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# Experimental Energy Study for Domestic Hot Water Storage Tanks

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## Abstract

In the last decade, energy and water become the most important commodities as the world is suffering from a critical shortage in water and energy. Researchers are working hard on renewable energy, and energy saving. In this paper, an experimental study of the usable energy for domestic hot water storage tank was performed. Different supply features and different flow rates have been considered. To save energy in the storage tank, the turbulent mixing must be eliminated. In this study a cover over the supply lines was imposed. It has been found that the cover for the side supply feature improves the temperature distributions in the tank. For the bottom supply feature investigations indicated important improvement in the total usable hot water. Approximately 17% saving in usable hot water was achieved by using a round curved cover on the bottom supply line. The achieved saving in energy and hot water will help in reducing the consumed energy in residential buildings and thus keep us in a better environment.



*Keywords:* Water Supply; Domestic Storage Tank; Hot Water Management; Energy Saving; Usable energy

## 1. Introduction

Recently, world starts suffering from critical shortage in energy. Most of the countries are non-oil producing countries that imports their energy from other countries. The significant increase in demand for energy by several emerging nations has driven the global energy consumption to unprecedented levels. As a result, the cost of energy has reached new levels and is expected to continue to rise. The ramifications of this large increase in energy cost, will pose serious challenges to the economies of most developing nations. Recently, the energy consumption for the residential sector in Jordan has jumped to 30% of the total consumed energy in the country [1]. This impose a heavy load on the national researchers to minimize the energy consumption in the residential buildings. Minimizing heat losses and reducing hot water consumption were the goals of different researchers over the past years. Therefore, different residential hot water systems, use patterns, and loads are investigated in [3,5,7,8,10]. Other researches studied insulation to reduce heat losses in the HWST [6,11]. Special heat exchangers were considered by Industrial Technology to recover the energy wasted during usage.

The studies were not limited to thermal insulation and reduction of water losses, many researchers attached the problem from managerial directions, such as water and water resources management in Abu-Dhabi [16], the role of women and modern water supply systems [9], water management practices [4], and demand side management [17]. Experimental analyses of hot water behavior in static mode of a full scale domestic electric HWST [13,18] have been done for different heating and cooling periods. The analyses reveal that thermal stratification is mainly dependent on the initial water temperature. The dynamic mode of HWST was analyzed by N. Beithou [12] and J. F. Seara et al. [14]. They analyzed different inlets and outlets of practical interest, and they proposed to use certain features to minimize the thermal stratification.

As creating new resources of water and clean energy is a hard task, some efforts were directed towered conservation and managing the available resources. Actually conservation of resources can be defined as more efficient or effective use of resources.

This study is directed to more effective use of the available energy in the HWST. Firstly it investigates deeply the hot water temperature variations within the HWST for two different supply features: bottom and side supply. Secondly the study proposes to eliminate the expected turbulent mixing by introducing a simple cover on the supply lines, then analyzes the resulting temperature distributions in both cases and concluded the best solution.

## 2. Experimental Test Rig

Available HWSTs in the market suffer from scientific support as shown in Figure 1., they engorge turbulent mixing of cold water with the available hot water in the HWST that reducing the delivered amount of usable hot water.

