Better efficiency for hot water cylinders

by Johan Delport, energy consultant, in collaboration with Multi Elements

The only electricity cost saving achievable with a hot water cylinder (HWC), or geyser, as it is generally called, is to use less hot water or to reduce heat losses from the HWC. To reduce the electricity consumption, due to losses, one can install more insulation around the hot water cylinder as well as the hot water pipes AND the cold water pipe, consider the position of the HWC (horizontal or vertical) or consider the heating element and thermostat.

This paper is a follow up on a previous paper [1], and gives a comparison of the three ways to improve energy efficiency of HWC's.

Energy efficiency possibilities of a HWC

There are two things that cause the use of electricity in a HWC [1]:

- *Hot water consumption in liters:* The liters consumed from the HWC are dependent on the HWC thermostat setting.
- *Heat loss from the HWC:* The heat inside the HWC will be transferred to the cooler outside. The warmer the HWC temperature and the colder the ambient temperature, the faster the heat loss.

For this paper we have used the most common HWC in South African homes, a horizontal HWC of 150 litres, with an element of 3 kW as our model.

There are three ways to improve the efficiency of a HWC:

- Vertical HWC vs. horisontal HWC
- Insulation
- Heating element and thermostat control

Each one of these possible improvements is discussed.

Vertical HWC vs. horizontal HWC

A horizontal HWC delivers less hot water than a vertical HWC [1]. The main reason for this is its construction (where the element and thermostat are situated) and not the losses. If a closer look is taken at the losses, the same equation is used to determine the losses for a horizontal HW as for a vertical HWC [2].

Insulation of a HWC

HWCs and pipes are insulated to minimize heat losses. However, every unit (vessel and pipes) experiences some losses. These losses are determined by the skin temperature, amount of surface area, and ambient conditions. Using [1], the losses can be calculated. By installing an additional layer of insulation, the average losses (vessel and pipes) are summarized in Table 1.

By insulating the HWC only (with a hot water tempeature of 66,1°C and outside temperature of 20°C) a reduction of 26 W is possible. This amounts to 228 kWh per year.

	HWC temperature °C	W losses without additional insulation	W losses with additional insulation`	Decrease in losses on W
HWC	70,3	73	45	28
HWC	66,1	67	41	26
4m of pipe	70,3	88	28	60
4m of pipe	66,1	80	26	54
Combined	70,3	161	73	88
Combined	66,1	147	67	80

Table 1: Losses associated with a HWC and 4 m of pipe.

Heating element and thermostat control of a HWC

One of the biggest energy wasting actions is the small draws of hot water from a HWC. The element will come on, because the thermostat will see a drop in temperature. To achieve better control, the idea of having two thermostats, controlling two elements was patented. The two elements are of the same size, e.g. : 2 x 2 kW or 2 x 1,5 kW. All of this is fitted into the normal single boss. This is referred to as a dual system. Each element is controlled by its own thermostat, one being set at 60°C and the other at 65°C. The two thermostats (and pockets) form part of a unitary design, as shown in Fig. 1.

The dual element concept

The principal is to use two individual element/ thermostat modules in one system. The thermostat of one element is set 5°C higher (typically 65°C) than the second element (typically 60°C), thus allowing an offset between elements switching on and off.

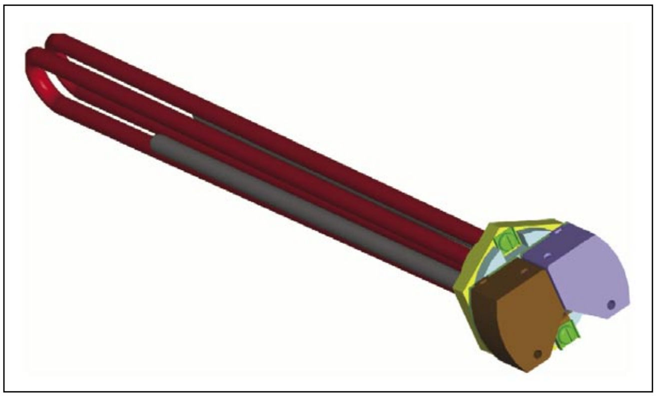

Fig. 1: Dual element (DE) system.

When a hot water tap is opened, initially only one element comes into operation, but when more than about 8 litres of water is drained from the geyser, the second element is activated, accelerating the heating rate of the water. In steady state conditions of no water usage, or for small water withdrawals such as hand washing and dish washing, only one element will be activated. The heating of this element is more than adequate to reheat to the thermostat setpoint after small withdrawals and to compensate for standing heat losses, i.e. keeping the temperature constant when no water is withdrawn from the HWC.

