South Africa Geyser: Cost-Efficiency Technical Study

Final Report

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Background

The residential sector accounts for approximately 17% of electricity use in South Africa, but as much as 35% during peak periods. Within households the geyser is responsible for between 40-50% of total consumption and contributes substantially to morning and evening peaks. The Department of Energy has also been planning the introduction of a mandatory Standards and Labelling (S&L) Programme for twelve residential appliances, which includes geysers. Of the twelve appliances, geysers are the only residential appliances having an existing mandatory Minimum Energy Performance Standard (MEPS) requirement. This MEPS, regulated by the standing loss test (SANS151) was put in place over 30 years ago and in the current context is considered low and ineffective.

A study undertaken in 2011/12 aimed to include a recommendation of more stringent MEPS for geysers, but yielded inconclusive results due to limited participation by geyser manufacturers. At that time, it was proposed that a detailed techno-economic study including cost effectiveness be undertaken. This report, supported by the Super-Efficient Appliance Deployment (SEAD) Initiative and with the participation of Lawrence Berkeley National Laboratory, intends to fill this gap.

The objective of this cost-effectiveness technical study is to determine the projected cost to manufacturers and consumers to reduce electric geyser standing losses to varying degrees in order to formulate a MEPS supported by analysis of net financial impacts to consumers. The study limited itself to insulation efficiency while acknowledging that there are other sources of heat loss, such as fittings and structural supports. These non-insulation losses are collectively referred to as 'by-pass' losses.

Standing Loss Test, Thermal Photography and Tear-down Measurements of Specific Geyser Models

In order to gauge the distribution of performance of the geyser market, 5 models were selected, purchased and subjected to testing. Due to a high degree of consolidation in the market, this sample is estimated to represent close to 90% of the market, in the most common capacity category of 150 litres. Each model was tested in a laboratory set up to replicate the specifications of the SANS 151 Standing Loss test. Major conclusions of the testing include:

- All units were found to be in compliance of the current MEPS;
- Adjusted standing loss measurements ranged from 1.87 kWh/24hr to 2.54 kWh/24h in the horizontal position, placing one model in the 'C' category, 4 in the 'D' range and one in the 'E' range;
- Significant differences were found in test results between the horizontal and vertical configurations; and
- Ambiguities in the test procedure configuration specifications were found to produce significant variation in results.

In addition to measurement, thermal photographs were made of each geyser from multiple angles. These photographs provide clear evidence of the 'hot spots', or sources of heat leakage, particularly from fittings and controls.

After testing and photographing, each geyser was subjected to tear-down and measurements were made regarding its construction, particularly the thickness of polyurethane insulation. The thickness of insulation averaged over different parts of the tank ranged from 20-26mm, but was highly non-uniform for some models.

Measurements of insulation level were combined with heat transfer relationships and test results in order to infer a 'bypass' loss of between 0.14 and 0.7 kWh/24h. This range indicates that on the order of 0.5 kWh/24h of standing loss reduction is available in addition to reductions from added insulation. Increasing insulation levels to 50mm is found to result in achievement of a 'B' level for the average geyser model.

Cost-Effectiveness of Increased Insulation from the Consumer Standpoint

Cost-effectiveness from a consumer stand-point considered *only* increasing the thickness of insulation and followed the following basic steps:

1. Evaluate the level of insulation of the baseline unit;
2. Consider the added material costs of increasing insulation thickness beyond the baseline, and implied incremental retail price to consumers;
3. Calculate the reduction in annual standing losses from added insulation according to heat transfer model and associated electricity bill costs; and
4. Evaluate the cost-effectiveness to consumers of added insulation by comparing incremental equipment costs to operating cost reductions.

The baseline insulation level is taken to be 20mm and options up to 125 mm were considered, although questions were raised by manufacturers regarding the feasibility of designs exceeding 50mm thickness.

As the testing and tear-down results show, there are significant other opportunities for reducing standing losses besides increasing insulation, and some of these may be more cost-effective. Therefore, the "insulation only" option is a "conservative" approach.

Table ES-1 Cost-Effectiveness Indicators for increased geyser insulation thickness

t	∆LCC	Payback	CCE
mm	R	year	R
20 (baseline)	-	-	-
25	-1,486	0.15	0.05
50	-4,596	0.30	0.10
75	-5,595	0.47	0.16
100	-6,010	0.66	0.23
125	-6,173	0.87	0.30

Cost-effectiveness indicators are shown in Table ES-1 for each value of insulation thickness *t* considered. The three indicators considered are 1) Incremental Life Cycle Cost (∆LCC); 2) Payback period in years; and 3) Cost of Conserved Energy (CCE). For all three calculations it was found that it is beneficial to the consumer to increase insulation up to 125 mm, with lowered life cycle cost, payback periods less than one year, and cost of conserved energy at a fraction of electricity prices.

Findings and Recommendations

This study provides much needed information based on measurement and quantitative analysis, to form part of the basis for discussions of geyser MEPS between Government, manufacturers, the national standards and testing authority and consumers. The report comes to the following conclusions:

- Geysers on the South African market are generally compliant with current regulations, but show significant opportunities for further reduction of standing losses
- Increasing insulation thickness is demonstrably cost-effective from the consumer standpoint in terms of increased material costs well beyond the 50mm level considered to be feasible by manufacturers
- As a result of this, and in light of other heat losses, a 'B' level is likely achievable by geyser manufacturers and cost-effective to consumers.
- Ambiguities in the current test procedure language and methodology may result in large variation in results and should be reviewed to increase precision.

1 Rationale for Research

1.1 Introduction and S&L Project Background

South Africa identified the energy savings potential of efficient appliances as far back as 1998 and has targeted the introduction of a component of S&L since that time. Key milestones include:

- The White Paper on Energy Policy (1998) recognized that standards and appliance labelling (S&L) should be the first measures to be put in place in implementing energy efficiency.
- The Energy Efficiency Strategy (2005) states under the Residential Sector Programme 'Introduction of mandatory standards and labelling'.
- In 2009 the South African Bureau of Standards (SABS) forms the Working Group 941 (WG941) who are mandated to develop SANS 941 which would identify the residential appliances to be targeted, the technical specifications, the measurement standards as well as the labels. SANS 941 identified appliances which have a high electricity consumption. The Department of Energy selected the following appliances for the first programme: air conditioners (up to 5 kW), consumer electronics, dishwashers, laundry machines, domestic refrigeration, lighting (electric lamps, street and industrial lighting), ovens, tumble dryers and **water heaters**.
- The UNDP/GEF funding is approved in 2011 with a budget of USD4.4m excluding the SA Government contribution.
- A study was commissioned by the Department of Industry and Business Unity South Africa (BUSA) in 2012 to conduct an impact assessment of a S&L programme on the local manufacturing industry, the potential electricity savings that could be achieved through the introduction of Minimum Energy Performance Standards (MEPS) and identifying the most appropriate MEPS for each appliance.
- A project manager was appointed in 2013, SABS has invested in new testing facilities and the regulations are expected to come into effect in 2015.

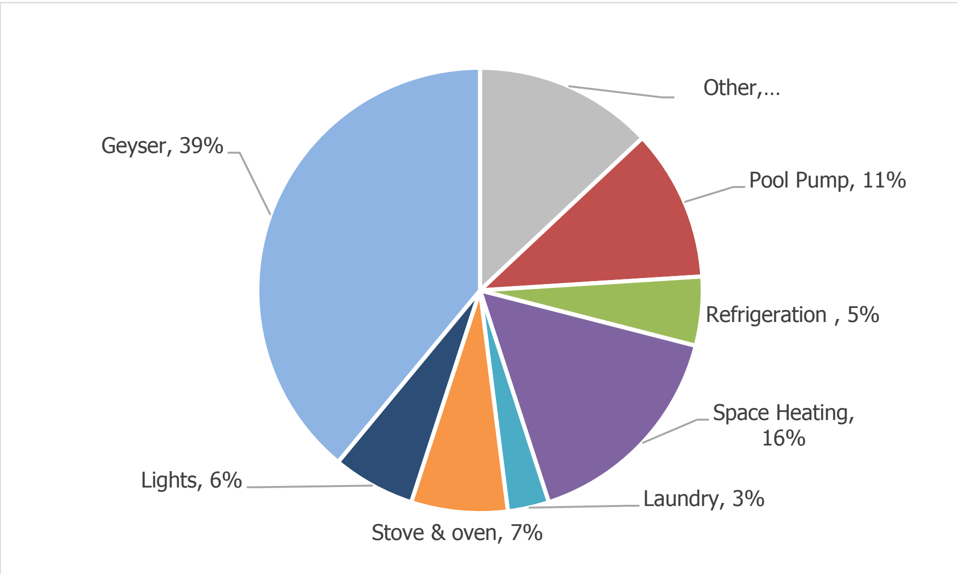
1.2 Residential Sector Electricity Consumption and Geysers

The residential sector uses about 17% of the total electricity generated in South Africa. During the periods of peak demand, which are from 07h00 to 10h00 and 17h00 to 21h00, residential demand is up to 35% of the total demand required. The appliance identified as the major contributor to this increase in demand is the geyser (Eskom, 2013).

Until recently almost all hot water in South African households were heated by electric resistance elements (geysers). Large tariff increases, which have seen the price of electricity triple for the period 2007-2012 and a Government funded rebate programme which promotes heat pump and Solar Water Heaters, has resulted in some households installing these technologies. But the roll-out has been largely disappointing (Uken, 2012) and the majority of household's continue to use electric geysers.

A document produced by the South African Government in 1995 estimated that electricity required for water heating in middle to upper income households makes up to 40-50% of total household electricity consumption (Meyer, 2000). A household survey conducted by Eskom in 2010 estimated that the average middle income household uses 1,100 kWh per month. This figure was revised downwards in the 2013 update which estimated the consumption to be 750-1,100 kWh per month, however the allocations remained the same. The breakdown is as follows:

Figure 1: Middle Income HH Electricity Usage by Appliance



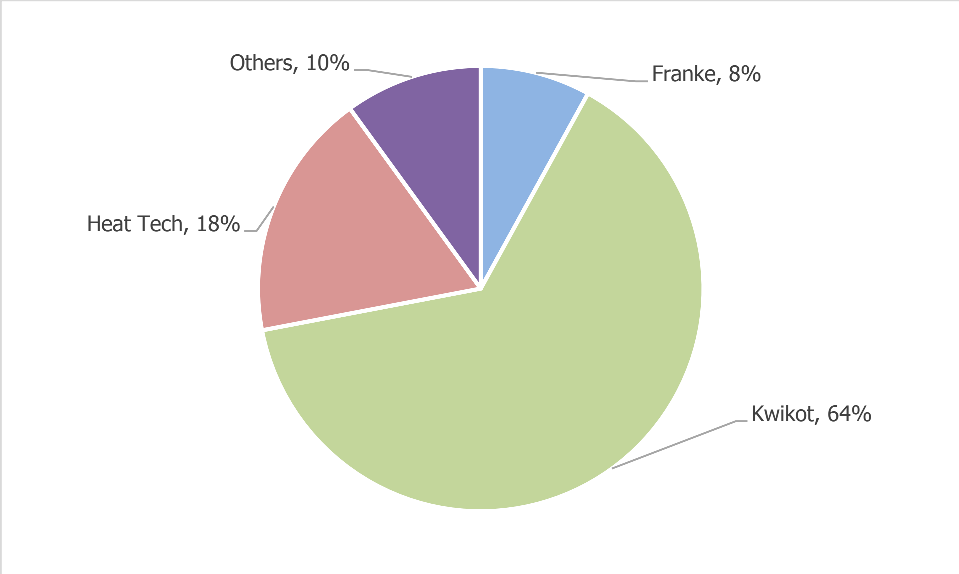
Eskom, 2013

1.3 The South African Geyser Market

The geyser manufacturing market in South Africa is well established and is controlled by a relatively few number of companies. Kwikot, the market leader, was established in 1903. Limited public research is available on the geyser market, but research undertaken by the authors through select interviews with key industry players and reports, found that approximately 450 000 electrical geysers were manufactured in SA during 2012. This number includes SWH with electrical back-up but excludes the low pressure non-electric solar units. The SWH market peaked at around 30,000 units per annum in 2011-2012 but could be less than 20,000 per annum in 2013 (H Weber Kwilot geysers who also manufacture and sell SWH). It is estimated that 45 % of geyser sales is for Insurance sector to replace failed units. This equates to approximately 200,000 units.

Industry players also noted that sales are expected to decline further in 2013 and 2014 due to the depressed economy which has impacted the construction sector. The market share by manufacturer is shown in **Figure 2**.

Figure 2: Estimated Market Share



Geysers for the residential market are available in five sizes and go up in increments of 50 Litres, starting at 50 L and going up to 250 L. The most popular model, which is the industry standard, is the 150L. Almost all manufacturing takes place in South Africa for the following reasons:

- Globally, the water heating market is a mature industry and each country tends to have its own set of unique set of standards and practises. This has served as a barrier to entry into the local market even though the national standard follows and aligns with the IEC standard, over time many additional requirements have been added to meet local conditions – such as water quality, installation practises, safety and user requirements. This falls out of the scope of this report but is dealt with at a high level under the findings section; and

- The local manufacturing and distribution channels are well established making it very difficult for an imported product or foreign supplier to enter the market. Most sales take place directly through installers, either plumbers, builders or the geyser replacement market. Because a homeowner cannot install their own geyser due to the complexity and the requirement of an electrical certificate of compliance (CoC) which can only be issued by an electrician, the product choice is not made by the household,

The key to gaining and maintaining a foothold in the market is being the supplier of choice to the limited entry points which are controlled by the procurers – plumbing companies, insurance companies, builders and to a much lesser degree the homeowner. These channels require a standard product, which is reliable and readily available nationally as they buy in bulk. None of these market players have any incentive to install the most efficient unit and generally speaking the only criteria is to install the lowest priced SABS-approved geyser. As such the household is left to pay the higher running costs resulting from higher standby losses of less efficient geysers.

Of the appliances chosen for the country's S&L programme, geysers were the only ones which had an existing National Standard and an operational testing laboratory at SABS. A new standard, the SANS 151 came into effect in 2013, and incorporates the existing standing loss test. This is defined as *'energy consumed by a full water heater connected to the electrical supply (after steady state conditions have been reached) during any 24 h period when no water is withdrawn'.* What this test determines is how effective the insulation of the geyser is at maintaining the temperature of the water stored in the vessel – the better the insulation the lower the losses. An electric geyser must meet or exceed the minimum losses as specified in the Standard (SANS151). The minimum performance which was decided upon by SABS and industry for the SANS 151 is shown in **Table 1**, however the performance levels did not change and there was therefore no requirement for manufacturers to improve the standing loss performance of their geysers. The permissible standing loss requirements have been in place for many years and go back as far as the mid 1970's. SABS certifies geysers based on the outcome of the mandatory testing which all geysers must undertake. However, it is SABS policy not to make the standing loss test results public and only confirmation is given that the geyser has passed the test and met the minimum requirements.

Table 1: Maximum Permissible standing loss per 24 hours (kWh)

Nominal capacity of water heater	Closed type of water heater
50 L	1.62
100 L	2.16
150 L	2.59
200 L	3.02

Source: SANS 151

Conclusion

Electric geysers are the biggest consumers of electricity in the SA household and the large volumes of annual installations, which range between 400,000 to 600,000 units per annum depending on the prevailing economic cycle, means that reducing the standing losses offers the greatest potential for large electricity savings for the effort and cost involved. It is the logical first step as the structure of the market is such that an intervention at the manufacturer level is the appropriate starting point as there are a relatively small number of manufacturers with limited models. Other favourable benefits are that the SABS has the necessary testing procedures and no additional investment or training would be required. Given that the manufacturers mutually agreed on the existing minimum performance requirement it is not unreasonable to assume that they have not adopted an overly stringent level.

1.4 Rationale for Research

The large energy savings potential from geysers made them a natural inclusion in the country's S&L programme. The FRIDGE study of 2012 was commissioned specifically to identify the impact that such a programme would have on local manufacturers and to identify, in consultation with industry, the most cost-effective MEPS that would raise the current energy consumption baseline per appliance with the lowest impact on the end consumer. The study was overseen by the DTI, Labour and the private sector and industry participation was voluntary. The industry was opposed to the introduction of a revised MEPS as they believed that they fell under the SANS 151 process, which has a maximum energy loss requirement, regardless of the fact that there was no improvement on this requirement. Only two geyser manufacturers, who jointly control less than 10%

of the market, were willing to participate. As a result the FRIDGE study was not able to complete a detailed analysis. A communication put out by the NRCS[1], stated:

> In the light of these comments, lack of agreement in the EU and elsewhere, and available evidence, the Government authorities have concluded that there is insufficient reliable information regarding SA needs for more efficient water heating systems to take a decision on MEP for water heaters. The FRIDGE study is useful but the conclusions are open to question due to the small number of local manufacturers that participated.
>
> It was decided that further research into the efficiency of water heaters is necessary before taking any decisions on MEP and a timetable for implementation. At least a year is required to complete such a study, and terms of reference will be drafted and tenders called for. SANEDI is investigating sources of funding.

1.5 Project Objective

The study's contribution to the geyser component of the Government's S&L programme, within limitations of resources and data availability, is to determine the projected cost to manufacturers and consumers to reduce electric geyser standing losses to varying degrees in order to formulate a MEPS supported by analysis of net financial impacts to consumers.

The Department of Energy's S&L project team commissioned a study (March, 2014) to conduct an Impact Analysis for the introduction of MEPS for electric geysers. This study has worked in cooperation with Link'd Consulting, the contractor chosen to execute the full project. The study will seek to: 1) To establish the likely cost and energy performance of each possible energy efficiency class; 2) To assess the impact of the proposed energy improvements; and 3) Determine the most appropriate MEPS for electric water heaters in line with the project objective to introduce more energy efficient appliances in the SA market.

The main output of this study, which was proposed and funded by SEAD with technical expertise and oversight from LBNL, is therefore a set of data inputs to be used in techno-economic analysis of alternative MEPS levels in order to make a recommendation.

2 Outputs, Test Facility and Measuring the Benefits

To make a recommendation of the most viable MEPS level to be adopted a techno-economic analysis was undertaken, made up of the following sub-tasks:

- **Product testing:** Geysers were purchased and delivered to the laboratory. Based on the dynamics of the market (Section 1.3) it was agreed that a minimum of five models tested would adequately represent the majority of the SA 150L geyser market. A field visit by an LBNL water heater efficiency expert was done in order to supervise testing of the equipment at the laboratory, and the geysers were tested

[1] VC 9004 & VC 9006 – Collated Comments 28 March 2013

according to the SABS test procedure and the standing loss measurements recorded. These measurements formed the technical baseline of the study;

- **Product tear-down measurements:** Once a model had been tested, they were disassembled and additional measurements made to determine the corresponding engineering configuration of the baseline. Measurements included exterior and interior dimensions of the units, thickness of insulation, type of insulation and thickness of outer casing;
- **Component cost determination**: Market information was gathered on material and labour costs of components to reduce standing loss (insulation) likely cost of re-tooling by manufacturers and mark-ups. This information is required to determine the baseline characteristics; and
- **Standing loss and cost determination**: This step determined the impact on standing loss from additional insulation using simulation of heat losses through the geyser tank and casing at standard (test procedure) temperatures for specific geometries. Finally, the total costs to manufacturers and final consumers of each level of added insulation was calculated, including impacts of added materials, labour, re-tooling and mark-ups, described in Section 2.3 below.

2.1 Test Facility

The steps outlined above required the use of a testing facility which could replicate the SABS 151 test chamber. The objective of this techno-economic analysis is to provide inputs into the broader economic analysis being done by Link'd Consultants and does not extend to product certification and testing, thus an accredited laboratory was not a requirement. To our knowledge there are only two SANS 151 accredited laboratories in the country, SABS and Test Africa, both of whom were approached but were unable to participate at the time. It was then decided to contact all the Electrical Engineering faculties who are actively involved in either geyser or solar water heating testing and measurement and verification (M&V) activities. The following were contacted:

- Tshwane University of Technology,
- University of the North West;
- University of the Witwatersrand;
- University of Pretoria; and
- Stellenbosch University.

Stellenbosch University was selected based on availability, ability to meet the technical requirements of the project, equipment, personnel, price and willingness.

Even though SABS were not able to participate at project inception, the research team interacted and kept them advised of developments and results.

2.2 Selection of Geysers

Although geysers come in many sizes (Table 1), the 150 L model is the most popular model and makes up over 70% of the replacement market[2]. Parameters describing the tank geometry and baseline insulation level used in the techno-economic analysis were therefore taken from this model as representative of the market overall. **Table 2** lists the models chosen and the reasons for doing so. The market share of these five models

[2] Meeting held with FOGI, May 2014

is in excess of 75% of 150L category. The geyser manufacturer names have been withheld to avoid any confidentiality issues.

Table 2: Selection of Geysers for Participation in the Study

Geyser	Reason for selection
Model A	Chosen for the large sales volumes
Model B	A shorter but 'fatter' version of the slimline. The objective was to compare the difference in standing losses between geysers from the same manufacturer, thus same process, based on a smaller surface area
Model C	Chosen for large sales volumes. The company agreed to participate in the study and provided costing information
Model D	Manufacturer is a small, regional player
Model E	National player but with a smaller market share

2.3 Measuring the Benefits – Cost Benefit Analysis

The following section has been adapted from the FRIDGE Study (2012) – Energy Performance and Labelling Requirements for Specific Residential Electrical Appliances and was written by Michael McNeill from Lawrence Berkeley National Laboratory (LBNL).

2.3.1 Why a Cost-Effectiveness Analysis

Determination of the targets of MEPS requires careful consideration and analysis. There are several important criteria that need to be balanced. The goal of any efficiency program is to reduce energy consumption or slow its growth. The primary benefits of energy reduction are many, and include financial savings to rate payers, reduction of GHG emissions and other pollutants, reduction of environmental impacts caused by energy extraction and energy security. On the other hand, implementation of energy efficiency is not without cost. Primary among these is the additional cost needed to improve appliance efficiency, and the costs to manufacturers to retool and modify production lines. These costs are generally passed on to consumers in the form of increased retail prices. Price impacts have further consequences on manufacturers. They can reduce competitiveness with imports if imported products already meet efficiency requirements. They can also reduce overall sales, leading to a loss of revenues and jobs. A complete analysis of proposed MEPS should take careful consideration of the following impacts:

- Energy Demand Reduction
- Peak Load Reduction
- Environmental Impacts
- Consumer Impacts
- Manufacturer and Employment Impacts
- Trade Impacts

Of these, one of the most important criteria for setting an efficiency target for MEPS is the *Consumer Impacts* analysis. Generally speaking, mandatory standards which impose a net financial penalty to consumers are undesirable and will be politically untenable. On the other hand, MEPS that can be demonstrated to provide large financial benefits provide a strong justification for the program. Therefore, cost-effectiveness analysis is ideally the primary determinant of MEPS targets. For example, MEPS can be chosen to maximize net financial savings or to maximize energy savings while still providing a net benefit.

A variety of metrics are used to evaluate cost-effectiveness of appliance efficiency standards. These include *payback period*, *benefit-cost ratio*, *life-cycle cost* and *cost of conserved energy*. Of these, the life-cycle cost calculation is most appropriate for capturing overall net financial impacts to consumers. Life-Cycle Cost is given by:

$$LCC = I + \sum_{n=1}^{L} \frac{OC}{(1+d)^n}$$

In this equation, *I* is the initial investment (equipment price), *OC* is the annual operating cost, *L* is the equipment lifetime and *d* is the discount rate. The life-cycle cost includes the full cost to the consumer of purchasing and operating an appliance over its lifetime. Annual operating cost is the annual energy use multiplied by the energy price. In general, efficiency improvements reduce operating cost, but increase the initial investment. The change in *LCC* relative to the base case can therefore either be positive or negative. If the operating cost decrease outweighs the initial investment increase the standard imposes a net savings to consumers and is determined to be cost-effective. If, on the other hand, the initial investment increase outweighs the operating cost decrease the standard imposes a net cost to consumers and is determined not to be cost-effective. The discount rate parameterizes the difference in present value of initial investment, which is immediate and operating cost, which is deferred.