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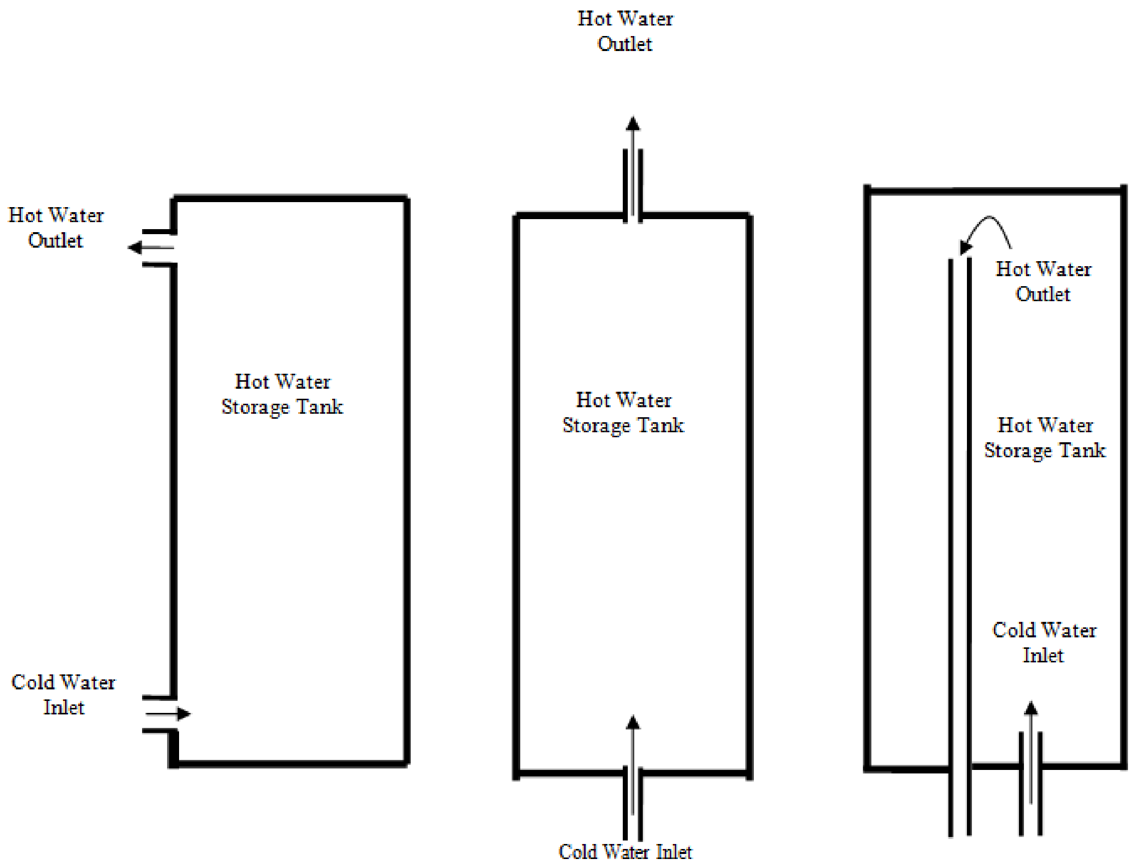
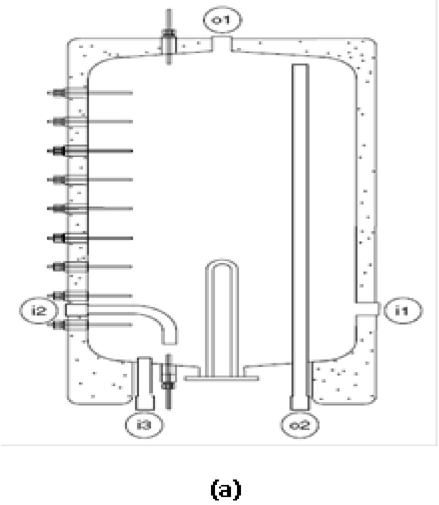



Figure 1: Features of hot water storage tanks in markets.

In the literature, scientists noticed the abovementioned problem. They tried to propose different solutions such as double hot water tanks, where the cold water enters the cooler tank and hot water leaves the hotter tank thus allowing mixing but with a lower temperature differences. Another solution was proposed by introducing a membrane to separate cold water from the hot water ASHRAE [2]. The proposed techniques seem to be costly and difficult to be implemented specially in the developing countries. Simpler and practical ideas were proposed by investigating the supply features of the DHWST [14, 15]. Jose´ et. al. [14] constructed a tank with different supply features to study dynamically the operation of a domestic hot water storage tank as shown in Figure 2.(a). The supply feature i2 was found to be the best of the investigated supply lines. On the other hand, Lana et. al.[15] investigated experimentally and numerically the thermal stratification in a solar domestic hot water system as shown in Figure 2.(b).