Initial heating of water in a HWC

Referring to Fig. 2, the dual element (DE - 4 kW) reaches the important 60°C usable level 20 minutes faster than the 3 kW standard unit. The DE then switches to only 2 kW, from there the change in heating gradient, thereafter arriving at 65° C setpoint with minimal overshoot. Also note that the 3 kW unit is only at 50°C when the DE system reaches 60°C.

Small hot water withdrawals

The biggest problem with small withdrawals is that the customer wants say 2,5 litres of hot water. But because of the hot water pipes in the house, 7,5 litres of hot water is left in the 15 m pipe to cool down. This gives a wastage of 300% of water consumed. This also causes an additional 4°C of losses.

With reference to Fig. 3, the setpoints of both the 3 kW standard and 4 kW dual are set to 65°C which is also used as the starting reference water temperature. This graph represents numerous practical in sito tests of small withdrawals. In every event of the

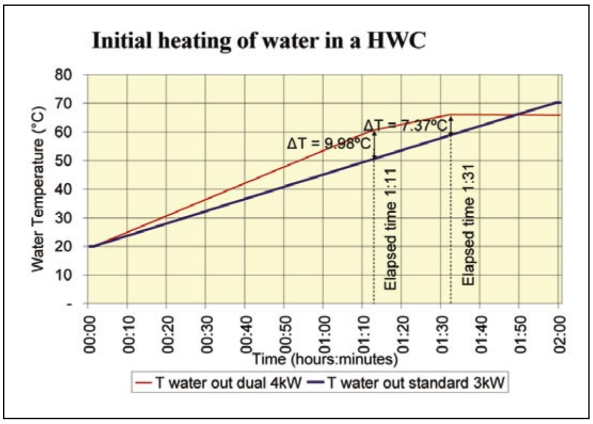

Fig. 2: Initial heating of water in a 150 litres HWC from tap temperature (20°C) to setpoint.

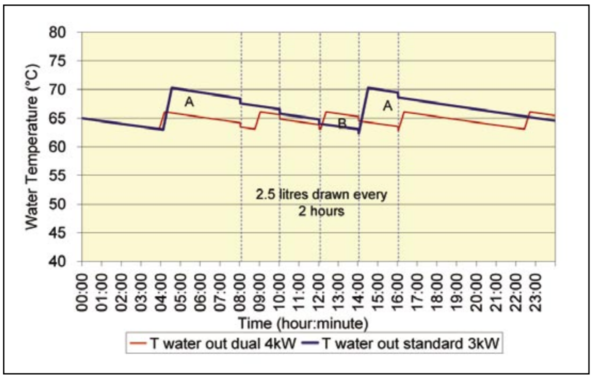

Fig. 3: Small frequent water withdrawals typical of daily usage.

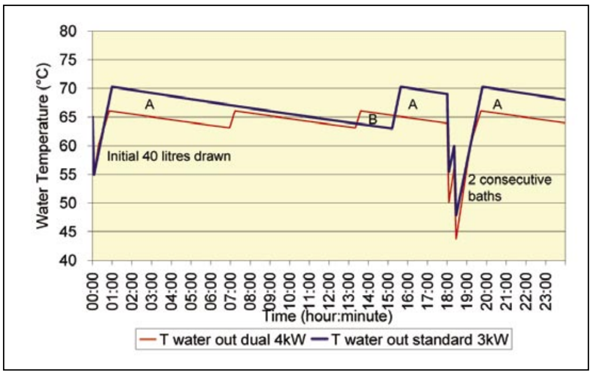

Fig. 4: Large water withdrawals (bath time) e.g. 40 litres.

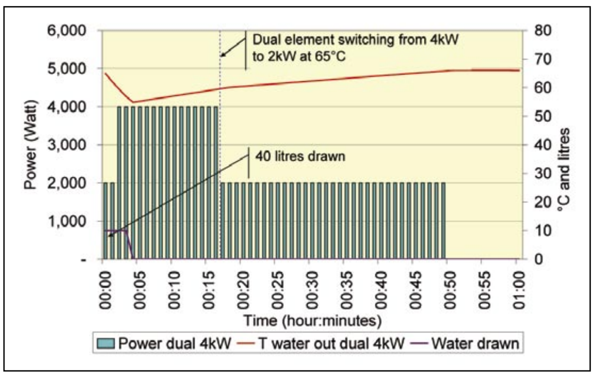

Fig. 5: Indication of DE power system consumption during large withdrawals.

thermostats switching on, the conventional 3 kW system overheats by an average of 4°C more than the DE, causing a larger oscillation around the setpoint. The DE regulates closer to the setpoint with a lower degree of overshoot. It was found that there is always at least 4°C difference in overshoot between the DE unit and the conventional element. This difference is depicted by Areas A where the standard unit uses more energy (area under the curve). Typically it amounts to 200 - 400 Wh depending on the HWC size. This is wasted energy which adds up to at least 18 kWh per HWC per month if only 3 small withdrawals are made during the day (200 Wh x 3 withdrawals x 30 days). For 5 withdrawals per day it increases to at least 30 kWh per HWC per month. This does not include any standing heat losses.

