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Design and Development of Automated Faucet Valve Regulating Mechanism

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Abstract

As the population in our world is increasing alarmingly there arise numerous problems pertaining to the survival of human beings. One major problem being water scarcity. The main reason behind this being increased demand for limited availability. Hence it's high time that we do some sort of water saving techniques. Most of the people use shower, and some use bathtubs for bathing. If using a shower then most of the time we must have felt the difficulty in getting the desired quality i.e. the required temperature of water. We have to manually mix both the incoming hot and cold waters for getting warm water conditions. In other words, hot and cold water flow valves need to be operated manually. This newly devised mechanism aims at automating the process of delivering water at the user's choice of temperature with affordable cost. Both the faucet valves are coupled to stepper motors which in turn is controlled by a microcontroller wherein provision is made for the user to set desired shower water temperature. This also takes into account in reducing the wastages in water consumption and power usage which else might occur otherwise during bathing process. It is a green technology which can be installed with all domestic water heaters and will fetch users the benefits of efficient water usage, energy and cost savings and increased comfort. We find many emerging trends like Tankless Water Heaters, Hands Free Faucets, etc which will provide you the best of bathing, but here arises the concept of high operating cost, high power ratings, and complex functioning, etc.

Keywords: Water scarcity, Shower, Faucet, Stepper motors, microcontroller.

Introduction

Water covers 71% of the Earth's surface [1]. It is vital for all known forms of life. Approximately one billion people still lack access to safe water and over 2.5 billion lack access to adequate sanitation [2]. Some observers have estimated that by 2025 more than half of the world population will be facing water-based vulnerability [3]. A report, issued in November 2009, suggests that by 2030, in some developing regions of the world, water demand will exceed supply by 50% [4].India is facing a problem of natural resource scarcity, especially of water in view of population growth and economic development. Due to growth of Population, advancement in agriculture, urbanization and industrialization has made surface water pollution a great problem and decreased the availability of drinking water. Many parts of the world face such a scarcity of water [5]. As Bangalore's population and area grows, more and more people are sharing the same water resources. As a result, conserving water is becoming increasingly important. The remarkable increase in population resulted in a considerable consumption of the water reserves worldwide [6]. Bangalore city faces growing gap between demand and supply of water due to limited availability of surface water [7].This paper presents an attempt to solve water scarcity problem in a way not to find means to increase the supply but to control the supply and utilization of the same in an effective manner.

Bangalore water supply and sewerage board

The Bangalore Water Supply and Sewerage Board (BWSSB) is the premier governmental agency responsible for sewage disposal and water supply to the Indian city of Bangalore. The projected demand for water supply by the year 2025 and in- creasing gap between supply and demand is portrayed in **Table 1** [7] and **Figure 1** [7].Hence we can conclude that as time passes there will increased demand for limited supply of water. So there arises a need to conserve the at present surviving water resources and

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steps to be undertaken to reduce water wastages. Many people are of the opinion that this water scarcity problem can be solved only by increased supply but here we like to highlight on the fact that the problem can be eliminated by using the at present available water efficiently.

Table 1. Water supply and demand in Bangalore city. [7]

Sl No	Description	Year				
		1991	2001	2007	2011	2025
1	Population (Millions)	4.08	5.80	6.52	7.34	9.70
2	Available Water (MLD)*	372	647	923	1459	1800
3	Water Demand (MLD)**	924	1433	1464	1575	2314
4	Supply and Demand Gap	552	786	541	116	514

*Projections are subject to availability of water from River Arkavathi; **Subject to 20 per cent of UFW up to 2010 and 15 per cent from 2011 onwards.

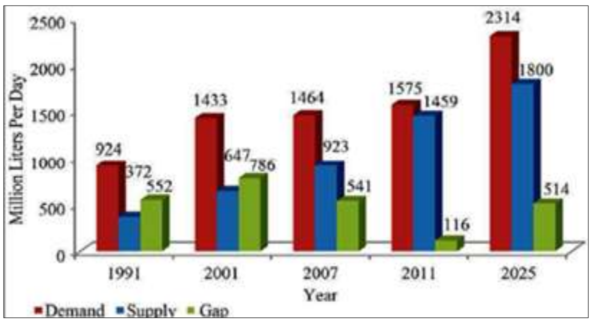

Figure 1. Demand & supply gap of water supply in Bangalore city.[7]

