An Investigation into the Functionality and Efficiency of an Electric Pressure Cooker Bought in Kenya Intended for the Domestic Market: 'Sayona PPS 6 litre'.

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Introduction

The ‘Sayona PPS 6 litre’ EPC was bought in Kenya, is also available in Nigeria, Pakistan and possibly elsewhere, but is not available in the UK via Amazon or elsewhere.

It is a conventional EPC having a mechanical, clockwork timer switch plus thermostatic control switches and a range of safety features similar to those found in other cookers (see: Table 1).

In the context of the MECS programme, the Sayona EPC is known to be available in-country in the global south and offers a simple control interface which is not dominated by pre-programmed menus oriented towards western foods. It is similar in the latter respect to the Tower TI6004.

This report examines and describes the cooker in detail for functionality, safety assurance, operational and thermodynamic behaviour, temperatures achieved and energy consumption. The tests comprise water boiling tests (WBT) of minimum, maximum and interleaving cooking loads. Water is used as a highly accurate and repeatable cooking load and, simply, many foods contain a high proportion of water.

The tests are repeated at lower supply voltages to emulate lower power appliances, to determine whether cooking is feasible at lower power, measure any delay or lengthening of cooking duration and assess any effect on energy consumption. Lower power appliances are likely to be a necessity to protect the prototype system battery both for cycle life and delivered energy per cycle at the present state of battery technology.

1. Summary

Safety

1 minor concern – the cooker is always ‘on’ when power is connected. This might lead to heating the hotplate for example after the pan is removed and when the cooker is unattended. However, the temperatures would be well regulated via the ‘keep-warm’ circuitry, the hotplate is deeply covered plus there is one further thermal fuse protection device.

1 major concern, common to several EPC’s examined – the lid partially comprises exposed metal surfaces. These lid surfaces reach temperatures exceeding 100°C during pressurised cooking and pose a considerable risk to cause burns.

Functionality

Capability/complexity = 5/1. Basic, mechanically timed electric pressure cooker, without unnecessary elaboration, well-matched to an emerging market. Claimed 6 litre capacity measures 5.8 litres to brim of pan; useful capacity 3-4 litres for food, up to 5 litres for water heating.

Longevity

Substantial construction, strong inner pan, universal silicone sealing ring. Three switches regularly directly control main power supply; contact life will depend entirely on switch quality. Power connection via the IEC plug and socket may become a source of failure; these could be changed in-country.

Inclusion

From a naive assessment; facile controls are suitable for most ages and abilities; not excessively heavy, stable; but lack of on-off rocker switch may be limiting. Conventional ‘stainless steel/black plastic’ appearance may not best suit users with visual impairments.

Cleaning

Easy; pan and splash guard can be removed.

Performance

The data gathered is summarised in Figures 1, 2 and 3.

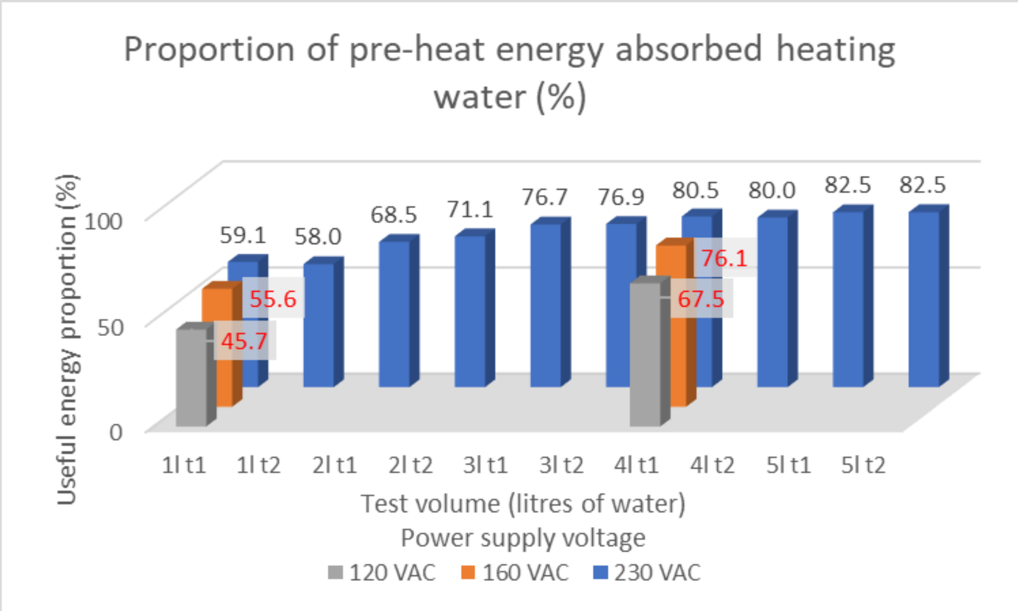


Figure 1.

Before the cooking phase begins, the cooker and load are pre-heated for a period of time which depends on the size of the load. The load in these tests were a range of volumes of water, repeated for test 1, test 2, etc, and at different supply voltages.

Figure 1 demonstrates that, as the load size increases, more of the pre-heating energy input is absorbed by the water compared to that absorbed by the cooker parasitic thermal mass; the cooker is more energy efficient when nearly full.

As the supply voltage is reduced, to represent a lower power appliance, the pre-heating duration increases. During this prolonged period there is more time for heat to radiate away from the cooker, as well as more time for more parts of the cooker to rise to higher temperatures, resulting in the proportion of energy usefully absorbed by the water reducing; i.e. more energy is wasted.

At 160VAC supply, approximately half-power, the increase in energy input is c.6%; at 120VAC, approximately quarter-power, the increase is 20-25%. At both voltages the cooker achieved pressurised cooking. However, for 4 litres at 120VAC, the pre-heat duration was almost 2.5 hours.

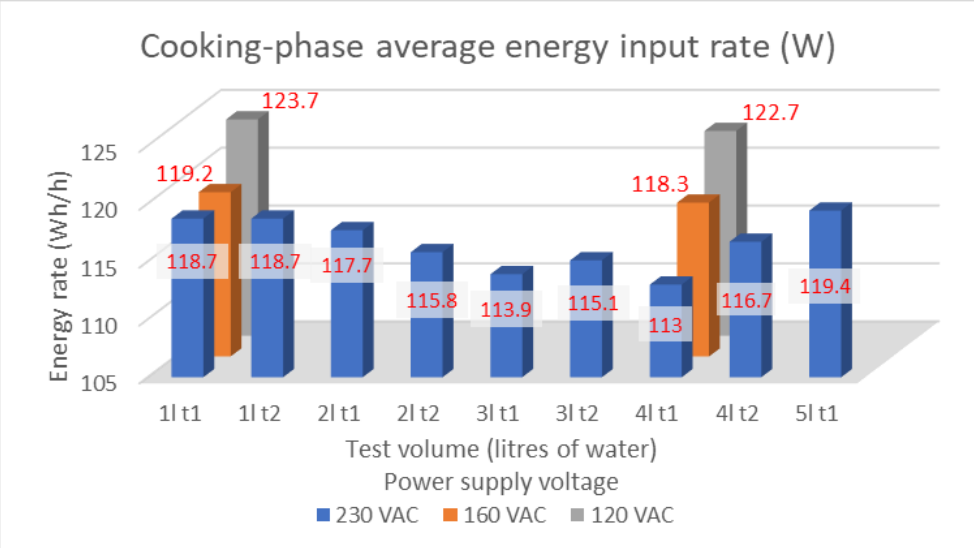


Figure 2.

After the pre-heating phase has raised the cooker and load to cooking temperature, power is pulsed or cycled during cooking, to maintain cooking temperature. The full-power pulses are averaged across the pulse duration plus the subsequent dwell period to calculate average energy input rate as displayed in Figure 2.

These data are notably consistent but the trend that is partly apparent might be explained as follows: for small loads, the pre-heat phase is as short as 10 minutes such that the cooker thermal mass lags the load temperatures. Consequently, the cooker is still absorbing energy as it continues to heat up during the cooking phase. For large loads, the pre-heat phase is longer so that more of the cooker is already up to higher temperatures and this radiates more energy away which needs to be replenished by a higher average energy input rate. The medium loads balance these two effects.

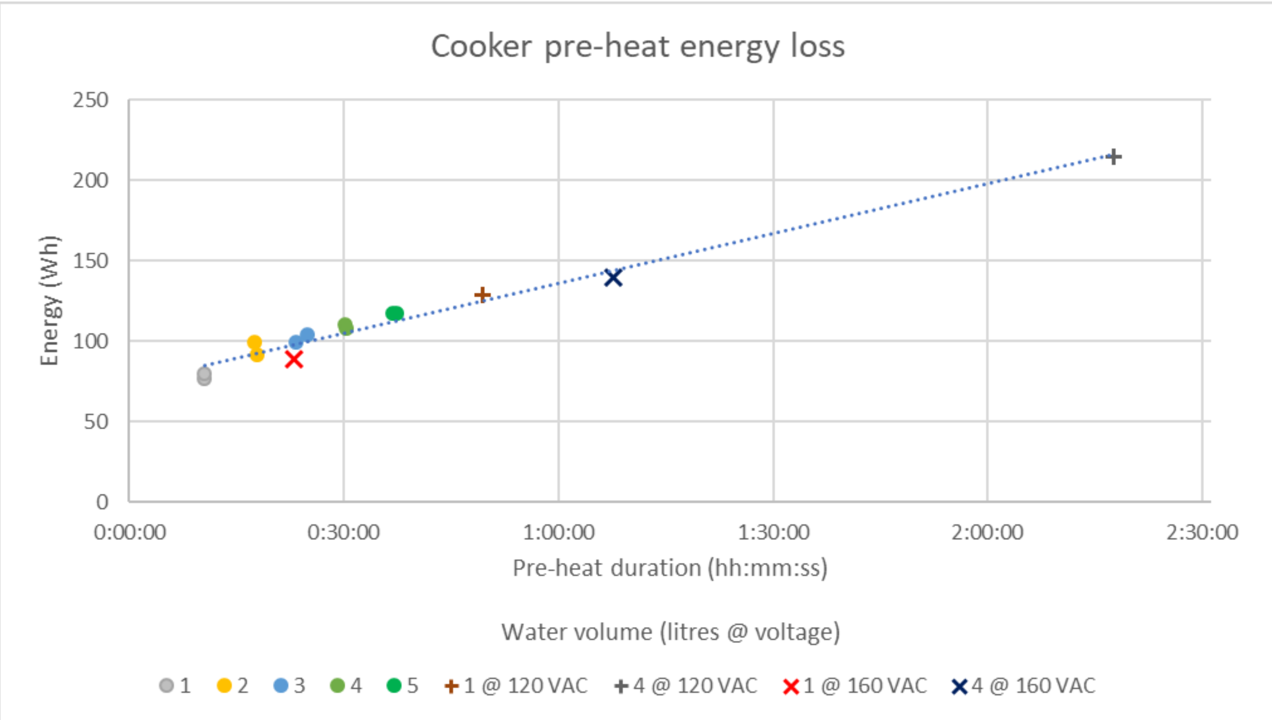


Figure 3.

Figure 3 confirms that the variable that fundamentally determines how much energy is wasted before cooking begins is pre-heat duration. Clearly this is related to load size (volume of water) but note the data specifically exclude the energy absorbed to heat the load.

2. Functions and Features

The Sayona EPC is designed for 230 VAC electrical supply and starts to heat as soon as it is connected, regardless of the timer position. However, this will only continue for a few minutes before the ‘keep-warm’ circuitry interrupts the power; rotating the timer control closes the timer switch which bypasses the keep-warm circuit and maintains power supply until the pre-set thermostatic switch ‘opening’ temperature is reached. The power is then cycled to maintain the thermostat between its upper and lower (opening and closing) set-point temperatures. This continues until the timer runs down to zero when the timer switch isolates the cooking circuit. Heating control is then via the keep-warm circuit which has lower set-point temperatures. This continues until the power supply is disconnected. Figure 4 Circuit Diagram shows these functions graphically.

Apart from the rotary timer, the Sayona EPC exterior features two lights marked ‘Heat’ and ‘Warm’ and a simple cooking guide sticker.

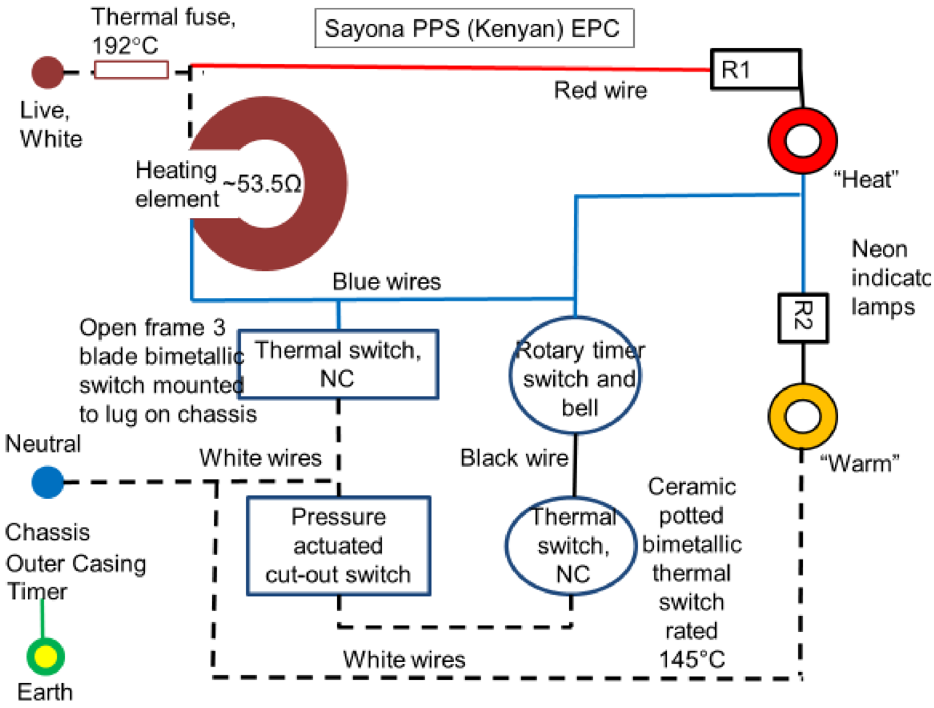


Figure 4 Circuit diagram.

Figure 5 General external and internal views (cooking pan removed).

Figure 6 Lid upper and lower views; splash guard/seal carrier is removed from central mounting stud.

The cooker lid features a removable splash guard to prevent food ingress to the steam vent and interlock vents. The guard is removable to allow cleaning via a central mounting stud and silicone washer.

Figure 7 Cooking pan and utensils provided; internal markings.

Figure 8 Cooking instruction label; rotary clockwork timer control knob and indicator lights; clockwork timer and bell.

3. Safety Features

Table 1 compares the Sayona PPS EPC with others previously examined for mechanical and electrical safety controls.

Briefly: The steam vent is a passive control to limit maximum gauge pressure rise within the pressure vessel. The pressure vessel is formed by the cooking pan and the cooker lid, sealed via a silicone ring. Pressure is limited via a mass bearing on a small orifice roughly 3mm diameter. The maximum static internal pressure sets the temperature, depending on local atmospheric pressure, at which steam will begin to escape. The dynamic steam flow rate at which the vent might be over-whelmed, leading to an uncontrolled back-pressure build-up and potentially catastrophic pressure vessel failure, has not been calculated.

The pressure activated lid interlock comprises a valve which rises when steam is escaping dynamically. The internal heightened pressure will then keep the valve closed. In the closed position, a lever is locked which prevents the lid from rotating and being removed.

The ceramic-encased thermostatic switch is a standard component, in this case mounted to the chassis, protruding up towards the base of the hot-plate and heating element. This operates on the power supply wire directly. The primary cooking temperature range is regulated by this switch.

One notable feature different from others is the absence of a temperature sensor mounted to a ‘sprung button’ in the centre of the hot plate. A second bimetallic thermostat of ‘open-frame’ style is mounted beneath the chassis to a lug or spigot protruding through the chassis, which is part of the heating element hot-plate encapsulation. This thermostat regulates the ‘keep-warm’ mode temperature range.

The pressure actuated power switch operates as follows. As pressure rises within the pressure vessel, the cooking pan and hotplate move down relative to chassis, away from the lid. This is resisted via a spring formed by a tempered steel disc. A lug protrudes down from the hot plate heating element encapsulation, through the chassis and bears on a mechanical switch operating on the main power supply wire. The switch is of open-frame design very similar to the bimetallic thermostatic switch, but it is unclear whether it performs both functions.

The thermal fuse is a standard component and operates on the power supply line connection and is mounted to a chassis leg inside a fibreglass insulating sleeve. It is not clear if this is resettable but the rated temperature, 192°C, is considerably above any recorded temperature, so it must be considered the final fail-safe feature.

