If P-Value is less than or equal the significance level, which is set typically at 5 % (R. Carparo, 2007), then H0 will be rejected (D. R. Anderson et al., 2018) and accordingly the test result will be significant (S. Ganesh & V. Cave, 2018). That means the water consumption at location i is more than the allotted budget.

3. Application and Results

Application is referring to the case study, it was done at Alfaisal University, specifically in College of Business building (CoB), which has three systems servicing it, and each system has two locations/ zones to be studied. The systems are potable, non-potable and firefighting, each system has inner ring and outer ring zones. The user here is the manager of operation and maintenance, whose reports to Facility management. He went through the recommended steps and started with arranging the As-Built drawing of the aforementioned building (Fig. 2). The monthly budget has been assigned as SR 2,000 and this value is equivalent to 373.1 m^3/month and 0.52 m^3/hr. This value has been calculated using solver in Excel considering the relevant tariffs as shown in Fig. 3. Then, Fig. 2 has been converted to Fig. 4 by using the template discussed in the methodology part. Also, the target for each location has been calculated using equation 1, for example with location 1, T1 = 0.13 * (50/ (50+50)) = 0.065 m^3/hr. Finally, data for each location has been collected through BMS for every one hour from Sunday February 15 to Saturday 22, 2020, one sided t-test has been run for each location in R and the result is tabulated as follows (Table 2).

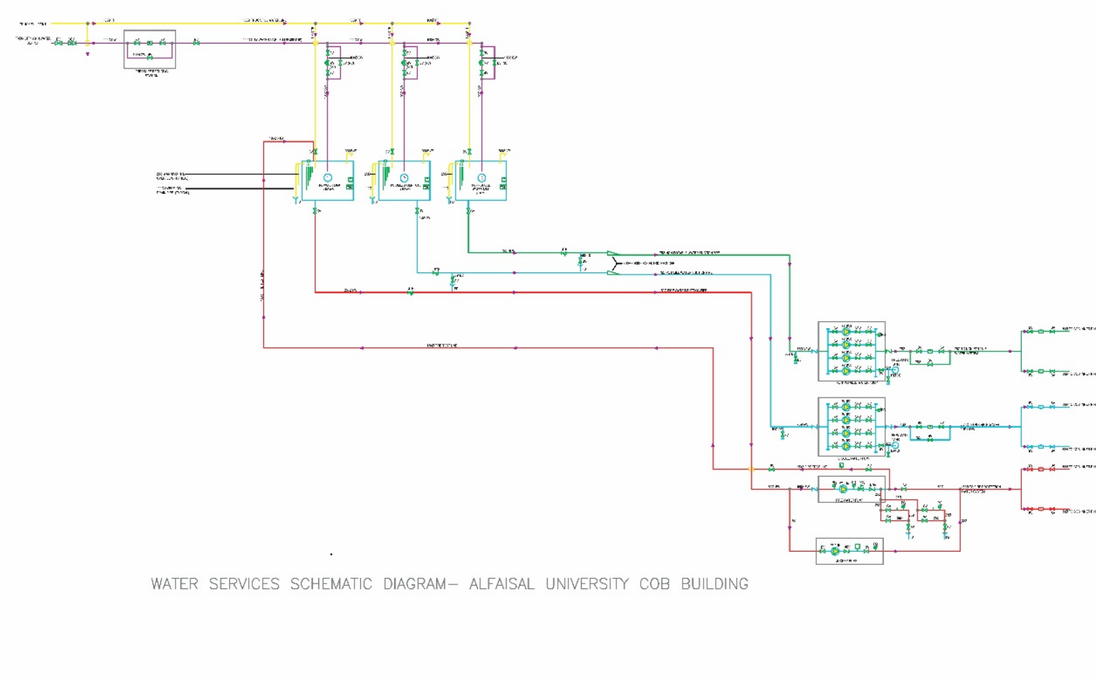

Fig. 2: CoB's ABD

Knowing water consumption from a given budget and tariff using solver						
Tariff			Estimated Consumption (m^3)	Unit Rate (SR)	Total Cost (SR)	Max. Range Cost (SR)
Range		m^3				
From	To					
1	15	15	15	0.10	1.5	1.5
16	30	15	15	1.00	15	15
31	45	15	15	3.00	45	45
46	60	15	15	4.00	60	60
Sub Totals		60	60		121.5	
>60			313	6.00	1878.5	
	Monthly Total Water Consumption Target (m^3)		373.1	⬅	2000	Monthly Total Cost (SR)/ Target Budget (SR)
		Target m^3/ hr	0.52			
Legends:						
	Input Value					
	Solver Output Value					
	Template Needed Output					