2.3.2 Data Needs

In the above calculation of appliance life-cycle costs, the key financial dependency on efficiency arises through the correlation between efficiency and retail prices. There are two main methods for determining this relationship.

Retail Price Analysis Option: In principle, this correlation is observable in the market before implementation of standards if the efficiency and retail price of various models is known. In practice however, this correlation is not easily observed, for several reason. First, if efficiency is not a strong market driver, difference in price will be dominated by capacity and other features. Second, in the absence of a mandatory regulation, efficiency ratings may not be measured, or the measurements may be unreliable. Finally, pricing may not directly reflect costs because profit margins may vary between brands and between 'baseline' and 'luxury' models.

Engineering Analysis Option: A more reliable method of determining the relationship is to assess manufacturer costs based on component costs needed to achieve a specific efficiency level. Mark-ups from manufacturers, distributors and retailers are then applied to these costs to arrive at expected retail prices. This method has the advantage that it is technically justifiable and that it provides manufacturers with a clear way to evaluate the validity of the analysis, and an example of options to improve efficiency.

An example of this type of analysis is shown in **Table 3**, which describes a main product class of U.S. refrigerators.

Table 3: Usage Profile

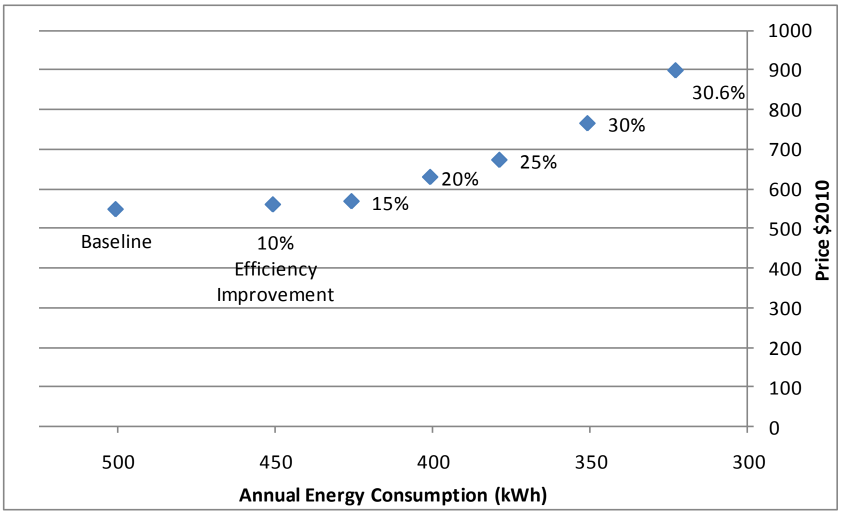
Efficiency Improvement	Design Option
Baseline	Technical specifications given in Table 5-A.2.1 of USDOE (2010e)
10%	Increase Condenser Size by 100% & Increase Compressor EER from 5.55 to 6.1
15%	Increase Compressor EER from 6.1 to 6.26 & Use Brushless DC Condenser Fan Motor

20%	Increase Evaporator Size by 14% & Use Adaptive Defrost & Use Variable Speed Compressor
25%	1.1 m^2 Vacuum Insulated Panel (VIP) in Freezer (FZR) Cabinet
30%	0.27 m^2 VIP in FZR Door & 7.1 ft^2 VIP in Fresh Food (FF) Door & 6.7 ft^2 VIP in FF Cabinet
30.6%	0.17 m^2 more VIP in FF Cabinet

Source: Table 5-A.3.1 of USDOE Refrigerator, Refrigerator-Freezer and Freezers Rulemaking Technical Support Document[3].

Using these engineering design options and the costs associated with them, a set of composite designs of increasing efficiency can be constructed. Starting from the baseline configuration, alternative designs are constructed for the appliance, a refrigerator in this instance (Figure 3), by replacing or adding components in turn, in order of cost-effectiveness. Each of these options is represented by a point in Figure 3. The resulting cost-efficiency curve has a typical shape with increasing costs per unit efficiency improvement.

Figure 3: Equipment Price vs. Efficiency for Top-Mount Refrigerator-Freezers



However, the nature and design of geysers is such that the most economically feasible interventions that a manufacturer can make (without a radical re-design of the technology) is to increase the thickness of the insulation, ensure that the insulation has a uniform thickness and that there are no 'weak spots' in the design which will allow for higher heat losses. An example of this is the compartment which houses the thermostat which is covered with a plastic or steel cover but which is not insulated.

This cost-effectiveness study is limited to opportunities for efficiency improvement by increasing or improving the insulation. It does not consider installation practises, insulation of inlet and outlet pipes or usage patterns as these cannot be controlled in the manufacturing process. We recognize that other opportunities for reduction of losses may exist, and in fact may be less expensive to implement than increasing insulation, but we consider the insulation case because it is the most straightforward and universally applicable efficiency improvement option. In this way, the analysis is conservative in that it focuses on a subset of options.

[3] Available at www1.eere.energy.gov/buildings/appliance_standards/residential/refrigerators_freezers.html

3 Standing Loss Measuring Arrangement and Test Methodology

3.1 Test arrangement

3.1.1 Test chamber

The standing loss tests were conducted in an environmental chamber with concrete walls and a concrete roof. The wall construction of the chamber features an air cavity for improving regulation of the inside temperature. Internal air circulation during the tests is facilitated using a portable, variable speed fan, while the inside temperature is controlled by means of a portable heater with adjustable temperature settings.

3.1.2 Geyser installation

In order to limit the effects of external piping on the measured losses, the geysers were installed in accordance with the following guidelines:

- The installation has no external hot water outlet piping. The hot water outlet is blocked with an industry standard copper screw-on cap fitted with a temperature sensor extending into the cylinder.
- The cold water supply is connected through a minimum of 1 m polycop pipe. The inlet pipe is connected to the geyser through a copper fitting with an integrated temperature sensor extending into the geyser.
- The installation has no vacuum breakers and associated external piping.
- An industry standard copper pressure relieve valve is fitted to the pressure relieve connection.
- All external connections, i.e. hot water outlet, cold water inlet and pressure relieve fitting are lagged to reduce heat loss.

The geyser is mounted using a dedicated, standalone steel frame such that the external clearances in both horizontal and vertical planes adhere the SANS 151 standard, i.e. at least 150 mm from any structural wall and with a clear space of at least 250 mm above and below the water heater and at least 700 mm at the sides and front.

3.1.3 Instrumentation

The design of the test arrangement is aimed at complying with the efficiency test procedures specified in section 7.4 of SANS 151. This translates into the following:

- The control reference temperature inside the geyser is regulated at 65 ± 1.5 °C over the test period of 48 hrs.
- The ambient temperature inside the test chamber is regulated at 20 ± 3 °C over the test period of 48 hrs.
- The cold water inlet temperature inside the geyser is measured and logged.
- The hot water outlet temperature inside the geyser is measure and logged.

The cold water inlet and hot water outlet temperature measurements are not used in determining the standing losses, but assists in understanding the thermodynamic behaviour of the hot water distribution inside the geyser.

The heating element is controlled with an RKC Instrument Inc. CB100 temperature controller operated in On/Off mode, using a PT100 Resistance Temperature Detector (RTD) for measuring the control temperature. The PT100 sensor is positioned inside the built-in geyser thermostat pocket at the inner end, using heat paste for improved thermal coupling with the copper jacket of the thermostat pocket.

The controller temperature, ambient temperature, cold water inlet temperature and hot water outlet temperature are measured using PT100 RTDs connected to a National Instruments NI 9211 thermocouple input module located in a CompactDAQ chassis. The temperature readings are logged with a 30 second sampling interval using a dedicated NI Labview program running on a computer connected to the CompactDAQ via an Ethernet link. The energy consumption is sampled using two meters, namely a PowerTrack logger and an Elster class 1 energy meter, using a 30s sampling interval. **Table 4** summarizes the specifications of the temperature control and measurement instrumentation used in the test arrangement.

Table 4: Summary of test instrumentation used in the standing loss tests.

Function	Manufacturer and model	Specifications
Temperature controller	RKC Instrument Inc. CB100 Digital Controller	Sampling rate: 0.5s Control method: On/Off, PID P, PI, PD Thermocouple types: K, J, R, S, B, E, T, N, PLII, U, L RTD types: PT100, JPt100 Accuracy: RTD Greater of ±0.3% of display value + 1 digit or ±0.8°C
Temperature measurement	PT100 Resistance Temperature Detectors	Three-wire PT100 Platinum Resistance Temperature Detectors
	National Instruments NI 9211 C-series thermocouple input module.	No of channels: 4-Channel. Sampling rate: 14 S/s Sampling resolution: 24-Bit Input voltage: ±80 mV Thermocouple types: J, K, T, E, N, B, R, S
	National Instruments CompactDAQ chassis	4 slots
Energy measurement	PowerTrack logger	Accuracy: 0.5% on active power
	Elster Energy meter	Class 1

3.2 Test methodology

The standing loss tests were conducted in accordance with SANS 151:2013 Edition 7.1: *Fixed electric storage water heaters*. The test procedure used in the investigation can be summarized as follows:

- The geyser is operated for a stabilizing period of at least 24 hrs with the control reference temperature inside the geyser at 65 ± 1.5 °C and the ambient temperature at 20 ± 3 °C.
- Following the stabilizing period, the geyser is operated for a standing loss test period of at least 48 hrs with the control reference temperature inside the geyser at 65 ± 1.5 °C and the ambient temperature at 20 ± 3 °C. The start of this test period is chosen to coincide with a switch-off event of the heating element. The following measurements are conducted:
    - Controller temperature using a sampling rate of 30s.
    - Ambient temperature using a sampling rate of 30s.

- Cold water inlet temperature using a sampling rate of 30s.
- Hot water outlet temperature with a sampling rate of 30s.
- Energy supplied to the heating element with a sampling rate of 30s.

- Visual and infrared images of the geyser body, water connection points and support structure are captured during the standing loss test period.

Calibration tests were conducted for the temperature sensors and measuring instrumentation at regular intervals between tests, using a heated water bath with a reference thermometer.

3.3 Standing loss calculations

3.3.1 Overview

The standing loss calculations are performed using the controller temperature, ambient temperature and energy measurement data recorded during the 48 hr standing loss test period. Where necessary, temperature sensor calibration data is used to correct the recorded temperature readings.

Two loss calculations, using two different approaches, are performed for each case.

3.3.2 Loss calculation using SANS 151 methodology

The loss calculation methodology specified in SANS 151 relies on the assumption that the mean control temperature inside the geyser is 65°C. The standing loss is calculated using the relationship

$$Q = \frac{45E}{2(65 - \theta_a)}$$

where

Q denotes the standing losses [kWh/24hr],

E denotes the total energy consumption [kWh]

and

θ_a denotes the mean ambient temperature [°C].

The mean ambient temperature θ_a, assuming a fixed temperature sampling rate, is calculated using the relationship

$$\theta_a = \frac{1}{N}\sum_{i=1}^{N} \theta_{a\,i}$$

where

$\theta_{a\,i}$ denotes the i^{th} ambient temperature reading [°C]

and

N denotes the total number of ambient temperature readings for the 48 hr standing loss test period.

The calculation methodology normalizes the calculated losses to a temperature differential of 45°C between the internal geyser temperature and ambient temperature.

3.3.3 Loss calculation using the average control temperature

The alternative loss calculation methodology uses the actual mean control temperature inside the geyser rather than the assumed figure of 65°C. The standing loss is calculated using the relationship

$$Q = \frac{45E}{2(\theta_c - \theta_a)}$$

where

Q denotes the standing losses [kWh/24hr],

E denotes the total energy consumption [kWh]

θ_c denotes the mean control temperature [°C].

and

θ_a denotes the mean ambient temperature [°C].

The mean control temperature θ_a, assuming a fixed temperature sampling rate, is calculated using the relationship

$$\theta_c = \frac{1}{N}\sum_{i=1}^{N} \theta_{c\,i}$$

where

$\theta_{c\,i}$ denotes the ith control temperature reading [°C]

and

N denotes the total number of control temperature readings for the 48 hr standing loss test period.

This methodology gives a more accurate representation where the mean control temperature is not exactly 65°C.

4 Test results

4.1 Overview

4.1.1 Geyser summary

Table 5 summarizes the manufacturer and model details for the geysers tested in the investigation, including the mounting orientations for which the tests were conducted. The units were tested for all mounting orientations, i.e. horizontal and/or vertical, listed in the manufacturer installation specifications. **Table 6** summarizes the standing losses determined for the various geyser models and mounting orientations.

Table 5: Geyser models and mounting orientations targeted in the investigation.

Geyser ID	Manufacturer	Model	Orientation
Geyser A	A	600 kPa 150l Model 1	Horizontal
			Vertical
Geyser B		600l kPa 150l Model 2	Horizontal
			Vertical

Geyser C	B	400 kPa 150l	Horizontal
			Vertical
Geyser D	C	400 kPa 150l	Horizontal
Geyser E	D	400 kPa 150l Model 1	Horizontal

Table 6: Summary of standing losses measured for the geyser models and orientations targeted in the investigation.

Geyser	Orientation	Standing losses [kWh/24hr]	
		SANS 151 methodology	Alternative methodology
Geyser A	Horizontal	2.23	2.22
	Vertical	2.33	2.34
Geyser B	Horizontal	1.90	1.91
	Vertical	2.24	2.26
Geyser C	Horizontal	1.86	1.87
	Vertical	1.77	1.79
Geyser D	Horizontal	2.51	2.54
Geyser E	Horizontal	1.90	1.92

4.1.2 Thermal images

The thermal images of the geyser under normal operating conditions provides valuable insight into the heat emissions from sources such as the water inlet and outlet connections, pressure release connection, thermostat and heating element fitting, mounting brackets, etc.

4.1.3 Teardown analysis

The teardown analysis involves cutting the geyser open along the length axis into two halves so that the line of cutting goes through the hot water outlet pipe. This allows the dimensions and condition of the insulation around the inner water cylinder to be determined.

4.2 Geyser A - Manufacturer A 600 kPa 150l Model 1

4.2.1 Standing losses

Table 7 summarizes the measured results for Geyer A, which is specified for horizontal and vertical mounting orientations. Figure 4 and Figure 5 show the recorded temperature and average power profiles for the horizontal and vertical orientation standing loss tests respectively.

Table 7: Measured results for geyser A for the standing losses test period.

Measurement parameter		Horizontal orientation	Vertical orientation
Control temperature [°C]	Minimum	64.5	64.2
	Maximum	66.7	65.2
	Mean	65.2	64.9
Ambient temperature [°C]	Minimum	17.4	15.1
	Maximum	18.5	17.1
	Mean	18.2	16.3
Energy consumption [kWh]		4.64	5.05
SANS 151 Standing losses [kWh/24hr]		2.33	2.34

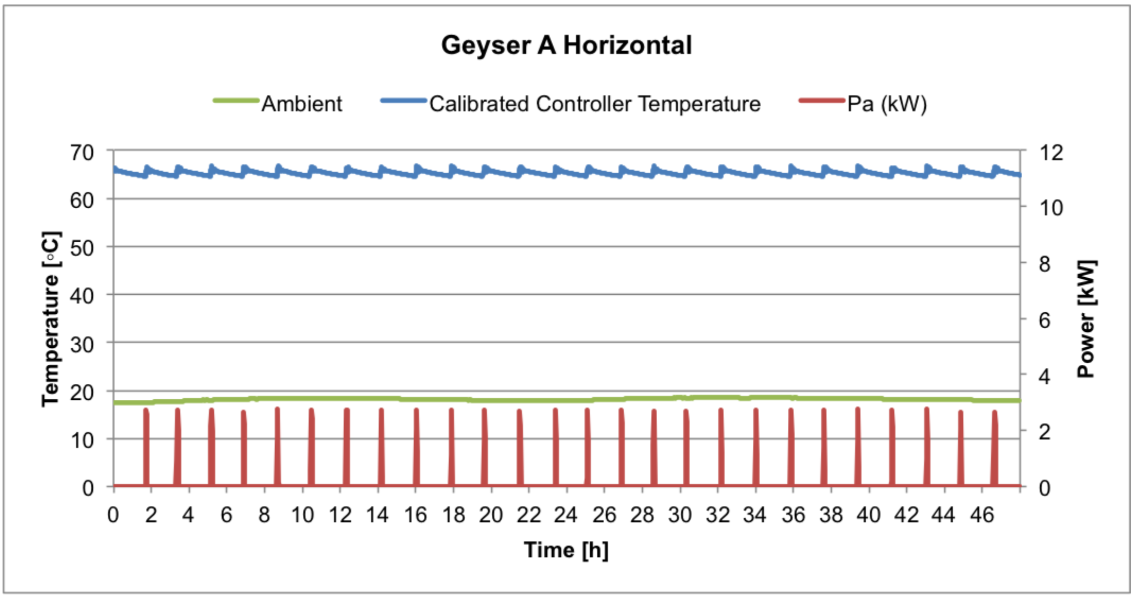


***Figure 4:** Temperature and average power profiles for the horizontal orientation standing losses test for geyser A.*

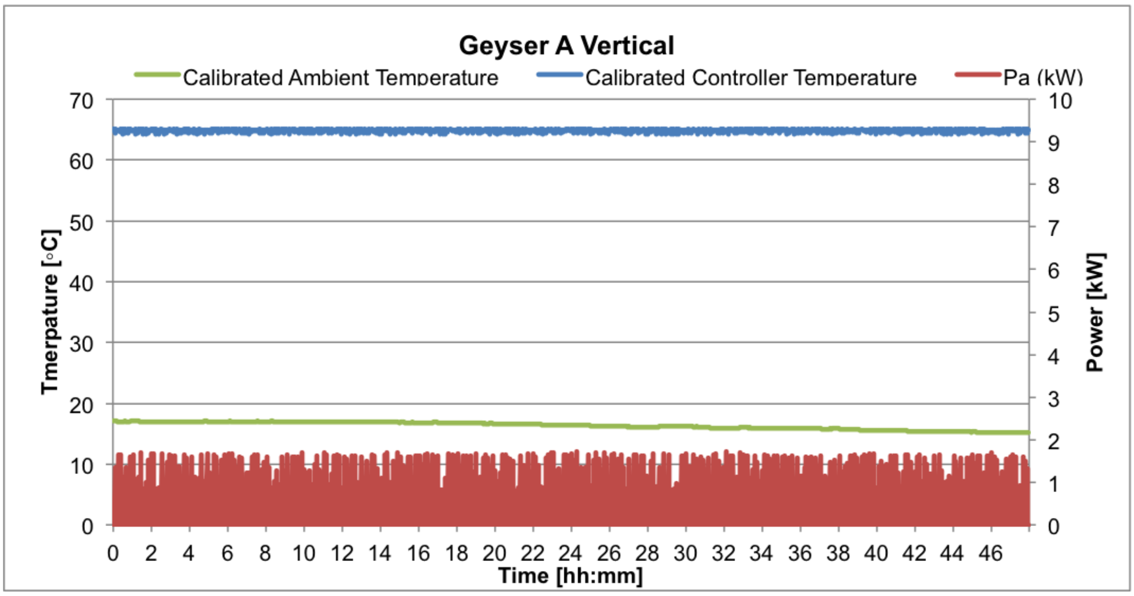


Figure 5: Temperature and average power profiles for the vertical orientation standing losses test for geyser A.

4.2.2 Thermal images

Figure 6: Thermal image for geyser A in horizontal orientation – Inlet end. and Figure 7 show thermal images of the inlet end and outlet end respectively for geyser A in the horizontal orientation. Figure 8 shows a thermal image of one of the mounting fittings.

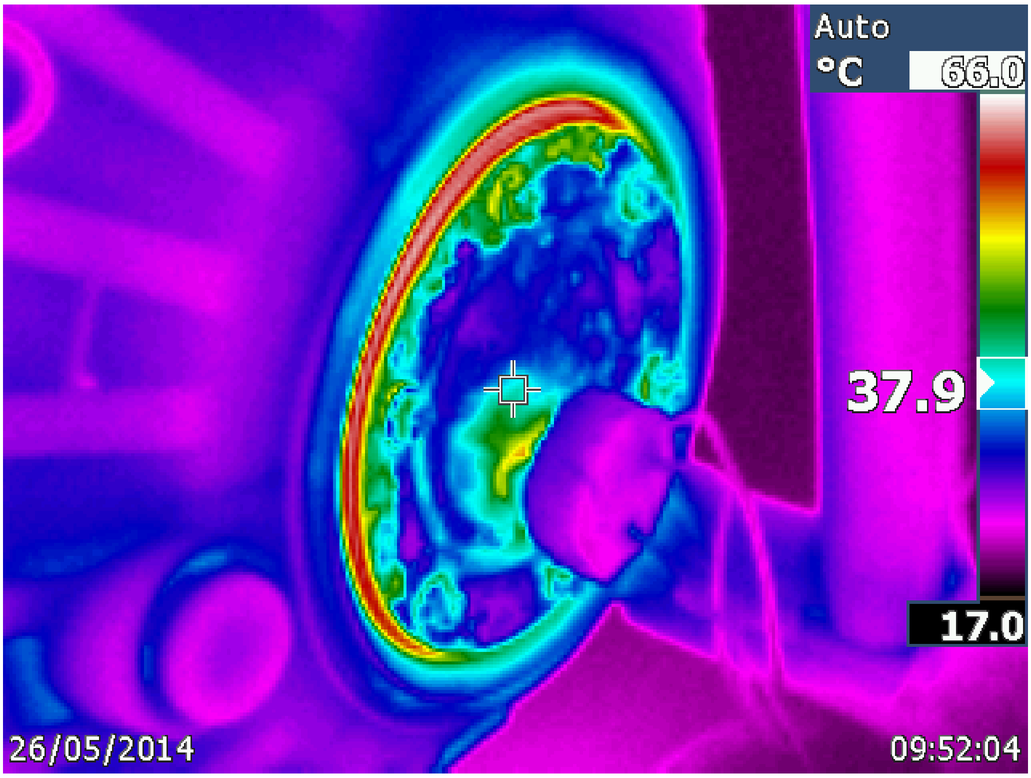


Figure 6: Thermal image for geyser A in horizontal orientation – Inlet end.

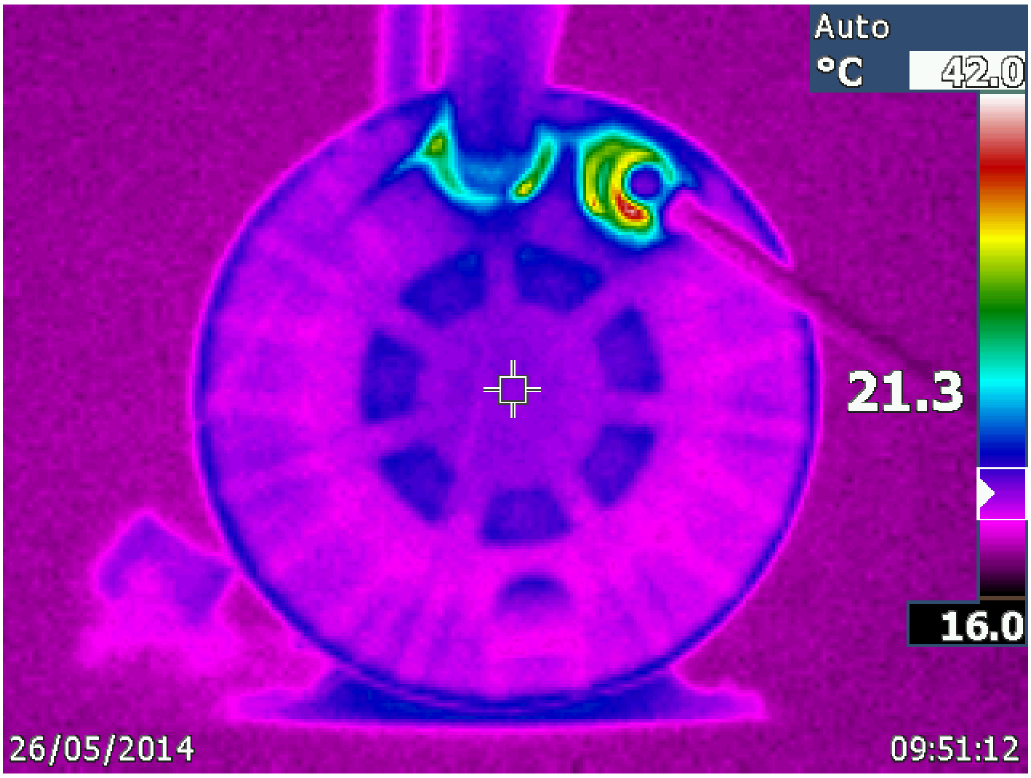


Figure 7: Thermal image for geyser A in horizontal orientation – Outlet end.