Research Methodology

Water is used for variety of domestic and industrial applications. In particular, domestic applications include bathing, cleaning, food processing, sanitation, gardening, etc. For bathing various methods such as bath tubs, using showers, and most common by collecting water in a container are adopted. Of these various techniques, bath tubs have a disadvantage of using more water while bathing. If you analyze the technique of collecting water in a container and having bath ,here according to the survey conducted by us in Bangalore, majority have a feeling of reduced level of comfort as they will have to collect the water in a mug and pour on their bodies manually. Even though it uses less water when compared to the water which is utilized while having bath by using shower and tubs. Also geysers are found to be used predominantly for delivering water at high temperatures. Heating of water needs lots of energy [8]. Water heating costs within households are the second largest energy cost on the electricity bill, with space heating taking up the biggest part [9]. The heating of domestic hot water is an important component of energy consumption in the residential sector in many countries. The energy consumed in the residential sector in the USA, for example, is second only to space heating in the residential sector. [10]. According to the survey conducted by us, water is heated using geysers for bathing needs in majority of the houses in Bangalore. Since its cost is less when compared to solar water heaters and also the replacement cost for using tankless water heaters is high. We have undertaken an operational research on this issue based on data in hand and arrived at a conclusion that while using common water heaters along with the showers the uncomfortability is because of the following reason.

To get the desired temperature of water from shower which is using common water heaters it is difficult because the water in the heater is getting heated continuously and if you are using shower to get desired temperature of water, user has to operate the valves (both hot and cold) repeatedly to get the desired temperature of water from the shower. Also the domestic geysers have no provision to regularly change the preset temperature limit up to which the water will be heated. So the user feels uncomfortable because of this manual operation, regularly. This project aims at utilizing water in an effective way with an objective to meet the demand without actually increasing the supply. Going back to history we have seen many technologies starting from showers, faucets and the recent trends like instant water heaters, thermostatic valves, hands free faucets which are aimed at providing the best of bathing. Whatever may be the case the availability of water is of major concern.

Objectives

After doing a thorough research on the above problem we have come up with a technique which can eradicate this problem taking cost, water savings and comfort level into consideration. To eradicate the above problem you can even change the present geysers with the latest available techniques such as tankless water heaters as such. But the cost of replacement is very high. You can also upgrade the system by using solar water heaters but it is not possible for everyone to afford such techniques since the cost would be high. So we have come up with a technique to upgrade the at present available systems taking cost, reduction of water wastage, comfort into consideration which according to our survey has

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higher value when compared to the above discussed alternative techniques. The main principle of operation of this newly designed system is to automate the process of water mixing phenomenon at the faucet alongside providing an added advantage of setting user desired water temperature and deliver the same. This system which constitutes basic components can be installed with most of existing domestic water heaters and faucets. The main objective is to minimize the wastages of water and power consumption. As per the experimental observations implementation of this system could save around 7 litre of water for a person during bathing. So if this technique is implemented all around Bangalore it could bring appreciable reduction in the gap between the demand and supply of water which is presently existing, the level of comfort will be increased, there will also be minimized wastages in the water and energy consumption accompanied with less installation cost.

Design and Development Process

Here the first step is to define the problem statement. The procedure involves determining the requirements of system, operational parameters and variables, and further design modifications if required .The following is an overview of the same:

- The system should be simple in operation, cheap and cater easy installation.
- It should be stable in operation under all circumstances.
- It should avoid the occurrence of accidents relating to skin burns, etc due to high water temperature coming in contact with human body.
- It should also facilitate manual mode of operation and not cater to undesired water let-offs.
- It should be eco-friendly.