Fig. 3: MT (monthly & hourly) for CoB

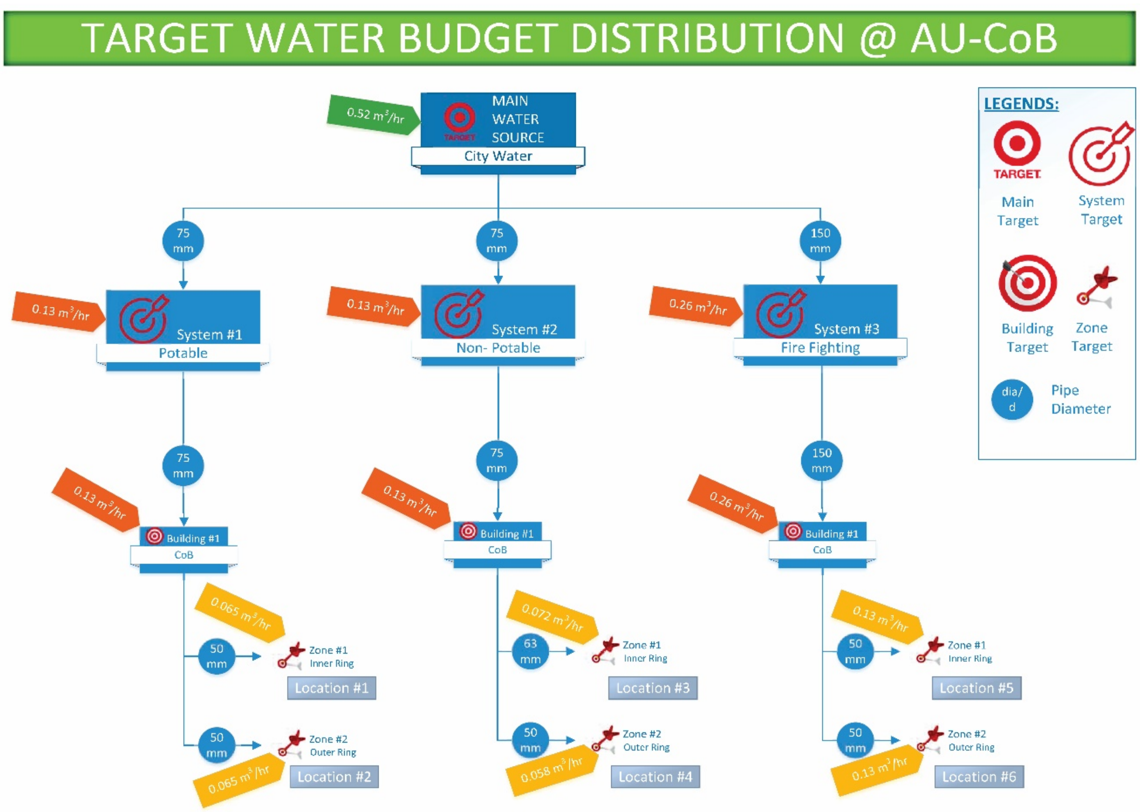

Fig. 4: CoB's Schematic

Table 2. Results of t-test

Location	1	2	3	4	5	6
P-Value	$3.583*10^{-16}$	$5.882*10^{-14}$	1	$4.046*10^{-10}$	1	1
Significant	√	√		√		
Insignificant			√		√	√

As can be seen from the above table, the t-test has given valid outputs and indicates that locations 1, 2 & 4 are significant as they have crossed the budget limits and therefore, it is highly recommended to be investigated and rectify the issue.

4. Conclusion

This framework has been successfully implemented in CoB and it can be done for other buildings either at Alfaisal University or any other buildings easily. This study will not only determine the deviation for the user but will also alarm the user for any issue within the water network. Also, it will help for saving this source, reducing the water bill and controlling the allotted budget. In the near future, it is planned to make budget control for water network at commercial buildings using DMAIC.