As with other EPC's examined, the bare metallic lid routinely reaches temperatures above 110°C which constitutes a considerable safety hazard. See Figure 12 Thermographic image.

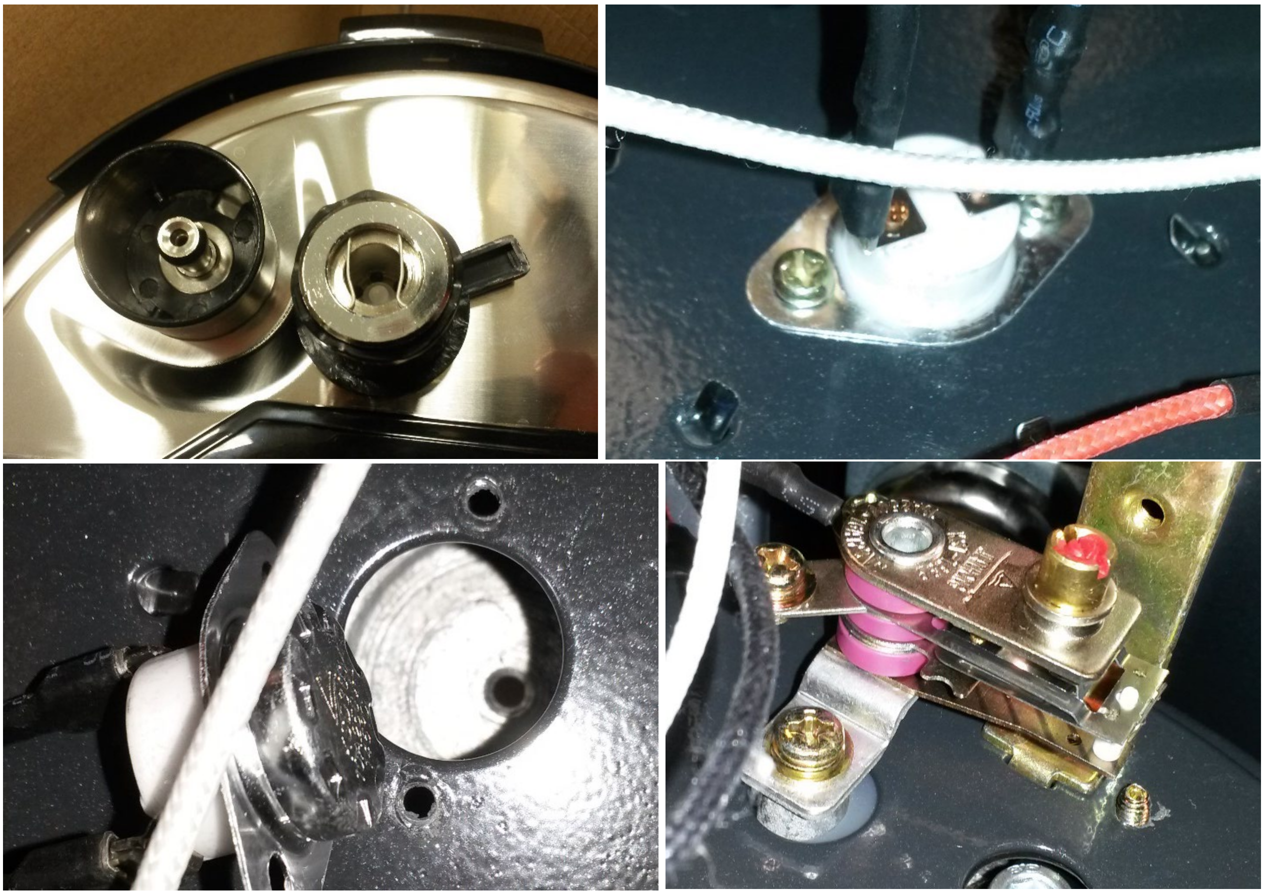


Figure 9 Steam vent orifice and weight; ceramic thermostat in position; removed exposing base of hotplate; bimetallic open-frame thermostatic switch mounted to spigot from hot-plate encapsulation protruding through chassis.

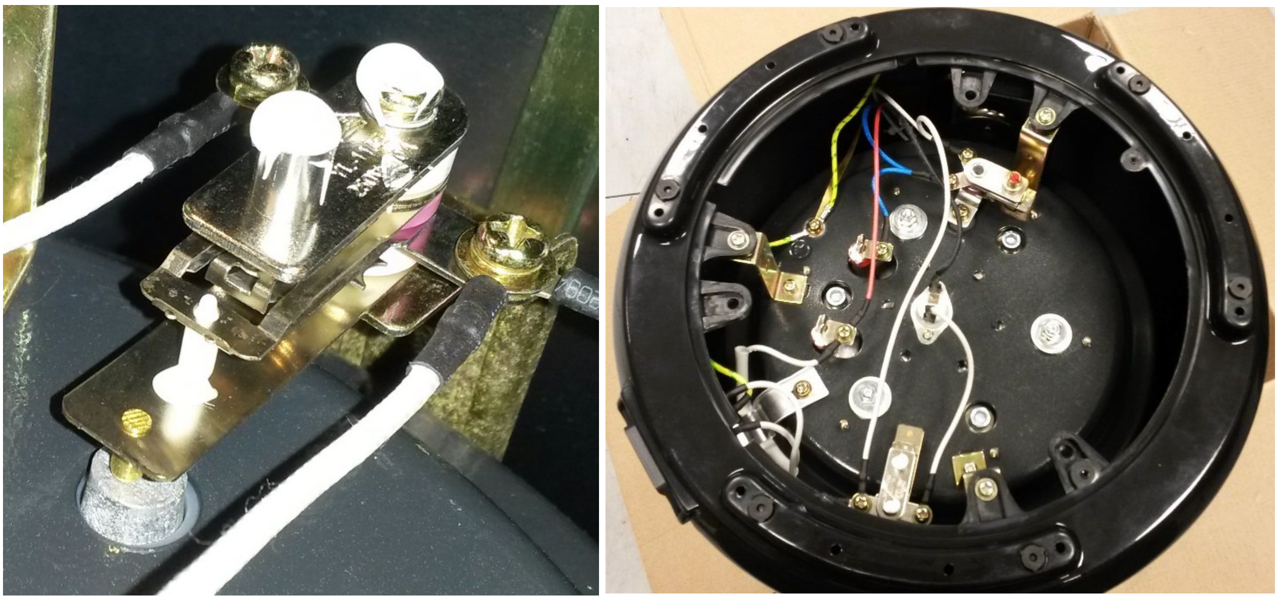


Figure 10 Pressure actuated cut-out switch showing operating boss from hot-plate encapsulation protruding through chassis; general view of cooker beneath chassis with base cover removed.

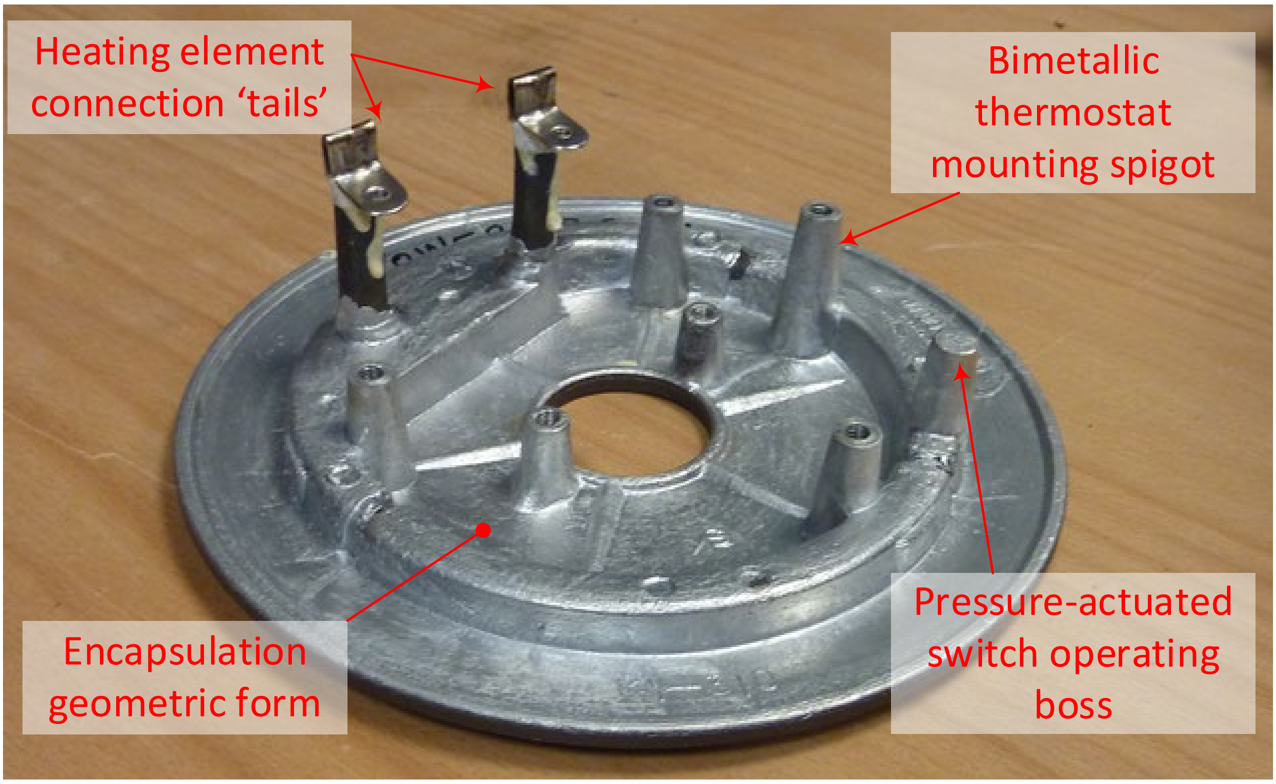


Figure 11 Underside view of hot-plate encapsulation showing pressure die-cast geometric form and salient features.

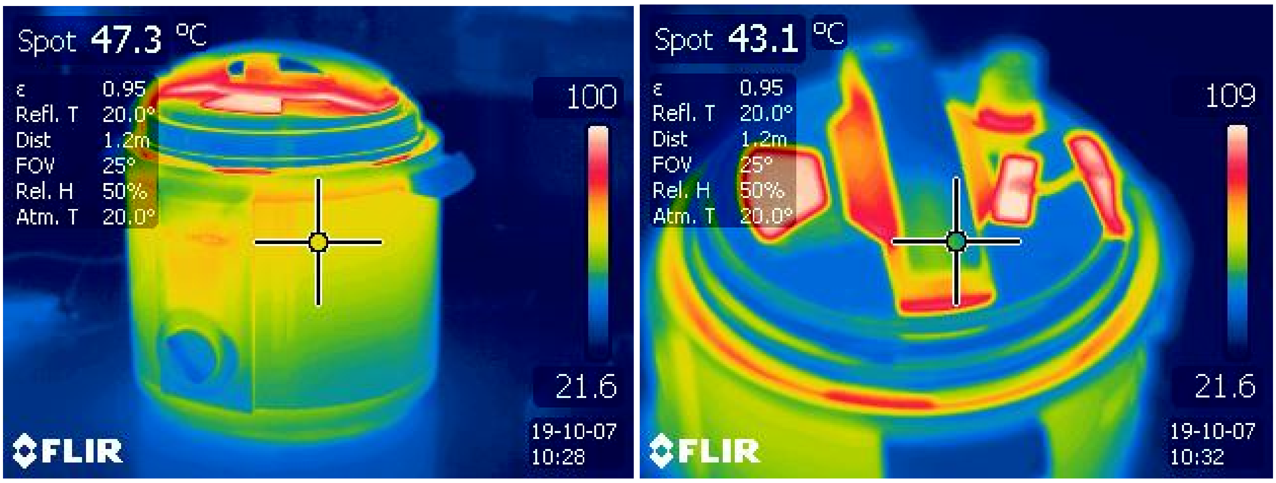


Figure 12 Thermographic images of the cooker. Note the emissivity is not correctly set to properly calibrate these images.

4. Examination of the Sayona PPS EPC

The Sayona EPC appears well made, not flimsy. Outer shell is notably thin brushed stainless steel, possibly having a lacquer coating to prevent marking. Plastic parts look brittle and uneven, similar to some others. Suspected poor thermal stability in manufacturing, possibly cooled too rapidly from the mould, but not insubstantial.

Heating element measures 53.5 Ω at c.20°C thus will consume .905 kW at 220 V or 1.075 kW at 240 V, the element temperature coefficient is unknown. Typical power logger figures were 1.1kW at 235V.

Capacity is claimed 6 litres on the carton. Pan is marked up to 10 cups and 1/5, 2/5 up to 4/5. 1/5 measures 1 litre, 2/5 measures 1.1 litres. Rim equates to 5.8 litres. Useful food capacity 3 - 4 litres.

Basic mechanical clockwork timer, 0 – 90 mins, switches power on and commences count-down once turned but note the cooker is also switched on when the plug is connected to a live power socket via the 'keep-warm' circuit loop. Cook and Warm indicator lamps.

Lid turns clockwise to unlock, similar to BES. Has a Made in China manufacturer's sticker.

No instruction book – simple table sticker on side near timer provides a few cooking times.

Pan appears to be grit blasted externally, powder coated internally, claimed 'non-sticked' (sic) coating applied. The inner coating is notably hydrophobic. Pan is unusually close fit in chassis – approx. 2 mm radial gap.

Unlike previous cookers examined, there is no sprung button! Thermal switch (ceramic encased thermostat) rated 145°C mounted centrally beneath chassis, protruding up toward hot plate, approx. 2.8cm gap overall.

Two bimetallic switches: temperature-only (thermostat) mounted to spigot from hot plate encapsulation carries main current; temperature rating unknown. Pressure operated switch mounted to chassis actuated by boss from hot plate encapsulation. Spring mechanism is via tempered steel disc as found in other EPCs.

One thermal fuse mounted to chassis side in silicone sleeve. Temperature marking 192°C.

Timer marked: AC 125V 15A AC 250V 15A E185572 Hangzou Guanzuan Electrical Appliances Ltd – 'Ltd' is not an official Chinese company status. Also displays a US registered trademark symbol.

Steam vent weight: 94.0g, orifice 3.36mm; max boiling point temperature 120.6°C.

	Mechanical				Electrical					
	Weighted pressure vent in lid	Pressure activated lid interlock	Other pressure operated sprung vent	Micro-switch	Ceramic encased thermostatic switch in hotplate	NTC thermistor sensor in sprung button	Open-frame bi-metal thermostatic switch on chassis	Combined* thermal/ pressure switch (*presumed)	Thermal fuse	Temperature probe (thermo-couple)
BES 12V Chinese domestic	Y	Y			Fixed to hotplate, 140°C					
Sayona PPS 6l	Y	Y			Y (marked 145°C, see text)		Y (mounted to hot plate lug)	Y (power wires)	192°C	
Tower TI6004	Y	Y			Y (In sprung button)		Y (power wires)	Y (power wires)	192°C	
Tower TI6005	Y	Y				Y (no earth wire)		Y (sensor wires)	192°C	
Amazon Basics	Y	Y		Y	Y (In sprung button)	Y		Y (sensor wires)	142°C	Y (in lid via contactless)
Instant Pot Duo	Y	Y		Y	Y (In sprung button)	Y		Y (sensor wires)	142°C	Y (in lid via contactless)
Aobosi YBW60-100Q1	Y	Y				Y		Y (sensor wires)	130°C (not on chassis)	
TEFAL EPC06	Y	Y	Y	Y (in lid)		Y			216°C x2	Y (in lid)
SAGE BPR700	Y	Y	Y	Y (in lid)		Y			192°C	Y (in lid + 1 other, a thermal fuse?)

Table 1 Safety features of electric pressure cookers. (Source: "A Comparison of Functions and Safety Features on Electric Pressure Cookers", Barton, Monk and Blanchard, 2019. White paper accessible from www.mecs.org.uk) Extended to include Sayona data.

5. Operation at 230 VAC

There are four phases of operation. These can be seen in Figure 13:

i) Pre-heat. When the rotary timer is initially rotated, power is applied continuously in order to warm the cooking load up to cooking temperature.

ii) Cooking. Power is cycled or pulsed to maintain the cooking load at a pre-set desired temperature, controlled via the pre-set thermostat temperature limits.

iii) Cooling. When the timer runs down to 0, the power is interrupted and the cooker and load cool down.

iv) Keep-warm. When the cooking load and cooker cool sufficiently far, the keep-warm thermostatic switch closes to maintain the cooking load at a pre-set desired temperature which is below the cooking temperature. This will continue until the power supply is removed when the cooker and load will cool back to the environmental temperature.