Lowering the thermostat setting of the standard 3 kW unit to limit the overshoot to the same level as the DE 4 kW resulted in the switch on level to decrease to under 55°C which is unacceptably cold. The reason for the difference of 4°C lies in the lower energy input by only one 2 kW DE element activated above 60°C.

This 2 kW is 33% less than the 3 kW standard unit which remains on at full power until setpoint is reached. The DE lower energy level input close to setpoint gives more time for heat transfer throughout the water cylinder resulting in the more consitent, and closer to setpoint reaction, of the thermostat.

Large hot water withdrawals

The problem with large withdrawals is not as big as with small withdrawals. If a bath of, say, 4 litres of hot water is drawn, the 7,5 litres of hot water left in the 15 m pipe to cool down is only 18,75% of the water consumed.

As can be seen in Fig. 4, similar to the small withdrawals the phenomena is the same whereby the 4°C difference in overshoot is visible for large withdrawals. Again areas A clearly indicate the wasted energy with every activation of the thermostat. One may correctly comment that the slightly higher water temperature of the 3 kW unit will result in less water being withdrawn for baths i.e. withdrawing 40 litres from a standard 3 kW system at 70°C implies taking 48 litres from the 4 kW DE at 66°C. Generally this energy difference amounts to not more than 50% compared to the wasted overshoot energy and will still result in a nett loss of just more than 200 W due to the overshoot during reheating. Note that for small withdrawals during the day the amount of water taken on both the standard and DE systems have been confirmed to be on average the same, therefore there is no energy saving of taking less hot water from the warmer 3 kW system as there potentially is with baths. The nett effect for small withdrawals is therefore a much higher waste of energy.

From Fig. 5 one can note the following. The first 2 kW element of the DE is activated at 63°C which is reached soon after the large withdrawal is started. Once the water temperature decreases further, to less than 58°C, the second element is activated to give full 4 kW power for reheating. The reaction time back to 60°C water temperature is approximately 15 - 16 minutes whereafter the 4 kW is reduced to 2 kW by the switching off of the lower level (60°C) thermostat.

To make the reaction of each heating system clear, the same initial water temperature of 65°C was used for both. The 4 kW DE's higher energy input results in the usable 60°C barrier being reached 5 minutes sooner than the conventional 3 kW unit. With the DE system switching to only 2 kW changes the heating gradient to slowly and more accurately creep up to the 65°C setpoint.

Fig. 7 reflects the power input condition of the sequence illustrated in Fig. 6. Both the 3 kW standard and 4 kW DE initially react (activates) almost simultaneously. The DE peaks to 4 kW for quick reaction time and after 15 minutes decreases to 2 kW. The 3 kW remains on for the full period of 58 minutes, worsened by the 4°C energy wasting overshoot. The maximum power input of 4kW is a 33% increase compared to the standard unit but to the benefit of the consumer giving him quicker response time.

Using a 3 kW DE system (1,5 kW + 1,5 kW)

If the municipality is worried that the additional 33% demand will cause a higher maximum demand, the two 2 kW elements can be replaced by two 1,5 kW elements.

From Fig. 8 the difference in the on times and size of the load is clear.

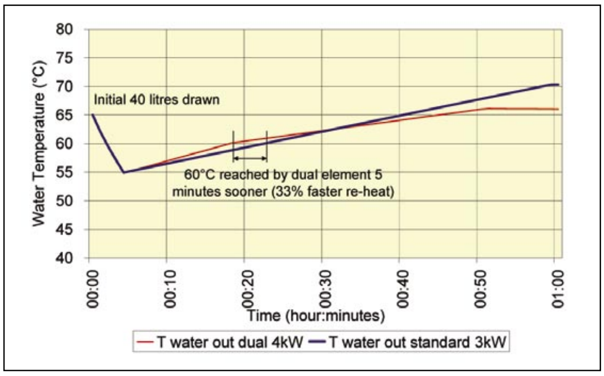

Fig. 6: Temperature comparison during reheat.

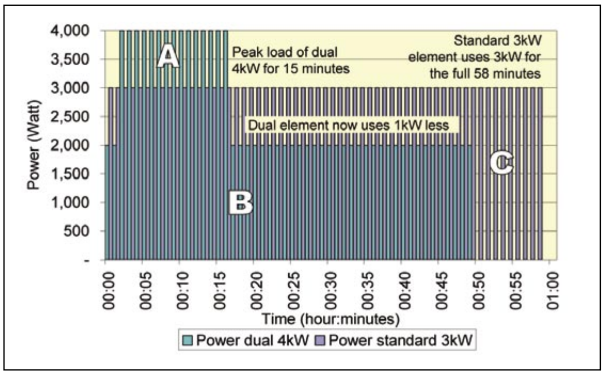

Fig. 7: Power comparison during reheat.