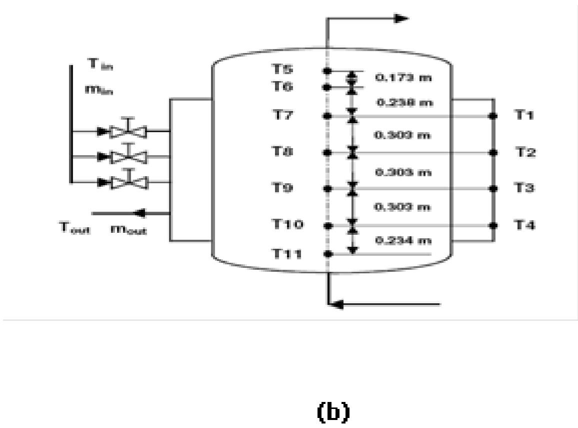




Figure 2: Schematic diagrams of proposed test HWST (a) Jose, [14] and (b) Lana [15].

In this study and aiming to eliminate the turbulent mixing between cold and hot water, the supply features were studied for both: side and bottom supply. Then simple practical covers over the supply lines have been imposed to minimize the mixing effects as shown in Figure 3.

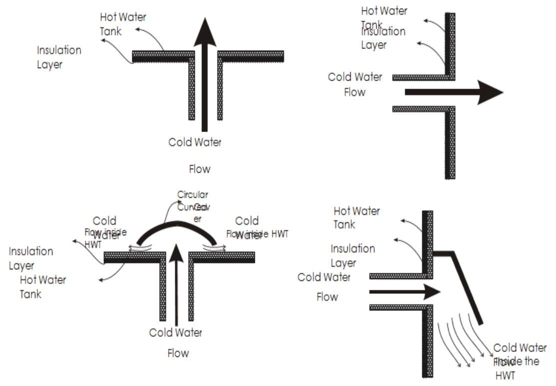



Figure 3: Supply features with the proposed cover.

In order to analyze and investigate the nature of hot water temperature variations within the HWST, data on the variation of the hot water temperatures should be collected under the different variable conditions. To achieve these data, an experimental rig has been constructed as shown in Figure 4. This rig consists of hot water reservoir, cold water reservoir, water pump, flow meter, hot water storage tank, and Data Acquisition System (DAS) (Lab-View software). The DAS automatically collect the temperatures from the storage tank at different times and positions then stores them in a separate excel file.

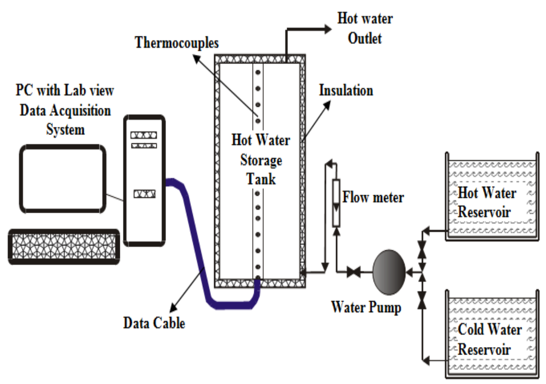



Figure 4: Schematic diagram for the experimental rig.

In the experiments performed, hot water is filled into the HWST from the hot water reservoir, circulated until having a uniform temperature of 62 $^{o}$C inside the tank; then the cold water is pumped from the cold water reservoir at a specific flow rate into the HWST through the supply line, either from side or bottom of the tank and mixed with the hot water, the temperature-changes resulting from the mixing process are then recorded for analyses purposes.

The dimensions of the HWST are listed in Table 1. This tank has a total capacity of 108 liters and is provided with 15 thermocouples mounted at the middle of the HWST to record the temperatures throughout the tank. Different supply flow rates were considered to understand the effect of flow rates on the mixing and heat transfer between the hot and cold water inside the HWST.

