Cape Peninsula
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EFFECTIVE GEYSER MANAGEMENT THROUGH INTELLIGENT HOT WATER USAGE PROFILING

By

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DECLARATION

I, Quinton Shaun Catherine, declare that the contents of this dissertation represent my own unaided work, and that the dissertation has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.

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Signed	Date

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ABSTRACT

This study presents an intelligent Hot Water Cylinder (HWC) usage profiling system to provide peak demand side management and improve HWC efficiency in a typical household. In this research HWCs will be referred to as geysers.

Research was done into various techniques available to improve energy efficiency in South Africa, as well as the different sectors South Africa's electricity supplier, Eskom, has highlighted where improvements in energy efficiency can be made. From this it was decided to refine the scope of the project to the residential sector, and more importantly geyser. A typical geysers operation and power consumption was researched and analysed to determine where efficiency improvements could be made. A system was required that would reduce the amount of energy consumed by the geyser, and provide the consumer with hot water at the same time. Based on the research it was decided to design a profile based geyser controller. The profiling system comprised of a PIC microcontroller, four digital temperature sensors and a time keeper used to determine individually based hot water usage profiles for the home. The profile was based on three parameters, namely the frequency (repetitiveness) of hot water being drawn, the length of the draw period, and the time of day when the water was drawn. Once the profile had reached a 90% accuracy, the profile implemented itself. Based on the profile, the controller then regulated the temperature of the geyser according to the demand of the household, without manual intervention. If the household's routine were changed, the profile would adapt itself accordingly. The controller is therefore fully intelligent and continues to refine the profile on a day to day basis. By introducing the profile based controller, the monthly average geyser temperature was reduced, reducing the amount of standing losses, which in turn reduced the total amount of energy consumed by the geyser. The profile controller was designed to aid in the reduction of the energy demand of geysers on the power grid. This will benefit both the consumer as well as Eskom, as Eskom will have a reduced power load, and the consumer will have a reduced electricity bill. The results of the experiments are shown, as well as a comparison between calculated versus measured results, to justify the accuracy of the calculations.

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LIST OF ABBREVIATIONS

AC - Alternating Current
BCD - Binary Coded Decimal
CMD - Command
CRC - Cyclic Redundancy Check
°C - Degree Celsius
DSM - Demand Side Management
DC - Direct Current
EEPROM - Electrically Erasable Programmable Read-Only Memory
GWh - Gigawatt hour
Hz - Hertz
HWC - Hot Water Cylinder
I^{2}C - Inter-Integrated Circuit
kW - kilowatt
ℓ - litre
MW - Megawatt
RTC - Real-time clock
SD - Secure Digital
SL - Service Level
SLP - Service Level Prediction
SPI - Serial Peripheral Interface
TOU - Time of Use
W - Watt

Chapter 1

INTRODUCTION

1.1 Problem Statement

Due to the recent power outages and increase in electricity tariffs, a market has opened for a system that can save the consumer money by reducing the household's energy demand. If the demand on Eskom is not reduced, additional power stations need to be built to accommodate this increase in demand.

Currently, during peak times, the demand for electricity exceeds the capacity to supply. This forces Eskom to cut power to certain areas. These power outages result in large financial losses to companies and business owners, not to mention disrupting individuals' day-to-day operations.

As the population increases, there is an increase in housing construction, increasing the energy demand. For these reasons, there is a market for systems that can increase energy efficiency and reduce the total energy demand from Eskom.

1.2 Background

The economy is expanding and the amount of people with access to electricity has increased from 61.3% in 1995 to 84.9% in 2004 as shown in Figure 1.1 (*Bredekamp, et al.,* 2006:211-216).

From 1994 to 2007, Eskom has seen a total energy demand growth of 50% (*Etzinger,* 2008).

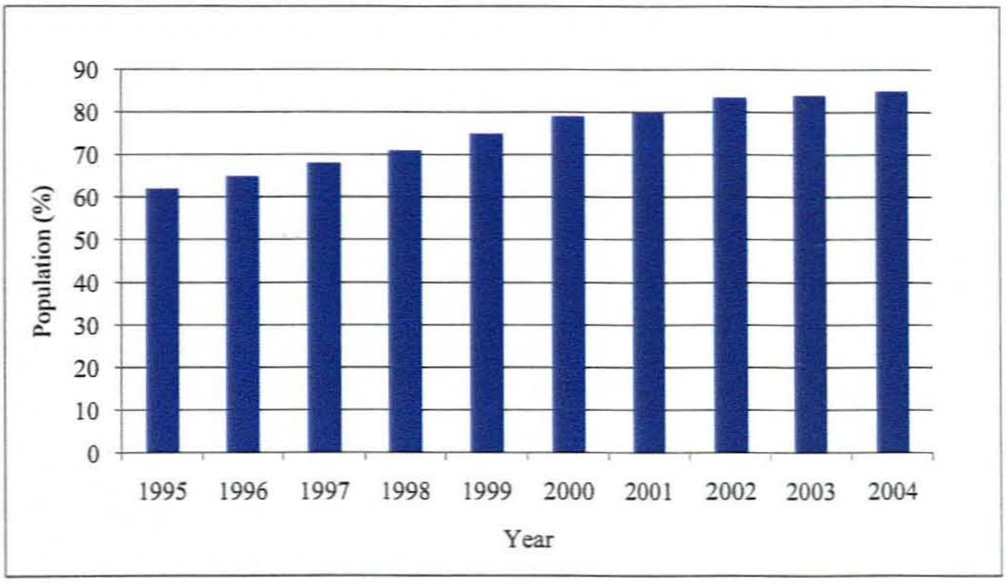


Figure 1.1: Population (%) with access to electricity for the years 1995 to 2004
(*Bredekamp, et al.,* 2006:211-216)

In the first quarter of 2006, the first of many power cuts started, as the energy supplier (Eskom) could not accommodate this increase in energy demand, especially during peak times. Since these power cuts, there has been a serious need for improvement in energy efficiency (*Eskom,* 2006).

In order to solve the energy crisis, Eskom introduced Demand Side Management (DSM). DSM involves the planning, implementation and monitoring of energy strategies to encourage end-users to use energy wisely (*Bredekamp, et al.,* 2006:211-216).

The DSM projects are aimed at three main sectors, namely residential, industrial/mining, and commercial sectors. These projects aim to reduce the energy demand on Eskom during the peak times of the day. These peak periods are derived from "Time of Use" (TOU) tables, which indicate the energy demand by households at various times of the day (*Singh and Dekenah,* 2006). Figure 1.2 shows the energy load profile, measured in megawatt (MW), on Eskom during 2007. In the figure, the peak times are from 07:00 to 10:00 in the morning and from 18:00 to 20:00 in the evening.

By reducing or shifting some of the peak demand to non-peak times, the load on Eskom during peak times can be reduced.

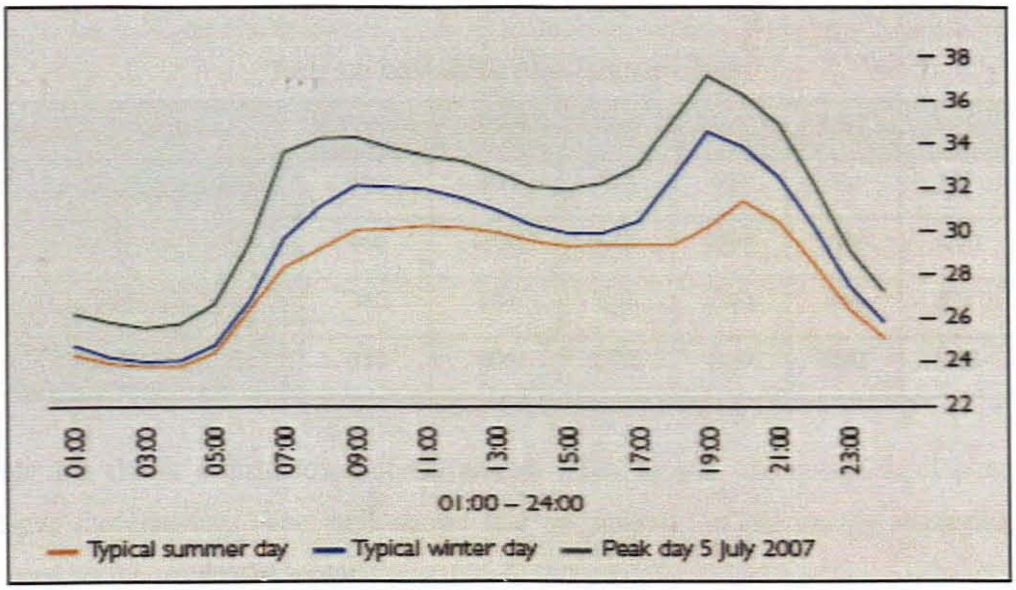


Figure 1.2: Energy load profile in GW for 2007 (*Eskom,* 2008)

The residential sector consumes around 17% of the total energy supplied by Eskom during non-peak times. The peak demand of each of the three sectors is shown in Figure 1.3. As seen in the figure, the residential sector consumes around 30% of the total energy during peak times (*Eskom,* 2006).

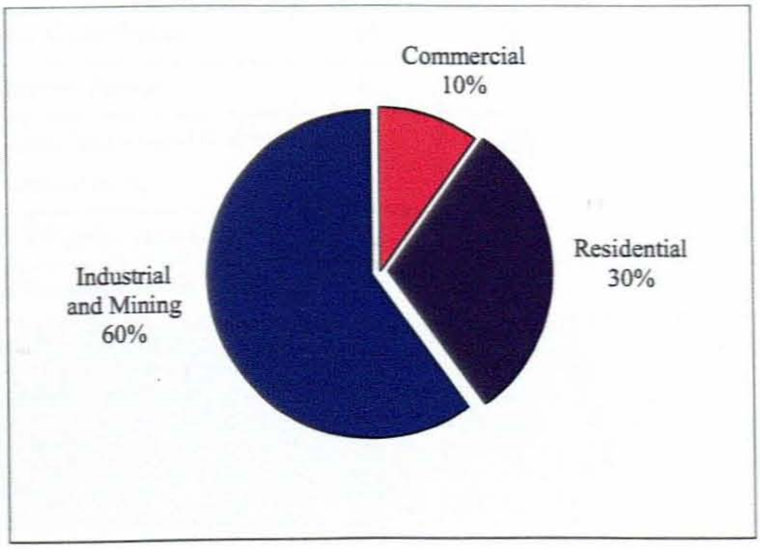


Figure 1.3: Peak electricity consumption per sector (*Eskom,* 2006)

Eskom has several DSM projects running, which aim to reduce the overall energy demand by 3000MW by the year 2012. The long-term goal is to save 8000MW by 2025 (*Etzinger,* 2008). The DSM annual target breakdown is shown in Table 1.1.

Table 1.1: DSM annual targets (*Etzinger,* 2008)

	2007	2008	2009	2010	2011	2012
Annual Demand (MW)	400	800	700	600	400	100
Cumulative (MW)	400	1200	1900	2500	2900	3000
Annual Energy (GWh)	350	556	930	1262	944	521
Cumulative (GWh)	350	906	1836	3098	4042	4563

Table 1.2 shows a breakdown of the annual DSM targets and how Eskom plans to achieve these savings. The table shows that the majority of the energy strategies are focused on the residential sector.

Table 1.2: DSM 4 year plan (*Etzinger,* 2008)

	2008/9	2009/10	2010/11	2011/12
PROGRAMMES	MW	MW	MW	MW
RESIDENTIAL				
Efficient Lighting (CFLs)	484	50	100	634
Solar Water Heating	16	50	100	166
Shower Aerators	5	10	20	35
Load Reduction (smart meter & time of use tariff)	20	415	450	885
Geyser & Pipeline insulation	1	50	50	101
Household Cooking Convert to Gas	36	123	130	289
COMMERCIAL	60	35	40	135
INDUSTRIAL	131	70	57	258
RE-DISTRIBUTION	47	30	20	97
TOTAL	800	833	967	2600

The environment is also impacted, as for every kilowatt-hour (kWh) of electricity saved, one less kilogram of carbon dioxide is generated by the power station and released into the atmosphere (*Eskom,* 2006).

As mentioned, the residential sector consumes 17% to 30% of the energy supplied by Eskom. Geysers are responsible for 30% to 50% of this demand (*Eskom,* 2006). Table 1.3 shows the breakdown of the electricity consumed in a residential home. The table shows that the geyser was the major contributing factor to the electricity consumption, as it amounted to 36% of the total energy demand.

Table 1.3: Residential electricity consumption (*Harris, et al.,* 2008: 141-148)

	ELECTRICITY CONSUMPTION	
	RESIDENTIAL	
APPLICATION	**kWh/year**	**(%)**
Water Heating	**4259**	**36.1**
Washing	326	2.8
Cooking	2447	20.7
Space Heating	404	3.4
Refrigerator/ Freezer	1829	15.5
Lights	1766	15
Other Appliances	766	6.5
Total	**11797**	**100**

1.3 Research questions

From the research, it was evident that geysers are one of the major contributing factors in residential energy consumption. This led to the conclusion that in order to reduce the energy demand of the residential sector, the energy efficiency of geysers needed to be improved. The energy consumption of geysers is explained in more detail in section 2.1.2. This then lead to the following research questions:

a) Can an accurate hot water usage profile be developed for a typical household?
b) If implemented does the profile reduce the standing losses experienced by the geyser?
c) Is the total energy consumption of the geyser reduced by implementing the profile, without inconveniencing the household?
d) Can the proposed profile controller be manufactured economically?

1.4 Objectives

The main objective of the research was to improve geyser efficiency and by doing so reduce the overall demand on Eskom. The following steps were followed:

- Research geysers and determine where energy savings can be made;
- research current control systems and compare attributes;
- propose and develop control topology for a geyser;
- test accuracy of control topology and implement into 10 homes and,
- carry out a case study on 10 homes to determine whether energy savings were achieved.

1.5 Delineation of research

This research focuses mainly on how to increase residential geyser energy efficiency and reduce peak demand by using an inexpensive, profile based control topology to determine hot water usage patterns in residential homes.

1.6 Significance and contributions of research

The study is of importance as it will benefit both the consumer and Eskom. By reducing the demand from the residential sector the total energy demand on Eskom will be reduced. This then will aid in the need for more efficient use of energy.

By increasing the energy efficiency in residential homes, less electricity will be wasted, resulting in a reduced monthly electricity bill for the home owner.

In summary, through the use of the intelligent geyser profiling system the home owner will be able to aid Eskom with their Demand Side Management (DSM) goals, without inconveniencing themselves, and save money at the same time.

1.7 Chapter structure

A literature study is done in **Chapter 2**, involving geysers and how they can be made more efficient, as well as the current topologies/ control techniques available for geysers. A comparison is then done between these control systems.

A control technique for geysers is introduced in **Chapter 3**. A detailed explanation is given about its design and control structure, focusing on energy efficiency. A step by step explanation is also given for the different development stages involved in the design.

Chapter 4 highlights the results obtained from the controller. Savings are calculated and a payback period deduced. A comparison is also done between calculated and measured savings in order to verify the results.

Finally, **Chapter 5** concludes the research by summarising all the chapters, the features of the controller and the results obtained. Recommendations are also made for future work in this field.

Chapter 2

CURRENT TECHNIQUES USED TO IMPROVE GEYSER EFFICIENCY

2.1 Introduction

This chapter investigates geysers, how they operate and how they can be made more efficient. A breakdown is given of the current control techniques available for geysers. A comparison is also done between these control systems, defining the scope of the project.

2.2 Geysers

2.2.1 Geyser operation and layout

Geysers are pressurised hot water containers, which are used to supply hot water to households. These containers are supplied via the mains (220VAC). A thermostat is used as a control switch to regulate the temperature of the water by adjusting the heating duration of the element. When the temperature reaches the set point on the thermostat , the element is switched off as shown in Figure 2.1.

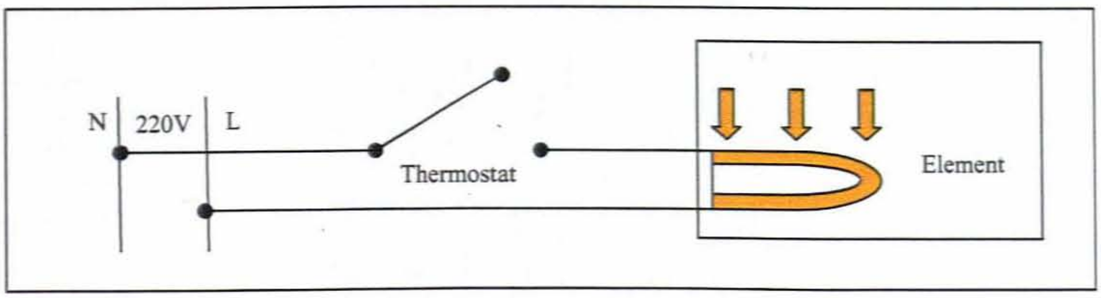


Figure 2.1: Block diagram of element off state

When the temperature of the geyser drops to approximately 6°C below the set point, the element is switched on and the water heated to the set point as shown in Figure 2.2 (*Harris, et al.*, 2008:141-148).

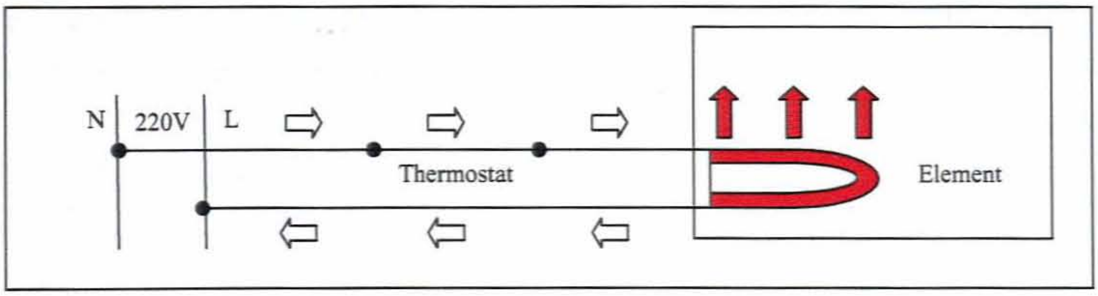


Figure 2.2: Block diagram of element on state

Figure 2.3 shows the typical layout of a geyser. As the water inside the geyser is heated by the element, the pressure inside the geyser increases. If the thermostat were to fail (i.e. short circuits and fails to switch the element off) the pressure inside the geyser would continue to increase. The geyser has a safety valve (6), whereby if the pressure has reached a certain point, the safety valve opens, releasing some of the pressure. If this is not done, the geyser may explode, resulting in water and structural damage. This is not ideal and is considered in the final design of the geyser controller.

1. Element
2. Thermostat
3. Anode
4. Pressure valve
5. Drain valve
6. Safety Valve
7. Tank
8. Flange
9. High density insulation
10. Drip tray
11. Drip tray overflow pipe
12 .Vacuum breaker
13. Outer Casing

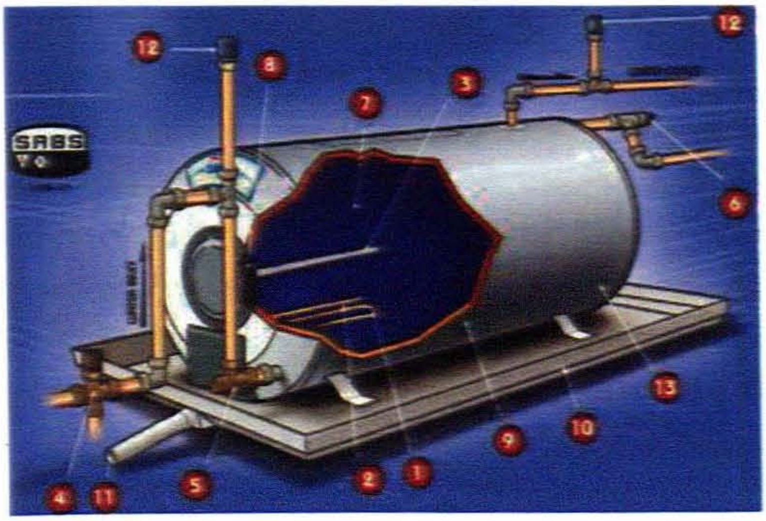


Figure 2.3: Geyser layout (*The Geyser Alliance Products (PTY) LTD*, n.d)

As a safety feature, the condition of the thermostat and heating element should be monitored every 5 years. The reason being, the element may be heating the water, but could be drawing exceptionally high loads. This may be due to calcium build up on the heating element. Calcium salts are present in the main water supply and unlike most substances, these calcium salts become less soluble at high temperatures. Over time, the unsolved salts gather, causing calcium build up (*Harris, et al.*, 2008: 141-148).

2.2.2 Geyser energy consumption

There are two common sizes of geysers found in residential homes. A 3kW, 150ℓ unit which can supply 2-3 people, and a 4kW, 200ℓ unit which can supply 4-5 people (*Monyane, et al.*, 2008: 105-109). Geysers use electricity in one of two ways, either through hot water consumption or through standing losses (*Delport*, 2006: 57-61).

a) Hot water consumption

When hot water is drawn from the geyser, cold water is used to replace the amount of water drawn. This results in a decline in geyser temperature. Once below the set point, the thermostat closes, switching on the heating element. The greater the consumption, the more electricity required to reheat the cold water to the thermostat set point.

In Figure 2.4, time interval 11:00 to 12:00, hot water was drawn, as there was a sudden decline in the geyser temperature (T_Geyser). Once the geyser temperature dropped below the set point, the element switched on (Element_On), reheating the water. In the time interval 19:00 to 21:00 another draw period occurred. This draw was longer than the one in the interval 11:00 to 12:00, resulting in a more significant drop in the geyser temperature. The element then switched on, but due to the greater consumption, the element had to be kept on longer to reheat the water to the same temperature. This just demonstrates the concept mentioned in the paragraph above. (*Delport*, 2006: 57-61).

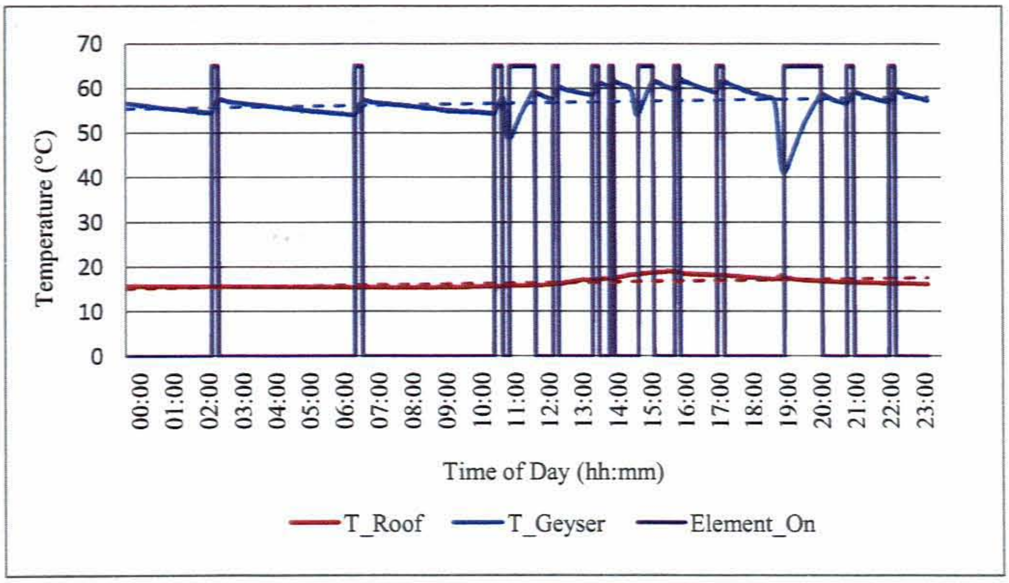


Figure 2.4: Element switching over 24 hour period

In order to reduce water consumption, devices such as water-saving, flow-restricting or aerated showerheads may be used. These showerheads either mix air with the water or reduce the flow at which water flows from the showerhead, i.e. reduce the ℓ/minute (*Harris, et al.*, 2008: 141-148).

The length of the hot water draw period was therefore not the main area of concern, as research showed (*Guy, et al.*, 2007) that this was dependant on a number of factors, each relating to the individual needs of the consumer, e.g. would the consumer adjust to the use of restricted flow showerheads. For this reason the main focus became the geyser temperature and standing losses.

b) Standing Losses

In an ideal system when a geyser heats the water to the required set point, the temperature would stay constant until water is drawn. Standing/ heat losses represent a real system and occur when the heat of the water inside the geyser is dissipated through the casing, as well as through the outlet pipes. The higher the geyser temperature and the colder the ambient temperature, the higher the rate at which the heat is lost (*Delport*, 2006: 57-61).

