Prototype for Water Reuse in House Showers: Savings and Economics

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Abstract—The main purpose of this paper is to demonstrate the savings and economics of using an automated watering system within households. The paper will argue about a device capable of optimizing water consumption allowing water reuse. Device will be automated and will use an electric and mechanical system to redirect water to different reservoirs. System will make use of a wide diversity of sensors such as temperature, presence, and volume. Since project is being developed under Mexican investigators, this system is focused in Mexican values. Due to savings made on water bill it is expected to also have a monetary saving, making it a win-win to humans and the environment. It is important to resemble that all calculation within this article were made to solve the Mexican water scarcity problem, particularly in the City of Aguascalientes, but can also be replicated to any location. The city of Aguascalientes has water scarcity problems. Because of this an analysis was made in order to preserve this natural and vital resource as much as possible.

Keywords—domotics, economics, optimization, savings, technological development, water, water consumption, water reduction, water sensors.

I. Introduction

As far as is known water is vital for human and civilization development. Water has been fundamental from ancient times until nowadays. Water use has gone from basic activities such as human consumption and irrigation to industrial activities such as clothing dyeing, and various industrial processes. Water is one of Earth's most valuable resources. Earth's surface is covered by up to 70% of water. From that percentage, only 3% is potable and suitable for human consumption. Such 3% of potable water can be found in rivers, lakes, underground aquifers, and finally glaciers [1].

The following study and project was developed and though for the City of Aguascalientes, which literally might translate to hot springs, located in the geographical centre of Mexico [2]. By 1970, in order to find underground aquifers, it was needed to excavate up to 33 metres and by 2005, excavations grew in depth up to 145 metres [3]. That makes 4.39 times what it was excavated back in 1970. During this time, Aguascalientes' aquifers have suffered due to the increase of population and industrial activities within the State. Both population and industrial growth have grown exponentially [4]. In 1970, there were 338,100 inhabitants in the city; by 2015, there were 1,312,500 inhabitants. That means in a 45-year period there was a population growth of almost a million people, 974,000 inhabitants exactly [5].

II. Related Work

In Aguascalientes, the problem of water scarcity is a sensitive issue. At a preoccupant rate aquifers are being emptied, recovering water is very expensive and takes a long of time to recover to its natural state. In addition to this problem water savings, water reduction and water reuse is a major problem.

Aguascalientes' municipality has launched several social programmes in an attempt to save water and promote its low consumption. Despite these attempts, there are not many people who get involved with them. On the other hand, existing water saving devices are expensive and not many households are capable of affording such devices.

According to recent studies in this field, the way most water is wasted is while bathing or showering. According to Mexico's National Water Commission, CONAGUA for its acronym in Spanish, the time when most water in Mexican society is wasted is during bath time. According to this State dependency, an average shower of 5 minutes is equivalent to 50 litres of water, or 13.21 gallons of water [6].

Due to this excess of wastewater, it is relevant to develop and implement new affordable technologies that might be able to save water and be environmentally responsible. In order to achieve the development of such device it is necessary to implement new technologies such as domotics.

Domotics is defined as the automation of homes. Such automation can go from the lights, HVAC systems (Heat, Venting and Air Conditioning), UPS systems (Uninterrupted Power Systems), and Security Systems, etc. It is necessary to say domotics is related to inmotics, the main difference is that the last one is the term used for building automation [7].

As told before domotics addresses home problems by using automation processes, but truth be told some automation devices are expensive, so there is a need to develop cheaper technologies and components in order to reach more homes and take advantage of its benefits. There is an opportunity

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niche to develop low cost domotic applications with easy installation. However, not only installation but also operation and management will be easy to all age people.

Due to the need of water conservation, it is necessary to address the issue of water saving in households, not only in Aguascalientes but also in areas where water supply is scarce with the use of a device, which uses domotics in order to operate autonomously and accordingly.

III. System Operation

Taking the current problem that preoccupies different governments such as Aguascalientes Government in its scarcity of water and lack of awareness and education on water savings as reference, it is tried to design and implement a low cost prototype in use of automation to recover water from households. This prototype will consist in creating a system that detects when watering can key is opened, passing the water through a pipe which will lead water to different reservoirs where water will be stored.