The design of system was formulated in such a way taking into consideration system effectiveness, cost, and safety .The experimental set up of Automated Regulating Mechanism is shown below:

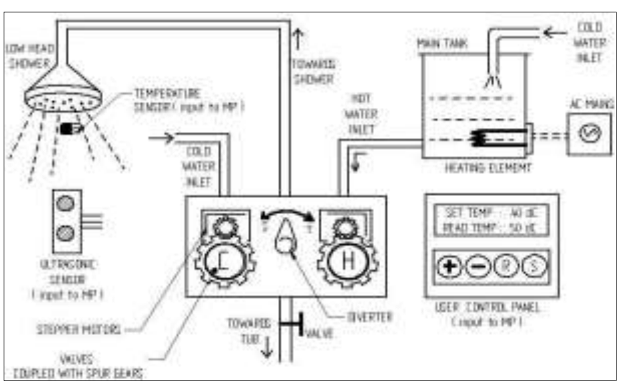

Figure 2. Experimental model of Automated Valve Regulating Mechanism

Nomenclature: (Referring to Figure 2)

- MP: 8051 Microcontroller.
- Faucet Valves:
  - C: Valve which controls Cold water flow.
  - H: Valve which controls Hot water flow.
- Diverter operational mode:
  - S: Direct incoming water to Shower alone.
  - T: Direct incoming water to Tub/Bucket alone.
- User Control Panel:
  - +: Increase Set Temperature.
  - -: Decrease Set Temperature.
  - R: Reset the Set Temperature.
  - S: Stop/Halt the system.

Specifications employed

1. Gear Specifications:

Formula

Velocity ratio= no of teeth on driven gear / no of teeth on driving gear=66/36=1.8:1…………… [11]

The minimum force required to rotate the Driven Gear (Valve) can be calculated as follows:

If applied a load of 322.32 grams then only the valve rotates. Hence minimum force required to rotate the valves is: 0.32232 kg=3.16N.Hence the minimum torque required would be 3.16*0.03375 =**0.10665 Nm**=106.65 mNm.Here, 0.03375m is the radius of the valve.

Since the angular displacement of both the mating gears will be same: $\mathbf{S_{driving\ gear} = S_{driven\ gear}}$ i.e., $\mathbf{(R^*\theta)_{driving} = (R^*\theta)_{driven}}$

- R= pitch circle radius (mm)
- θ= angular displacement (deg)

$\theta_{driving\ gear} = 15.24$ deg assumed**

Therefore (17.75 * 15.24) = (32.625* θ)

Hence for **15.24 deg rotation** of driving gear, the driven gear will rotate:

θ = (17.75* 15.24) / 32.625 = **8.3deg**

Since maximum value for $\theta_{driven} = 90$ deg due to valve model constraints, the maximum value for $\theta_{driving} = 165$ deg.

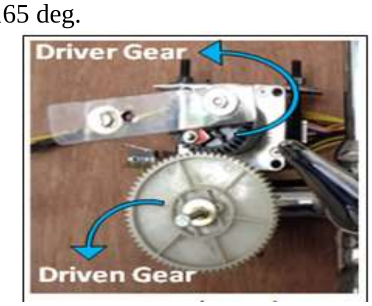

Figure 3. Gears in mesh as designed in the experimental model.

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****Reasons behind Assumption of $\theta_{driving\ gear}$ =15.24 deg:**

Our project aimed at providing the user to set temperatures between 20 deg C to 60 deg C. And we decided to apply changes in valve position for every temperature intervals of 2 deg C .In other words if the difference between the user desired temperature and the shower water temperature is above +/-2 deg C then there will a change in either valve positions. If user desired temperature is T1 and shower water temperature is T2 then, **20 deg C<= (T1 & T2) <= 60 deg C**

We have limited the maximum VALVE rotation from 90 deg to 83 deg because

- Avoid damages in valves due to the force applied from motors.
- Microcontroller program compatibility.

Hence for θ_{driven} to be 83 deg, $\theta_{driving}$=152 deg (maximum values). Here the change in the valve position was desired as **ALTERNATIVE**, which means for a particular temperature combination if Hot water flow valve is set to new angular position by keeping the Cold water flow valve angular position constant then for the next combination the Cold water flow valve will be set to new angular position keeping the other constant then again alteration is done to Hot water flow valve and so on.

