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Research Article

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IOT to Combat Climate Change in West Africa: Development of IoT-Driven Smart Water Use and Control Meter (SWUCOM) to Mitigate Shower Water Waste in Niger

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ABSTRACT
Water-saving devices (WSDs) are well-known examples of Environmentally Sound Technologies (ESTs) used for water conservation and waste reduction. This work presents the development of an Internet of Things (IoT) based EST prototype of a WSD system for mitigation-driven shower water management in Niamey hotels. The developed Smart Water Use and Control Meter (SWUCOM) device was tested for three (3) days. The results show that the average daily shower water per guest in Niamey hotels is estimated at 92.07L. Furthermore, when making assumptions in some scenarios, it is demonstrated that SWUCOM can reduce the amount of shower water consumed by up to 45.70%. With its various features, the use of SWUCOM goes beyond shower water management. The paper therefore also highlights SWUCOM potential use as a smart meter in water distribution and consumption in cities and in irrigated agriculture, and its envisaged improvement to target smart cities and smart agriculture development in West Africa.

Keywords: Climate Change, Water Waste, Water-Saving Devices (WSDs), Environmentally Sound Technologies (ESTs), Internet of Things (IoT), Water Management Sensors, Smart Water Use and Control Meter (SWUCOM)

Introduction

Climate change is a real and global threat to many natural resources including water. It is shown that a change and variability in climate is already heavily impacting the hydrologic cycle, leading to challenges in water availability, and water allocation at the global level, and more severely at African regional, basin, and local levels [1]. Besides climate change, urbanization is also another significant challenge in Africa in this 21st century, affecting not only the socio-economic and administrative development, but also the natural resources, particularly water resources [2]. By 2050 it is predicted that 67% of the world population is expected to be living in urban areas, with the most rapid levels of urbanization taking place in developing countries especially those in West Africa [3]. In addition, the continuously growing population in combination with the escalating urbanization and economic growth increase the demand for water. With the combination of all these multiple factors (climate change, urbanization, population growth), especially in urban areas, water stress is expected to increase significantly worldwide by mid-century, particularly in Africa, Asia, Australia, New Zealand, and Southern Europe, as well as Latin and North America [4]. In other words, the combined negative impacts of climate change, urbanization and population growth pose serious challenges on water resources in developing countries especially in West Africa where resources to mitigate these impacts are limited.

Specifically in Niger, several research studies have highlighted the growing pressure on water resources as one of the consequences of climate change [5-7] and also as the result of the continuously growing population in combination with escalating urbanization and economic growth increase the water demand [8,9]. Their general assessment highlighted that due to recurrent climate change impacts such as floods and droughts, the Niger River, which is the main surface water used for agriculture and drinking water supply in Niamey, cannot meet the total water demand of the surroundings of the city, and also confirmed that the demand

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for groundwater supply to meet drinking and agricultural water use needs in Niamey is increasing, due to rapid population growth and urbanization[9]. Despite all these phenomena (climate change, population growth, and urbanization) that threaten water resources, water is often wasted in certain places, such as showers in hotels. Researchers from the US have explained that due to the lack of control by hotels in general, a significant amount of water is wasted by guests every day, especially in showers [10]. Moreover, in Niamey, poor people represent 40% of the global population and are suffering to get access to drinking water. They spend more time and pay on average five times more the price of water than the non-poor to get drinking water, which is seen as a social inequality [11]. Therefore, given the threats and wastage of water resources in the city of Niamey, good management of water resources is essential for everyone and everywhere, without exception. "Since the 1970s, it has been demonstrated that good water management is possible, financially feasible, and practicable within urban low-income areas when considering the use and applications as well as the approaches of appropriate technologies that are known today as Environmentally Sound Technologies (ESTs)" [12]. Water-Saving Devices (WSDs) are well known examples of ESTs used for good water management and wasted water reduction in domestic, agricultural, and industrial sectors [12]. Nowadays, with the exponential development of Internet of Thing (IoT) technologies, many water-saving devices are designed to reduce water wastage and enable better management of the resource.

With the purpose of contributing to overcome the issue of water waste in Niamey hotels, the sepecific objectives of this work is to investigate the reality of Water waste in Niamey hotels, propose suitable water use efficiency requirements that can contribute to reducing shower water waste in hotels, and demonstrate how IoT technologies can be used by African scientists in African context to develop a smart WSD system that meets the identified water use efficiency requirements for water waste reduction.