The idea of this device is to rescue and store non-polluted and grey water with an automated prototype. Grey water is the term used for water, which is not highly contaminated. Such prototype will be able to detect temperature and when shower water is open. Until water reaches a desired temperature, according to user's set off, water will be sent through an alternate pipe to a non-polluted water reservoir until it reaches the desired temperature. This non-polluted water reservoir will be a water tank, which is commonly placed on a house rooftop.

In this first water reservoir water will be collected for future reuse. The entire operation will be fully automated without user intervention. On the other hand, grey water will be stored in a different water reservoir.

When water reaches user's set temperature, user will be notified with an alarm letting user know water is ready to take a shower or bath. After alarm activates, it is expected that user will go inside the shower, so a presence sensor is turned on in order to see if user has gone inside shower.

When sensor detects a person inside the shower, an alternate pipe will redirect water to a grey water reservoir. It is necessary to separate non-polluted water from grey water because of chemicals used in bath products. The water stored in the grey water reservoir will be later used in bathroom flushes. Thus creating a wastewater recycling, at a point where the consumption of this vital liquid also presents great consumptions.

This prototype aims to develop from low cost sensors and a simple installation without compromising quality due to its lower costs. By saving and reusing water will be beneficial in order to recover the initial investment.

The amount of water to be stored in these two water reservoirs will depend in two factors. First factor will depend on temperature. For example, if water temperature is set to a desired temperature value of 30 ºC but the water is 15 ºC more water will be stored in the non-polluted water than if water was 20 ºC. This will happen due to energy required to raise water temperature from an initial temperature to a final temperature, other factors to count will be ambient temperature, and air pressure.

Second factor will be dependent on time wasted by every single user in the shower or how much amount of water a single user uses to bath. Because of the nature of this issue, it is necessary to determine the amount of time wasted inside the shower, the amount of water or a combination of both the water flow in a period of time in litres per second. Having the previous data will allow to calculate the volume of the grey water reservoir.

On the other hand, the grey water reservoir will be calculated based on average consumptions. Due to this, it is necessary to implement security measures. Such measures include the water flow going in and out from this water reservoir.

In order to determine the amount of water going out of this reservoir it must be known the times bathroom are being flushed on a single day on how many litres of water is disposed on a single flush independent on what is being thrown away, urine or muck.

In the case grey water reservoir is up to its capacity, an internal alarm will be activated. At this point, the system will detect the grey water reservoir capacity and if there is water coming from the shower.

For safety and sanitary reasons, it is necessary to install in both reservoirs the water outlet at the bottom of such water reservoirs. The main reason of this action is to avoid stagnation, which might cause several diseases or attract different bugs such as mosquitoes, which are carriers of different viruses such as Zika, among others [8]. The main purpose of this prototype apart from reusing water is to create an awareness culture in population to save water not only in Aguascalientes but also worldwide or where water is fundamental to human development.

IV. Philosophy Control

As told before the system will be an automated prototype. System will have a simple SCADA, which means Supervisory Control and Data Acquisition, in order to allow the user and system communicate easily. SCADA is developed under a DGLUX5® environment for its simplicity, easy communication with peripherals, and wide comprehensive management. Such programme will work according to the logic written below. DGLUX5® is a software based on HTML5 and Drag & Drop management which enables individuals or workgroups to design real-time, data-driven applications without the need of typing a single code line. DGLUX5® allows real time communication, which reduces time and money in project design [9].

In figure 1 (whose nomenclature is described in figure 3) automated system logic is shown and will be explained in the next paragraphs. System will begin asking the user "Would you like to start saving water?" To this question, there are two possible options: "Yes" or "No". Depending on what the user choose the system will activate different tasks.

If the chosen option was "No" system will activate a three-way valve redirecting the total amount of water to sewer system. Even non-polluted water will be redirected to sewer system. If the chosen option was "Yes" the system will work as follows. After the user has answered "Yes" another dialog prompt will be displayed asking for set point temperature in which water is desired in order to take a shower or bath. Water will start to heat up.