Standing losses incurred due to heat dissipation in the pipes and the geyser casing can be calculated using equation (2.1) (*Delport*, 2005: 139 – 144):

$$q_{losses} = \frac{(T_h - T_{ambient})}{\frac{\Delta x}{k} + \frac{1}{h}} \qquad (2.1)$$

where:

q_{losses} = heat loss in W/m^2
T_h = water temperature inside the geyser (°C)
$T_{ambient}$ = air temperature outside geyser (°C)
Δx = thickness of the insulating layer (m)
k = thermal conductivity (W/m.K)
h = surface heat temperature coeffient (W/m^2.K)

In this study, for all calculations relating to q_{losses}, a standard 150ℓ geyser was used. The thickness of the insulating layer or wall thickness of the geyser is taken as 0.035m, the conductivity is 0.055W/m.K and the surface heat temperature coefficient is 6.3W/m^2.K (*Delport*, 2005: 139 – 144).

In order to calculate the amount of energy (Watt) dissipated by the geyser per hour, the q_{losses} (W/m^2) must be multiplied by the area of the cylinder (m^2). The shape of the geyser is cylindrical and the area of a cylinder is given by equation (2.2) (*Sidebotham*, 2002: 143):

$$A = 2\pi r^2 + 2\pi rh \qquad (2.2)$$

where:

r = radius = 0.219m
h = height which is length = 1m

Using the more common 150ℓ geyser as an example the area was calculated to be 1.677m^2. For example, if the thermostat is set to 65°C and the ambient temperature is 20°C, the amount of energy dissipated (standing losses) by the geyser amounts to 2.278 kWh per day. If the thermostat is set to 55°C and the ambient temperature at 20°C, the standing losses amount to 1.772 kWh per day. By lowering the thermostat temperature to 55°C, the standing losses of the geyser are reduced by 0.506 kWh per day.

Setting the thermostat temperature to 45°C, the standing losses amount to 1.266kWh. This results in a saving of 1.012 kWh per day or 31.372 kWh per 31-day month when compared to that of a thermostat set at 65°C. Taking the cost of electricity at R0.4738 per kWh as on the 14/11/08, a savings of R14.86 is possible. By reducing the thermostat temperature, the amount of energy required to maintain that temperature is also less, resulting in less energy consumed (*Delport*, 2006: 57-61). If all the geyser temperatures in residential homes are reduced, without inconveniencing the household, the demand on Eskom can be reduced significantly (*Mathews & Kleingeld*, 1995: 45-52).

Table 2.1 shows the summary of standing loss savings achievable when comparing different thermostat settings to that of a thermostat set to 70°C. The ambient temperature was taken at 20°C and the cost of electricity at R0.4738 per kWh as on the 14/11/08. At 70°C the losses equal to 2.531 kWh/day.

Table 2.1: Summary of standing loss savings achievable for a single geyser

Thermostat Setting Option	Lowered Thermostat Setting (°C)	Standing Losses (kWh)/day	Usage at 70°C/day	Savings (kWh)/month	Savings (R)/month
1	65	2.278	2.531	7.84	R3.72
2	60	2.025	2.531	15.69	R7.43
3	55	1.772	2.531	23.53	R11.15
4	50	1.519	2.531	31.37	R14.86
5	45	1.266	2.531	39.22	R18.58
6	40	1.012	2.531	47.01	R22.31

2.2.3 Geyser notch testing

Research done by (*Delport*, 2006:47-50) used notch testing to determine the geyser load profile for 2800 geysers for both winter and summer months. The term "notch testing" refers to the switching off of all geysers for a short period, where after they are switched back on. The resultant dip in the load profile is what is known as the "notch," and represents the total geyser load for that period of testing (*Harris, et al.*, 2008: 141-148).

The geyser load profiles for both winter and summer are shown in Figure 2.5. Due to the colder winter months, the average ambient temperature is lower than that of the average ambient summer temperature. An increase in energy consumption is shown from summer to winter to compensate for this decline in ambient temperature.

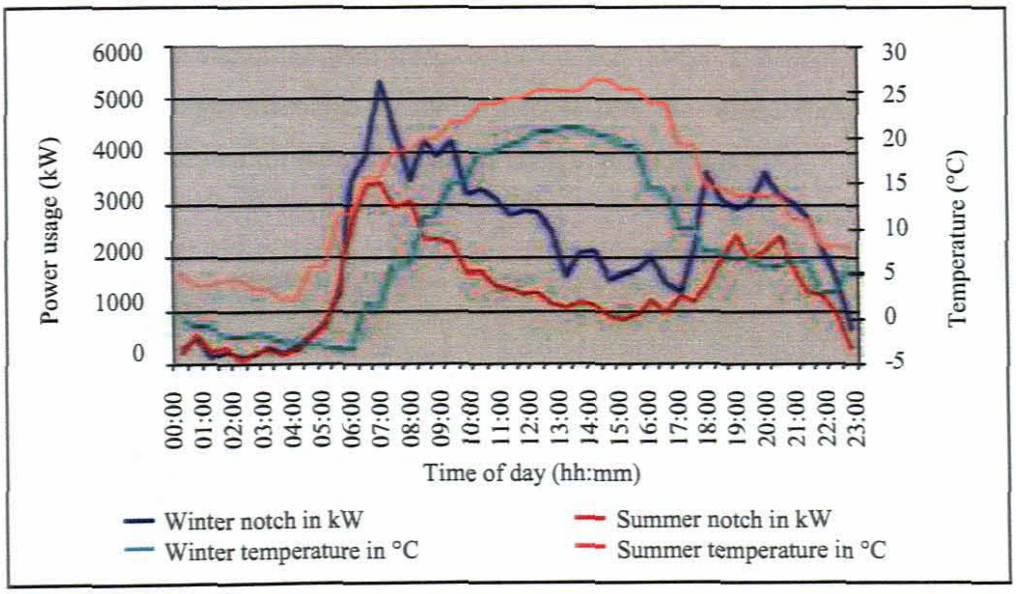


Figure 2.5: Notch tests for 2800 geysers (*Delport*, 2006:47-50)

By using equation (2.1) and (2.2) the hourly standing losses were calculated for summer and winter. Figure 2.6 shows the hourly standing losses calculated using the results obtained from the notch tests in Figure 2.5. The standing losses calculated in Figure 2.6 are more in winter than in summer due to a greater difference between the ambient temperature and the temperature of the geyser in winter (see section 2.2.2b) (*Delport*, 2006:47-50).

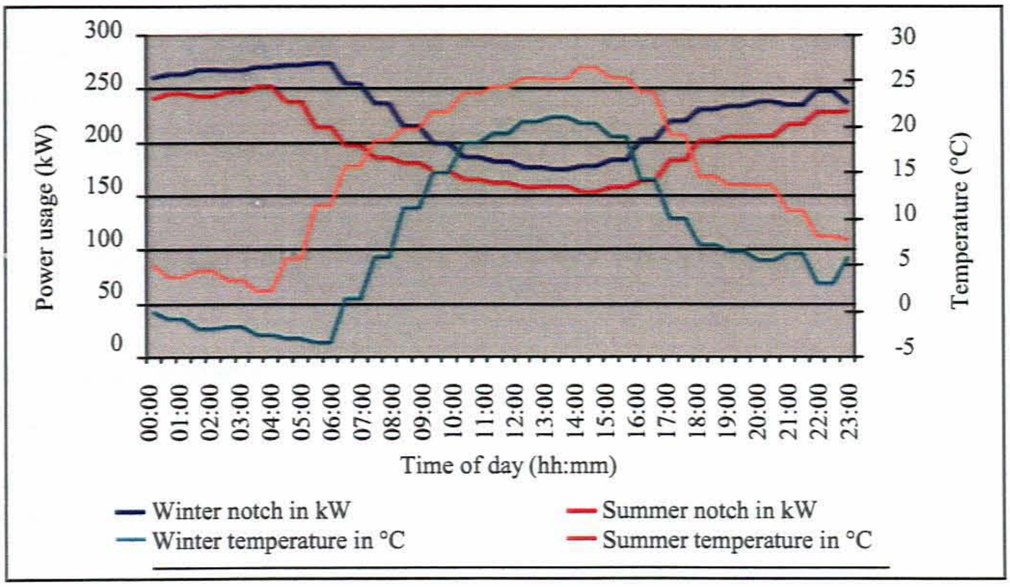


Figure 2.6: Calculated standing losses derived from notch tests (*Delport*, 2006:47-50)

By subtracting the standing losses from the notch test, (*Delport*, 2006:47-50) was able to determine the energy consumed by the geysers to heat the water. Figure 2.7 shows the volume of water drawn for the 2800 geysers used in the notch testing.

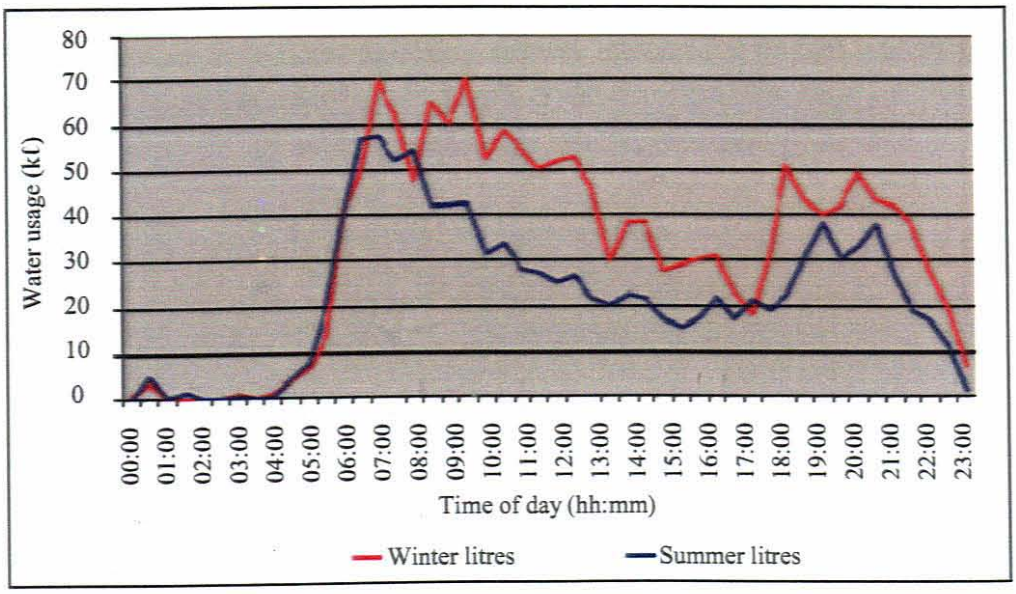


Figure 2.7: Calculated water usage for 2800 geysers (*Delport*, 2006:47-50)

From Figure 2.7 it is apparent that the volume of water drawn is higher during winter than in summer. This may be from to people taking longer showers or baths in winter due to the decline in ambient temperature (*Delport*, 2006:47-50).

2.3 Available geyser techniques to reduce energy usage

2.3.1 Geyser blankets

Research done by (*Harris, et al.*, 2007:153-158) and (*Bosman, et al.*, 2006: 57- 64) revealed that by covering the geyser and pipes to and from the geyser with an insulating blanket, one can significantly improve the geysers efficiency.

Figure 2.8 shows the heating cycle of a 3kW 150ℓ geyser over a 24 hour period. During this period, no hot water was drawn. The energy used in this 24 hour period therefore represented the standing losses experienced by the geyser. The geyser thermostat was set to 65°C and the average ambient temperature for the 24 hour period was 19°C. The standing losses were calculated to be 2.3kWh for the day. The average heating cycle time (intervals between the element switching on) was measured at 6 hours and 14 minutes (*Harris, et al.*, 2007:153-158).

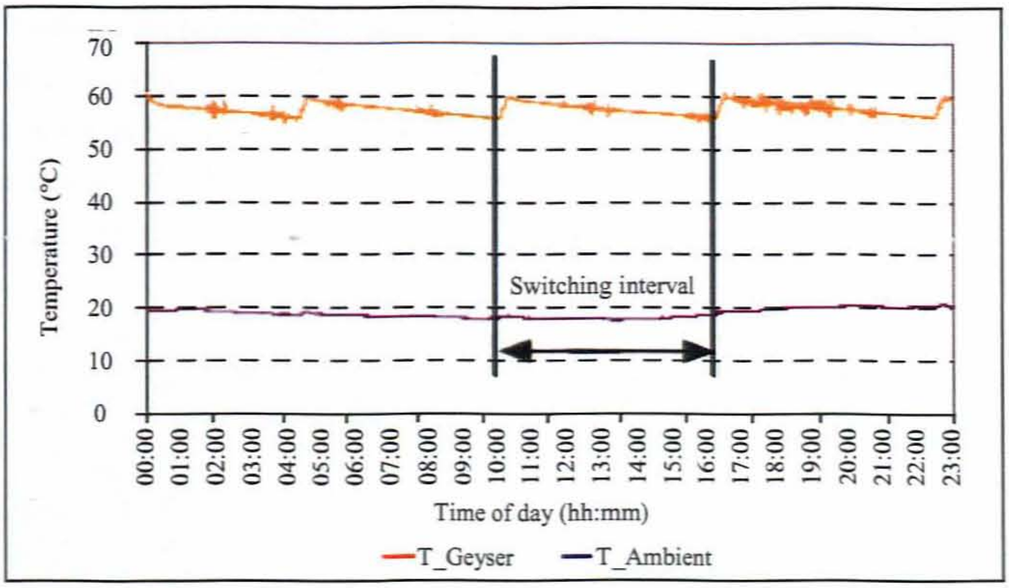


Figure 2.8: Geyser temperature for uncovered pipes and geyser for 24 hour period

(*Harris, et al.*, 2007:153-158)

Figure 2.9 shows the same experiment setup as in Figure 2.8, but with the geyser and the outgoing pipes covered with an insulating blanket. The geyser was monitored over a 24 hour period with the thermostat set to 65°C and an average ambient temperature of 20°C.

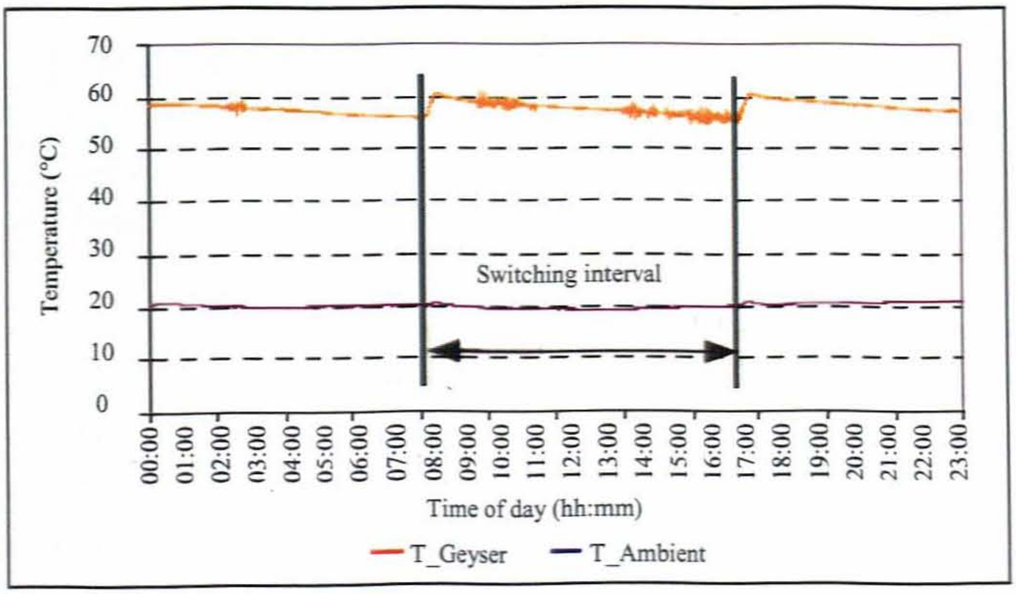


Figure 2.9: Geyser temperature with blanket and pipe insulation for 24 hour period

(*Harris, et al.*, 2007:153-158)

By insulating the geyser and the pipes, the cut in time of the element was increased from 06:14:20 to 09:22:11 (hh:mm:ss). This means less heating cycles, which in turn results in less power being used. Due to the increased cut in time of the element, a kWh/day reduction from 2.3kWh/day to 1.68kWh/day was achieved. This amounted to an overall savings of 27%. The summary of the results obtained are shown in Table 2.2.

Table 2.2: Results from insulating the geyser and pipes (*Harris, et al.*, 2007:153-158)

	Not covered	Pipes covered	Geyser covered	Geyser & Pipes covered
Standing loss (kWh/day)	2.3	2.0	1.8	1.68
Savings (%)	/	13.04	21.74	26.97
Cut-in time (hh:mm:ss)	06:14:20	07:20:39	08:12:59	09:22:11

Bosman et al (*Bosman, et al.*, 2006: 57- 64) did a study on installing geyser blankets to 2kW 100ℓ cylinders. The results obtained were simulated results and not measured. A summary of the results is shown in Table 2.3.

Table 2.3: Geyser with and without geyser blanket (*Bosman, et al.*, 2006: 57- 64)

Temperature setting	Without (kWh)	With (kWh)	Difference (kWh)	Cost (R)
75°C	987	809	178	R84.34
65°C	818	670	148	R70.12
55°C	650	532	118	R55.91

The results of (*Harris, et al.*, 2007:153-158) and (*Bosman, et al.*, 2006: 57- 64) showed that by covering a geyser with an insulating blanket, the efficiency can be improved from 18% to 27%. From Table 2.3 it can be seen that by reducing the geyser temperature from 75°C to 55°C, a larger percentage saving is made than installing a geyser blanket on a geyser set at 75°C. This increases savings from 18% to almost 35%.

As households may not all require hot water 24 hours a day, it will be beneficial to have a system which could reduce the geyser temperature during certain "unwanted" periods of the day.

2.3.2 Dual element system

As the name suggests, the dual element system refers to two elements in one. For example, instead of having a 3kW element, you have two 1.5kW elements together, which form one design, as shown in Figure 2.10 (*Delport*, 2006: 57-61).

Each element has its own thermostat. The thermostat of the one element is set 5°C higher (typically 65°C) than the second (typically 60°C). This allows for an offset between the two elements. When short water draw periods are experienced, e.g. hand or dishwashing, only the higher set element will switch on. If larger amounts of water are drawn, e.g. shower, bath, the second element will be switched on, speeding up the heating process (*Delport*, 2006: 57-61).

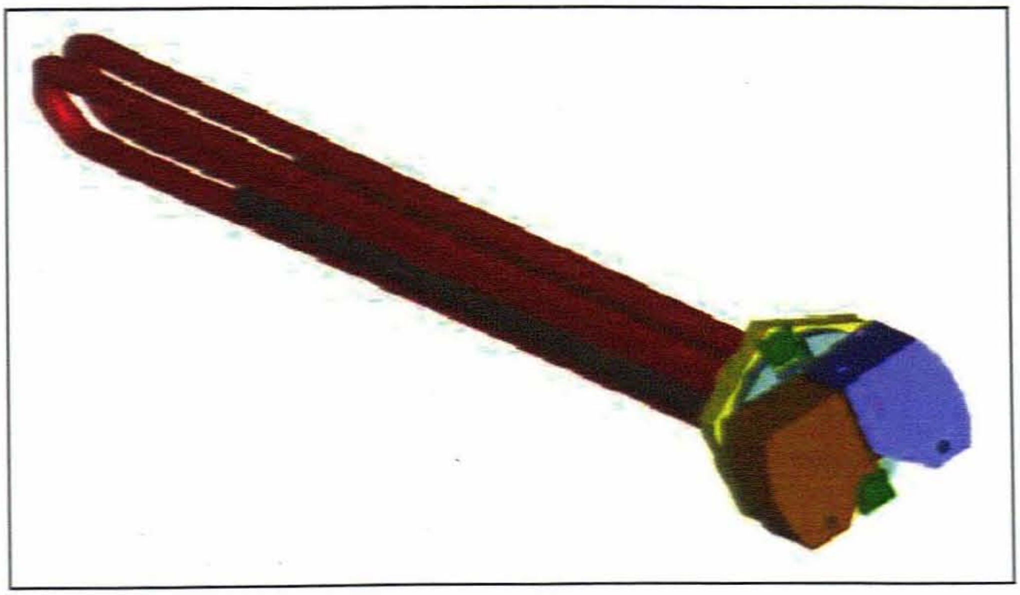


Figure 2.10: Dual element diagram (*Delport*, 2006: 57-61)

a) Short draw periods

When there is a short draw period, e.g. 2.5ℓ of hot water for a hand wash, an extra 7.5ℓ of hot water is required to fill the 15m of pipes leading to the basin.

Once the draw period is complete, the heat from the 7.5ℓ used to fill the pipes is dissipated through the pipes. In this example a 300% energy loss is experienced (*Delport*, 2006: 57-61).

When the geyser is in its reheating cycle, the conventional element may overshoot the set point temperature of the thermostat by an average of 4°C. With the dual element system the overshoot area is reduced as shown by the areas marked A in Figure 2.11. The overshoot typically amounts to 200-400Wh per overshoot depending on the size of the geyser (*Delport*, 2006: 57-61). The dual element system will therefore give a more stable set point temperature, but at the cost of shorter cut in times i.e. the dual element will switch on more frequently, but for shorter periods.

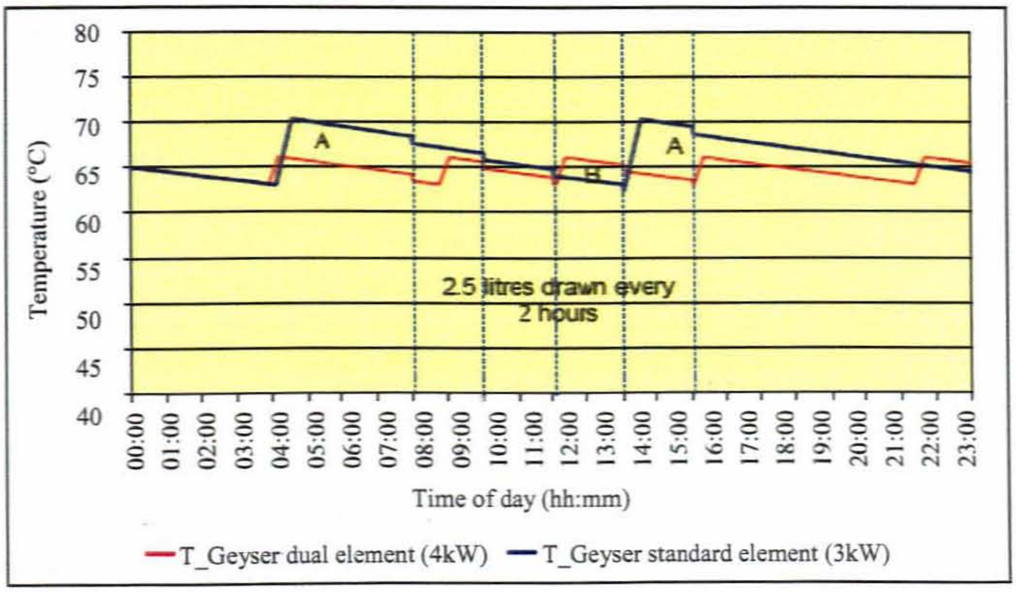


Figure 2.11: Heating cycles for short draw periods (*Delport*, 2006:57-61)

b) Large draw periods

The same heat loss occurs with large draw periods as with short draw periods, however the problem is not as significant. The reason being the water left in the pipes is of a smaller ratio when compared to the total amount of water drawn. For example, 40ℓ of hot water is drawn, the 7.5ℓ of hot water left in the 15m piping only contributes to 18.75% of the 40ℓ consumed and therefore only an 18.75% energy loss is experienced.

Figure 2.12 shows the comparison between the conventional element and the dual element for large draw periods. The overshooting as in the case of short water draws are still present and is shown by A (*Delport*, 2006: 57-61).

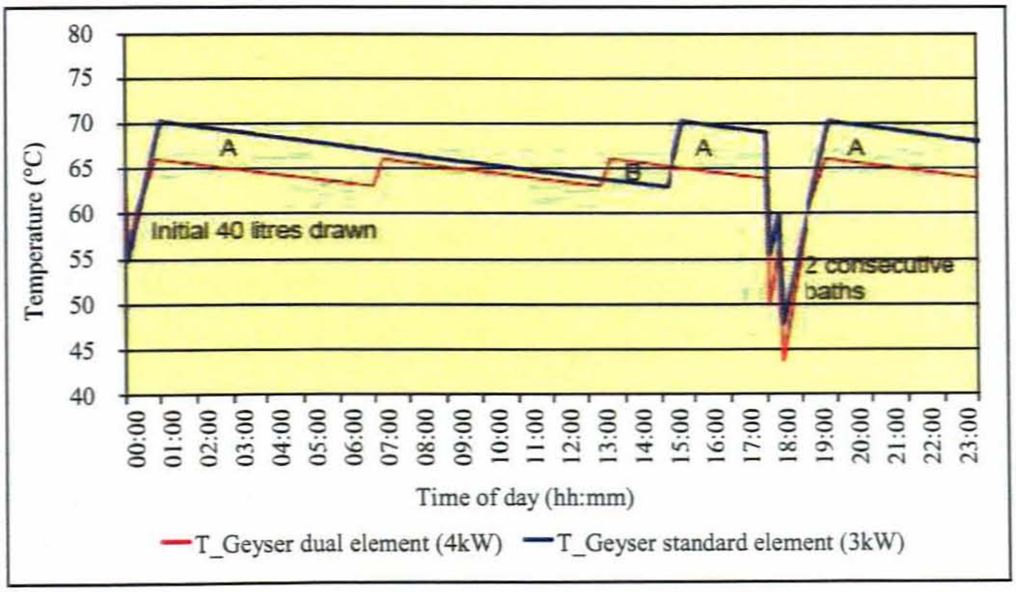


Figure 2.12: Heating cycles for large draw periods (*Delport*, 2006:57-61)

Figure 2.13 shows a comparison between the power consumption of the conventional and the dual element systems. From the figure, a minimum savings of 40kWh per month is possible, which results in a 13% total energy saving (*Delport*, 2006: 57-61).