Acknowledgements

Foremost, we want to offer this endeavor to Almighty Allah for the wisdom he bestowed upon us, the strength, peace of mind and good health in order to finish this research successfully, under Alfaisal university's supervision. The completion of this research could not have been possible without the kind support and help of many individuals, whose names may not all be enumerated. Their contributions are sincerely appreciated and gratefully acknowledged. We, however, would like to extend our sincere thanks to Prof. Mohammed Alhayaza, President, Dr. Maha Bint Mishari AlSaud, vice president for external relation and development and Prof. Khaled Alkattan, vice president for Admin and finance for their encouragement and perpetual support. Big thanks to Dr. Muhammad Anan, acting dean of college of engineering and Eng. Kaleemoddin Ahmed, operation and maintenance manager for their efforts and cooperation. Finally, this work was supported by a Boeing Research Grant (324129) at Alfaisal University, KSA.

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Biographies

Malek Almobarek is a Saudi national. He was born on April 1983 in Kuwait city. He took his primary and secondary education at AlMawardi School where he was a consistent honor student. He graduated in Industrial Engineering from King Saud University in the year 2009. He did assistance to his professors at the same university with tutorial & site visits for the students before starting his experience journey by taking up a job as Plants Equipment Specialist in O&M department at GASCO, Riyadh. He worked there from May 2009 to Sep 2011. He then moved to Dallah Hospital, Dallah Health Co., Riyadh to work as Engineering Department Manager from Sep 2011 to Nov 2013. Thereafter, He joined Alfaisal University as Facility manager in Dec 2013 and currently discharging his duties as Senior Facility Manager. The areas of responsibility in his current job include Buildings and grounds maintenance; Projects; Cleaning; Catering and Leasing; Health and Safety; Procurement and Contract management; Security; Space management; Waste disposal; Mails, Housing and Transportation; Utilities and Campus infrastructure. It is here that he decided to further his studies while continuing to work and joined in master of Engineering Management (MEM) program that Alfaisal University was offering. He scored GPA 4.0/4.0 and completed a research thesis on Water Budget Control Framework Using DMAIC Approach for Commercial Buildings. He graduated in April 2020 with a first honor and has enrolled into a PhD program of Design, Manufacturing and Engineering Management at University of Strathclyde, UK. Eng. Malek is a result oriented, Innovative, resilient and collaborative. He is not only very good in academics, but also he is an expert in Facility and Project Management; Procurement and Inventory Management; Supply Chain Management; Emergency Response; Environmental Control; Security Control; Contractor Oversight; Resource Allocation; Building Regulations; Building Systems; Fire Safety; Scheduling; Processes and Procedures; Hazardous Waste, etc. He is a member of Saudi Council of Engineering in the capacity of Professional Engineer and loves travelling, reading, bowling and watching debates on TV

Abdallah Alrshdan is an assistant professor in Industrial Engineering at Alfaisal University, Saudi Arabia. He teaches courses in Ergonomics, Work Design, Data analytics, and Quality Engineering. His PhD in Industrial Engineering is from Wichita State University. His current research focuses on ergonomics product design, applications of AI in the design and manufacturing process, and lean production. He worked as a production manager at ALL Cell technologies in USA building Li-ion batteries used for electrical cars and continues as a consultant in the research and development department. Dr. Alrshdan is currently the chair of the Industrial Engineering department and the head of quality assurance. He serves as a reviewer for different international journals and session chair in international Industrial Engineering conferences.

Sobhi Mejjaouli is currently an Assistant Professor in the Industrial Engineering Department at Alfaisal University, Riyadh. Dr. Mejjaouli had a Bachelor and a Master Degree in Industrial Engineering from the National School of Engineers of Tunis in Tunisia before working for Johnson Controls as a Manufacturing Quality Engineer. After that, he joined University of Arkansas at Little Rock, USA, where he got his PhD in Systems Engineering while teaching and conducting research. Dr. Mejjaouli's work was published in venues such as Journal of Manufacturing Systems, well-known IEEE and ISERC conference proceedings, as well as in book chapter format in the Springer Book Series: Studies in Computational Intelligence. His major research areas are: Supply Chain Engineering and Management, Manufacturing, Transportation Systems, and Applications of RFID and Sensor Networks