2.8051 Microcontroller Port Details:

sfr ldata = 0x90;	PORT-1 FOR LCD DATA
sbit en = P3^4;	PORT-3.4 FOR LCD ENABLE
sbit rs = P3^5;	PORT-3.5 FOR LCD REGISTER SELECTION
sbit A1 = P0^0;	HOT MOTOR COIL A
sbit B1 = P0^1;	HOT MOTOR COIL B
sbit C1 = P0^2;	HOT MOTOR COIL C
sbit D1 = P0^3;	HOT MOTOR COIL D
sbit A2 = P0^4;	COLD MOTOR COIL A
sbit B2 = P0^5;	COLD MOTOR COIL B
sbit C2 = P0^6;	COLD MOTOR COIL C
sbit D2 = P0^7;	COLD MOTOR COIL D
sbit R_S = P2^0;	RUN AND STOP SWITCH
sbit SET = P2^1;	TEMPERATURE SET SWITCH
sbit UP = P2^2;	UP SWITCH
sbit DOWN = P2^3;	DOWN SWITCH
sbit LIM_1 = P2^4;	HOT MOTOR ZERO LIMIT SWITCH
sbit LIM_2 = P2^5;	COLD MOTOR ZERO LIMIT SWITCH
sbit TRIG = P2^6;	TRIGGER FOR ULTRASONIC SENSOR
sbit ECHO = P2^7;	ECHO SIGNAL FROM ULTRA SONIC SENSOR

Table 2. 8051 Microcontroller port details as employed in the experimental model.

Constructional Details:

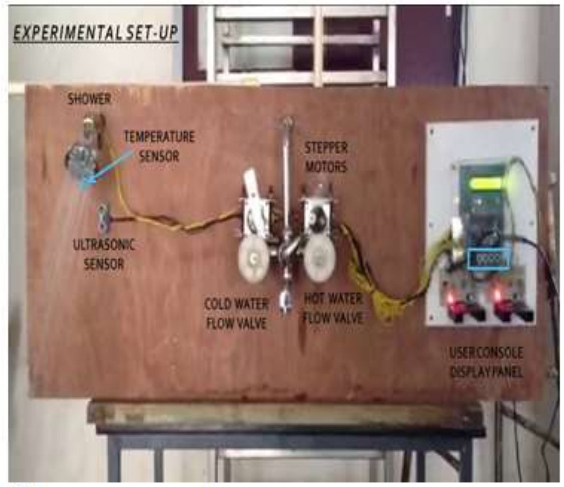

Figure 4. Experimental Set-Up of Automated Faucet Valve Regulating Mechanism

Figure 4 describes the complete set-up of the system. Basic components like Spur gears, stepper motors, sensors and a microcontroller constitute Automated Faucet Valve Regulating Mechanism. Referring to figure 5,The driven gears (white) are attached to the valves by inserting screws after removing off the valve caps. The driver gears (black) are first attached to the motor shaft by suitable coupling .The stepper motors used here is of model 23KM-K343-P1V hybrid type manufactured by MINEBA. Then the motor along with these gears are fixed rigidly onto the valve body using screws to ensure that the both are gears are in mesh without any stress. The meshing of gears is carefully designed for efficient transmission of torque. A rocker arm is attached to each of the driver gears. These serve the function of triggering of a limit switch, which indicates the microcontroller that zero (valve full close position) is reached and no further rotation of the motor is required. It is from this point where the step angles of both the motors are measured. Here another advantage is that users can also manually operate the valves if desired without any difficulty. This model is designed to deliver the required water temperature only at the shower. Hence for the system to work efficiently the faucet diverter should be directed towards the shower. By employing another temperature sensor at the tap side and correspondingly altering the program parameters, water at user required temperature can be delivered at the tap side also. This feature can be included in the proposed design modification.

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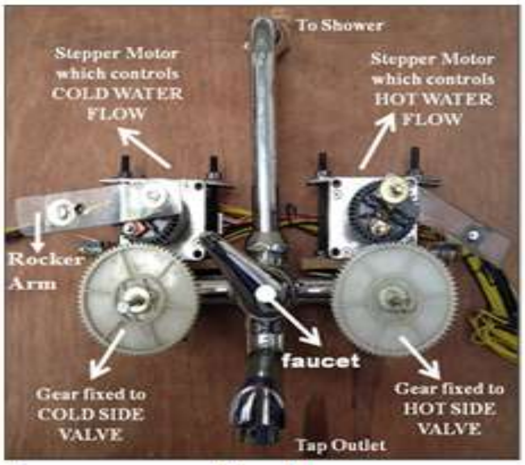

Figure 5. Hot and Cold water flow paths designed for experimental purposes.