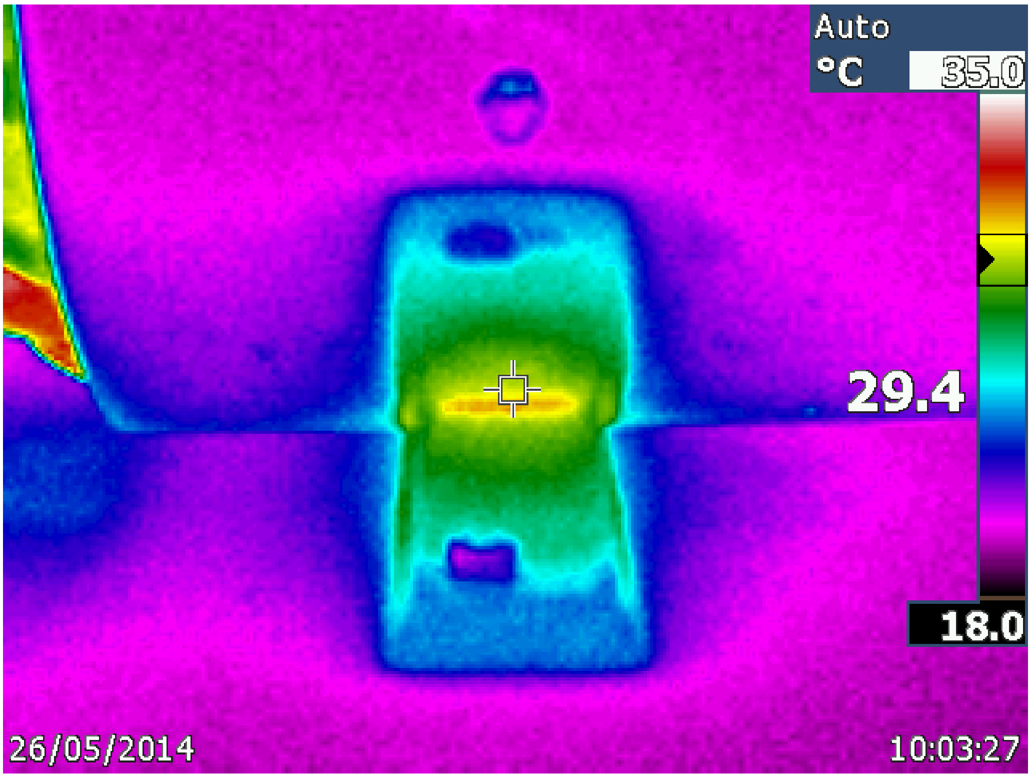


Figure 8: Thermal image geyser A in horizontal orientation – Mounting.

Figure 9 and Figure 10 show thermal images of the inlet end and outlet end respectively for geyser A in the vertical orientation. Figure 11 shows a thermal image of one of the mounting fittings.

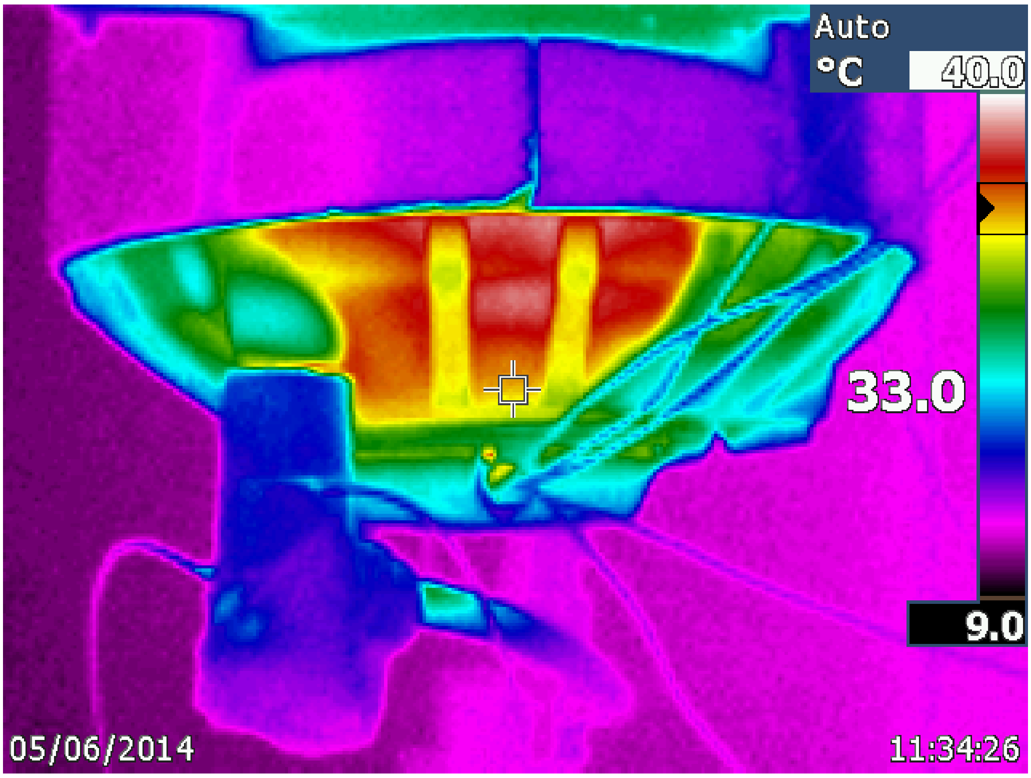


Figure 9: Thermal image for geyser A in vertical orientation – Inlet end.

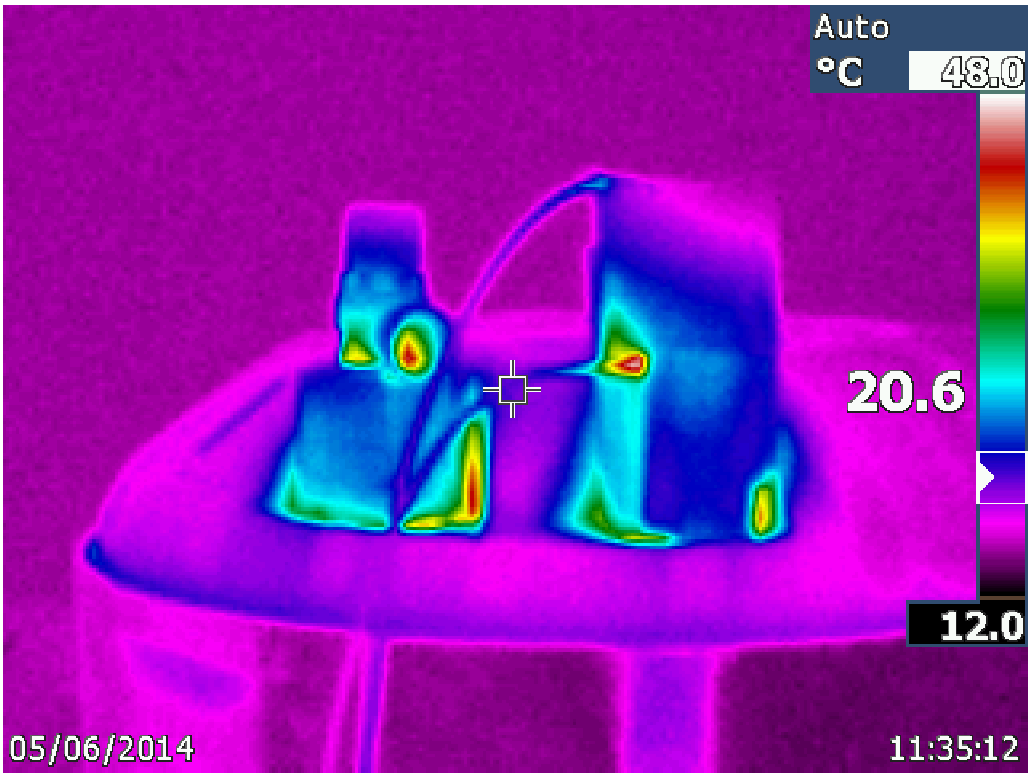


Figure 10: Thermal image for geyser A in vertical orientation – Outlet end.

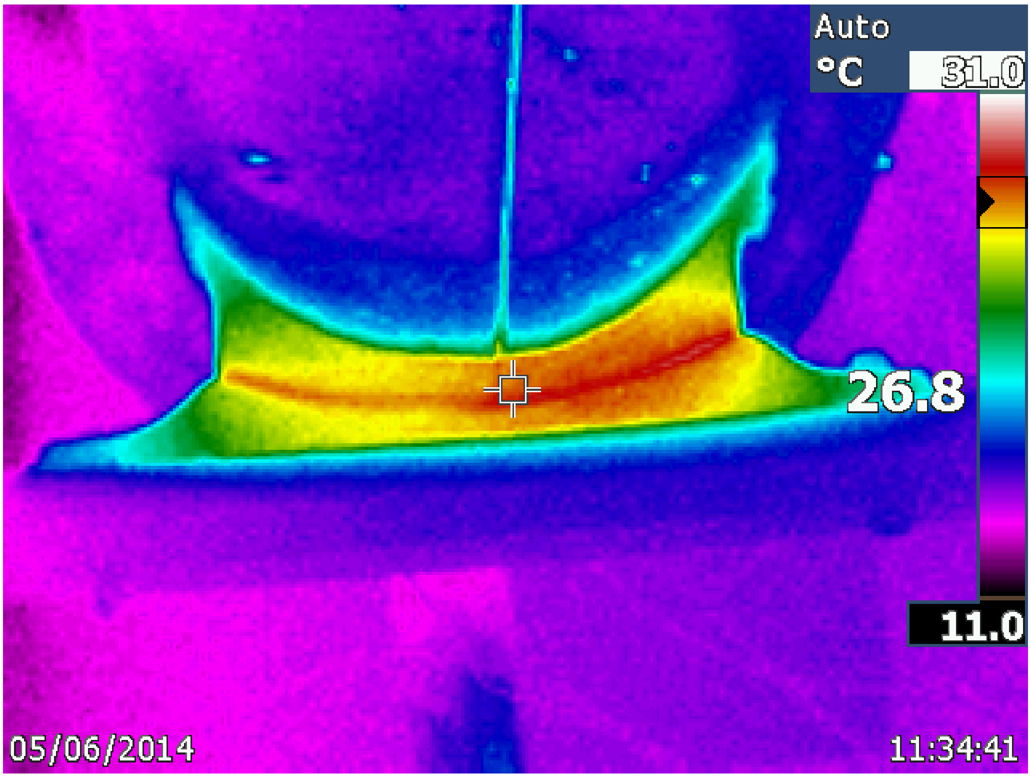


Figure 11: Thermal image for geyser A in vertical orientation – Mounting.

4.2.3 Teardown

Figure 12, Figure 13 and Figure 14 show cross-sections of the full geyser, inlet end and outlet end of geyser A. In the radial dimension, the insulation layer is thicker on the hot water outlet side (upper side in horizontal orientation) compared to the cold water inlet side (bottom side in horizontal orientation). In the length dimension, the insulation layer is thicker at the outlet end compared to the inlet end. The spatial dimensions of the insulation layer suggest that the geyser is designed for horizontal orientation. The insulating foam layer is of uneven density and there are voids (lack of insulation) at the bottom end. **Table 8** lists approximate dimensions for the foam insulation layer of the geyser.

The spiral heating element is positioned at the inlet end in the length dimension and in the centre of the cylinder in the radial dimension. The copper thermostat pocket is positioned in the centre of the spiral heating element and extends beyond the heating element into the cylinder.

Table 8: Approximate foam insulation dimensions for geyser A.

Orientation	Radial position	Thickness [mm]
Horizontal	Bottom side	5
	Upper side	35

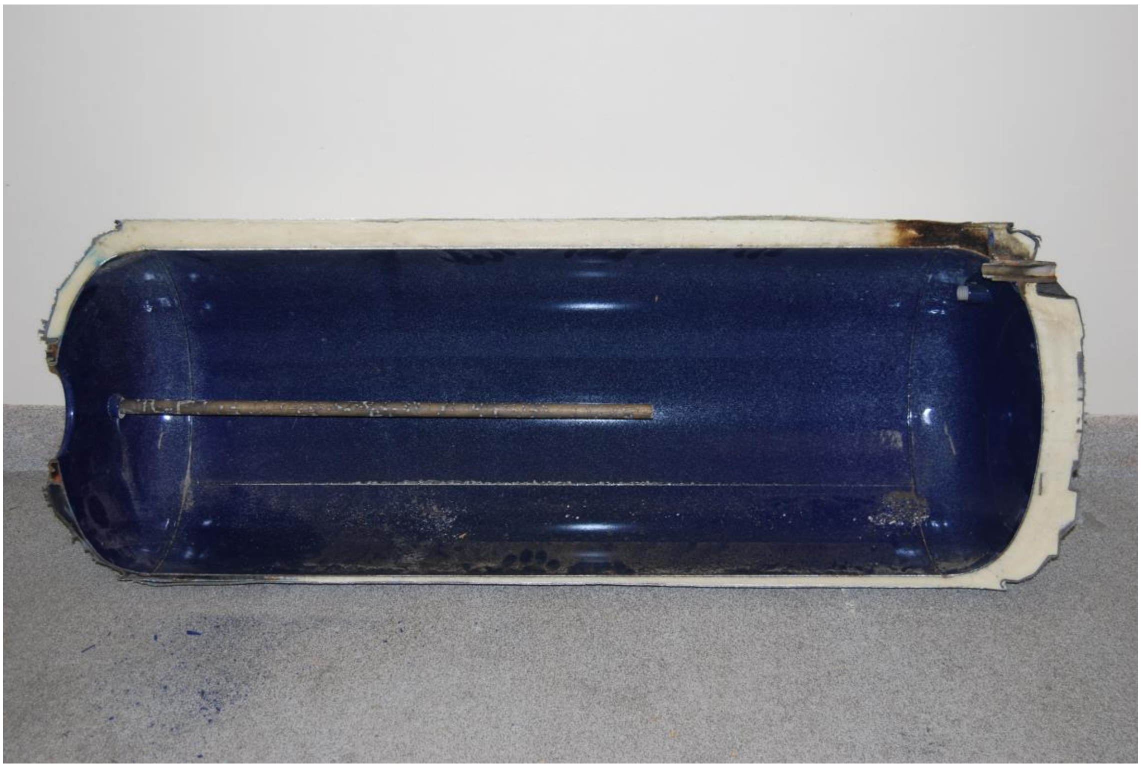


Figure 12: Cross-section of geyser A.

Figure 13: Cross-section of geyser A – Inlet end.

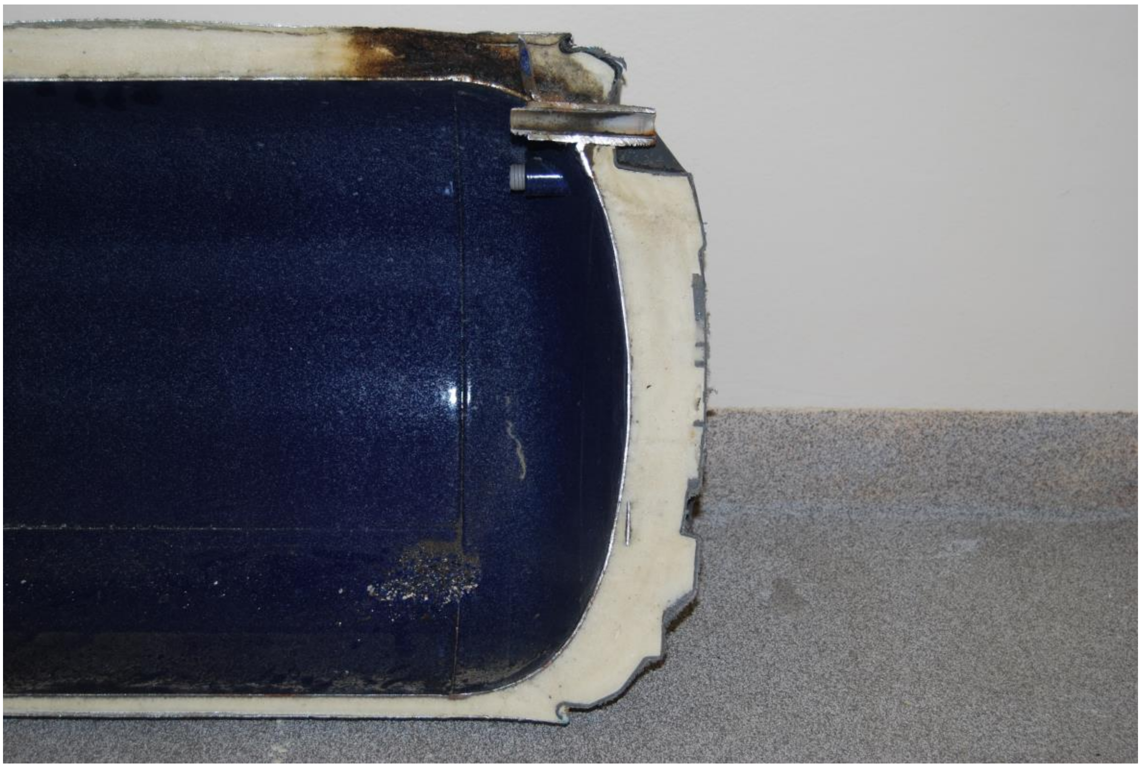


Figure 14: Cross section of geyser A – Outlet end. The burn marks are a result of the cutting process.

4.3 Geyser B -Manufacturer A 600 kPa 150l Model 2

4.3.1 Standing losses

Table 9 summarizes the measured results for geyser B, which is specified for horizontal and vertical mounting orientations. Figure 15 and Figure 16 show the recorded temperature and average power profiles for the horizontal and vertical orientation standing loss tests respectively.

Table 9: Measured results for geyser B for the standing losses test period.

Measurement parameter		Horizontal orientation	Vertical orientation
Control temperature [°C]	Minimum	64.3	64.3
	Maximum	66.7	67.1
	Mean	64.8	64.5
Ambient temperature [°C]	Minimum	20.3	17.8
	Maximum	21.2	21.4
	Mean	20.3	20.4
Energy consumption [kWh]		3.77	4.43
SANS 151 Standing losses [kWh/24hr]		1.90	2.24

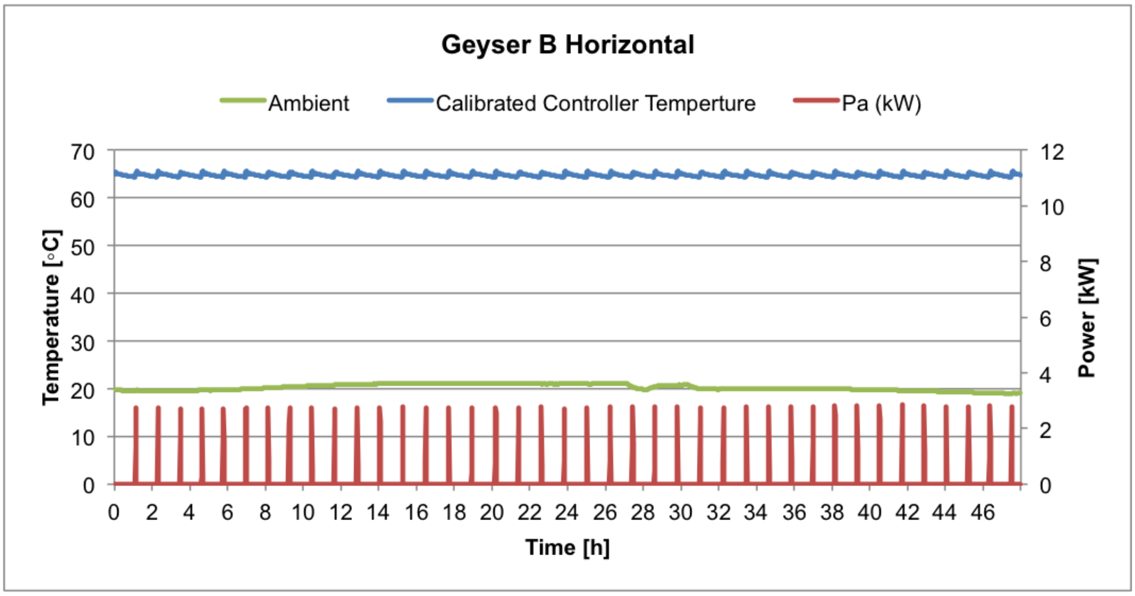


Figure 15: Temperature and average power profiles for the horizontal orientation standing losses test for geyser B.

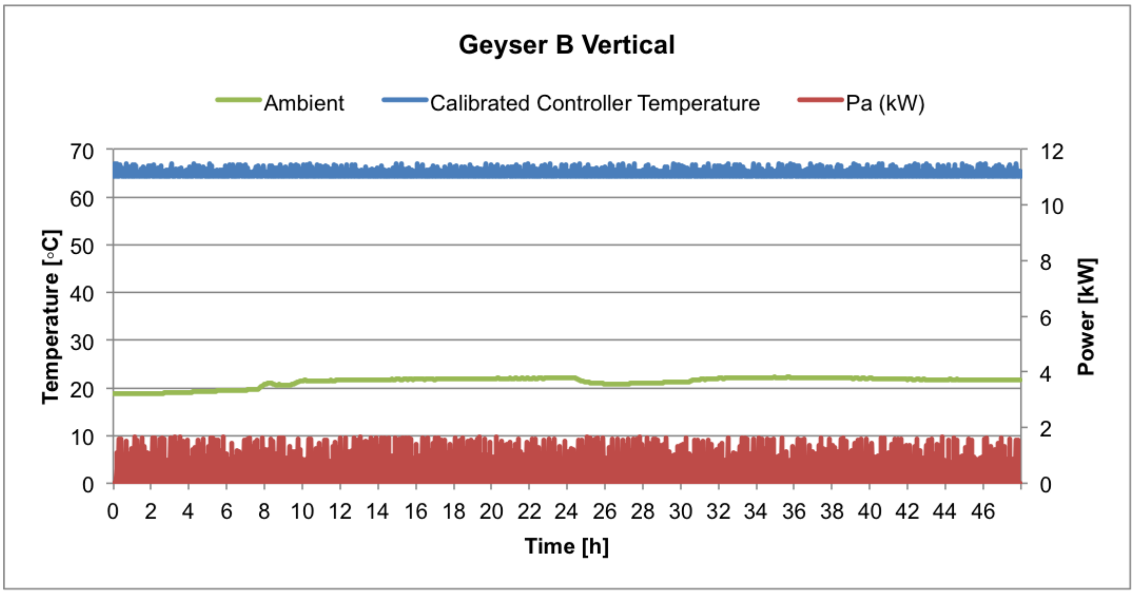


Figure 16: Temperature and average power profiles for the vertical orientation standing losses test for geyser B.