Table 1: Dimensions of the hot water storage tank.

| **Hot Water Storage Tank** | |
|---|---|
| *Height* | ***0.78 m*** |
| *Internal diameter* | ***0.42 m*** |
| *Number of thermocouples* | ***15*** |
| *Distance between thermocouples* | ***0.05 m*** |
| *Insulation thickness* | ***0.04 m*** |
| *Tank total capacity* | ***0.108 m$^3$*** |

## 3. Experiments Performed

In this study, bottom and side supply lines were considered. Experiments were performed for different low and high flow rates and for covered and uncovered supply lines.

### *3.1. Side Supply Feature: Without Cover:*

The side supply feature was considered to understand the mixing nature of cold and hot water if no cover is used. Different flow rates were executed in this part. The temperatures all over the HWST were collected and then plotted in order to find the influence of the considered flow rates on the temperature distributions in the tank versus time. Experiments were done first for flow rates of 1.9, 3.5, and 10 L/min without using a cover on the supply line.

In the plotted figures the most left curve represents the lowest thermocouple, whereas the most right curve represents the highest thermocouple, the distance between each two thermocouples is 5 cm. Figure 5. shows the temperature distributions for the 15 thermocouples located inside the HWST for the case of uncovered supply line with flow rate 1.9 L/min. It indicates smooth temperature distributions from the first to the last thermocouples in the tank.

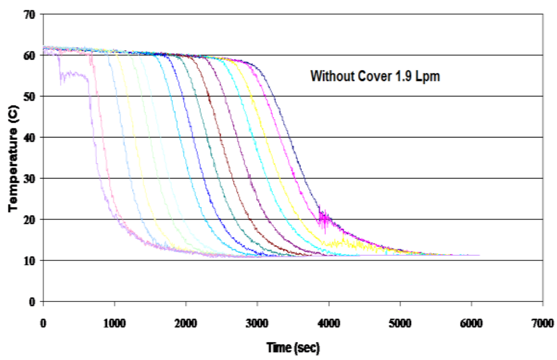



Figure 5: Temperature distributions of the 15 thermocouples versus time. Side supply without cover. Flow rate = 1.9 L/min.

In this study a minimum usable hot water temperature of 42 oC is selected. With such a usable temperature a total amount of 100 Liters was achieved.

The flow rate of cold water is then increased up to 3.5 L/min. The obtained data are plotted in Figure 6. The figure shows smooth temperature distributions in the tank as the previous case, but a total usable hot water of about 95 Liters was achieved.

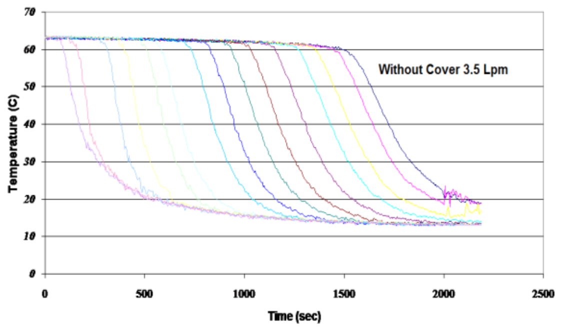



Figure 6: Temperature distributions of the 15 thermocouples versus time. Side supply without cover. Flow rate = 3.5 L/min.

Finally, the cold water flow rate was increased up to 10 L/min. The obtained data were plotted in Figure 7.

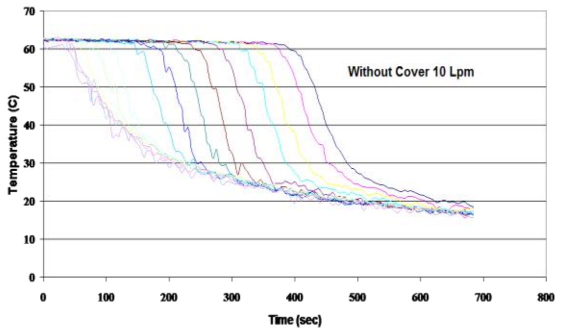



Figure 7: Temperature distributions of the 15 thermocouples versus time. Side supply without cover. Flow rate = 10 L/min.

