An Internet of Things Solution for Sustainable Domestic Water Consumption

Ankur Ravindra Bodhe
Department of Electronics and Instrumentation Engineering
R.V. College of Engineering
Bangalore, Karnataka-560059
Email: ankur_bodhe@yahoo.co.in

Rahul Singh
Department of Information Science and Engineering
R.V. College of Engineering
Bangalore, Karnataka-560059
Email: rahulsingh95@hotmail.com

Abhishek Bawa
Department of Information Science and Engineering
R.V. College of Engineering
Bangalore, Karnataka-560059
Email: bawaabhishek@gmail.com

***Abstract*—The Internet of Things (IoT) enables an explicit interconnection between various devices and digital services, and such technology can be further exploited to benefit society as well as municipal authorities. This paper proposes a smart architecture (named Salle de B(r)ains) developed with an inspiration to curb water wastage and to sustain the availability of water for domestic use. In the preceding lustrum, the quantum of water has significantly subsided, and more number of droughts have been recorded due to water scarcity. Spreading awareness about water usage among individuals is imperative in order to successfully tackle this issue and manage water distribution. One major area within households where water is wasted is in bathrooms and hence, although applicable at any location of water consumption, the proposed prototype focuses on domestic water consumption in bathrooms. The prototype utilizes concepts such as Wi-Fi communication, web-app development, Cloud storage and data analytics in order to accomplish its objective of mitigating water wastage, and educating users about their water consumption. An added feature of humidity control helps maintain a sanitary bathroom environment.**

***Index Terms*—Internet of Things (IoT), Sensors, ESP8266, Wi-Fi, MySQL, Cloud, Data analytics, ESP8266, Smart bathroom, Statistical Analysis, Smart Technology, Web-app development**

I. Introduction

The advent of industrialization, urbanization and development in cities as well as suburban areas has provoked a significant impact on the environment, which has led to disastrous consequences. One among such consequences is the depletion of natural resources. Water is a quintessential resource in any region, due to its ubiquitous need. Leaky faucets, extended tub baths, and lavish usage have escalated the amounts of water wasted in bathrooms. Ingenious yet simple solutions with the effective use of technology and resources to conserve water would benefit society. With the significant scarcity of water, it has been important for citizens to be frugal in utilizing water. It is essential to realize that the quantity of water consumed in most Indian cities is not determined by the demand but the supply [1]. This paper addresses a way of regulating water supply based on suggestions made to authorities and monitoring organizations, in accordance with cumulative data acquisition.

The word smart is used to describe everything from cell phones to homes, which feature more communication and interactivity between the user and the product. If the current situation with respect to negligent water wastage is to be ameliorated, then it is important to make bathrooms smart as well. Some household activities, like washing clothes, bathing, flushing, and washing dishes and utensils are the most water consuming activities [1]. It might seem trivial, but cumulatively, a notable amount of water is being wasted in bathrooms. Several times there is wastage of water due to over spilling. Most people are ignorant of their lavish usage of water. Toilet flushing is the single highest use of water in the average home, so it also presents a prime opportunity for water conservation.

The water monitoring system focuses on certain aspects of a Smart Bathroom and aims to mitigate water shortage problems faced by people. It intends to educate the user about his/her water usage and thereby make suggestions to effectively reduce water consumption, besides tracking and generating statistics and graphical data analysis. In a world where we envision every device to be connected to the internet and to each other, it is only fitting to envision a solution that involves the creation of an interconnected system. This paper establishes a network of interconnected devices ranging from sensors to routers and the online database. A centralized monitoring facility is responsible for data acquisition and data analysis. It promotes the sustainable use of water [8] and helps diagnose faults at an early stage by providing an interactive suggestive system based on the statistics accumulated.

A. Water Usage Analysis

Technological developments have provided for desalination techniques that could help purify water from the oceans and render it potable. As far as India is concerned, current desalination techniques are economically not feasible to keep up to the demand of usable water for human activities. Hence this leaves the country to utilize groundwater and water supplied from the rivers and freshwater lakes.