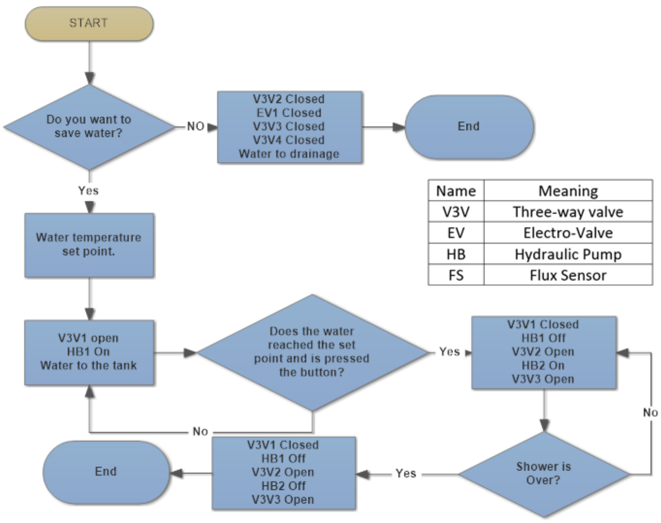

Fig. 1. Automated System Logic. Nomenclature for devices being used is described in figure 3.

Heating process can be in different manners. Water can be heated using conventional boiler based on natural or LP gas or on renewable energies such as Solar Thermal technology. Being Solar Thermal technology the eco-friendliest technology to heat up water [10].

System will be independent on how water is heated, but will be able to send an alert to conventional or electronic systems to start heating water. Alert will not be compatible with Solar Thermal since there is no spark or combustion taking place in this heating process.

Once temperature has been set, the system will use a temperature sensor near the watering can. This temperature sensor will determine if water has reached the desired user's temperature. If water has not reached the desired temperature, water will be redirected using a three-way valve and a small pump to the non-polluted water reservoir commonly located on a house rooftop. In terms of net energy, the amount of water that did not reach the desired temperature apart from being deposited on the non-polluted water reservoir will transfer heat energy to the water stored there in other words water will heat up indirectly.

Water being heated indirectly will be an energy save for future baths or showers since heating systems will need to increase the differential of heat lower than initially expected. For example, let's consider two different masses of water being mixed together into a uniform mix. First mass will be 100 grams of water at 25ºC, second mass will be 75 grams of water at 40 ºC. Specific heat for water is C_p=1 cal / gºC. Applying thermodynamic laws we know the basis of thermal equilibrium [11] where $Q_1=mC_p(T_f-T_i)$ and $Q_2= mC_p(T_i-T_f)$ and $Q_1=Q_2$. Applying those formulae, we get the final temperature of mixture, which will be $T_f = 31.43\ ºC$.

As shown above, just from redirecting heated water to the non-polluted water reservoir, water temperature will be raised in small quantities up to 6 ºC, in large quantities of water it is expected to raise water temperature up to 2.2% of its original temperature. Calculations were made considering 1,000 Kg of water at 22 ºC mixed with 50 Kg at 32 ºC. This calculation is dependent on amount of water mass being mixed and the temperature of both fluids. This raise in water's temperature will originate a small saving in electric energy and fossil fuels if boiler is fuelled by conventional sources.

Once water has been heated up, a light will indicate user temperature has been reached. This light will indicate the user when to enter the shower area. In order to allow water coming out from the watering can, user will push a button. This will allow system to save more water. In order to let water outlet, two conditions must be accomplished: 1.- Water has reached desired temperature. 2.- User is inside the shower area and ready to take a shower or bath. Until both conditions are accomplished, system will continue redirecting water to the non-polluted water reservoir independent of its temperature.

In the prototype to detect when water flow is needed in the shower, there are two possible options, using a push button to indicate system user's presence or use a presence sensor. Presence sensor will be more helpful in order to point system when to stop a water flow. On the other hand, push button will be needed to be pressed again to stop water flow from watering can. Once both conditions are met, water temperature and user presence, water will start to flow. At this point system will redirect water flow to a grey water reservoir –using the three-way valve-. This grey water reservoir will be located under the sink or in other sites depending on available space within the bathroom area. It is important to measure the flux of water either in litres or in kilogram per second in order to determine the minimum volume required for this water reservoir. For example, let's consider an average shower of 6 minutes long. Efficient watering can flow is considered at 6 litres per minute. Conventional watering cans spend from 15 to 25 litres per minute. An average Mexican family is composed of 5 members [12]. Every family member showers daily in a week. The following calculations are necessary in order to determine total water waste.

