공학석사학위논문

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ARWA KHATATBEH

Arwa Khatatbeh 의 석사 학위논문을 인준함

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Household Water conservation using IoT and suggestion of sustainable strategy

By

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A dissertation submitted in partial fulfillment of the requirements for the degree of Master in Civil and Environmental Engineering

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Abstract

Household Water conservation using IoT and suggestion of sustainable strategy

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Much of the water conservation effort has focused on the technological advancement of water-using appliances to make them more water efficient. However, since user interaction with water-using appliances is a major influence on the amount of water used by the appliance, which is itself influenced by the habits, rituals, and expectations of water use, more research is needed that focuses on the user. In this research, IoT application is illustrated through a real implementation of one household water consumption monitoring system. A novel wireless water consumption monitoring system is designed, in which flow rate sensors are placed at different detection spots in a house to collect data, there are two main categories of water saving measures to reduce water use: technical measures include network improvement, repair leaks, developing water-efficient appliances; nontechnical measures cover information, education, awareness that may change consumptive habits. This research focuses on both of them and presents the ways of intervening people's water consumption behavior by using the Internet of Things (IoT) technologies; This thesis explores a new approach for disaggregating of the end use of residential water consumption by using new technology for real-time monitoring and develop sustainable strategies. The first stage of the study was developing IoT flow meter sensor and installed it in the selected representative household for five months in Ajlune cities, Jordan, for monitoring water consumption in each part of the home. The second stage undertook household survey about the amount of water they used in each part, daily routine, and the highest part of consuming water. The third stage is to suggest some sustainable strategies.

The main goal of this research is to decrease water use consumption by improving family members awareness by using IoT flow meter sensors and suggest some sustainable strategies.The result shows that thebehaviors of family members were changed and LPCD at this house was: 126 Liter, but reduced to 109 Liter after monitoring.

Keyword: IOT technology; Household Water conservation; scarcity in Jordan; Water management.

Student number: 2016-22949

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CHAPTER 1. INTRODUCTION

Water is one of the most important natural resources on the earth to life, prosperity and wealth. As (Caldari 2004)remarked, water has played a crucial role in the location, function , and growth of communities. However, the water crisis has been announced by the World Economic Forum as the No. 1 global risk based on the impact to society (as a measure of devastation) and the 8th based on the likelihood of occurring within 10 years(World Economic Forum 2015) The World Health Organization has reported that 750 million people around the world lack access to safe water, which is approximately one-ninth of the world's population(UNICEF and World Health Organization 2017). More disturbingly, these numbers will continue to grow. In this chapter, we will introduce about water problems in Jordan and Ajlune city and introduce IOT as a solution.

1.1 Research Background

Water conservation and prediction at the household level is an increasingly important issue to urban utilities (Syme, G. J. et al., 2004). Population growth, changes in land use, and climate change are putting pressure on existing water resources worldwide, and it is not certain that supplies are adequate to meet the increasing demand for water (Bates et al. 2008). The main issue in many regions about water is to diminish the water consumption and provide higher standard purified water (Jorgensen et al., 2009). Water usage at a household level can be effectively reduced by increasing consumers' awareness and changing their inappropriate water use behaviors in the daily routine,(e.g., brushing teeth with a running tap, using the toilet as a dustbin, leaving a leaky faucet unfixed, etc..).To cut off such wastage, a real-time household water consumption monitoring system is required, through which the detailed information of the amount and the way water is used in a household can be collected, and further analyses to identify wastage and find potential saving opportunities(integrated model, 2009).

In this research a novel wireless monitoring system for water consumption at a household level is designed using the concept of IoT, in which sensors are installed at different detection points in a house for data acquisition, and the acquired data is routed to a remote computer server and mobile phone for analysis via the local WiFi and the Internet. To increase the IoT sensor efficiency in water saving, we suggested some conservation strategies and Evaluate cost for these conservation strategies. Monthly water consumption bills data from 2016-2017 were used for calculation and comparison. Or the family and survey were conducted before and after installing IoT sensors.

1.1.1 Internet of Things

The Internet of Things (IoT) is a scenario in which objects, animals or people with communication, sensory or action capability are uniquely addressed and inter-connected via wired/wireless technologies to achieve desired goals. Since the concept of IoTwas introduced in 2005, the deployment of it has been seen in a diversity of domains, such as smart cities and homes (Zanella et al. 2014)(S. Yang et al. 2015), smart grid (Monnier et al. 2014), healthcare (Niyato, Hossain, and Camorlinga 2009)environment monitoring (Niyato, Hossain, and Camorlinga 2009), emergencies (L. Yang, Yang, and Plotnick, 2013), logistics(Broil et al. 2009),industrial control (Broil et al. 2009)(Breivold and Sandstroem 2015) and etc.. IoT has also been applied for water resource management, e.g. monitoring of tap water quality in cities(A.N.Prasad et al., 2015) ,detection of leakages (Sadeghioon et al. 2014)and wastes in rivers and sea(Russel et al., 2013) ,monitoring of water level variations in rivers(Tejaswitha and Jagadeesh 2016),dams and reservoirs, detection of liquid presence outside tanks and pressure variations along pipes, drinking water distribution system(Eliades et al. 2014) . In this paper, a novel wireless monitoring system for water consumption at a household level is designed using the concept of IoT, in which sensors are installed at different detection points in a house for data acquisition, and the acquired data is routed to a remote computer server for analysis via the local WiFi and theInternet. The designed system was installed and tested. It has been demonstrated that it is capable of providing remote, near real-time monitoring of water consumption indifferent households. It can be considered as the application of IoT in the field of household water management.

1.1.2 Water consumption end use and Water conservation strategies

'End use' refers to sites where water is used in the home, such as toilets, showers and washing machines. Water end use behaviors describe the water consumption activities that happen in people's daily lives. This information could help identify appropriate targets for behavior change interventions relating to the daily use of water. There is several water consumption behavior studies over the last few decades. Using the kitchen as an example (Richter, Christian,2012). Social models of household water use behavior emerged from studies that attempted to predict household water consumption. One social model developed by (Gregory and Di Leo 2003) emphasized environmental behavior where awareness. Much of the data used in the development of the model comes from end-use studies. As the first major measurement study attempting to classify residential water use into end uses, the Residential End Uses of Water Study (REUWS) analyzed 10-second meter readings at over 1,000 houses across the U.S(Mayer, P. and DeOreo, W., 1999).

Jordan ‘s households face highly intermittent piped water supply, leading them to supplement it with water from storage tanks and informal private tanker operators, develop an agent-based model (ABM) that highlights the relevance of this idea in a case study of household water consumption in Jordan’s capital, Amman.

Water conservation is often the most cost-effective source of additional water supply for water-stressed urban regions to maintain supply reliability with increasing population and demands or shorter-term droughts.

1.1.3 Market Studies

Other information used to develop conservation strategies comes from market penetration studies of conservation devices. The site was used to know the price and some specification about the water saving device.

1.2 Research objects and scope

The herein described research was conducted to provide data and knowledge to address the research mentioned above gaps. The principal objectives of this research were:

1. Technical: develop IOT flow meter sensor to Investigate water pattern

2. Economic: evaluates the cost of conservation strategies.

3. Social: develop conservation strategies to improve water use efficiency

More specifically, it aimed to decrease water consumption by increase people awareness using online monitoring and suggest some strategies that family can decide for best option to decrease water consumption to the last limit.

The research was conducted within the following scope:

a) The study was limited to the context of one home in Ajlune city, Jordan

b) The research focused on household water consumption

c) Research conducted only on for five months.

1.3 Research Method Overview

This interdisciplinary study required a research design adapting methods from the experimental, social science and computer science fields. In this research, we will focus how to improve flow meter sensor and install it for each unit in one family home in Ajlune city, Jordan monitoring for five months and see the difference in water use during the time after that and making some conservation strategies and evaluate the cost of these strategies.

1.4 Assumption and limitation

1.4.1 Assumption

a) The participants will answer the survey questions honestly and candidly.

b) We assume water consumption in 2016, 2017, 2018 has the same seasonal change percent.

c) We assume monthly water consumption for that family for the 2016 year is same as2017.

d) Cost of installation is not included in calculation cost.

e) The fixture that mentions in this research has a different time life.

1.4.2 Limitation

Although this research was carefully prepared, I am still aware of its limitations and shortcomings.

a) Sample size, this research conduct only for one home it remains true that sample sizes that are too small cannot adequately support claims of having achieved valid conclusions however this reach can be the first step to other research make it wide.

b) Time limitation: this research conduct for only five months so its lack of seasonal variation data.

c) Missing some data during the blackout, in Jordan during the winter season,blackout happened if its heavy rain or storm, since the research conduct in winter so blackout happened and we missed some data.

d) Technical problem: End-to-end self-healing mechanism.

Although the IoT flow meter monitoring system has built-in self-healing mechanism to overcome the instability of public Internet network, it still cannot maintain the system without human intervention. The system uses the household's broadband Internet access to realize the wider data access.However, the system is not integrated with the broadband router and cannot control the broadband router. Once, the broadband router fails to regain the Internet access. It is required households recycle the power of the router to regain the Internet access.

CHAPTER 2. LITERATURE REVIEW

This chapter presents background information and a review of the literature pertinent to the research. The topic is introduced through an overview of the water crisis and details of water consumption with particular reference to the study region of Ajlune city, Jordan.

A description of integrated IOT technology in water demand management is outlined along with Ajloun city's example of this water management principle. Elements of the system and how its work is all presented. A thorough overview of water supply system in Jordan is presented. A summary of advanced water consumption monitoring technologies, earlier end use water consumption studies, and dual reticulated precincts are presented. The chapter concludes by outlining current gaps in the body of knowledge and detailing the research approach for this study.

2.1 The water condition in Jordan

In the arid Middle East, there is always talking of a future water shortage. In Jordan, it's already happening. Streams are drying up, and water levels across the desert Arab kingdom are falling. A rationing system has been implemented such that citizens get water from public supplies just one to two days a week.