With the rapid growth of urbanization in India and nearly 40% of India expected to be urbanized by 2030 [2], analysis of water supply and usage scenario in cities of India is very

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important and significant. Currently, the urban population of India has 70.1% of its dependency on municipal water, 21% on tube wells/bore wells, and 6.7% on open wells and the rest on other sources such as procuring water via tanks through private suppliers. At an Urban level, water is used for a plethora of activities ranging from domestic purposes to small scale businesses and commercial activities. According to the

Table 1: Activity-wise Distribution of Water Consumption in Cities

(Per Cent of Total Consumption by Households/Day)

Activity	All 7 Cities	Delhi	Mumbai	Kol-kata	Hydera-bad	Kanpur	Ahmeda-bad	Madu-rai
Bathing	28.2	31.7	23.7	37.1	25.6	29.1	22.8	26.6
Washing clothes	18.6	14.2	24.3	14.0	20.9	16.3	21.4	18.9
Drinking	4.2	5.0	4.2	2.6	4.3	3.8	4.9	4.9
Cooking	3.0	3.7	1.7	2.3	3.1	3.2	3.3	4.2
Toilets	20.0	16.5	21.6	15.9	24.1	20.1	19.1	25.7
Cleaning house	7.3	7.0	6.6	11.7	3.5	5.7	12.4	1.9
Washing utensils	16.3	16.5	17.4	16.1	16.5	15.4	15.2	16.1
Others	2.4	5.6	0.5	0.3	2.0	6.3	0.9	1.7
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Bureau of Indian Standards (BIS), the minimum amount of water to be supplied in urban areas for domestic consumption should be 200 lpcd (liters per capita per day). Regardless of the standards set by BIS, every municipal corporation has set its own standard for the minimum water to be supplied. The Mumbai municipal corporation recommends 135 lpcd as the minimum water consumption required, while the Delhi municipal corporation recommends 225 lpcd [6]. Irrespective of different recommendations from different municipal corporations in the cities, it is important to keep note that water in urban areas is supplied based on the availability and not on the demand of water. Table 1 [6] illustrates the water consumption for household activities collected from different cities. In this regard, it has been found out that, of all the domestic activities, water consumption in the bathroom for bathing accounts for about 28% of the total consumption. Cumulatively, water consumption in the bathroom accounts to approximately 48% of the total water consumption in a household.

Surface water from inland rivers and basins proves to be an important and significant source for municipal water for the cities. Considering the demand for water, the water consumption trends in the cities, and the different standards set by the municipal boards, around 85% of the households in the cities face acute water shortage during summer [4]. One of the methods of ensuring sustained water supply to urban crowd is to modulate the water consumption by the citizens. This ensures that during low availability from the main sources of water to the municipal supply, it would ensure that the population is not caught off guard when there is low supply and hence a cutoff from water supply during scarcity would not occur.

II. Proposed Framework

For the proposed solution to work as intended, it must be supported by a sophisticated and robust architectural model to facilitate smooth communication across devices and routers within the network. Figure 1 is a graphic depiction of the architectural framework of the communication network. Firstly, the consumption data is curated from the devices installed at the user end to the Cloud in the form of CSV files, from which meaningful data is drawn [7].

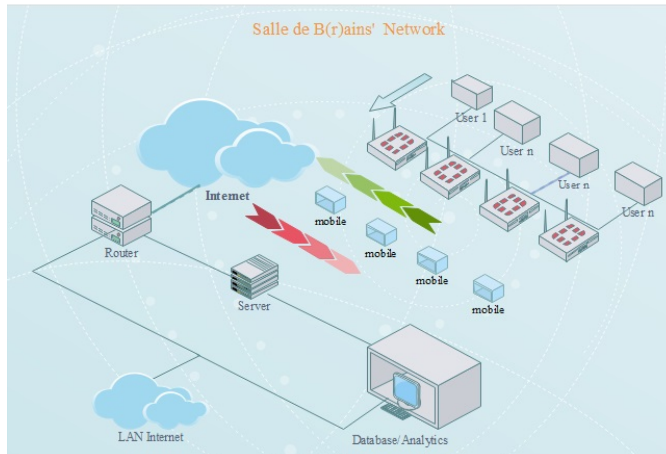

Fig. 1. Network Framework Overview

Although several options exist for communication and data transfer, elementary and globally accepted protocols and standards, which suit the application and its simplicity of design have been used. All established communication utilizes the TCP/IP protocol suite, and data transfer and data reception is conducted using Wi-Fi, predominantly. At the user end, the sensors installed in the bathroom are connected to an Arduino UNO via the appropriate circuitry. The dynamically generated data transmitted by the sensors to the Arduino is communicated using an ESP8266 Wi-Fi module which is connected to the Arduino board. This data is transmitted using the user's Wi-Fi router to the Database/Analytics set-up, using the internet, as shown in the figure.