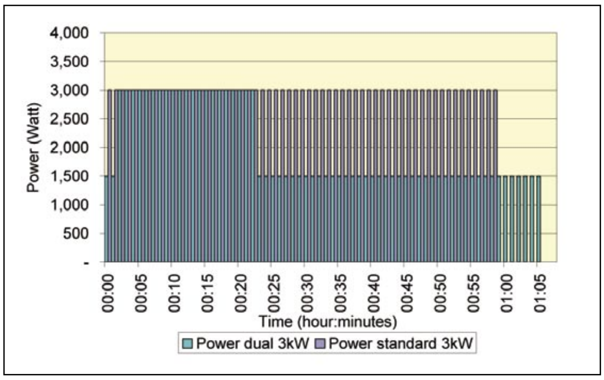

Fig. 8: Power comparison during reheat, 3kW standard vs. 3kW dual.

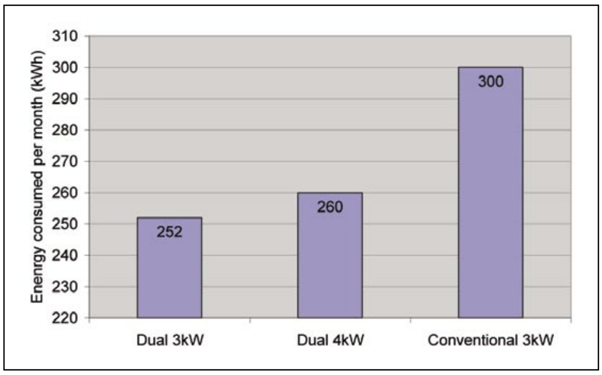

Fig. 9: Monthly consumption for different options

The impact of the dual element on energy saving

Proof by tests, measurements and theoretical verification shows that a minimum of 40 kWh per month can be saved per DE installation. This equates to (40 000 Wh/(30 days x 24 hours)) = 55,55 W saving in demand per DE installation.

Annual HWC element sales in South Africa total more than 720 000. If 50% of the annual sales were DE type, then the saving in demand would be 360 000 x 55,55 W = 19 998 MW.

Fig. 9 shows the monthly energy consumption of the HWC for a house with two people.

The reduction is clear. It must be emphasised that the dual 3 kW system will take longer to turn off than any one of the other options. This may cause cold water complaints. The dual 4 kW system, on the other hand, according to Fig. 7, reheats the water the quickest.

Additional benefits

The following are additional benefits:

- The DE successfully reduces overshoot and improves temperature control resulting in at least 30 – 50 kWh energy saving (HWC size depending) per HWC per month.
- The 4°C lower average HWC cylinder temperature plus reduction in heat losses from 4°C cooler piping give at least a further 17 kWh saving in standing heat losses per HWC per month.
- Given the facts above, a very conservative minimum saving of 40 kWh per HWC per month with a DE system is definitely achievable. This represents a saving of at least 13% of 300 kWh per month.
- More than 50% reduction of lime build-up in geyser storage tanks and on the heating elements due to improved control and lower DE heat flux of 0,05 W/mm^2 compared to the 0,1 W/mm^2 of the conventional element.
- Accelerated reheating by the 4 kW dual element decreases the reheating time by 50% in 100 litre HWCs and 33% in 150 litres HWCs. During the long periods of low demand only 2 kW is activated when required compared to the 3 kW of the conventional element.
- Lower thermostat switching currents result in a longer life for the thermostat. Current is reduced from 13,0 A 8,7 A per thermostat in the DE system.
- Redundancy in having two independent elements with thermostats. This offers back-up should one of the two elements or thermostats fail.

Conclusion and recommendations

The energy supplier will have a higher peak load, but for a shorter period of 15 minutes, less than 30% of the time of the 3 kW unit's full demand time. This should be manageable with efficient load control, especially since the duration of the peak is reduced to only 33% of the standard 3 kW HWC.

There is an even bigger saving with the dual 3 kW system, but it must be emphasised that the dual 3 kW system will take longer to turn off than the other options. This may cause cold water complaints. The dual 4 kW system, on the other hand, reheats the water the quickest.

Acknowledgement

This paper was first presented at the Domestic Use of Energy Conference held at the Cape Peninsular University of Technology in April 2006, and is reproduced with permission.

References

[1] Delport GJ. The Geyser Gadgets that work / do not work. Paper presented at the 13th Domestic Use of Electrical Energy Conference, Cape Town, 29 - 31 March 2005. Paper included in the conference proceedings, page 139 - 144.

[2] http://www.owenscorning.co.za

Contact Johan delport, johan.delport@absamail.co.za ❖