The rest of this paper is organized as follows. Section II presents the related works while the section III gives an overview of materials and methods used to investigate water use in some hotels in Niamey, and those used to develop the proposed Smart Water Use and Control Meter (SWUCOM) system. Results and discussion, and then challenges are highlighted in section IV and section V, respectively. Finally, the section VI concludes and also highlights some perspectives of this work.

Related Works

Nowadays, several smart WSDs based on IoT technologies have been designed and implemented to reduce water wastage and improve water management, particularly in homes and hotels. For example, in the US, HydroSense is a novel low-cost, accurate, small-size, low-power, and wireless device for monitoring water use in hotel room showers [10]. However, it has some shortcomings since hotel guests/clients can continue to use the water in the shower as they wish without any restrictions or even a warning. From Europe, a European Commission Funded FP& project used smart water meters based on IoTs to monitor domestic water consumption [13]. The system comprises a wireless sensing device, a wireless gateway, and a remote server for data storage. This device system may be more expensive and need an external power supply to operate. Developed in the UK, the Connected Shower is a bespoke IoT device that captures water flow, temperature, showerhead movement, and shower product weight. Its main target was to understand shower water consumption. After a week's deployment in six households, participants in different households had a varied range of shower use. The range was from 2 to 10 minutes on average, each consuming between 21 to 145 liters on average [14]. Therefore, this device did not really contribute to water waste reduction. From Asia, several smart water meters were recently developed water management and metering, but none of them directly addressed the issue of limiting waste reduction by limiting water consumption [15-17]. In addition, they all require an external power supply to operate, which constitutes a potential huge limitation to their use in developing countries where power supply outages are recurrent. The device developed in this work will address all these issues and expects to contribute to significantly reducing water waste. We were not able to find to the best of our knowledge any IoT-powered WSD developed in Africa by the time this article was written and hope that our work will contribute to fill the gap.

Materials and Methods

Study Area

Niamey is the capital of Niger and is located on the Niger River in the far west of the country. It covers an area of 552.27 km2 with an estimated population of 1,407,635 in 2020 and a high density of 2548.82 inhabitants/km2. Niamey has been chosen as a study area to conduct this work in Niger. The reason is that Niamey, being the capital has more hotels than all the other cities in Niger. For instance, in 2019, the total number of hotels in the country is 198 while Niamey alone has 99 (i.e., 50%) of these hotels [4].

Research Methodology

To develop a WSD that methodically reduces water waste, it is important to at least know the current shower water consumption per hostel guest in Niamey, and to identify acceptable rules / requirements that, if efficiently applied, can lead to an efficient reduction of water waste under showers.

Therefore, the following methodology was setup to guide our research activities.
As an entry point, a general literature review is conducted to find out (i) existing work and information on the daily shower water use per guest in hotels in Niamey and to discover (ii) the eventual existence of water use efficiency requirements already proposed for water waste reduction in general and in showers in peculiar.

When the literature review is not enough to have data on the daily shower water use, surveys are to be submitted to a sample of hotels and to the regional directorate in charge of touristic activities (DRTA) which also monitors hotels. In any case, the data collected from various sources in the literature or from the surveys will have to be cleaned and processed to compute the daily average amount of showering water per guest.

In a roughly similar way, when no water reduction efficiency requirements are found in the literature, or when after analysis, those discovered in the literature seem to not be efficient enough to reduce shower water waste regarding the context, water use reduction efficiency requirements with consideration of the study context will have to be proposed or customized, respectively.

Afterwards, both the calculated daily average amount of showering water and the identified requirements for an efficient shower water waste reduction serve as guiding references to the development of an efficient WSD.

The SWUCOM development has to include the hardware design, the microcontroller programming and the data transmission and storage in the cloud. Fig. 1 below shows the flow chart of the general methodology that guided this work.

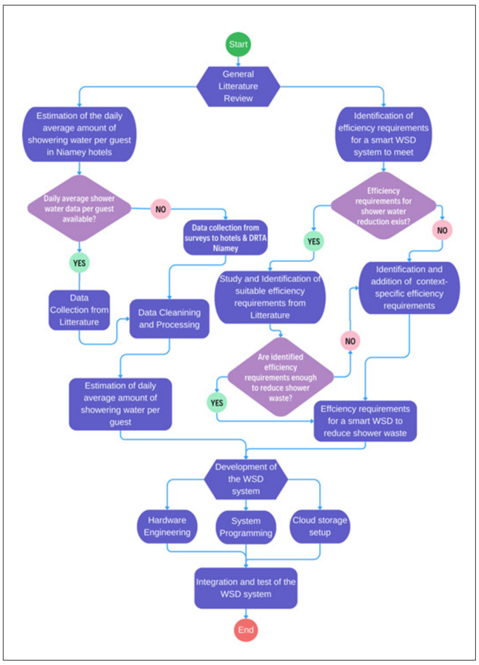

Figure 1: Flowchart of the methodology process.