With Jordan's population expected to continue to rise, the gap between water supply and demand threatens to widen significantly. By the year 2025, if current trends continue, per capita water supply will fall from the current 145 m^3/yearr to only 91 m^3/year, putting Jordan in the category of having an absolute water shortage. On a per capita basis, Jordan has one of the lowest levels of water resources in the world. Most experts consider countries with a per capita water production below 1000 m^3/year to be water-poor countries (Tabieh et al. 2012).

Jordan has endured deficits in water resources since the early 1960s. The country is classified as water scarce. Its rank is number ten in the world concerning the insufficiency of water (World Population Data Sheet, 1995). Jordan might face a serious long-term water crisis caused by some natural and human factors. Due to the arid and semi-arid climate, available water resources are limited. Also, population growth and economic development are increasing demand on the available water resources, which affect not only the quantity but also the quality of water resources.

In the high water scarcity in Jordan, the average per capita use is lower than in most other countries. Water production before network losses is about 120 liters per person and day while actual consumption is close to 80 liters per capita.

2.1.1 The Hashemite Kingdom of Jordan

The Hashemite Kingdom of Jordan, The Hashemite Kingdom of Jordan, lies in the eastern part of the Mediterranean region to the east of Israel and has a land area of approximately 90 000 km^2 (Figure 1). Topographically it is diverse, and the major topographic and geomorphologic features in Jordan control the drainage pattern. The overall drainage system in Jordan consists of two main flow patterns. The first drain water towards the Jordan Rift Valley, through deeply incised wadis and rivers dissecting the Jordan Valley-Dead Sea escarpments, to discharge ultimately into the Dead Sea. The second drain water through shallow streams and washes, which generally flow eastwards from the western highlands towards the internal desert depressions and mudflats. The climate of Jordan ranges from the Mediterranean to arid. The Rift Valley and the Highlands belong to the semi-arid to arid climate zone, which is largely affected by moist westerly air masses in winter. In summer, dry easterly and north-easterly desert winds affect the Kingdom. Winds are generally westerly to south-westerly. A Mediterranean climate dominates most of the highlands on both sides of the Jordan River and in the mountain chains east of the Dead Sea and Wadi Araba extending as five far south as Ras El Naqeb. Dry summers with an average maximum annual temperature of 39℃ occur between April and October. In the winter months, from November to March, the average minimum annual temperature is 0-1 ℃. In winter, the average mean daily temperatures recorded at Amman Airport and DeirAlla were 10℃ and 17℃ respectively, for the period (1981-1998).

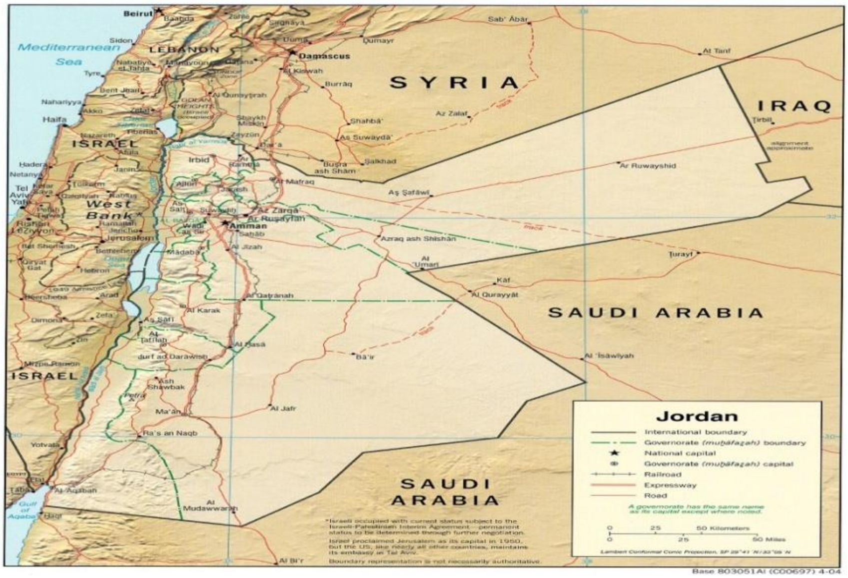


Figure 2.1. The general geography of Jordan

a. Ajlune city

Ajloun Governorate lays in the northwestern part of the Hashemite Kingdom of Jordan. The governorate is divided into five administrative municipalities. Ajloun municipality (147 km^2), the center of the governorate, about (71 km^2) northwest of Amman. The area has been historically one of the most densely populated regions in Jordan. The population is about (52000) citizens. The most common economic activity is in the public sector, in agriculture, forestry, and tourism. (World Water Week in Stockholm, 2016).

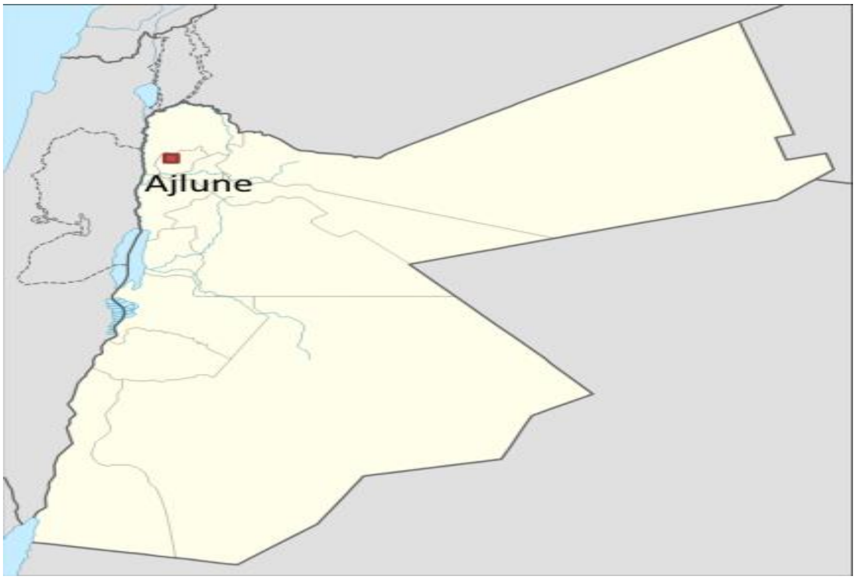


Figure 2.2. Ajlune city (Jordan Water Sector: Facts and Figures)

b. Main problems and challenges in Ajlune:

1. Technical

There is a lack of comprehensive urban planning practices at the municipal level, particularly in water and wastewater infrastructure planning for random urbanization and infrastructure services.

a) Shortage of specific data

b) The lack of adequate knowledge about practicing water harvesting and grey water use and possible benefits for the community at households and young population sectors.

c) There is a lack of proper enforcement policies for efficient use of water at the local level

d) High poverty rate (25.6%) leads to the inability of households to use more efficient water consumption practices.

2. Social

Lack of water consumption's awareness.

3. Economic

High water price and the high cost of researches.

2.2 Water supply system in Jordan

Despite Jordan's severe water scarcity, more than 97% of Jordanians have access to an improved water source, and 93% have access to improved sanitation. This is one of the highest rates in the Middle East and North Africa (Jordan Water Sector.2016). However, water supply is intermittent, and it is common to store water in rooftop tanks. As a result of water scarcity public water supply is rationed through intermittent supply (water is supplied only once or twice a week for 12-24 hours). People are compelled to invest in storage tanks and to buy additional water from private vendors to satisfy their water needs and to improve supply reliability. In summer water demand is increasing due to high temperature and increase in population greatly by people returning from abroad. The number of new customers within Amman is increasing at about 5% each year. But even during the winter season household water supply is not 24 hours a day and seven days a week, although interruptions are less frequent (supply of 2-3 days a week) (Water Meters,2010).

2.3 IoT Technology in water management

Smart water meters are a form of IoT, a network of technologies which can monitor the status of physical objects, capture meaningful data, and communicate that data over a wireless network to a computer in the cloud for software to analyze in real time and help determine action steps. Technologies are capable of monitoring objects such as smart water meters and other electronic devices, organisms, or a natural part of the environment such as an area of ground to be measured for moisture or chemical content. A smart device is associated with each object which provides the connectivity and unique digital identity for identifying, tracking, and communicating with the object. A sensor within or attached to the device is connected to the internet by a local area connection (such as RFID, NFC, or BTLE) and can also have wide area connectivity. Typically, each data transmission from a device is small in size, but the number of transmissions can be frequent. IoT involves many, many things interacting with each other to produce actionable information (S.Guhathakurta et al. , 2007).

Each sensor will monitor a specific condition or set of conditions such as vibration, motion, temperature, pressure, or water quality. More IoT applications have become feasible because the cost and size of such devices continue to decrease and their sophistication for measuring conditions keeps increasing. Cisco estimates that 500 billion devices will be connected to the internet by 2030 (Smart Water Meter Adoption Rates, 2010).

The widespread implementation of simple, smart water meters for residential customers would help save millions of gallons of water in California and elsewhere. The IoT can be used to determine when, where, and how much water is needed in landscape and agricultural irrigation. Given the amount of water used in agriculture, tax incentives should be used to motivate the adoption of IoT and other conservation measures in that industry. The IoT can help reduce water shortages by providing actionable information which enables users to be more efficient and less wasteful. More smart meter and platform products became available in the market in 2016, but there does not appear to be any market leader yet. The products vary from the very basic to those that integrate water metering networks with leak detection and usage monitoring applications.

2.4 IoT flow meter sensor

Effective water management involves supplying water according to the real requirement, and thus measuring water is an essential step in water management systems. There are many water flow measurement techniques as well as different types of water flow meters used to measure the volume of water flow in pipelines, but these all are too costly. This article describes ideas for design and development of low-cost automatic water flow meters, with the help of readily-available and low-cost water flow sensors. Accurate flow measurement is an essential step both regarding the qualitative and economic points of view.

