Asian Journal of Water, Environment and Pollution, Vol. 7, No. 4, pp. 1-7.

Water Conservation in Hot Climate Buildings by Temperature Control

Abdullah S. Al-Ghamdi
Civil Engineering Department, King Abdulaziz University, Jeddah, Saudi Arabia
✉ alghamdi@kau.edu.sa

Received March 15, 2010; revised and accepted July 30, 2010

Abstract: This article presents measurements of water temperature in underground and overhead tanks commonly used in intermittent water supply system in the city of Jeddah, Saudi Arabia, during summer months. The measurements indicate that diurnal water temperature variation and stratification in concrete underground tank is very limited with an average temperature of water of about 34.64 °C. In contrast, the overhead galvanized steel, and to lesser extent, the fiberglass tanks exhibit high diurnal temperature variation and stratification.

The investigations indicate that the maximum water temperature in overhead tank exceeds the safe and comfortable temperature range for regular use. A considerable amount of valuable water will be wasted as the residents draining out the hot water from the plumbing system in addition to the possibility of scalding and burns in sensitive skins of some consumers. Recommendations to eliminate the hot temperature problem and conserving water are presented in the paper.

Key words: Domestic water temperature, water conservation, intermittent water supply.

Introduction

Due to the shortage in water supply, the water authorities in most cities in third world countries rely on intermittent water supply system. In this system, the city is divided into a number of small sectors, and the water is pumped rotationally between the sectors according to an operational schedule. The frequency of water pumping to a given sector could be several days, or may be weeks. In this intermittent water supply system, each household should be equipped with an underground tank to store the water during the pumping period and an overhead (rooftop) tank to balance the pressure in the internal plumbing system in addition to a pump to provide the necessary energy to elevate the water from the underground tank to overhead tank. During the day time, the water in the overhead tank is exposed to direct sun radiation and the water temperature in the tank warms up, especially in hot climate where the outside temperature may exceed 50 ^{o}C during summer months. Depending on the material of the overhead tank and the exposure time of the tank to the sun radiation, the water temperature in the overhead tank is expected to exceed the ambient air temperature. As a result, the water temperature in the plumbing system inside the building may exceed the tolerable temperature for normal residential use and may cause scalding. Some residents may open the water tap in their apartment during mid-day hours and keep the water running out for sometime to drain out intolerable high temperature water, which results in a waste of valuable natural resource. The purpose of this contribution is to assess the water temperature variations in the overhead and underground tanks in Jeddah City, Saudi Arabia, during the summer months and propose solutions for controlling the temperature in the plumbing system.

Background

Saudi Arabia lies in an arid region with limited fresh water supply. The major cities in the country depend primarily on desalinated sea water which provides more than 90%

of the water supply for the major cities. In 2007, the Saudi Water Conservation Corporation (SWCC) produced 1066 million cubic metres of desalinated water to supply water to Saudi major cities from 30 desalination plants located on Red Sea and Arabian Gulf coasts (SWCC, 2007). Due to the high cost of desalinated water and the gap between the demand and supply, the water authorities run water distribution systems in major cities on intermittent basis. The pumping frequency differs from city to city and from time to time within the same city based on available water supply and seasonal fluctuation in demand, but usually ranges from once every to two days to once every few weeks. The residents rely on having their own underground tanks to store the water during the pumping period to be utilized later when the pumping is terminated. They also use water tankers to supply their underground tanks if the no-pumping period is extended for long time and the water demand in the building is more than the water stored in the underground tank during the pumping period. It is a common practice that each building is equipped with an overhead (rooftop) tank to balance the water in the plumbing system. The water is pumped from the underground tank to the overhead tank and then flow by gravity into the plumbing system. In the past, the overhead tanks were made basically from galvanized steel, but in recent years these tanks are replaced mostly with fiberglass type. The overhead tanks as well as part of the piping system are exposed to direct sun radiation and the water temperature in the plumbing system is highly affected by the outside temperature. Saudi Arabia climate is mainly desert climate with extremely high temperature in the summer and cold in the winter in most cities. The extreme temperature recorded in some cities show that the outside temperature may exceed 57 ^{o}C in mid-day hours during the summer months as shown in Table 1.