For a single person:

$$\left(6\frac{litres}{minute}\right)\left(6\frac{minutes}{day}\right) = 36\frac{litres}{day} \quad (1)$$

$$\left(36\frac{litres}{day}\right)\left(7\frac{days}{week}\right) = 252\frac{litres}{week} \quad (2)$$

For the whole family:

$$\left(252\frac{litres}{week,person}\right)(5\ person) = 1260\frac{litres}{week} \quad (3)$$

By the calculations made above it is possible to determine the volume of the grey water reservoir for a single bathroom, in this case 1.26 cubic metres ideally. It's an ideal calculation since watering can is water efficient but not most houses have this technology. It is important to resemble this calculation has only considered the water inlet but not the outlet. On the other hand, let's assume the same Mexican family. A toilet that uses up to 10 lpf, litres per flush, and also an efficient toilet uses up to 4 lpf, not available in most houses. Finally, let's assume every single member of the family uses the toilet 3 times a day.

For a single person:

$$\left(10\,\frac{litres}{flush}\right)\left(3\,\frac{flushes}{day}\right) = 30\,\frac{litres}{day} \quad (4)$$

$$\left(30\,\frac{litres}{day}\right)\left(7\,\frac{days}{week}\right) = 210\,\frac{litres}{week} \quad (5)$$

For the whole family

$$\left(210\,\frac{litres}{week,person}\right)(5\;person) = 1050\,\frac{litres}{week} \quad (6)$$

By the calculation made above it was determined the water outlet from the grey water reservoir. Final calculation is to consider net balance from the water inlet and water outlet. Total water expense was 1,260 litres per week used in shower and stored in the grey water reservoir. Total water reuse was 1,050 litres per week.

$$Net\ Water\ Stored = Water\ Inlet - Water\ Outlet \quad (7)$$

$$Net\ Water\ Stored = 1260 - 1050 = 210\,\frac{litres}{week} \quad (8)$$

By that means, every single week there is a surplus of grey water stored. However, out this calculation it was only counted water use from toilet and shower, but not the faucet. Faucet can also be implemented within the system, but since water to be used is grey water it will not be hygienic or sanitary recommended. There is no need to risk human health just for saving a few litres of water.

On the other hand, taking advantage of the grey water reservoir being stored / placed under the sink it will be possible and easy to reuse water from faucets. Again, let's consider the same Mexican family in which every family member uses the faucet 6 times per day. Average use of faucet is 1 minute. Faucet uses 4.5 litres per minute, lpm.

For a single person

$$\left(4.5\,\frac{litres}{minute}\right)\left(1\,\frac{min}{use}\right)\left(6\,\frac{use}{day}\right) = 27\,\frac{litres}{day} \quad (9)$$

$$\left(27\,\frac{litres}{day}\right)\left(7\,\frac{days}{week}\right) = 189\,\frac{litres}{week} \quad (10)$$

For the whole family

$$\left(189\,\frac{litres}{week,person}\right)(5\;person) = 945\,\frac{litres}{week} \quad (11)$$

As shown above quantity of water used in an efficient watering can, which is 1,260 litres/week, is almost the same as a conventional faucet, 945 litres/week. Because of this, it is necessary to implement efficient systems in all areas where water is used.

It is vital to resemble the importance of a mesh within the grey water reservoir in order to prevent particles from getting into the pipes. Particles to be meshed will be hair and large particles. If there are small and dangerous particles within the grey water it will be recommended not to store that water instead, redirect that water to the sewer system [13].

Considering the water surplus per week there will be a moment where grey water reservoir is to its full capacity. There will be water sensors within the reservoir determining the actual volume of water stored. When grey water reservoir has reached its full capacity, an alert will be sent to the controller. At this moment controller under the system will redirect incoming water to the sewer system until volume from the reservoir is freed. Grey water reservoir logic will work as shown in Fig. 2.

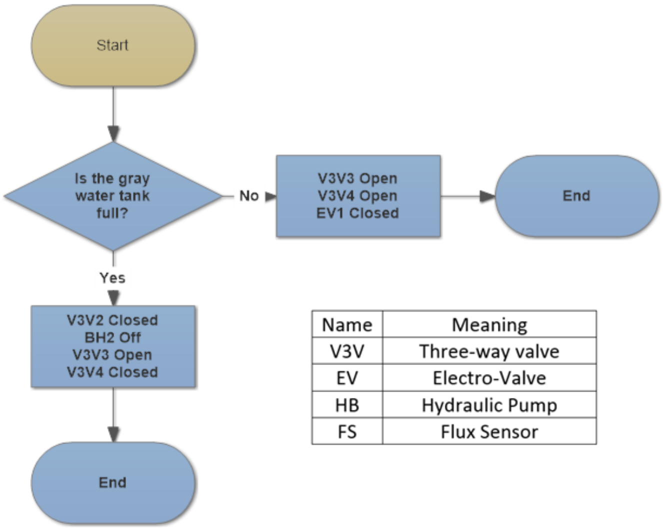

Fig. 2. Grey Water Reservoir Logic. Nomenclature for devices being used is described in figure 3.