Flow meters have proven excellent devices for measuring water flow, and now it is very easy to build a water management system using the renowned water flow sensor YF-S201. This sensor sits in line with the water line and contains a pinwheel sensor to measure how much water has moved through it. There is an integrated magnetic Hall-Effect sensor that outputs an electrical pulse with every revolution. The "YFS201 Hall Effect Water Flow Sensor" comes with three wires: Red/VCC (5-24V DC Input), Black/GND (0V) and Yellow/OUT (Pulse Output). By counting the pulses from the output of the sensor, we can easily calculate the water flow rate (liter/hour – L/hr.) using a suitable conversion formula.

Features:

i. Maximum water pressure: 1.75 MPa
ii. Working range: 1-30 L/min, 1-60 L/min
iii. Size: Approx. 5.6*3.5*3.5 cm (L*W*H)
iv. External diameter: 1.9 cm
v. Inner diameter: 1.1 cm
vi. Cable length: 10.5 cm

Figure 2.3. Flow meter sensor(YF-S201)
(www.electroschematics.com)

Now, have a look at the math's that used in mine. In our lab experiment, we used YF-S201 water flow sensors and done the homework well with observed readings (±11 accuracy). To measure the quantity of water being passed in a particular time through the water flow sensor, it was first passed through the water flow sensor which was taken as the input interface in the flow. Formulas are applied to measure the number of rotations/pulses in a minute of rotation.

Flow rate can be determined inferentially by different techniques like a change in velocity or kinetic energy. Here we have determined flow rate by a change in velocity of water. Velocity depends on the pressure that forces the through pipelines. As the pipe's cross-sectional area is known and remains constant, the average velocity is an indication of the flow rate. The basic relationship for determining the liquid's flow rate in such cases is Q=VxA**,** where Q is flow rate/total flow of water through the pipe, V is the average velocity of the flow, and A is the cross-sectional area of the pipe (viscosity, density and the friction of the liquid in contact with the pipe also influence the flow rate of water).

- Pulse frequency (Hz) = 7.5Q, Q is flow rate in Litres/minute
- Flow Rate (Litres/hour) = (Pulse frequency x 60 min) / 7.5Q

CHAPTER 3. RESEARCH METHOD AND DESIGN

This chapter details the research methodology and design adopted for this study. Specified within are the research approach, design and analytical techniques adopted to satisfy the developed research objectives. An explanatory mixed methods design was selected as the most suitable approach to suit the diverse research objectives.

3.1 Overview of the research method and design

This study adopts a mixed method design through development, collection, analysis and suggests strategies of both quantitative and qualitative data and research approaches through the various phases of the research process. The amalgamation of quantitative and qualitative approaches provides a better understanding of the research questions and problem, strengthens the research design and completes the research through the provision of more detailed qualitative data to complete the quantitative component of the research(Brewer and Hunter 1989, pp. 28) state that mixed methods is a 'legitimate inquiry approach' while the combination of quantitative and qualitative data is said to provide a 'very strong mix' (Miles and Huberman, 1994, pp. 42).Mixed methods offset the weaknesses of both quantitative and qualitative research providing strength to the methodology; it assists in answering questions which cannot be answered by one method alone; it provides comprehensive evidence for research problems; and allows the use of multiple methods to address research problems Mixed methods can also be considered as 'merging, integrating, linking or embedding' both the quantitative and qualitative strands of research (Creswell, J. W., 2008.) A mixed method approach was adopted due to the army of data types required to meet the developed research objectives. The explanatory mixed method design was determined to be the most applicable of the four potential mixed method approaches, to satisfy the research objectives (Creswell, J. W., 2005).

This chapter divided into two parts first part about water conservation using IoT and the second part is about potential strategies.

3.2 Part 1: Water conservation using IoT (monitored and surveyed)

3.2.1 Site description

This work was conducted in one home in Ajlune city, which one of governorate in Jordan country. Home has three tanks each one $2m^3$; these tanks connect to supply home with tap water figure (3.1).

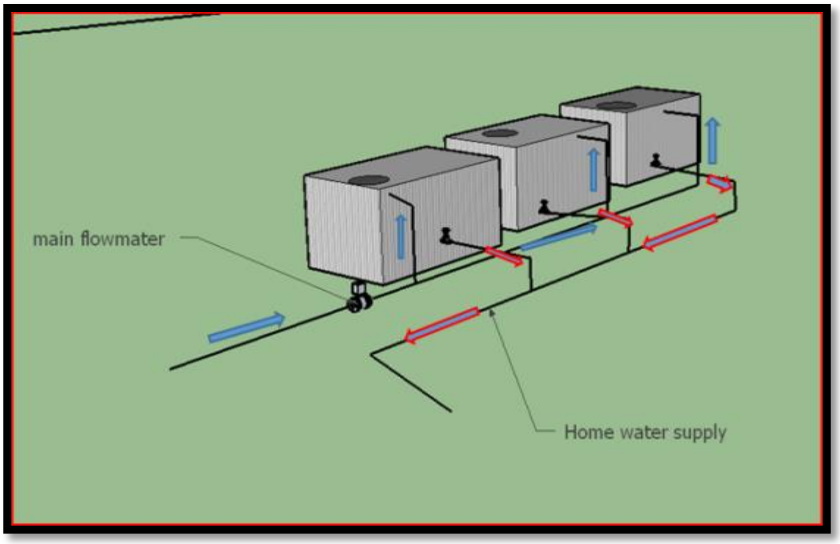


Figure 3.1. Three tanks connect together to supply water to the home

3.2.2 Home information

3.2.2.1 Household size

The number of household members affects the amount of water used in a house (S. Gaudin,2006); (E. Wentz and P. Gober, 2007). A household of a large size normally uses more appliances with greater frequency, resulting in more water usage than a small size household. (F. Arbus, R. Barbern, and I. Villana, 2004) Found that the water consumption increases with the household size, although it is not a proportional increase. For example, a household with two people use less water than a household with four people, but not half as less. However, household size was found to be an insignificant factor of water usage in (S. Guhathakurta and P. Gober, 2007) This finding does not necessarily contradict findings of other researchers but rather reflects the fact that interior water use is substantially less than outdoor uses. The household size that may not affect exterior water use, e.g., a house with only one resident may have as much lawn to water as a household with four residents. Similarly, (A. S. Polebitski and R. N. Palmer, 2010) found that increasing household size was associated with improved interior water efficiency, resulting in per capita savings despite overall household consumption increasing.

So this home has five people, and the home size is 200 m^2, this home has two kinds of toilet sitting and squatting toilet, shower and kitchen faucet, laundry machine.

3.2.2.2 Ages of household members

The water use behaviors can be quite different among different ages of household members. Households with children could be expected to use more water. Youngsters might use waterless carefully, e.g., taking more shower, doing more frequent laundering, while retired people might be much thriftier. These expectations are confirmed by studies such as (C. Nauges and A. Thomas, 2000).

In this study the ages of household members are as follow:

Father 59 years old, mother 57 years old, girl 24 years old, boy 24 years old, girl 16 years old.

3.2.2.3 Income level

Income is a significant factor in water consumption. (S. Guhathakurta and P. Gober, 2007)indicates that income rises result in a corresponding increase in water consumption, but again not a proportional increase (J. M. Dalhuisen, at el 2003; M. E. Renwick and R. D.Green, 2000).

For this family the GDP: (18000$/year) Within 35% of the Jordanian people income.

3.2.2.4 Education level

The education level influences the water consumption in a household as well. It has been shown in (K. Millock and C. Nauges, 2000). That the education level is positively correlated with lower water consumption and higher water conservation behaviors. Educated people tend to be more aware of the importance of water resource, more informed of the global water crisis, and thus more eco-conscious. Highly educated parents might pass the right water use habits to their children. In this study, the education level and work of household members are as follow Father (high school, retired), mother (high school, housewife), girl (bachelor, nurse), boy (bachelor, engineer), girl (student).

3.2.2.5 The quantity of water needed (LPCD)

The quantity of water consumed per person per day was calculated depending on previous bills, LPCD = 126 (L/person/day) for this family.

3.2.3 IOT design of the application

The IoT-based water system was deployed by using handmade IoT-based flow meter sensor sensors (magnetic flow meter sensors), which were wired to pipe (Fig. 3.2). The data recorded by the sensor were transmitted by the integration of a wireless gateway in the consumer network. A controller board WeMos D1 board was deployed for system design. The board contains11 digital I/O pins and one analog (input) pin. The board can be connected using a Micro-B type USB cable.

In the proposed system, YF-S201 Water flow sensor with a range up to 1-60 L/min is configured to determine the flowrate in the pipe. The sensors work by sending waves, and the reflected waves provide the distance in centimeter. In this study, the IoT “ThingSpeak” web service was used, which is a big open API service that works as a host for different kind of sensors to monitor the sensed data at the cloud level and composite a singular feature of porting the sensed data to the MATLAB R 2016 a by read API key and using a channel ID. The API key is assigned to the accommodations and able to track data at the finical sample in particular intervals and display them on a mobile phone using the ThingSpeak application.