It is obvious from the figure that as the flow rate increases, the temperature distributions start having fluctuations which affect the total usable hot water from the hot water tank. For instance, the 10 L/min cold water flow rate reduces the usable hot water capacity down to 70 liters.

### *3.2. Bottom Supply Feature: Without Cover:*

Most of the tanks in the market implement the bottom supply feature because it is easy for manufacturing. In order to investigate this supply feature, experiments were performed for flow rates of 3, 6, and 9 L/min without using a cover on the supply line. The temperatures all over the HWST were collected and then plotted to find the influence of the considered flow rates on the temperature distributions in the tank versus time.

Figure 8 shows the temperature distributions for the case of 3 L/min. flow rate without cover. Compared with the side supply feature, higher fluctuations were observed and lower total usable hot water was obtained. This behavior becomes clearly noticeable as the flow rate increases. Figures 9 and 10 show the temperature distributions for 6 and 9 L/min, respectively. It is obvious that the temperatures become highly fluctuating and the usable hot water is reduced dramatically. This emphasizes the bad effects of using bottom supply feature, especially for high flow rates.

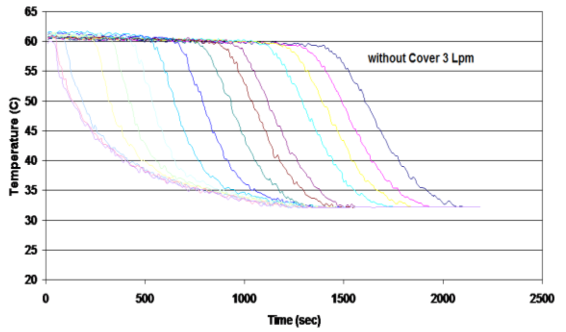



Figure 8: Temperature distributions of the 15 thermocouples versus time. Bottom supply without cover. Flow rate = 3 L/min.

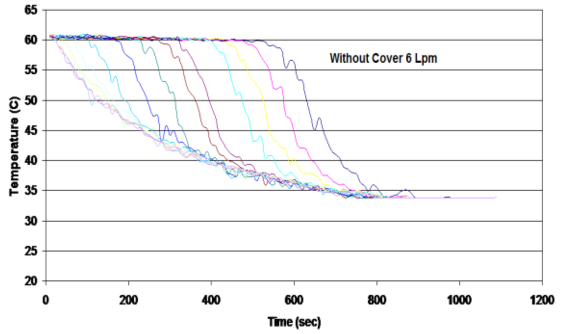



Figure 9: Temperature distributions of the 15 thermocouples versus time. Bottom supply without cover. Flow rate = 6 L/min.

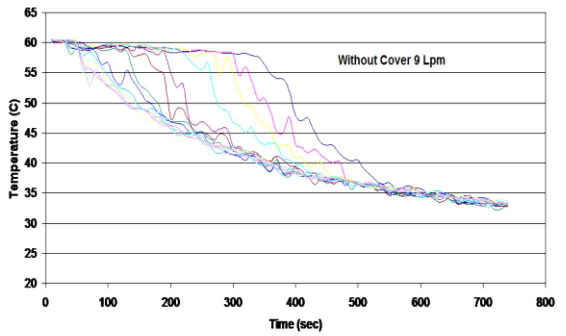



Figure 10: Temperature distributions of the 15 thermocouples versus time. Bottom supply without cover. Flow rate = 9 L/min.

Figure 11 shows the total usable hot water versus cold water flow rate for side and bottom supply features. The figure indicates that the side supply feature yields better results than bottom supply feature in the case of uncovered supply lines.

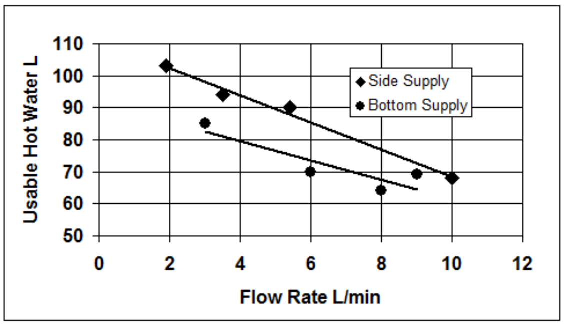



Figure 11: Total usable hot water versus cold water flow rate for bottom and side supply of cold water.