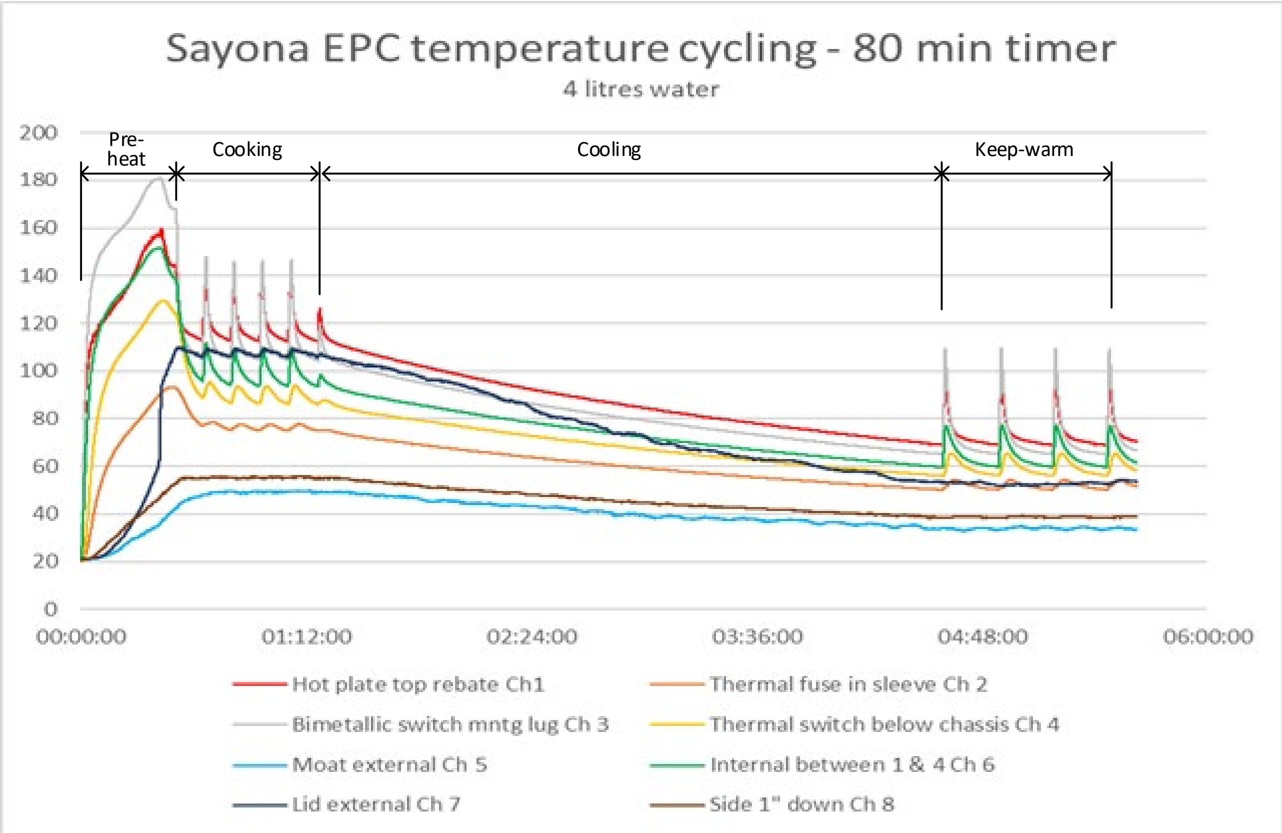


Figure 13 Typical temperature plot showing power applied for 80 minutes including pre-heat and cooking, followed by several hours for the cooker to cool until the 'keep-warm' phase commences.

<u>Keep warm.</u>

Cooker is 'on' when power is connected, regardless of timer position: current flows from Line through heating element, as well as Red lamp marked 'Heat', then via bimetallic thermostat switch to Neutral. (Orange lamp is shorted by bimetallic switch.) When bimetallic switch reaches set temperature and opens, red lamp extinguishes and orange lamp marked 'Warm' illuminates. In fact, in this state, the cooker is overall cooling down, excepting any thermal lags. Figure 13 Ch 3 shows this temperature profile.

During the keep-warm phase, the power will cycle controlled by the temperature band of the bimetallic switch, the grey line in Figure 8. The temperature band is approximately 40°C. Tests were conducted to determine if the cooker would rise to cooking temperature in this mode by leaving the timer at ‘0’; a typical test is depicted in Figure 13.

Although the cooker reached stable cyclic temperatures at the measured locations, the pressure interlock did not engage. Toward the latter part of the test, the duty cycle had fallen to c. 9%. Thus, the average energy input was between 40 - 60 W, which appeared too low to raise the load to atmospheric steam point (i.e. 100°C). The water is assumed to be slightly below the top-plate rebate temperature (Ch.1), c. 62°C.

Thermocouples were attached using Kapton™ tape with the junction ‘potted’ in thermal paste. The temperatures can therefore be regarded as representing the adjacent surface temperature with effectively zero Rso loss (the surface boundary layer non-linear heat flow resistance effect).

The Sayona EPC has a feature not previously observed which offers a different insight into the heat flows and system behaviour. This is that the open-frame bimetallic thermostatic switch is mounted directly to a spigot of the hot plate encapsulation (rather than on the chassis as seen previously). The bimetallic switch mounting lug thermocouple is cycling between 58°C and 100°C approximately (keep warm mode). The thermocouple is approximately 1cm from the bimetallic blade so it is assumed there is some thermal lag between the two positions, since the heat source is the hot plate while the heat sink is the air beneath the chassis. The initial cycle is approximately 3 mins, presumably because the lug heats quickly but also loses heat to the air beneath the chassis (as well as the hotplate being cooled by the water) equally quickly whilst the air remains cool. A different ambient temperature would have an effect on this, slowing the heating rate by extending the cooling part of the cycle. This is essentially the effect visible in the latter cycles’ extending cooling decay curves.

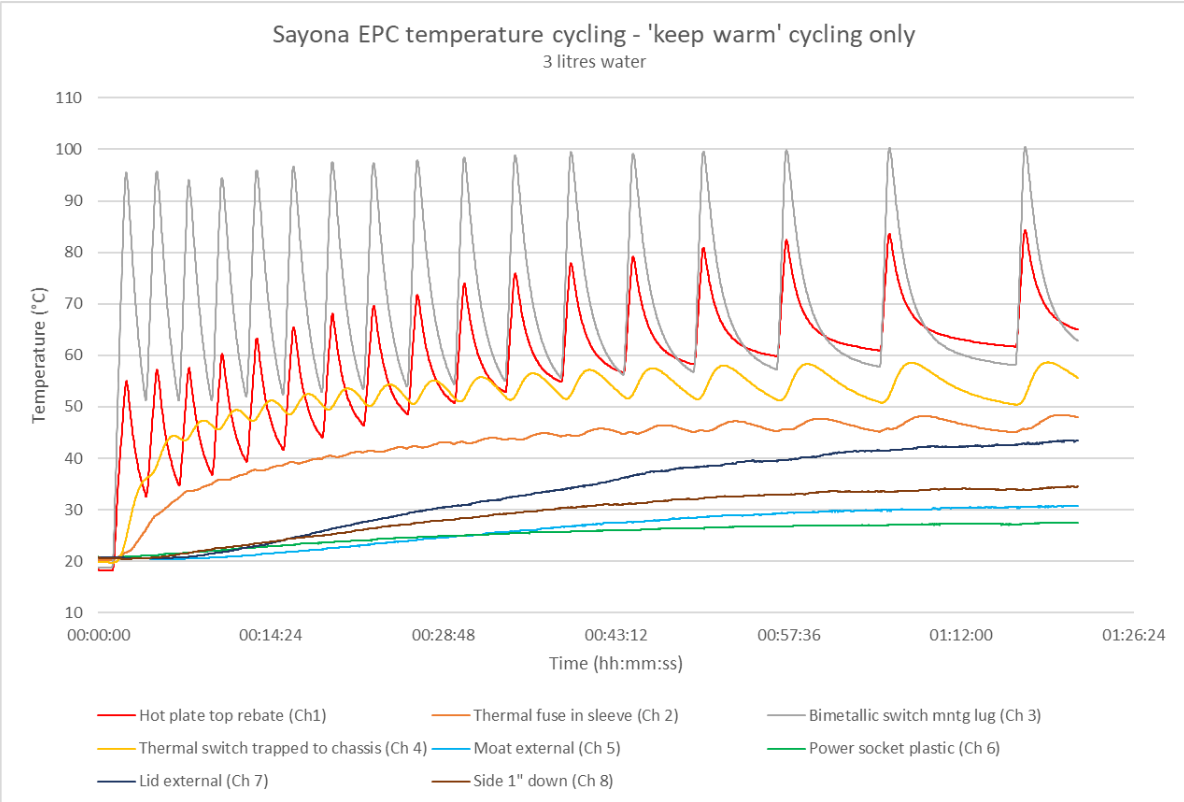


Figure 14 Temperature plot for heating using keep-warm circuit only; no pre-heat phase. During this test, Ch6 thermocouple was attached to the power socket internally but the socket remained cool so was not tested in subsequent tests.

The hot-plate upper-surface rebate is as close to water temperature as is likely to be possible to measure without piercing the pressure vessel in order to contact the water directly; even then, measurement would be necessary in one or more positions to account for thermal currents during initial heating. The thermal mass of the water, being generally cooler than the hot plate, stabilises the rebate temperature. Thus the hot plate lug is hotter during heating but cools faster when power is off, particularly near the end of the test when the whole is reaching balance.

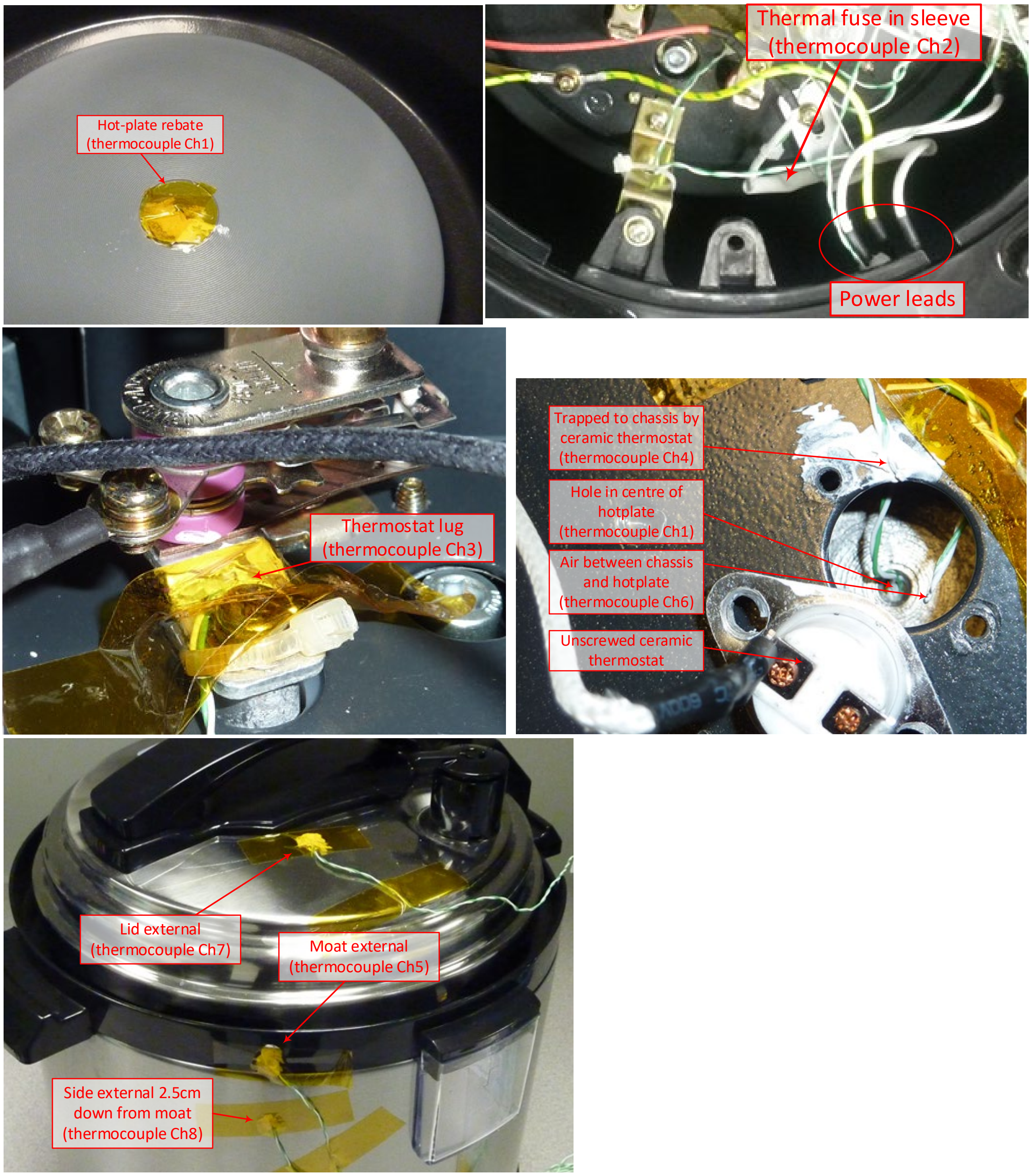


Figure 15 Thermocouple positions.

Cooking.

Rotating the timer switch bypasses the keep-warm bimetallic switch and current flows through red lamp and heating element via timer, ceramic thermostat, pressure actuated switch. The ceramic thermostat is marked 145°C which is considerably above the temperatures reached in Figure 9 and it appears from the graphs to cycle around 95 +/- 5°C. It is unusual to use a ceramic encased thermostat because cycle life can be as low as 6000 cycles. Assuming 6 cycles per meal x 3 meals per day would create potential failure within 1 year. It is possible the reason for the choice is the much narrower set-point temperature band and that the mid-point temperature to achieve the desired pressure-cooking temperature was determined empirically.

It will be necessary to perform a mechanical force test to determine the pressure switch operating point.

When the timer reaches 0, control returns to the keep-warm circuit. Eventually, temperatures fall sufficiently that the open-frame bimetallic thermostatic switch closes and the cooker enters a keep warm cycle that matches the latter cycles of Figure 10. Figure 9 is the overall progress of an 80-minute cooking cycle followed by several hours of cooling down followed by 'keep warm' cycling at lower temperatures. Figure 12 is the latter phase of this sequence in expanded time detail. Figure 13 is the initial heating phase in expanded time detail.

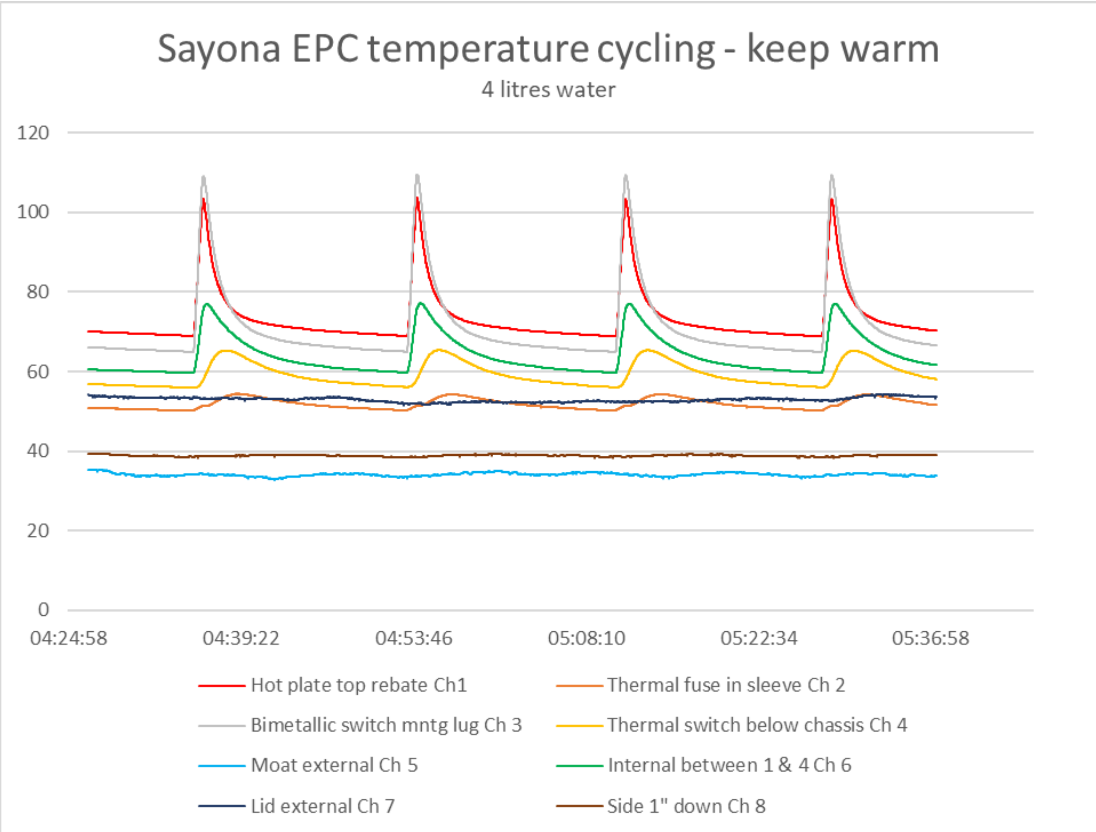


Figure 16 Post-cooling keep-warm temperature profiles.