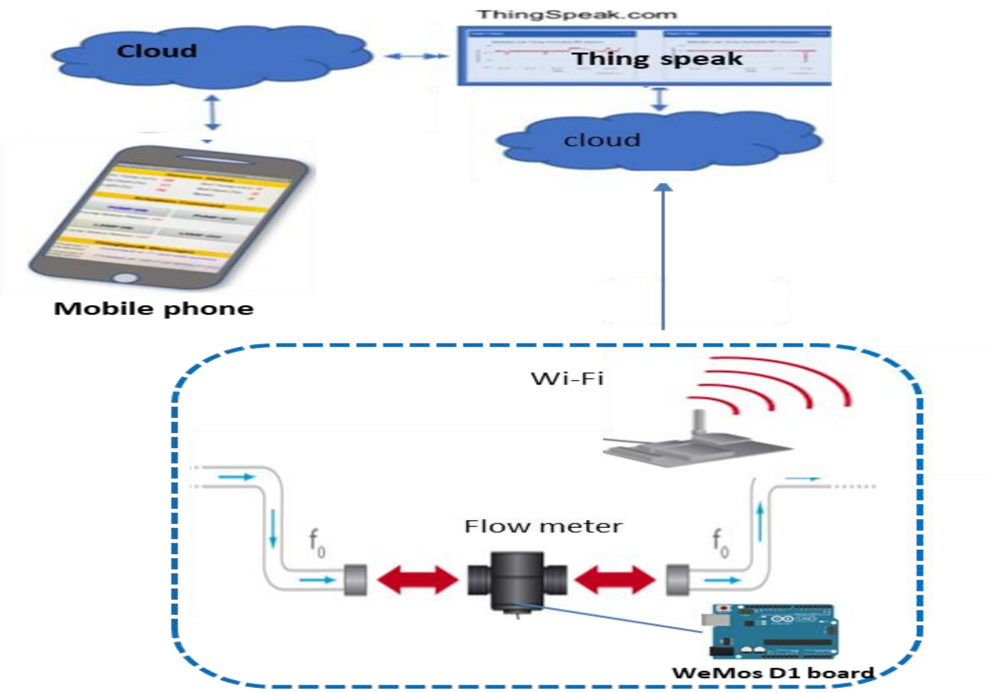


Figure 3.2. System diagram of monitoring system IoT based flowmeter system

3.2.3.1 Components Require:

1. **YF-S201 Water flow sensor**

This sensor sits in line with your water line and contains a pinwheel sensor to measure how much liquid has moved through it. There's an integrated magnetic hall effect sensor that outputs an electrical pulse with every revolution. The hall effect sensor is sealed from the water pipe and allows the sensor to stay safe and dry.

2. **WeMos D1 board**

WeMos D1 R2 development board for Arduino / NodeMCU has Arduino Uno R3 footprint and breaks out the ESP8266 WiFi module. This board is awesome for the Internet of Things (IoT) development projects and can be programmed using the Arduino IDE.

3. Interactive code

We used Arduino Uno software; the Arduino language is merely a set of C/C++ functions that can be called from your code. Your sketch undergoes minor changes (e.g., automatic generation of function prototypes) and then is passed directly to a C/C++ compiler.

3.2.4 Install flow meters inside and outside the home

The flow meter installed inside the home for:

1. Sitting Toilet

The flow meter (1-30 L/min) installed to sitting toilet to monitor water consumption in this part, (figure 6) the flow rate of this toilet is (10 L /flush).

2. Squatting Toilet

The flow meter (1-30 L/min) installed to the faucet that usually used for flushing (1 L /flush),(figure 7).

3. Shower

The flow meter (1-30 L/min) installed on the shower head which has(10L/min) flow rate.

4. Kitchen faucet

The flow meter (1-30 L/min) installed on the kitchen faucet which has(10L/min) flow rate.

5. Laundry machine

The flow meter (1-60 L/min) installed in the laundry machine which consumes water (78L/cycle).

Figure 3.3. Install flowmeter sensor for sitting toilet

Figure 3.4. Install flowmeter sensor for squatting toilet

Figure 3.5. Install flowmeter sensor for shower

Figure 3.6. Install flowmeter sensor for sink

Figure 3.7. Install flowmeter sensor for washing machine

The flow meter installed outside

IoT flow meter (1-60 L/min) installed at the line that supplies home to know total consumption for that family the pipe that supply home is ¾ inch diameter.

3.2.5 Survey

We did Survey for a family member before and after five months of installing sensors to know how thinking is changing within five months. There is some specific question that use in the survey to know daily activity for all family member; you can find the form of the survey in the appendix.

3.2.6 Seasonal Dynamics of Water Uses

To know the seasonal effect in our result, we calculate a seasonal factor for each semester depending on bills data for that family in 2016; we assume that 2016 and 2017 it has same seasonal change for (figure 6) shows:

a. Average water consumption in 2016 for that family is 18.5 m^3 / month.

b. A 3% of a peak factor demand needs during summer months over the average water requirement

c. Seasonal variation from OCT to FEB 1.7% is under average.

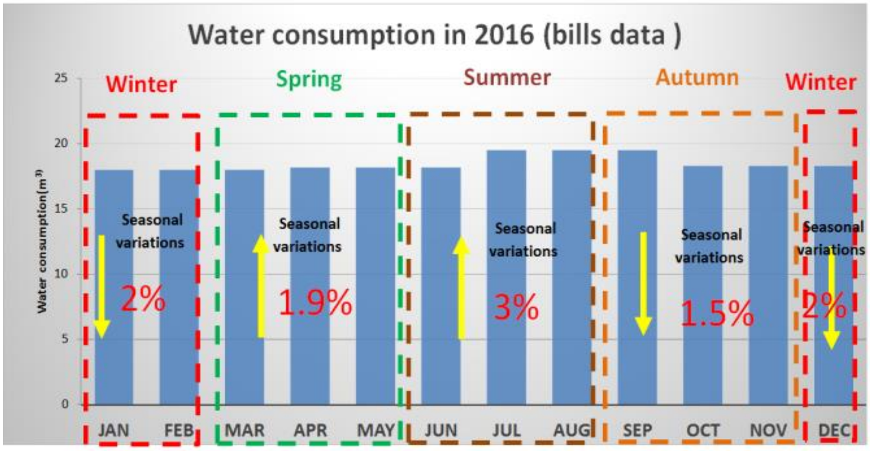


Figure 3.8. Seasonal change in water consumption in 2016

3.3 Part 2: Potential strategies

To increase the IoT sensor efficiency in water saving, we suggested some strategies showed in (Table 3.1).

Table 3.1 Potential strategies to increase IOT system efficiency

A) Installation of saving-water equipment's

Indoor use includes water used in faucets, showers, toilets, clothes washer, According to the 2010 baseline survey, Jordanian residential indoor water-use accounts on the average for around 97 percent, 90 percent, and 98 percent of the total water use in the service areas of Miyahuna, Yarmouk Water Company, and Aqaba Water, respectively.

Each conservation action has house-specific effectiveness in reducing water use and an associated cost. For water save equipment, we have many options to choose the best one we can recommend it.

1) Faucets and Showers

A) Installation of saving-water equipment's.	**End-Use Affected**	**Long-term Actions**
	Shower	Retrofit showerheads
	Toilet	Change the toilet to save water toilet
	Faucet	Retrofit bathroom, sink faucets
	Laundry	Install conserving laundry machine
B) Installation of RWH system.	Home	Install RWH system

The faucets and showers flow rates exceeding the benchmark or standard can easily be reduced without affecting the comfort of the water user by adopting appropriate flow regulator technology 11 for these fixtures. This will result in a 10 percent to 30 percent reduction of the flows of lavatory and kitchen faucets and showers. We find the lifetime faucet and the shower head is five years.

2) Toilet

The majority of toilets in Jordan's homes that are located in the three utility service areas are the gravity type, though there are also Turkish (squat) toilets. Toilets' flushing varies from 2 liters/use for bucket type Turkish toilets to more than 10 liters/flush. For this family, it was 7 liters/flush, and the lifetime is 12 years.

3) Laundry

Clothes washers have varied the water-use amount, and many companies do the best to decrease the amount of water use for this family, the life time for laundry is.

B) Rainwater Harvesting

Rainwater harvesting is a technology used for collecting and storing rainwater from roof-tops, land surfaces, road surfaces, or rock catchments using simple systems such as pots, tanks, and cisterns. Rainwater harvesting has been used in Jordan since 850 BC. Some distinctive historical examples that incorporate effective water-harvesting systems exist today in the country. These include the cut-stone reservoirs of the Nabatean city of Petra, as well as the underground cisterns found in the Umayyad desert palaces, Crusader-period castles, and traditional village houses. Even though rainwater harvesting is still practiced and appreciated as a principal source for drinking and cooking in many suburban and rural areas of the Northern and central Governorates, Greater Amman, Karak, Tafila, and Badia; urban dwellers neglected it with the arrival of modern urban water supply. However, water scarcity and shortage during the past two decades revived interest in rainwater harvesting as an alternative supplemental water source that is part of the National Water Strategy. USAID and other international donors have initiated some initiatives with the Ministry of Water and Irrigation (MWI), Non-Governmental Organizations (NGOs), and Community Based Organizations (CBOs) to construct rainwater harvesting systems to augment water supply in rural areas. The Ministry of Public Works and Housing (MPWH), in cooperation with MWI, has recently included rainwater harvesting in the new water and sanitation plumbing code. This code illustrates where and how rainwater harvesting is feasible and cost-effective. The reader is referred to this code for details related to the feasibility of rainwater harvesting and design of rainwater collection systems.

How Much Can RainwaterBe Capture?

The amount of harvested rainwater is directly related to the size of the impervious area and the average annual precipitation. Considering 80 percent rainwater collection efficiency, to account for losses due to evaporation, splash-out from gutters, and first flush diversion, the annual potential amount of harvested rainwater is calculated as follows:

Annual rainwater captured potential (m^3) = Impervious area (m^2) x annual rainfall (mm) x 0.80/1000. For instance, a home in Ajlune that receives 350 mm average annual rainfall and has 200 m^2 of roof area, the potential rainwater that can be captured is approximately 56 m^3.

3.3.1 Options for saving-water equipment's

To choose the best option that can use it at home, we have to find some options in the market and evaluate them For each option that used in this study, it has a different flow rate and a different price on the market (Table 3.2). These options are an independent option, so we choose randomly and evaluate them, and we found that the option 3 is the best option.

Table 3.2.1 Options for saving water equipment's for different flow rate

Average flow rate	Toilet L/ flush	Faucet L/min	Shower head L/min	Laundry machine L/ cycle
Average flow rate of existing fixtures	10	11.4	9.8	78
Option 1	7	8.3	7.6	66
Option 2	6	5.7	4.5	60
Option 3	4	4.5	3.8	54

Table 3.2.2 Options for saving water equipment's for different price

Price ($) *(Dollar exchange rate 2018)*	Toilet	Faucet	Shower head	Laundry machine	IOT sensor	RWH system
Option 1	75	7	5	500	70	400
Option 2	62	4.5	3.5	430	250	325
Option 3	55	3	2.5	320	25	250

3.3.2 Strategies evaluation

To evaluate water conservation strategies, we calculate water save effectiveness and cost-effectiveness.