Implementation Methods

After not finding in the literature any existing scientific or administrative publication on shower water consumption in Niamey hotels, two on-site surveys were carried out to get the data needed to reach the different objectives of this work: the first one was conducted at the Direction Regionale du Tourisme et de l'Artisanat (DRTA) of Niamey, and the second one was submitted to a sample of hotels.

Afterwards, the following main activities were carried out:

(i) Cleaning and processing of the raw data collected during the on-site survey carried out in seventeen (17) hotels in Niamey.
(ii) Estimation of the daily average amount of showering water per guest in Niamey hotels.
(iii) Determination of water use efficiency requirements a smart WSD system should align with
(iv) Development of a user-friendly smart WSD system based-on Internet of Things components and technologies and with consideration of previously determined efficiency requirements.

Data Cleaning and Processing

Water consumption data and other types of data (occupancy rate, room number, bed number, etc.) necessary to calculate/estimate the daily average amount of showering water per guest for 2019 to 2021 were only obtained. Data cleaning and processing operations were applied to remove unwanted data and compute the following indicators of shower water consumption.

Estimation of Daily Average Amount of Showering Water Per Guest in Niamey Hotels

Such an estimation was methodologically done step by step by first computing preliminary estimations regarding: (i) the Daily Average Amount of Showering Water per Hotel (*DAASWH*), (ii) the Average Number of Guests Per Day per Hotel (*ANGPDH*), (iii) the daily Average Amount of Showering Water Per Guest per Hotel (*DAASWPGH*). Then, was finally computed the Daily Average Amount of Showering Water Per Guest in Niamey Hotels (*DAASWPGNH*)

Estimation of Daily Average Amount of Showering Water of a Hotel

The formula used to calculate the daily average amount of showering water of a hotel ***DAASWH*** is as follows:

$$DAASWH = \sum_{i=1}^{n} \frac{TWCPMH_i}{n} \qquad \text{(III.C.2.1)}$$

Where:
***TWCPMH*:** Total Water Consumption Per Month of a Hotel,
n = is the number of days of data obtained.

D.2.2 Calculation of the Average Number of Guests Per Day in a Hotel ***ANGPDH***

$$ANGPDH = (NGBH \times ORH)/100 \qquad \text{(III.C.2.2)}$$

Where:
NGBH: is the Number of Guest Beds in a Hotel, and
ORH: is the Occupancy Rate of the Hotel.
D.2.3 Calculation of the Daily Average Amount of Showering Water Per Guest in a Hotel ***DAASWPGH***

$$DAASWPGH = DAASWH/ANGPDH \qquad \text{(III.C.2.3)}$$

D.2.4 Estimation of Daily Average Amount of Showering Water Per Guest in Niamey Hotels

DAASWPGNH

$$DAASWPGNH = \sum_{j=1}^{h} \frac{DAASWPGH_j}{h} \qquad \text{(III.C.2.4)}$$

Where:
h = is the number of sampled hotels in Niamey.

D.3. Determination of water use efficiency requirements a smart WSD system should align with
This step was two-folded:

(i) Selection from the literature of suitable-efficiency requirements that can contribute to reducing shower water waste in hotels at the global level.
(ii) Identification and addition of context-aware efficiency requirements to take into account the local context.

Afterwards, a full list of the efficiency requirements that a smart WSD system should meet to be able to reduce shower water use in Niamey was established.

Development of SWUCOM, an IoT-Driven WSD

Given the applied side of this work, many materials and tools were gathered to achieve the hardware engineering of the SWUCOM, its microcontroller system programming, and the cloud data storage setup. For instance, electronic components used for the development of the SWUCOM include Arduino mega, water flow sensor, solenoid valve, relay module, water turbine generator, GSM/GPRS module, SD card memory, and SD card module, keypad, real-time clock (RTC) module, liquid crystal display (I2C, 2*16), piezoelectric buzzer, light emitting diodes (LEDs), breadboard, and a lithium battery (11.2V, 2Ah).

Arduino Integrated Development Environment (IDE) was used in this engineering work for the programming and upload of code into the SWUCOM microcontroller. Also, ThingSpeak, an open data platform for the Internet of Things (IoT), was used for storing in the cloud the data measured and automatically sent by the SWUCOM to Thing Speak.