A low flow shower head is employed here to trigger an invigorating spray of water. As shown in figure 6 a temperature sensor (T) is attached at the near end of shower outlet which serves as a feedback element providing the temperature of water at the shower to the microcontroller. Throughout the water delivery process drops of water trickle onto the sensor. Just below the shower has been placed an ultrasonic sensor (U).The ultrasonic sensor used here if of model HC SR-04 type manufactured by NSK. This sensor detects the presence of an obstacle (here human) within a specified range. The reason for implementing this is that if the user wants to take some interval between bathing (i.e. for lathering oneself), then the sensor sends a signal to the microcontroller to close both the valves. And if the user is back then the valves are operated upon to establish the water supply again. It also minimizes water wastages which occur during bathing.

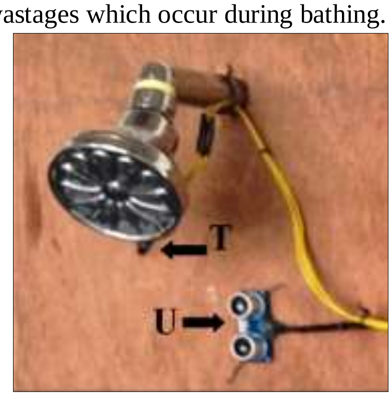

Figure 6. Positioning of Temperature sensor (T) and Ultrasonic Sensor (U)

Step by Step Functioning of System:

Step1: User will switch on geyser for heating water

Step2: User will switch on the microcontroller switch

Step3: Then the user console display will be activated

Step4: The microcontroller awaits user to input his desired temperature

Step5: Once user desired temperature is input then microcontroller will check the presence of user below the shower within a specified range (up to 30 cm).

Step6: If user is present then continue if not then it will not proceed further till user presence is sensed.

Step7: Then the microcontroller will set both the hot and cold valves to 8 deg. This will allow equal amounts of hot and cold waters to mix and get delivered at the shower

Step8: The temperature sensor placed at the shower will sense this initial temperature of water output and this will form the basis for comparison between the user desired temperature and shower water temperature

Step 9: This comparison will decide the changes in the position of either valves based on the truth table and hence the system will try to achieve the temperature of water delivered at the shower as desired by the user.

Step 10: If at any instant the user wants to change the set temp, then RESET button should be pressed.

USER DESIRED TEMPERATURE OF WATER (T_1°C)	TEMPERATURE OF WATER AT SHOWER (T_2°C)	CHANGE IN HOT VALVE POSITION	CHANGE IN COLD VALVE POSITION
T_1°c	Less by high amount	OPEN HOT VALVE	
	Less by moderate amount		CLOSE COLD VALVE
	Less by small amount	OPEN HOT VALVE	
	T_2°c=T_1°c	NO CHANGE	NO CHANGE
	More by small amount	CLOSE HOT VALVE	
	More by moderate amount		OPEN COLD VALVE
	More by high amount	CLOSE HOT VALVE	

Table 3. Consolidated logic of system functioning with respect to different temperature combinations possible in this system.