Action	Effectiveness's of Actions(L/day)	Formula
Retrofit shower head	32	$Qs= \left(\left[weighted\ avg.\ \frac{L}{min}\right] - \left(\frac{L}{min}\ lowflow\right)\right)\left(\frac{minute}{shower}\right)\left(\frac{showers}{week.person}\right)\left(\frac{person}{house}\right)\left[\frac{1\ week}{7\ days}\right]$

Retrofit faucet	90	$Qs= \left(\left[weighted\ avg.\ \frac{L}{min}\right] - \left(\frac{L}{min} Aerated\right)\right)\left(\frac{minute}{day.person}\right)\left(\frac{person}{house}\right)$
Replacement toilet to save water toilet	45	$Qs= \left(\left[weighted\ avg.\ \frac{L}{min}\right] - \left(\frac{L}{min} new\ weighted\right)\right)\left(\frac{flushes}{day.person}\right)\left(\frac{person}{house}\right)$
Retrofit laundry machine	12	$Qs= \left(\left(Std.\frac{L}{cycle}\right) - \left(\frac{L}{cycle} Efficient\right)\right)\left(\frac{cycle}{week.person}\right)\left(\frac{person}{house}\right)\left[\frac{1\ week}{7\ days}\right]$
Installing IoT flow meter Sensor	70	$Qs= (reduction\ in\ water\ use\ \%)\left(total\ water\ use\ \frac{L}{day}\right)$
Installing RWH system	140	$Qs= (reduction\ in\ water\ use\ \%)\left(total\ water\ use\ \frac{L}{day}\right)$

Table 3.3. Water saved effectiveness for action.

3.3.2.1 Calculate water saved effectiveness

Each conservation action saves a given amount of water (effectiveness), depending on the initial state of the household. For example, the relationship estimating the amount of water saved by installing a water-conserving laundry machine is 12 L/day depending on equation on the table.

3.3.2.2 Calculate cost effectiveness

The following are key steps to carry out a cost-benefit analysis to retrofit residential faucets, showerheads, and toilets. The retrofit consists of installing flow regulators for faucets and showerheads and replacement of toilet trim (flushing system). By taking in our account.

Step 1: Identify the Investment Cost the investment cost for this example represents.

Retrofit costs that include the cost of the water-saving devices (WSDs) and their installation or replacement. The calculator below shows the approximate cost for the retrofit of each fixture, based on the Jordanian market.

Step 2: Identify the Benefits

Plumbing-fixture retrofit holds the most promise for water-saving and financial benefit. The financial benefits are roughly the savings in your water and energy bills as a result of savings in water consumption, wastewater, and hot water.

Step 3: Calculate the Payback Period and Benefit-Cost Ratio

The payback period represents the amount of time required to recover the investment cost. It is simply the ratio of the investment cost over the annual financial benefit. The benefit-cost ratio for a given fixture is equal to the present value of the benefit during the life of this fixture divided by the investment cost for its retrofit.

CHAPTER 4. RESULT

4.1 Daily Water consumption

Daily water consumption shows the behavior of people (over-consumption, zero water consumption). Average water consumption per month de-creasing 13% with time, related to increase awareness of family.

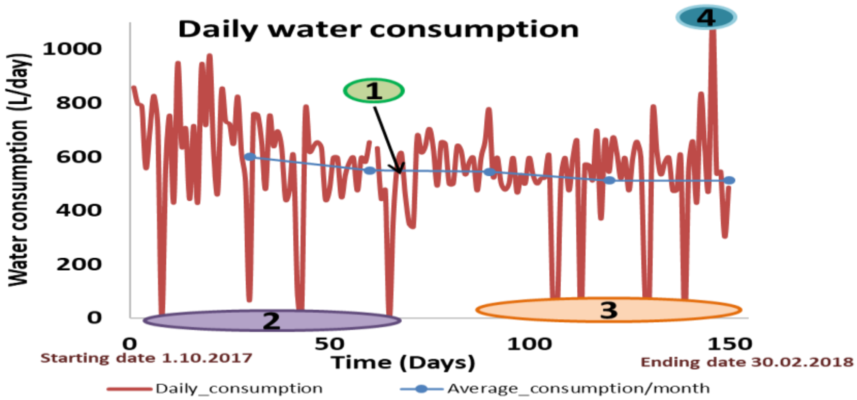


Figure 4.1. Daily water consumption

From this figure we can see number 1 is show Average consumption per month and its decreasing 13%with time, related to increase awareness of fami-lyhowever number 2&3 represent the zero water consumption value.

1. Average consumption per month
2. Family outside of home.
3. Missing data during blackout at winter.
4. Increased use of water due to an occasion.

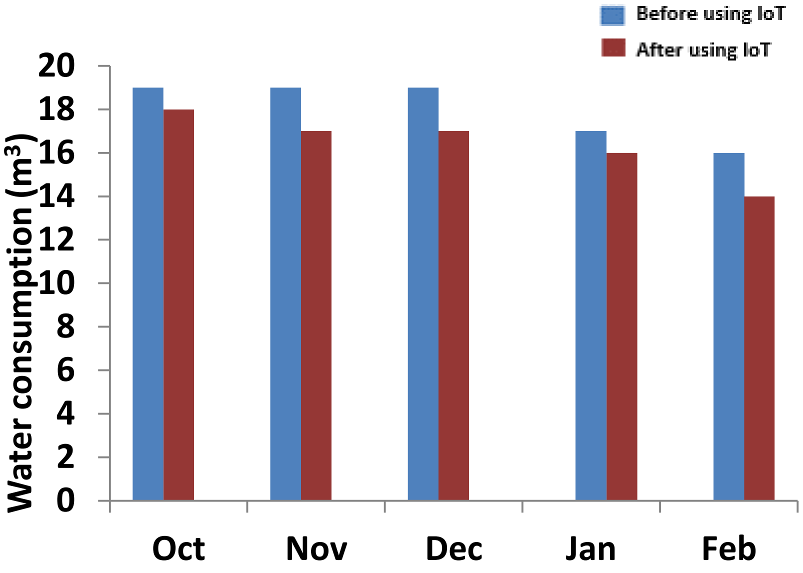


Figure 4.2. Comparison of water consumption before and after using IoT

4.2 Comparison of water consumption.

To compare water consumption before and after installing IoT, we use previous bills in 2016,2017; result shows 13% of water saved after installing IoT sensors. AndLPCD at this house was: 126 (L/d/person), but reduced to 109 (L/d/person) after monitoring without any change of the water supply unit.

4.3 Behaviour of water consumption

4.3.1 Average water consumption during a week

IoT data shows that the average water consumption during week was on Friday , however Friday is the first day of the weekend, after asking this family about high water consumption on Friday , they said regarding all family member and visitor stay in home and also regarding the behavior of people in that day because its religious day most of the family member take a shower for going to pray .

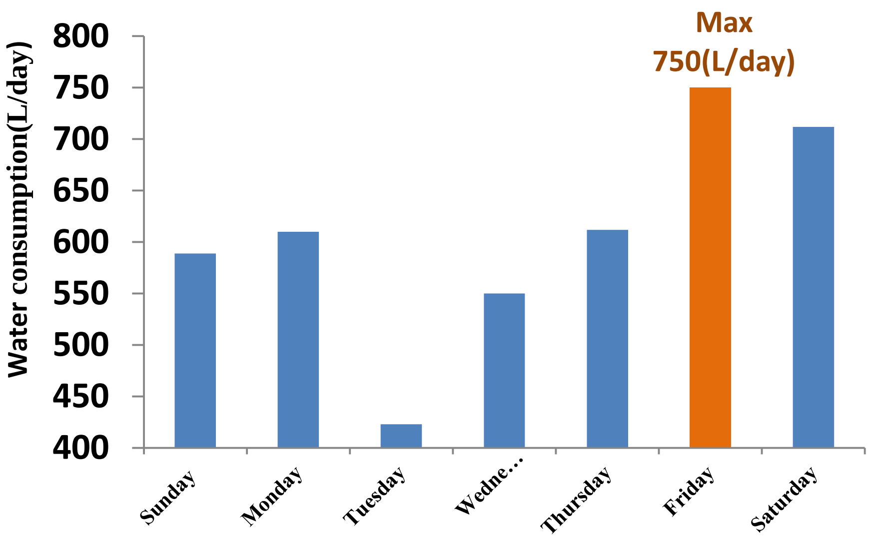


Figure 4.3. Average water consumption during a week

4.3.2 Average water consumption during a day

After monitoring water consumption during all days in the week we also monitoring during the hour of the day, the result in figure (14) shows that maximum water use during the day in lunchtime, after asking this family we found that this family is usually doing housework and cooking that time.

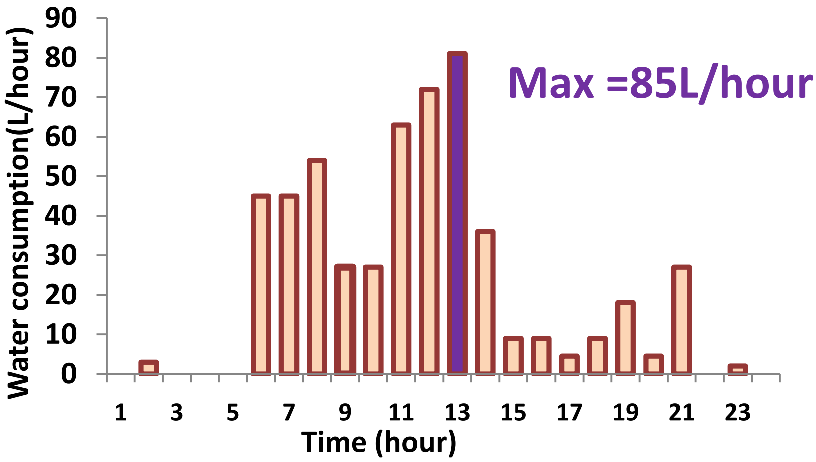


Figure 4.4. Average water consumption during a day

4.4 Water consumption at each unit

We monitored each unit to know the water consumption in each unit, and the result shows that the average water consumption decreased with time but this decrease includes 1.7 % of seasonal change and this result shows that the family awareness is increased for this family.