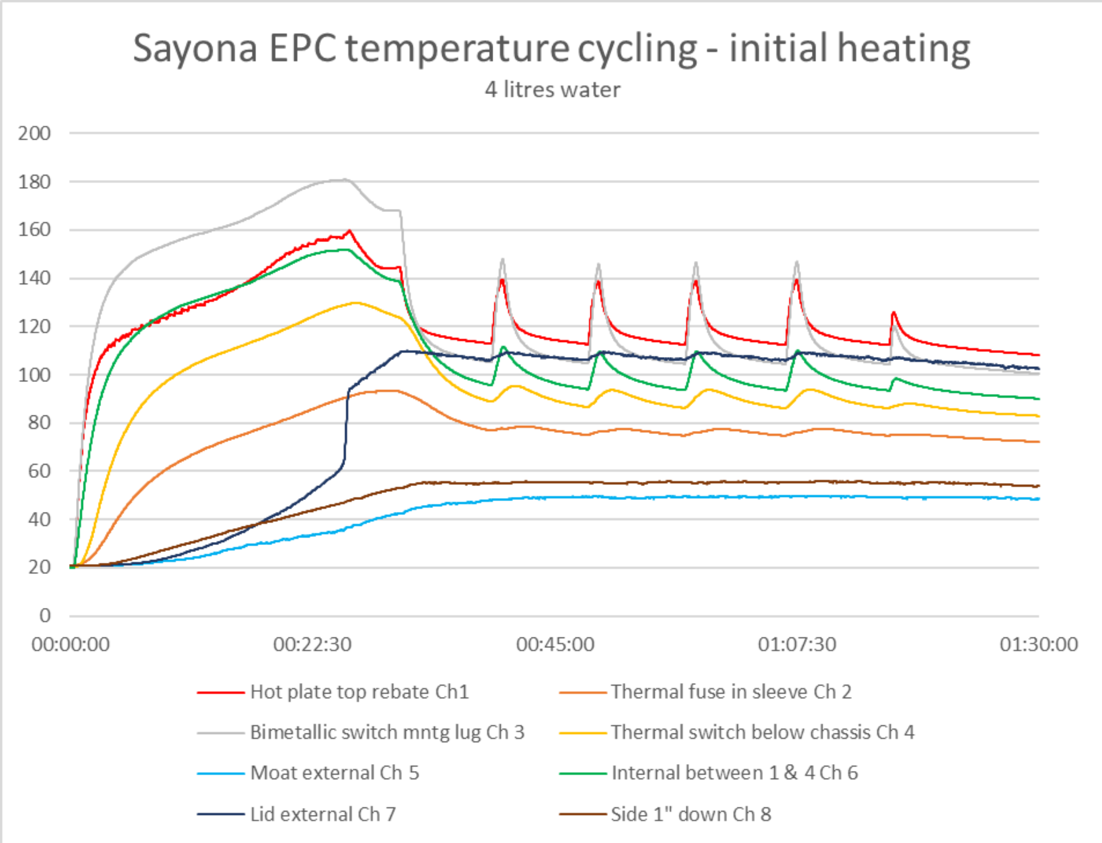


Figure 17 Pre-heat and cooking phase temperature profiles.

<u>Temperature Analysis</u>

A number of events are apparent from the temperature logs which have not been observed during previous EPC testing. Figure 17 illustrates the following points. During the pre-heat and cooking phases, power is regulated by the ceramic encase thermal switch Ch4.

Power is applied at 15s. There is a 10s lag before temperatures begin to react. A switch 'click' is heard at 125s as Ch3 moves through 100°C, which is presumably the bimetallic switch opening. This aligns with the upper cycling temperature during 'keep-warm' cycling, accepting there is some thermal over-shoot in the recorded temperatures.

After the initial temperature rise surge on the lug, rebate and internal air temp (Ch3, Ch1, Ch6), a steady state rise rate is observed from around 400s, later for the air. At this point, the air rises above the chassis temperature (the air Ch6 is between the hotplate lower surface and chassis upper surface).

At around 700s, an inflexion in the rise rate of the lug and rebate is observed and the rate accelerates. This is surmised to be due to increasing thermal movement within the water although no other thermocouple is positioned to corroborate this.

At around 860s, there is a similar inflexion in the lid external temperature Ch7. This is surmised to be due to increasing amounts of hot water vapour rising above the splash guard, contacting the lid under-surface, and exiting via the interlock valve.

At around 1170s, for the lug and rebate (Ch3, Ch1), another inflexion reverses the rise rate increase for the lug and rebate. The air also reflexes at 1300s (Ch6). It is surmised the increasing thermal activity of the water is increasing the effectiveness of heat transfer away from the hotplate.

At 1520s – 1560s, the lug, rebate and air reach peak temperatures. At the same time, the lid rapidly increases then equally rapidly ceases increasing rapidly, returning to the preceding rise rate. It is believed this is when the water starts to boil vigorously next to the hotplate. At 1523s, steam begins to vent rapidly from the interlock valve until at 1534, the lock lifts and closes the vent.

At 1560s, the lid has reached 95°C. The vigorous boiling will transfer heat away from the hot plate, hence the chassis, lug and air, more effectively, so these parameters fall, but to the lid so the lid continues to rise. The cooker is now pressuring.

At 1760s the lug and rebate stabilise but the air continues to drop despite being slightly below the chassis and rebate.

According to the power logger data, power is switched off at 1835s. There is an immediate dip in the temperatures and the lug and rebate both fall rapidly as power is removed and heat is transferred into the water. The lug falls further and faster than the rebate; the rebate is stabilised by the water thermal-mass, the lug is surrounded by air beneath the chassis. The rebate cycles between 113°C and 138°C, presumably somewhat above and slightly below local water temperature. The lid continues to rise to 109.5°C at 1855s, presumably slightly below max water temperature.

According to the power logger data, power is resumed at 2345s, and temperature cycling begins at 2350s.

The ceramic thermostat protruding through the chassis into the air remains below the lug, rebate and air temps at all times, although this is measured at the chassis/thermostat metal can interface.

The moat (Ch5) is at a lower temperature than the outer side 1” below the moat (Ch8): this is the reverse of previous observations and may be due to the smaller air gap between pan and chassis around the sides.

Energy Analysis.

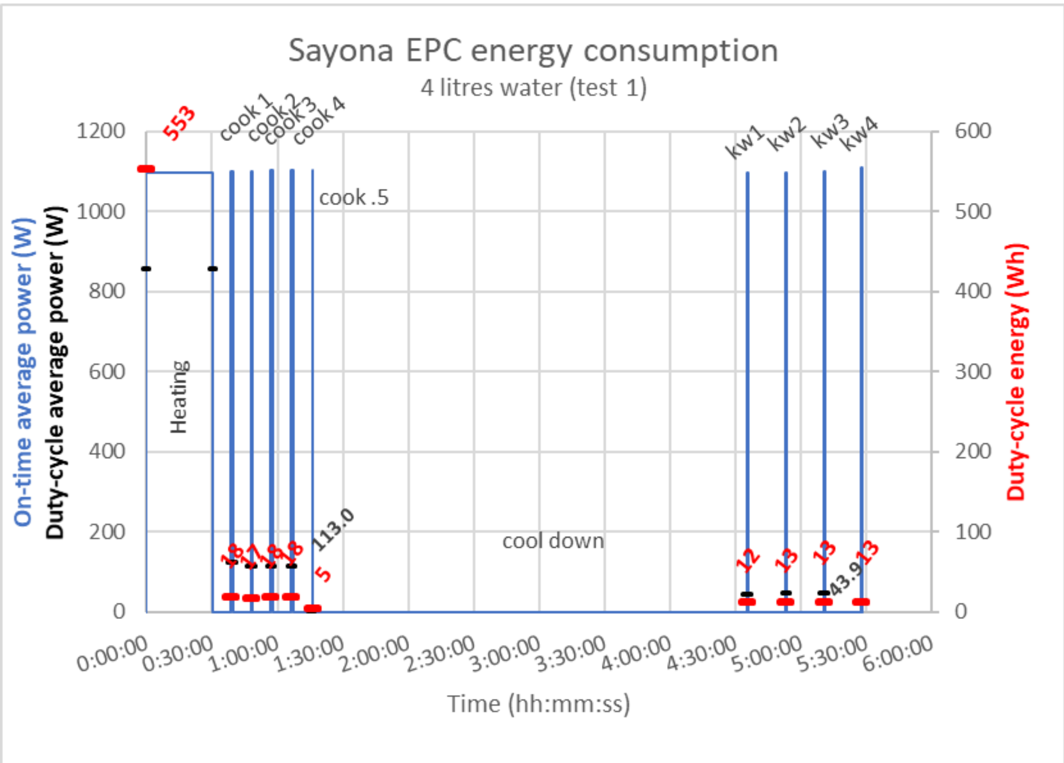


Figure 18. Power and energy consumption profiles. (The 5th cooking cycle was interrupted by the timer switch reaching zero.)

A 40-minute cooking cycle, typical of previous EPC tests, is always preceded by a period of heating to raise the cooking load and cooker to pressurised-cooking temperature (see CREST white papers at www.mecs.org.uk for a comparison of these cookers' performances). However, the previous 6 EPCs were bought from a Western marketplace and mostly incorporate integrated circuit power-control and thermocouple temperature sensors. From the test data, these appear to start to modulate power as the load approaches cooking temperature. It is assumed this takes advantage of the food beginning to cook at temperatures below maximum, in order to shorten the overall cooking duration. The result is that it is not clear when the designated cooking period begins and thus not obvious how much energy should be assigned to the pre-heating period. This is discussed further in the white paper mentioned above.

In contrast, the Sayona timer simply sets the on-off period; power modulation relies on the thermostats as described above. Consequently, it is trivial to identify the pre-heating period and calculate the cooking-period power requirements. Figure 18 illustrates the point. In many ways, this is closer to the behaviour of conventional cooking methods. A cook should quickly become familiar with the total amount of time to allow for a given quantity of food or water. Extending or shortening the time is a trivial task.

For the test data shown in Figure 18, as an example, the pre-heating period lasted 30 minutes and input 553 Wh of energy, of which 444 Wh or 80% is required to heat 4 litres of water from the measured 20°C start temperature to the assumed 115°C final temperature, midway between the measured lid external temperature and the calculated steam vent temperature, based on Cp = 4.21 kJ/kg/K approximated from the Cp values at the start and finish temperatures. The remaining energy is partially lost to the environment as radiated heat, partially absorbed by the cooker thermal mass and a small amount lost as steam before the interlock vent closes. These losses are consistent across load amounts and thus represent a greater parasitic proportion for smaller loads. The cooker is therefore most efficiently used when 'full'.

The subsequent energy input rate is approximately 113 W per hour during the cooking phase; this is calculated by dividing the power pulse energy input by the cycle time. Cycle time is calculated as the sum of power pulse duration plus dwell time. This input rate is required to replenish energy lost through radiation to the environment plus an insignificant amount that is absorbed by molecular changes during the cooking process. Total energy required for 40 minutes cooking of 4 litres of water would be (113 * 40/60) + 553 pre-heat energy = 624 Wh which would take 70 minutes overall.

The loss/replacement rate provides an interesting comparison with the energy input rate (40 - 60 W) observed during the earlier 'keep-warm' experiment and generally explains why the cooker could not raise the temperature above boiling point in this mode.

Table 2 contains equivalent data for heating different water quantities.

4. Operation at 120, 160 VAC

These tests assess whether the cooker will achieve pressurisation if connected to a lower voltage AC source and hence lower power input. 120V will deliver approximately one quarter of the rated power which the cooker would draw when connected to a conventional 230VAC mains supply. 120VAC represents a strong mains voltage in north America. The net result is a prolonged pre-heating period and different cyclic behaviour during cooking. The pre-heating period is prolonged >450% (i.e. 4.5 times longer) at 120 VAC; this is expected when applying a quarter of the usual power. The increase is 220-235% at 160 VAC and half power.

These prolonged heating periods cause additional radiative losses simply from the extended time period and the situation that, during the extended pre-heat, more of the cooker mass will rise to higher temperatures.

In contrast, the lower power during cooking causes lower peak temperatures, for example on thermocouple Ch3, which is a positive effect since radiative heat losses are proportional to source-sink temperature difference (first order approximation). The consequence can be seen in the temperatures of thermocouple Ch6 which measures the air temperature below the hot plate within the chassis. The implication of this air being cooler is that there have been lower radiative losses into this space. However, the external temperatures are not significantly affected; the lid external temperature is close to the saturated steam temperature of the cooking load (water) which appears to be the same as with other supply voltages. The moat (Ch5) and external surface (Ch8) temperatures are related to heat radiated and conducted from the top of the chassis which is closely connected to the lid and top of the cooking pan, which are predominantly affected by the water/steam temperatures.

Thus, overall, as well as the more than double and quadruple pre-heat times, there is a 20-25% energy penalty from applying 120VAC and 6% penalty from using 160VAC, incurred during the pre-heat phase; these are predicted to be off-set by the reduced drain on the battery loaded at 0.25kW and 0.5kW (effectively 0.25C and 0.5C) respectively, compared to when loaded at 1kW or 1C (this battery drain vs capacity effect has not been fully quantified at this time). The average cooking energy input rate is also slightly elevated at the lower voltages, possibly due to more of the cooker mass achieving raised temperatures during the prolonged pre-heating period, and hence radiating heat away more rapidly.

Volume of water (load) litres	Name	Start temp (°C)	Final temp (°C)	Water heating (theoretical) energy requirement (Wh)	Pre-heat phase, measured energy input (Wh)	Pre-heat duration (mm:ss)	Pre-heat phase input energy absorbed to heat water (%)	Water mass lost as steam (g)	Energy lost in steam (Wh)	Pre-heat phase energy loss (Wh)	Cooking phase, measured average energy input rate (W)	Pre-heat plus 40mins cooking, measured energy input sum (Wh)	Calc'd energy input sum, measured pre-heat + 40/60 * cooking average (Wh)	Purpose of test
1	80min test1	20	115	111.1	188.1	00:10:29	59.1	12.5	1.39	77.0	118.7	270.4	267.2	General performance
1	80min test2	21	115	109.9	189.5	00:10:31	58.0	12.5	1.38	79.6	118.7	273	268.6	General performance
2	80min test1	22.5	115	216.3	315.8	00:17:31	68.5	n/a	n/a	99.5	117.7	393.2	394.3	General performance
2	80min test2	18.4	115	225.9	317.6	00:17:53	71.1	n/a	n/a	91.7	115.8	392.7	394.8	General performance
2.7	80min	20.2	115	299.3	391.3	00:21:39	76.5	23	2.56	92.0	114.3	463.2	467.5	Compare to Mr D or other vacuum cooker
3	80min test1	17.7	115	341.4	445.1	00:24:54	76.7	n/a	n/a	103.7	113.9	538.5	521.0	General performance
3	80min test2	20.1	115	332.9	432.7	00:23:17	76.9	n/a	n/a	99.8	115.1	532.5	509.4	General performance
4	80min test1	19.8	115	445.3	553	00:30:20	80.5	n/a	n/a	107.7	113	624.6	628.3	General performance
4	80min test2	21	115	439.7	549.7	00:30:09	80.0	?	n/a	110.0	116.7	631.4	627.5	General performance
5	80min test1	20.7	115	551.4	668.6	00:36:51	82.5	16.5	1.82	117.2	119.4	750.1	748.2	General performance
5	80min test2	20.4	115	553.1	670.3	00:37:19	82.5	18	2.00	117.2	109.1	734.8	743.0	General performance
1	120VAC 80min	22.3	115	108.4	237.1	00:49:24	45.7	26.5	2.88	128.7	123.7	n/a	319.6	Performance at reduced power
4	120VAC 200min	19.9	115	444.9	659.2	02:17:33	67.5	30	3.34	214.3	122.7	735-756	741.0	Performance at reduced power
1	160VAC 160min	19.5	115	111.7	200.7	00:22:58	55.6	6.5	0.73	89.0	119.2	284.2	280.2	Performance at reduced power
4	160VAC 160min	20.1	115	443.9	583.5	01:07:39	76.1	16	1.78	139.6	118.3	663	662.4	Performance at reduced power
2.7	single cycle	21.8	115	294.3	391.9	00:22:07	75.1	12	1.31	97.6	n/a	n/a	n/a	Compare to Mr D or other vacuum cooker
4	single cycle	19.4	115	447.2	555.7	00:31:09	80.5	n/a	n/a	108.5	n/a	n/a	n/a	Compare to Mr D or other vacuum cooker
1	0min	21	66	52.6	n/a	n/a	n/a	1	0.05	n/a	40.9	n/a	n/a	Heat using 'keep-warm' circuit
3	0min	18.3	61.6	151.9	n/a	n/a	n/a	n/a	n/a	n/a	57.6	n/a	n/a	Heat using 'keep-warm' circuit
4	0min	21.4	68.7	221.3	n/a	n/a	n/a	19.5	1.08	n/a	43.8	n/a	n/a	Heat using 'keep-warm' circuit

Table 2. Summary of temperature and energy data. (Imported from spreadsheet)

Column definitions.