High water temperatures may cause scalding and burns to vulnerable people. Those at risk from scalding/burning include children, the elderly and individuals with sensory impairment, or who cannot react appropriately, or quickly enough, to prevent injury. The temperatures at which scalding can occur are constant, but the degree of potential scalding depends on the actual temperature and volume of delivered hot water and the contact time. Evidence on scalding indicates that risk increases rapidly from temperatures of 45^{o}C and above. For example, partial thickness burns will occur within 30 seconds at 55^{o}C, reducing to less than five seconds at 60^{o}C and above (Moritz and Henriques, 1947; NHS, 1988; DTI, 1999). Skin sensitivities vary greatly throughout the population, as do the risks from high temperatures for the population with specific medical conditions. The Health and Safety Executive (HSE) of United Kingdom states the maximum hot water and surface temperatures for safe use. Although these are recommended for all healthcare premises and those premises registered under the Registered Homes Act 1984 but are applicable for other types of occupied building (Moritz and Henriques, 1947). These limits are shown in Table 2.

Table 2: Maximum temperature limits for different residential applications

Max. Temp	*44*	*41*	*41*	*38*
Application	Unassisted bath fill	Shower	Washbasin	Bidet

A considerable amount of water is wasted daily in hot climate cities due to draining out the hot water from the plumbing system by the residents to reach a more convenient and safer colder water temperature. This valuable wasted water may be saved and utilized if the plumbing system is adjusted to avoid the exposure of plumbing system components to outside high temperature.

Field Measurements

To assess the hot water problems in residential houses a number of field measurements were conducted in some residential houses in Jeddah during summer months of 2009. The time variation of air, tank and water temperatures were measured during July and August 2009 in fiberglass and galvanized steel overhead tanks and underground concrete water tanks using thermocouples and a data logger. The measurements in each location were extended over a number of days to account for the possible variation in water consumptions and outside temperature.

Table 1: Extreme water temperature in some cities in Saudi Arabia

City	*Riyadh*	*Jeddah*	*Yanbu*	*Medina*	*Makkah*	*Abqaiq*	*Dhahran*	*Turaif*
T_{min} ^{o}C	-7.2	9	6.3	-1	8	NA	-0.5	-12.2
T_{max} ^{o}C	48.9	49	49.5	49	49.8	57.1	51.1	47.8

Source: http://www.mherrera.org/temp.htm

Table 3: Summary of temperature ranges in the underground concrete tank

Temperature ºC	*Ambient air*	*Water*			
		d =60 Cm	*d = 150 cm*	*d = 290 cm*	*Average*
Max.	37.23	34.94	35.05	34.40	34.74
Min.	28.01	34.49	34.26	34.27	34.43
Average	32.79	34.73	34.86	34.34	34.64

The underground water tanks are usually concrete tanks with depth ranging from 2.5 to 3 m. The volume of the tank depends on the size of the building and the anticipated time for no pumping period in the network. Currently there are no standards for the size of the underground tank, it is kept for the designer to estimate the adequate tank volume. To monitor the temperature variations in underground tanks, temperature sensors were fixed outside the tank to measure the ambient temperature and at three different levels inside the 3 m deep tank (at depths of 60 cm, 150 cm and 290 cm from tank top level) to monitor any stratifications that may exist in the tank. Temperatures were measured and recorded over an interval of one minute. The time variation of the air and water temperatures for the underground concrete water tank is shown in Figure 1. This figure shows that although the outside temperature was fluctuating between 28.01 and 37.23 ºC during the measurement period, the temperature inside the tank maintained a uniform average value of 34.64 ºC during day and night hours. The maximum, minimum and average values for the outside air temperature and water temperature are summarized in Table 3. The values in Table 3 indicate that the water in underground tank is well insulated by the ground and its temperature remains within acceptable range.