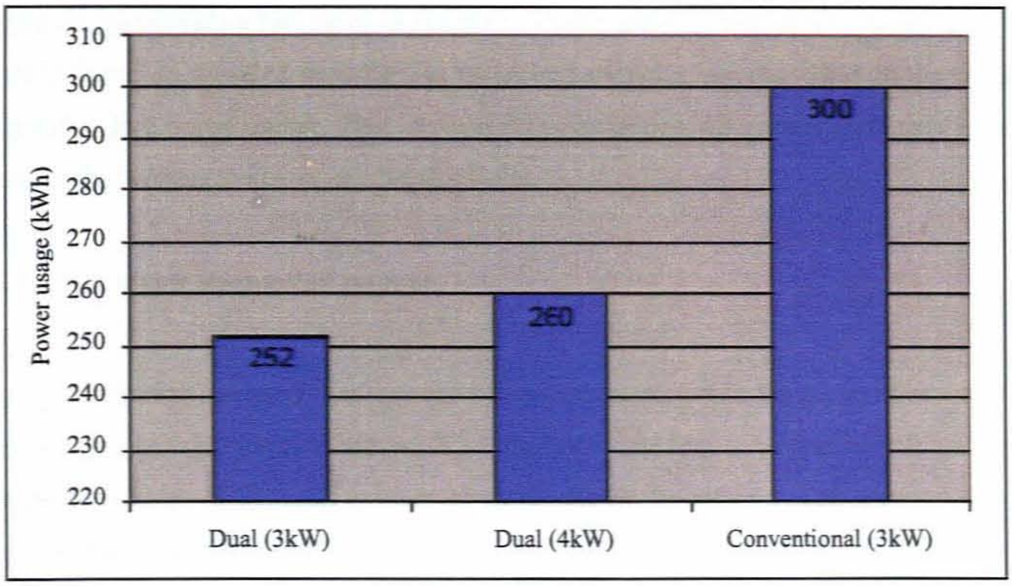


Figure 2.13: Power usage comparisons for a month period (*Delport*, 2006: 57-61)

2.3.3 Ripple relays

The most extensively used control technique in South Africa is ripple control (*Beute, et al.*, 2006: 41-46). Ripple relays are used by municipalities or sub-vending customers of Eskom for DSM to control the loading effect of geysers in the residential areas. The main purpose of the ripple relay is to shift the heating load of geysers out of peak demand times. This is done by switching off the geysers to a large number of homes for short periods during these peak demand times (*Beute, et al.*, 2006: 41-46). Command signals are sent to the ripple relays via the distribution network (mains) or by radio frequency, switching the geysers either on or off (*Pandaram*, 2006: 15-20). The command signals for the relays are sent from the control centre, via the substation, to the consumer's home.

If ripple control is not managed correctly, the relays may insert additional load peaks on Eskom, resulting in additional costs (*Delport, et al.*, 2006: 63-66).

Ripple relays provide a low level of control, as there are only two states, on and off. Hot water is therefore supplied according to tables and statistics, not according to the needs of each individual home owner. This may lead to conditions where home owners have no access to hot water (*Beute, et al.*, 2006: 41-46).

2.3.4 Hot water circulation pumps

Circulation pumps are used to utilise the hot water that is left in the pipes after water has been drawn. As mentioned in section 2.2.2 the hot water left in the piping can amount to a large percentage of the total amount of water drawn. In conventional systems, this hot water is left to cool down to the ambient temperature, resulting in energy being wasted. Figure 2.14 shows a closed loop circulation pump layout. The circulation pump is used to pump the hot water left in the pipes back into the geyser via the cold water pipes (Calmeyer, 2003: 123-128). This saves energy as it reduces the cut in time of the element.

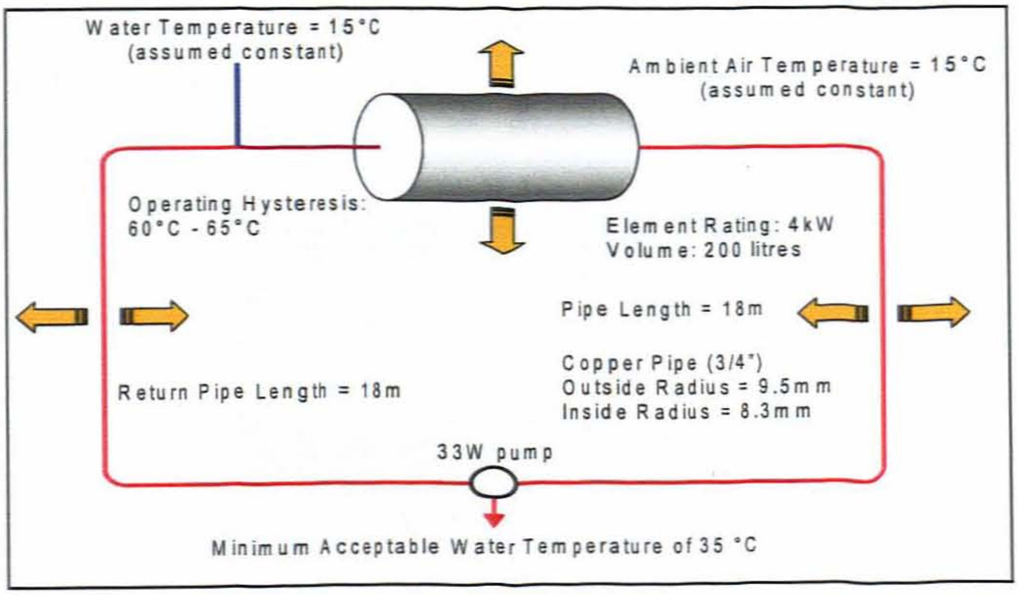


Figure 2.14: Closed loop circulation pump layout (Calmeyer, 2003: 123-128)

An added advantage to this system is that in colder places the continuous circulation of water also prevents the pipes from freezing (Calmeyer, 2003: 123-128).

2.3.5 Programmable Timers

To ensure that the home owner has hot water according to the home's usage profile, a higher level of control was required. Two devices available that provide a higher level of control are the Electro Smart (*Electro Smart*, n.d.) and Geyser Wise (*Geyser Wise*, n.d.) systems.

2.3.5.1 Electro Smart

Figure 2.15 shows the Electro Smart controller. This controller is installed next to the distribution board. It has eight different time settings, i.e. one can set eight different times in the day when hot water is required (*Electro Smart*, n.d.).

The difference between the Electro Smart controller and a timer is that the Electro Smart controller detects current. The heating cycles of the geyser are still controlled according to the times entered by the home owner, but if a heating cycle was in progress, the controller will wait for the geyser to reheat the water, before switching it off (*Electro Smart*, n.d.).

Figure 2.15: Electro Smart controller (*Electro Smart*, n.d.)

By reducing the temperature during the day, the average temperature of the geyser is reduced, reducing the standing losses. Savings up to 20% are advertised with the Electro Smart system.

2.3.5.2 Geyser Wise

Figure 2.16 shows the Geyser Wise controller. Its operation is similar to that of the Electro Smart, whereby the specific times of the day when hot water is required is entered manually by the user. Geyser Wise has the following features (*Geyser Wise*, n.d.):

- Digital water temperature reading/control;
- user interface;
- microprocessor control;
- earth leakage protection;
- element failure detection;
- leaking hot water pipe detection;
- scale build-up detection;
- probe failure detection;
- high temperature cut out at 85°C;
- load shifting capability to off peak periods;
- real-time Clock;
- four daily programmable time settings, Mondays to Sundays and,
- battery backup on power failure.

Figure 2.16: Geyser Wise controller (*Geyser Wise*, n.d.)

Both the Electro Saver and Geyser Wise systems require qualified technicians to install, which adds additional cost to the controllers. The Geyser Wise costs R1200 including installation and at a 20% energy savings as promoted (and taking the average electricity usage per household at 1000kWh) the payback period equals to ±13months or a little over a year (*Geyser Wise*, n.d.).

The Electro Smart costs R7999 including installation. Using the same parameters as the Geyser Wise, payback period equals 84 months or 7 years.

Although theses programmable timers offer a higher level of control than ripple relays, they still require manual setting of hot water usage times. If the household requires hot water at times other than that set on the user interface, the settings have to be changed manually using the interface module.

2.3.6 Smart Meters

At the moment South Africa is experimenting with two way communication techniques/ systems used for measuring energy consumption, known as smart meters. These smart meters generally refer to a type of advanced meter that identifies consumption in more detail than a conventional meter, and optionally communicates that information back via some network to the local utility for monitoring and billing purposes (*Makwarela*, 2007). This type of metering can offer the following with regard to geysers (*Beute, et al.*, 2006: 41-46):

- Notify recipient of tampering to the meter;
- obtain geyser on/off state without notch testing;
- obtain geyser's temperature and,
- measure geyser energy consumption.

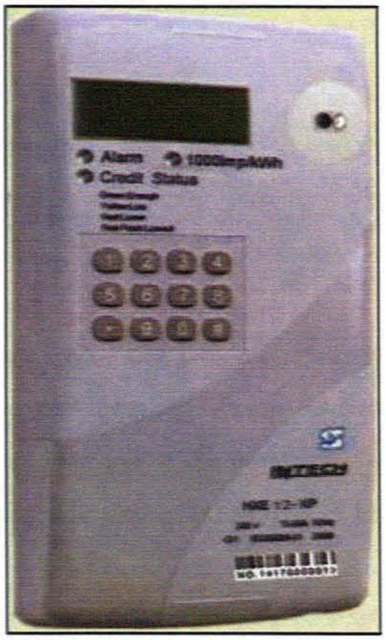


Figure 2.17: Standard Eskom prepaid meter (*Eskom*, n.d.)

Figure 2.17 shows a standard prepaid meter from Eskom. These meters are a form of smart metering, as power consumption is measured and usage regulated according to the amount of kWh's purchased. These meters can become an inconvenience, as electricity is purchased in units. If the units run out, the home owner has no electricity until more units are purchased.

The most effective method of demand side management that offers the least amount of customer inconvenience, is distributed control. This type of control requires the following in a home to be effective (*Wacks*, 1991: 168-174):

- Real-time access to information in home;
- computer-based intelligence at the house to:
  - Interpret the data;
  - determine consumer preferences and,
  - issue commands to selected appliances.
- a home automation communication network and,
- appliances that can reduce power consumption.

2.4 Summary

From the research on geyser blankets, pipe insulation and the dual element method it was deduced that by improving geyser efficiency, energy savings of 13% to 30% could be achieved.

The different control techniques researched showed that by lowering the temperature of the geyser, not only reduces the standing losses, but also reduces the total energy consumption of the geyser. For example if the geyser temperature was kept at 45°C, the standing losses are less than that of a geyser set to 65°C (see Table 2.1).

For this reason, there will be a slower decline in temperature, as less heat is dissipated through the casing of the geyser. This means less reheating cycles of the element for the same period as that of a geyser set at 65°C, resulting in less energy consumed.

Currently there are several control techniques/ topologies available to improve the energy efficiency of the geyser, but few that incorporate individually based hot water usage profiles for the home which adapt automatically to any changes to the profile. Smart meters and programmable timers provide a higher form of intelligence, but are expensive resulting in a long payback period.

For these reasons, an inexpensive, fully intelligent geyser profiling system was needed. The system would require an intelligent controller, which would be able to develop a profile on the individual household's hot water usage and implement itself without manual intervention. The aim of the profile is to reduce standing losses by reducing the geyser's temperature when hot water is not needed and to provide hot water when hot water is needed.

Chapter 3

GEYSER PROFILE CONTROLLER

3.1 Introduction

Hot water has become an important necessity in the human lifestyle. The most common device used to heat water in a home is a geyser.

This chapter investigates the different parameters required to develop a hot water usage profile of a household, the controller design used to develop this profile and the program written to implement the profile.

3.2 Profile Parameters

In order to establish a profile of a household the following parameters were needed:

- Flow;
- time of day;
- length of draw period;
- roof temperature and,
- geyser water temperature.

Figure 3.1 shows the basic structure of the profile controller. Five stimuli, or parameters were used to develop a hot water usage profile on the household. Once the profile was developed, the microcontroller controlled the geyser's temperature according to the profile.

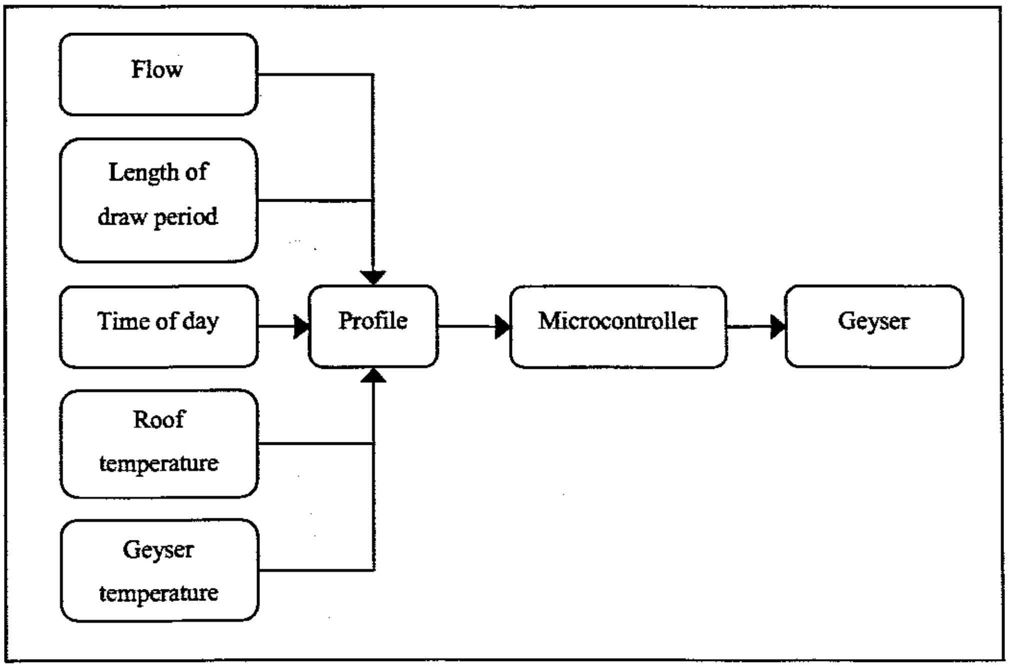


Figure 3.1: Block diagram of profile controller

a) Flow

The flow of hot water was required, as this would inform the controller when hot water was drawn from the geyser. There are several flow sensors available, but many of them are intrusive and expensive. A non-intrusive and inexpensive sensor was required to measure flow. It was therefore decided to use a temperature sensor.

When no hot water is drawn, the temperature of the outgoing pipe from the geyser is generally at the same temperature as that of the roof. When hot water is drawn, the pipe heats up to the temperature of the geyser water. Based on this concept it was possible to measure whether or not hot water was being drawn, by measuring the temperature of the outgoing pipe leading from the geyser.

b) Length of draw period

The length of the draw period was necessary to determine the type of draw, e.g. shower/bath or hand wash.

c) Time of day

The time of day was required, as this would provide the time axis for the profile developed. In order to achieve this, a real-time clock (RTC) was used.

d) Roof temperature

The roof temperature was required in order to calculate the standing losses. From equation (2.1), one can see that the ambient temperature is required. This refers to the temperature surrounding the geyser. For the calculations in this document the roof temperature was required, as this was the temperature surrounding the geyser.

e) Geyser water temperature

The geyser water temperature was required to regulate the water temperature accurately according to the profile developed. The type of temperature sensors used is explained in section 3.3.2.

Once the parameters were defined, a device was designed to record these values for data analysis. The device designed was a data logger.

3.3 Data Logger Design

As mentioned, a data logger was required to log all the parameters. An additional sensor was used to log the ambient temperature. This was done to illustrate that there is a difference between the roof and ambient temperature.

The data logger consisted of four temperature sensors (roof, ambient, flow and geyser temperature) and a RTC. The processor used to log all the data was a microcontroller and the information stored on a Secure Digital (SD) card. Figure 3.2 shows the layout of the data logger and pictures of the system can be seen in Appendix A.

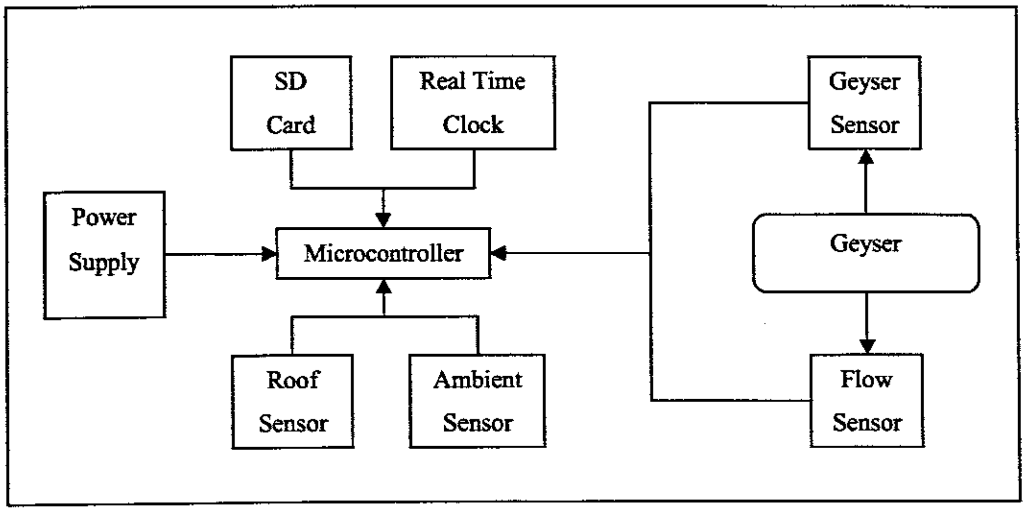


Figure 3.2: Block diagram of data logger

3.3.1 Microcontroller

The microcontroller that was chosen was the PIC 16F876A. This was due to the number of I/O pins available, fast operating speed (20MHz) and its capability to communicate via I^2C and SPI. The microcontroller was therefore adaptable to any changes in the circuit, which might occur during the design and development stages. It was programmed using the PIC Basic program.

3.3.2 Temperature sensors

To ensure that the full range of temperature fluctuations were recorded, the sensors operating range had to be at least from 0°C to 80°C. Two choices of temperature sensors were available, analogue and digital.

The first sensor looked at was the LM35. It is a low cost precision temperature sensor with the output voltage being linearly proportional to the temperature in degrees Celsius (°C). The LM35 has a wide operating temperature range from -55°C to 150°C which was required to measure the fluctuating geyser temperature. Figure 3.3 shows a block diagram setup of the LM35 (*National Semiconductor*, 2000).

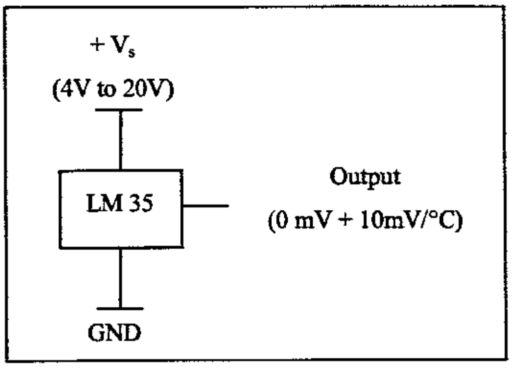


Figure 3.3: LM 35 layout (*National Semiconductor*, 2000)

As a basic Centigrade temperature sensor operating from a 5V supply, the LM 35 gave an output of 10mV/°C. Even though the PIC16F876A has a 10-bit ADC, giving a sensitivity of about 5mV per bit, the layout of the sensors posed a problem. The reason being, the temperature sensors were scattered across the roof and the distance between the sensor and the data logger was of varying length depending on each home's geyser setup. If the distance became too long, the internal resistance of the wire connecting the sensor to the data logger would cause a voltage drop across the wire. This would cause an inaccuracy in the temperature readings as there was a small change in V/°C. The temperature of the roof would also introduce an error, due to the fact that resistance increases with temperature.

Additional circuitry could be added to eliminate the effects of resistance on the readings, but this would make implementation of the sensors complex and add additional cost.

The second sensor considered was the DS18B20. This is a 1-wire digital thermometer with programmable resolution. It was more expensive than the LM35, but it gave a digital representation of the temperature. This eliminated the effect of wire resistance as the output was represented by a combination of digital 1's (5V) and 0's (0V) and not by an analogue voltage.

The DS18B20 also came in a TO-92 package with only a pull-up resistor (R_{PU}) needed as external circuitry. Its operating temperature is -55°C to 125°C, which was more than adequate. The DS18B20 uses the 1-wire communication protocol. PIC Basic allowed for easy communication between the PIC and the DS18B20, as it has ready programmed instructions for 1-wire communication (*Maxim*, 2007). It was, therefore decided to use the DS18B20. The hardware setup is shown in Figure 3.4.

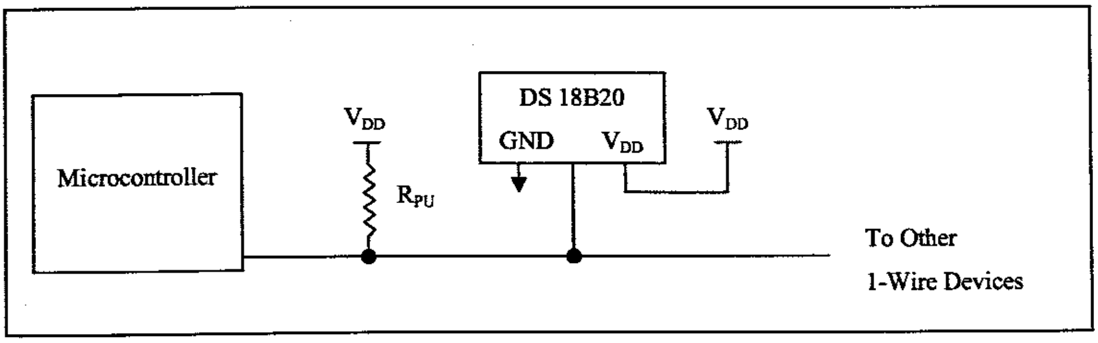


Figure 3.4: DS18B20 hardware setup (*Maxim*, 2007)

As mentioned, four temperature sensors were used to measure the ambient, roof and geyser temperatures, as well as the temperature of the outgoing pipe 1m away from the geyser. The reason for placing the temperature sensor 1m away from the geyser is that at a distance of 1m, the outgoing pipe is close to the temperature of the ambient (roof) air. The closer the sensor is placed to the geyser, the hotter the outgoing pipe temperature is, due to the heat being dissipated from the geyser.

This then introduces an offset and can result in inaccurate readings. The sensors were therefore placed 1m away to avoid the inaccuracy.

The ambient sensor was placed outside the roof to measure the ambient air. The roof temperature sensor was kept onboard the data logger, as the data logger was placed inside the roof. The geyser temperature sensor was placed on the metal plate where the thermostat enters the geyser denoted A in Figure 3.5. In order to determine whether hot water was drawn a temperature sensor was placed on the outgoing pipe on the junction where all the pipes supplying the home come together, denoted B in Figure 3.5.

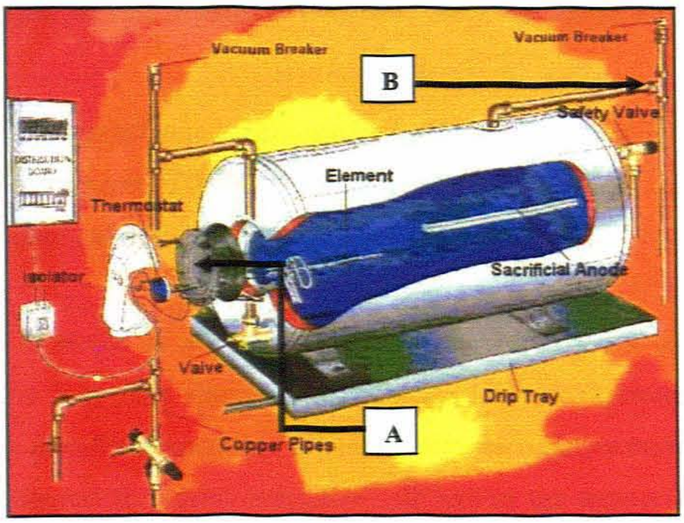


Figure 3.5: Controller sensor layout (*Mutual & Federal*, n.d.)