A Cloud server is deployed in order to efficiently store large amounts of dynamic data which is accumulated from several houses. The data decipherment, inspection, results generation and analysis phases are conducted within a local area network, and the necessary data is wired back to the respective user's devices through the Internet via the router at this end. Thus, a cycle of data communication is developed between the end users and the system, which is entirely wireless.

A. Sensors

For a smart IoT based solution for water analysis, it is important to consider the method and process that is used to quantify and measure the parameter being analyzed. The parameters being measured are:

i. Water Flow rate

ii. Water level

iii. Humidity

1) Water flow-rate sensing to analyze water consumption: To measure the water consumption we measure the flow of water using a flow meter that measure the rate of outflow of water. There is a cornucopia of techniques to measure the flow. Some of the common sensors used for measurement of flow are Inductive flow sensors, thermal mass flow sensors, gravity based flow sensors, turbine based and Hall Effect flow sensors. Of the various types of flow sensors available, the Hall Effect flow sensor YF-S401 is used. The Hall Effect water flow sensor is a low cost, easy to install sensor with a high sealing performance and provides stable readings.

The sensor consists of a plastic valve with a rotor that provides Hall Effect sensing whenever water flows through the sensor. As the water flows through the sensor, the magnetic rotor spins at a rate proportional to the flow of the water through the sensor. The rotor provides for the magnetic field to the Hall Effect sensor and a series of voltage pulses are generated whose frequency is proportional to the flow rate [5].

This frequency of voltage pulses is read by the micro-controller and the liquid flow data is calculated.

2) Water level detection and over-spill warning: The water level is an important parameter to be measured which would help identify an event of water overflowing in the bathroom. To raise an alarm or to provide an indication whenever water overflows in any container of any volume in the bathroom (tub, bucket, etc.), two parameters must be analyzed:

a. Water flow-rate

b. Water level

In an event of over spilling, the water level remains constant while the tap is still open. If the water level remains constant and the water flow-rate from the tap is a non-zero value, an event of over spilling has occurred. Along with the flow sensor that is used, an ultrasonic distance sensor is used to measure the level of water. The ultrasonic distance sensor used for experimentation and prototyping is the HCSR04.

Water overflow detection is established by using a combination of data acquired from the flow sensor and the level sensor. Table 2 describes the logic used to detect an event of water spilling out of a bucket or a tub.

For example, when the truth value for water level is LOW(constant) and water flow is HIGH(non-zero), this means that the water tub is overflowing with water, and hence a timer starts at this point and the exact amount of water wasted is calculated based on the rate of flow intimated by the flow sensor and the duration. This value can be estimated from the following equation:

$$\omega = \Sigma(\rho * T) \tag{1}$$

where ρ is the flow rate in litres/minute and T is the time in minutes, ω is the quantity of water wasted.

The ultrasonic distance sensor works on the principle of time of flight ranging. It consists of a transmitter and a receiver. With an initial 10 μs trigger pulse, the transmitter sends a series of short pulses. A pulse reflected of the water surface is detected by the receiver and the time taken to receive the pulse is noted down. The duration of the pulse from the time it is sent is noted down and the distance is proportional to this time of flight.

Table 2: Water Level Monitoring

LEVEL	FLOW	INFERENCE	RESULT
LOW(COSTANT)	LOW (ZERO)	FLOW IS ZERO, HENCE NO OVERFLOW	NO WASTAGE
LOW(COSTANT)	HIGH (NON-ZERO)	WATER OVERFLOWING	WATER OVERFLOWING
HIGH(CHANGING)	LOW (ZERO)	WATER TUB EMPTYING, NO OVERFLOW	NO WASTAGE
HIGH(CHANGING)	HIGH (NON-ZERO)	WATER TUB FILLING, NO OVERFLOW	NO WASTAGE

Fig. 2. Ultrasonic Sensor Attachment

3) Humidity sensing: Another important parameter to be controlled is the humidity of the bathroom. Higher humidity content involves increased dampness in the bathroom which inevitably poses health hazards due to increased microbial growth and leads to respiratory illnesses with symptoms ranging from sneezing and difficult breathing, to chronic coughs and migraines [3].