Overhead tanks are usually horizontal, cylindrical or spherical fiberglass tanks manufactured in size ranging from 0.30 m^3 to 10 m^3, but the widely used sizes in residential buildings are ranging from 2 m^3 to 6 m^3. In older part of the city some galvanized steel rectangular and cylindrical shape tanks are still in use. The water temperatures in overhead tanks were measured for both fiberglass and galvanized tanks to assess the differences. Two measurements were done on fiberglass tanks: In the first case the tank is isolated from the network and is used for emergency only to simulate the extreme case. The other case is for a tank in operation where water flows into the tank from underground tank and out of the tank to the plumbing system according to the actual demand in the building. The tank outside temperature and the water temperatures at two different levels inside the tank to account for stratifications were measured and recorded at five minutes intervals.

Figure 2 illustrates the temperature variation inside and outside the isolated overhead tank. The figure shows that the outside temperature of the tank exceeds 51 ºC in mid-day hours, while the maximum temperature in the upper layer of the tank approaches 41.88 ºC. The figure also shows that the water inside the tank is stratified during the mid-day hours where the upper water layers are heated, but during night hours the water stratifications disappear. The upper layer exhibits a pronounced variation between day and night hours, while bottom layer shows lesser variation in temperature between day and night hours as summarized in Table 4.

Table 4: Summary of temperature ranges in the isolated fiberglass water tank

Temperature, ºC	*Outside tank temperature*	*Water temperature*	
		D = 70 cm	*D = 137 cm*
Max	51.65	41.88	39.09
Min	29.72	35.20	34.32
Average	37.32	37.79	37.06

The water temperature variation of a fiberglass tank in operation is measured and depicted in Figure 3. Temperature sensors were located at four different locations: outside wall of the tank, at two different levels inside the tank and in the piping system leading from the overhead tank to the internal plumbing system. This piping system is usually a standard grey colour PVC pipe with a diameter ranging 1-2 inches. A considerable part of this pipe is exposed to direct sun radiation and the water temperature in this pipe during non-flow period is expected to be higher than the temperature of the water in the better insulated fiberglass water tank due to the higher absorptivity of the PVC pipe to radiation heat energy and the low wall thickness (about 5 mm). The water temperature in the tank exhibits stratification especially during mid-day hours when the temperature of the upper layer is warmer than the bottom layers. But during night hours the temperature stratifications diminish. The fluctuation of the upper layer temperature between day and night hours is pronounced. The bottom layer has less fluctuation and maintains an average temperature of 33.56 °C and standard deviation of 0.94. The temperature of water in the piping system during the mid-day hours is higher than that in the bottom of the