Start temperature: Measured at hot-plate upper-surface rebate, thermocouple Ch1

Final temperature: This is estimated from the temperature cycling graphs as being above the lid external maximum temperature but also above the hot plate rebate minimum temperature.

Water heating (theoretical) energy requirement (Wh): calculated from volume of water in the test in litres using Cp = 4.21 kJ/kg/K as the average of Cp = 4.18 @ 20°C and Cp = 4.23 @ 115°C.

Pre-heat phase, measured energy input (Wh): measured energy input up to first thermostat opening (power off).

Pre-heat duration: measured time from power connection up to first thermostat opening.

Pre-heat phase input energy absorbed to heat water (%): calculated energy / measured energy *100%.

Water mass lost as steam (g): as the water rises to 100°C, an amount of steam escapes through the interlock vent before the vent closes. This represents an energy loss. The amount of water remaining after the test was measured to assess the impact on energy loss. The data are shown in Table 2: the results are inconclusive but a relatively low amount of energy is carried away. The escape generally lasts for 10 seconds although this is longer at lower voltages because the steam generation rate and rate of increase is lower so the rate necessary to lift the valve takes longer to achieve.

Energy lost in steam: calculated assuming the mass lost is lost at 100°C.

Pre-heat phase energy loss: simply pre-heat phase energy input minus theoretical water heating energy. This wasted energy is the sum of energy absorbed heating the cooker plus energy radiated away from the cooker as it warms up. The cooker parasitic energy is a relatively static amount; the radiated heat energy is proportional to the cooking duration and pre-heat duration preceding it.

Cooking phase measured average energy input rate: as full power is applied in pulses during the cooking phase, this is averaged over the full cycle time, per cycle. This value is the final value recorded. Some tests were not stable by this time so some values are not consistent.

Pre-heat plus 40 minutes cooking time energy input – measured: this should represent the total energy input required to cook for 40 minutes for this cooker.

Pre-heat plus 40 minutes cooking time energy input – calculated: using measure pre-heat energy input plus the final average rate should allow the total energy input required to cook for any amount of time. However, assuming 40 minutes cooking time allows comparison with the previous measured value; the comparison indicates the validity of this approach.

Thermocouple positions.

Thermocouple positions are similar to previous EPC tests with the following differences.

Ch 1 – (no sprung button) mounted through a 3mm hole present in the centre of the hot plate into a 1mm x 20mm diameter central rebate. This is expected to provide the temperature at the interface between the hot plate and the pan and contents, without disturbing the plate-pan surface fitting.

Ch 2 – Thermal fuse inside silicone tube but wrapped in 3 layers of Kapton tape for electrical insulation from mains-voltage exposed fuse lead-out wires.

Ch 3 – (no electronics in Sayona) mounted to bimetallic switch mounting lug, close to hot plate spigot; this is expected to record switch opening and closing temperatures but has to remain electrically isolated since the switch contacts carry the mains voltage power input. An apparent lag is however visible.

Ch 4 – (top of chassis not expected to be of great value) trapped beneath ceramic thermostat mounting lugs and chassis lower surface. The switch is approximately 2.8cm away from the hot plate encapsulation lower surface and was not expected to rise to high temperature, based on previous test chassis temperatures that have been recorded.

Ch 5 – moat external, as previous tests.

Ch 6 – (bottom of case not of great value) power socket plastic. Metal contact temperature would be more interesting but, again, carry live mains voltage. Subsequently discovered to remain relatively cool so the thermocouple was removed to a position between TC1 and TC4, i.e. in the air space between the heat plate lower surface and chassis bottom upper surface.

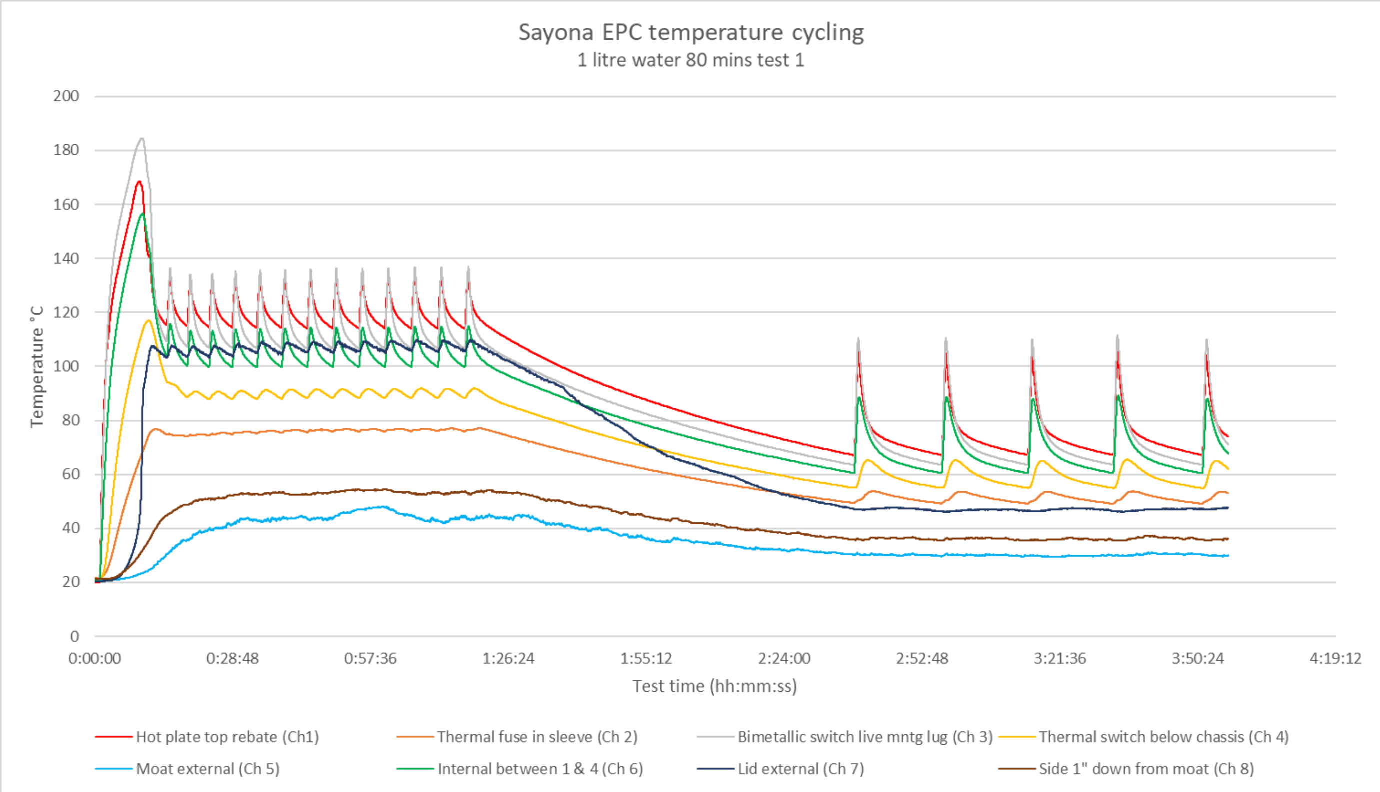
Ch 7 – lid upper surface, as previous tests. This cooker has an aluminium splash guard/condensation plate beneath the lid.

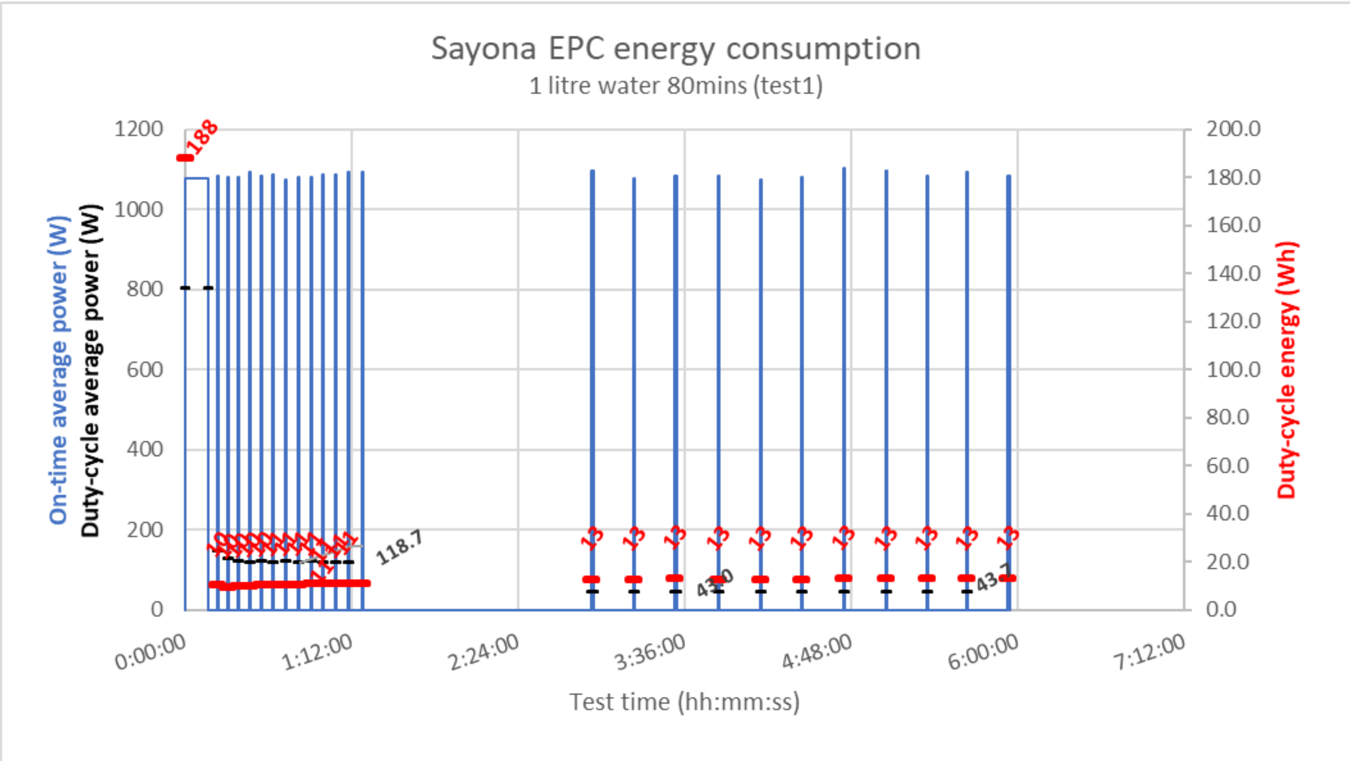
Ch 8 – 1" down case outer adjacent to moat. This can indicate if the moat is conducting heat to the case or if it is radiating from the chassis.

	Weighted pressure vent in lid (+/- 0.5g)	Orifice diameter (mm)	Static gauge pressure at which valve starts to vent (kPa) 100 kPa ~ 1 atmospheres)	Max temperature rise at vent pressure	Pressure marked on weight
BES 12V Chinese domestic	82.5g	4.00	64.4	14.4	n/a
Tower TI6004	78.5g	3.12	100.7	20.5	G90 kPa
Tower TI6005	81.5g	3.12	104.5	21.1	G90 kPa
Amazon Basics	83g	3.05	111.4	22.2	n/a
Instant Pot Duo	82g	3.05	110.1	22.0	105-135
Aobosi YBW60-100Q1	85.5g	2.87	129.6	24.8	100
TEFAL EPC06	80.5g	3.16	100.7	20.5	n/a
SAGE BPR700	81g	3.00	112.4	22.3	n/a
Sayona PPS 6l	94	3.36	104.0	20.6	n/a

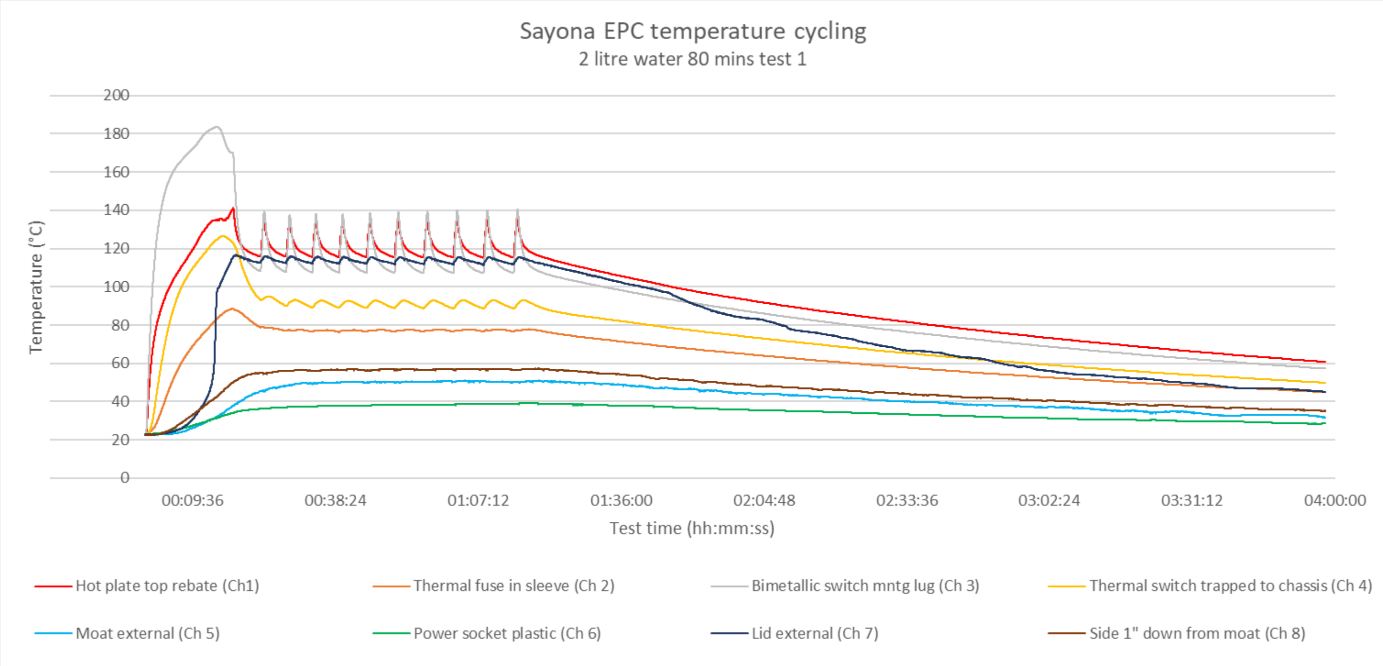
Table 3. Pressure release vent static opening pressure and calculated temperatures (Source: "A Comparison of Functions and Safety Features on Electric Pressure Cookers", Barton, Monk and Blanchard, 2019. White paper accessible from www.mecs.org.uk) Extended to include Sayona data.