4.4.1 Faucet

The figure (4.5) shows that average water use decreased by 14%with times after applying IoT and this decreasing regarding increase awareness of people and seasonal change.

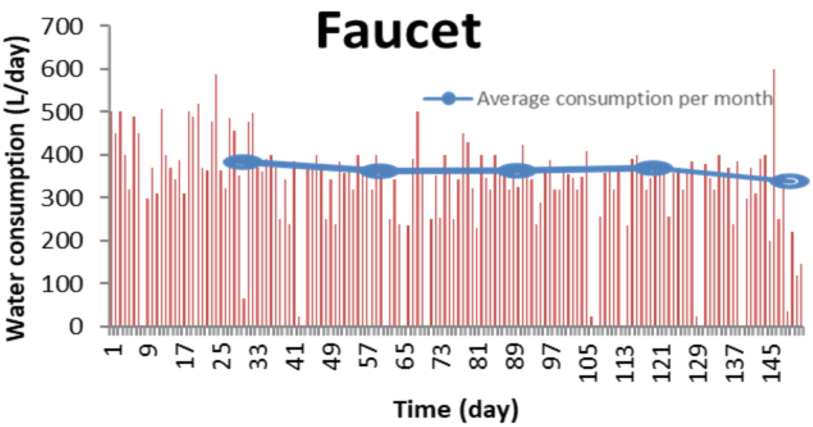


Figure 4.5. Daily water consumption in a faucet for five months (1/10/2017-30/2/2018**)**

4.4.2 Shower

The figure (4.6) shows that Water use decreased by 17% with times in the shower after applying IoT and this decreasing regarding increase awareness of people and seasonal change.

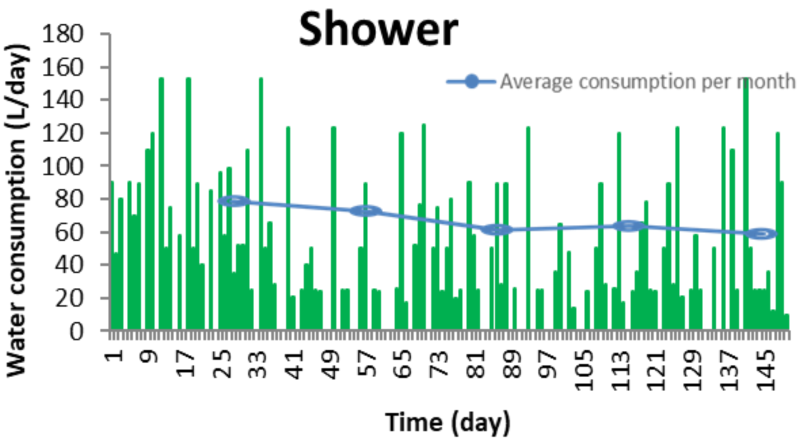


Figure 4.6. Daily water consumption in the shower for five months (1/10/2017-30/2/2018**)**

4.4.3 Toilet

The figure (4.7) shows that Water use decreased by 16 % with time, however, its expected not decrease but after asking the family the make their strategies to decrease consumption, like they don't make flush every time, and they put 2 litters bottle in tank of toilet to decrease the amount of water flushing, so these strategies decrease water consumption.

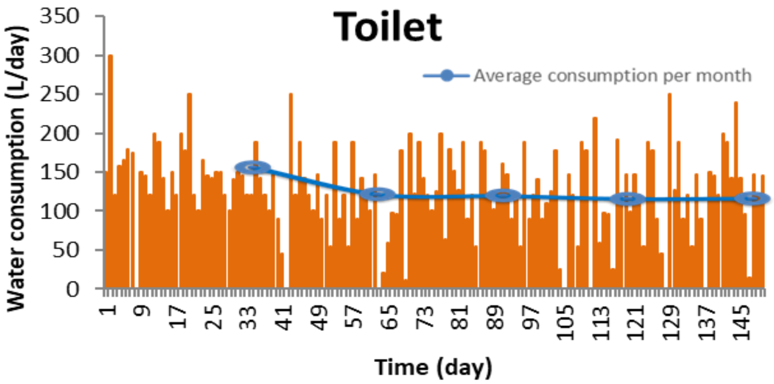
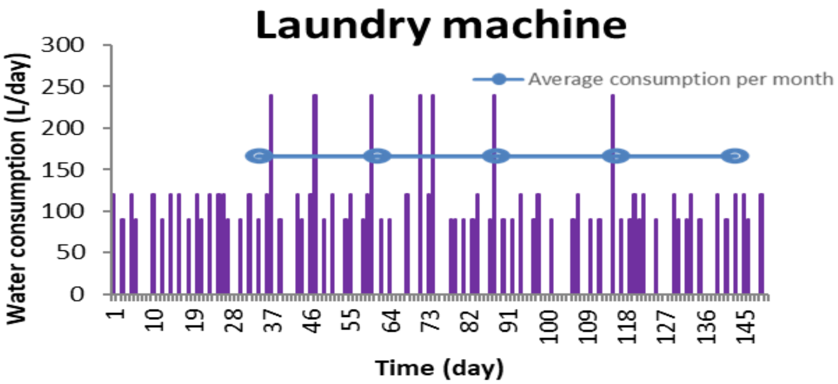


Figure 4.7. Daily water consumption in the toilet for five months

(1/10/2017-30/2/2018**)**

4.4.4 Laundry machine

The figure (4.8) shows that no change in water consumption with the time that's be-



cause we can't control machine.

Figure 4.8. Daily water consumption in the laundry machine

for five months

4.5 Survey result: Recognition of water use

4.5.1 Survey before using IoT

The figure shows the survey result before using IoT the LPCD for this family as they expect 92 (L/ day/person) and the most amount of water consumption in using the shower.

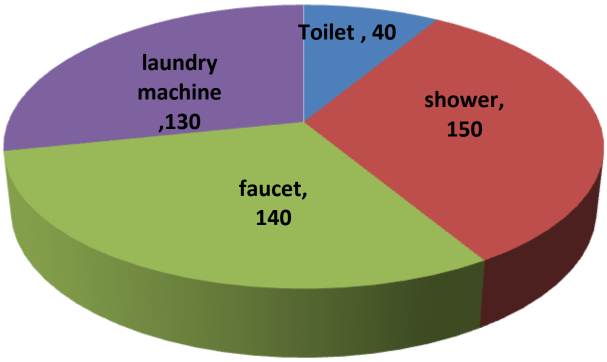


Figure 4.9. Survey before installing IoT

4.5.2 Survey after using IoT

The figure shows the survey result after using IoT the LPCD for this family as they expect 102 (L/ day/person) and the most amount of water consumption in using the shower.

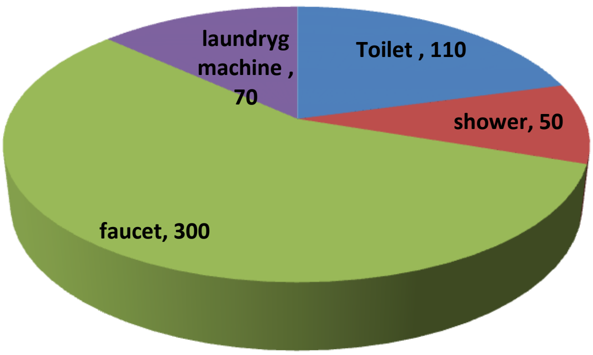


Figure 4.10. Survey after installing IoT

4.5.3 Real data (IoT)

The figure shows that the real average data of water consumption in each unit from this result the LPCD = 109 (L/ day/person) and the faucet is the largest part consume water

LPCD for the real data is higher than family expectation before using IOTand faucet is largest part consume water sensors that means the family has underestimation about amount of water they were used and where the highest part consume water however after installing IOT the result of survey after using

IOT closed to real data result that may because of increasing of family awareness so they can make right decision to save more water by Retrofit the biggest part of consuming water .

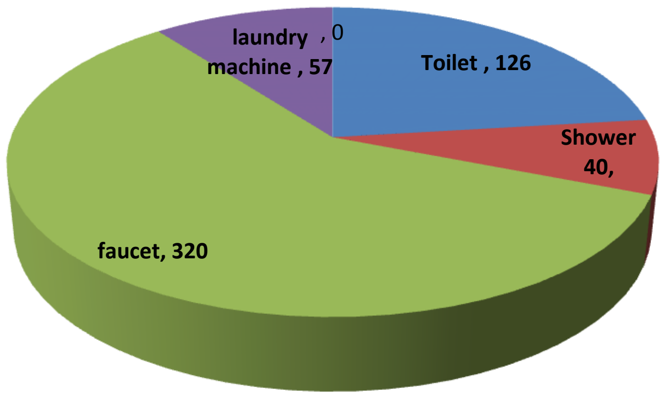


Figure 4.11. Real time data after installing IoT sensors

4.6 Water saved effectiveness

The faucet has the highest portion of water consumption. 33% decreased of water consumption by Retrofitting faucet. But (Campbell et al., 2004) reported that retrofitting only is not always effective you need to change people behavior. Installing an RWH system will cover the most of daily demand for the toilet.