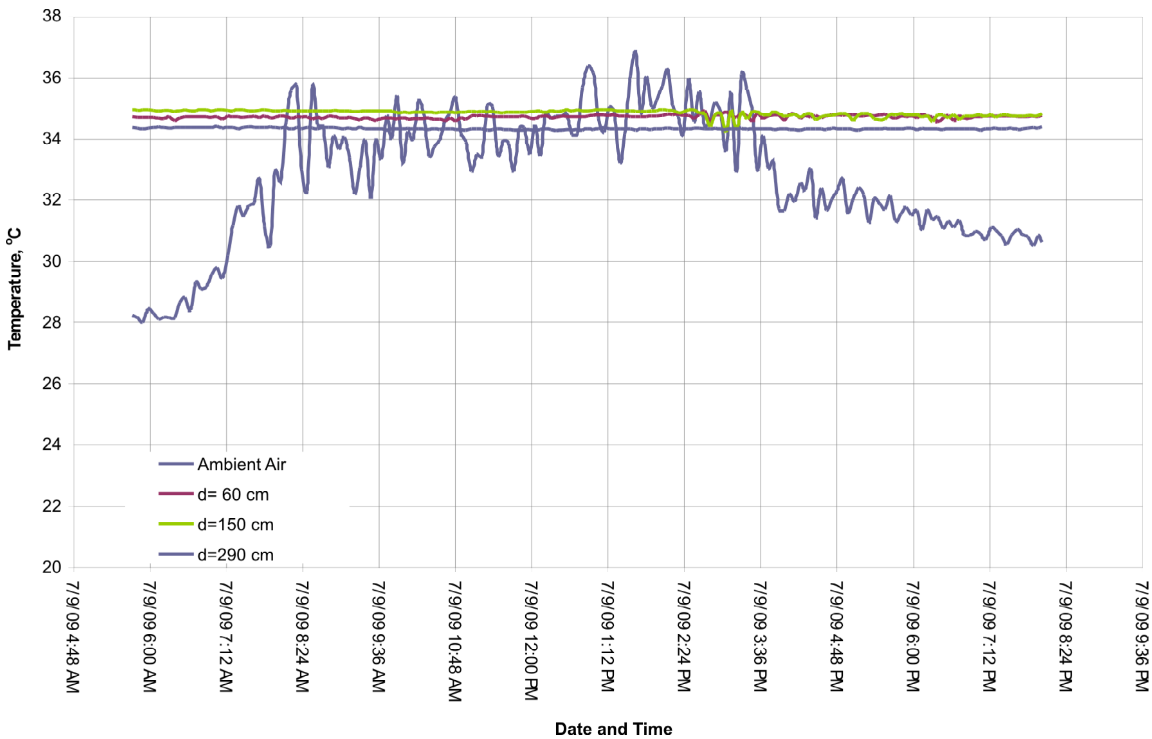

Figure 1: Temperature variations in underground concrete tank.

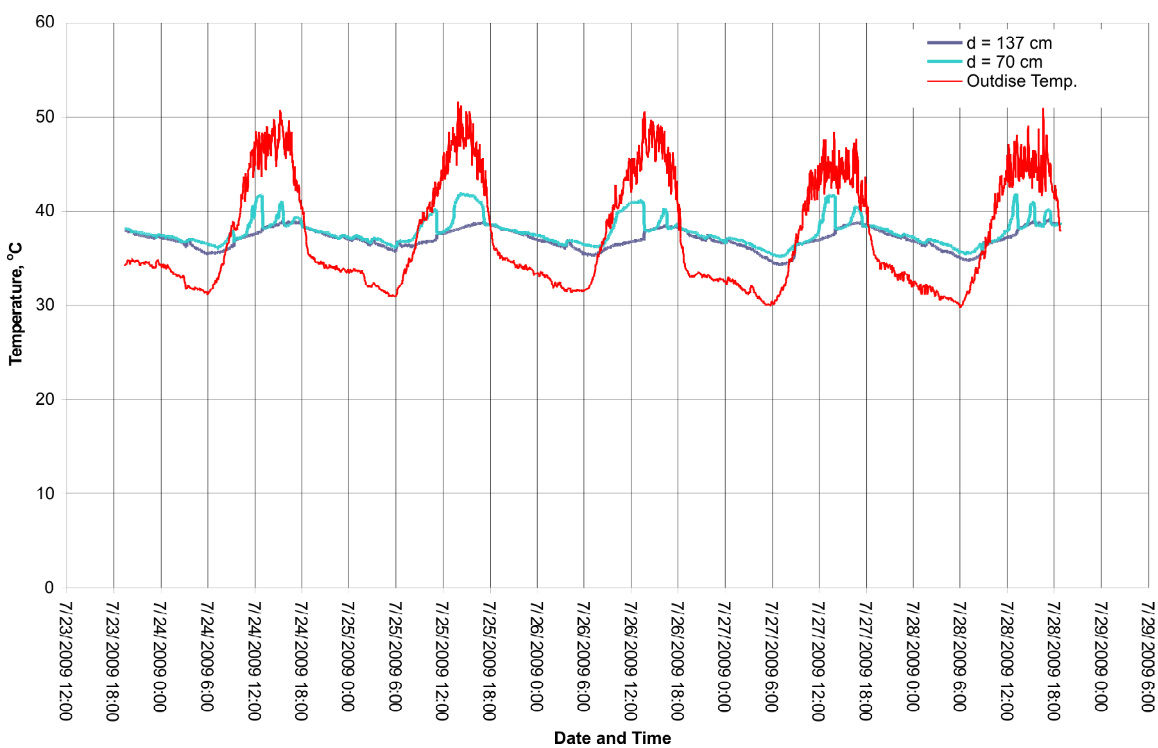

Figure 2: Temperature variation for the isolated fiberglass overhead tank.