*3.3. Side Supply Feature: With Cover:*

As noted above, the bottom supply feature reduces dramatically the amount of usable hot water. This is mainly because of the turbulent mixing between cold and hot water inside the tank. Jose´ et. al. noted this problem, they constructed a tank with different supply features to study the operation of a domestic hot water storage tank. The supply feature i2 [figure 2.(a)] was found to be the best from the investigated supply lines, as it introduces the water to the bottom of the storage tank; this has mainly improved the amount of the usable hot water especially for the medium flow rates. In high flow rates the water will clash with the bottom of the tank and splash upward again. As the main purpose of this study is not to limit consumer with low flow rates, a simple practical covers were imposed on the supply lines to distribute the supplied water at high flow rates in a uniform manner. The side supply line was covered with a plate to forbid the water from flowing upward after sticking the far side of the tank. Figure 12. represents the temperature distributions all over the tank for cold water flow rate 3 L/min.

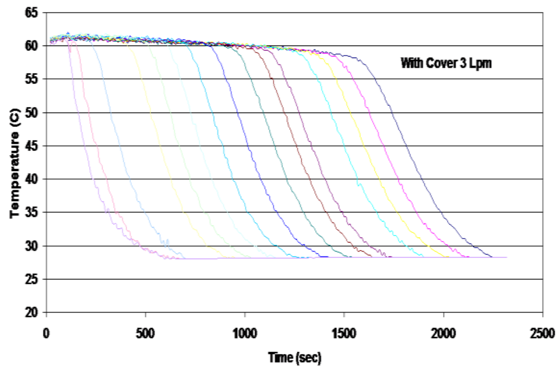



Figure 12: Temperature distributions of the 15 thermocouples versus time. Side supply with cover. Flow rate = 3 L/min.

By comparing the related figures for side supply with and without cover Figures 6, and 12 it is noted that the curves become smoother whereas the amount of the usable hot water supply does not show distinguished differences.

Figure 13, and 14 show temperature distributions for side supply line with cover, for cold water flow rates of 6 and 15 L/min respectively.

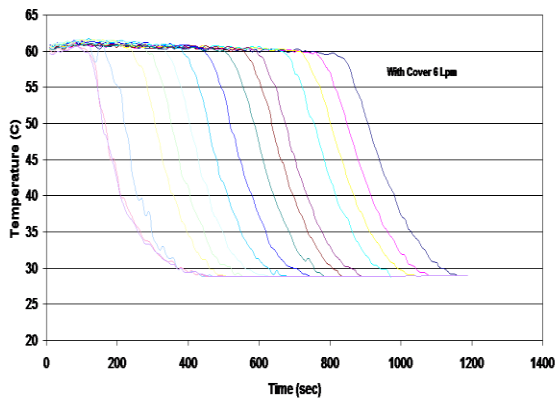



Figure 13: Temperature distributions of the 15 thermocouples versus time. Side supply with cover. Flow rate = 6 L/min.

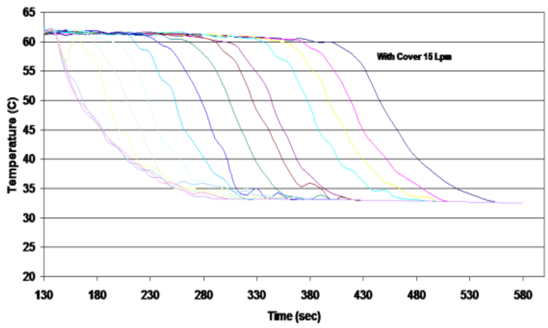



Figure 14: Temperature distributions of the 15 thermocouples versus time. Side supply with cover. Flow rate = 15 L/min.