In order to cater to this problem, a humidity sensor is placed in the bathroom that would help monitor the humidity levels and control an exhaust fan by turning it on if the humidity levels are beyond the permissible limits. Table 3 explains the functionality of the set-up as integrated within the bathroom. The process ensures that the humidity level is maintained below the specified percentage of humidity, which in this case is 55%.

The humidity sensor used is the DHT11 which provides temperature as well as the relative humidity. The DHT 11 measures the relative humidity by measuring the electrical resistance between the two electrodes. The DHT11 uses either a salt or a conductive plastic polymer as the humidity sensing substrate with the electrodes applied to the surface of the

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substrate. Whenever water vapor comes in contact with the substrate, the ions are released by the substrate, thus increasing the conductivity between the electrodes. The change in resistance between the electrodes is proportional to the relative humidity. The DHT11 converts the resistance measurement to relative humidity using an IC that is mounted on the sensor. The IC also stores the calibration coefficients and controls the data signal transmission between the sensor and the micro-controller [5].

Table 3: Humidity Monitoring

HUMIDITY	EXHAUST FAN	INFERENCE	NEXT STATE
LOW(LESS THAN 55%)	LOW (OFF)	HUMIDITY-PERMISSIBLE	EXHAUST FAN REMAINS OFF
LOW(LESS THAN 55%)	HIGH (ON)	HUMIDITY-PERMISSIBLE	EXHAUST FAN TURNS OFF
HIGH(GREATER THAN 55%)	LOW (OFF)	HUMIDITY-NOT PERMISSIBLE	EXHAUST FAN TURNED ON
HIGH(GREATER THAN 55%)	HIGH (ON)	HUMIDITY-NOT PERMISSIBLE	EXHAUST FAN REMAINS ON

B. Circuit Architecture

The sensors described in the previous section have been integrated for data acquisition and data transmission. The connections established to the micro-controller are depicted in Figure 3. The ESP8266 Wi-Fi module uses the Wi-Fi protocol for data communication.

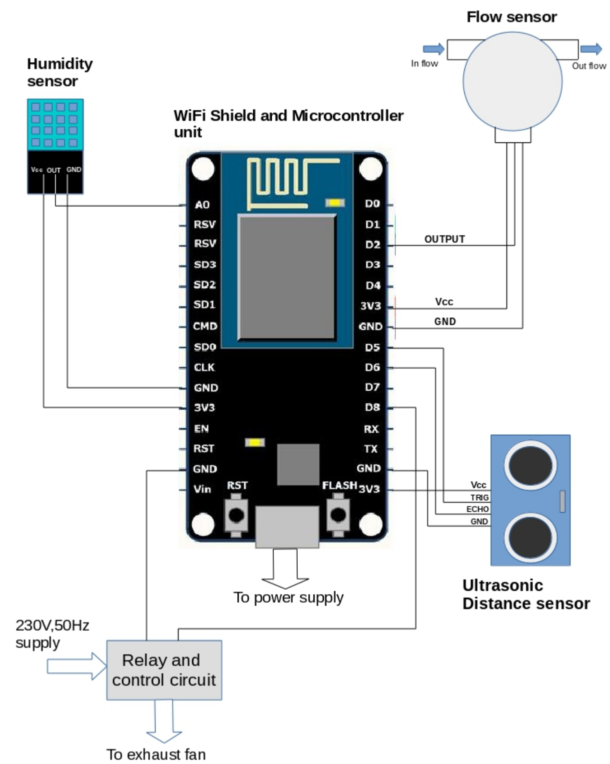

Fig. 3. Circuit diagram

III. Operation

The prototype essentially analyzes the water consumption pattern in the bathroom, and sends the data to the back-end system via the Internet. Analysis of the water consumption patterns is conducted at the database in the back-end. Based on the quantity of water available in the primary source of supply (such as reservoirs), whose data is provided by the government agency, an ideal water consumption value is calculated. A report is generated and delivered wirelessly to the user-end by means of a web application viewable on the users mobile.