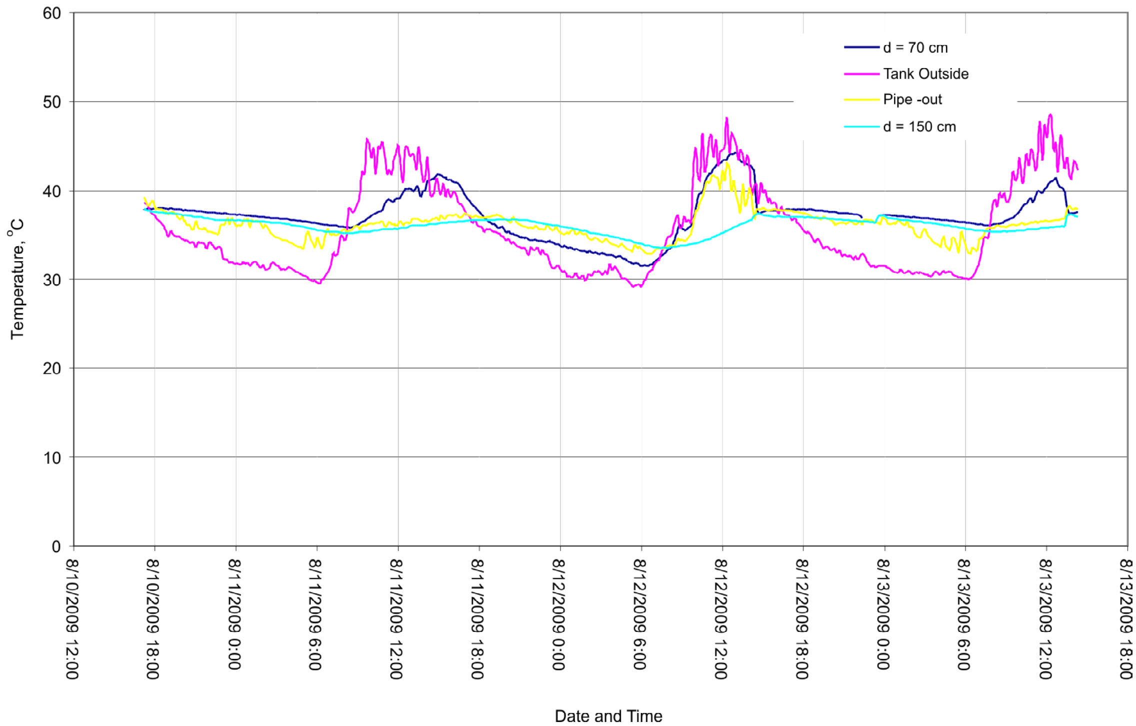

Figure 3: Temperature variation for the fiberglass overhead tank in operation.