4.3.2 Thermal images

Figure 17, Figure 18 and Figure 19 show thermal images of the side view, inlet end and outlet end respectively for geyser B in the horizontal orientation. Figure 20 shows a thermal image of one of the mounting fittings.

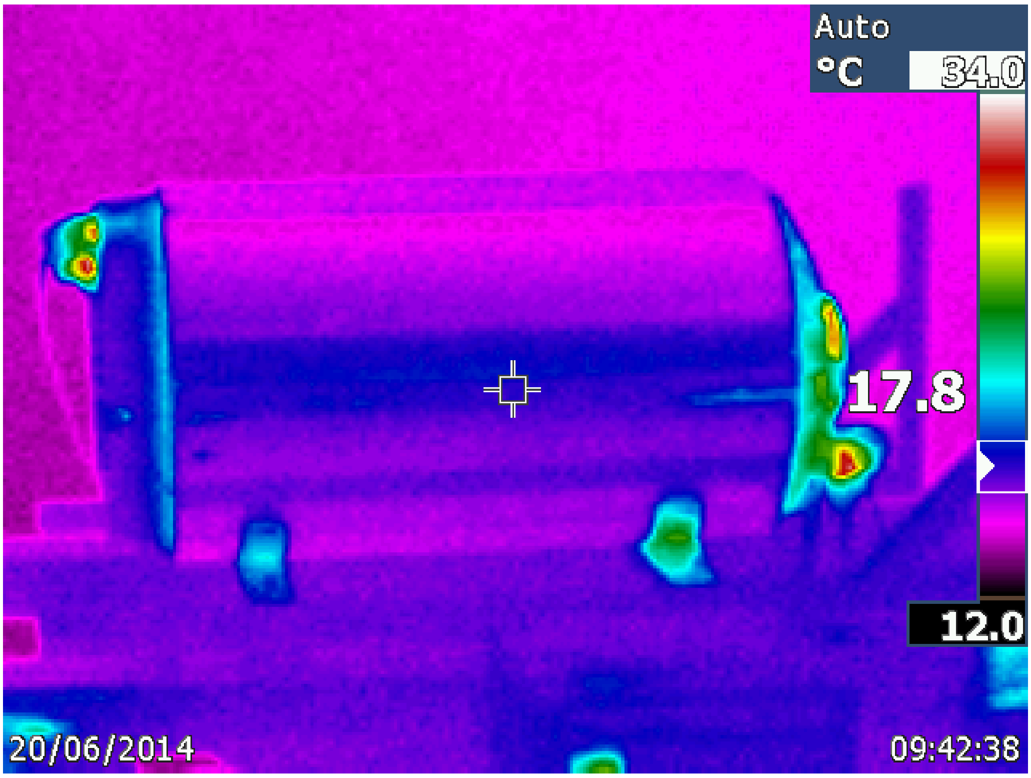


Figure 17: Thermal image for geyser B in horizontal orientation – Side view.

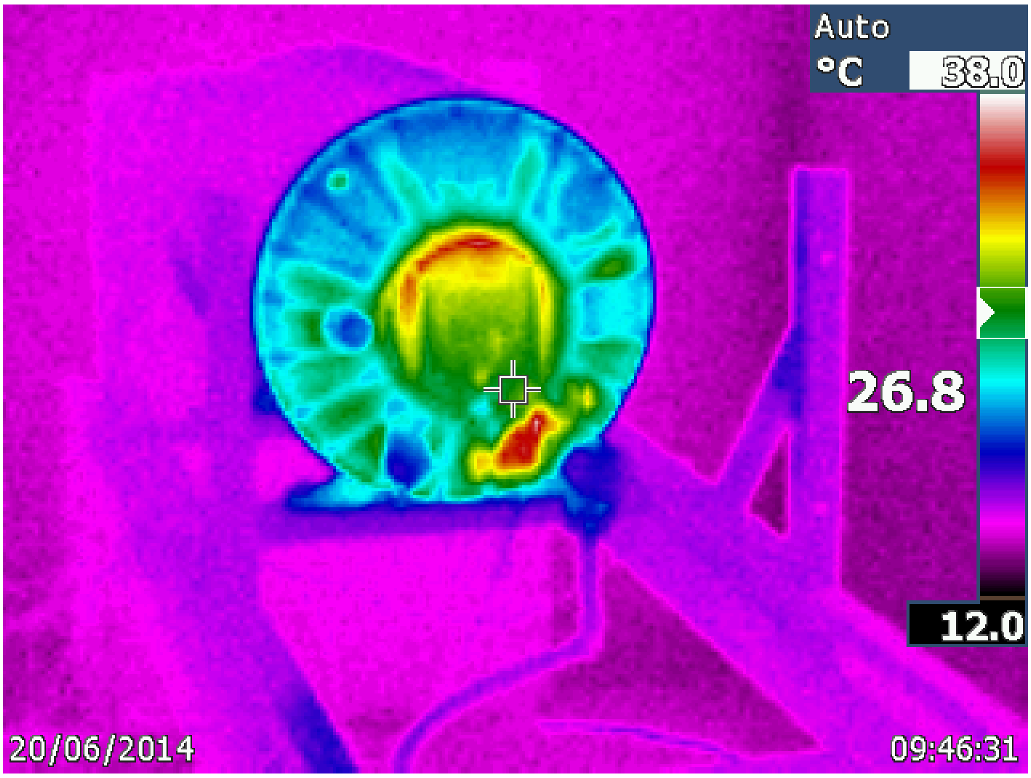


Figure 18: Thermal image for geyser B in horizontal orientation – Inlet end.

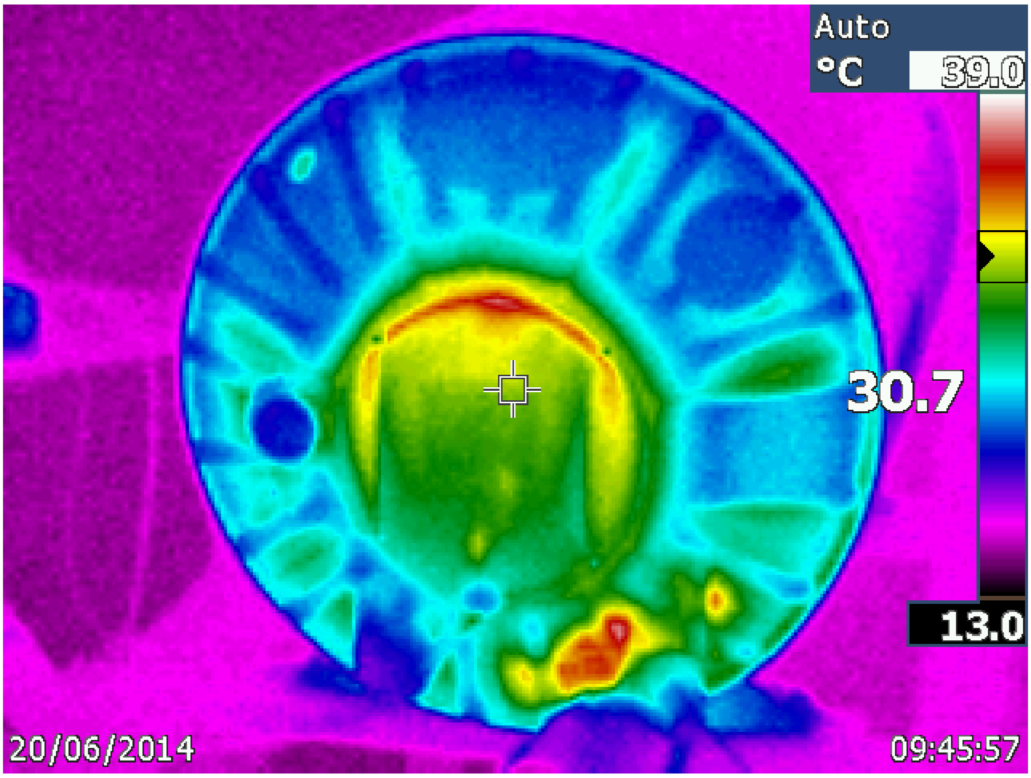


Figure 19: Thermal image geyser B in horizontal orientation – Outlet end.

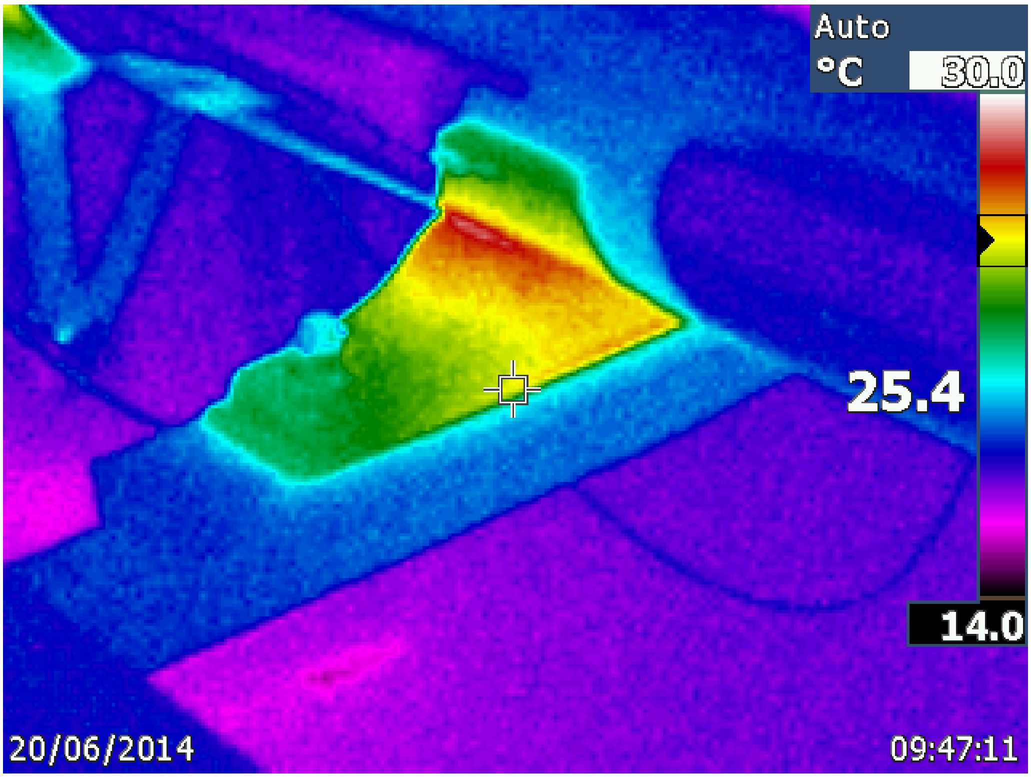


Figure 20: Thermal image for geyser B in horizontal orientation – Mounting.

Figure 21, Figure 22 and Figure 23 show thermal images of the side view, inlet end and outlet end respectively for geyser B in the vertical orientation. Figure 24 shows a thermal image of one of the mounting fittings.

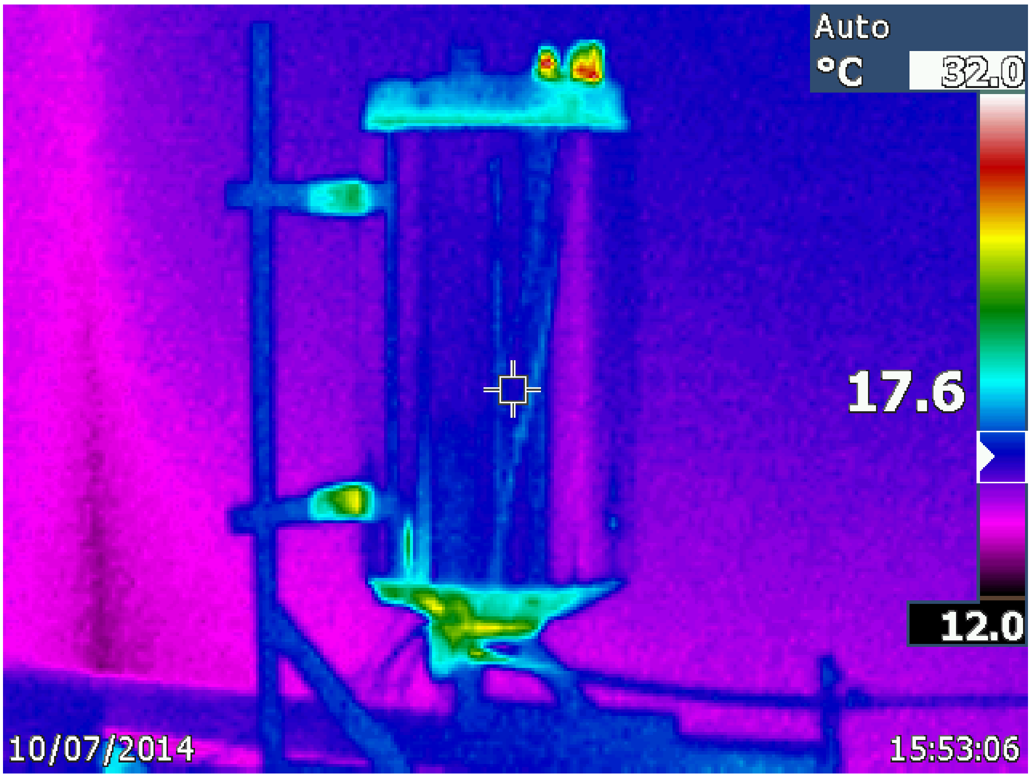


Figure 21: Thermal image for geyser B in vertical orientation – Side view.

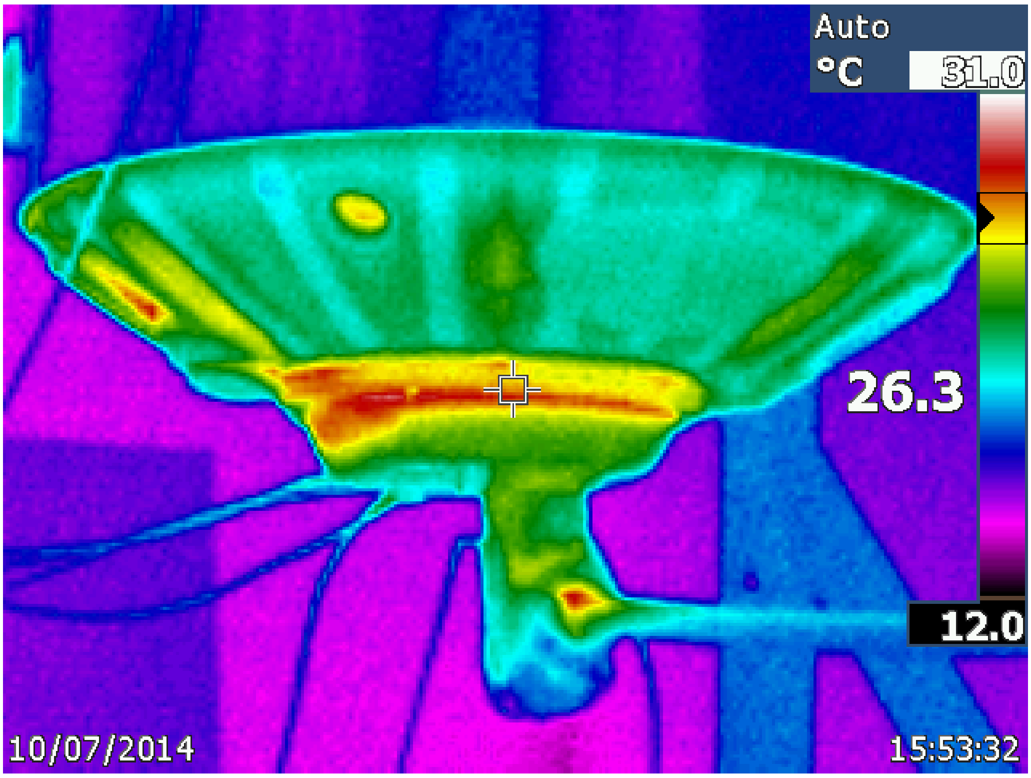


Figure 22: Thermal image for geyser B in vertical orientation – Inlet end.

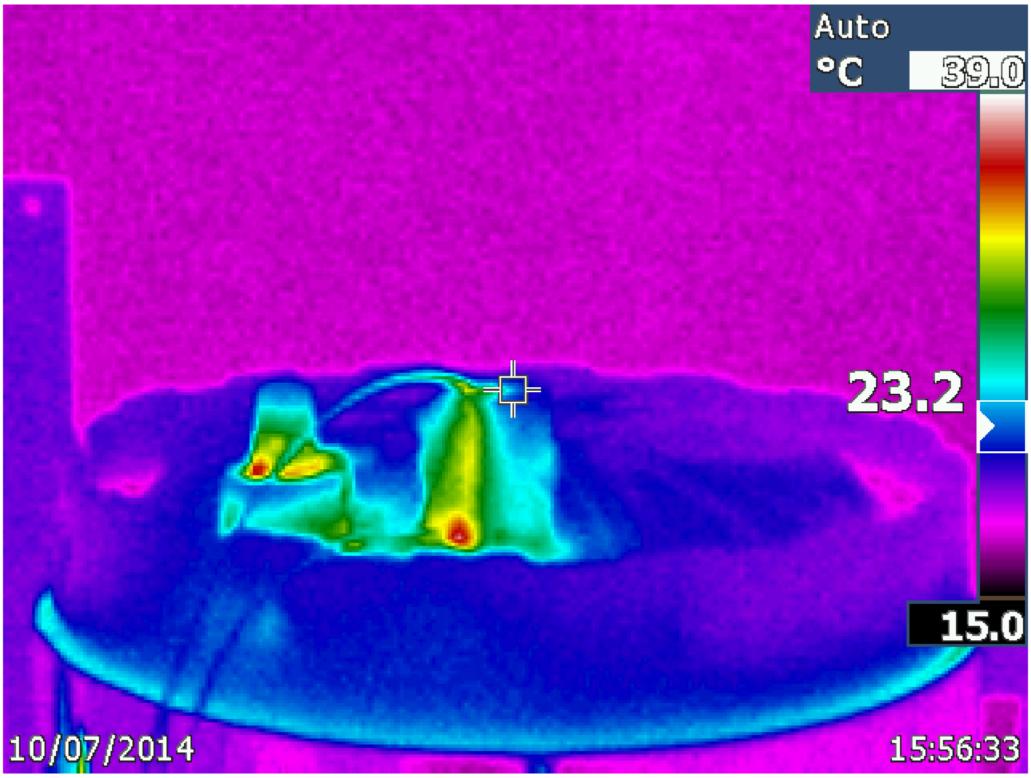


Figure 23: Thermal image for geyser B in vertical orientation – Outlet end.

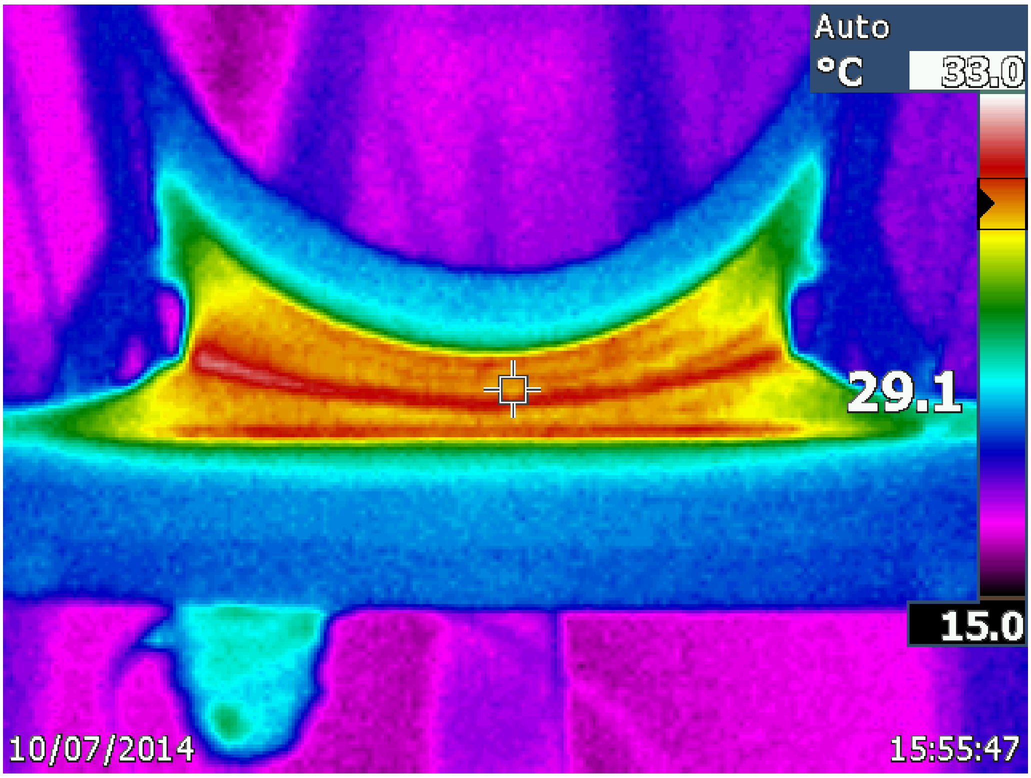


Figure 24: Thermal image for geyser B in vertical orientation – Mounting.

4.3.3 Teardown

Figure 25, Figure 26 and Figure 27 show cross-sections of the full geyser, bottom end and top end of geyser B. In the radial dimension, the insulation layer is thicker on the hot water outlet side (upper side in horizontal orientation) compared to the cold water inlet side (bottom side in horizontal orientation). In the length dimension, the insulation layer is thicker at the outlet end compared to the inlet end. The spatial dimensions of the insulation layer suggest that the geyser is designed for horizontal orientation. **Table 10** lists approximate dimensions for the foam insulation layer of the geyser. Overall, the insulating foam layer is of uniform density.

The spiral heating element is positioned at the inlet end in the length dimension and in the centre of the cylinder in the radial dimension. The copper thermostat pocket is positioned in the centre of the spiral heating element and extends beyond the heating element into the cylinder.

Table 10: Approximate foam insulation dimensions for geyser B.

Orientation	Radial position	Thickness [mm]
Horizontal	Bottom side	10
	Upper side	31

Figure 25: Cross-section geyser B.

Figure 26: Cross-section of geyser B – Inlet end.

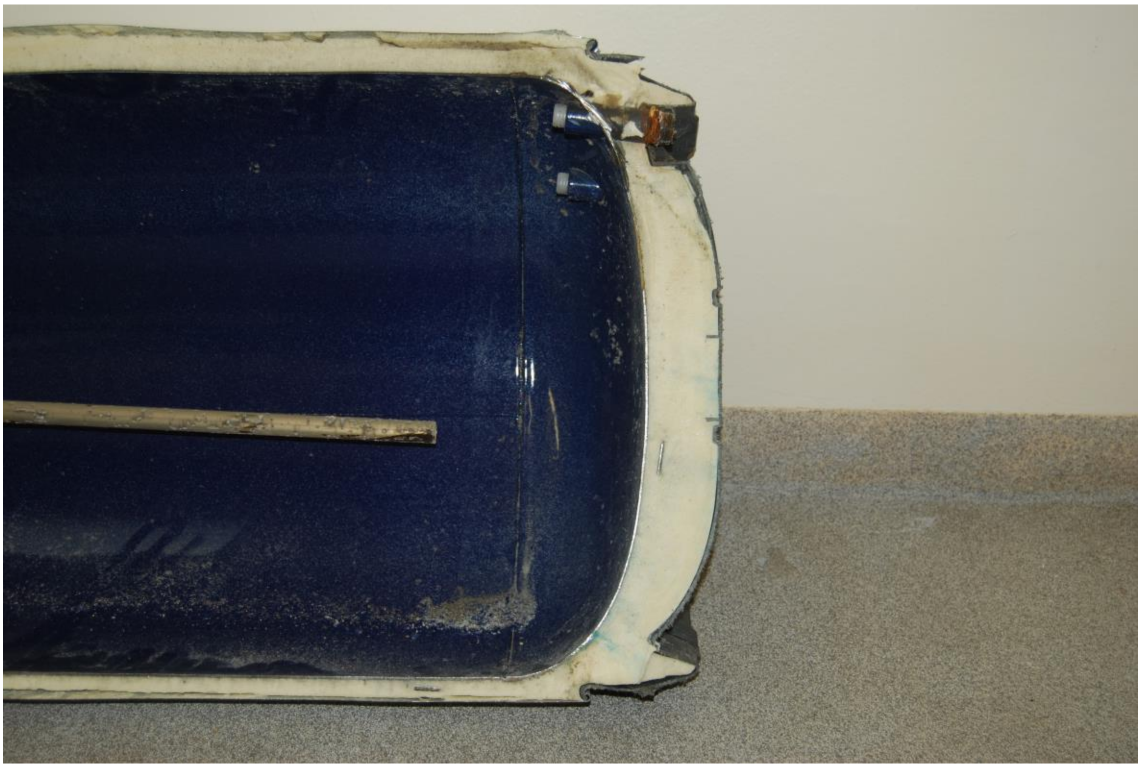


Figure 27: Cross section of geyser B – Outlet end.