The web application acts as a means to view dynamically generated reports on the daily water consumption of its respective users. It provides customized suggestions for sustainable water usage.

A. The Back-end System

The back-end consists of a database that contains the water consumption in the bathroom for each of the households where the device is installed. The system essentially computes an ideal water consumption value for each household based on certain parameters and procedures as mentioned below. To begin with, data of water consumption per day is collected from each individual device and tabulated. The water consumption per day pattern is analyzed and an average consumption value is found out.

$$average = (\Sigma(consumption))/N \quad (2)$$

where N is the number of households the device is installed in. The database also then notes the demand of water from a particular area which is calculated by summing up the individual water consumption values for each household. The algorithm running on the database assumes that the amount of water required for the subsequent days would be equal to the amount of water consumed in the preceding days. The database also acquires data from the reservoirs provided by the government agencies. The Reservoir levels for the supply to Bangalore city are provided by the Karnataka State Disaster management board on a daily basis. Water supply boards generally supply water as per the demand in an area, unless there is a shortage where the supply cannot meet the demands. The government agency would provide another piece of information that notes the amount of time the water in the reservoir should be sustained for. The period of time the water in the reservoir should be sustained for varies based on the climatic conditions and the forecasts of the meteorological agency. By noting down the period of time the water should be available in the reservoir, the amount of water to be consumed is found out.

$$amount(perday) = \frac{Q}{T} \qquad (3)$$

Here Q is the quantity of water available in the reservoir and T is the number of days for which water can be sustained. This amount of water to be consumed per day is then used to indicate the amount of water the household must consume. The web page provides a graph showing the water consumption for the day and the ideal water consumption value or the should be consumption value. Also, suggestions are displayed accordingly. The operations in the database can be summarized with the flow diagram as shown in Figure 4.

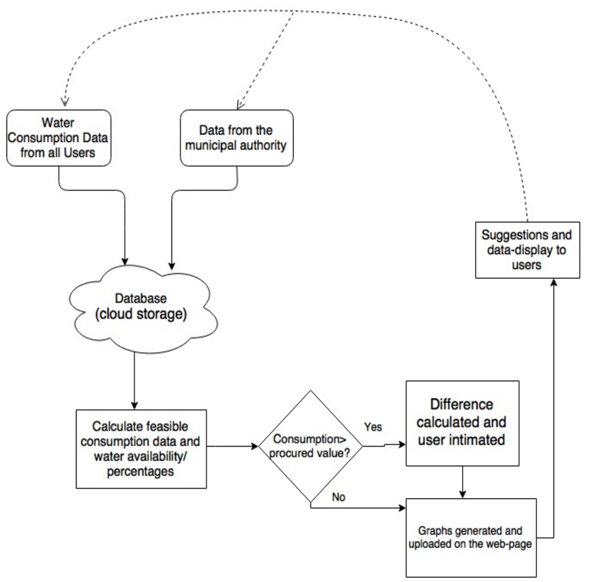

Fig. 4. Flow diagram of operation

The data is stored in a MySQL database, developed using phpMyAdmin in order to provide a GUI for users to interpret the raw data in a graphical form.

B. Front-end

The web-application is designed to be an online portal for informing the user about his/her water consumption pattern over a period of time. Post login, the user is directed to the landing page (which is their dashboard) as seen in Figure 5(b). As depicted in Figure 5, it contains 2 graphs, one is a pie chart which indicates the water usage based on area of use, and the second graph indicates an hourly water usage analysis. The web portal consist of 3 tabs: one tab consists of information about the proposed solution, as shown in Figure 5(c), the second displays a table that indicates the water usage by a particular user over the requested period of time and the third tab contains a suggestion page which is used to suggest to the user as to which area of the washroom the water usage can be minimized or controlled, as show in Figure 5(d). The web-app is view-able on any mobile device capable of connecting to the Internet.