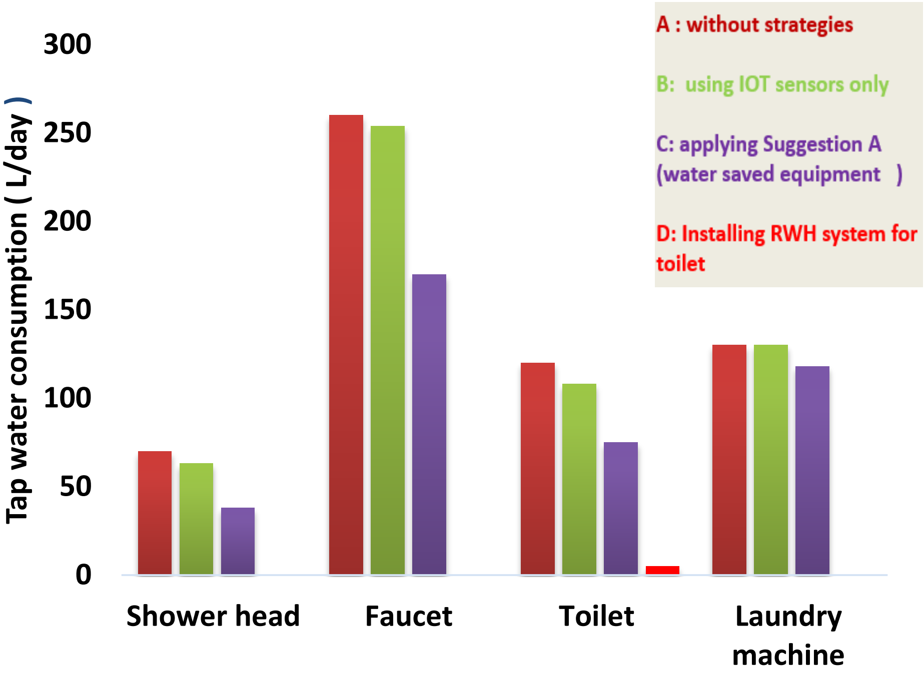


Figure 4.12. Tap water consumption for different cases

4.7 Cost evaluation for conservation strategies

4.7.1 Options evaluation

To choose the best option and use it in our study we evaluate the options that mention in chapter 3 and the result shows which is the best options.

4.7.1.1 Payback period

The payback period for toilet IOT sensor and RWH system show that options 3 is the best one however for the facet and showerhead option two is the best

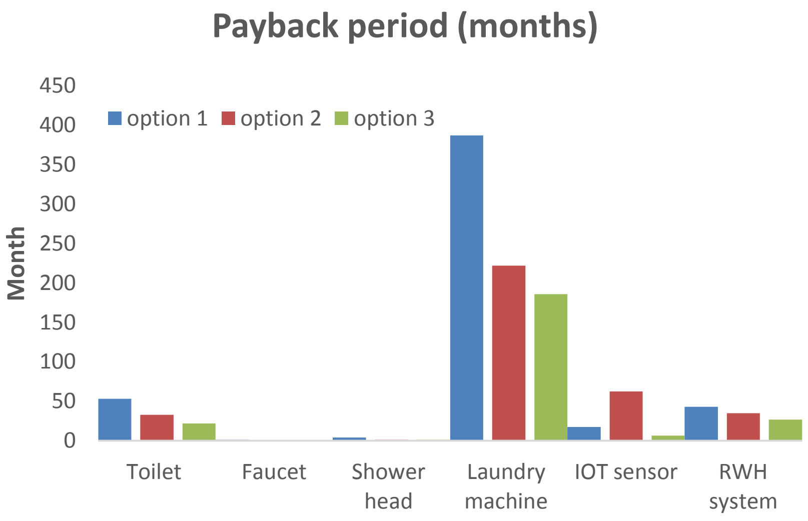


Figure 4.13. Payback period (months) for different cases

4.7.1.2 Benefit-cost ratio

For facet the benefit-cost ratio of option one is the best option, however, for the toilet, showerhead, laundry machine and RWH system, option 3 is the best option

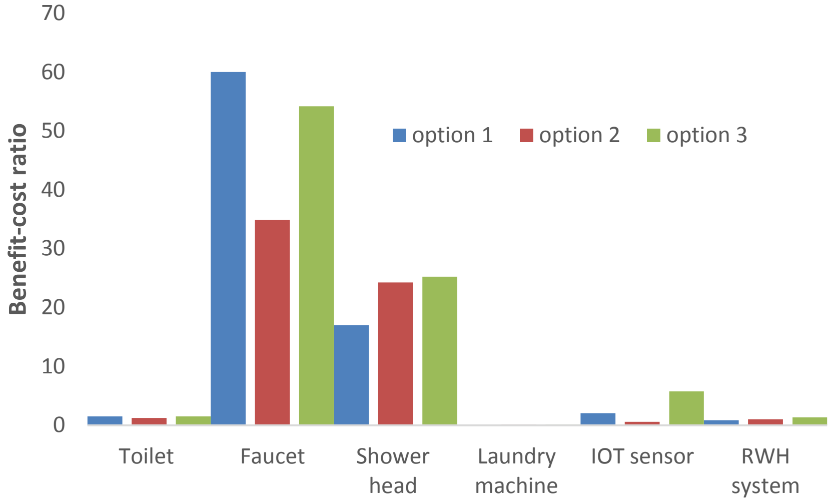


Figure 4.14. Benefit-cost ratio for different cases

4.7.1.3 Water saved per1$ investment

The result shows that for shower head option two is the best, however for others option three is the best options.

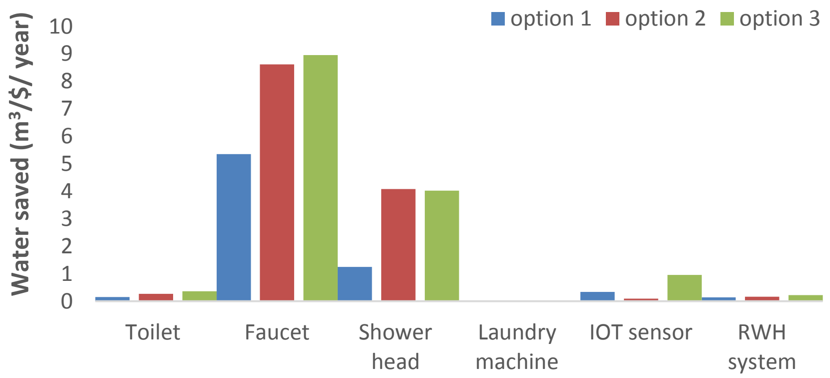


Figure 4.15. Water saved per1$ investment for different cases

4.7.1.4 Total annual savings ($)

For total annual saving, we can see that for IoT sensors and RWH system all option is the same because there's no effect on options in total annual saving. So we can see that option 3 is the best options for other features.

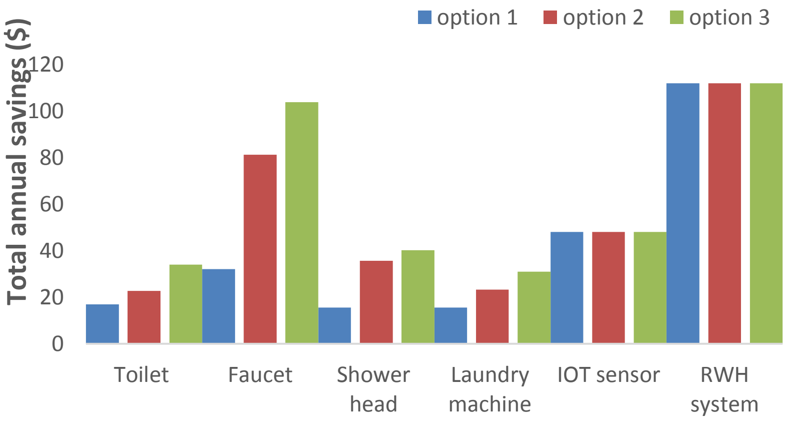


Figure 4.16. Total annual savings ($) for different cases

4.7.2 Identify the Investment Cost

Depending on the previous section for analyzing the best option we found going to the option 3 is the best choice, so we analyzed the cost depending on option three.

4.7.2.1 Water saved per1$ investment

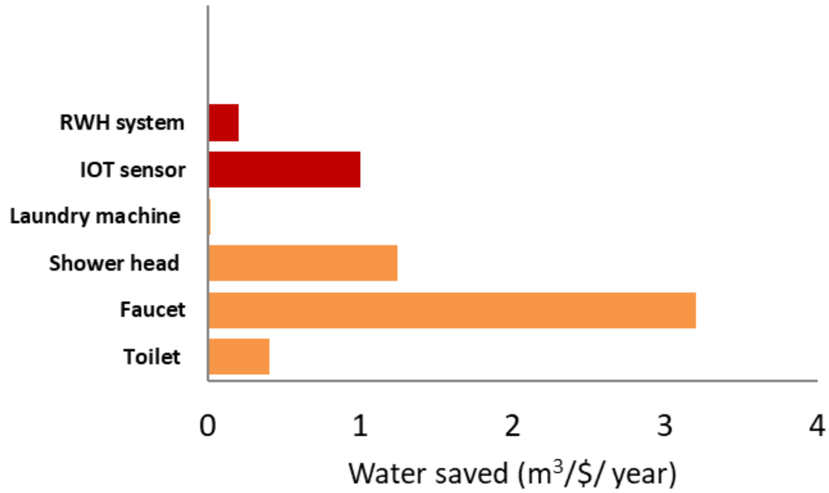


Figure 4.17. Water saved per1$ investment

From a figure of water saved per 1 $ investment, we can find that faucet is the best option and then shower head and IoT sensors, and in term of water saving for 1$ investments we will save 1m^3/ year by installing IoT sensors**.**