A "start temperature conversion" command is required by the DS18B20 in order to begin the conversion. The sensor then starts the conversion. Once conversion is complete, the DS18B20 replies with the temperature reading in binary format. The flow diagram showing the sequence for reading temperature from the DS18B20 is shown in Figure 3.6.

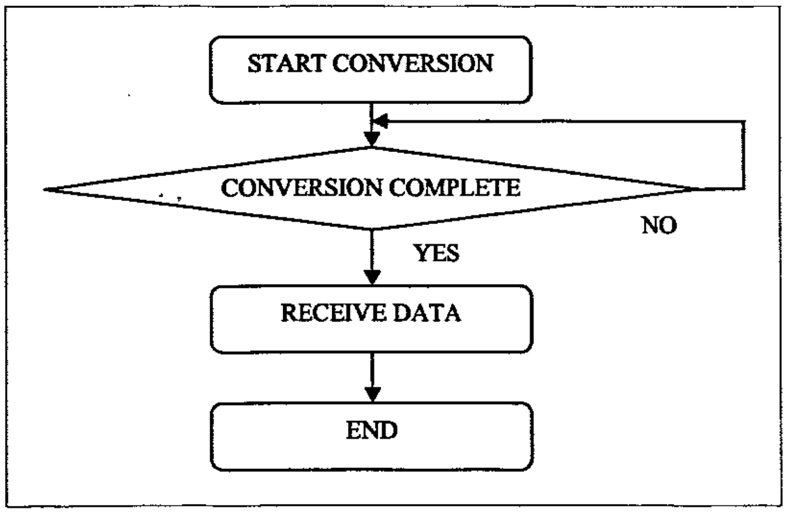


Figure 3.6: Flow sequence for temperature conversion (*Maxim*, 2007)

The resolution of the temperature sensor can be configured to either 9, 10, 11 or 12 bits, corresponding to increments of 0.5°C, 0.25°C, 0.125°C and 0.0625°C per degree Celsius change in temperature (*Maxim*, 2007).

The temperature is stored as a 16-bit two's complement number in the temperature register (see Table 3.1). The sign bits (S) indicate if the temperature is positive or negative. If S = 0, then the temperature is positive and for negative numbers S = 1. If the DS18B20 is configured for 12-bit resolution, all bits in the temperature register will contain valid data. For 11-bit resolution, bit 0 is undefined. For 10-bit resolution, bits 1 and 0 are undefined, and for 9-bit resolution bits 2, 1 and 0 are undefined (*Maxim*, 2007).

Table 3.1: Temperature register format (*Maxim*, 2007)

	bit7	bit6	bit5	bit4	bit3	bit2	bit1	bit0
LS Byte	2^3	2^2	2^1	2^0	2^{-1}	2^{-2}	2^{-3}	2^{-4}
	bit15	bit14	bit13	bit12	bit11	bit10	bit9	bit8
MS Byte	S	S	S	S	S	2^6	2^5	2^4

Table 3.2 gives examples of digital outputs and the corresponding temperature reading for 12-bit resolution conversions (*Maxim*, 2007).

Table 3.2: Temperature/data relationship (*Maxim*, 2007)

TEMPERATURE	DIGITAL OUTPUT (BINARY)	DIGITAL OUTPUT (HEX)
+ 125°C	0000 0111 1101 0000	07D0h
+ 85°C	0000 0101 0101 0000	0550h
+ 25.0625°C	0000 0001 1001 0001	0191h
+ 10.125°C	0000 0000 1010 0010	00A2h
+ 0.5°C	0000 0000 0000 1000	0008h
0°C	0000 0000 0000 0000	0000h
-0.5°C	1111 1111 1111 1000	FFF8h
-10.125°C	1111 1111 0101 1110	FF5Eh
-25.0625°C	1111 1110 0110 1111	FE6Fh
-55°C	1111 1100 1001 0000	FC90h

3.3.3 Real-time clock (RTC)

As mentioned, a RTC was required to determine the time of day, as well as the length of the water draw period. This would provide the time axis for the profile developed.

To accomplish this, a RTC was used. The DS1307 is a cost effective, low power BCD (binary coded decimal) clock/calendar. It communicates using the I^2C protocol and provides the user with the seconds, minutes, hours, day, date, month and year upon request (*Maxim*, 2006).

The RTC is a user-friendly Integrated Circuit (IC), as it requires a simple I^2C read and write command to transfer data. When powered up the clock needs to be configured or "set." Once configured, the clock will continue to operate. Data can then be requested from the RTC at random, using a simple read instruction (*Maxim*, 2006).

Once a read instruction is sent, the RTC will respond with the data. The data is in Binary Coded Decimal (BCD) format. BCD is a way of expressing each decimal digit with a binary code. Each binary representation is 4 bits long (2^3, 2^2, 2^1, 2^0).

If for example the BCD number is 0010 0100, in order to convert this to its decimal equivalent, the BCD number is split up into its 4-bit binary representation and handled individually. The first 4-bit value 0010 equals $0+0+2^1+0 = 2$. The same is done for the second 4-bit binary value. This equals 4. The equivalent decimal number for the BCD 0010 0100 is 24 (*Floyd*, 2000: 74-75). In order to process the information received from the RTC, the data was converted using the steps above into its equivalent decimal representation.

The information from the DS1307 was received in the following order: seconds, minutes, hours, day, date, month and year. The sequence of operation in obtaining the data from the DS1307 is shown in Figure 3.7.

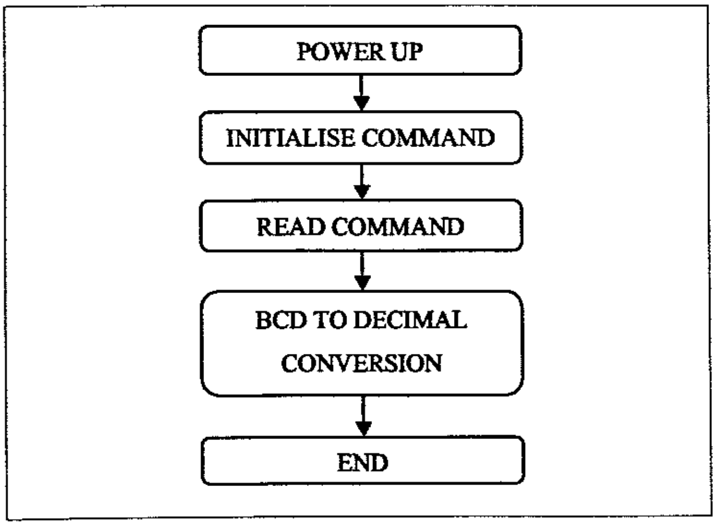
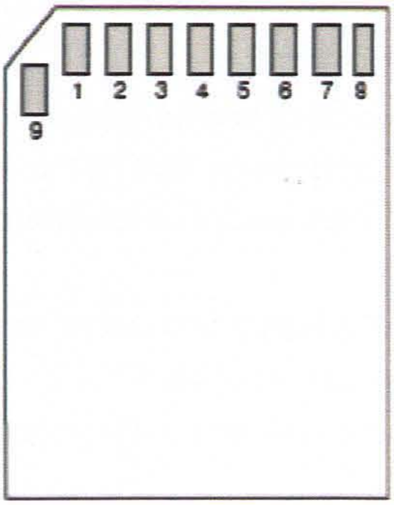


Figure 3.7: Sequence to receive information from DS1307(*Maxim*, 2006)

The DS1307 has an additional feature, namely power failure detection. When power is removed from the clock, the clock switches over to the battery backup. A 90mAh 3V coin battery was used. Due to the low power consumption of the DS1307 in power failure mode the CR2016 coin battery can supply the clock for ±20years (*Maxim*, 2006). The circuit for the DS1307 is shown in Figure 3.8. R_{PU} refers to pull-up resistors necessary for I^2C communication between the RTC and the microcontroller.



PIN	NAME	DESCRIPTION
1	CS	Chip Select
2	DI	Data In
3	V_{ss}	GND
4	V_{dd}	V_{cc}
5	SCLK	Clock
6	V_{ss2}	GND
7	DO	Data Out
8	IRG	Not Used
9	NC	Not Used

Figure 3.9: Pin configuration of the SD card (*SD Association*, 2006)

The SD card operates at voltage levels between 2.7V to 3.6V (*SD Association*, 2006). The data logger, however, runs at 5V. A LM317 voltage regulator was used in combination with two resistors to provide a 3.3V supply voltage to the SD card. In order for the microcontroller to communicate with the SD card, only four pins were necessary.

When the PIC sent an instruction to the SD card, the voltage also had to be at 3.3V. For this reason, a voltage divider circuit was designed to ensure 3.3V was achieved as required by the SD card. The circuit is shown in Figure 3.10.

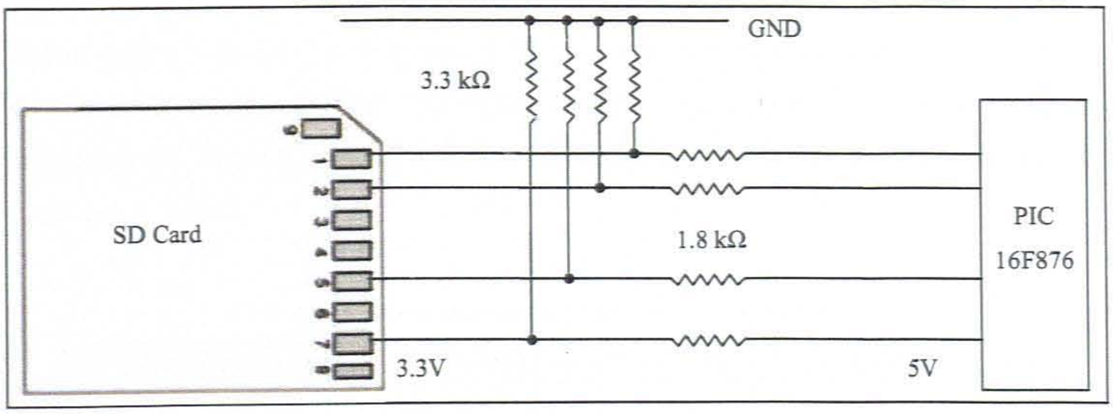


Figure 3.10: Voltage divider circuit, for PIC to SD Card communication

3.3.4.2 SD Card communication

Communication between an SD card and a host controller can take place in either SD mode or SPI mode (*Anon*, 2008). SPI mode was chosen, because the PIC 16F876A microcontroller has a standard SPI interface.

In order for data to be transferred to and from the SD card, certain instructions had to be used. Table 3.3 shows the instructions used to initialise read and write instructions between the SD card and the microcontroller.

Table 3.3: SPI commands for SD card (*Anon*, 2008)

Command Index	Hex Value	Response	Description
CMD0	$40	R1	Software reset
CMD16	$50	R1	Change R/W block size
CMD17	$51	R1	Read a block
CMD24	$58	R1	Write a block
CMD55	$55	R1	Next command will be a ACMDXX
ACMD41	$41	R1	Initialise the card

SD commands are written as CMDXX or ACMDXX, where CMD and ACMD refer to general command and application-specific commands. The XX refers to the command number. Each command consists of a 48 bit or 6 byte frame. This command frame always starts with a 01 followed by the 6-bit command number. Next a 4-byte argument followed by a 7-bit CRC with a stop bit '1' is sent. In SPI mode the CRC is optional for all commands except "CMD0" which has a CRC value of 0x95 hexadecimal, with an argument of 0. Table 3.4 shows a command broken up into its various components (*SD Association*, 2006).

Table 3.4: Command structure (*SD Association*, 2006).

First Byte			Bytes 2-5	Last Byte	
0	1	Command	Argument (MSB First)	CRC	1

The SD card works on a command response system, whereby after every command received by the SD card it replies with a response. Each command number has an expected response token. For SPI mode there are three different types of response tokens that can be expected: R1, R2 and R3. The three responses are shown in Table 3.5, Table 3.6 and Table 3.7 (*SD Association*, 2006).

Table 3.5: Response token R1 (*Anon*, 2008)

Byte	Bit	Meaning
1	7	Start Bit, Always 0
	6	Parameter Error
	5	Address Error
	4	Erase Sequence Error
	3	CRC Error
	2	Illegal Command
	1	Erase Reset
	0	In Idle State

Table 3.6: Response token R2 (*Anon*, 2008)

Byte	Bit	Meaning	Byte	Bit	Meaning
1	7	Start Bit, Always 0	2	7	Out Of Range
	6	Parameter Error		6	Erase Parameter
	5	Address Error		5	Write Protection
	4	Erase Sequence Error		4	Card ECC Failed
	3	CRC Error		3	Card Controller Error
	2	Illegal Command		2	Unspecified Error
	1	Erase Reset		1	Write Protect Erase Skip, Lock/ Unlock Failed
	0	In Idle State		0	Card Locked

Table 3.7: Response token R3 (*Anon*, 2008)

Byte	Bit	Meaning
1	7	Start Bit, Always 0
	6	Parameter Error
	5	Address Error
	4	Erase Sequence Error
	3	CRC Error
	2	Illegal Command
	1	Erase Reset
	0	In Idle State
2-5	ALL	Operating Condition Register, MSB First

3.3.4.3 SD Card Initialisation

The SD card requires a specific sequence of commands in order for it to be initialised. Before communication can take place, the SPI clock frequency of the microcontroller needs to be set at 400 kHz. Once complete the microcontroller must send at least 74 clocks via the DI pin while keeping the CS pin high, before attempting to communicate with the SD card. This gives the card time to initialise any internal state registers (*Anon*, 2008).

Next, the CS pin must be set low while a software reset (CMD0) is sent to the SD card. This will reset the card and set it into SPI mode. This is the only command where the CRC is of importance and must be set to 0x95. The card is then continuously polled with the initialisation command (ACMD41) until the idle bit is equal to "0." This then indicates that the card is initialised and ready to receive general commands (*Anon*, 2008).

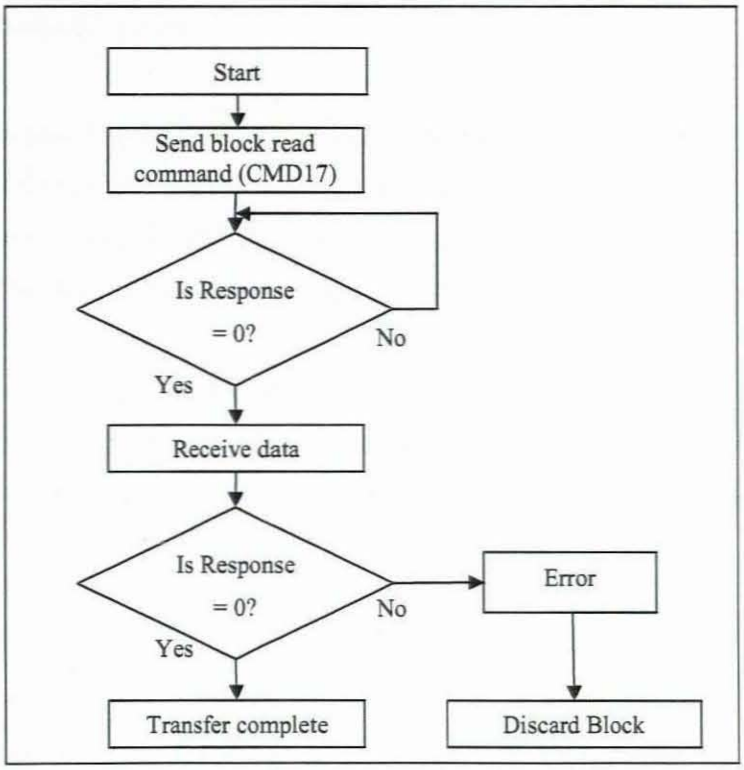


Figure 3.13: SD card read flow diagram

An error loop is again introduced in programming as in the case of a block write. Once a block read is complete, the SD card will reply with an error token as seen in Table 3.9.

Table 3.9: Error token (*Anon*, 2008)

Bit	Meaning
7	Always 0
6	Always 0
5	Always 0
4	Card Locked
3	Out of Range
2	Card ECC Failed
1	Card Controller Error
0	Unspecified error

If no error occurred, the SD card will reply with a "00000000". This then means that the read was successful.

3.3.5 Power supply circuit

The most cost effective form of power circuit design is a transformless power supply. These types of power supplies make use of capacitors instead of a transformer. There are two main problems with transformerless power supplies. The first being limited current capability and the second being lack of isolation from the mains (*Burroughs*, 2002: 1-26).

It was decided to design the data logger with a transformerless power supply, as this device did not require large currents and would be placed in a non-conductive container in the roof of the home owner, providing isolation. The power supply circuit is shown in Figure 3.14.

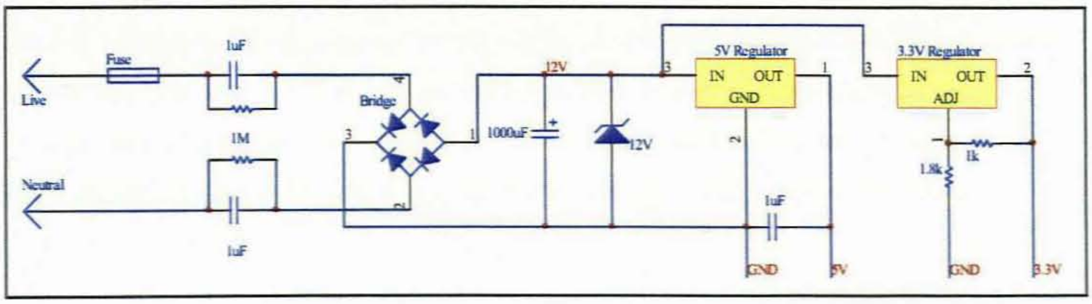


Figure 3.14: Transformerless power circuit design (*Burroughs*, 2002)

A 100mA fuse was used to protect the circuit against current surges. A 1MΩ resistor was placed in parallel with the input capacitors to provide a discharge path for the voltage stored in the capacitor when the circuit was disconnected from the mains. The input capacitor provided the current for the circuit. By increasing the value of the capacitor, the current supplied to the circuit increased. Increasing the current capability, however, increased the size of the capacitor. This was a trade-off between the amount of current required and the size of the power supply circuit.

The maximum current required by the data logger was ± 50mA. The circuit was therefore designed to be able to supply 70mA.

The impedance of the input capacitor is given by equation (3.1):

$$X_c = \frac{V}{I} \tag{3.1}$$

where V = 220V AC and I = 70mA. X_c was then calculated as 3143Ω. The capacitor size was then calculated using equation (3.2):

$$C = \frac{1}{(2*\pi*f*X_c)} \tag{3.2}$$

where f = 50Hz and X_c = 3143Ω. C was calculated as 1.01μF (1 μF).

The circuit was then connected to a full-wave bridge rectifier, which was used to rectify the AC voltage to DC as required by the circuit. A 1000μF capacitor was placed over the output from the rectifier to smoothen the ripple that was present on the DC side. The DC voltage was stepped down via two LM317 voltage regulators to 5V DC and 3.3V DC respectively. The complete schematic for the data logger can be seen in Appendix B.

3.4 Program

The data logger was initially programmed to determine whether the parameters defined could be deduced and logged as mentioned in the design stage. The following geyser characteristics were looked at:

- How the water temperature of the outgoing pipe rises when water was drawn;
- could it be determined with reasonable accuracy when hot water was drawn;
- could the draw period be measured and,
- did different draw periods affect the geyser's water temperature?

As mentioned earlier four temperature sensors were used to measure ambient, roof, thermostat and outgoing pipe temperatures. These temperatures were originally recorded every second. The data on the SD card was then imported into Microsoft Excel spreadsheet, via the hardware serial out function of PIC Basic. Figure 3.15 shows data logged for Saturday 26/07/08. The data logger was left to gather information for 31 days. From this it was concluded, that saving the data every second was unnecessary, as hot water usage up to a minute had little or no effect on the cooling gradient of the geyser's water temperature. For this reason, the data was logged every minute.

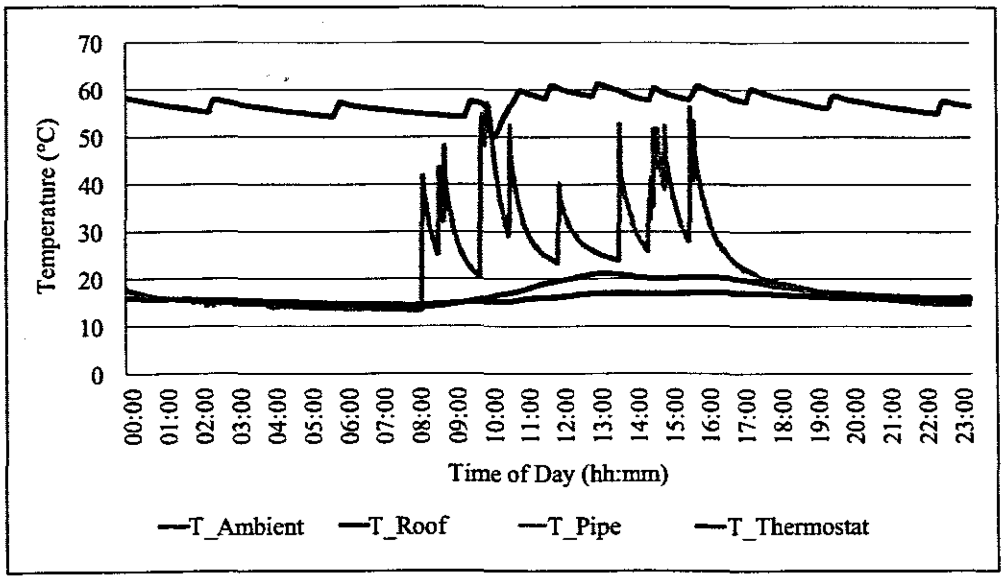


Figure 3.15: Data logged for 26/07/08

It is also apparent that the ambient and roof temperatures differ. For this reason the roof temperature was used in the calculations instead of the ambient temperature, as the roof temperature is the temperature surrounding the geyser. Figure 3.15 also shows that the outgoing pipe temperature remains proportional to the roof temperature, unless hot water is drawn. If hot water is drawn, the pipe temperature rises from the roof temperature to the geyser temperature. It could therefore be determined when the hot water draw period started.

When the draw period ends, there is a decline in the pipe temperature. The warmer the roof temperature, the slower the decline. This decline in temperature is faster than the decline in ambient temperature during any given period of a day. The program could therefore distinguish between a decline in ambient temperature and a decline in water temperature. As soon as a draw period started, the program would search for a decline in pipe temperature. A "draw stop" condition would occur when the pipe temperature declined with more than 5°C. While a draw period is present, the length of the period is also measured. Figure 3.16 shows the program sequence followed in determining when hot water was drawn and what the length of the draw period was.

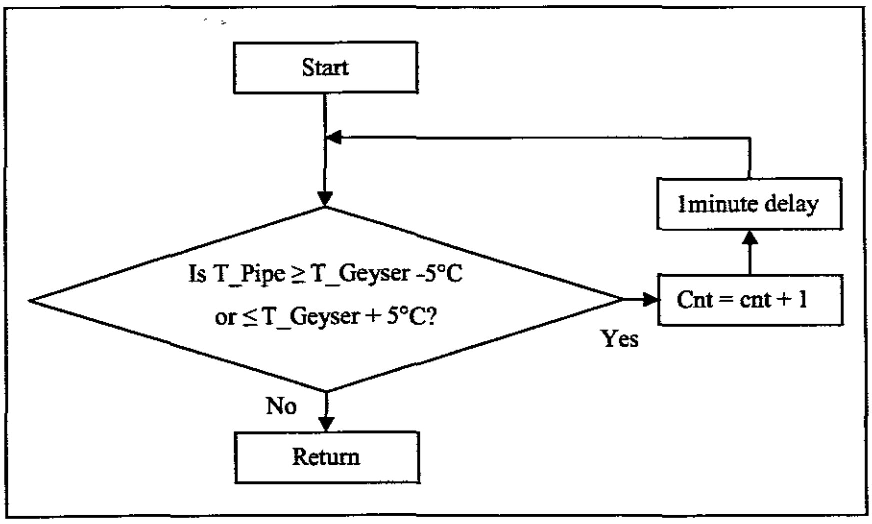


Figure 3.16: Flow diagram of program used to determine when hot water was drawn

3.4.1 Profile

Now that it was possible to read when and for how long hot water was used, a profile needed to be developed according to the household's hot water usage patterns and be able to implement itself after an acceptable accuracy level was achieved.

In order to determine a hot water usage profile, the following sequence was followed:

- Determine how frequently and when hot water is being used during the day;
- allocate a temperature setting according to the frequency of use;
- predict when hot water is going to be used based on gathered data;
- refine profile until acceptable accuracy is achieved;
- implement profile and,
- continue refining profile after implementation.

A typical example of a profile based on the hot water usage for a home is shown in Figure 3.17.