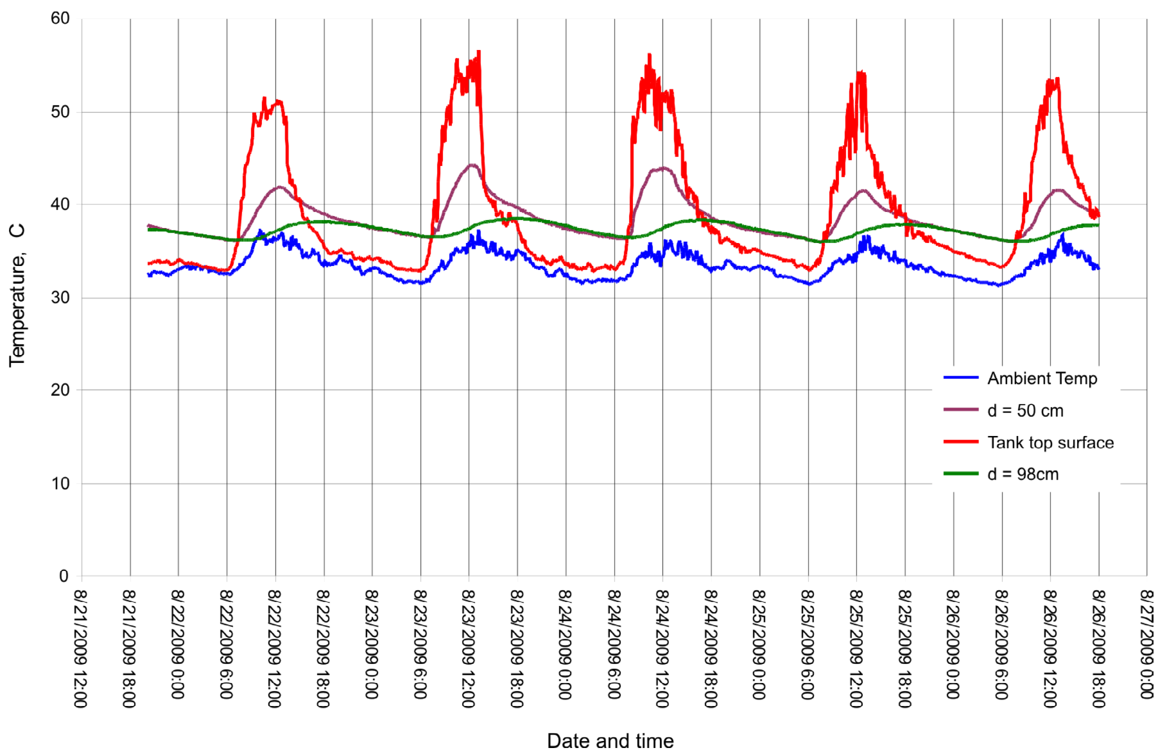

Figure 4: Temperature variation for the isolated galvanized steel overhead tank.

tank and approaches the temperature in the upper layer of the water in the tank. As shown in Table 5, the temperature in the upper layer of the tank and in piping system exceeds 44.20 °C and 43 °C, respectively, which is above the safe water temperature limits stated by HSE as pointed out in Table 2. However the temperature in

Table 5: Summary of temperature ranges in fiberglass water tank in operation

Temperature, ºC	*Outside tank temperature*	*Water temperature*		*Average water temperature*	*Pipe-out*
		D = 70 cm	*D = 150 cm*		
Max	48.51	44.24	37.89	40.08	43.02
Min	29.15	31.47	33.56	18.19	32.87
Average	35.71	37.14	36.03	36.28	36.15

Table 6: Summary of temperature ranges in galvanized steel water tank

Temperature, ºC	*Ambient air*	*Water temperature*		*Average water temperature*	*Top surface*
		D = 50 cm	*D = 98 cm*		
Max	37.29	44.23	38.48	41.01	56.64
Min	31.28	29.52	35.99	33.66	32.86
Average	33.53	38.62	37.24	37.93	39.02

the pipe is depending on the water consumption in the building; higher water consumption will reduce the exposure time for the water to sun radiation and the water temperature in the pipe will approach the tank bottom layer temperature.

Water and air temperatures were also measured in a galvanized steel tank. Four temperature sensors were located to measure the temperatures of the ambient air, the tank outside wall and at two depths inside the tank. The data of the measurement is illustrated in Figure 4. This figure indicates that the temperature of the top side of the tank exceeds 55 ^{o}C in the mid-day hours due to the high absorptivity of the tank to the direct sun radiation. The temperature of the tank surface ranges from 0 to 58% greater than the ambient air temperature. The high conductivity of the galvanized steel and the thin wall thickness (less than 3 mm) lead to high water temperature inside the tank in the upper layers of the tank with a maximum value approaching 44.23 ^{o}C in the mid-day and a high variation of temperature between day and night hours ranging from 29.52 ^{o}C in the night to 44.23 ^{o}C in the mid day as shown in Table 6. The temperature in this layer is always above the ambient air temperature and ranges from 7% to 32% higher than ambient air temperature. The bottom layer temperature exhibits less variation between day and night hours with the difference between the maximum and minimum value of about 2.5 ^{o}C.