Results

This section presents the main findings of this engineering research and development work. First of all, the survey results are presented followed by the estimated daily average amount of showering water per guest in Niamey hotels. Next, the inventory and proposition of some efficiency requirements, and then the development, and testing the SWUCOM are highlighted. Finally, an overview of the evaluation and estimating efficiency of the SWUCOM is provided.

Survey Results

Two (2) on-site surveys were carried out for the purpose of this work. From the first one carried out at the DRTA of Niamey findings are shown in the table below:

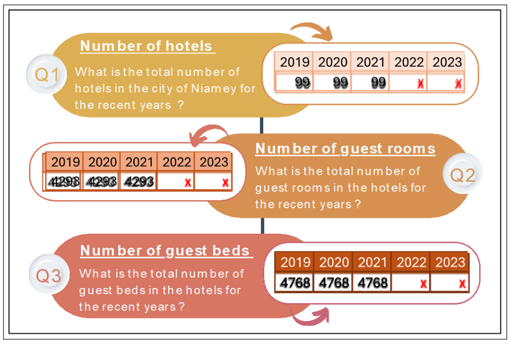

Figure 2: Number of hotels, rooms and beds in Niamey from survey data

Figure 2 highlights the data collected at the DRTA of Niamey. We can see that the number of hotels, the number of guest rooms, and the number of guest beds in Niamey for the recent years (2019, 2020, 2021) are the same and correspond to 99, 4293, and 4768, respectively. The non-evolution of hotels number in Niamey during these years can be explained by the impact of COVID-2019 which did not favor the apparition of new hotels given that even the existing ones were struggling to avoid closing. Data for 2022 and 2023 were not available yet.

The second survey conducted to collect shower water consumption data sample initially targeted seventeen (17) hotels in Niamey but 10 of them accepted to share their data. Fortunately, the data collected from these 10 hotels (out of 99) show that collectively, they account for 684 hotels guest rooms (over 4293) and 1041 hotels guest beds (over 4768), which represent respectively 14,50%, 33,40%, and 40,70% of the total number of hotels, guest rooms, and guest beds available in Niamey. This strong sample of surveyed hotels also comprised all classes of hotels: high class (4 and 5 stars), middle class (2 and 3 stars), and low class (1 star and unclassified).

Based on the ten (10) questions (see Table 1) submitted to each hotel of the sample, the collected data clearly highlight an alarming situation regarding the monitoring of water consumption in guest rooms characterized by:

(iii) Zero green-certified hotel,
(iv) Not any type of WSD installed in the showers of guest rooms,
(v) No hotel has established any requirement to reduce shower water waste; and
(vi) No hotel was able to monitor/control the daily shower water consumption of guest rooms.

Table 1: List of questions submitted to hotels

No	Question
1.	Is your hotel certified green or not?
2.	What is the number of rooms in your hotel?
3.	How many beds do you have for guests?
4.	What is the occupancy rate of the rooms?
5.	Have you installed a water-saving device in the showers of your hotel? If yes, what type?
6.	Are there any efficiency requirements applied in your hotel to reduce shower water waste? If so, what are they?
7.	Are you able to monitor/control the daily shower water consumption of each guest/room in your hotel? If so, how?
8.	What is the percentage of shower water consumption by guests compared to the overall water consumption in your hotel?
9.	What factors/parameters increase shower water waste in your hotel?
10.	If available, can you share your data on water consumption in showers in your hotel for the recent years?

As for the factors/parameters that can lead to excessive water consumption by clients in the showers, the answers include: occurrence of hot period in Niamey (March-April-May), use of large flow-meters allowing high flow rate of about 18L/min, and occupancy rate.

Estimation of the Daily Average Amount of Showering Water per Guest in Niamey Hotels

The methods used to estimate step by step the Daily Average Amount of Showering Water per Guest in Niamey Hotels (DAASWGNH) were formulated in sections III.C.2.1 to

III.C.2.4. Figure 3 displays the estimated Daily Average Amount of Shower Water per Guest for each Hotel (DAASWGH). It also highlights in red the overall estimate of the Daily Average Amount of Showering Water per Guest in Niamey Hotels (DAASWGNH) which was computed by making the average of all of DAASWGH as formulated in section III.C.2.4.

By analyzing Figure 3, one can see that high class hotels are those in which the daily average amount of shower water per guest is higher than the average. A middle class hotel (H02) was recorded with the highest value of the daily average amount of shower water per guest with 134.06L. However, low class hotels are clearly under the daily average amount of shower water per guest.