4.7.2.2 Total annual savings ($)

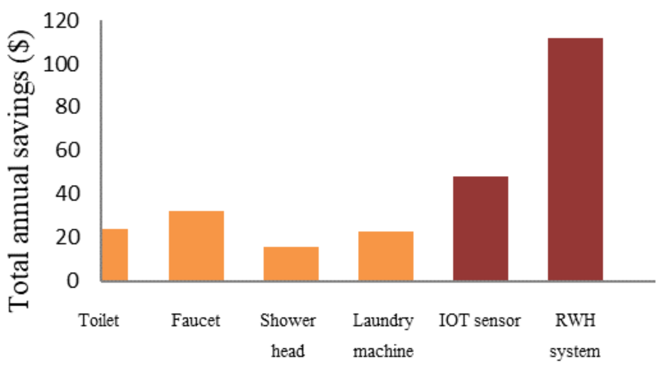


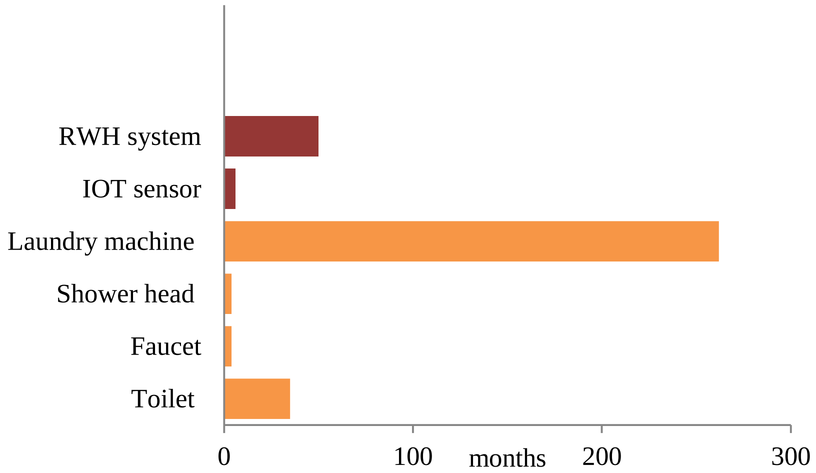
Figure 4.18. Total annual savings ($)

Forty-eight (48) $ per year the saved money of installing IOT sensors, however, we can see that the RWH system has the highest value of water saving, but this does not indicate it is the best economic option.

4.7.3 Calculate the Payback Period and B/C Ratio

4.7.3.1 Payback period

For payback is the length of time required to recover the cost of an investment, the laundry machine is the longest period and then an RWH system and toilet.



The faucet, it's the shortest period that means it is the best option for payback period.

Figure 4.19. Payback period (months)

4.8.3.2 Benefit-cost ratio

Benefit-cost ratio is the ratio of the benefits of a project or proposal, expressed in monetary terms, relative to its costs, also expressed in monetary terms. In this figure, we can see the best benefit-cost ratio is faucet and shower head then IoT sensors.

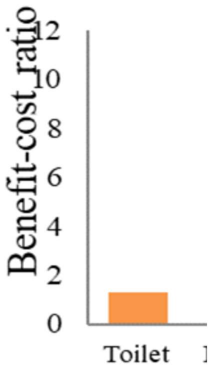


Figure 4.20. Benefit-cost ratio

CHAPTER 5. CONCLUSION CONTRIBUTION AND FUTURE WORK

Presented in this final chapter, is a summary of the key findings of this research. The contributions the research are detailed along with recommendations for future research directions.

5.1 Research summary and outcome

5.1.1 Research summary

Part 1: water conservation using IoT (monitored and surveyed)

IoT sensor developed and installed and monitored for five months at Ajloun, we found that LPCD at this house was: 126 Liter, but reduced to 109 Liter after monitoring. Behavior change reduced, But not firm. More detailed data can be found. Like seasonal, daily, hourly change, consumption by each element.

Part 2: a conservation strategy

Behavior change does not cost much. But it is not as big as Equipment change. And from the B/C ratio of equipment change, Priority for changes found.

The main outcome of the research: IoT was installed, and the water consumption pattern can be found. This can be used to develop the strategy.

The secondary outcome of research: Several strategies were suggested based on it like Change equipment priority: 1. Faucet 2. Showerhead 3. Toilet 4. Laundry machine.

5.2 Study contribution

Regarding the research contribution, some lessons learned have been summarized which may highlight the future direction of IoT research from practical aspects.

Developing IoT sensors in the field of water management and applied it is the file will be helpful to spread IoT idea in the field of water management, and to apply the idea for big scale.

Contributions to the existing body of knowledge about water consumption in Ajlune city and provide the householder with a good awareness of water consumption in a meaningful and effective presentation.

5.3 Future research direction

5.3.1 Policy Suggestion

a. The government can make regulation as follows:

b. Support IOT flow meter and install it on All public buildings: compulsory for new buildings and recommended to the possible extent for existing buildings. New public facilities such as parks, parking lots, and schools: to the possible extent. Private buildings: recommended for new buildings subject to building permission Large development plans such as new town projects IOT system as a priority. And the government can connect cities with Free Wi-Fi.

c. Government support for scientific research and new technologies in the IoT field. And give incentives fora family that decreased water use.

d. The government can make regulation for Priority of changing as flow:

1. Facet 2. Showerhead 3. Toilet 4. Laundry machine

5.3.2 Technological advancement needed

Using machine learning algorithms to handle and predict missing data. For example, Solve missing data form Blackout. AndUsing machine learning to control water consumption by predicting water use in the future and giving the alarm to decrease water consumption.

5.4 Conclusion

This paper reports a case study of IoT for water usage management. The IoT based water consumption system was developed in Ajlune city in Jordan. The system has been in use since October 2017 and receiving the water consumption data in real time until February 2018 and provide the householder a good awareness of water consumption in a meaningful and effective presentation.

This study aims to provide the householder with a good awareness of water consumption in a meaningful and effective presentation. And give them the best solution to save more water.

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Appendix A

Cost-Effectiveness calculator for long-term action)

		Inside home				Total consumption		Formula
		Toilet	Faucet	Shower head	Laundry machine	IOT sensor	RWH system	
a	Average flow rate of existing fixtures (baseline water-use)	**7**	**10**	**10**	**54**			
b	Percent of water-use (%)	16	40	11	19			
c	Annual consumption (m3)	37.8	94.4	25.96	44.84	236	236	c=b x annual consumption = b*236 m3
d	Average flow rate of retrofitted fixtures (benchmark water-use)	4	8.3	7.6	45			
e	Number of fixtures	1	1	1	1	5	1	
f	Cost of retrofit for each fixture ($)	35	5	5	500	25	500	
g	Total cost of retrofitting ($	70	10	5	500	125	500	g=e x f
h	Percent of saving per fixture	0.42	0.17	0.24	0.23			h= (a – d)/a
i	Average annual water savings (m3)	15.87	16	6.2	10.2	24	56	i= h x c
j	Average annual savings in water and wastewater ($) (1)	23.8	24	9.3	15.3	36	84	j= 1.5 x i
k	Percent of water heated	0	20	40	30	20	20	
l	Annual energy savings(2) ($)	0	8	6.2	7.6	12	28	l= k x i x 2.5
m	Total annual savings ($)	**23.8**	**32**	**15.5**	**22.9**	**48**	**112**	**m=l+j**
	Life time (years)	**12**	**5**	**5**	**14**	**6**	**8**	
n	Discounted benefits over life time of fixture(3) ($)	96.9	97.3	37.8	50	146	339	
o	Benefit-cost ratio	**1.3**	**9.73**	**7.56**	**.082**	**5.82**	**0.6**	o=n/g
p	Payback period (months)	**35**	**4**	**4**	**262**	**6**	**53**	r=(g/m)X12
q	Water saved per1$ investment	**0.4**	**3.2**	**1.24**	**0.02**	**1**	**.0.1**	Q=i/f

(1)Water supply and wastewater tariff = JD1.5/m3

(2) Cost of energy (Diesel) per heated cubic meter of water = JD2.5/m3

(3) j is Life time of each fixture, and 7 percent return rate, n= j*((1/(1+rate)1) + (1/(1+rate)2) + (1/(1+rate)3) + (1/(1+rate)4) + (1/(1+rate)5))

(4) Annual rainwater captured potential (m3) = Impervious area (m2) x annual rainfall (mm) x 0.80/1000

국문초록

현재수자원 확보를위한대부분의발전은 물을 더 효율적으로 사용하기 위한 기기의 기술적 발전에 초점을 맞추고 있다. 그러나 물사용자의습관, 인식및예상으로 물사용시설과 상호 작용함으로서시설의물소비량에 큰 영향을 미친다. 때문에수자원확보를위한연구에서는사용자에게 초점을 맞춘 연구가 필요하다. 본 연구에서는 IoT 를활용한 가정용 물 소비 모니터링 시스템을실제구현하여해당데이터를분석했다. 새로운 무선 물 소비량 모니터링 시스템은 가정 내의 다양한 지점에 유량 센서를 배치하여 데이터를 수집하도록 설계되었다. 물사용을줄이기위한주요한두가지범주의물절약방법으로나눌수있다. 기술적방법으로는네트워크개선, 누수방지, 효율성을증대시킨물사용시설개발이있고, 일반적인방법으로는소비습관을바꿀수있는정보, 교육, 인식전파가있다. 본연구는인터넷을이용하여사람들의물소비를저감하는방법을제시한다. 본논문은실시간모니터링및개발을위한새로운 IoT(사물인터넷)기술을이용하여주거용물소비를통합관리하는새로운지속가능한전략을탐구했

다. 지속가능한전략연구의첫단계는 IoT 유량센서를개발하여 5 개월간요르단아즈린시에서선정한한가정에설치하여각지점의물소비량을모니터링했다. 두번째단계는일상생활에서각지점에서사용되는물의최대량에대한가구설문조사를실시했다. 세번째단계로해당데이터를토대로물소비저감에대해지속가능한전략을제안했다. 본연구의주목표는 IoT 유량센서를활용해가족들의물소비인식을높이고지속가능한전략을제시하는것이다. 결과적으로가족구성원들의물소비패턴바뀌었고, 이집의 LPCD 는모니터링후 126L 에서 109L 로줄었다.

Keyword 주제어: IOT 기술; 가정용수자원보존; 요르단의희소성; 수도관리

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