It was very interesting to notice the differences between the related figures 13 and 14. As the flow rate increases the used cover over the supply line eliminated the fluctuations in the temperature distributions even for the high flow rates. This results in slightly higher amounts of usable hot water as shown in Figure 15 and the more important uniform supply temperatures.

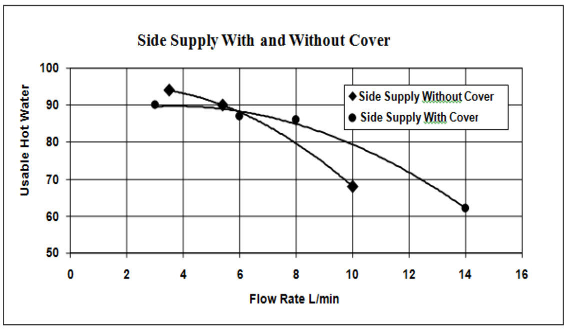



Figure 15: Usable hot water versus cold water flow rate for side supply feature.

*3.4. Bottom Supply Feature: With Cover:*

The bottom supply feature is considered to be easier in the manufacturing process, but it has extremely bad effects of the total usable energy in the HWST. Aiming to overcome the bad effects of high flow rates and to distribute the water smoothly and horizontally as much as possible, a round curved cover (like a cone) has been imposed on the bottom supply line. Experiments were performed for different flow rates of, 3, 6, and 9 L/min. The obtained temperature distributions are plotted in Figures 16, 17, and 18, respectively.

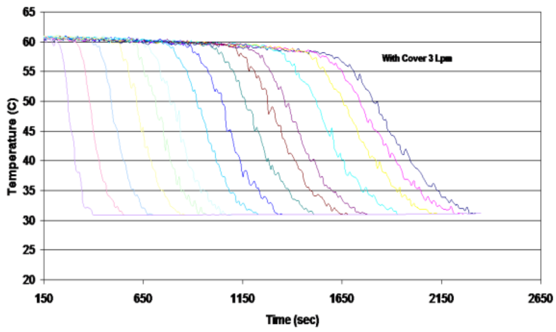



Figure 16: Temperature distributions of the 15 thermocouples versus time. Bottom supply with cover. Flow rate = 3 L/min.

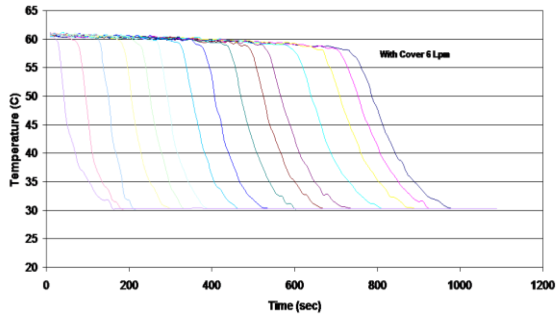



Figure 17: Temperature distributions of the 15 thermocouples versus time. Bottom supply with cover. Flow rate = 6 L/min.

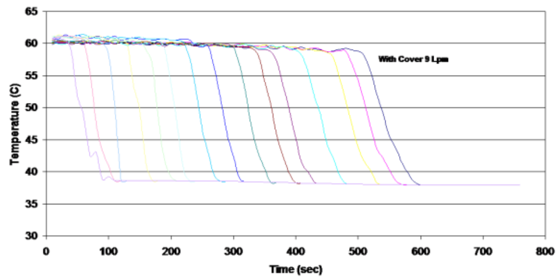



Figure 18: Temperature distributions of the 15 thermocouples versus time. Bottom supply with cover. Flow rate = 9 L/min.

Figure 16 represents temperature distributions for the covered bottom supply line with flow rate of 3 L/min. In this figure the temperature distributions for the 15 thermocouples do not show smoother curves than that in the uncovered case; that's because of the low flow rate. The distinct improvement for this flow rate lie in the total usable hot water; the uncovered case delivered 85 liters hot water whereas the covered case delivered 91 liters.