Appendix 1. Temperature and power test results graphs @ 230 VAC

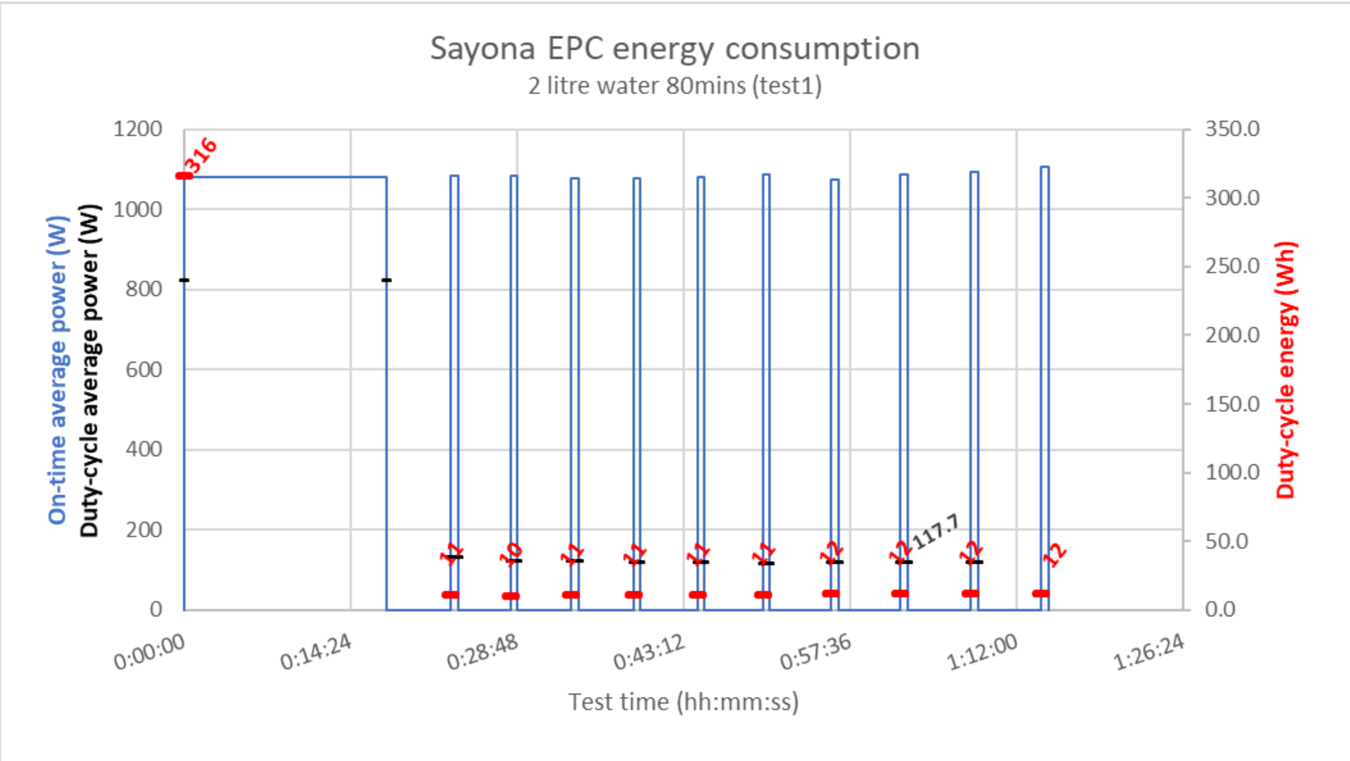




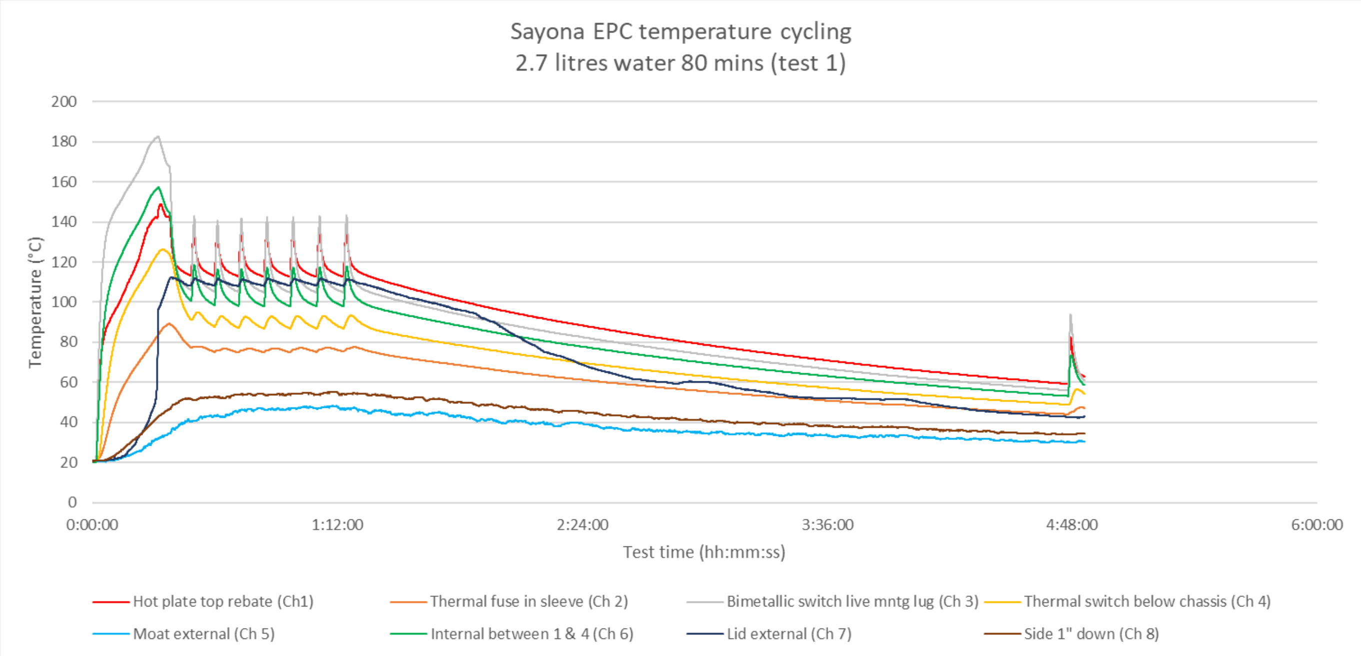
The average energy input when stable at pressure = 118.7 W. After cooling to lower temperatures when the keep-warm mode power cycle switches on, the average energy input = 43.7W. Test 2 gave very similar data, see table 2. Note: more power cycle data were recorded than temperature cycle data.



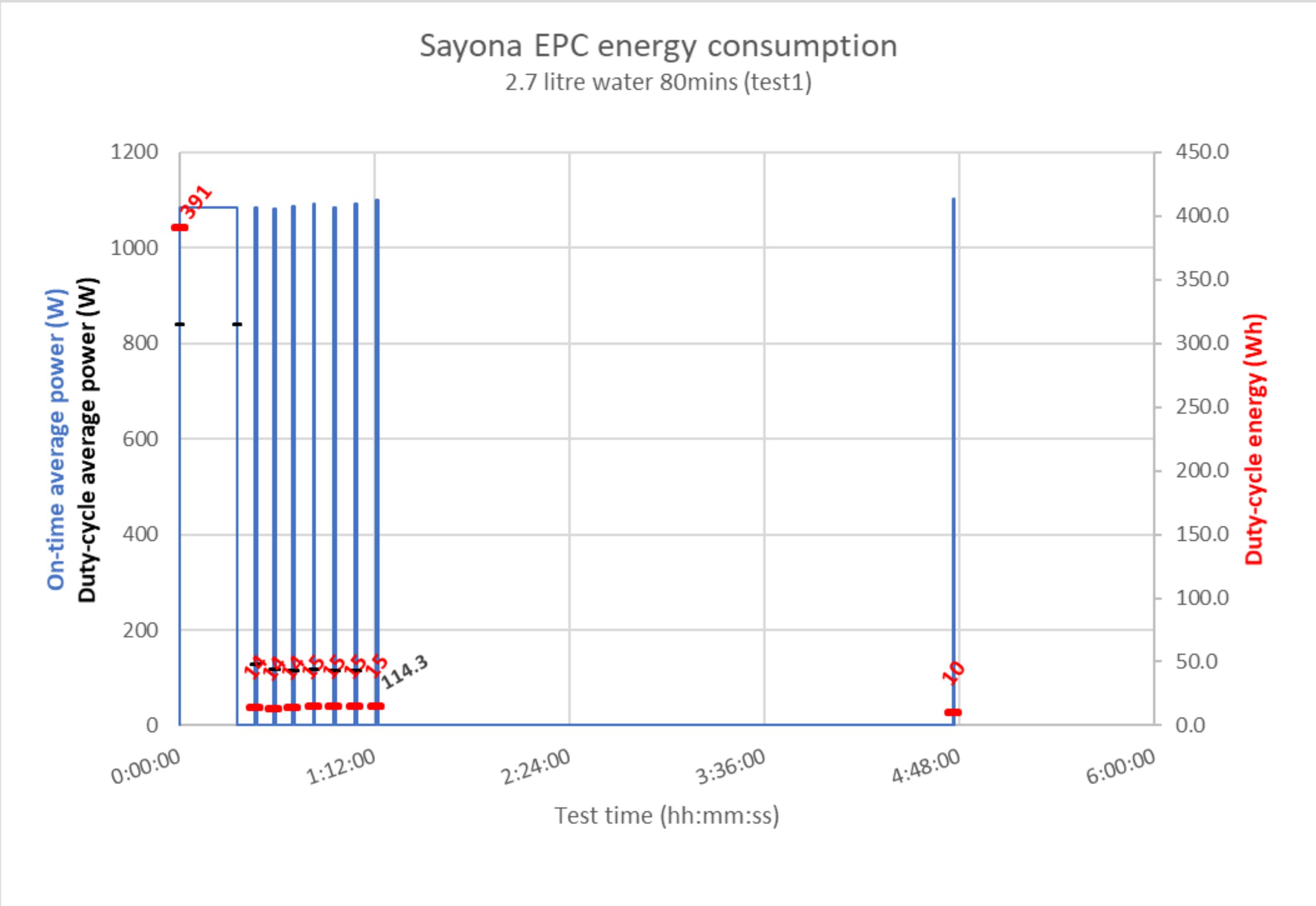
Sayona EPC temperature cycling
2 litre water 80 mins test 1
Temperature (°C)
Test time (hh:mm:ss)
Hot plate top rebate (Ch1)
Thermal fuse in sleeve (Ch 2)
Bimetallic switch mntg lug (Ch 3)
Thermal switch trapped to chassis (Ch 4)
Moat external (Ch 5)
Power socket plastic (Ch 6)
Lid external (Ch 7)
Side 1" down from moat (Ch 8)



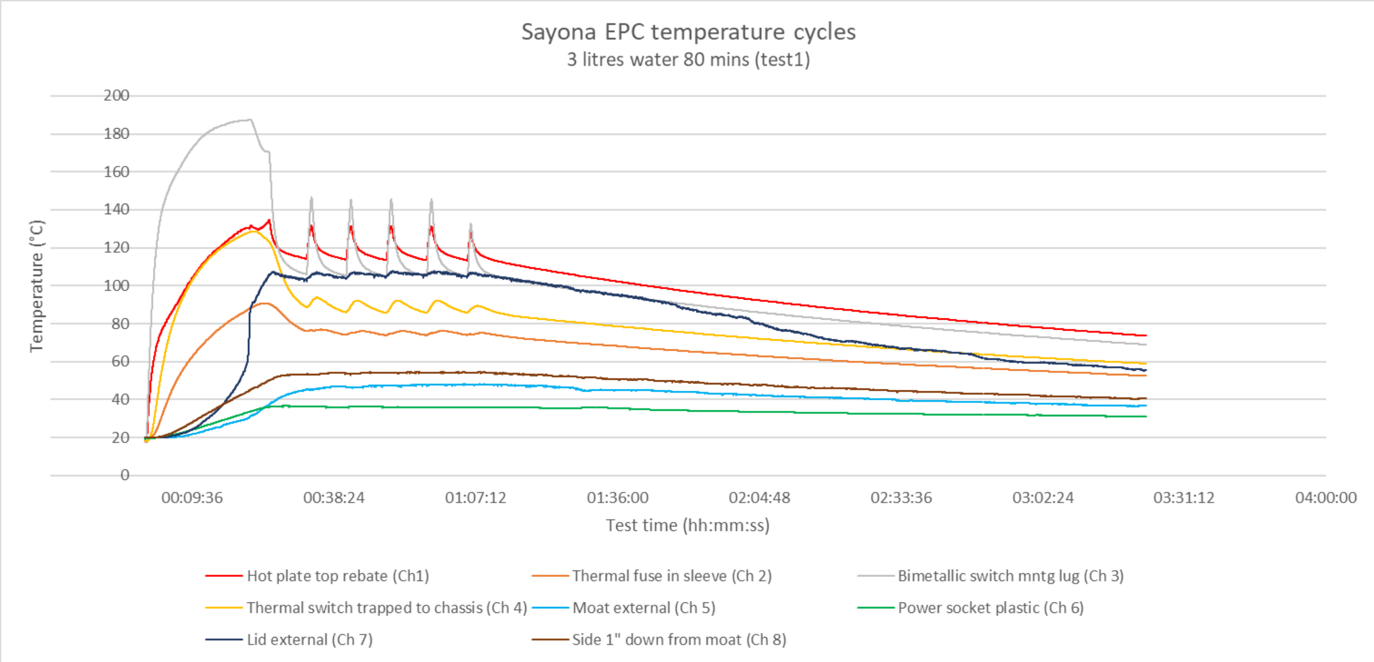
Sayona EPC energy consumption
2 litre water 80mins (test1)
On-time average power (W)
Duty-cycle average power (W)
Duty-cycle energy (Wh)
Test time (hh:mm:ss)
316
117.7

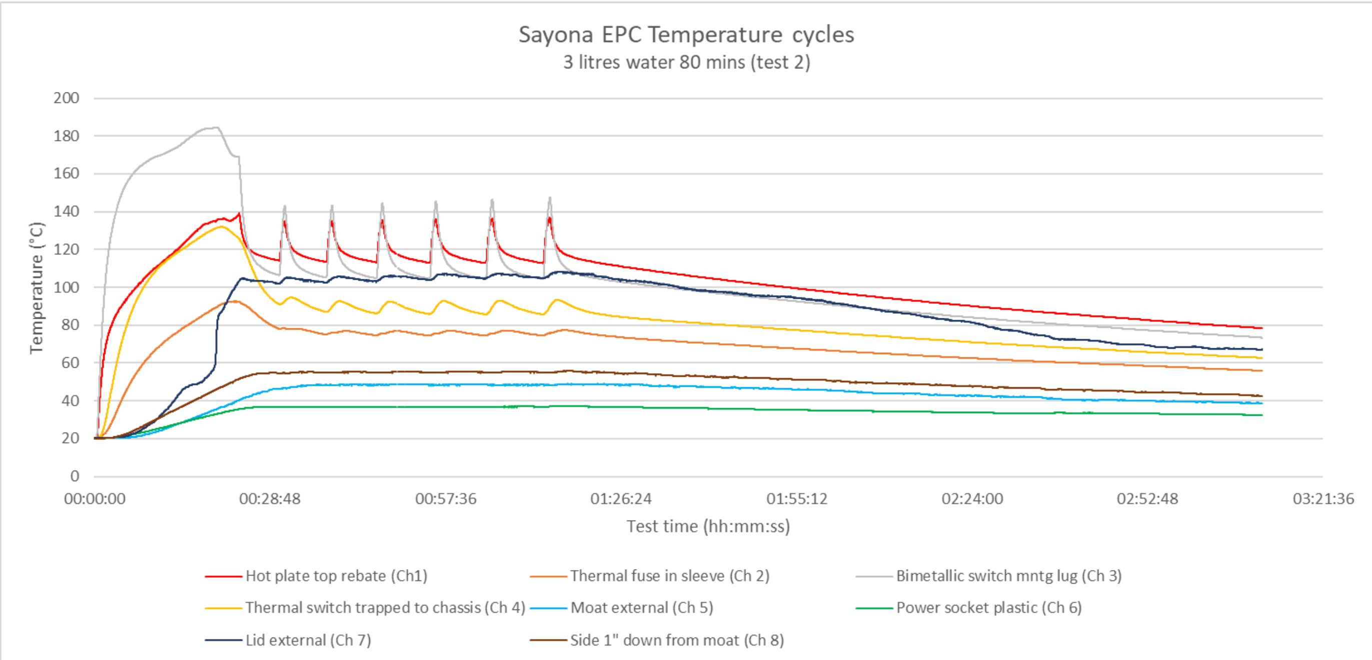


Sayona EPC temperature cycling
2.7 litres water 80 mins (test 1)
Temperature (°C)
200
180
160
140
120
100
80
60
40
20
0
0:00:00
1:12:00
2:24:00
3:36:00
4:48:00
6:00:00
Test time (hh:mm:ss)
Hot plate top rebate (Ch1)
Thermal fuse in sleeve (Ch 2)
Bimetallic switch live mntg lug (Ch 3)
Thermal switch below chassis (Ch 4)
Moat external (Ch 5)
Internal between 1 & 4 (Ch 6)
Lid external (Ch 7)
Side 1" down (Ch 8)