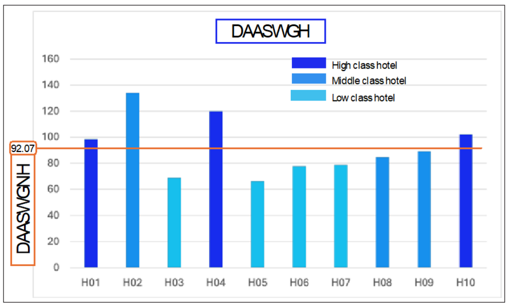

Figure 3: Anonymized DAASWGH and DAASWPGNH in liters/day

Identification of Efficiency Requirements to Reduce Shower Water Waste in Niamey

In the literature, some efficiencies requirements to reduce shower water waste were proposed for water conservation and good management in general, and for showering in particular. Indeed, according to Farmer (2019), one approach to water conservation in a shower is the use of low flow showerhead studied personal water use habits for domestic uses and found that the water consumption for showering is considerably high compared to other uses [18,19]. In a survey carried out, during the same study fifty (50) people from different social background were asked why they do not shoot the tab off when the water is not needed during shower-taking sessions. The response given by most of those people is as follows: "Closing and opening the tab is a boring action and is difficult to repeat several times during a period of 10 or 15 minutes, the average required time for taking a shower". We think that people will continue doing these kinds of bad habits if their daily amount of shower water is not limited. Following Maslow's hierarchy of needs, WHO in its 2013 technical note and other scientists have set standards for minimal water use per capita per day as depicts in Fig. 3 [20-22]. The Figure shows the hierarchy of water requirements following Maslow's hierarchy of needs. in which the daily amount of water needed in an emergency by a person is 30L for drinking, cooking and body washing.

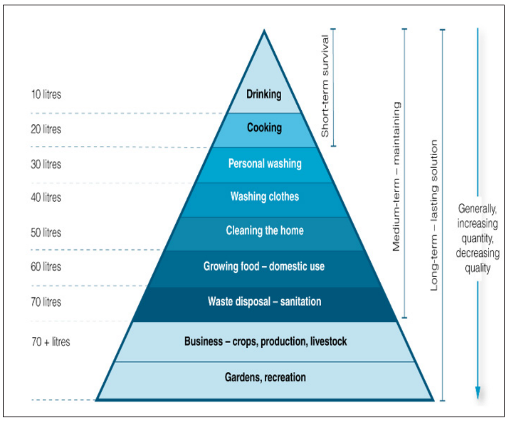

Figure 3: Hierarchy of water requirements following Maslow's hierarchy of needs

However, the mentioned scientific literature, though highly relevant, are global measures and metrics which do not capture the specific local context of Niger.

Subsequently

- Considering that Niger is a Sahelian country experiencing droughts and water scarcity,
- Taking into account that the city of Niamey alone accounts more than 4,768 beds in its hotels, which corresponds to about 53.65% of the national capacity of hotels in Niger ("INS Niger," 2020),
- Knowing that none of the surveyed hotel: (i) was able to monitor/control the daily shower water consumption of guest rooms, nor had established any requirement to reduce shower water waste;
- Knowing that the estimated average daily amount of shower water per client in the hotels of Niamey rises up to 92.07L, therefore very high,
- Perceiving the potential water waste in Niamey hotel showers and at national scale,
- Aware of the diversity and categories (high, medium, low class) of the hotels considered in this work, and
- Considering WHO minimal water use per capita per day in emergency sitution(30L for drinking, cooking and body washing).

our research investigation has identified the following water use efficiency requirements (Table 2) which are achievable in low-income countries and that can lead to reducing shower water waste in hotels:

Table 2: Proposed water-saving efficiency requirements

No	Requirement	Description
1	Maximum shower water daily allowance	limit the daily allowance of shower water per guest to 50L (for shower only) in hotels in Niamey.
Education Level Requirements *Initiatives to educate and engage guests and staff in water conservation.*		
No	**Requirement**	**Description**

2	Guest Education Programs	Informational materials and initiatives to educate guests on water responsible use such as In-room information cards and digital signage on water-saving tips
3	Staff Training Programs	Training hotel staff on water efficiency practices such as water conservation and maintenance of water-saving devices.
4	Incentive Programs for good water conserving for Guests	Rewards and incentives for guests who conserve water such as souvenir gifts or discounts on hotel bills.
5	Disincentive Programs for big water wasters	Charging guests extra for excessive water usage based on a maximum shower water usage allowance to be determined at Policy level
Infrastructure Level Requirements *Physical upgrades and foundational changes to the hotel's water systems such as design, construction, and modification.*		
No	**Requirement**	**Description**
6	Low-Flow Plumbing Fixture	Installation of low-flow showerheads, faucets, and toilets throughout the hotel
Technology Level Requirements *Advanced devices, smart systems, and software for water efficiency without major structural changes to the building.*		
No	**Requirement**	**Description**
7	Water Saving Devices	Devices tracking and displaying real-time water usage with sensors and timers for water flow, temperature and usage control
8	Mobile Apps for Water Management	Apps for monitoring and managing water usage allowing guests to set shower preferences and track usage