4.4 Geyser C - Manufacturer B 400 kPa 150l Model 1

4.4.1 Standing losses

Table 11 summarizes the measured results for geyser C, which is specified for horizontal and vertical mounting orientations. Figure 28 and Figure 29 show the recorded temperature and average power profiles for the horizontal and vertical orientation standing loss tests respectively.

Table 11: Measured results for geyser C for the standing losses test period.

Measurement parameter		Horizontal orientation	Vertical orientation
Control temperature [°C]	Minimum	64.3	64.3
	Maximum	65.6	66.0
	Mean	64.8	64.4
Ambient temperature [°C]	Minimum	16.4	17.5
	Maximum	18.2	19.3
	Mean	17.4	18.5
Energy consumption [kWh]		3.93	3.65
SANS 151 Standing losses [kWh/24hr]		1.86	1.77

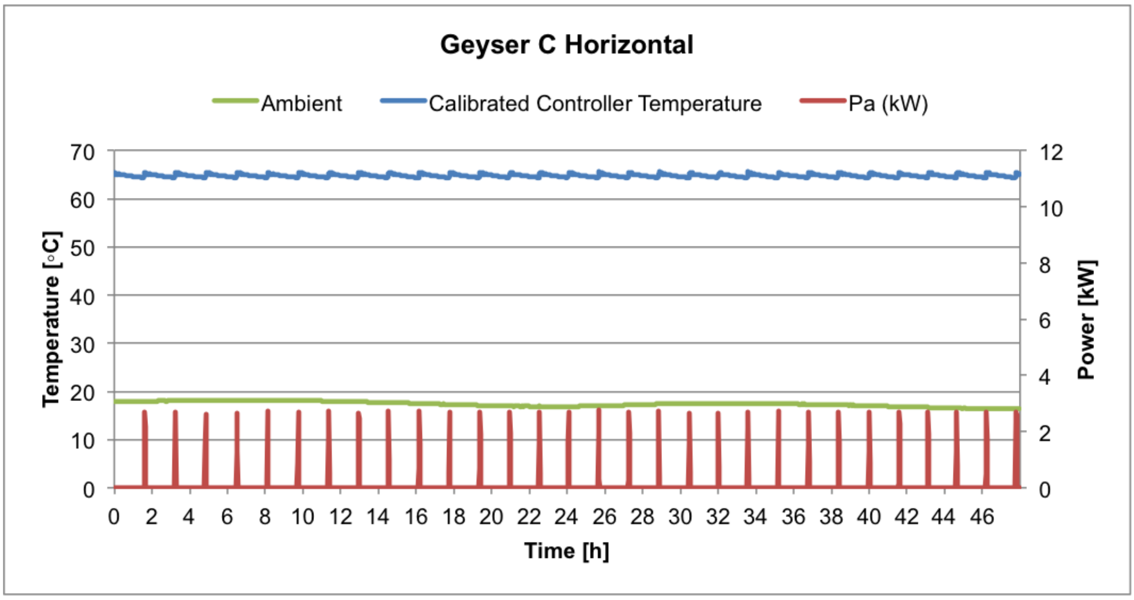


***Figure 28:** Temperature and average power profiles for the horizontal orientation standing losses test period for geyser C.*

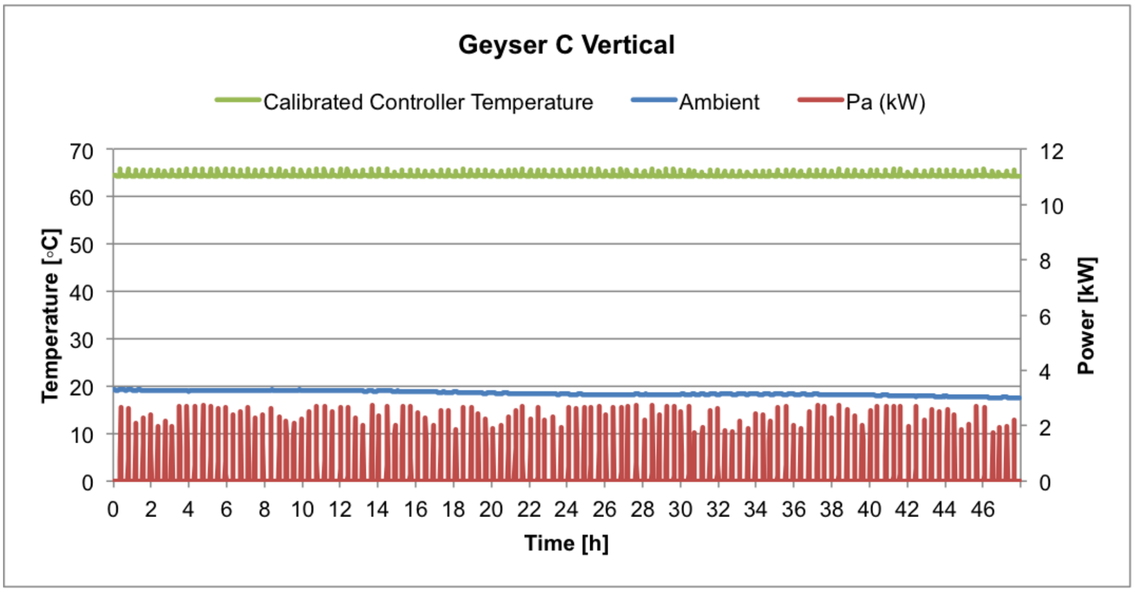


Figure 29: Temperature and average power profiles for the horizontal orientation standing losses test period for geyser C.

4.4.2 Thermal images

Figure 30, Figure 31 and Figure 32 show thermal images of the side view, inlet end and outlet end respectively for geyser C in the horizontal orientation. Figure 33 shows a thermal image of one of the mounting fittings.

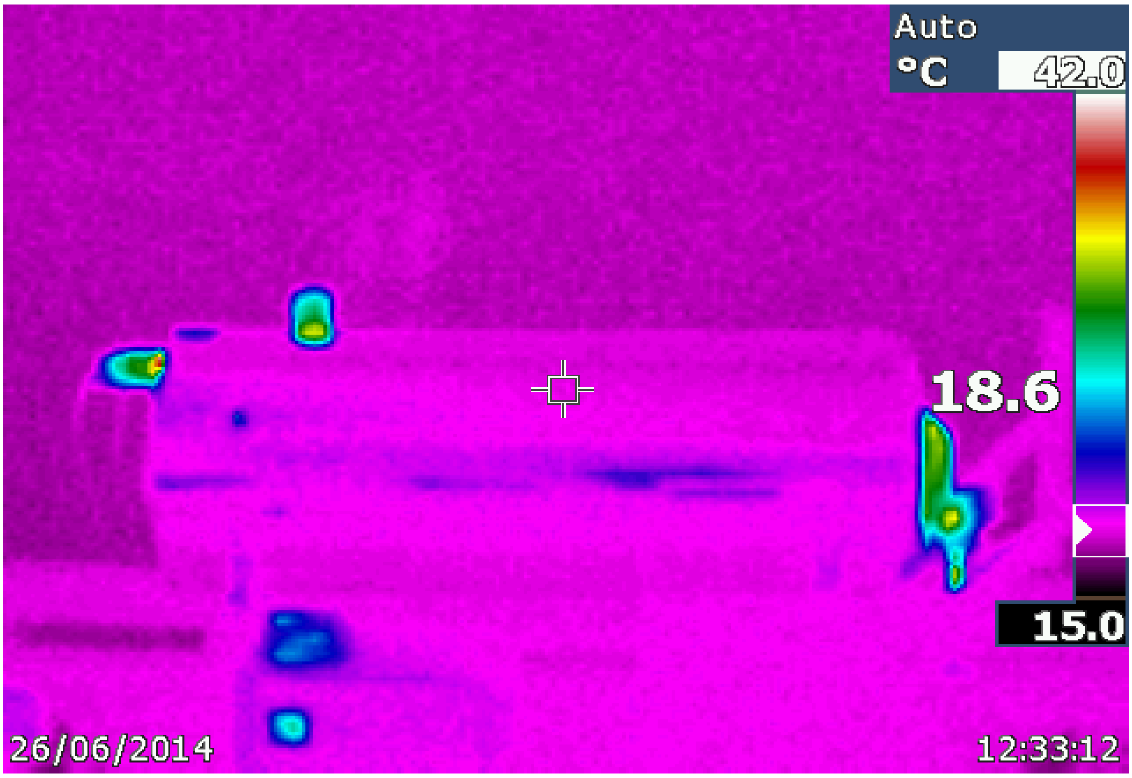


Figure 30: Thermal image of geyser C in horizontal orientation – Side view.

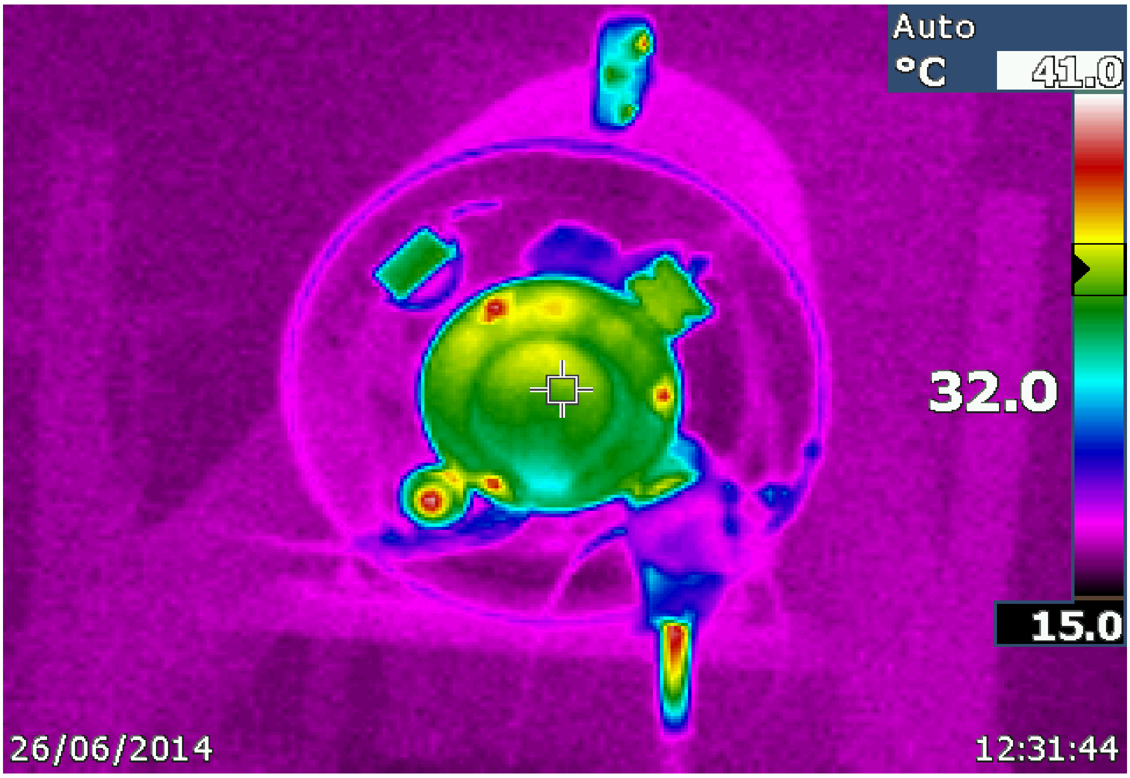


Figure 31: Thermal image geyser C in horizontal orientation – Inlet end.

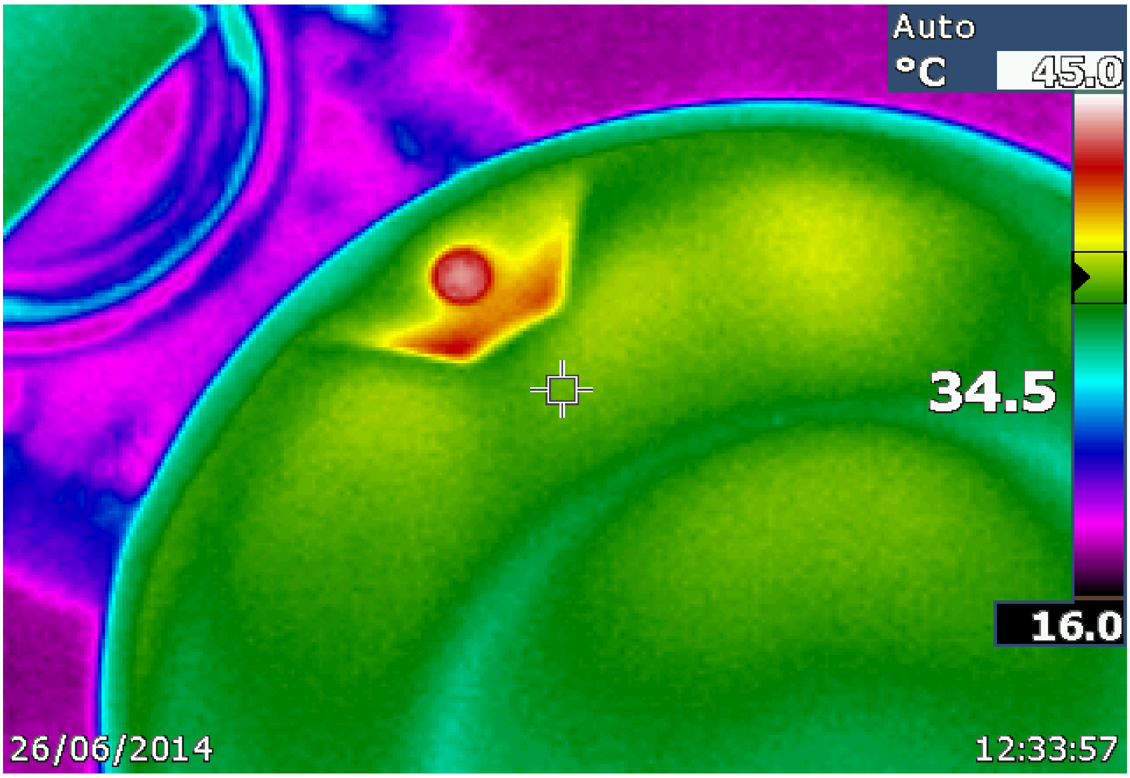


Figure 32: Thermal of geyser C in horizontal orientation – Outlet end.

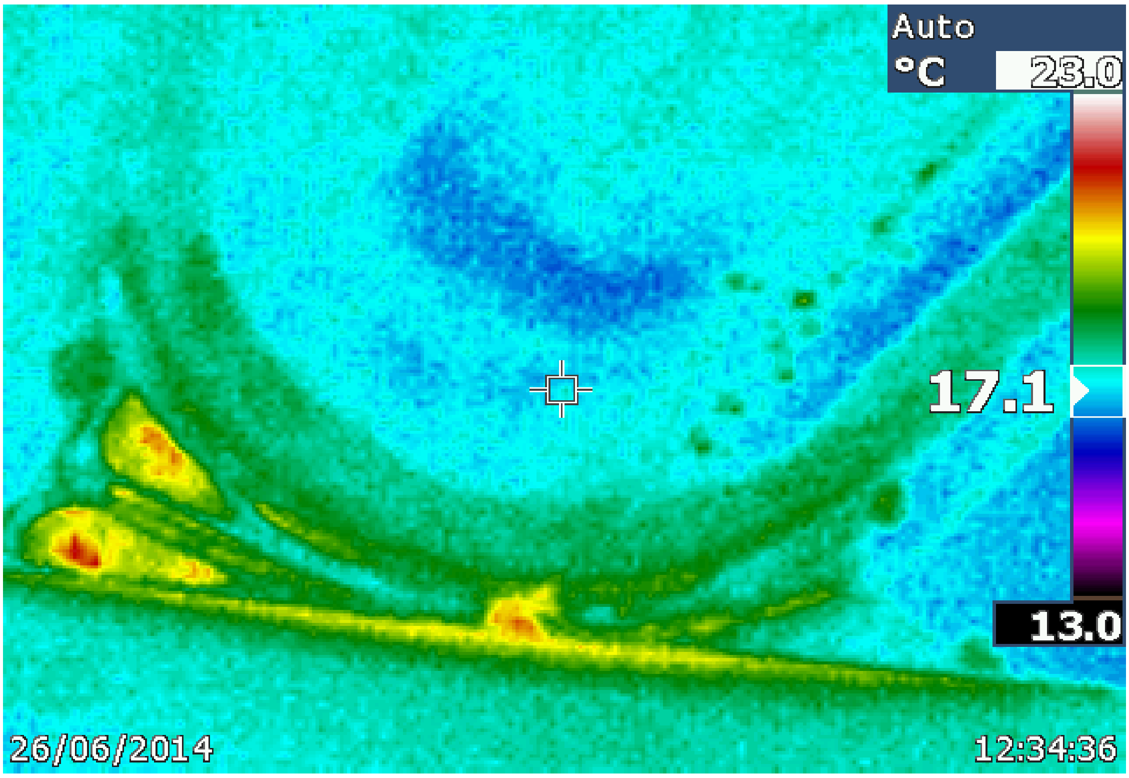


Figure 33: Thermal image of geyser C in horizontal orientation – Mounting.

Figure 34, Figure 35 and Figure 36 show thermal images of the side view, inlet end and outlet end respectively for geyser C in the vertical orientation. Figure 37 shows a thermal image of one of the mounting fittings.

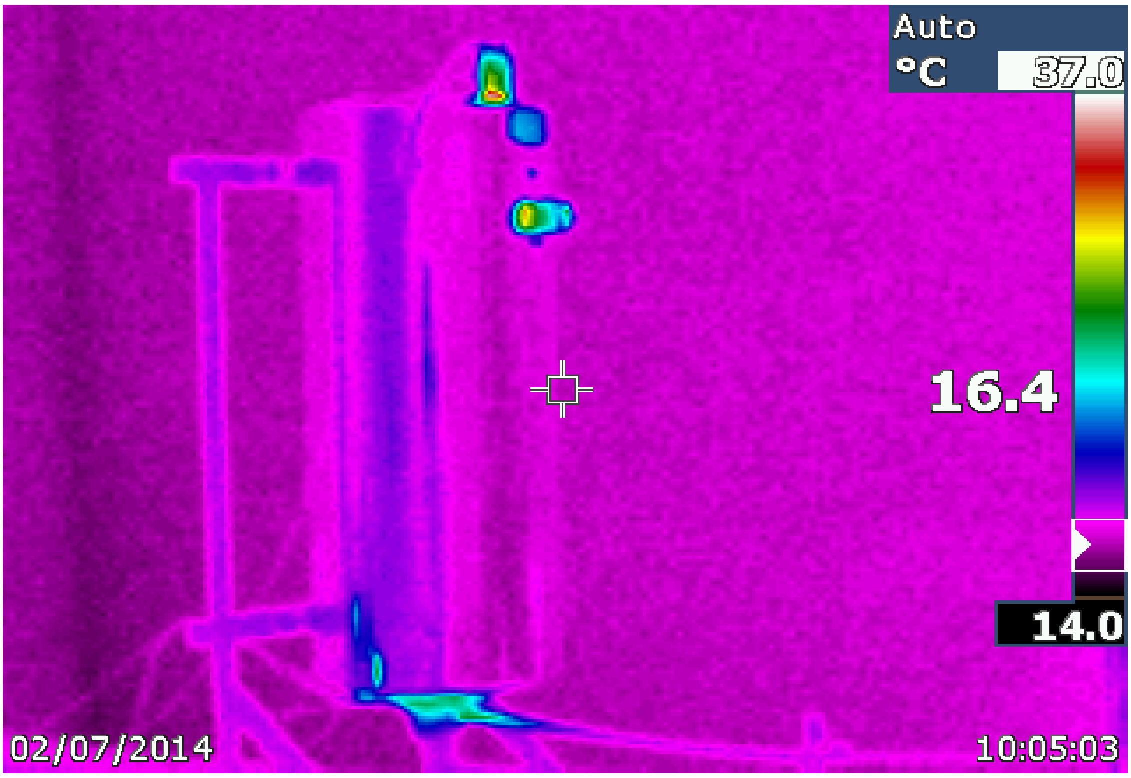


Figure 34: Thermal image of geyser C in vertical orientation – Side view.

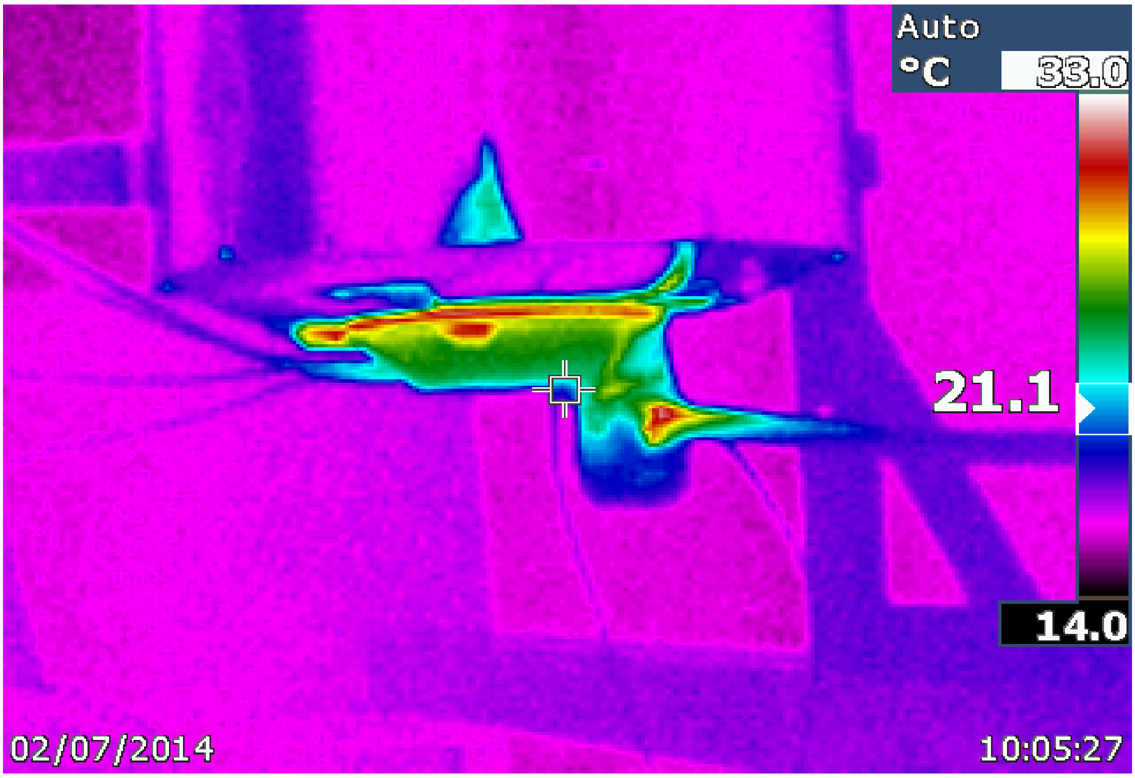


Figure 35: Thermal image of geyser C in vertical orientation – Inlet end.