Continuing with the process, after there is no presence of a person within the shower a new dialog will appear in screen. Some of the data to be shown in the new dialog is:

1. Time spent on shower.
2. Litres used within such time.
3. The amount of litres of water saved and stored in the grey water reservoir.
4. Graphics showing global average and user's consumption in shower.
5. History graphics of the user showing time and litres spent during the day, week, and month.
6. A window showing water use and how much people in need for water scarcity you could be helping by saving water. This option was implemented to create environmental conscience of this precious and vital resource.

In case of power cut, three way valves will automatically use mechanical systems not electronic, to redirect water to sewer system independent of water's polluted or non-polluted state.

V. Prototype Design

According to the guidelines explained before in figure 1 and 2, about how automated system will work, the next step is to show user how system will be connected in order to allow water savings. System will make use of devices described in figures 1 and 2. Such devices will help system operate accordingly. Automated system will be implemented in toilet, shower and faucets in bathroom.

In figure 3, a SCADA system was implemented in order to allow system and user knowing the water flow within pipes. Within the SCADA, the automated system will be able to activate or deactivate three-way valves and other sensors. The main idea of implementing an SCADA system is to allow final user and easy management of system. Having a SCADA system will allow user manipulate inlets and outlets of water, water temperature, see water reservoirs capacity, and finally detect system failures such as water leaks comparing water inlet and outlet.

Figure 3 represents a simulation of the system under function, as shown above system is "ON" and it can be seen sensors measuring water flow and temperature. Three-way valves are redirecting the water flow according to state either of activation "ON" or "OFF".

VI. Results

For the calculations made in here there were taken three different devices: a watering can, a faucet, and a toilet. For each device, it was found low, medium and high consumption devices. Making it a total of 9 devices to compare and try different mixes. The URREA water company manufactured all devices. Technical data are shown in Tables 1, 2, and 3.

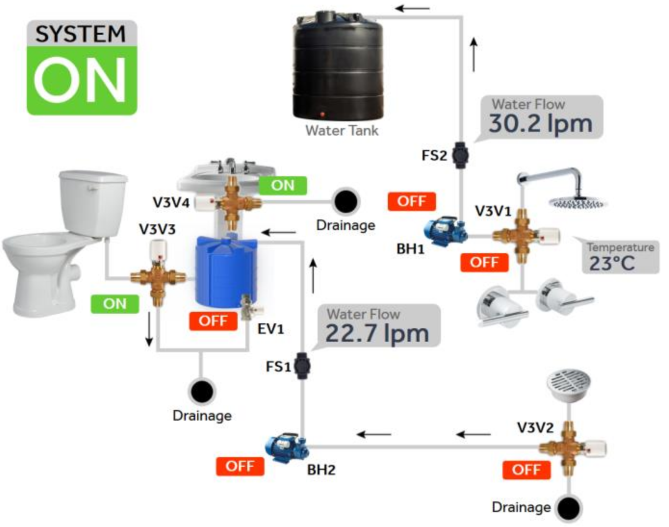

Fig. 3. Prototype Design.

TABLE 1. Types of watering cans.

Brand	URREA	URREA	URREA
Model	2212	2095B	3002B
		Spending	
Pressure	**Low**	**Medium**	**High**
0.2 (Kg/cm^2)	2.1 lpm	3 lpm	7.2 lpm
1 (Kg/cm^2)	6.0 lpm	6.6 lpm	9.6 lpm
3 (Kg/cm^2)	6.3lpm	11.0 lpm	21.0 lpm
6 (Kg/cm^2)	6.8 lpm	15.0 lpm	29.1 lpm

TABLE 2. Types of faucets.

Brand	URREA	URREA	URREA
Model	9294EO	252	46
		Spending	
Pressure	**Low**	**Medium**	**High**
0.2 (Kg/cm^2)	3.0 lpm	2.5 lpm	9.0 lpm
1 (Kg/cm^2)	4.2 lpm	5.0 lpm	12.5 lpm
3 (Kg/cm^2)	5.3 lpm	8.5 lpm	19.6 lpm
6 (Kg/cm^2)	5.8 lpm	11.5 lpm	24.5 lpm

TABLE 3. Types of toilets.