Conclusion and Recommendations

Field measurements were carried out to assess the water temperature fluctuations in underground concrete water tank, overhead fiberglass and galvanized steel tanks in the city of Jeddah, Saudi Arabia during summer months of 2009. The field measurements indicate that water temperature variation in concrete underground tank between day and night is very limited with an average temperature of the water in the tank of about 34.64 ^{o}C, and the stratification was very minimal. In contrast, the overhead galvanized steel, and to lesser extent, the fiberglass tanks exhibit high variation in temperature between day and night hours and a considerable stratification in these tanks during the mid-day hours.

The water temperature in both the fiberglass and galvanized steel overhead tanks exhibits stratification especially during mid-day hours when the temperature of the upper layer is warmer than the bottom layers. But during night the stratification diminishes. The fluctuation of the upper layer temperature is pronounced while the bottom layer fluctuation is minimal. The galvanized steel exhibits a higher variation of temperature in the upper layer of the water between day and night hours ranging from 29.52 ^{o}C in the night to 44.23 ^{o}C in the mid day. The temperature in the upper water layer of the tank ranges from 7% to 32% above the ambient air temperature in mid-day hours. In both tank types, the temperature in the upper layers of water exceeds 44 ^{o}C which is above the safe water temperature limits stated by HSE.

The temperature of water in the piping system during the mid-day hours is higher than that in the bottom of the tank and approaches the temperature in the upper layer of the water in the tank. The temperature in the piping system exceeds 43 ^{o}C, which is above the safe water temperature limits stated by HSE.

The investigations indicate that the water temperature in overhead tanks exceeds safe and comfortable temperature range for regular use in mid-day hours and it is expected that a considerable amount of valuable water will be wasted by the residents draining out the hot water from the plumbing system. Besides it is quite possible that scalding or burns in sensitive skins may occur to some consumers. This valuable water can be saved and possible scalding can be avoided by changing the current plumbing practices in hot regions. The following recommendations may be used to reduce/eliminate the hot temperature problem:

1. The overhead tank should be shaded and all the piping system leading from the tank to the plumbing system should be insulated to reduce the heat exchanged between the water and the surroundings.
2. Galvanized water tank must be avoided and it is highly recommended to replace the existing ones by fiberglass type tanks.
3. The temperature in overhead tank can be controlled by providing a temperature controlled valve that allows the hot water to reticulate from overhead tank and the external piping system to the underground water tank to maintain an acceptable water temperature in overhead tank.
4. A better control of the water temperature can be achieved if the overhead tank is completely eliminated from the system by installing a booster pump that pumps water directly from underground tank into the plumbing system and eliminating all the external pipes from the plumbing system.

Acknowledgements

The work was sponsored by Sheikh Mohammed bin Hussein Alamoudi Chair on Water Networks Research, King Abdulaziz University.

References

Saudi Saline Water Conversion Corporation (SWCC) (2007). Annual Report, No. 34, Riyadh, Saudi Arabia (in Arabic).

http://www.mherrera.org/temp.htm, visited 28 August 2009.

Moritz, A.R. and F.C. Henriques (1947). Studies of thermal injury; the relative importance of time and surface temperature in the causation of cutaneous burns. *Am J Pathol*, **23:** 695-720.

NHS Estates (1998). Health Guidance Note – 'SAFE' hot water and surface temperatures'. NHS Estates.

DTI (1999). Government consumer safety research – Burns and scalds accidents in the home. Consumer Affairs Directorate, DTI.

Asian Journal of Water, Environment and Pollution

Volume 7 Number 2 **April – June, 2010**

Contents