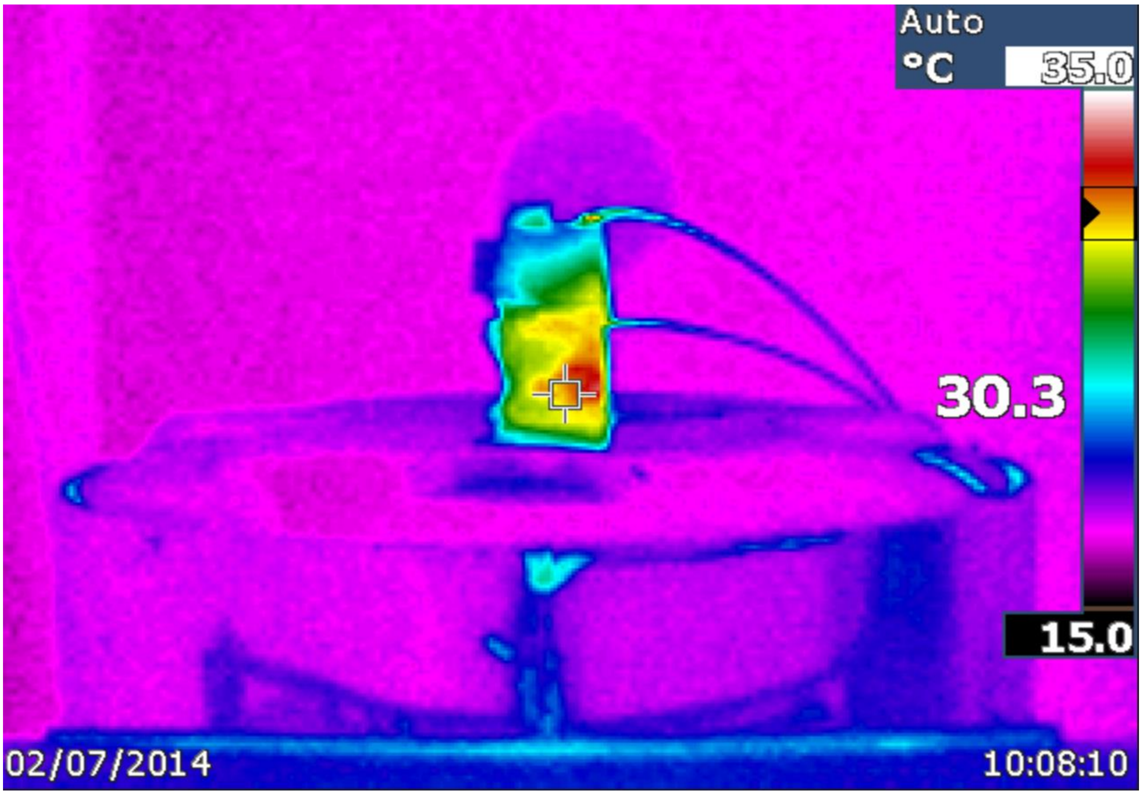


Figure 36: Thermal image of geyser C in vertical orientation – Outlet end.

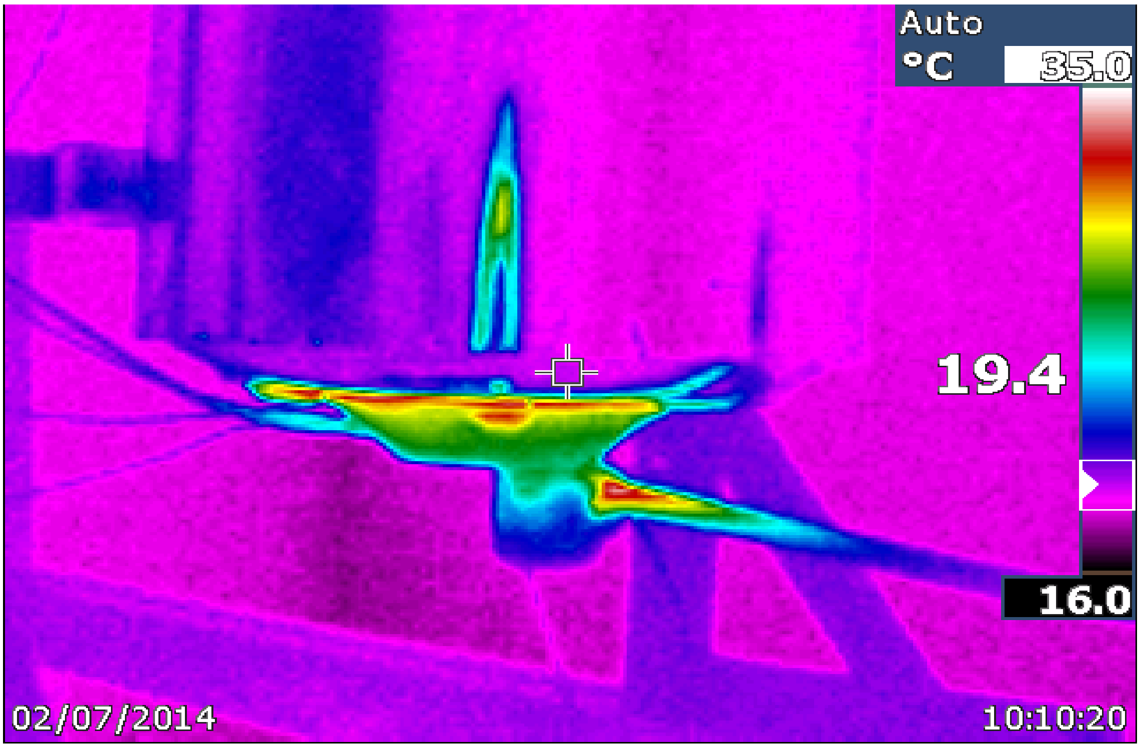


Figure 37: Thermal image of geyser C in vertical orientation – Mounting.

4.4.3 Teardown

Figure 38. Figure 39 and Figure 40 how cross-sections of the full geyser, inlet end and outlet end for geyser C. In the radial dimension, the insulation layer is evenly distributed around the peripheral of the inner cylinder with no voids or gaps. In the length dimension, the insulation layer is thinner at the outlet end compared to the inlet end. **Table 12** lists approximate dimensions for the foam insulation layer of the geyser. Overall, the insulating foam layer is of uniform density.

The spiral heating element is positioned at the inlet end in the length dimension and in the centre of the cylinder in the radial dimension. The copper thermostat pocket is positioned in the centre of the spiral heating element and extends beyond the heating element into the cylinder.

Table 12: Approximate foam insulation dimensions for geyser C.

Orientation	Radial position	Thickness [mm]
Horizontal	Bottom side	25
	Upper side	27

Figure 38: Cross-section of geyser C.

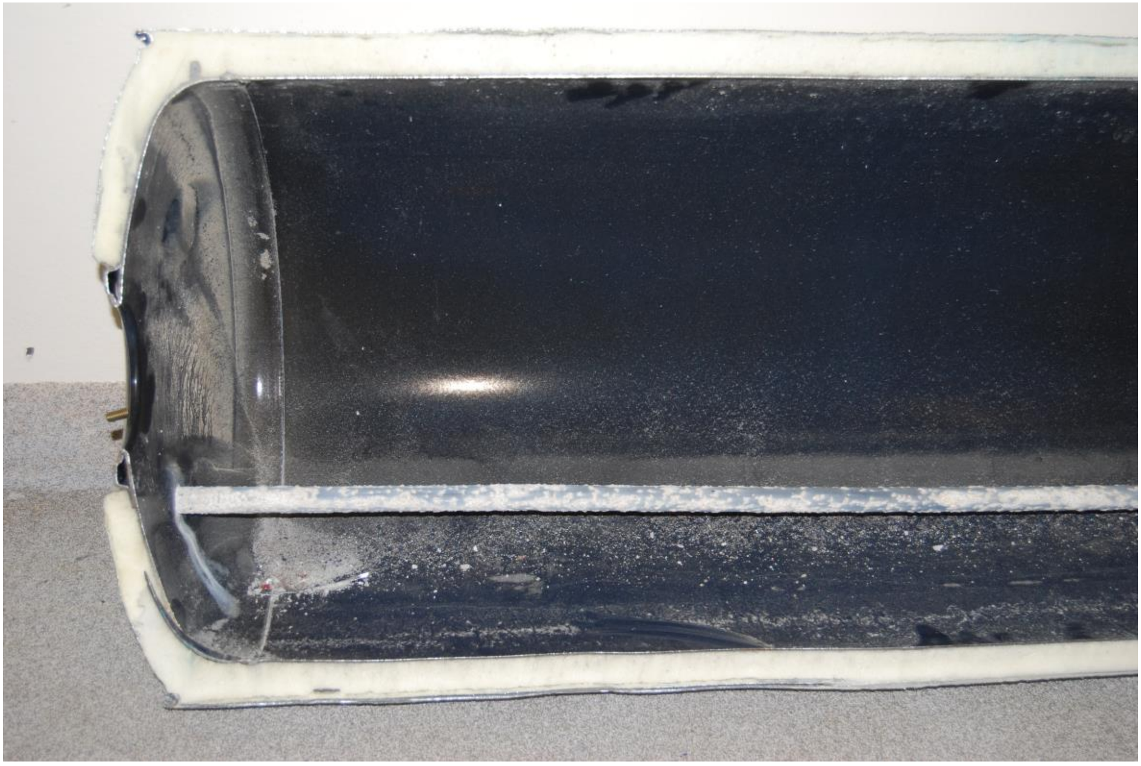


Figure 39: Cross-section of geyser C – Inlet end.

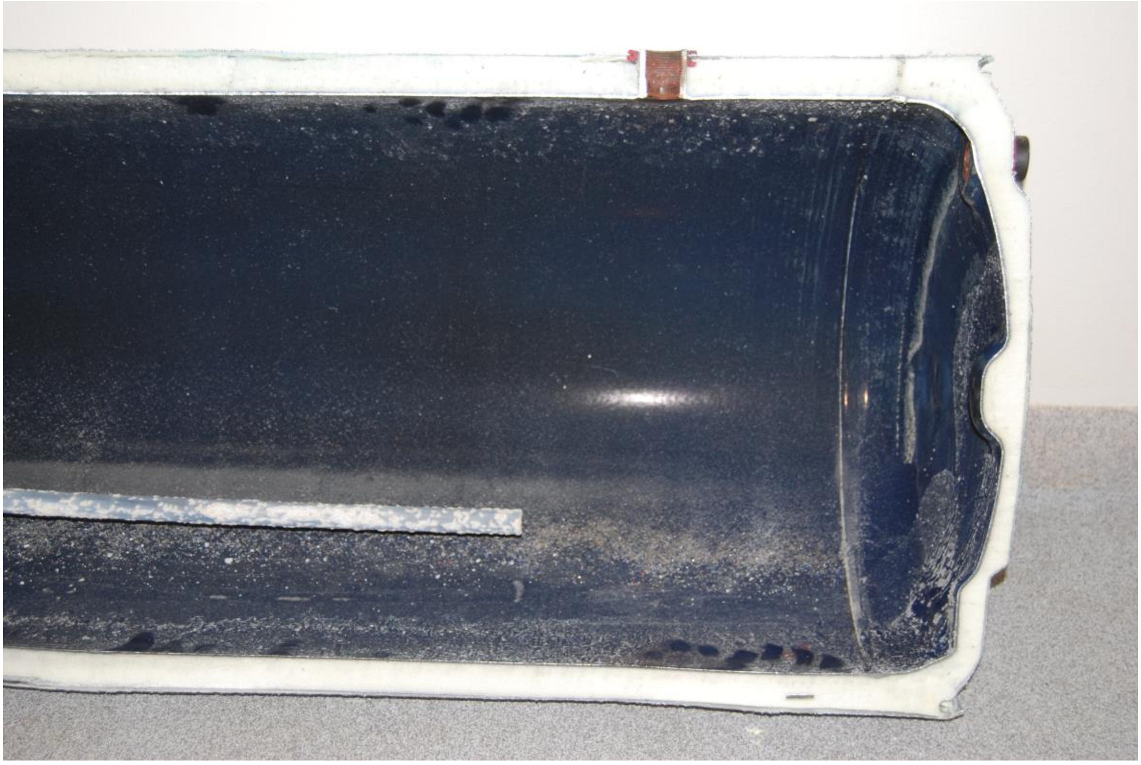


Figure 40: Cross section of geyser C – Outlet end.

4.5 Geyser D - Manufacturer C 400 kPa 150l Model 1

4.5.1 Standing losses

Table 13 summarizes the measured results for geyser D, which is specified for horizontal mounting orientation only. Figure 41 shows the recorded temperature and average power profiles for the horizontal orientation standing loss test.

Table 13: Measured results for geyser D for the standing losses test period.

Measurement parameter		Horizontal orientation	Vertical orientation
Control temperature [°C]	Minimum	64.3	-
	Maximum	66.6	-
	Mean	64.5	-
Ambient temperature [°C]	Minimum	20.3	-
	Maximum	21.5	-
	Mean	21.0	-
Energy consumption [kWh]		4.91	-
SANS 151 Standing losses [kWh/24hr]		2.51	-

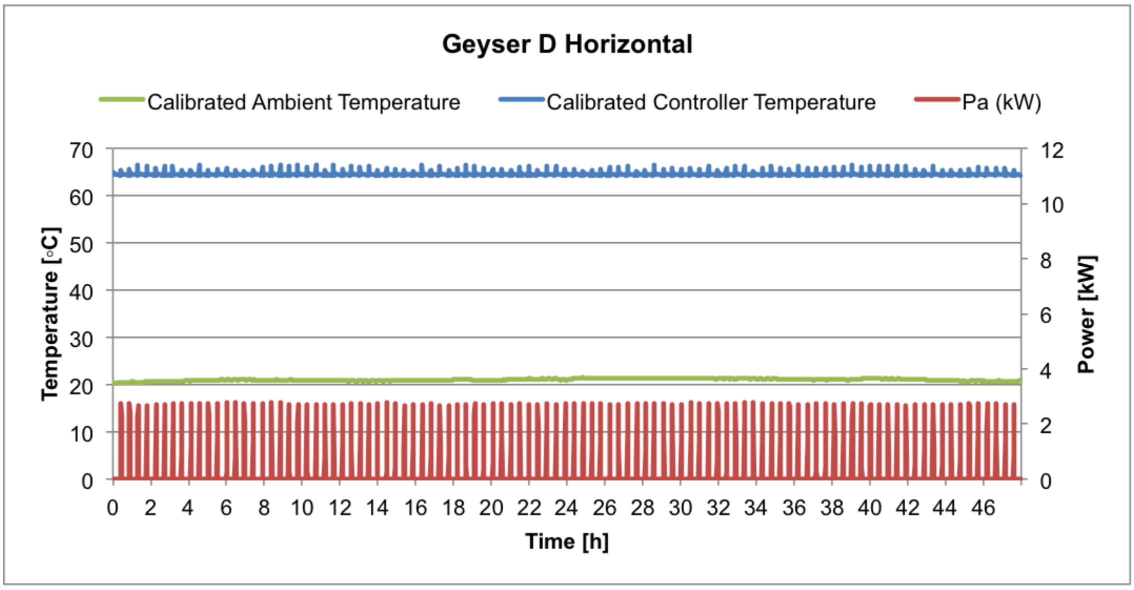


Figure 41: Temperature and average power profiles for the horizontal orientation standing losses test for geyser D.

4.5.2 Thermal images

Figure 42, Figure 43 and Figure 44 show thermal images of the side view, inlet end and outlet end respectively for geyser D in the horizontal orientation. The hot spots associated with the external connection points are clearly visible.

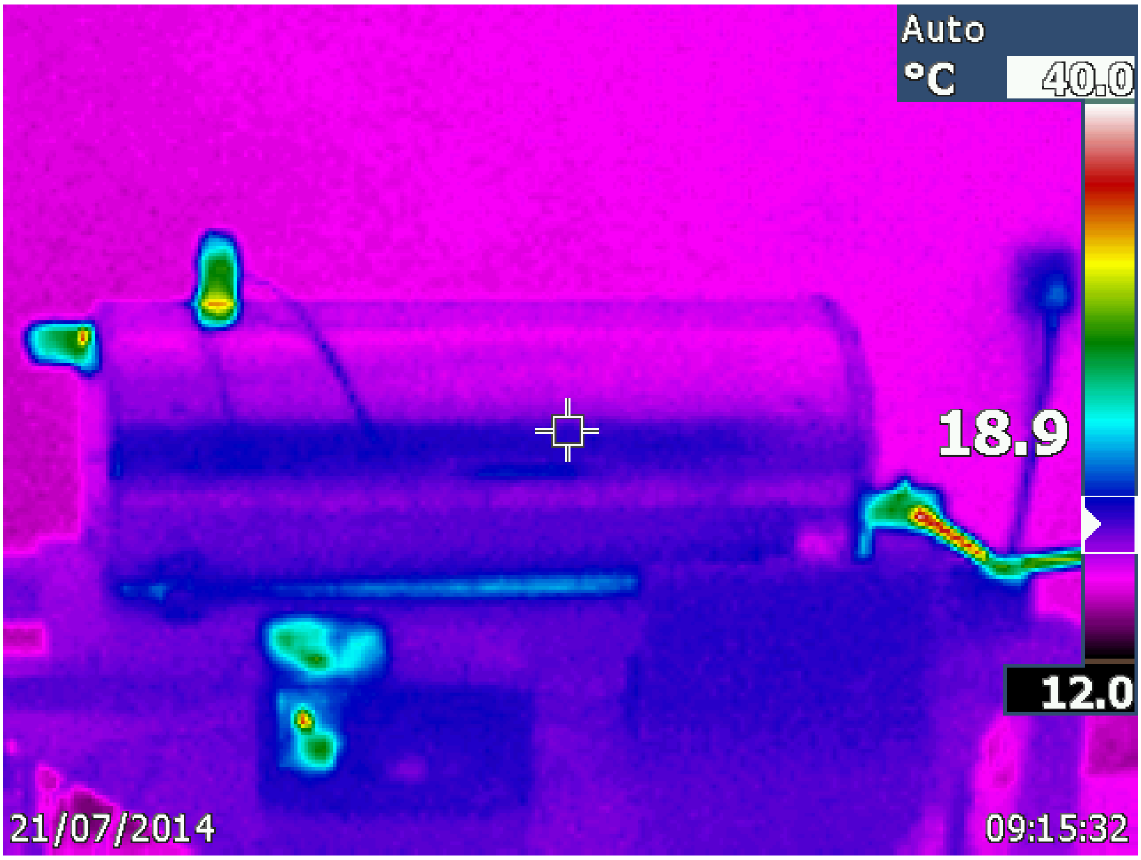


Figure 42: Thermal image for geyser D in horizontal orientation – Side view.

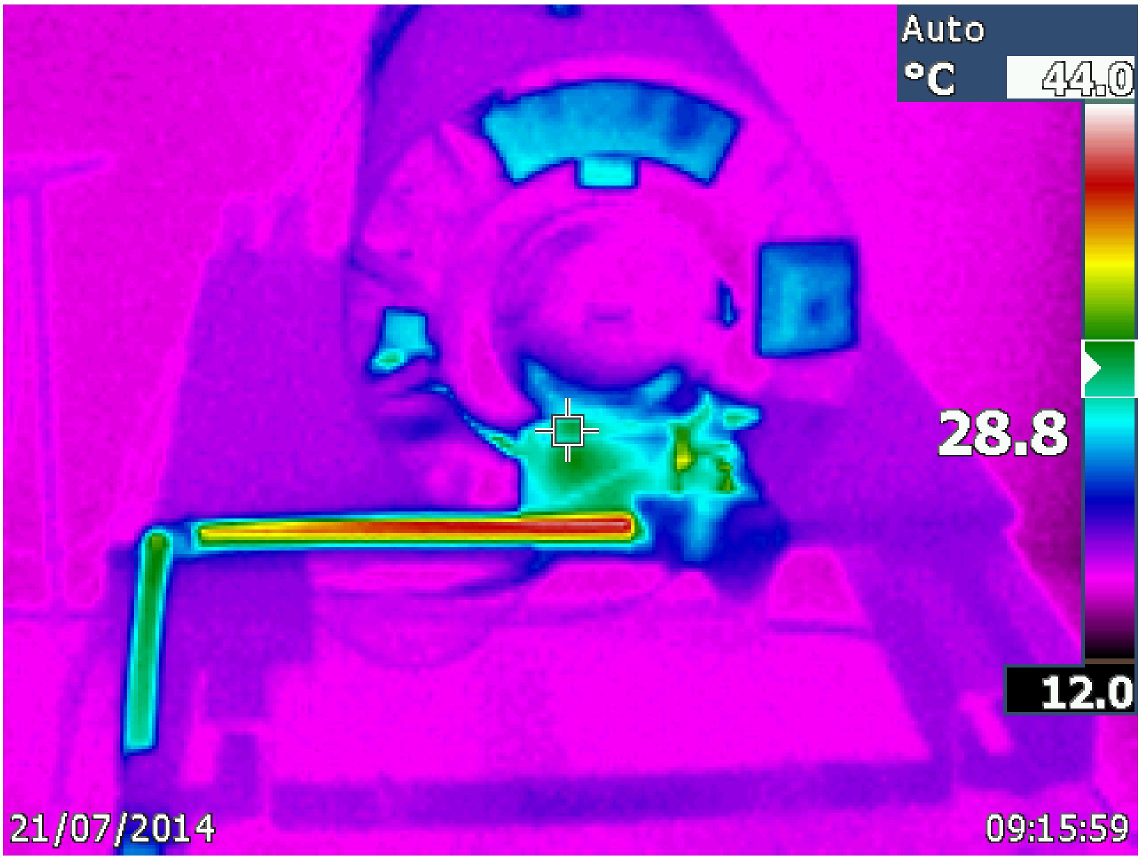


Figure 43: Thermal image for geyser D in horizontal orientation – Inlet end.