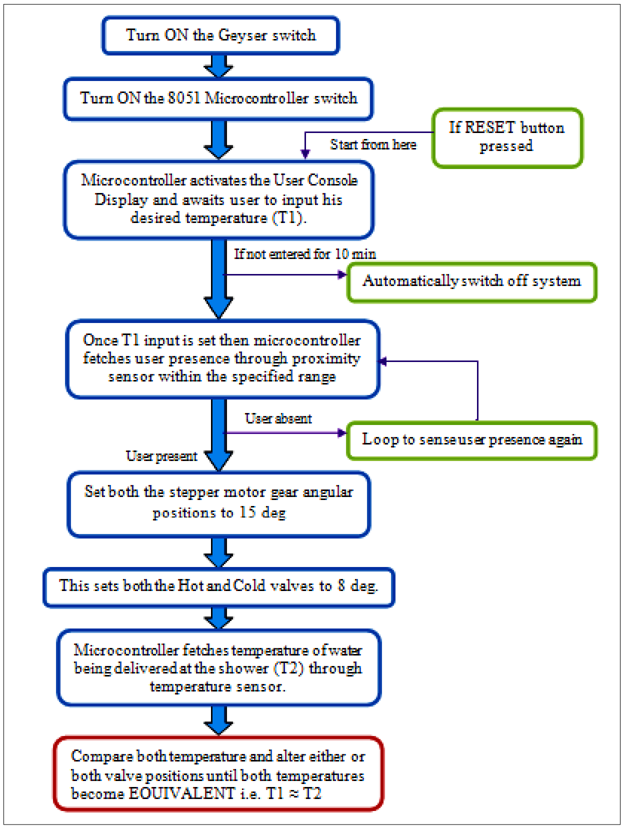

Figure 7. Flow Chart of System functioning

Benefits and Limitations

When compared to tankless water heaters which feature to deliver water at user desired temperature, the cost incurred in installing this automatic valve mixing technology is less than that of purchasing the latter. This new technique aims at minimizing the power consumption and wastages in water which else might occur otherwise. Since the sensors and microcontroller function at nanoseconds level the response time of the system is less. In devising the equipment, focus is been made that there is no compromise made on satisfied availability of water to user. In other words water is used efficiently for the purpose. Due to simple in operation this system can be used by users of all ages. The main advantage relies on the fact that users can directly enter their desired temperature over a wide range.

The prime driving force within us in developing this technique was that if there is at least 1% reduction achieved in water and energy consumption by a single home then if used widely , would definitely emerge as a new hope finding its place in water saving technologies . If produced on a large scale, the overall equipment cost would be <=Rs: 3000/-.

The main parameter which affects the system performance is the flow pressure of water at both the hot and cold inlets. The head losses should be minimized and piping design should be effective for efficient functioning of this system. Precise design and programming is required. Proper insulation is required for electrical components to avoid contact with water leading to electric shock.

Proposed Design Modifications:

At present, the water heater and the microcontroller units are isolated. Hence if both the units are made to function synchronously then the efficiency of the system will increase. The system should also include the function of delivering the required quality of water at the tap, this can be done by incorporating another temperature sensor at the tap and corresponding changes has to be done in the program. Should be used as add-on equipment in solar water heaters which will further reduce the wastages in power and water consumption. These emerging technologies should be provided to the citizens under government subsidized class of products which will lead to increased demand in market.

Power Consumption Savings

If we analyze the residential electricity consumption, it can be noted that a major part would be accounted for water heating application .The same can be observed from Figure8 [12].One of the main objective is achieving savings in power consumption during geyser utilization by lowering the heater thermostat temperature.

Assumptions:

- 150 lit capacity electric water heater
- Ambient water temperature=20 deg C
- Heating element=3 KW
- In Bangalore for 1KWH=Rs .3/- (on an average)

<u>**Case 1**</u>: if T2=70 deg C (thermostat setting)

$Q=150 * 4.19 *(70 – 20) =31425$ kJ

$1KWH=36*10^5$ J

Hence 31425 kJ= 8.729 KWH

Hence a 3KW heating element will consume 8.729 KWH to heat water from 20 to 70 deg C which will cost around Rs: 26.187/-

<u>**Case 2**</u>: if T2=60 deg C

Similarly: Q=6.98 KWH

Cost= Rs.20.95/-

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Hence it is inferred that lowering thermostat temperature would cut down costs incurred for heating water.

Application	kWh/year	(%)
Water heating	4259	36.1
Washing	326	2.8
Cooking	2447	20.7
Space heating	404	3.4
Refrig/ freezer	1829	15.5
Lights	1766	15
Other appliances	766	6.5
Total	11797	100

Figure 8. Residential electricity consumption breakdown [12]

Table 4. Savings in power consumption achieved as a result of lowering thermostat temperature of water heater based on experimental observations.