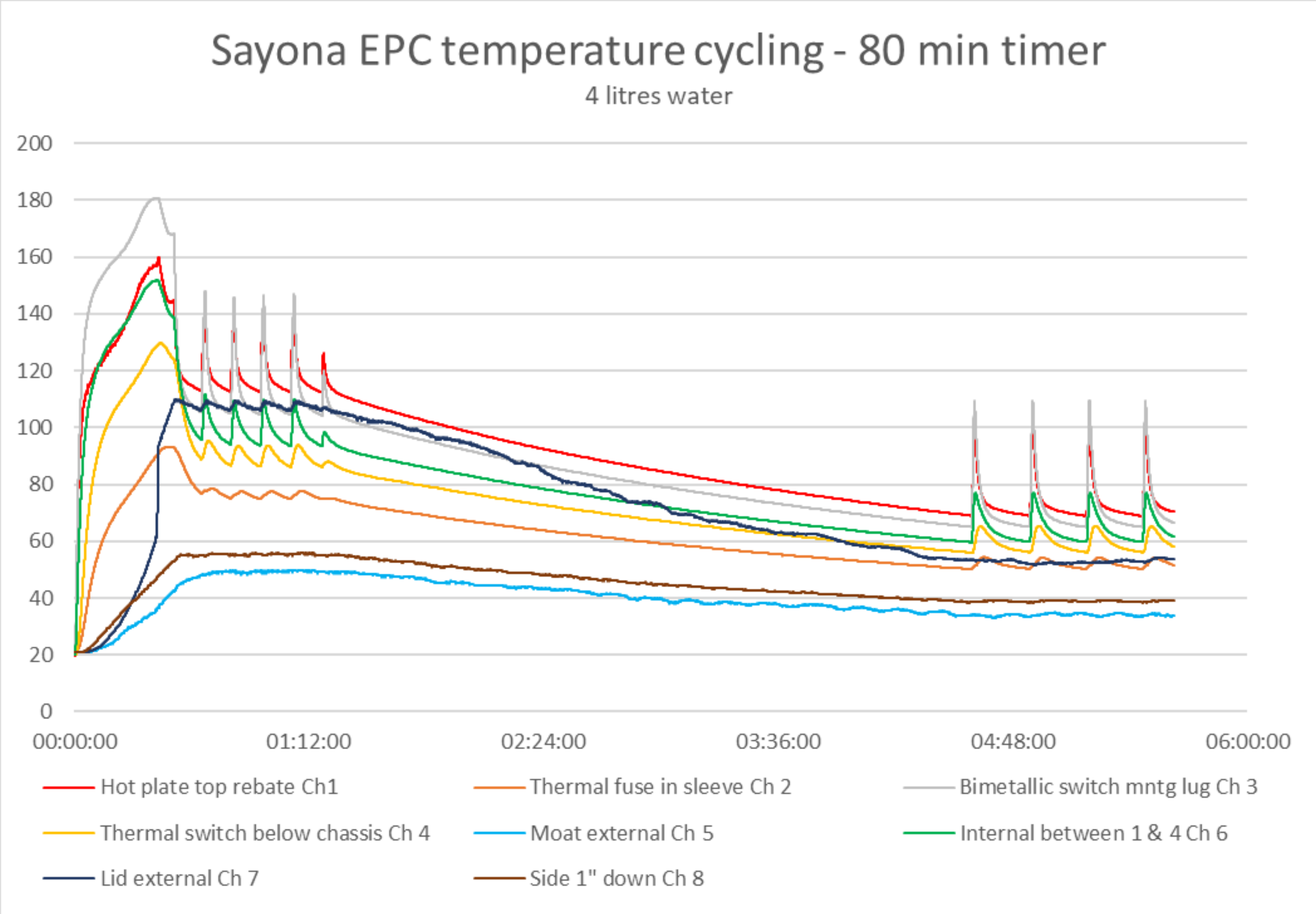


Sayona EPC energy consumption
2.7 litre water 80mins (test1)
On-time average power (W)
Duty-cycle average power (W)
Duty-cycle energy (Wh)
1200
1000
800
600
400
200
0
450.0
400.0
350.0
300.0
250.0
200.0
150.0
100.0
50.0
0.0
391
114.3
10
0:00:00
1:12:00
2:24:00
3:36:00
4:48:00
6:00:00
Test time (hh:mm:ss)

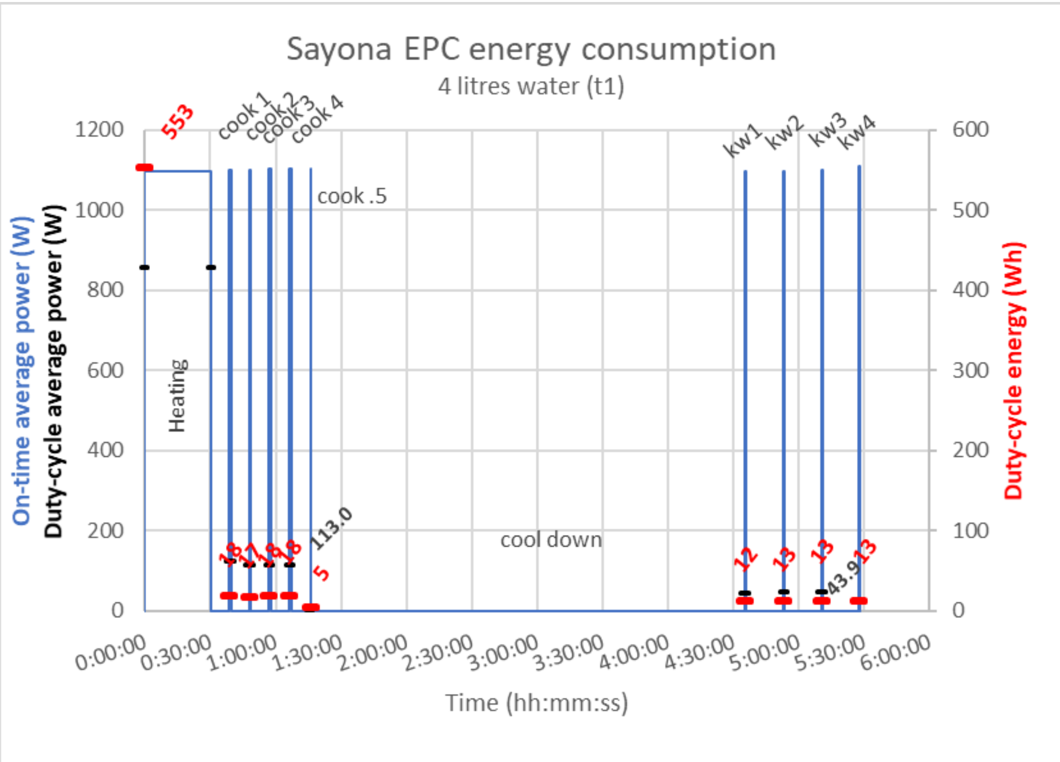




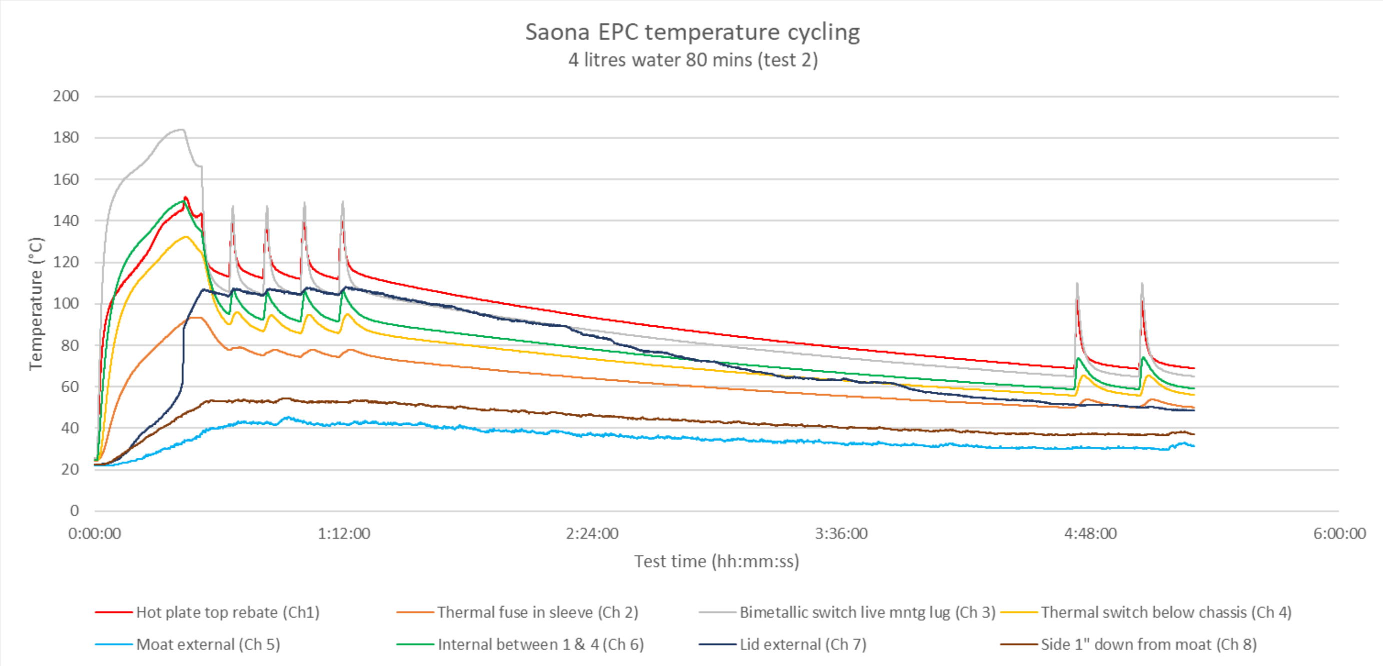
Test 1 terminated before 80 minutes at 1hr 5mins because the cooker timer is ‘fast’.

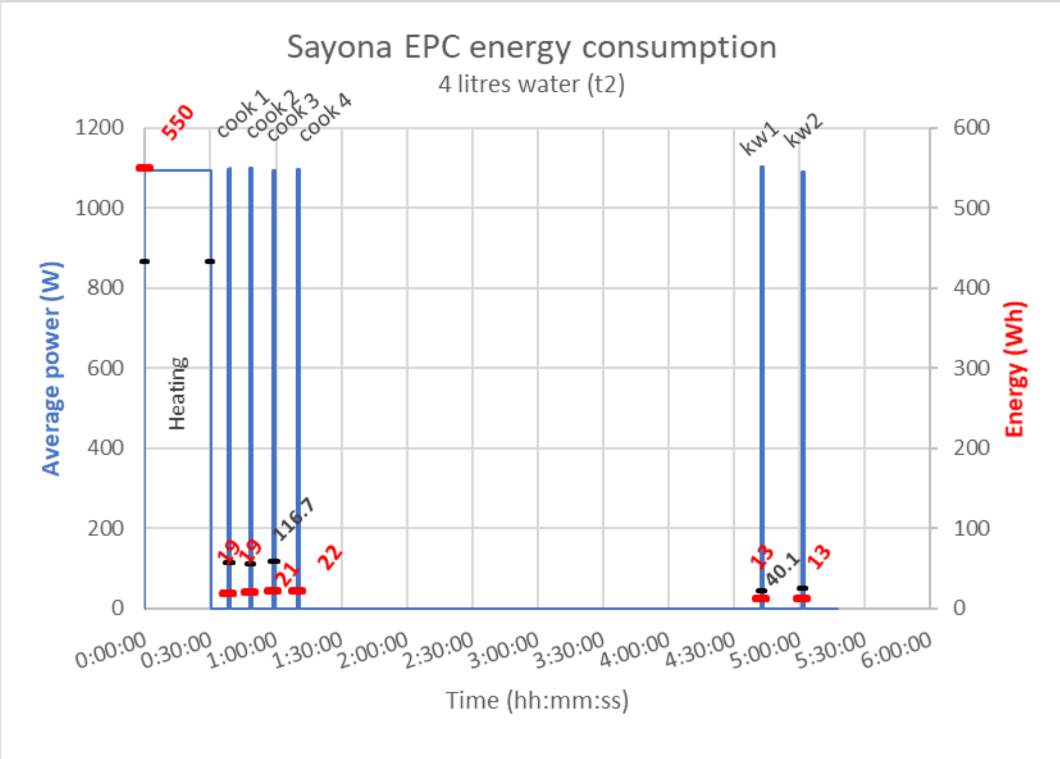


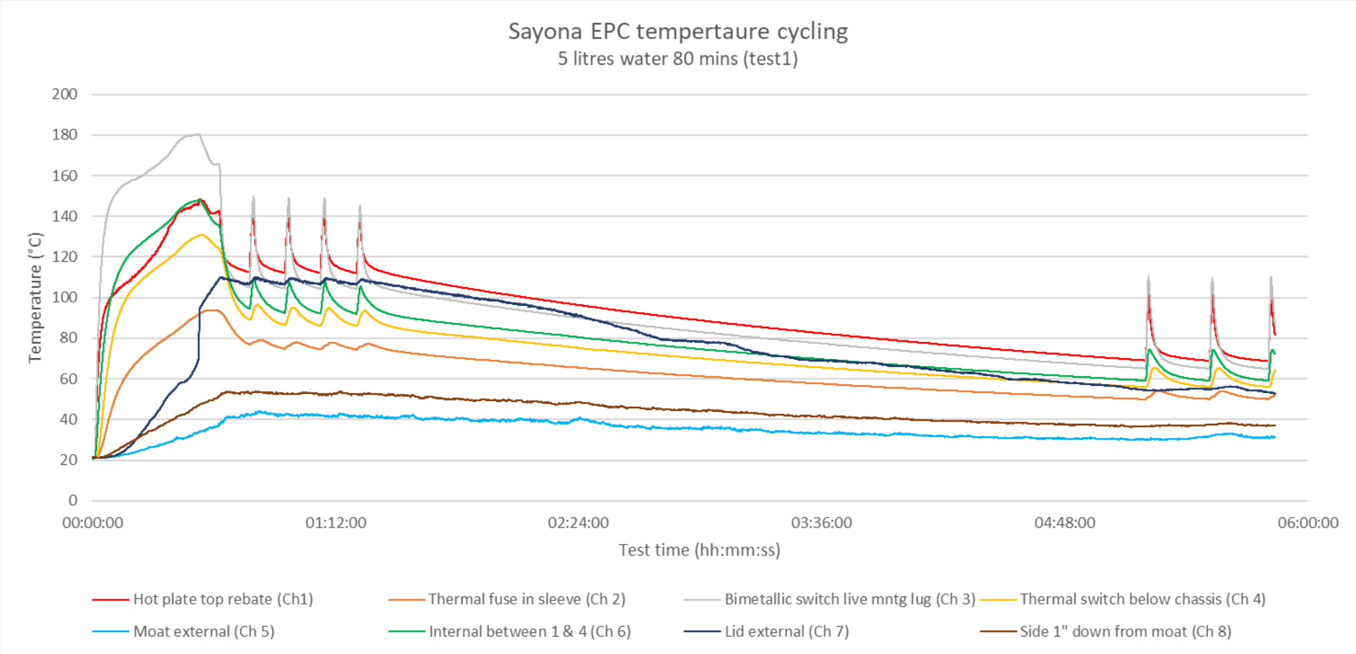
Sayona EPC temperature cycling - 80 min timer
4 litres water
200
180
160
140
120
100
80
60
40
20
0
00:00:00
01:12:00
02:24:00
03:36:00
04:48:00
06:00:00
Hot plate top rebate Ch1
Thermal fuse in sleeve Ch 2
Bimetallic switch mntg lug Ch 3
Thermal switch below chassis Ch 4
Moat external Ch 5
Internal between 1 & 4 Ch 6
Lid external Ch 7
Side 1" down Ch 8