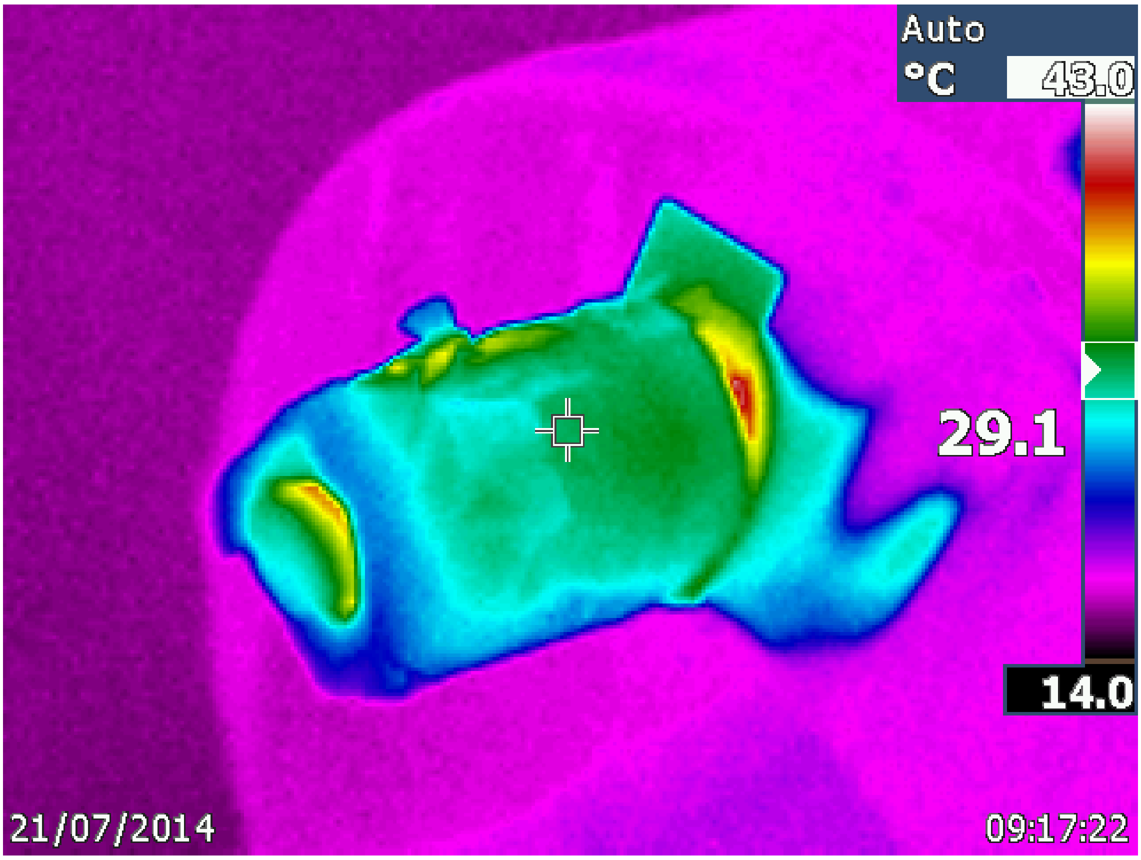


Figure 44: Thermal image for geyser D in horizontal orientation – Outlet end.

4.5.3 Teardown

Figure 45, Figure 46 and Figure 47show cross-sections of the full geyser, inlet end and outlet end of geyser D. In the radial dimension, the insulation layer is thicker on the hot water outlet side (upper side in horizontal orientation) compared to the cold water inlet side (bottom side in horizontal orientation). In the length dimension, the insulation layer is of similar thickness at the outlet end and inlet end. **Table 14** lists approximate dimensions for the foam insulation layer of the geyser. Overall, the insulating foam layer is of uniform density.

The hairpin-shaped heating element is positioned at the inlet end in the length dimension and at the bottom of the cylinder (horizontal orientation) in the radial dimension. The copper thermostat pocket is positioned in close proximity and above the heating element and is shorter than the heating element. This is expected to impact on the losses in the sense that the heat source is close to the side of inner cylinder, possibly increasing the losses due to a hot spot in this vicinity. The cold water inlet is close to the heating element, giving rise to additional heat loss in the cold water inlet piping, especially in the case of a horizontal inlet pipe. This is illustrated by the thermal image shown in Figure 43, which shows a relatively high temperature for the inlet pipe.

Table 14: Approximate foam insulation dimensions for geyser D.

Orientation	Radial position	Thickness [mm]
Horizontal	Bottom side	20
	Upper side	23

Figure 45: Cross-section of geyser D.

Figure 46: Cross-section of geyser D – Inlet end.

Figure 47: Cross section of geyser D – Outlet end.

4.6 Geyser E - Manufacturer D 400 kPa 150l Model 1

4.6.1 Standing losses

Table 15 summarizes the measured results for geyser E, which is specified for horizontal mounting orientation only. Figure 48 shows the recorded temperature and average power profiles for the horizontal orientation standing loss test.

Table 15: Measured results for geyser E for the standing losses test period.

Measurement parameter		Horizontal orientation	Vertical orientation
Control temperature [°C]	Minimum	64.3	-
	Maximum	66.6	-
	Mean	64.5	-
Ambient temperature [°C]	Minimum	20.3	-
	Maximum	21.5	-
	Mean	21.0	-
Energy consumption [kWh]		3.66	-
SANS 151 Standing losses [kWh/24hr]		1.90	-

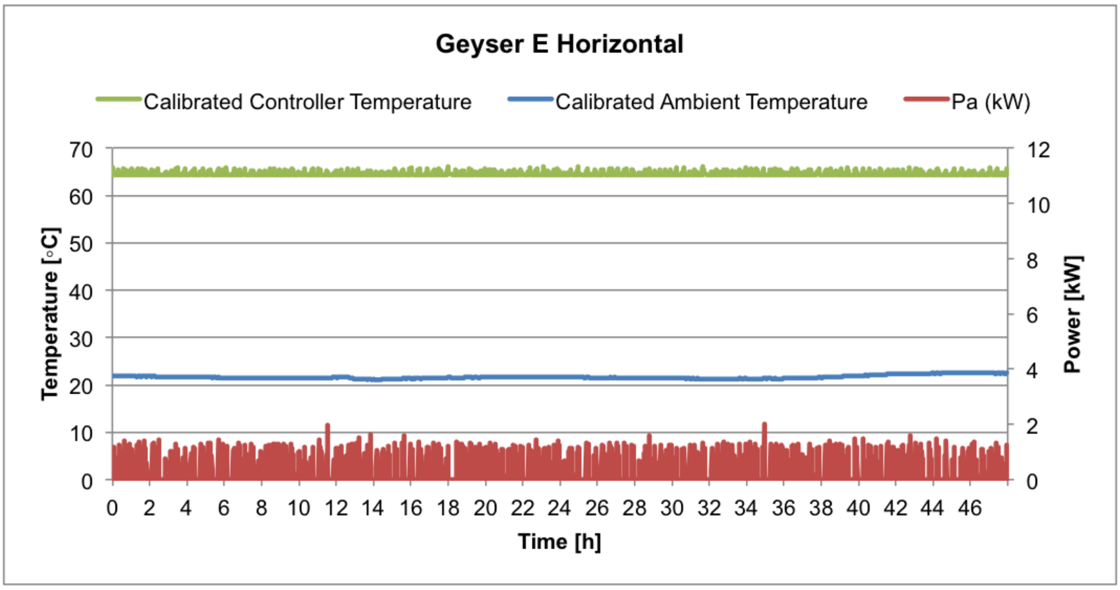


Figure 48: Temperature and average power profiles for the horizontal orientation standing losses test for geyser E.

4.6.2 Thermal images

Figure 49, Figure 50 and Figure 51 show thermal images of the side view, inlet and outlet end respectively for geyser E in the horizontal orientation. The hot spots associated with the external connection points are clearly visible. Figure 52 shows a thermal image of one of the mounting fittings.

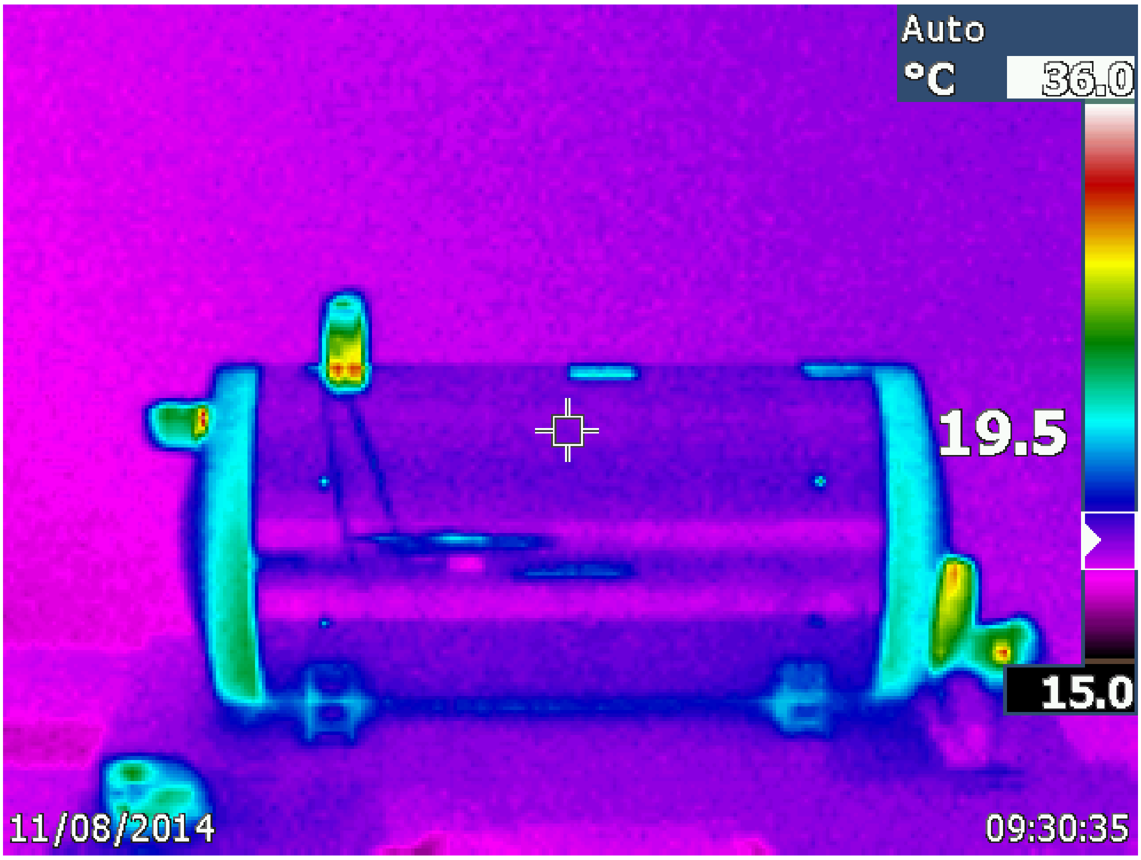


Figure 49: Thermal image of geyser E in horizontal orientation – Side view.

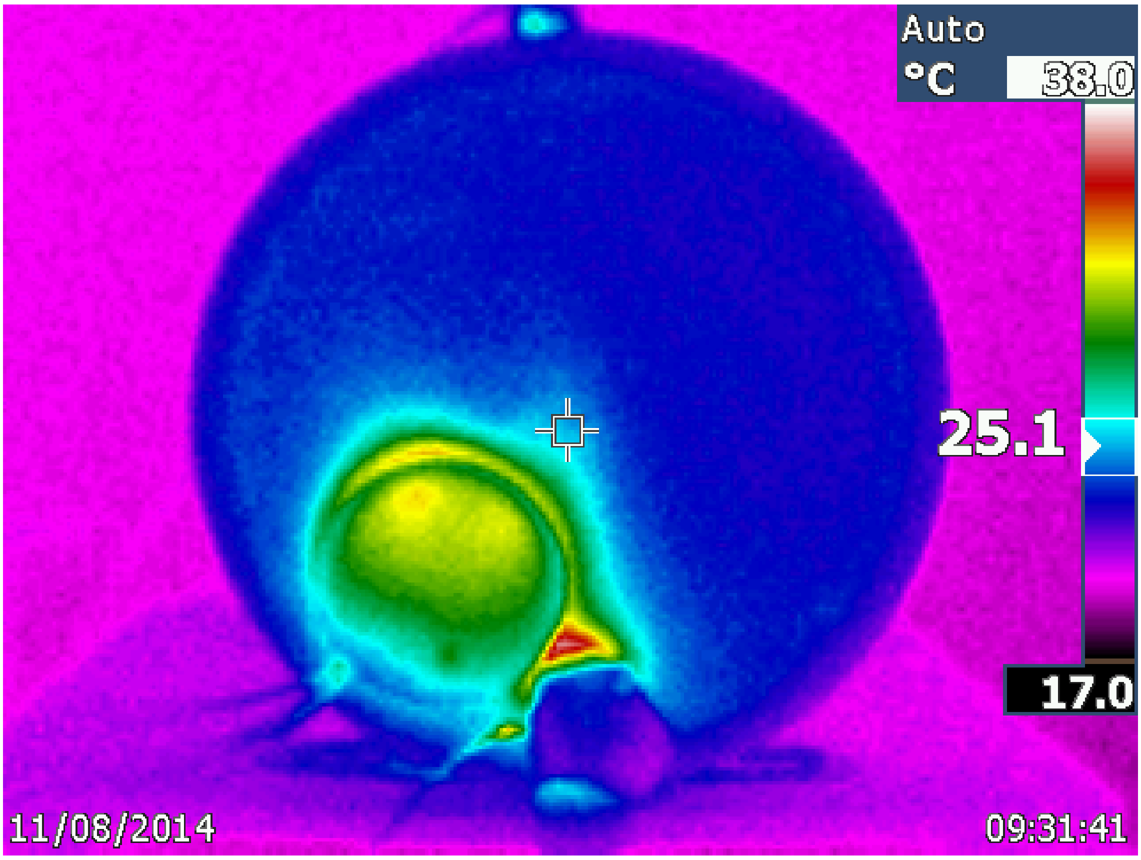


Figure 50: Thermal image of geyser E in horizontal orientation – Inlet end.

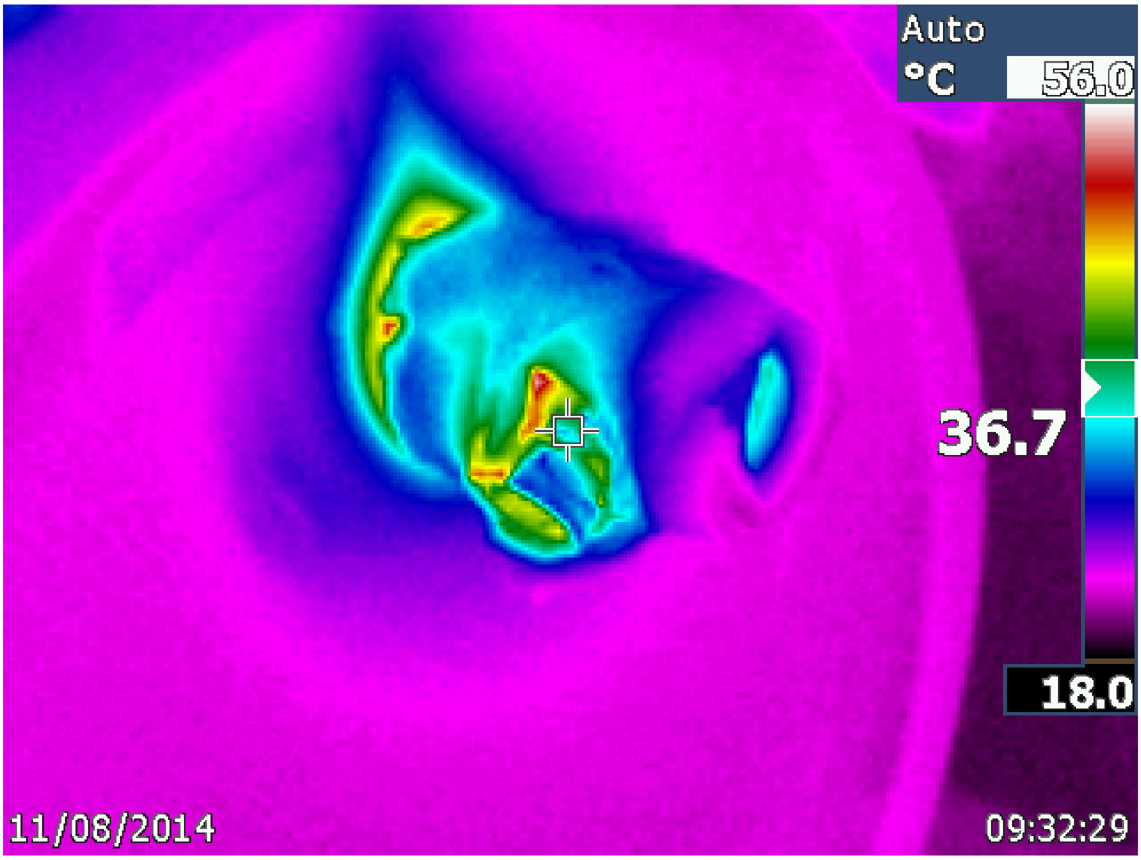


Figure 51: Thermal image of geyser E in horizontal orientation – Outlet end.

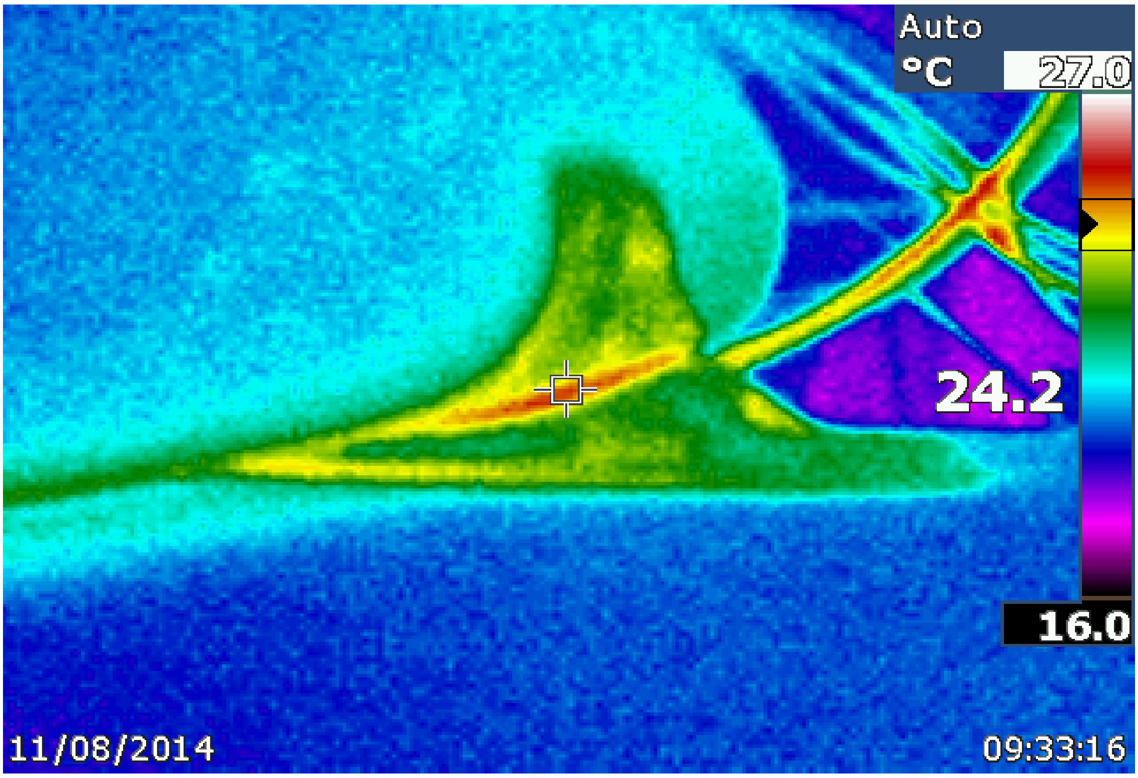


Figure 52: Thermal image of geyser E in horizontal orientation – Mounting.

4.6.3 Teardown

Figure 53, Figure 54 and Figure 55 show cross-sections of the full geyser, inlet end and outlet end of geyser E. In the radial dimension, the insulation layer is thicker on the hot water outlet side (upper side in horizontal orientation) compared to the cold water inlet side (bottom side in horizontal orientation). In the length dimension, the insulation layer is of similar thickness at the outlet end and inlet end. **Table 16** lists approximate dimensions for the foam insulation layer of the geyser. Overall, the insulating foam layer is of uniform density.

The hairpin-shaped heating element is positioned at the inlet end in the length dimension and at the bottom of the cylinder (horizontal orientation) in the radial dimension. The copper thermostat pocket is positioned in close proximity and above the heating element, offset to the side in the horizontal dimension, and is shorter than the heating element. This is expected to impact on the losses in the sense that the heat source is close to the side of inner cylinder, possibly increasing the losses due to a hot spot in this vicinity. The cold water inlet is close to the heating element, giving rise to additional heat loss in the cold water inlet piping, especially in the case of a horizontal inlet pipe.

Table 16: Approximate foam insulation dimensions for geyser E.

Orientation	Radial position	Thickness [mm]
Horizontal	Bottom side	30
	Upper side	15

Figure 53: Cross-section of geyser E.

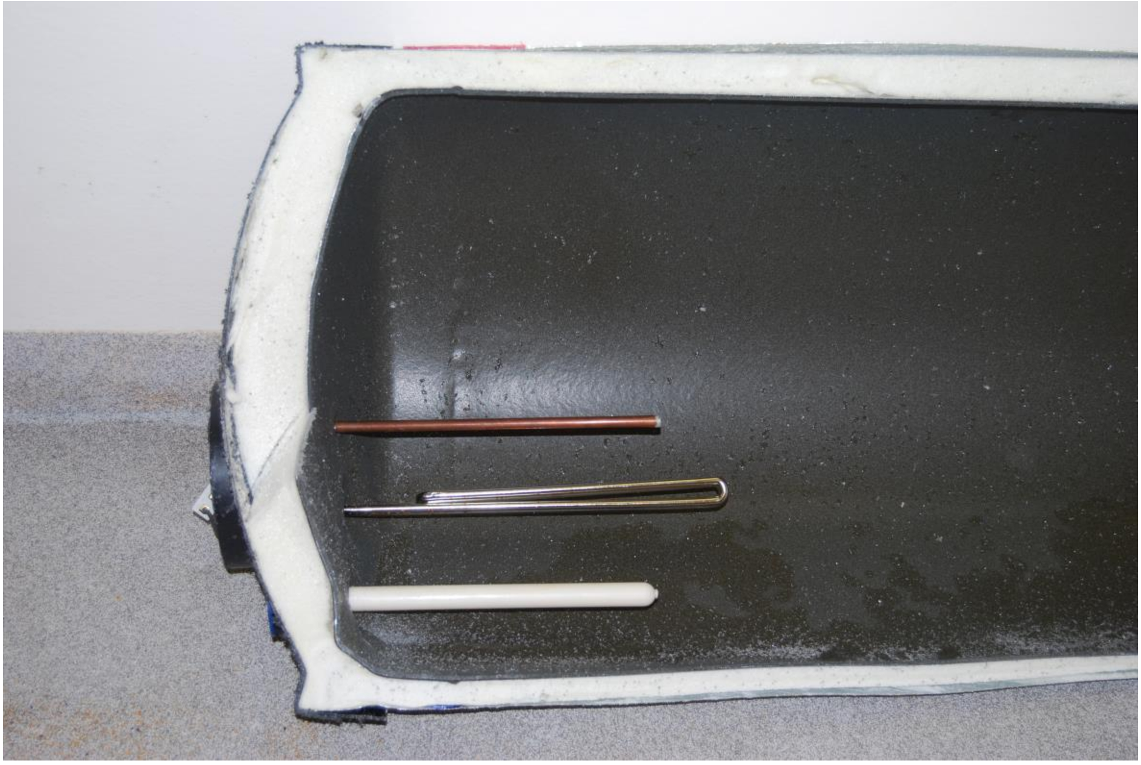


Figure 54: Cross-section of geyser E – Inlet end.