Thermostat setting (deg C)	Cost incurred for running geyser @ 1 hour in a day	Annual cost (*30days*12 months)	Annual Savings (Rs.)
70	**Rs. 27/-**	**Rs. 9,400/-**	**-**
60	**Rs.21/-**	**Rs.7,500/-**	**Rs.1900/**
50	**Rs.16/-**	**Rs.5,600/-**	**Rs.3800/**

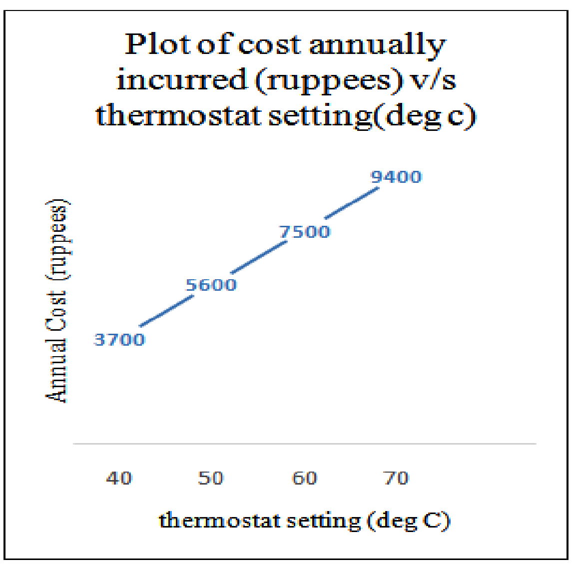

Figure 8. Plot of Annual Cost against thermostat setting. Decrease in thermostat setting would lead to reduced investment on geyser utilization.

Thermo-stat setting (°C)	Standing losses (kWh)/day	Savings (kWh) month	Savings /(R)/ month
65	2.278	7.84	R 3.72
60	2.025	15.69	R 7.43
55	1.772	23.53	R 11.15
50	1.519	31.37	R 14.86
45	1.266	39.22	R 18.58
40	1.012	47.01	R 22.31

Figure 9. Power savings and reduced standby losses achieved by lowering thermostat temperature as compiled from an external research journal [12].

Water Consumption Savings

Since water for the intended purpose (i.e, bathing) is utilized effectively, there is no compromise made on satisfied availability as required by the user. The only aim of this project here is to minimize all the unaccounted wastages in water consumption occurred during bathing process. By experimentation it is calculated that nearly 7 litres of water can be saved while bathing, if this system is implemented.

Table 5. Water consumption savings achieved based on experimental observations

Water consumed for bathing (bath per person per day)			Cost (On an average Per 1000 litres consumption=Rs 6/-) Based on BWSSB Tariffs**			Total cost incurred (Rs) For 1000 persons		
Using Shower (15 min)	Using Tub (15 min)	Using Proposed System (15 min)	Shower	Tub	Proposed System	Shower	Tub	Proposed System
30lt	35lt	23lt	0.18	0.21	0.138	180	210	138

**BWSSB: Bangalore Water Supply & Sewage Board

Hence the above table clearly depicts the difference in quantity of water consumed by using normal shower and by installing the Automated Regulating Mechanism. The above observation proves that if this system is implemented, then it would definitely contribute to reduce the gap between the demand and supply of water to an appreciable extent.

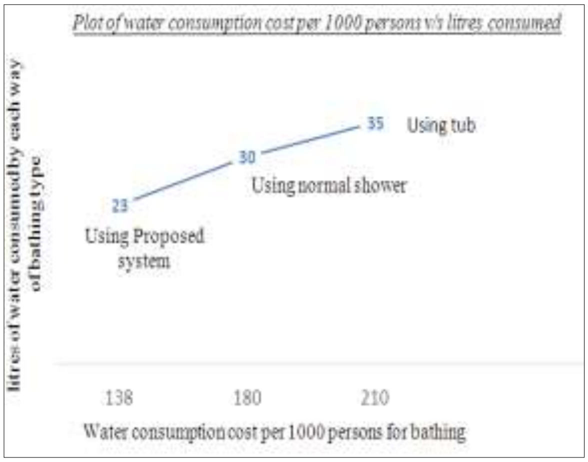

Figure 10. Water consumption savings based on experimental observations

Conclusions

It is clear from the experimentation that reduction in wastages of energy and water can be minimized without causing any reduced comfort for user while bathing if this system is implemented. Wide implementation would be possible only if the system can be purchased and installed with less cost. This can be achieved by mass production, Government initiated subsidy schemes, social awareness etc. This system can also be implemented concurrently with other green energy devices like solar water heaters would contribute to increased savings. The system proves to be reliable because different users can benefit from the same as provision is made to input a wide range of input temperatures. Hence this project directly or indirectly aims to minimize the wastages occurred in energy and power consumption while bathing taking into account that no compromise be made on satisfied availability of water for the user.

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