	Low	**Medium**	**High**
		Spending (lpf)	
	4.8	9	13

With devices been described on Tables 1, 2, and 3, multiple combinations were made in order to resemble the amount of water spent, therefore economic savings. All calculations were made for a single person at different water pressures inside pipes.

As shown in figure 4, a person using watering system with low efficient devices at a pressure of 6 Kg/cm^2, consumes up to 336.1 litres/day while a person using a high efficient system consumes 84.2 litres/day. In other words, a person using a low efficient system will use as much as 4 times a high efficient system. Due this consumption, it is expected for the low efficient user to pay more money for water bill. An example of such situation will be explained below.

For economic savings, let's make an example. Comparison will be made using a high, medium and low efficient system within a house. All calculations will be made considering a five-member family and a pipe pressure of 3 kg/cm^2. Let's consider 1,000 litres as a cubic metre, and a monthly base volume of 20 m^3.

Let's also consider the prices shown in Table 4 per cubic metre of water in American dollars. The exchange rate for an American dollar will be 18.50 Mexican pesos, last updated on May 28th, 2017.

According to Table 4 this family will be paying the amount of money shown in Table 5, which will be dependent on water saving systems.

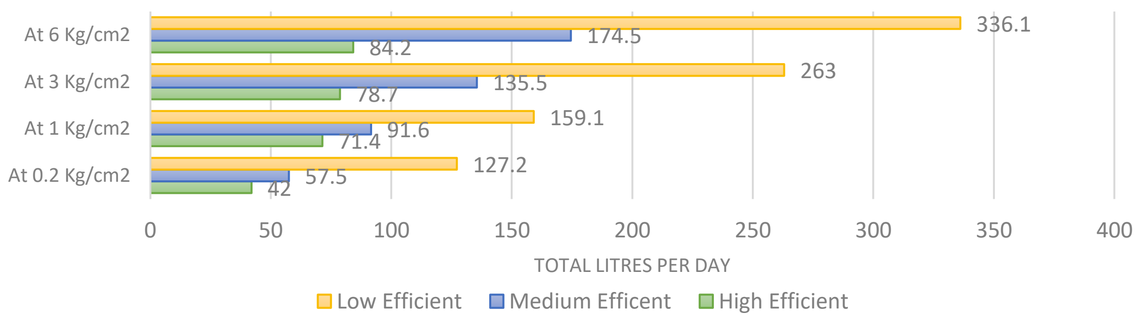

Fig. 4. Comparison between technologies per single person.

TABLE 4. Aguascalientes' domestic water tariffs [14].

Monthly Base Volume	Monthly Base Payment (USD)	Price (USD/m3)	Additional m3 (USD/m3)
10	11.3	1.1	0.5
15	13.8	0.9	0.5
20	16.3	0.8	1.7
30	32.8	1.1	2.9
50	90.6	1.8	5.7
75	307.2	4.1	10.3
100	565.1	5.7	5.7

TABLE 5. Final payment.

Base Volume = 20 m3	Monthly Base Pay (USD)	Additional m3 (USD/m3)	Monthly Consumption (m3)	Available m3 of Water	Additional m3 (USD)	Total Payment (USD)
High Eff.	16.3	1.7	11.57	8.43	0	16.3
Med. Eff.	16.3	1.7	19.92	0.08	0	16.3
Low Eff.	16.3	1.7	38.66	-18.66	30.8	47.1

As shown in Table 5, a family with low efficient devices pays almost up to 2.9x what a family with high efficient devices. The monetary difference is 30.8 USD. On the other hand, the family with medium efficient devices is almost to limit where there is need to pay additional cubic metres of water hence the need of low consumption water systems.

VII. Conclusions

Although different systems exist to generate a considerable saving in water consumption, the culture in Aguascalientes does not teach this value. Even less to realize the importance of consumption in home in spite of the fact that aquifers are disappearing. The Aguascalientes' government subsidizes a part of water price, so users do not realize the real cost. Because of cheap prices, people do not worry about their water consumption, and most important do not worry about saving water [15].

With this prototype, it is sought to generate strong savings, as we have observed throughout the article, to raise awareness of people in daily consumption. That is why on the screen we see so much accurate data, such as consumption and savings, as well as motivational phrases such as "With this shower you've saved 'X' litres of water" in order to have a social impact, thus achieving a saving and water reuse culture in Aguascalientes that is not only based on economics.

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