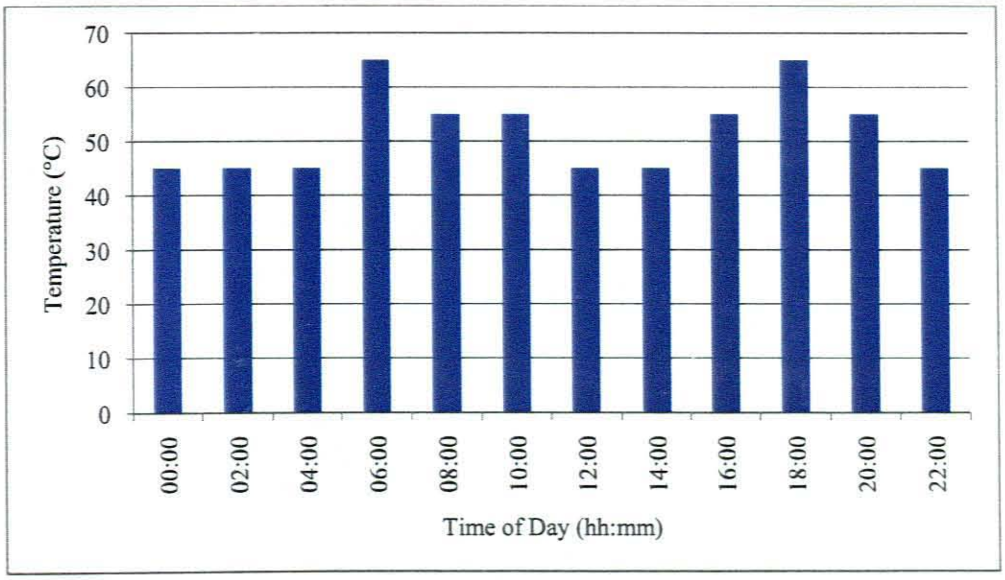


Figure 3.17: Example of a profile based on hot water usage of a home

3.4.1.1 Temperature settings

The aim of the final controller is to regulate the geyser temperature according to the profile gathered by the microcontroller. This profile consists of preset temperatures determined by the three stimuli: flow, temperature and frequency of use (i.e. time).

It was decided to have three preset temperature settings. For the remainder of this study the temperature settings will be referred to as service levels. These settings were low (45°C), medium (55°C) and high (65°C).

The low or standby setting was chosen at 45°C. The reason for this was due to the disease known as Legionellosis. Legionnaire's disease or Legionellosis, is caused by bacteria known as Legionella pneumophila. This bacteria is considered very serious, as it is responsible for numerous fatalities worldwide every year (*Ecosafe*, n.d.).

Legionella pneumophila proliferate (grow in numbers) in stagnant water from 20°C - 45°C, with the optimum proliferation temperature being between 32°C - 37°C. At temperatures below 20°C the bacteria remain dormant. When the water temperature is kept at 60°C the bacteria is killed after 20-30 minutes and at temperatures above 70°C killed immediately (*Ecosafe*, n.d.). Figure 3.18 shows a microscopic view of the Legionella bacteria.

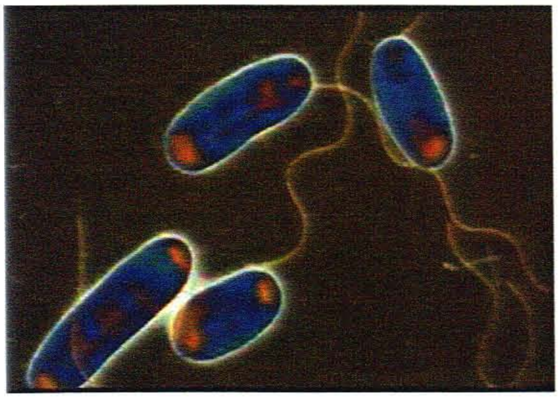


Figure 3.18: Microscopic view of the Legionella bacteria (*Ecosafe*, n.d.).

A high setting of 65°C was chosen as research previously done by (*Delport*, 2005: 139-144) showed that 64.3°C is the average temperature setting of thermostat controlled geysers. This setting was also chosen to accommodate high consumption or large draw periods. This would typically be a shower or bath.

A medium setting was chosen at 55°C. This was to accommodate short draw periods e.g. hand washes.

The controller would therefore build up the profile based on the frequency of hot water drawn. The higher the frequency for the particular time interval, the higher the service level chosen.

3.4.1.2 Time intervals

Using a 150ℓ 3kW geyser as an example, the maximum time required to heat the water in a geyser from the low setting (45°C) to the high setting (65°C) was calculated using equation (3.3) (*Walser*, 2002):

$$\text{Power} = \frac{\text{Energy (J)}}{\text{Time(s)}} \tag{3.3}$$

$$P = \frac{cm\Delta T}{t}$$

where:

P = power (3000W)
c = specific heat capacity (4187 J kg^{-1} $°C^{-1}$)
m = mass (150kg)
ΔT = change in temperature (20°C)
t = time

When substituting the variables into the equation the time taken to heat the water from 45°C to 65°C using a 3kW element would be ±1 hour 09 minutes. The power equation holds true for all sizes of geysers (*Walser*, 2002).

For this reason, 2 hour intervals were chosen. This then gives the controller adequate time to heat the geyser. A day profile therefore consisted of twelve 2 hour intervals. The frequency of hot water use was determined for each of the twelve intervals and saved in a corresponding 2 hour interval variable.

3.4.1.3 Prediction

Each 2 hour interval recorded the actual service level (SL) and the service level predication (SLP) made by the controller. By comparing the actual service level and the service level prediction, the accuracy of the system was determined.

Each of the 2 hour slots contained twelve bytes of information used for data analysis and calculations. These bytes of information were time, day, date, month, year, roof temperature, day count, actual service level, service level prediction, minutes of hot water used, probability that hot water was to be used for that 2 hour period and percentage accuracy of the service level prediction. The probability that hot water might be used in a 2 hour interval was calculated using equation (3.4) (*Bertsekas, et al.*, 2002:11):

$$\text{Probability} = \frac{\text{number of elements of A}}{\text{n}} \qquad (3.4)$$

This formula is known as the discrete uniform probability formula. In the program, "number of elements of A" refers to a counter which counts how many times hot water was drawn in a particular 2 hour interval. The "n" refers to another counter used to count how many days have elapsed. For example if hot water was used in the specific 2 hour interval, a 1 was added to a counter called "water used". If this was the first day of implementation, then the day count will also equal 1. The probability that hot water was going to be used again in that particular 2 hour interval was:

$$\begin{aligned} \text{Probability (\%)} &= (\text{water used/day count})*100 \\ &= (1/1)*100 \\ &= 100\% \end{aligned}$$

If it were day two and water was not used in the same 2 hour interval, then:

$$\text{Probability (\%)} = (1/2)*100 = 50\%$$

The probability was multiplied by 100 to give a percentage and grouped in either of the three service levels depending on the percentage value as seen below:

- If probability was between 0% and 33% then service level = Low = 45°C
- If probability was between 33% and 66% then service level = Medium = 55°C
- If probability was between 66% and 100% then service level = High = 65°C

For the two examples given, the service levels would be 65°C and 55°C respectively. A flow diagram representing the process in calculating the service level (SL) is shown in Figure 3.19.

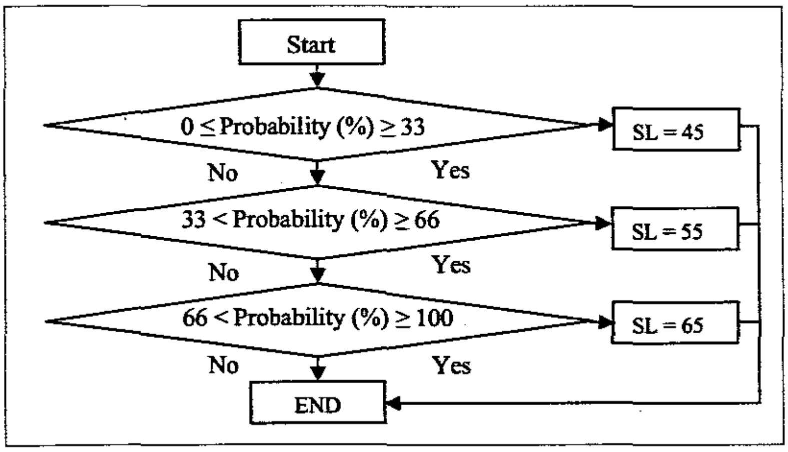


Figure 3.19: Flow diagram of service level calculation

Although the minutes used were saved per 2 hour interval, this was not used in deriving the resultant service levels. The reason being that repetitiveness was seen as of higher priority than amount of minutes drawn. The amount of minutes drawn was, however, used in the results and is explained.

Along with the service level for the 2 hour period, a prediction was also saved. The service level predication is done at the beginning of the 2 hour slot. It makes a prediction of what the service level will be for the current 2 hour interval. This is done by recalling the previous day's service level value for the current 2 hour slot. Table 3.10 shows an example of how the service level prediction (SLP) was calculated.

Table 3.10: SLP calculation example for a single 2 hour interval

Day	Was water used	Calculation	Service Level	SLP
1	Yes (cnt = 1)	1/1 = 100%	65	Default = 65
2	No (cnt = 1)	1/2 = 50%	55	65
3	No (cnt = 1)	1/3 = 33%	55	55
4	No (cnt = 1)	1/4 = 25%	45	55
5	No (cnt = 1)	1/5 = 20%	45	45

The reason for having a service level (SL) and a prediction was to see if the controller could accurately predict the next 2 hour interval's service level and if so, after how many days could it do so accurately? The accuracy of the service level prediction (SLP) was calculated as seen in Figure 3.20.

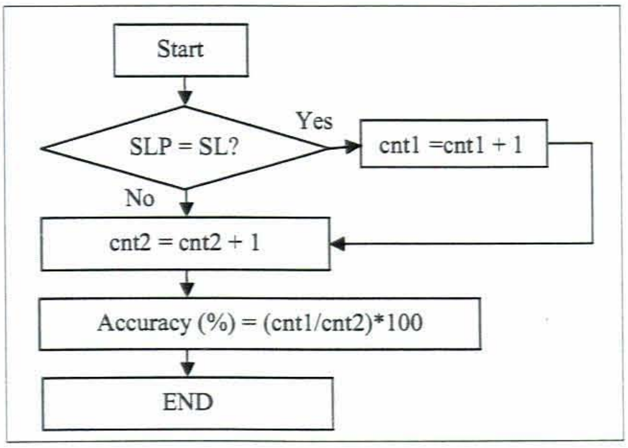


Figure 3.20: Flow diagram for accuracy calculation

The cnt2 is a counter used to count the number of predictions made and therefore increased with every 2 hour interval. The cnt1 is a counter used to count the number of correct predictions made by the controller.

The accuracy of the prediction is therefore a ratio between how many correct predictions were made over the total number of predictions. Once an accuracy of 90% was achieved, the profile would implement itself and control the geyser temperature accordingly. After implementation, the profile continues to refine itself.

In order to regulate the geyser temperature, a control circuit was required.

3.4.2 Implemented system

The geyser in a home requires 220V AC to operate. The controller could not be used to control the device directly. For this reason, a control circuit was designed.

3.4.2.1 Control circuit

It was decided to control the geyser using a relay. The relay of choice had a coil voltage of 24V DC. The reason for choosing 24V DC, was due to the lower coil resistance, resulting in less current being drawn by the relay. The control circuit had to switch a 3kW element. The power rating of the relay was calculated by using equation (3.5).

$$I = \frac{P}{V} \tag{3.5}$$

When substituting the variables P (3000W) and V (220V AC), the current drawn by the 3kW element was calculated at 13.63A. A 16A relay was chosen. The relay coil required 27mA to be energised. The microcontroller can only supply 20mA and therefore a circuit had to be designed to increase its current capability. This was done by using a BD139 transistor. Figure 3.21 shows the control circuit designed. A 1N4007 diode was placed across the coil of the relay. This was to prevent reverse voltage spikes across the coil when power was removed.

Once installed, the program developed a profile based on the hot water usage patterns of that particular home. After an accuracy of 90% was achieved, the data logger implemented the profile gathered.

3.4.2.2 Pre-heat cycle

In order for the geyser's temperature to be at the required setting for the 2 hour interval, the controller would have to predetermine the time required to heat the water to that specific setting. This was done by determining the time left in the current 2 hour interval and using equation (3.3), the time required to heat the geyser's temperature from the current to the required temperature.

By comparing the time left to the time required, the geyser temperature was pre-heated according to the profile setting. A flow diagram representing the sequence followed is shown in Figure 3.23.

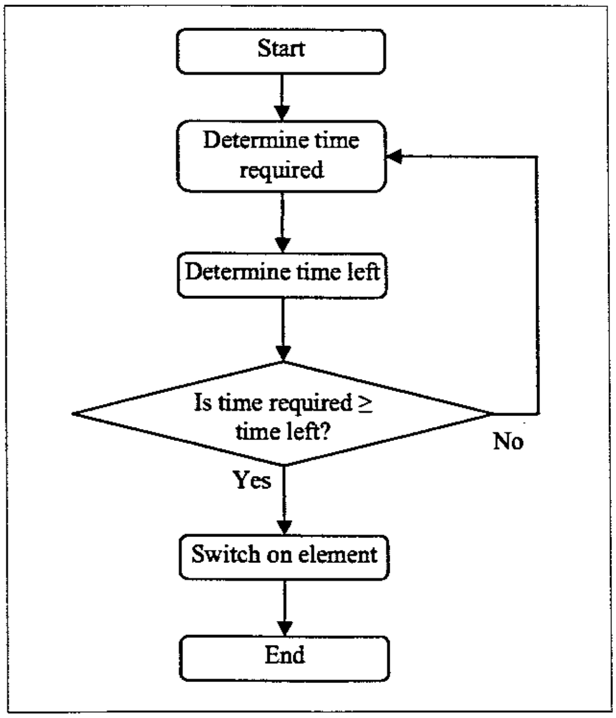


Figure 3.23: Pre-heat cycle calculation

3.5 Summary

A data logger was designed in order to determine a profile based on the parameters "frequency of hot water use" and "time of usage". From this, a prediction was made of when hot water was required. Ten of these data loggers were implemented in ten different homes in order to determine whether a profile-based controller could be designed. These data loggers also determined the accuracy of the predictions and recorded the amount of days taken to reach a 90% accuracy. All of the data loggers were left in the homes for a 31 day period to determine the maximum accuracy that could be achieved within a month.

Chapter 4

RESULTS

4.1 Introduction

In this chapter standing losses are verified by comparing calculated standing losses to measured standing losses under the same conditions. As equation (2.1) is referred to extensively in this chapter, it is reintroduced as equation (4.1) below:

$$q_{losses}=\frac{(T_h-T_{ambient})}{\frac{\Delta x}{k}+\frac{1}{h}} \qquad (4.1)$$

Once a comparison is drawn between calculated and measured standing losses, the results obtained from the 10 data loggers installed into the various homes are shown. A thermostat controlled baseline profile is then deduced followed by the profile controlled geyser system.

4.2 Standing Losses

In order to justify the use of equation (4.1), the standing losses were verified for the three service levels used, i.e. 45°C, 55°C, 65°C. This was done by comparing the calculated standing losses with the measured standing losses for each of the three service levels. For the calculated standing losses the values for T_h and $T_{ambient}$ in equation (4.1) were logged every minute using the data logger and an average calculated for the period. For the measured standing losses, a single phase AC power meter was used. For all three temperature comparisons, the geyser was left standing for three days with no hot water drawn.

4.2.1 Standing losses at 45°C

Calculated

$$q_{losses}=\frac{(T_h-T_{ambient})}{\frac{\Delta x}{k}+\frac{1}{h}}$$

$$= (45-31)/ ((0.035/0.055) + (1/6.3))$$

$$= 17.61\text{W}/\text{m}^2$$

$$P_{losses} = \text{qlosses}*(\text{area of geyser})$$

$$= 17.61*1.677$$

$$= 29.53\text{W per hour}$$

$$= 29.53*24$$

$$= 0.71\text{kWh per day}$$

Measured

The power consumed by the geyser was measured at 2.25kWh for the three days. Figure 4.1 shows the heating cycles of the geyser over a 24 hour period. The power consumed for the period amounted to 0.75kWh and is represented by two heating cycles present between time intervals 20:00 to 21:00 and 18:00 to 19:00.

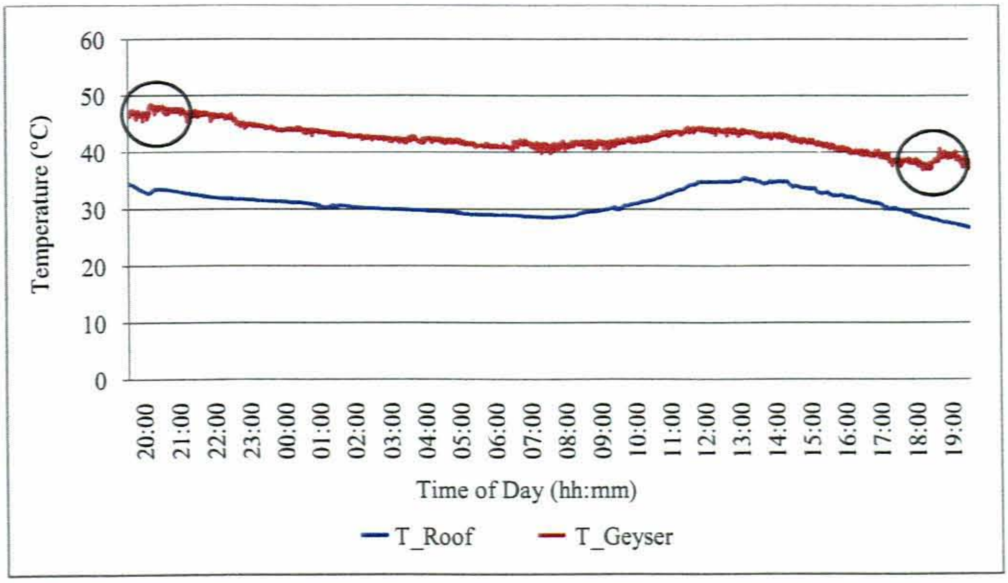


Figure 4.1: Geyser set to 45°C and left standing for 24 hours

4.2.2 Standing losses at 55°C

Calculated

$$q_{losses} = \frac{(T_h - T_{ambient})}{\frac{\Delta x}{k} + \frac{1}{h}}$$

$= (55-33)/((0.035/0.055) + (1/6.3))$

$= 27.67\text{W}/\text{m}^2$

P_{losses} = qlosses*(area of geyser)

= 27.67*1.677

= 46.4W per hour

= 46.4*24

= 1.11kWh per day

Measured

Figure 4.2 shows the geyser set at 55°C and left standing for 24 hours with no hot water being drawn. Two heating cycles of the geyser are present between time intervals 03:00 to 04:00 and 14:00 to 15:00, which amounted to 1.18kWh for the day.

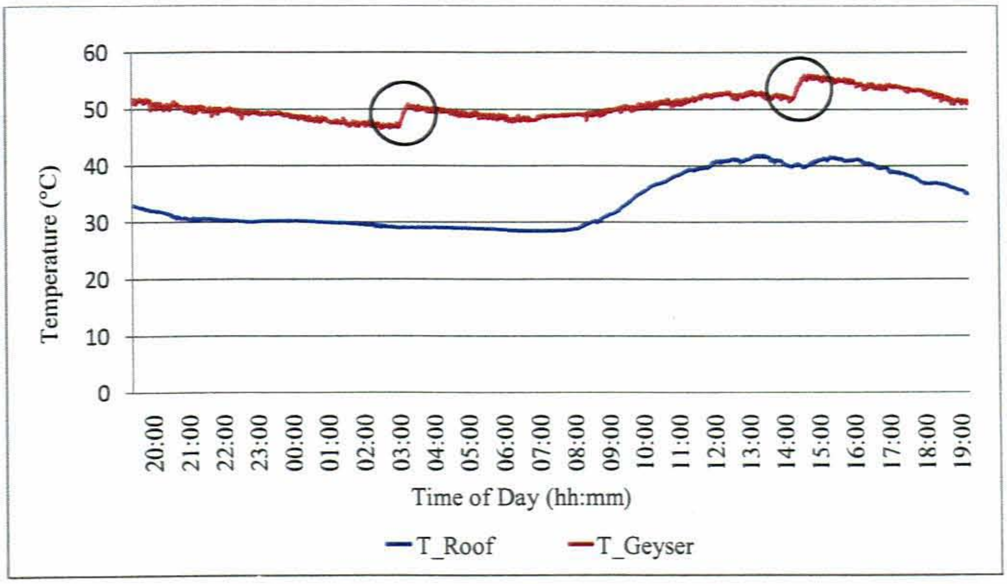


Figure 4.2: Geyser set to 55°C and left standing for 24 hours

4.2.3 Standing loss at 65°C

Calculated

$$q_{losses} = \frac{(T_h - T_{ambient})}{\frac{\Delta x}{k} + \frac{1}{h}}$$

$= (65-27)/ ((0.035/0.055) + (1/6.3))$

$= 47.79\text{W}/\text{m}^2$

P_{losses} = qlosses*(area of geyser)

= 47.79*1.677

= 80.15W per hour

= 80.15*24

= 1.92kWh per day

Measured

The final standing loss test was setting the geyser to 65°C. The power consumed was 6.03kWh for the three day period. Figure 4.3 shows the geyser's temperature over a 24 hour period with no hot water drawn. Three heating cycles occurred between the intervals 09:00 to11:00, 12:00 to 14:00 and 17:00 to 19:00. This amounted to 2.01kWh for the day.

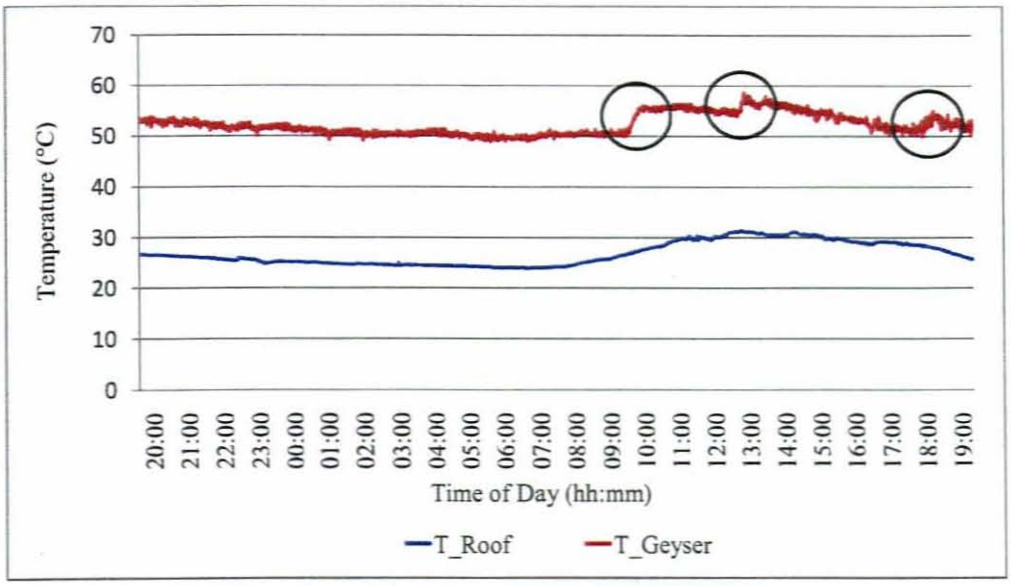


Figure 4.3: Geyser set to 65°C and left standing for 24 hours

4.2.4 Comparison between calculated and measured standing losses

The comparison between the calculated and measured values revealed that the calculation values were very similar to that of the actual/measured values. In Table 4.1 it is shown that the calculations were between 94% to 96% similar, justifying the use of equation (4.1). The reason for the slight difference between measured and calculated is due to small sampling size. If comparison was done over a greater period, it is believed that the calculated versus measured values would agree even more closely.

Table 4.1: Similarity comparison between calculated and measured values

Temperature	Calculated	Measured	Similarity
45°C	0.71kWh	0.75kWh	95%
55°C	1.11kWh	1.18kWh	94%
65°C	1.92kWh	2.01kWh	96%

The calculations and measurements also highlighted the higher the geyser temperature, the higher the standing losses.

4.3 Profile developing

Ten data loggers were built and installed into various homes with different lifestyles to determine whether it was possible to develop an accurate hot water usage profile. The ten home types are shown in Table 4.2.

Table 4.2: Home groups

Home	Residents	Employed	Student	Children
1	3	1	2	
2	3	2	1	
3	4	2	1	1
4	2	1	1	
5	4	2	2	
6	3		3	
7	3	1		2
8	1	1		
9	3	2	1	
10	4	2	1	1

Figure 4.4 shows the profile retrieved from the data logger for Home1. In the interval 06:00 to 08:00 Home1 repetitively drew hot water and therefore a high setting (65°C) was assigned to that time interval. The intervals 10:00to 12:00, 16:00 to 18:00, 18:00 to 20:00 and 20:00 to 22:00 showed scattered hot water draws and therefore a medium setting (55°C) was assigned to those intervals. The remaining intervals showed very little or no hot water draws and therefore a low setting (45°C) was assigned to them. The complete data set logged for Home 1 is shown in Appendix D and the profiles of all ten homes are shown in Appendix C.