An important notice is observed in the curves for the temperature distributions of medium and high flow rates. Comparing figures 9 and 10 for the uncovered bottom flow with figures 17 and 18 for the covered bottom flow show the big improvement in the temperature distributions, that is fluctuations in side the HWST have been eliminated. Figure 18 for covered bottom flow [9 L/min) shows very smooth temperatures inside the tank and prove that water in the tank moves in laminate manner. This motion of the cold water without mixing with hot water in the HWST is the main target of this research.

Figure 19 shows the total usable hot water versus flow rate for both covered and uncovered bottom supply. The covered bottom supply delivered a noticeable increase in the usable hot water, with almost no variation with flow rate. In this way the problem of using high flow rates could be eliminated, and consumer can no more worry about the used flow rate.

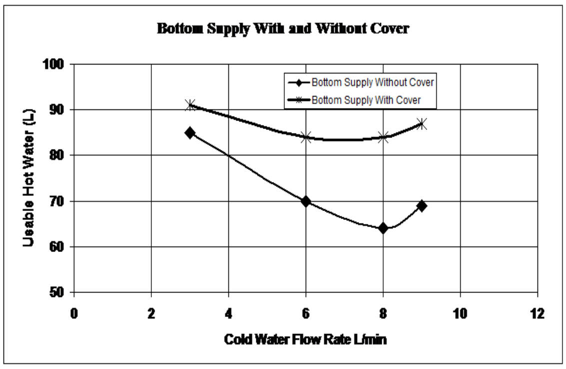



Figure 19: Usable hot water versus cold water flow rate.

Furthermore, figure 19 shows the amount of hot water saved by using the round cover on the bottom supply line. At 9 L/min the uncovered feature delivered approximately 69 liters, whereas the covered feature delivered 87 liters, with approximately 17% saving. The achieved saving in energy and hot water will help in reducing the consumed energy in residential buildings, and thus keep us in a better environment.

To eliminate completely the effects of turbulent mixing, a current study for a domestic hot water tank with a porous layer is under investigation see Figure 20.

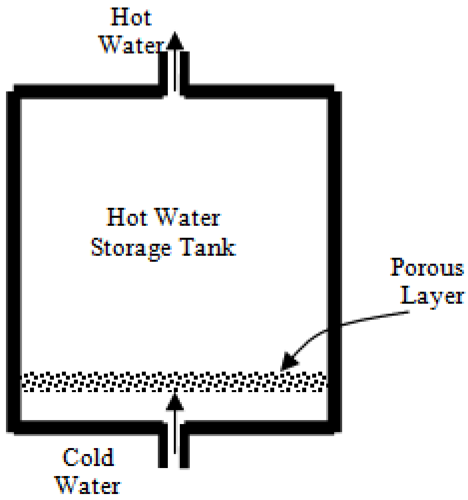



Figure 20: Domestic Hot Water Tank with a Porous Layer.

## 4. Conclusions

World these days suffers from critical shortage in water and energy. The reduction in water usage and energy consumption is one of the main goals of researchers. In this paper, an experimental study of the usable energy for domestic hot water storage tank was performed. Different experiments with different supply features and different flow rates have been performed. The temperature distributions for the side and bottom supply features were analyzed. To eliminate the turbulent mixing, covers over the supply lines were imposed. It has been found that the cover for the side supply feature improves the temperature distribution in the tank, but it does not show a distinguished improvement on the amount of usable hot water. As the bottom supply feature is easier in manufacturing, the investigations indicated important improvement in the total usable hot water. For 3 L/min flow rate, the uncovered case resulted in 85 liters hot water whereas the covered case supplied 91 liters. More over, at 9 L/min the uncovered feature gave approximately 69 liters whereas the covered feature gave 87 liters, with approximately 17% saving. The achieved saving in energy and hot water will help in reducing the consumed energy in residential buildings, and thus keep us in a better environment. To eliminate completely the effect of turbulent mixing, a current study for a domestic hot water tank with a porous layer is under investigation.

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