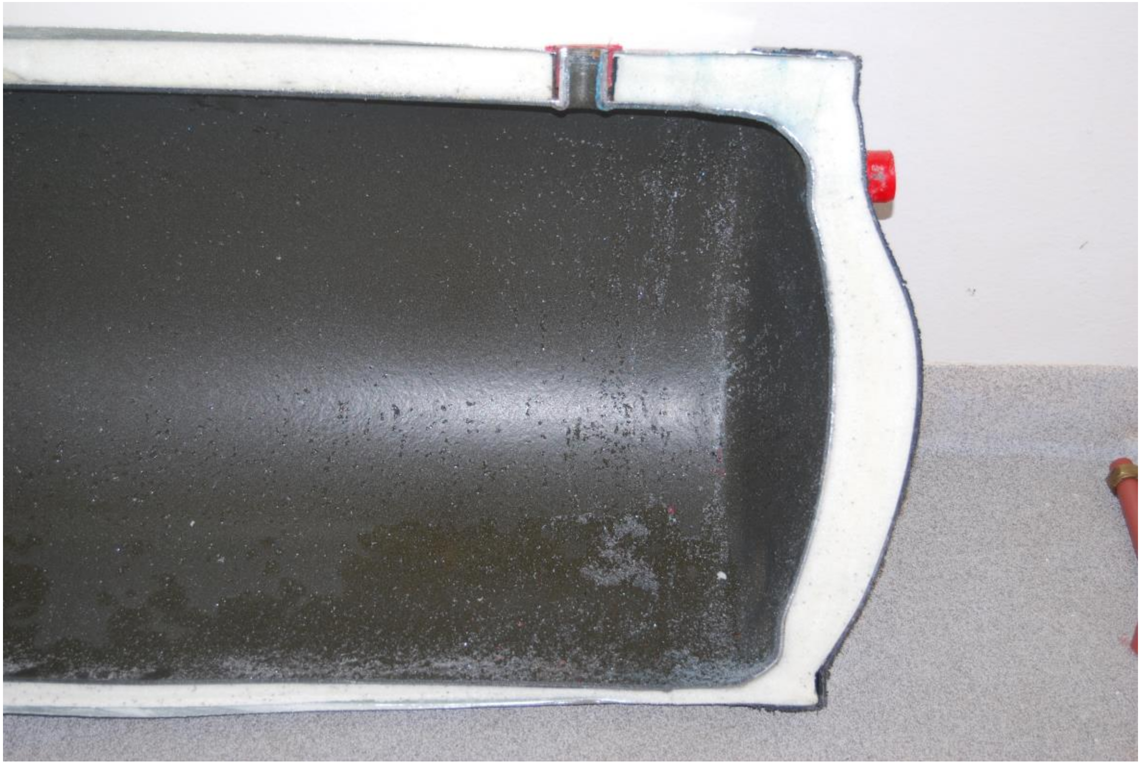


Figure 55: Cross section of geyser E – Outlet end.

4.7 Findings and recommendations

4.7.1 Test methodology

The investigation raised a number of questions in regard of the experimental procedures for determining the standing losses. These include the following:

- The average power profiles recorded for the different test configurations show that the controller behavior and the associated thermodynamic behavior of the water inside the geyser are highly dependent on the geyser orientation and the relative positions of the heating element and control temperature sensor. The following details apply:
  - *Geysers with a spiral heating element and thermostat pocket located in the center, where the tip of the thermostat pocket extends beyond the heating element:* The temperature controller switches on and off at a much lower rate for the horizontal orientation compared to the vertical orientation. This is due to the fact that, for the vertical orientation, the sensor mounted in the tip of the thermostat pocket is positioned in the path of the rising hot water plume generated by the heating element.
  - *Geysers with a heating element and thermostat pocket located off-center towards the lower cylinder wall:* The tests were only conducted for the horizontal orientation in these cases. The temperature controller switches on and off at a high rate, similar as for vertically orientated geysers with a heating element and thermostat pocket located in the center. This is due to the fact that the sensor mounted in the tip of the thermostat pocket is positioned in the path of the rising hot water plume generated by the heating element.

  The effects of the position of the control temperature sensor on the thermodynamic behavior imply that the temperature distribution inside the cylinder is also affected. This in turn affects the heat energy stored in the geyser for a given control temperature, which in turn affects the loss rate.
- External connection points such as the cold water inlet connection, hot water outlet connection and pressure relieve connection can contribute significantly to the overall losses associated with the test installation. The standing loss tests were conducted for the following conditions:
  - No external hot water connection.
  - A pressure relieve valve fitted to the pressure relieve connection.
  - A vertical polycop cold water inlet pipe entering from below the geyser.
  - Insulation lagging wrapped around the external connection points.
- The losses are affected by the routing of the cold water inlet pipe. A vertical inlet pipe section entering from the top of the geyser or a horizontal inlet pipe section increases the pipe losses due to the relatively higher water temperature inside the pipe compared to a vertical connection entering from the below the geyser.

SANS 151 is not entirely clear on some aspects of the test configuration to be used in the standing loss tests, including the position of the control temperature sensor, the configuration of external piping fittings, lagging of external connections and the routing of the cold water inlet pipe.

4.7.2 Geyser construction and insulation design

The teardown results show that some of the geysers are designed to deliver lower loss figures for the horizontal orientation compared the vertical position. This is confirmed by the relatively lower loss figures measured for Geyser A and Geyser B in the horizontal orientation compared to the vertical orientation. In the case of Geyser C, the insulation layer is uniform in the radial dimension and a lower loss figure is reflected for the vertical orientation. From an energy efficiency perspective, therefore, it is important to differentiate between the loss specifications for the horizontal and vertical orientations. This is not addressed in the current standard.

The test results, especially the thermal images, show that heat loss can be reduced by the following improvements in most of the cases:

- Improving the insulation around the thermostat and heating element fittings.
- Improving the insulation around the sacrificial anode fitting.
- Reducing the heat losses associated with the external connections.
- Improving the thermal insulation between the hot central cylinder and the mounting brackets. All geysers tested show relatively high temperatures for the mounting brackets and the external cylinder surfaces in the vicinity of the mounting brackets.
- Optimizing the insulation design for a particular orientation and providing clear orientation specific heat loss performance figures.

Quality control in the manufacturing process is critical for achieving consistent loss figures across batches of individual units. In this context, it is particularly important to exercise quality control with regard to the following:

- The spatial positioning of the inner cylinder within the outer cylinder.
- The foam injection process.

5 Cost Benefit Analysis

5.1 Introduction

The calculation of consumer-perspective cost-effectiveness compares incremental increases in equipment prices with decreases in energy consumption (standing losses) as a result of adding insulation. In the following analysis, heat losses through the jacket and insulation, which is assumed to be uniform, are calculated through the use of thermal flow equations and simplified geyser geometry. Likewise, increases in material costs are calculated as the additional volume of insulation and steel surface area needed to enclose the water tank in a thicker insulating layer. Therefore, while simplified, the calculation relies on well-understood relations of thermodynamics and economics of material costs.

This analysis focuses only on the insulation efficiency measure while acknowledging other sources of heat loss and opportunities for improvement. These losses, e.g. through the fittings, structural supports and across other thermal bridges are described collectively as "bypass losses". In addition, some negative effect may be caused by non-uniformities in the insulation. All such losses are parameterized though the results of the heat loss laboratory measurements described above. It should be noted, however, that the cost-effectiveness analysis depends only on incremental changes in insulation thickness, and should be largely independent on other sources of heat loss. Finally, because we consider only the insulation measure, the analysis can be considered conservative, because it doesn't include additional, and perhaps less costly measures for reducing losses that geyser manufacturers may take advantage of.

The baseline geyser is modeled according to measurements taken of Geyser 'A', which is understood to be the market leader. This geyser had an average insulation thickness of about 20mm[4]. The tank cylinder diameter is 406mm. Although the endcaps are rounded at both ends, the tank was modeled as a horizontal cylinder with a length of 1158.6mm in order to generate a volume of 150l. The insulation was modeled as constant around the radius of the cylinder and 20mm on both ends.

5.2 Standing Loss Calculation

Heat loss calculations for varying insulation thickness are done according to formulas in the *Heat Transfer* chapter of the *2013 ASHRAE Fundamentals Handbook*.[5] The following assumptions were made to allow the simplified calculations:

- During the standing loss test the water in tank is at a constant, uniform temperature
- The air in the room and the inner surfaces of the walls of the room are at a constant, uniform temperature
- The water heater jacket is at a uniform temperature
- The heat losses through fittings are constant regardless of insulation thickness

For the purposes of loss estimation, the water tank is assumed to be a perfect cylinder of radius r_0 of 203mm and length L of 1.194m, with an outer jacket and variable insulation thickness between the tank and jacket t (mm). The radius of the jacket is therefore $r = r_0+t$. Losses are estimated according to the SABS test procedure temperature specifications:

T_{tank} = temperature of water in geyser tank (assumed uniform) = 65°C (SANS 151)

T_{amb} = ambient temperature = 20°C (SANS 151)

The heat loss is calculated as conductive heat transfer through the insulation from the water to the jacket of the geyser. This must equal the heat loss from the jacket to the environment. The heat loss from the jacket is calculated as the sum of the convective heat transfer to the air in the room and radiative heat transfer to the walls of the test room. The jacket temperature at equilibrium Ts is such that the sum of radiative and convective losses equal conductive losses through the insulation. Conductive losses through the cylindrical and end surfaces are given by:

$$q_{cyl} = 2\pi kL(T_{tank}-T_s)/ln(r_0/r_i)$$

$$q_{end} = k\pi r_0^2(T_{tank}-T_s)/t$$

Total losses through the insulation are qtot=qcyl+qend. The parameter k is the thermal conductivity of the insulation for polyurethane foam with HCFC-141b blowing agent,

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[4] The insulation thickness of this unit were highly non-uniform, ranging from 5mm to 35mm. However, all of the units measured had average insulation thicknesses of between 20mm and 26mm, so 20mm is assumed to be a good representation of the baseline.

[5] 2013 ASHRAE Handbook - Fundamentals SI Edition. Atlanta, GA: ASHRAE, 2013. http://handbook.ashrae.org/Handbook.aspx.

assumed[6] to be .021 W/(m.K). Convective heat transfer is given by 2*qendc+qcylc where:

$q_{endc} = h_v A_e\,(T_s - T_{amb})$

$q_{cylc} = h_h A_h\,(T_s - T_{amb})$

In this equation hv is the convective heat transfer for a vertical surface (W/(m2.K)) , Ac is the area of the end cap of the geyser and hh is the convective heat transfer coefficient for a horizontal cylinder.

$h_v = 1.33\,(\Delta t/D)^{1/4}$

$h_h = 1.04\,(\Delta t/D)^{1/4}$

Radiative heat transfer is given by:

$q_{rad} = \varepsilon A \sigma\,(T_s^4 - T_{amb}^4)$, where

ε is the total emissivity, A is the total surface area of the geyser (m^2) and · is the Stefan-Boltzmann constant (W/(m^2·K^4)). Given the equilibrium conditions, T_s can not be solved for directly, so we determined it iteratively using the Excel "Goal Seek" function. Using these parameters, we determine T_s and q_{tot} for insulation thickness t ranging from 20mm to 125mm. The results are given in **Table 17**.

Table 17: Conductive heat loss dependence on insulation thickness

t	T_s	$q_{tot}(t)$	$q_{tot}(t)$	Δq_{tot}
mm	°C	W	kWh/24h	kWh/24h
20 (baseline)	25.6	77.0	1.85	-
25	24.7	64.2	1.54	-0.31
50	22.5	36.7	0.88	-0.97
75	21.7	26.9	0.65	-1.20
100	21.3	22.0	0.53	-1.32
125	21.0	19.0	0.46	-1.39

It is important to note that q_{tot} is only the heat transfer via insulation. In practice, and as observed by the test results, geysers may also experience significant heat transfer through the fixtures, structural supports and other components. Therefore, the losses included in q_{tot} will be less than those measured by the test procedure and the basis of the efficiency rating. For the purposes of the incremental insulation analysis, however, the reduction in q_{tot} as a result of added insulation is the relevant parameter to the incremental cost calculation.

5.3 Material Costs

The impact of increased costs of insulation material and sheet metal on incremental equipment cost to consumers (retail price) of geysers can be expressed as:

$$\Delta EC = (P_{Ins} \times \Delta V + P_{steel} \times \Delta A) \times markup$$

[6] Fanney, A. Hunter, Robert R. Zarr, and Jareb D. Ketay-Paprocki. "Thermal Performance of Residential Electric Water Heaters Using Alternative Blowing Agents." ASHRAE Transactions 2000 106, no. 2 (July 2000): 1–13

In this equation, P_{Ins} is the unit cost of insulation (per unit volume), ΔV is the increase in volume due to added insulation thickness, P_{steel} is the unit price of sheet steel (per unit area) and ΔA is the increase in tank surface area due to added insulation thickness. These costs are multiplied by a factor *mark-up* that includes all mark-ups from manufacturer to end consumer, and assumes that mark-ups apply consistently to all component costs. The resulting incremental equipment cost ΔEC, is the additional amount paid by geyser purchasers.

The calculation uses the geometrical parameters described above. Unit material prices for polyurethane and steel are referenced in the Appendix. **Table 18** provides each variable and resulting incremental equipment cost for a range of insulation thickness *t*.

Table 18: Incremental equipment cost dependency on insulation thickness

t	ΔV	ΔA	P_{Ins}	P_{Steel}	Mark-up	Total Cost
Baseline = 20mm	m^3	m^2	R/m^3	R/m^2		R
25 mm	0.01	0.07	1,120	110	1.35	25
50 mm	0.07	0.41	1,120	110	1.35	161
75 mm	0.13	0.78	1,120	110	1.35	313
100 mm	0.20	1.17	1,120	110	1.35	484
125 mm	0.29	1.59	1,120	110	1.35	673

In general, most of the incremental cost estimated in this way arises from the additional cost of insulation, but the costs of extra steel are not negligible. The overall cost for increasing insulation from 20 to 50 mm is about R 160, or roughly 7-10%[7] of the retail price of a 150 liter geyser.

5.4 Cost-Effectiveness calculation

The parameters listed in Table 17 and 18 form the basis to determine the net costs to consumers of increasing geyser insulation, which is a trade-off between higher retail equipment prices and reduction in electricity bills. The former is given by the parameters in Table 17 for each level of insulation. The latter is calculated from Δq_{tot} , combined with electricity prices.

In order to calculate operating cost savings, we use the current price of electricity of 1.52 R/kWh for the first year of operation. We then assume increases of 12% per year for 5 years.

Table 19: Operational Cost Savings

t	ΔEC	Δq_{tot}	Δq_{tot}	ΔOC (year 1)	ΔOC (year 6)
mm	R	kWh/24h	kWh/year	R	R
20 (baseline)	-	-	-	-	-
25	25	-0.31	-112	-171	-301
50	161	-0.97	-353	-537	-946
75	313	-1.20	-438	-667	-1,175
100	484	-1.32	-481	-733	-1,291
125	673	-1.39	-508	-772	-1,360

[7] Based on the retail prices paid by Stellenbosch University to procure geysers for the study

This simple calculation demonstrates the main result of the cost benefit calculation that the expected incremental equipment cost to consumers would be paid for in less than a year in all cases at current prices. Three main indicators of cost-effectiveness can be calculated using these parameters: Incremental Life-Cycle Cost (∆LCC), Payback Period and Cost of Conserved Energy (CCE). They are defined as follows:

- *Incremental Life-Cycle Cost (∆LCC)* – The difference between the total of equipment costs and operating costs over the life of the equipment in the high efficiency case, relative to the baseline
- *Payback period* – The number of years after which operating cost savings equals incremental equipment cost
- *Cost of Conserved Energy (CCE)* – incremental equipment cost per unit energy saved over the life of the equipment

Lifecycle Cost and Cost of Conserved Energy calculations rely on an estimate of the average lifetime of a geyser, which we assume to be 10 years. In addition, since they project savings and investment over a period of time, each uses a discount rate factor, which we assume to be 10%. The details of the calculation of each cost-effectiveness indicator are given in (McNeil & Bojda). The results are given in **Table 20**.

Table 20: Cost Effectiveness Indicators for increased insulation thickness

t	∆LCC	Payback	CCE
mm	R	year	R
20 (baseline)	-	-	-
25	-1,486	0.15	0.05
50	-4,596	0.30	0.10
75	-5,595	0.47	0.16
100	-6,010	0.66	0.23
125	-6,173	0.87	0.30

The previous analysis clearly demonstrates the cost effectiveness to consumers of adding up to 125mm of insulation to the baseline geyser in South Africa, independent of the metric used. Incremental cost is highly negative in each case, and is increasing, to over R 6,000 over the life of the geyser for higher insulation levels. Likewise, payback periods are all under one year. Finally, CCE is only a fraction of the current electricity price of 1.52 R/kWh. There are several main factors explaining these results:

- High energy consumption (losses) – standing losses in geysers currently exceed 1.5 kWh/day or about 550 kWh per year. A reduction of the order of 50% or more of these losses represents a very high savings for households.
- Low technology baseline – by international standards, geyser efficiency technology is still relatively low, allowing for significant "low hanging fruit" with relatively simple measures.
- High electricity prices – current residential electricity rates in South Africa are fairly high, and forecast to further increase, making electricity savings more valuable than in other markets and sectors.

This analysis takes into account only the material costs of increased insulation and steel casing material, implicitly assuming no incremental labour costs to manufacture the redesigned equipment. In addition, retooling costs are not included. On the other hand, the analysis considers only increased insulation thickness to reduce losses. In practice, and as the laboratory tests and tear down analysis revealed, there are significant other heat transfer channels in designs currently on the market, and therefore an opportunity for additional savings, potentially at low additional cost to manufacturers.

5.5 Analysis of target levels

Label levels are calculated for a 150l geyser according to the formulas provided by SANS 151 (**Table 21**). The MEPS level, given by SANS 151, is also shown.

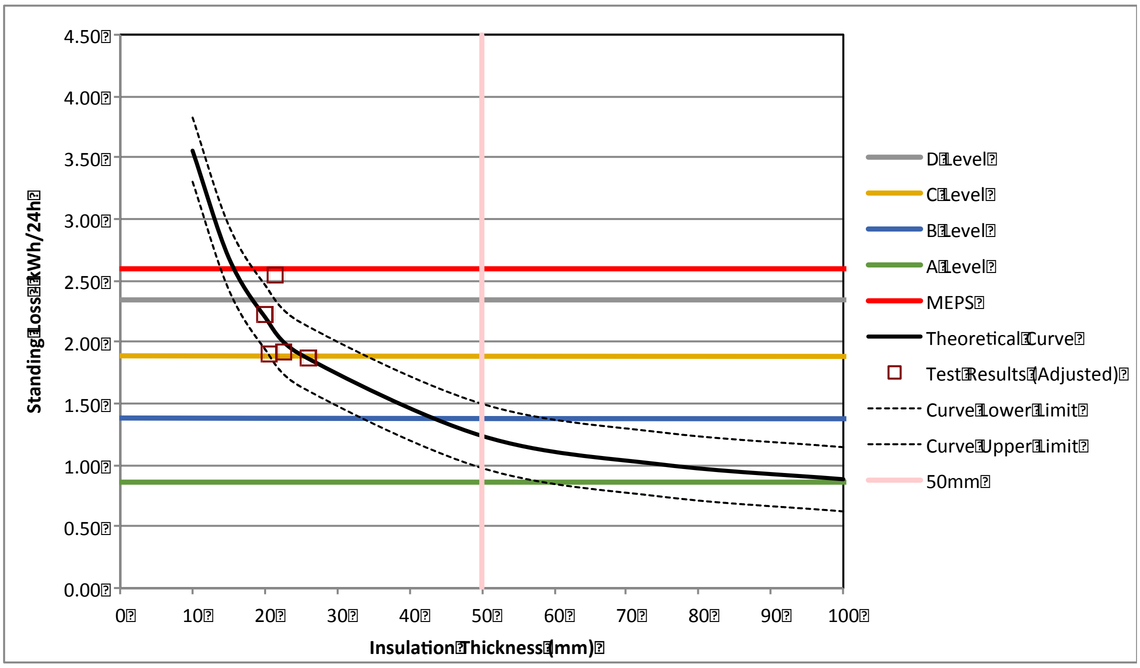

Figure 56: Theoretical curve relating to standby losses

Table 21: Label levels according to SANS formula

Efficiency Level	Formula	S (V=150l)
A	$S \leq 5 + 4.16V^{0.4}$	0.86
B	$S \leq 11 + 6.25V^{0.4}$	1.38
C	$S \leq 16.66 + 8.33V^{0.4}$	1.88
D	$S \leq 21 + 10.33V^{0.4}$	2.34
E	$S \leq 26 + 13.66V^{0.4}$	3.06
F	$S \leq 31 + 16.66V^{0.4}$	3.71
G	$S > 31 + 16.66V^{0.4}$	> 3.71
MEPS	SANS 151 Table 2	2.59

Test results are corrected for temperature using the ‘alternative’ method. Using this method, all of the geysers save one meet the MEPS level. We emphasize that the laboratory tests performed were intended to provide insight about the relative insulation level and performance of geysers in the South African market, *not* to determine compliance. Furthermore, while efforts were made to configure the test set up as closely as possible to the specifications of SANS 151, the laboratory, which was built for research purposes, was not accredited for this purpose.

Measured insulation thickness from the tear down analysis, taken to be the simple average between top and bottom measurements in the horizontal configuration range between 20 and 26mm. According to Table 21, the best performing model lies in the 'C' range, three models are in the 'D' range and the poorest performing model lies in the 'E' range.

A theoretical curve relating insulation thickness to standing losses was created using the determination of $q_{tot}(t)$ shown in Table 17. In addition to these losses, however, we determined the 'bypass losses' by comparing the expected value of q_{tot} at SANS 151 temperatures to the adjusted test result and taking the difference. The result is that bypass losses range from 0.14 to 0.70 kWh/24h and have a mean value of 0.36 kWh/24h and a standard deviation of 0.26 kWh/24h. The resulting curve is the sum of $q_{tot}(t)$ and the mean value of bypass losses. The dotted lines above and below this curve are one standard deviation above and below the mean, respectively.

We consider the particular scenario of increasing insulation thickness to 50mm, which is clarified with a vertical line in the graph. The intersection of this line lies in comfortably in the 'B' range. The lower limit approaches the 'A' level, while the upper limit slightly exceeds the 'C' limit. We draw the following conclusions:

- Test results are consistent with expectations given current regulations
- Most geysers on the market have only a moderate amount of insulation
- Test results are consistent with this level of insulation, but additional observable losses are significant, and with significant variation
- It is likely that by increasing insulation levels to 50mm or beyond, manufacturers could feasibly and cost-effectively raise geysers to the B level
- Additional opportunities are likely to exist in reducing losses through the reduction of 'bypass' losses.

The final point is crucial. The variation in test results for similar levels of insulation and the significant implied 'bypass losses' are supported by the teardown analysis and infrared photography showing the clear evidence of heat leakage. In addition, the teardown analysis observed cases in which the thickness of insulation was far from uniform around the geyser tank. It is unclear what the impact of uniformity on insulation is on performance. While this study made some observations on this aspect, more research is needed to draw meaningful conclusions. The possibility of tightening these loss areas gives manufacturers another degree of freedom with which to improve performance. This may be potentially less costly than increasing insulation to 50mm, or it may allow to increase performance even beyond the 'B' level.

Finally, we consider increasing insulation before the 50mm level. While this is possible in principle, and is demonstrably cost effective from a materials-cost point of view, manufacturers have indicated that technical issues limit the feasibility of greatly exceeding 50mm. To the degree that this can be done, however, further insulation may provide a 'performance buffer' for manufacturers.

6 Appendices

6.1 Appendix 1: Values used for calculations (150 L Geyser)

item	value	units	notes
insulation			
price	35	R/kg	email from Theo Covary 18 June 2014
density	32	kg/m^3	molded density for polyurethane foam with HCFC-141b blowing agent
insulation price	1,120	R/m^3	
steel			email from Theo Covary 18 June 2014
price	330.56	R/Sheet	GALVANISED – CQ, ISQ.230 - Z275 SPELTER SHEETS
area	3.00125	m^2	NOMINAL SIZE MILLIMETRES, 2450 x 1225 x 0.8
steel price	110.14	R/m^2	
discount rate	10%	per year	assumed
lifetime	10	years	based on discussions with FOGI
electricity price	1.52	R/kWh	average of Johannesburg (R1.15) and Cape Town (R1.52) with 14% VAT
annual electricity price increase	12.00	%	based on NERSA approvals of 8% per year for 5 years
Mark-up	1.35		average incremental mark-up from manufacturer to retail for electric storage water heaters in replacement and new home applications