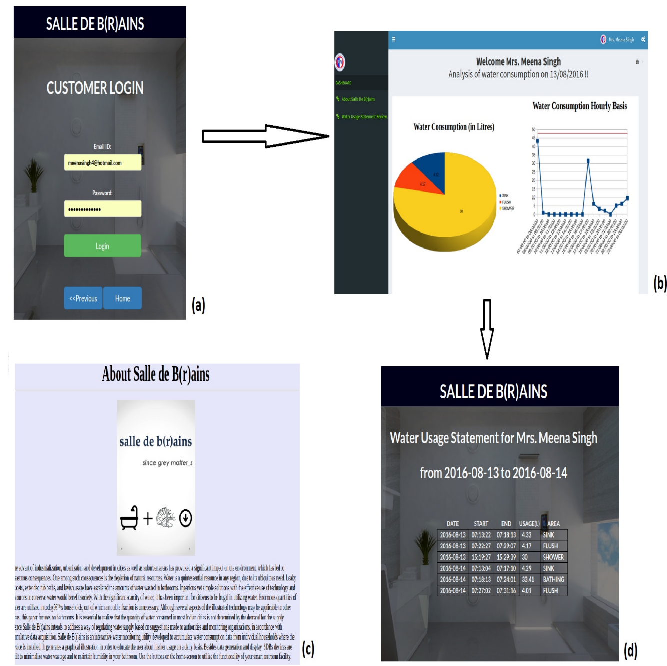

Fig. 5. Web-Application

IV. Case Study

The prototype developed, has been tested in-order to assess and analyze the effectiveness of the system. The procedure adopted for experimentation involved independently testing the device in three households for a period four days. The experimentation involved collecting data from the showers and taps of bathrooms and testing the effectiveness of the device. Figure 7 illustrates the experimental set-up in House 1.

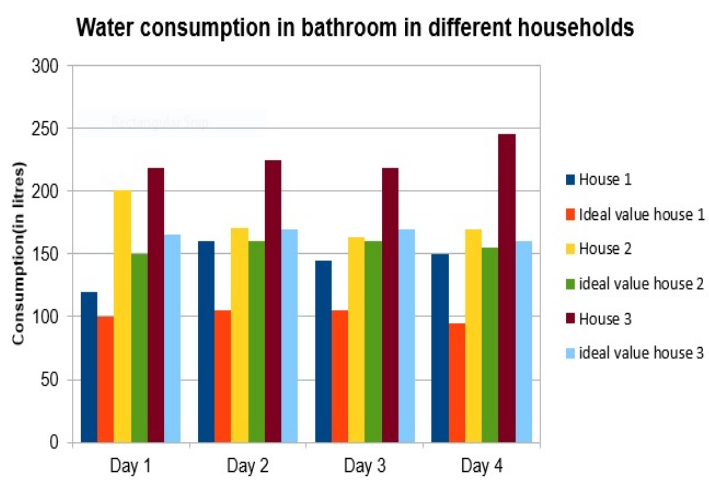

Fig. 6.

The graph shown in the figure provides the water consumption patterns in each household and the web application is used to provide the usage pattern to the user and also provide a recommended water consumption data point based on the data generated by the database. Figure 5(b) shows the data analysis pattern for House 1 where the pie chart indicates the sections where the water is consumed such as shower, sink and flush. The line graph indicates the consumption patterns over the whole day. These graphs give a clear indication of where water can be used judiciously and also indicates the areas where there is excessive consumption. This report was generated daily. On conduction of the experiment, a graph of daily water consumption values for three households for a period of four days has been recorded and is shown in figure 6. The graph shown in figure 6 provides the water consumption for the three households with the corresponding ideal water consumption value for each household. It has been found that one out of the three households have improved their water consumption by adhering to the recommended water consumption levels provided by the system. We estimate that with more number of devices installed in the households and if these households adhere to the ideal water consumption values and suggestions displayed by the web application, there could be a significant reduction in demand of water and this in-turn would help reduce interruptions in water supply over time.

Fig. 7. Arrangement of the sensors in the bathroom

V. Conclusion

The exponential growth rate of population in urban areas and increasing scarcity of water has made it obligatory to find effective measure to utilize water in an efficient way and ensure that day to day activities are not hampered. With the vast growth and development of the IoT, using smart devices that are connected to each other could be an efficient and powerful technology that can be used to ensure frugal usage of water.

In this paper, a smart bathroom IoT solution for sustainable water consumption in bathrooms has been proposed and prototyped, that helps modulate the amount of water used in households. Along with analyzing water usage patterns, to ensure hygiene and sanity, a humidity control mechanism has also been implemented to ensure that the bathroom has low dampness levels and to prevent microbial growth in the bathroom.

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