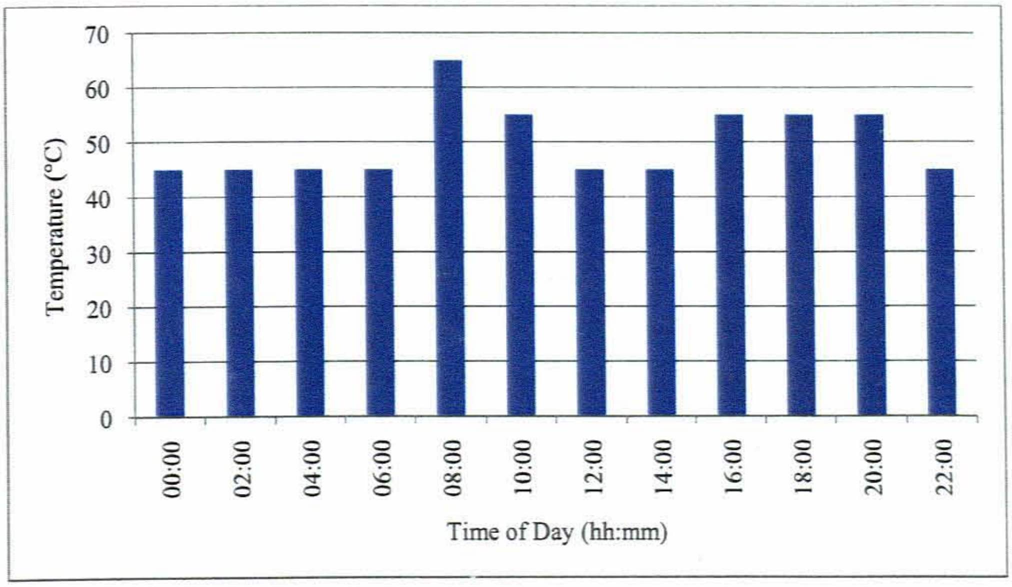


Figure 4.4: Profile retrieved from data logger for Home1

Figure 4.5 shows a comparison between the actual service level (SL) calculated for the specific 2 hour period and the service level prediction based on the profile in memory for Home1. Initially no service level prediction is made as seen in the interval between 10:00 to 22:00, as the data logger has no information in memory. Once sufficient data is logged service level predictions (SLP) are made as seen in the interval 00:00 onwards.

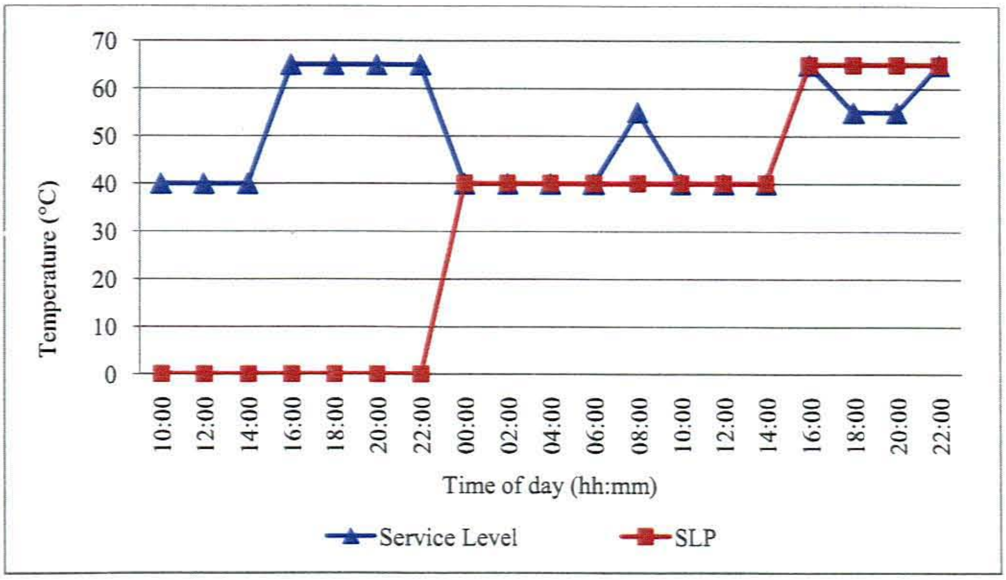


Figure 4.5: Service level versus service level prediction for Home1

Figure 4.6 shows the accuracy of the profile in Home1 after 31 days. From the 4th to the 8th one can see the accuracy of the predictions varying drastically. As explained in section 3.4.1.3 the accuracy calculation compares the actual service level (either 65°C, 55°C, 45°C) in the 2 hour interval to the service level prediction for the specific 2 hour interval. Initially all of the twelve 2 hour intervals equal 65°C, as this was the default setting chosen. The interval where the profile in Home1 started refining itself also equalled 65°C, as hot water was drawn by the household. This therefore resulted in an accuracy of 100%, which is not a true reflection of the total accuracy of the system. As more data is gathered one can see the accuracy stabilising. To solve this the profile was left to refine itself for a month before it implemented itself. After 31 days the profile in Home1 had an accuracy of 94% , with a 97.5% accuracy the last 10 days (last 120 predictions).

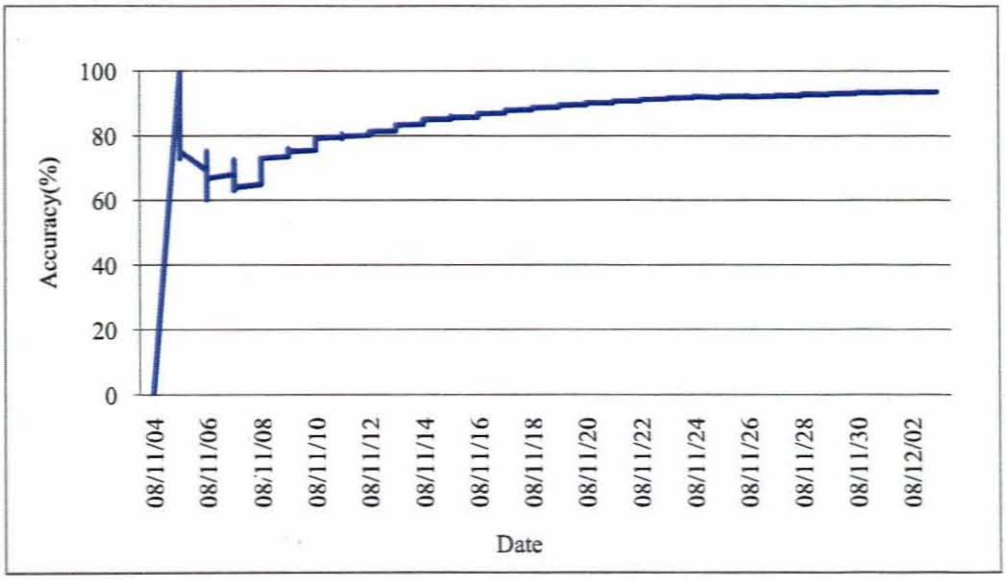


Figure 4.6: Accuracy of Home1's profile after 30 days

Figure 4.7 shows the time taken for the profiles in each of the 10 homes to reach 90% accuracy. Worst-case scenario the predictions only reached a 90% accuracy after 28 days. This was in Home6, which consisted of a student and two parents.

A best-case scenario of 3 days was achieved. This was in Home9 and consisted of a single working person living in a bachelor flat.

The reason for the varying accuracy times just highlights the fact that although we as humans have different lifestyles, we are still creatures of habit. The average time taken in the 10 homes to reach 90% was 18 days.

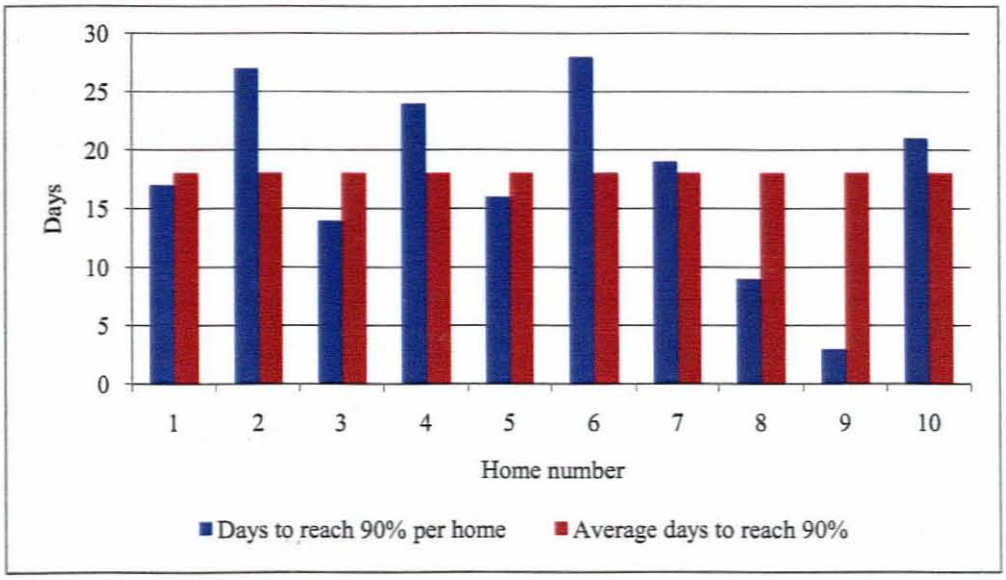


Figure 4.7: Time (days) taken for the profiles to reach 90% accuracy

Figure 4.8 represents the accuracies of all 10 homes after 31 days. All of the ten controllers installed reached a minimum of 91% accuracy after 31 days. A maximum accuracy of 98% was achieved and an average of 94.4% for the 10 homes.

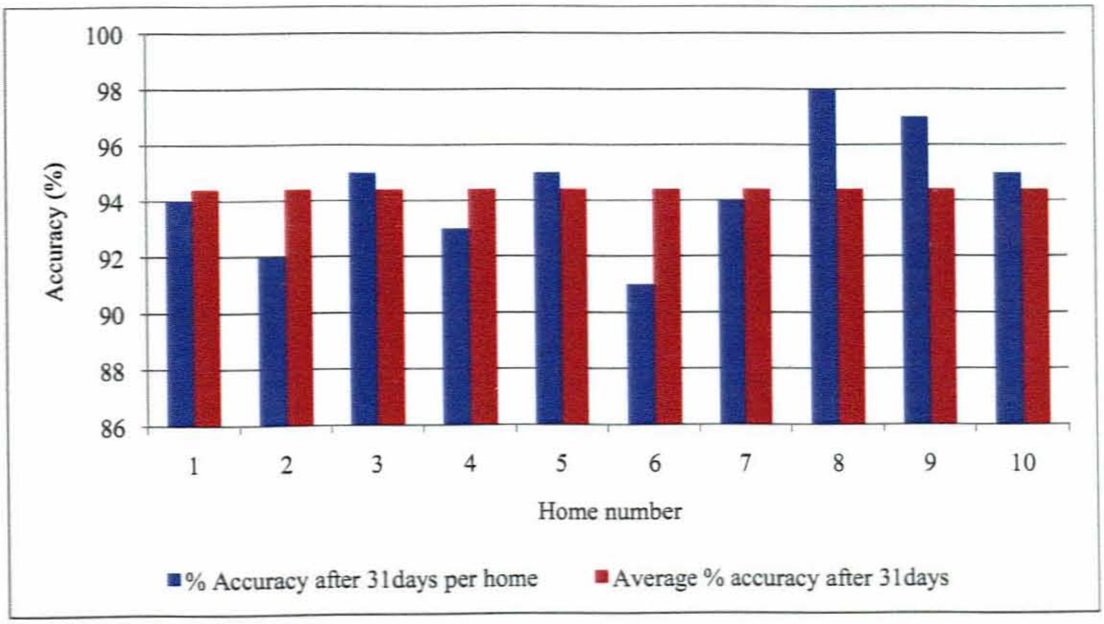


Figure 4.8: Profile accuracies for the 10 homes after 31 days

Figure 4.9 shows the accuracy of the profiles for the last 120 predictions (10 days). A minimum accuracy of 97,5% was reached, which means that out of the last 120 predictions, 117 predictions were correct. The average for the 10 homes amounted to 98.95%.

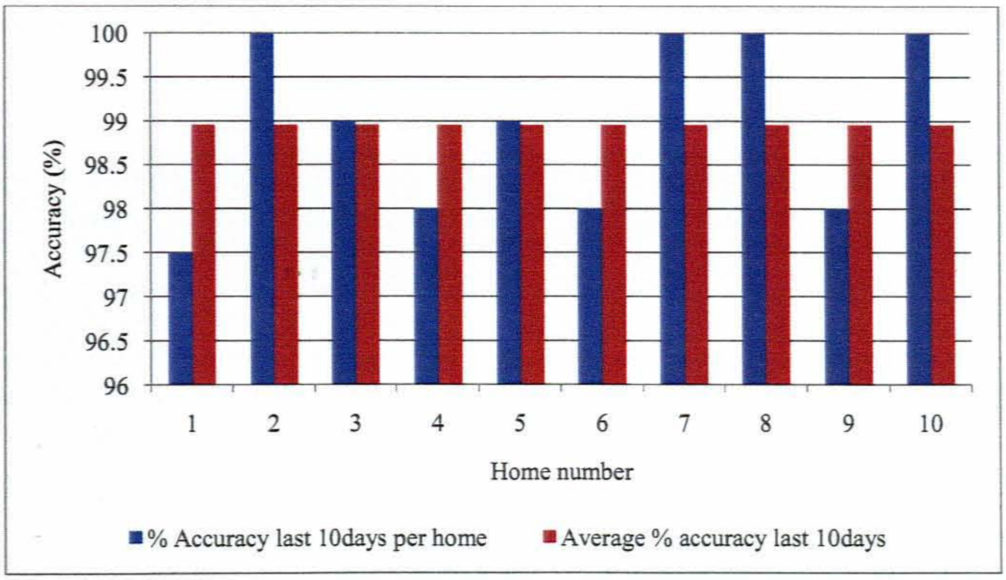


Figure 4.9: Profile accuracies for the 10 homes for the last 120 predictions

4.3.1 Calculated standing loss savings

Table 4.3 shows how the losses per 2 hour interval were calculated and compared to that of a thermostat set at 65°C. The service level (SL) per 2 hour interval for Home1 is also shown. The temperature used in the calculation was the roof temperature, which represents the ambient temperature neccessary for calculation purposes.

Table 4.3: Standing loss savings for a 24 hour period (Home1)

TIME	SL	Temperature	kW consumed for the 2 hours	kW consumed for geyser set at 65°C	Savings (kW)
00:00	45	25.56	0.08	0.16	0.08
02:00	45	24.12	0.08	0.17	0.09
04:00	45	23.5	0.09	0.17	0.08
06:00	45	23.43	0.09	0.180	0.08
08:00	65	23.5	0.17	0.17	0
10:00	55	25.62	0.12	0.16	0.04
12:00	45	28.56	0.06	0.15	0.09
14:00	45	30.81	0.06	0.14	0.08
16:00	55	32.18	0.10	0.16	0.06
18:00	55	28.75	0.11	0.16	0.05
20:00	55	25.5	0.12	0.16	0.04
22:00	45	24.18	0.09	0.14	0.05
Total			1.27	1.91	0.74

The total savings calculated for Home1 for the day amounted to 0.74kWh or 22.94kWh for a 31 day month.

Percentage standing loss savings = savings (kW)/ consumption at 65°C (kW)

= 0.74/1.91*100

= 38%

Figure 4.10 shows the monthly savings of all 10 homes. These savings were calculated and compared to the calculated standing losses experienced by a geyser with a thermostat set to 65°C. These savings are profile dependant. Home3 showed the most calculated savings for the month, which amounted to 28.21 kWh. Home2 showed the least - namely 19.84 kWh.

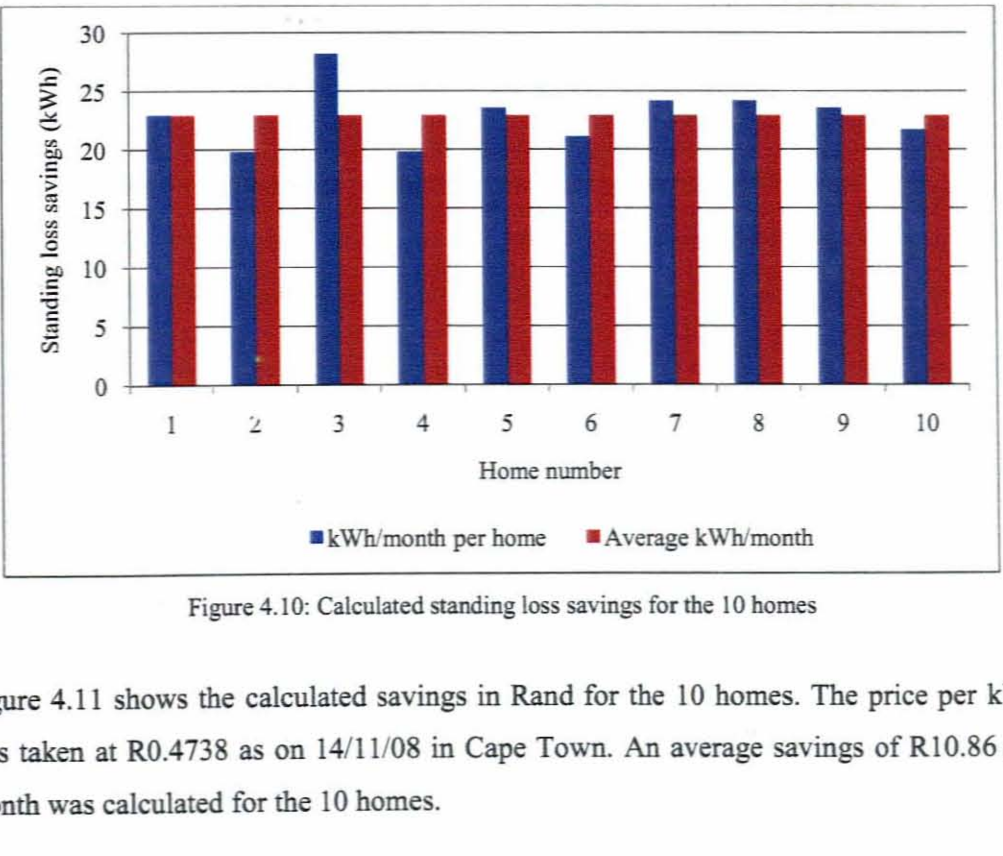


Figure 4.10: Calculated standing loss savings for the 10 homes

Figure 4.11 shows the calculated savings in Rand for the 10 homes. The price per kWh was taken at R0.4738 as on 14/11/08 in Cape Town. An average savings of R10.86 per month was calculated for the 10 homes.

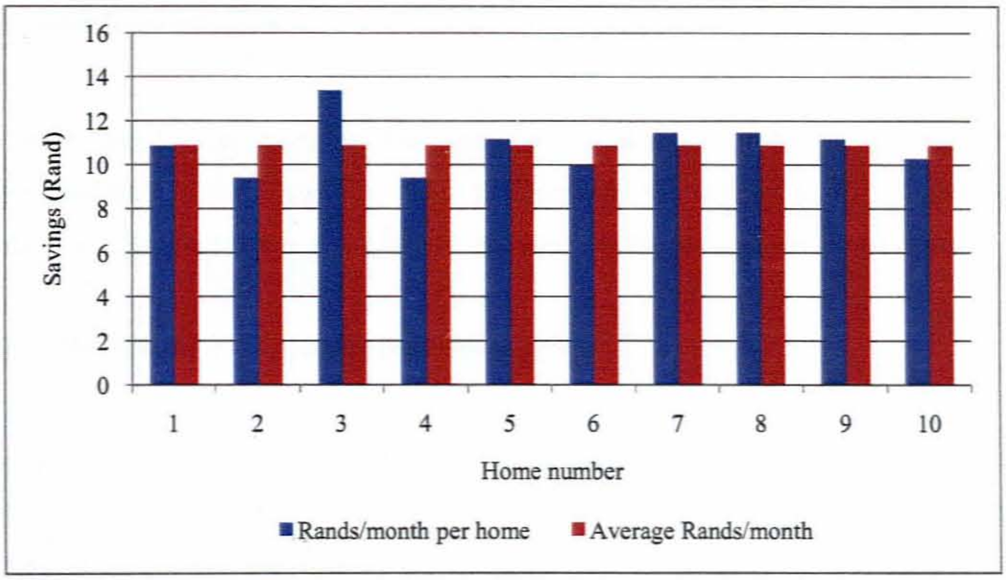


Figure 4.11: Calculated Rand savings for the 10 homes

Figure 4.12 shows the percentage standing loss savings for the 10 homes. By using a hot water profiling system, the standing losses were reduced considerably. Savings of 33% to 49% were calculated.

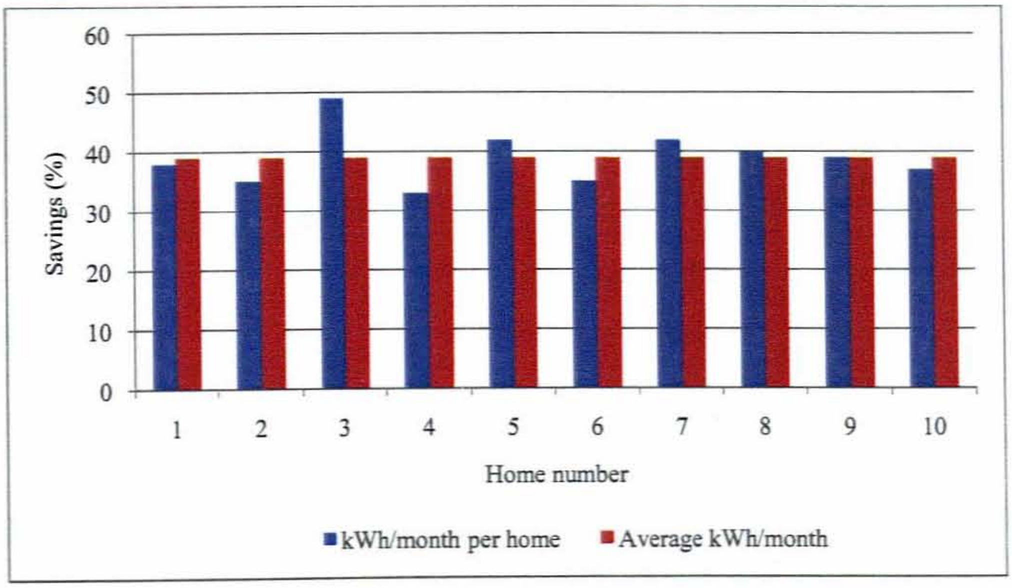


Figure 4.12: Percentage standing loss savings per month for the 10 homes

4.4 Implementation

To verify the savings made by the controller, a baseline profile was required before implementation of the system in order to determine the savings made by the profile controller. This would then give a before and after profile for comparison purposes.

4.4.1 Baseline of a thermostat controlled geyser

In order to determine a baseline, the geyser was monitored for a month, logging the roof and geyser temperatures. During this period, the power consumption was also measured using a single phase AC power meter. Figure 4.13 shows a 24 hour extract taken from the baseline profile. The complete baseline is included in Appendix E.

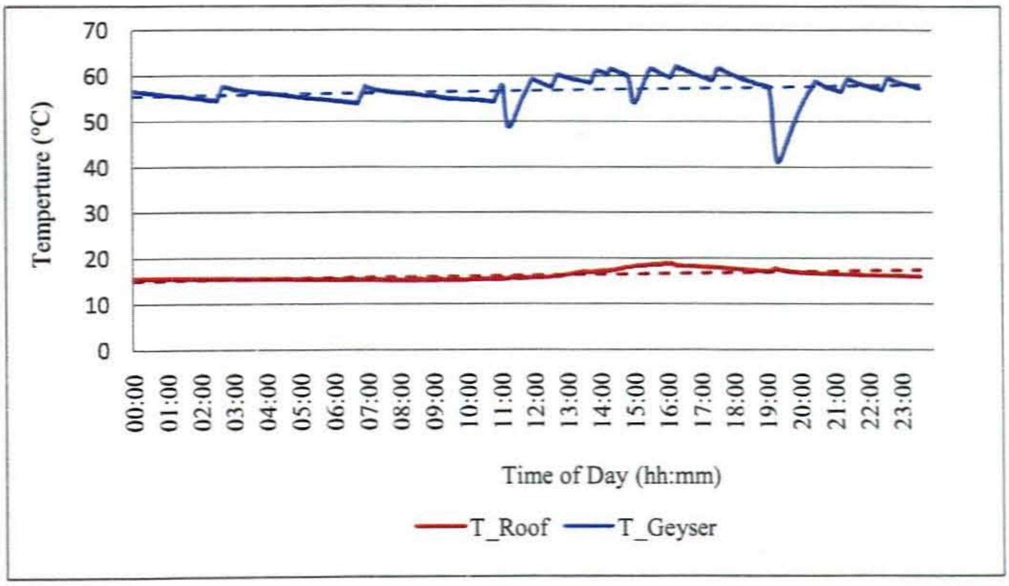


Figure 4.13: Day extract of baseline geyser and roof temperatures

From the data logged, a baseline for the roof and geyser temperatures was determined. An example of a day baseline is illustrated in Figure 4.13. The dotted lines represent the average roof and geyser temperatures.