- Limit the daily amount of shower water per guest to 50L in hotels in Niamey but with the possibility of exceeding this limit.
- Use a flow meter with a maximum flow rate of 10L/min instead of the flow meter used in Niamey hotel showers, which offer a flow rate of up to 18L/min (Source: a survey conducted in Niamey hotels).
- Give an alert to the user when 3L of water remains in the daily shower water consumption limit.
- Record the duration and amount of water per shower a guest takes. This will allow each hotel to have full control over the shower water consumption of their guests
- Setup an automatic water usage monitoring system to to have full control over the shower water consumption

Development of the SWUCOM

This section presents the development of the SWUCOM based on IoT technologies and that will user-friendly manage shower water use in Niamey hotels concerning the efficiency requirements listed above. It highlights the three (3) main parts of the development such as:

Design of the Hardware Part of the SWUCOM

The design of the hardware part of the SWCOM consists of connecting the different electronic components listed in Section III, among each other, and upload a program that makes the hardware execute different functionalities. After the connection between different elements was completed as seen in Fig. 4 below, the implemented Arduino program was uploaded to the Arduino Microcontroller.

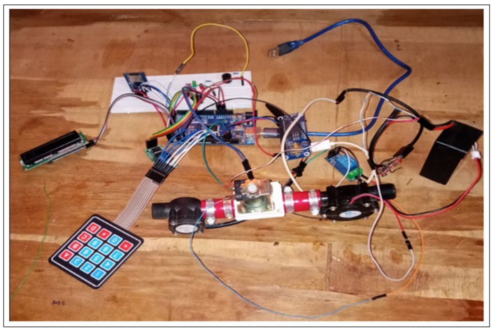

Figure 4: Connection between different elements of the SWUCOM

Data Sending to the Cloud

Nowadays, IoT is an emerging field of technology where devices or objects can connect and transfer data over a network without human intervention [25]. These objects or things have sensing capabilities, and they have unique identifiers for addressing and communication. To transfer data from devices over the internet, cloud computing provides the infrastructure for that data to travel to its destination [26]. Over the years, vendors have created many connected devices, and in the same vein, a lot of IoT cloud platforms have been developed. Examples of IoT cloud platforms include:

Thingsboard, thingworx, IBM Watson IoT, node-red, thinger, sparkfun, thingspeak, etc. The latter one was released to the market by ioBridge, and it now has support from MATLAB, thus, giving the user access to advanced data analytics tools.

For the SWUCOM to send data to the cloud, the ThingSpeak platform was chosen. The reason for its choice is that it offers multiple advantages such as:

- ThingSpeak allows registered users to collect, display, analyze, make inferences, and act on the data;
- It allows the user to process his data. That is to integrate, convert, calculate new data, and develop IoT applications.
- Further tools enable data interchange between ThingSpeak and web apps or social media platforms.
- Users can visualize their sensor data using MATLAB's several built-in plots or display data in gauges, charts, or custom plots.

Operating Principle of the SWUCOM

To well describe the operating principle of the SWUCOM, a sequence diagram (Figure. 5) was developed using Unified Modeling Language (UML). UML is a standardized modeling language consisting of an integrated set of diagrams, developed to help system and software developers in specifying, visualizing, constructing, and documenting the artifacts of software systems, as well as in business modeling and other non-software systems.

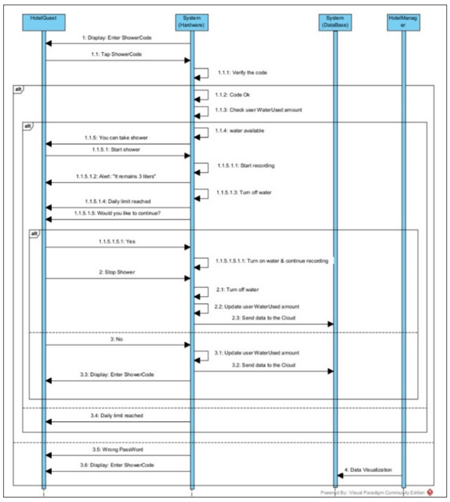

Figure 5: Description of the operating principle of the SWUCOM

Testing of the SWUCOM

The SWUCOM was developed and tested to execute a lot of tasks such as:

- Measuring a hotel guest's shower water consumption. Thus, the water flow sensor is used to measure the shower water volume. But, before even its insertion into the system, the water flow sensor (model: YF-S201) was first tested by implementing an Arduino code which was also uploaded to the Arduino microcontroller. The obtained results are given in (see Fig. 36 filed6 and filed7 corresponding to the delay and the amount of shower water used respectively). It should also be noted that the water flow sensor used has a maximum flow rate of 10L/min, thus allowing efficient use of water rather than wasting it.
- Being a self-powered device. However, when the water passes through the water turbine generator (Model: GOSO F-50 12V), it will generate a voltage of 12V which will charge the internal lithium battery. This battery is used to supply power to the whole system. So, the smart WSD doesn't need any external power supply.
- Ensuring the management of the daily shower water consumption of the customers. Since the guest rooms in Niamey hotels have a maximum number of two beds, the SWUCOM has an internal storage memory in which four user codes and their daily water quantities are stored. Each time a client uses his code to shower, the system will automatically remember his last consumption. Also, each day when it is 00:00, the SWUCOM will automatically reset the daily amount for each user to zero for the new day that starts.
- Ensuring data sending to the cloud (online database). Every time a customer finishes showering, the SWUCOM will automatically send some data to the cloud i.e., the online database (ThingSpeak) through the GSM/GPRS module. Eight (8) types of data are sent namely hotel name, hotel city, guest room number, guest shower code, date, duration of shower, amount of water used by guest, and maximum daily amount of water used by guest.

Finally, the smart WSD system is very user-friendly because it guides the user during its use. Indeed, when the user is at step i, the smart WSD will show him step i+1. For example, when the customer is showering, in addition to showing him his current water consumption, it will tell him which button to press in case he wants to stop the water for a few moments to lather up for example, or to completely stop his shower.

The prototype of the SWUCOM was tested for three (3) days but not in a shower. The test was conducted by connecting the device to a tap from the 1st to the 3rd of July 2022. The SWUCOM worked very well for each user. Indeed, each of the four (4) users' passwords was used once a day to do a test just for a short time (not more than four (4) minutes.

Estimating the Efficiency of the SWUCOM

To estimate the efficiency of the SWUCOM after its implementation, we made three (3) assumptions:

- In 2020, the total number of guest rooms in Niamey hotels was 4293.
- The estimated daily average amount of showering water per guest in Niamey hotels is 92,07L.
- From the survey data, the estimated average occupancy rate of Niamey hotels is 61,5%.

Based on the assumptions made, table 5 below shows the daily, monthly, and annual amount of shower water consumption in Niamey hotels when each of the following scenarios is considered:

- the SWUCOM is not installed and the daily average amount of showering water per guest is equal to 92.07.
- the smart WSD system is installed in every hotel guest room in Niamey and each guest in Niamey hotels decides to respect the limit of the daily amount of shower water per guest which is 50L.
- the smart WSD system is installed in every hotel guest room in Niamey and some hotel guests decide to consume beyond the limit of their daily amount of shower water.

Table 3: Shower water consumption in Niamey hotels based on the assumptions and scenarios made

Period	Water consumption (m3) when 1, 2, 3, & (a)	Water consumption (m3) when 1, 2, 3, & (b)	The Gain (a) – (b)	Water consumption (m3) when 1, 2, 3, & (c)
Daily	269.97	146,616 (45.70%)	123.354	146.616 + X
Monthly	8099.36	4398,48 (45.70%)	3700.88	4398.48 + Y
Annually	98542	53514,84 (45.70%)	45027.16	53514.84 + Z

Table 3 quickly shows that if the three (3) assumptions made and scenario (b) are considered, about 45027.16 m3 (45027160 L) amount of water will be saved annually which is equivalent to 45,70% of the amount of water consumed when (a). Furthermore, if we keep the three (3) assumptions and scenario (c), we will still have saved water depending on the number of hotel guests who will continue to be faithful to respect their limit of the daily amount of shower water. In that case, this work would try to recommend to different hotels see how they can add charges on guests who use more than their limit.

On the other hand, hotels should contribute to the protection of the environment by funding national and international organizations in charge of environmental protection.

Discussion

Hawrylak et al. (2015) implemented an IoT-based WSD called HydroSense in the U.S. According to them, hotels significantly contribute to increased water consumption in the U.S. and around the world.

This is because most hotels are not able to monitor shower water use in guest rooms.

Thus, HydroSense, a novel low-cost, accurate, small-size, low power, wireless device was designed for monitoring water use from hotel room showers in the U.S. Its target is to promote water conservation among hotel guests [10]. But in reality, HydroSense was designed to improve hotel revenue in the U.S., i.e., hotel guests who use a large amount of water for showering will be charged for excessive water use.

Alegre et al. (2017) in their study entitled “Assessment of water-saving equipment to Support the urban management of Water”, have analyzed the environmental and economic impacts of the implementation of water-saving equipment in residences in the municipality of Caruaru-PE. Since 2012, the Northeast of Brazil is suffering a severe drought, regarded as the longest over the past 50 years; as a consequence, many of the reservoirs that supply the municipalities are collapsing, which means it no longer offers the conditions for capturing water for human consumption [27]. So, Alegre et al. (2017) have carried out this work to contribute to find a solution to the water problem faced by the Northeast of Brazil. After the study, the results demonstrated that it is possible to save up to 40% of consumed water only with the implementation of water-saving equipment, with a mean return time of six and a half years. Therefore, it is possible to understand that the use of water-saving equipment represents an important instrument of water management.

To the best of our knowledge, there is still no study related to the implementation of WSDs in order to contribute to water conservation before, in the whole of West Africa. Niger is no exception.

However, the proposed IoT-based smart WSD called SWUCOM was developed to reduce shower water waste in Niamey hotels. After testing the SWUCOM and based on some assumptions made, the results show that a significant amount of water could be saved in Niamey hotels. Indeed, about 45,70% of consumed shower water could be saved.

Additional information about this work: Within the framework of the 6th International FabLabs Solidarity Challenge "Aqua Makers" launched by Orange in 2023, this work has been selected among the 13 best projects (the only project chosen for all of West Africa) at the semi-final step. For more information, see the link below: https://challengefablabs.fondationorange.com/en/projet-propose/hari-tech-stop-wasting-water-in-the-shower/

Challenges

Technological challenges were faced in order to pass from the developed prototype of the SWUCOM to a final product, i.e., a product/device that can be used by everyone and for long time. Among these challenges are:

- Printed Circuit Board (PCB) assembly.
- 3D printing for boxing the device to obtain a finished product.

This can be explained by the fact that PCBA assembly and 3D printing technologies in low-income countries like Niger and Burkina Faso are still rare or non-existent. What's more, even the electronic components used to develop the SWUCOM cannot be found in our countries, having been ordered and imported from China. This also means long waiting times to receive them.

Conclusion and Perspectives

This research can be considered a first step for the development of WSDs in West Africa. It investigated the potential use of IoT-based smart WSD system called SWUCOM for water conservation in showers of Niamey hotel guest rooms. WSDs are well-known as examples of ESTs used for good water management and wastewater reduction in domestic, agricultural, and industrial sectors. This work proposed to evaluate the efficiency of the SWUCOM when it’s implemented in Niamey hotels. Therefore, this work confirms that the developed SWUCOM efficiently contributes to significant water conservation in Niamey hotels based on some assumptions made. Indeed, the main findings of this research are:

- The estimated daily average amount of shower water (L) per guest in all Niamey hotels is DAASWPGNH = 92.07L.
- A proposition of some water use efficiency requirements to reduce shower water waste in Niamey hotels was done. These efficiency requirements are:
- Limiting the daily amount of shower water per guest to 50L in hotels in Niamey, but with the possibility of exceeding this limit.
- Using a flow meter with a maximum flow rate of 10L/min instead of the flow meter used in Niamey hotel showers, which offer a flow rate of up to 18L/min (Source: a survey conducted in Niamey hotels).
- Giving an alert to the user when 3L of water remains in the daily shower water consumption limit.
- Recording the duration and the amount of shower water each guest takes. This will allow each hotel to have full control over the shower water consumption of their guests.
- The SWUCOM efficiently contributes to significant water conservation in Niamey. When implemented, about 45,70% of consumed shower water could be saved in Niamey hotels.

However, apart from hotel showers, the SWUCOM could be installed in all places where water is used in a non-moderate way such as university campuses, residences, and even in the domestic sector to check who among family members are those who waste too much water. In addition, this work is envisaging the potential use of the SWUCOM to the measurement and control of water distribution for water management and distribution companies, in irrigated agriculture for more water conservation. Therefore, the employment of the SWUCOM in Niger and other west

African countries will significantly contribute to reach the target of smart cities and sustainable development in these countries.

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