Table 4.4 represents the total kWh used from 12/03/09 to the 12/04/09. This amounted to 238.3kWh. At a cost of R0.4738 per kWh the geysers electricity consumption amounted to R 112.91.

Table 4.4: Total usage and cost analysis

Period	Thermostat Setting	kWh Used	Minutes Used	Cost
12/03/09-12/04/09	65°C	238.3	680	R 112.91

Using the average geyser and roof temperatures measured for the month, as shown in Table 4.5, the standing losses were calculated. They amounted to 57kWh or R 27.17 for the month. The standing losses therefore contributed to 24% of the total energy consumed by the geyser. By subtracting the standing losses from the total energy consumed the amount of actual kWh used for water consumption by the geyser was calculated at 180.96kWh or R 85.74.

Table 4.5: Breakdown of usage and cost analysis

T_Roof (Average)	T_Geyser (Average)	Standing Losses (kWh)	Cost	Water Used (kWh)	Cost	Total (kWh)
25.33°C	61.87°C	57	R 27.17	180.96	R 85.74	238.3

4.4.2 Profile controlled geyser

Figure 4.14 shows how the temperature of the geyser was controlled according to the profile developed by the controller over a 24 hour period. The temperature of the geyser over and undershoots that of the profile by 3°C. This was done to emulate a conventional thermostat. The complete profile controlled system is included in Appendix Fr.

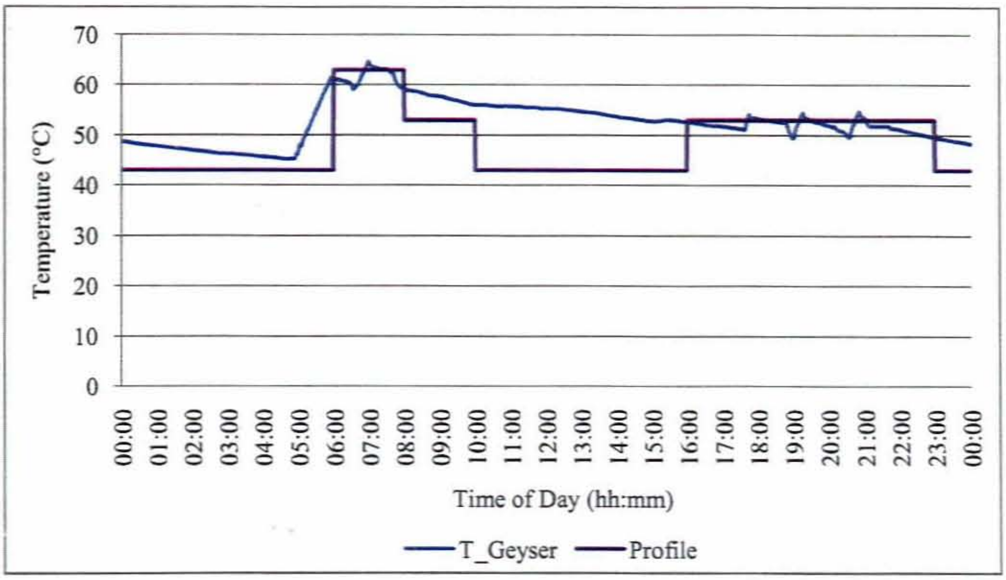


Figure 4.14: Implemented system showing the profile for a 24 hour period

Figure 4.15 shows the implemented system and the element switching times according to the profile as seen in Figure 4.14. The pre-heat stage is illustrated in Figure 4.15 for the interval 04:55 to 06:00. The controller calculated in the interval 04:00 to 06:00 that it required 65 minutes to heat the water from the current temperature of 45.8°C to the required service level of 65°C for the next 2 hour interval.

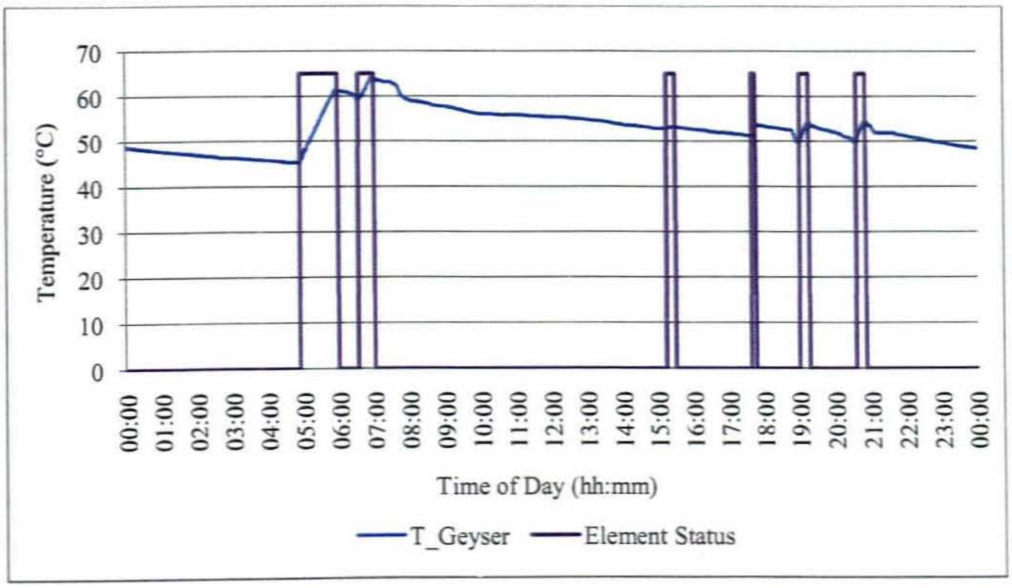


Figure 4.15: Implemented system showing element status

Table 4.6 shows the comparison between the average temperatures of the thermostat and profile controlled geyser over a month period. The table summarises the results obtained before implementation and after implementation. The profile controller reduced the average temperature of the geyser by almost 10°C, while at the same time still providing hot water when required, as per the profile.

Table 4.6: Average geyser temperature comparison

Baseline	Implemented system	Difference
61.87°C	52.35°C	9.52°C

Table 4.7 shows a comparison between the average roof temperatures for both the baseline and after implementation systems over the period of a month. The baseline system has a roof temperature 3.5°C higher than the implemented system. This means that when substituting the variables for equation (4.1) the temperature difference between the geyser and the roof is less than that of the implemented system, which results in less standing losses for the same period. This is explained in more detail in section 2.2.2b. If the comparisons were of the exact same roof temperatures, the profile controller would show increased savings.

Table 4.7: Average roof temperature comparison

Baseline	Implemented system	Difference
25.33°C	21.8°C	3.53°C

4.5 Cost and payback period

Table 4.8 shows the comparison between the energy usage of the thermostat controlled geyser and that of the profile controlled geyser. Both systems had a total hot water draw of 680 minutes for the month period. A saving of R35.50 was made in the month. As a result, the total energy demand of the geyser was reduced by 31.5%.

For example, comparing a geyser set at 65°C and a geyser set at 55°C. If 50ℓ of hot water is drawn, then 50ℓ of cold water is used to replace it. Assuming a cold water temperature of 20°C for calculation purposes the resultant temperatures of both examples can be calculated using equation (4.2). The results are shown in Table 4.10 and show the temperature difference for the two examples.

Table 4.10: Resultant geyser temperatures

Geyser temperature	Water drawn	Resultant temperature	Temperature difference to reheat
65°C	50ℓ	50°C	15°C
55°C	50ℓ	43.33°C	11.67°C

Using the equation for heat energy from equation (3.3) ($E = mc\Delta T$), the amount of power required to reheat the water with temperatures differences from Table 4.10 can now be calculated and is shown in Table 4.11.

Table 4.11: Energy required to reheat geyser of different set point temperatures

Geyser set point	Temperature difference to reheat	Energy (joules)
65°C	15°C	9.42MJ
55°C	11.67°C	7.33MJ

From Table 4.11 it can be seen that more energy is required to reheat the geyser when a higher temperature setting is used. The principle applies to the profile controller, as the controller has different temperature settings for different periods of the day. The more water drawn during these intervals, the more the energy savings will be. This then explains the large energy usage savings shown in Table 4.9.

4.6 Summary

The results obtained showed that a hot water usage profile could be designed with accuracies reaching 98% in certain homes. A final profile controller was then designed and implemented into Home1, where it was discovered that the profile controller reduced the energy consumed by the geyser by 31.5%. This 31.5% consisted of both standing losses, as well as actual energy consumption savings.

Chapter 5

CONCLUSION AND FUTURE WORK

5.1 Conclusion

The current energy crisis in South Africa has led to a need for more efficient systems. Eskom established a Demand Side Management (DSM) department, which has several energy awareness programmes running to help with the current energy crisis. These programmes include researching and implementing new energy efficient technologies, geyser blankets, solar water heating, CFL lighting, gas conversions for cooking and load shedding.

The residential sector contributes to around 30% of the total demand from Eskom during peak times. These are from 07:00 to 10:00 in the morning and from 18:00 to 20:00 in the evening. Of this peak demand, the geyser contributes to almost 50% of the residential consumption.

From the research, it was apparent that by reducing the average geyser temperature, the amount of energy used by the geyser could be reduced. A profile based system was therefore designed, built and tested. The profile controller had two stages, the profile developing stage and the implementation stage. Once the profile had been developed and after it reached an accuracy better than 90%, the controller implemented the profile.

From the results the following research questions were answered:

a) Can an accurate hot water usage profile be developed for a typical household?

Ten data loggers were implemented into homes with varying lifestyles and number of inhabitants. From the profiles retrieved from the data loggers after a period of a month, the accuracies revealed that the controller predictions of when hot water was to be drawn ranged from 91% to 98%. The results therefore showed that a hot water usage profile could be designed.

b) If implemented does the profile reduce the standing losses experienced by the geyser?

After the profile was implemented for a period of a month it was discovered that the standing losses of the geyser was reduced from 57kWh (thermostat controlled geyser) to 41.86kWh (profile controlled geyser). This therefore amounts to a 27% standing loss savings, which agree with earlier reported savings by reducing standing losses with a geyser blanket (*Harris, et al.,* 2007:153-158)

c) Is the total energy consumption of the geyser reduced by implementing the profile, without inconveniencing the household?

In Table 4.9 it was shown that the geyser's total energy consumption was reduced from 238.29 kWh (thermostat controlled geyser) to 163.27 kWh (profile controlled geyser). This amounts to a 31.5% energy reduction. The average temperature of the geyser was reduced by almost 10°C and at the same time still provided the household with hot water when required.

d) Can the proposed profile controller be manufactured economically?

The geyser controller cost including labour for installation is roughly R 485 depending on fluctuating prices. With a savings of 31.5% or R35.55 per month, the payback period of the controller is ± 14months. The profile based controller will therefore be paid off over one year.

In conclusion, an economically viable profile based controller was designed that reduced the energy consumption of the geyser, and at the same time provided hot water when required. This system is therefore beneficial to both Eskom and the consumer. Not only does the profile based geyser controller improve the efficiency of the geyser, but by pre-heating the geysers temperature according to the service levels, the electricity peak of the geyser on the utility will be shifted according to the profile of the home.

When calculations were done in this study, the price of electricity in Cape Town was R0.4738 per kWh. With electricity prices escalating, future savings are expected to increase, as well as the corresponding payback period being reduced accordingly.

5.2 Future work

The current system developed presents an hourly profile (two-hour intervals) based on the time of day. The sample size therefore increases with every new day. Possible additions to the profile based geyser controller are to refine the program so that day-by-day profiles are developed. The theory behind this is that people tend to do washing and other activities on specific days of the week. If this holds true, the profile will be more accurate if it develops day-by-day profiles. This will result in even larger savings as the profile becomes more personalised. A possible disadvantage of the day-by-day profile is that it might take longer to reach its 90% accuracy threshold as it only updates the profile once a week for each of the twelve two-hour intervals.

The controller can be connected to an alarm system, so when a fault is encountered, a warning signal can notify the home owner. A current sensor can also be added to measure the power consumption. The consumption can then be displayed on a screen, providing a type of feedback to the household.

It is envisaged that savings achieved by profiling geysers could also be extended to certain other household, commercial and industrial appliances by using similar smart technologies.

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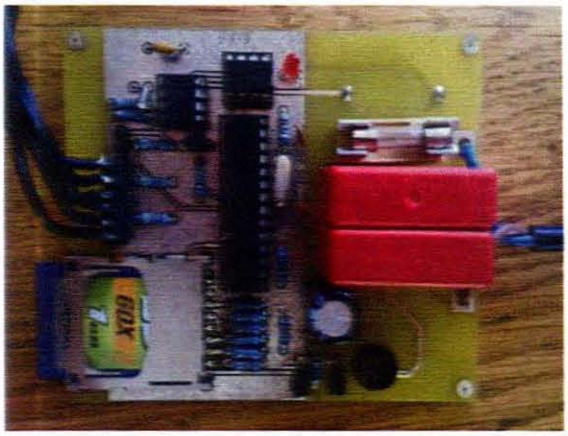
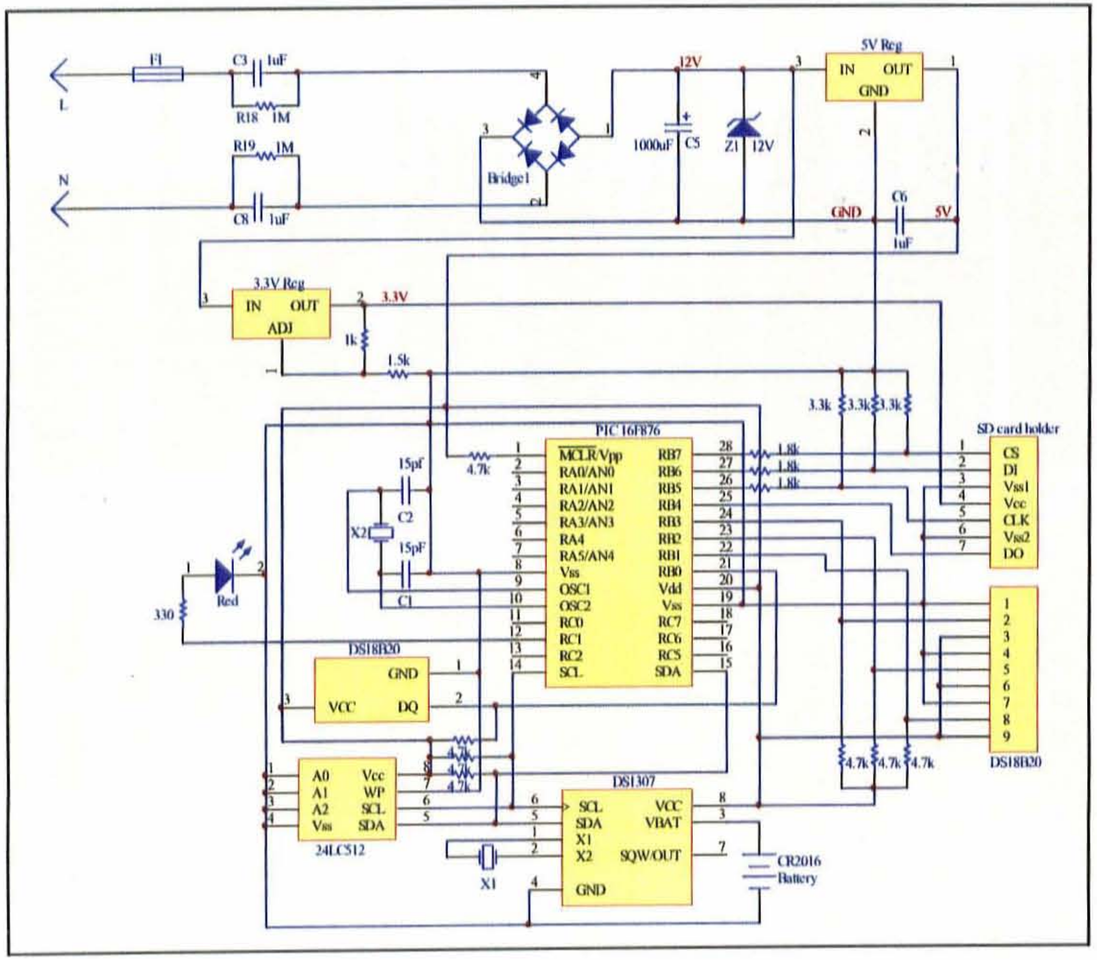
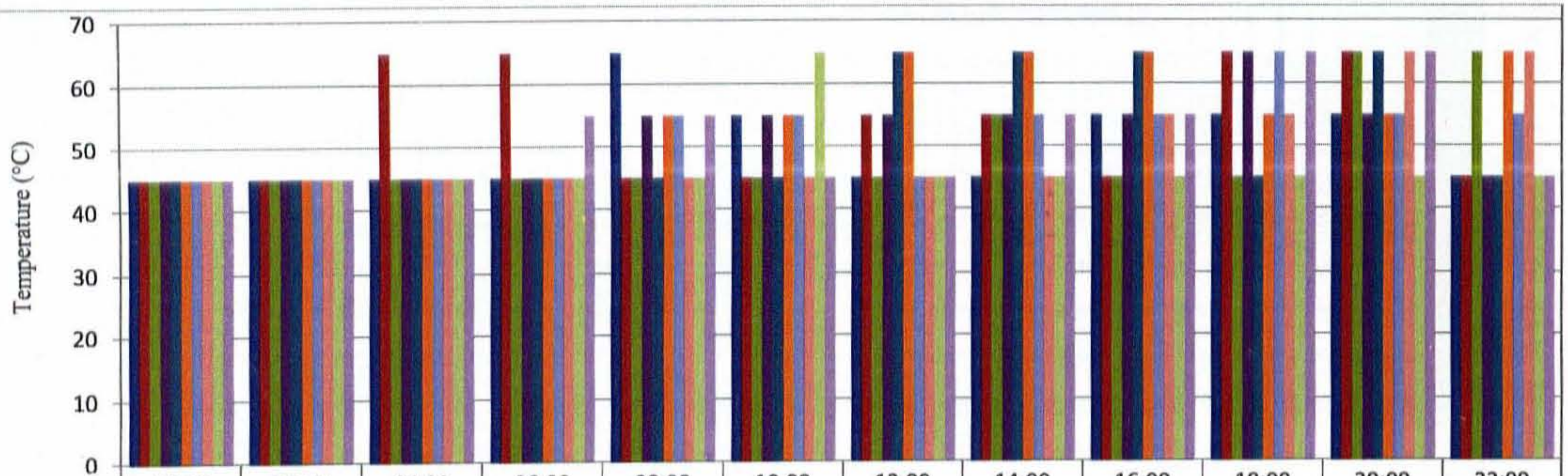
Appendix A - Data logger pictures



Appendix B - Data logger schematic



Appendix C - Hot water usage profiles for all ten homes



	00:00	02:00	04:00	06:00	08:00	10:00	12:00	14:00	16:00	18:00	20:00	22:00
■ Home 1	45	45	45	45	65	55	45	45	55	55	55	45
■ Home 2	45	45	65	65	45	45	55	55	45	65	65	45
■ Home 3	45	45	45	45	45	45	45	55	45	45	65	65
■ Home 4	45	45	45	45	55	55	55	55	55	65	55	45
■ Home 5	45	45	45	45	45	45	65	65	65	45	65	45
■ Home 6	45	45	45	45	55	55	65	65	65	55	55	65
■ Home 7	45	45	45	45	55	55	45	55	55	65	55	55
■ Home 8	45	45	45	45	45	45	45	45	55	55	65	65
■ Home 9	45	45	45	45	45	65	45	45	45	45	45	45
■ Home 10	45	45	45	55	55	45	45	55	55	65	65	45

Appendix D – Complete data logged for Home1

Time (HH:MM)	Date (Y/M/D)	T Roof (°C)	Day Count	SL (°C)	SLP (°C)	Draw (Minutes)	Probability (%)	Accuracy (%)
10:00 AM	08/11/04	26.125	1	45	0	0	0	0
12:00 PM	08/11/04	31.25	1	45	0	0	0	0
02:00 PM	08/11/04	34.3125	1	45	0	0	0	0
04:00 PM	08/11/04	34.625	1	65	0	2	100	0
06:00 PM	08/11/04	33.3125	1	65	0	4	100	0
08:00 PM	08/11/04	29.0625	1	65	0	17	100	0
10:00 PM	08/11/04	26.625	1	65	0	30	100	0
12:00 AM	08/11/05	25.5625	2	45	45	0	0	100
02:00 AM	08/11/05	24.125	2	45	45	0	0	100
04:00 AM	08/11/05	23.5	2	45	45	0	0	100
06:00 AM	08/11/05	23.4375	2	45	45	0	0	100
08:00 AM	08/11/05	23.5	2	55	45	11	50	80
10:00 AM	08/11/05	25.625	2	45	45	0	0	83
12:00 PM	08/11/05	28.5625	2	45	45	0	0	86
02:00 PM	08/11/05	30.8125	2	45	45	0	0	88
04:00 PM	08/11/05	32.1875	2	65	65	13	100	89
06:00 PM	08/11/05	28.75	2	55	65	0	50	80
08:00 PM	08/11/05	25.5	2	55	65	0	50	73
10:00 PM	08/11/05	24.1875	2	65	65	6	100	75
12:00 AM	08/11/06	23.125	3	55	45	15	33	69
02:00 AM	08/11/06	22.5	3	45	45	0	0	71
04:00 AM	08/11/06	21.625	3	45	45	0	0	73
06:00 AM	08/11/06	21.3125	3	45	45	0	0	75
08:00 AM	08/11/06	21.75	3	65	55	13	66	71
10:00 AM	08/11/06	24.375	3	55	45	12	33	67
12:00 PM	08/11/06	27.1875	3	55	45	4	33	63
02:00 PM	08/11/06	29.0625	3	55	45	14	33	60
04:00 PM	08/11/06	30	3	65	65	3	100	62
06:00 PM	08/11/06	27.5625	3	55	55	0	33	64
08:00 PM	08/11/06	23.8125	3	55	55	0	33	65
10:00 PM	08/11/06	22.125	3	65	65	2	100	67
12:00 AM	08/11/07	21.125	4	55	55	1	50	68
02:00 AM	08/11/07	20.625	4	45	45	0	0	69
04:00 AM	08/11/07	20.1875	4	45	45	0	0	70
06:00 AM	08/11/07	19.875	4	45	45	0	0	71
08:00 AM	08/11/07	20.4375	4	65	65	21	75	72
10:00 AM	08/11/07	24.75	4	45	55	0	25	70
12:00 PM	08/11/07	28.875	4	45	55	0	25	68
02:00 PM	08/11/07	33.4375	4	45	55	0	25	66
04:00 PM	08/11/07	33.5625	4	65	65	0	75	67
06:00 PM	08/11/07	30.375	4	45	55	0	25	65
08:00 PM	08/11/07	25.5625	4	45	55	0	25	63
10:00 PM	08/11/07	23.1875	4	65	65	20	100	64
12:00 AM	08/11/08	22.4375	5	55	55	7	60	65
02:00 AM	08/11/08	22	5	45	45	0	0	66
04:00 AM	08/11/08	21.6875	5	45	45	0	0	67
06:00 AM	08/11/08	21.4375	5	45	45	0	0	68
08:00 AM	08/11/08	21.9375	5	65	65	12	80	68
10:00 AM	08/11/08	24.125	5	45	45	0	20	69

12:00 PM	08/11/08	28.375	5	45	45	0	20	70
02:00 PM	08/11/08	31.875	5	45	45	0	20	70
04:00 PM	08/11/08	29.8125	5	65	65	1	80	71
06:00 PM	08/11/08	27.375	5	45	45	0	20	72
08:00 PM	08/11/08	25	5	45	45	0	20	72
10:00 PM	08/11/08	22.875	5	65	65	3	100	73
12:00 AM	08/11/09	21.875	6	55	55	0	50	73
02:00 AM	08/11/09	21.25	6	45	45	0	0	74
04:00 AM	08/11/09	20.6875	6	45	45	0	0	75
06:00 AM	08/11/09	20.1875	6	45	45	0	0	75
08:00 AM	08/11/09	22.375	6	65	65	18	87	75
10:00 AM	08/11/09	27.875	6	55	45	18	37	74
12:00 PM	08/11/09	33.625	6	45	45	0	25	75
02:00 PM	08/11/09	36.875	6	55	55	21	50	75
04:00 PM	08/11/09	36.4375	6	65	65	0	75	75
06:00 PM	08/11/09	32.375	6	45	45	1	25	76
08:00 PM	08/11/09	26.5	6	55	45	23	37	75
10:00 PM	08/11/09	24.125	6	65	65	4	100	75
12:00 AM	08/11/10	23.0625	7	55	55	0	44	75
02:00 AM	08/11/10	22.1875	7	45	45	0	0	76
04:00 AM	08/11/10	21.75	7	45	45	0	0	76
06:00 AM	08/11/10	21.125	7	45	45	5	11	77
08:00 AM	08/11/10	22.5	7	65	65	9	88	77
10:00 AM	08/11/10	26.875	7	55	55	0	33	77
12:00 PM	08/11/10	30.875	7	45	45	0	22	78
02:00 PM	08/11/10	33.25	7	55	55	0	44	78
04:00 PM	08/11/10	33.25	7	65	65	0	66	78
06:00 PM	08/11/10	28.9375	7	45	45	0	22	79
08:00 PM	08/11/10	24.625	7	55	55	18	44	79
10:00 PM	08/11/10	23.1875	7	65	65	3	100	79
12:00 AM	08/11/11	22.625	8	55	55	0	40	79
02:00 AM	08/11/11	22.25	8	45	45	0	0	80
04:00 AM	08/11/11	21.75	8	45	45	0	0	80
06:00 AM	08/11/11	21.1875	8	45	45	0	10	80
08:00 AM	08/11/11	21.75	8	65	65	8	90	81
10:00 AM	08/11/11	23.75	8	45	55	0	30	79
12:00 PM	08/11/11	27.375	8	45	45	0	20	80
02:00 PM	08/11/11	28.875	8	55	55	24	50	80
04:00 PM	08/11/11	28.25	8	55	65	0	60	79
06:00 PM	08/11/11	26.3125	8	45	45	14	30	79
08:00 PM	08/11/11	22.5	8	55	55	0	40	80
10:00 PM	08/11/11	21.4375	8	65	65	1	100	80
12:00 AM	08/11/12	20.375	9	55	55	3	45	80
02:00 AM	08/11/12	19.4375	9	45	45	0	0	80
04:00 AM	08/11/12	18.8125	9	45	45	0	0	80
06:00 AM	08/11/12	18.5625	9	45	45	0	9	81
08:00 AM	08/11/12	18.625	9	65	65	14	90	81
10:00 AM	08/11/12	19.9375	9	55	45	6	36	80
12:00 PM	08/11/12	20.375	9	45	45	0	18	80
02:00 PM	08/11/12	20.9375	9	55	55	0	45	80
04:00 PM	08/11/12	19.8125	9	55	55	0	54	81
06:00 PM	08/11/12	19.3125	9	45	45	0	27	81
08:00 PM	08/11/12	19	9	55	55	19	45	81

10:00 PM	08/11/12	18.9375	9	65	65	14	100	81
12:00 AM	08/11/13	18.75	10	55	55	0	41	81
02:00 AM	08/11/13	18.75	10	45	45	0	0	82
04:00 AM	08/11/13	18.625	10	45	45	0	0	82
06:00 AM	08/11/13	18.4375	10	45	45	0	8	82
08:00 AM	08/11/13	19	10	65	65	18	91	82
10:00 AM	08/11/13	21.5	10	55	55	11	41	82
12:00 PM	08/11/13	25.125	10	45	45	0	16	83
02:00 PM	08/11/13	27.4375	10	55	55	0	41	83
04:00 PM	08/11/13	26.375	10	55	55	1	58	83
06:00 PM	08/11/13	25.1875	10	45	45	0	25	83
08:00 PM	08/11/13	21.9375	10	55	55	1	50	83
10:00 PM	08/11/13	20.8125	10	65	65	2	116	83
12:00 AM	08/11/14	20.1875	11	55	55	2	46	83
02:00 AM	08/11/14	19.5625	11	45	45	0	0	84
04:00 AM	08/11/14	19.375	11	45	45	0	0	84
06:00 AM	08/11/14	19.25	11	45	45	0	7	84
08:00 AM	08/11/14	20.875	11	65	65	17	92	84
10:00 AM	08/11/14	25.4375	11	55	55	10	46	84
12:00 PM	08/11/14	29.6875	11	45	45	0	15	84
02:00 PM	08/11/14	32.4375	11	55	55	0	38	84
04:00 PM	08/11/14	31.75	11	55	55	0	53	85
06:00 PM	08/11/14	28.6875	11	45	45	4	30	85
08:00 PM	08/11/14	24.25	11	55	55	0	46	85
10:00 PM	08/11/14	21.875	11	65	65	1	100	85
12:00 AM	08/11/15	21	12	55	55	12	50	85
02:00 AM	08/11/15	20.5	12	45	45	0	0	85
04:00 AM	08/11/15	19.6875	12	45	45	0	0	85
06:00 AM	08/11/15	19.4375	12	45	45	0	7	85
08:00 AM	08/11/15	21.1875	12	65	65	15	92	86
10:00 AM	08/11/15	25.5625	12	55	55	22	50	86
12:00 PM	08/11/15	29.1875	12	45	45	8	21	86
02:00 PM	08/11/15	31.4375	12	55	55	0	35	86
04:00 PM	08/11/15	31.25	12	55	55	26	57	86
06:00 PM	08/11/15	28.25	12	55	45	2	35	85
08:00 PM	08/11/15	24	12	55	55	0	42	85
10:00 PM	08/11/15	22.375	12	65	65	0	92	86
12:00 AM	08/11/16	21.625	13	55	55	0	46	86
02:00 AM	08/11/16	21.125	13	45	45	0	0	86
04:00 AM	08/11/16	20.8125	13	45	45	0	0	86
06:00 AM	08/11/16	20.5	13	45	45	0	6	86
08:00 AM	08/11/16	21.375	13	65	65	0	86	86
10:00 AM	08/11/16	25.625	13	55	55	0	46	86
12:00 PM	08/11/16	30.75	13	45	45	3	26	86
02:00 PM	08/11/16	33	13	55	55	5	40	86
04:00 PM	08/11/16	32.625	13	55	55	7	60	87
06:00 PM	08/11/16	29.375	13	55	55	2	40	87
08:00 PM	08/11/16	24.1875	13	55	55	3	46	87
10:00 PM	08/11/16	22.125	13	65	65	1	93	87
12:00 AM	08/11/17	21.3125	14	55	55	0	43	87
02:00 AM	08/11/17	20.875	14	45	45	0	0	87
04:00 AM	08/11/17	20.6875	14	45	45	0	0	87
06:00 AM	08/11/17	21.125	14	45	45	2	12	87

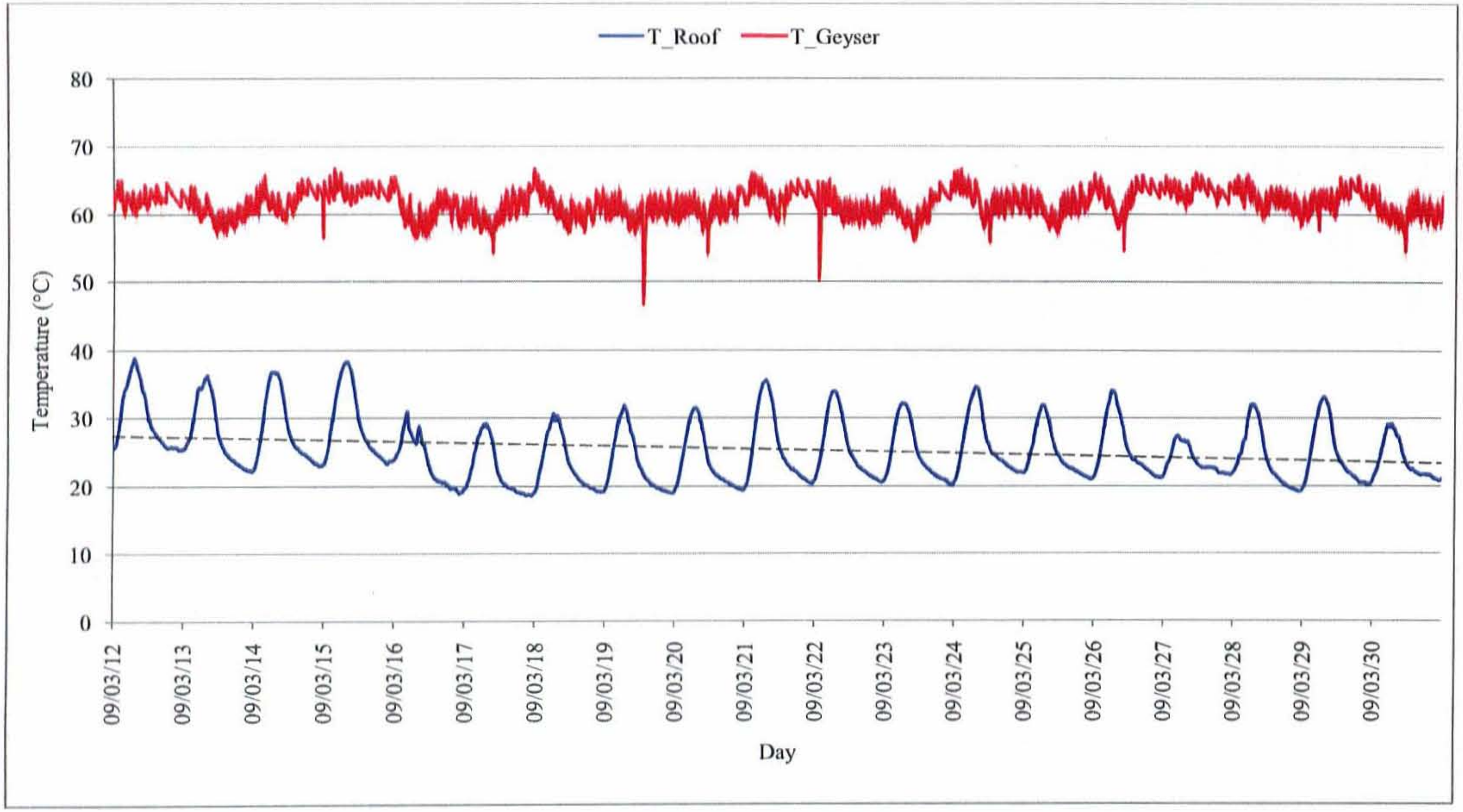
08:00 AM	08/11/17	22.625	14	65	65	12	87	87
10:00 AM	08/11/17	25.1875	14	55	55	0	43	87
12:00 PM	08/11/17	29.5	14	45	45	0	25	87
02:00 PM	08/11/17	31.5625	14	55	55	2	43	88
04:00 PM	08/11/17	30.3125	14	55	55	0	56	88
06:00 PM	08/11/17	27.125	14	55	55	0	37	88
08:00 PM	08/11/17	23.375	14	55	55	15	50	88
10:00 PM	08/11/17	21.6875	14	65	65	0	87	88
12:00 AM	08/11/18	20.875	15	55	55	0	41	88
02:00 AM	08/11/18	20.3125	15	45	45	0	0	88
04:00 AM	08/11/18	20	15	45	45	0	0	88
06:00 AM	08/11/18	19.6875	15	45	45	0	11	88
08:00 AM	08/11/18	21.625	15	65	65	10	88	88
10:00 AM	08/11/18	26.4375	15	55	55	0	41	88
12:00 PM	08/11/18	29.1875	15	45	45	0	23	88
02:00 PM	08/11/18	31.8125	15	55	55	0	41	88
04:00 PM	08/11/18	31.0625	15	55	55	0	52	88
06:00 PM	08/11/18	28.875	15	55	55	0	35	89
08:00 PM	08/11/18	24.8125	15	55	55	20	52	89
10:00 PM	08/11/18	22.8125	15	65	65	5	88	89
12:00 AM	08/11/19	22.0625	16	55	55	0	39	89
02:00 AM	08/11/19	20.625	16	45	45	0	0	89
04:00 AM	08/11/19	20.25	16	45	45	0	0	89
06:00 AM	08/11/19	19.625	16	45	45	0	11	89
08:00 AM	08/11/19	21.6875	16	65	65	12	88	89
10:00 AM	08/11/19	26.625	16	55	55	0	50	89
12:00 PM	08/11/19	31.1875	16	55	55	13	44	89
02:00 PM	08/11/19	31.5625	16	55	55	0	38	89
04:00 PM	08/11/19	30.375	16	55	55	0	38	89
06:00 PM	08/11/19	29.5	16	55	55	4	55	89
08:00 PM	08/11/19	25.5625	16	55	55	22	55	89
10:00 PM	08/11/19	23.6875	16	65	65	0	83	89
12:00 AM	08/11/20	23	17	55	55	0	36	90
02:00 AM	08/11/20	22.1875	17	45	45	0	0	90
04:00 AM	08/11/20	21.6875	17	45	45	0	0	90
06:00 AM	08/11/20	21.3125	17	45	45	0	11	90
08:00 AM	08/11/20	23.3125	17	65	65	11	89	90
10:00 AM	08/11/20	28.5625	17	55	55	0	37	90
12:00 PM	08/11/20	34.75	17	45	55	0	26	90
02:00 PM	08/11/20	34.3125	17	55	55	0	37	90
04:00 PM	08/11/20	33.5625	17	55	55	2	53	90
06:00 PM	08/11/20	30.9375	17	55	55	0	37	90
08:00 PM	08/11/20	27.8125	17	55	55	15	58	90
10:00 PM	08/11/20	26	17	65	65	5	84	90
12:00 AM	08/11/21	22.25	18	55	55	0	35	90
02:00 AM	08/11/21	21.5	18	45	45	0	0	90
04:00 AM	08/11/21	20.5	18	45	45	0	0	90
06:00 AM	08/11/21	19.4375	18	45	45	0	10	90
08:00 AM	08/11/21	21.1875	18	65	65	12	90	90
10:00 AM	08/11/21	25.625	18	55	55	0	35	90
12:00 PM	08/11/21	29.0625	18	45	45	0	25	90
02:00 PM	08/11/21	30.8125	18	55	55	0	35	91
04:00 PM	08/11/21	31.4375	18	55	55	0	50	91

06:00 PM	08/11/21	28.4375	18	55	55	0	35	91
08:00 PM	08/11/21	26.4375	18	55	55	0	55	91
10:00 PM	08/11/21	23.75	18	65	65	15	85	91
12:00 AM	08/11/22	21.625	19	55	55	0	33	91
02:00 AM	08/11/22	21.4375	19	45	45	0	0	91
04:00 AM	08/11/22	20.8125	19	45	45	0	0	91
06:00 AM	08/11/22	20.75	19	45	45	0	9	91
08:00 AM	08/11/22	21.5625	19	65	65	11	90	91
10:00 AM	08/11/22	25.0625	19	55	55	11	38	91
12:00 PM	08/11/22	31	19	45	45	0	23	91
02:00 PM	08/11/22	33.1875	19	55	55	0	33	91
04:00 PM	08/11/22	32.6875	19	55	55	0	47	91
06:00 PM	08/11/22	29.8125	19	55	55	2	38	91
08:00 PM	08/11/22	24.9375	19	55	55	13	57	91
10:00 PM	08/11/22	21.8125	19	65	65	5	86	91
12:00 AM	08/11/23	21.4375	20	55	55	0	31	91
02:00 AM	08/11/23	20.6875	20	45	45	0	0	91
04:00 AM	08/11/23	20.5	20	45	45	0	0	91
06:00 AM	08/11/23	21.0625	20	45	45	3	14	91
08:00 AM	08/11/23	22.875	20	65	65	15	91	91
10:00 AM	08/11/23	25.4375	20	55	55	12	41	91
12:00 PM	08/11/23	29.6875	20	45	45	0	23	91
02:00 PM	08/11/23	31.6875	20	55	55	12	36	92
04:00 PM	08/11/23	30.25	20	55	55	0	45	92
06:00 PM	08/11/23	27.0625	20	55	55	0	36	92
08:00 PM	08/11/23	23.8125	20	55	55	0	55	92
10:00 PM	08/11/23	22.3125	20	65	65	17	86	92
12:00 AM	08/11/24	20.9375	21	55	55	0	30	92
02:00 AM	08/11/24	20.3125	21	45	45	0	0	92
04:00 AM	08/11/24	20	21	45	45	0	0	92
06:00 AM	08/11/24	19.4375	21	45	45	0	13	92
08:00 AM	08/11/24	21.4375	21	65	65	13	91	92
10:00 AM	08/11/24	25.875	21	55	55	0	39	92
12:00 PM	08/11/24	29.0625	21	45	45	0	22	92
02:00 PM	08/11/24	31.8125	21	55	55	0	35	92
04:00 PM	08/11/24	31	21	55	55	5	48	92
06:00 PM	08/11/24	28.8125	21	55	55	4	39	92
08:00 PM	08/11/24	24.75	21	55	55	18	57	92
10:00 PM	08/11/24	22.75	21	65	65	7	87	92
12:00 AM	08/11/25	21.75	22	45	55	0	29	92
02:00 AM	08/11/25	20.4375	22	45	45	0	0	92
04:00 AM	08/11/25	19.875	22	45	45	0	0	92
06:00 AM	08/11/25	19.375	22	45	45	0	13	92
08:00 AM	08/11/25	21.625	22	65	65	9	92	92
10:00 AM	08/11/25	26.5625	22	55	55	10	42	92
12:00 PM	08/11/25	31.5	22	45	45	0	21	92
02:00 PM	08/11/25	31.625	22	55	55	0	33	92
04:00 PM	08/11/25	30.625	22	55	55	0	46	92
06:00 PM	08/11/25	29.5	22	55	55	4	42	92
08:00 PM	08/11/25	25.8125	22	55	55	10	58	92
10:00 PM	08/11/25	23.75	22	65	65	9	88	92
12:00 AM	08/11/26	23.0625	23	45	45	0	28	92
02:00 AM	08/11/26	22.1875	23	45	45	0	0	92

04:00 AM	08/11/26	21.6875	23	45	45	0	0	92
06:00 AM	08/11/26	21.375	23	45	45	0	12	92
08:00 AM	08/11/26	23.1875	23	65	65	10	92	92
10:00 AM	08/11/26	29	23	55	55	0	40	92
12:00 PM	08/11/26	34.75	23	45	45	0	20	92
02:00 PM	08/11/26	34.1875	23	55	55	6	36	92
04:00 PM	08/11/26	33.625	23	55	55	0	44	92
06:00 PM	08/11/26	30.625	23	55	55	0	40	92
08:00 PM	08/11/26	27.125	23	65	55	16	60	92
10:00 PM	08/11/26	26.0625	23	65	65	8	88	92
12:00 AM	08/11/27	21.875	24	45	45	0	27	92
02:00 AM	08/11/27	21.25	24	45	45	0	0	92
04:00 AM	08/11/27	20.6875	24	45	45	0	0	92
06:00 AM	08/11/27	20.1875	24	45	45	0	12	92
08:00 AM	08/11/27	22.375	24	65	65	10	92	92
10:00 AM	08/11/27	27.875	24	55	55	0	38	92
12:00 PM	08/11/27	33.625	24	45	45	0	19	92
02:00 PM	08/11/27	36.875	24	55	55	0	35	92
04:00 PM	08/11/27	36.4375	24	55	55	0	42	92
06:00 PM	08/11/27	32.375	24	55	55	0	38	92
08:00 PM	08/11/27	26.5	24	55	55	13	58	92
10:00 PM	08/11/27	24.125	24	65	65	12	88	92
12:00 AM	08/11/28	22.0625	25	45	45	0	26	92
02:00 AM	08/11/28	20.625	25	45	45	0	0	92
04:00 AM	08/11/28	20.25	25	45	45	0	0	92
06:00 AM	08/11/28	19.625	25	45	45	0	11	93
08:00 AM	08/11/28	21.6875	25	65	65	13	93	93
10:00 AM	08/11/28	26.625	25	55	55	7	41	93
12:00 PM	08/11/28	31.1875	25	45	45	0	19	93
02:00 PM	08/11/28	31.5625	25	55	55	0	33	93
04:00 PM	08/11/28	30.375	25	55	55	0	41	93
06:00 PM	08/11/28	29.5	25	55	55	6	41	93
08:00 PM	08/11/28	25.5625	25	55	55	11	59	93
10:00 PM	08/11/28	23.6875	25	65	65	9	89	93
12:00 AM	08/11/29	20.875	26	45	45	0	25	93
02:00 AM	08/11/29	20.3125	26	45	45	0	0	93
04:00 AM	08/11/29	20	26	45	45	0	0	93
06:00 AM	08/11/29	19.6875	26	45	45	0	11	93
08:00 AM	08/11/29	21.625	26	65	65	9	93	93
10:00 AM	08/11/29	26.4375	26	55	55	0	39	93
12:00 PM	08/11/29	29.1875	26	45	45	0	18	93
02:00 PM	08/11/29	31.8125	26	55	55	0	32	93
04:00 PM	08/11/29	31.0625	26	55	55	5	43	93
06:00 PM	08/11/29	28.875	26	55	55	0	39	93
08:00 PM	08/11/29	24.8125	26	65	65	7	61	93
10:00 PM	08/11/29	22.8125	26	65	65	4	89	93
12:00 AM	08/11/30	21.625	27	45	45	0	24	93
02:00 AM	08/11/30	21.125	27	45	45	0	0	93
04:00 AM	08/11/30	20.8125	27	45	45	0	0	93
06:00 AM	08/11/30	20.5	27	45	45	0	10	93
08:00 AM	08/11/30	21.375	27	65	65	8	93	93
10:00 AM	08/11/30	25.625	27	55	55	11	41	93
12:00 PM	08/11/30	30.75	27	45	45	0	17	93

02:00 PM	08/11/30	33	27	55	55	0	31	93
04:00 PM	08/11/30	32.625	27	55	55	7	45	93
06:00 PM	08/11/30	29.375	27	55	55	0	38	93
08:00 PM	08/11/30	24.1875	27	65	65	15	62	93
10:00 PM	08/11/30	22.125	27	65	65	0	86	93
12:00 AM	08/12/01	25.5625	28	45	45	0	23	93
02:00 AM	08/12/01	24.125	28	45	45	0	0	93
04:00 AM	08/12/01	23.5	28	45	45	0	0	93
06:00 AM	08/12/01	23.4375	28	45	45	0	10	93
08:00 AM	08/12/01	23.5	28	65	65	11	93	93
10:00 AM	08/12/01	25.625	28	55	55	0	40	93
12:00 PM	08/12/01	28.5625	28	45	45	0	17	93
02:00 PM	08/12/01	30.8125	28	55	55	0	30	93
04:00 PM	08/12/01	32.1875	28	55	55	0	43	93
06:00 PM	08/12/01	28.75	28	55	55	0	37	93
08:00 PM	08/12/01	25.5	28	65	65	8	63	93
10:00 PM	08/12/01	24.1875	28	65	65	0	83	94
12:00 AM	08/12/02	20.9375	29	45	45	0	23	94
02:00 AM	08/12/02	20.3125	29	45	45	0	0	94
04:00 AM	08/12/02	20	29	45	45	0	0	94
06:00 AM	08/12/02	19.4375	29	45	45	0	10	94
08:00 AM	08/12/02	21.4375	29	65	65	15	94	94
10:00 AM	08/12/02	25.875	29	55	55	0	39	94
12:00 PM	08/12/02	29.0625	29	45	45	0	16	94
02:00 PM	08/12/02	31.8125	29	45	55	0	29	93
04:00 PM	08/12/02	31	29	55	55	0	42	93
06:00 PM	08/12/02	28.8125	29	55	55	0	35	93
08:00 PM	08/12/02	24.75	29	65	65	17	65	93
10:00 PM	08/12/02	22.75	29	65	65	0	81	93
12:00 AM	08/12/03	25.5625	30	45	45	0	22	93
02:00 AM	08/12/03	24.125	30	45	45	0	0	93
04:00 AM	08/12/03	23.5	30	45	45	0	0	94
06:00 AM	08/12/03	23.4375	30	45	45	0	9	94
08:00 AM	08/12/03	23.5	30	65	65	13	94	94
10:00 AM	08/12/03	25.625	30	55	55	0	38	94
12:00 PM	08/12/03	28.5625	30	45	45	0	16	94
02:00 PM	08/12/03	30.8125	30	45	45	0	28	94
04:00 PM	08/12/03	32.1875	30	55	55	0	41	94
06:00 PM	08/12/03	28.75	30	55	55	0	34	94
08:00 PM	08/12/03	25.5	30	65	65	21	66	94
10:00 PM	08/12/03	24.1875	30	65	65	0	78	94
12:00 AM	08/12/04	23.0625	31	45	45	0	20	94
02:00 AM	08/12/04	22.1875	31	45	45	0	0	94
04:00 AM	08/12/04	21.6875	31	45	45	0	0	94
06:00 AM	08/12/04	21.375	31	45	45	0	8	94
08:00 AM	08/12/04	23.1875	31	65	65	10	95	94
10:00 AM	08/12/04	29	31	55	55	0	37	94
12:00 PM	08/12/04	34.75	31	45	45	0	15	94
02:00 PM	08/12/04	34.1875	31	45	45	6	30	94
04:00 PM	08/12/04	33.625	31	55	55	0	39	94
06:00 PM	08/12/04	30.625	31	55	55	0	33	94
08:00 PM	08/12/04	27.125	31	65	65	16	67	94
10:00 PM	08/12/04	26.0625	31	65	65	8	80	94

Appendix E - Baseline of thermostat controlled geyser



Appendix F - Profile controlled geyser