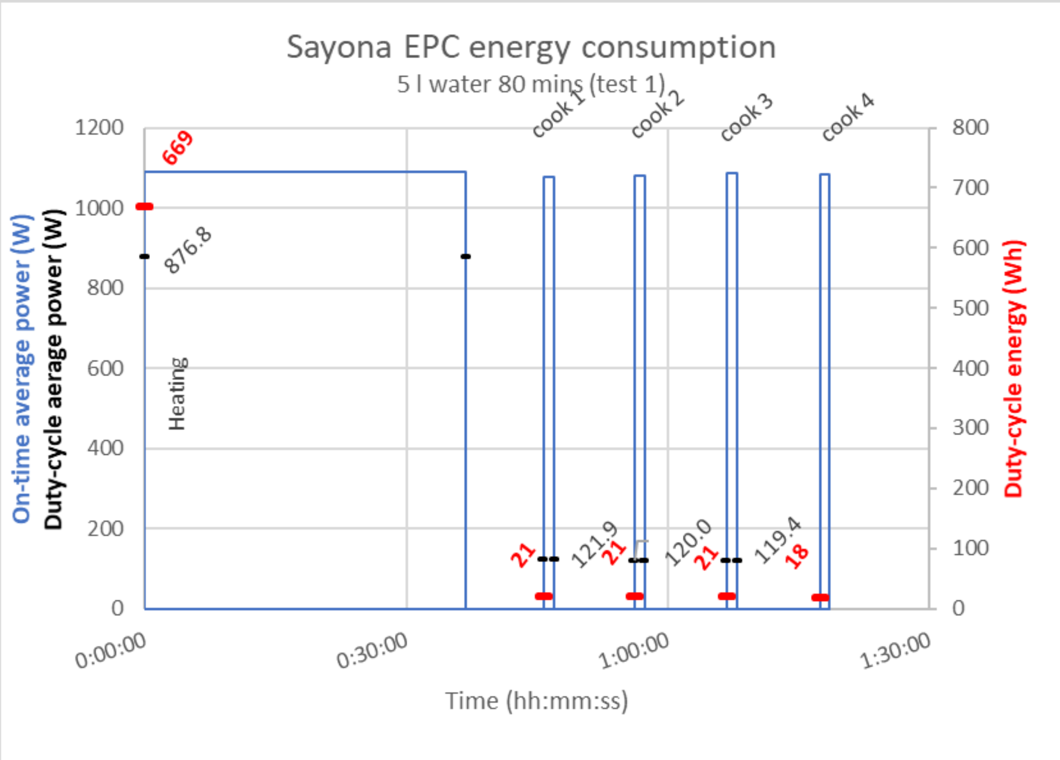


Sayona EPC energy consumption
4 litres water (t1)
553
cook 1
cook 2
cook 3
cook 4
cook .5
kw1
kw2
kw3
kw4
Heating
cool down
113.0
5
12
13
13
13
43.9
On-time average power (W)
Duty-cycle average power (W)
Duty-cycle energy (Wh)
1200
1000
800
600
400
200
0
600
500
400
300
200
100
0
0:00:00
0:30:00
1:00:00
1:30:00
2:00:00
2:30:00
3:00:00
3:30:00
4:00:00
4:30:00
5:00:00
5:30:00
6:00:00
Time (hh:mm:ss)

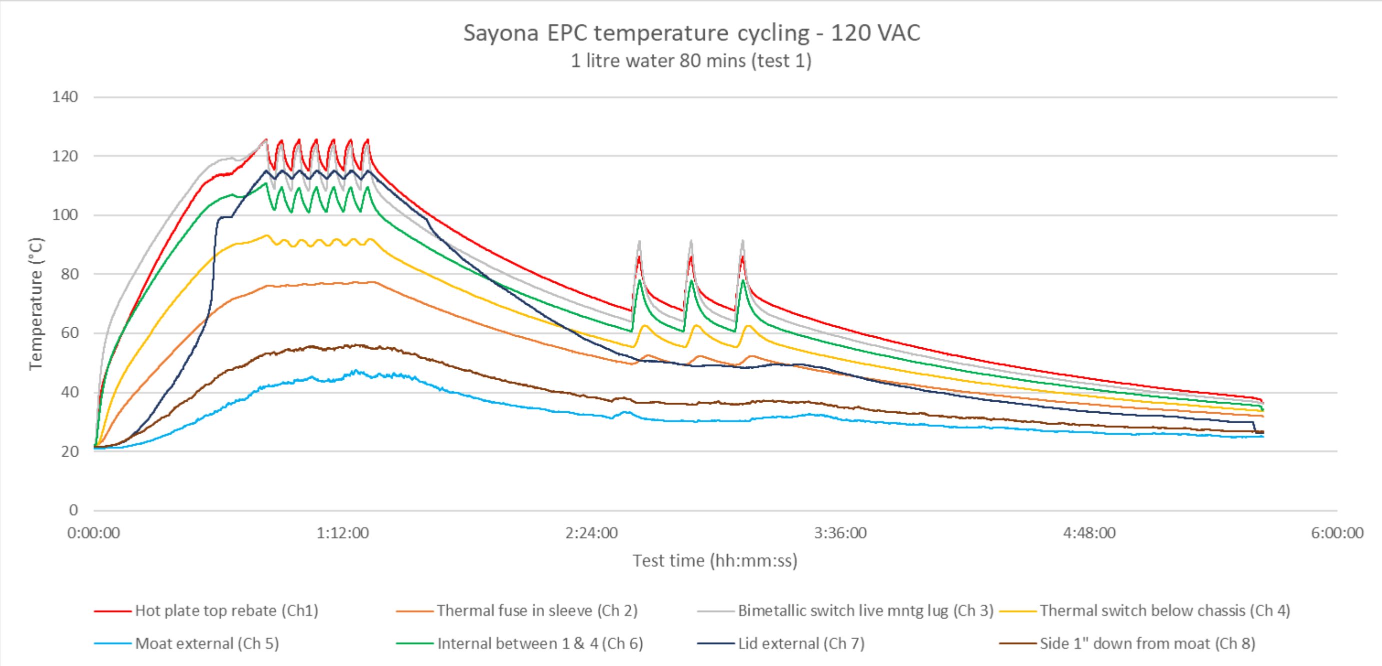

Saona EPC temperature cycling
4 litres water 80 mins (test 2)
Temperature (°C)
200
180
160
140
120
100
80
60
40
20
0
0:00:00
1:12:00
2:24:00
3:36:00
4:48:00
6:00:00
Test time (hh:mm:ss)
Hot plate top rebate (Ch1)
Thermal fuse in sleeve (Ch 2)
Bimetallic switch live mntg lug (Ch 3)
Thermal switch below chassis (Ch 4)
Moat external (Ch 5)
Internal between 1 & 4 (Ch 6)
Lid external (Ch 7)
Side 1" down from moat (Ch 8)

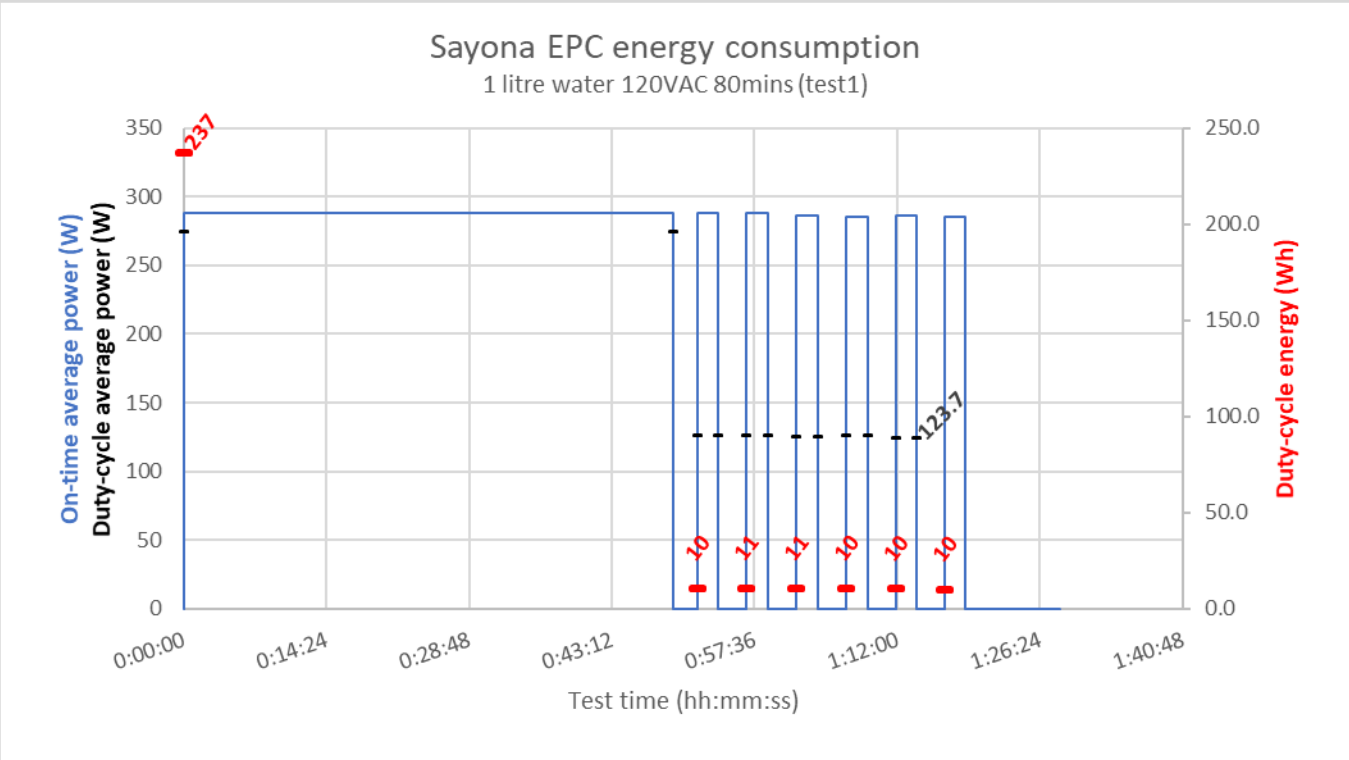

Sayona EPC energy consumption
4 litres water (t2)
Average power (W)
Energy (Wh)
550
cook 1
cook 2
cook 3
cook 4
kw1
kw2
Heating
19
19
21
116.7
22
13
40.1
13
1200
1000
800
600
400
200
0
600
500
400
300
200
100
0
0:00:00
0:30:00
1:00:00
1:30:00
2:00:00
2:30:00
3:00:00
3:30:00
4:00:00
4:30:00
5:00:00
5:30:00
6:00:00
Time (hh:mm:ss)

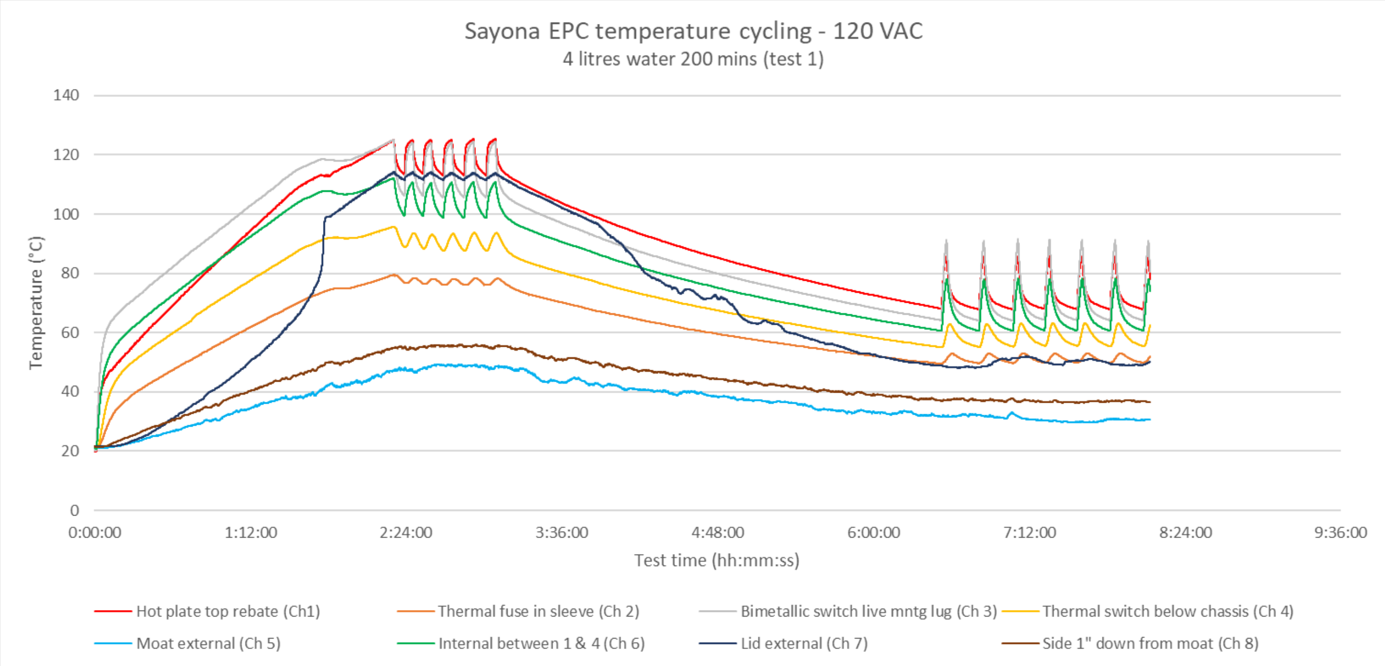

Sayona EPC tempertaure cycling
5 litres water 80 mins (test1)
Temperature (°C)
Test time (hh:mm:ss)
00:00:00
01:12:00
02:24:00
03:36:00
04:48:00
06:00:00
Hot plate top rebate (Ch1)
Thermal fuse in sleeve (Ch 2)
Bimetallic switch live mntg lug (Ch 3)
Thermal switch below chassis (Ch 4)
Moat external (Ch 5)
Internal between 1 & 4 (Ch 6)
Lid external (Ch 7)
Side 1" down from moat (Ch 8)

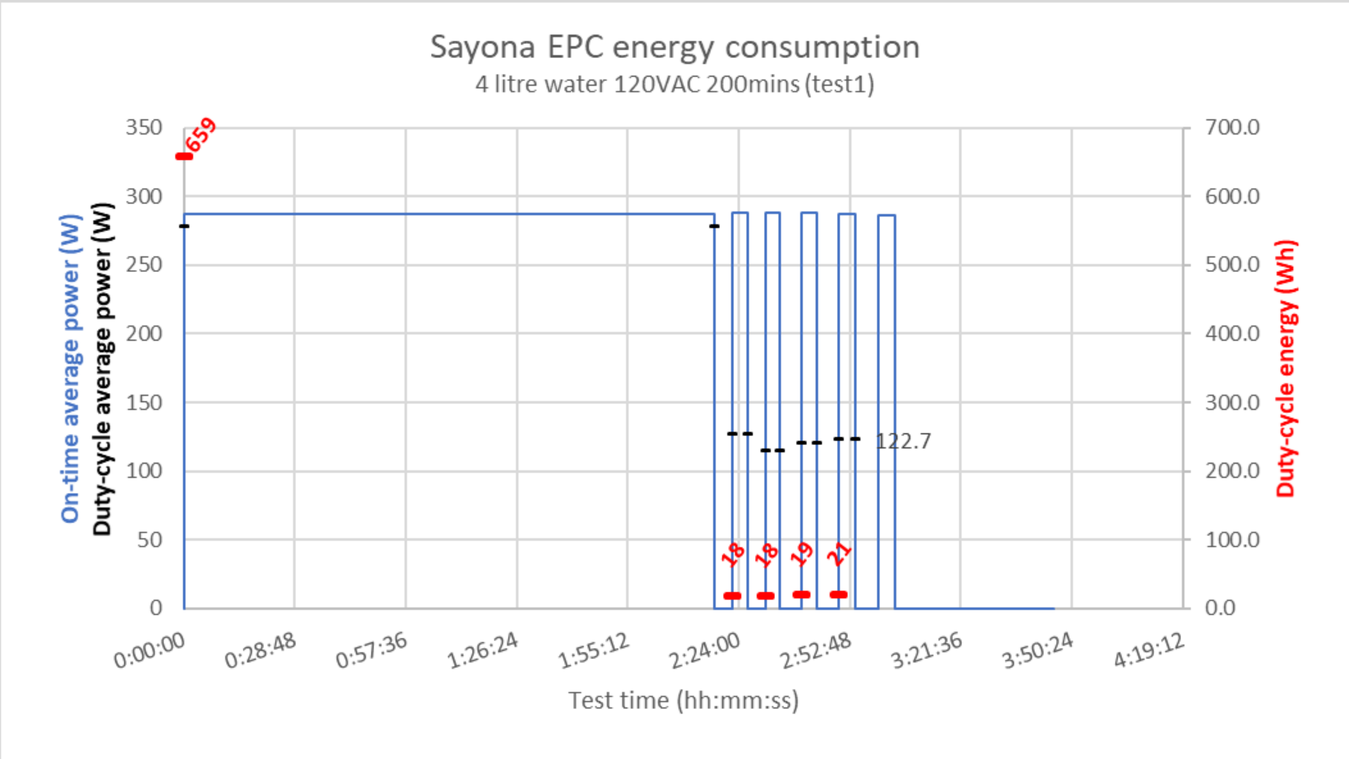

Sayona EPC energy consumption
5 l water 80 mins (test 1)
cook 1
cook 2
cook 3
cook 4
669
876.8
Heating
21
121.9
21
120.0
21
119.4
18
On-time average power (W)
Duty-cycle aerage power (W)
Duty-cycle energy (Wh)
Time (hh:mm:ss)
0:00:00
0:30:00
1:00:00
1:30:00

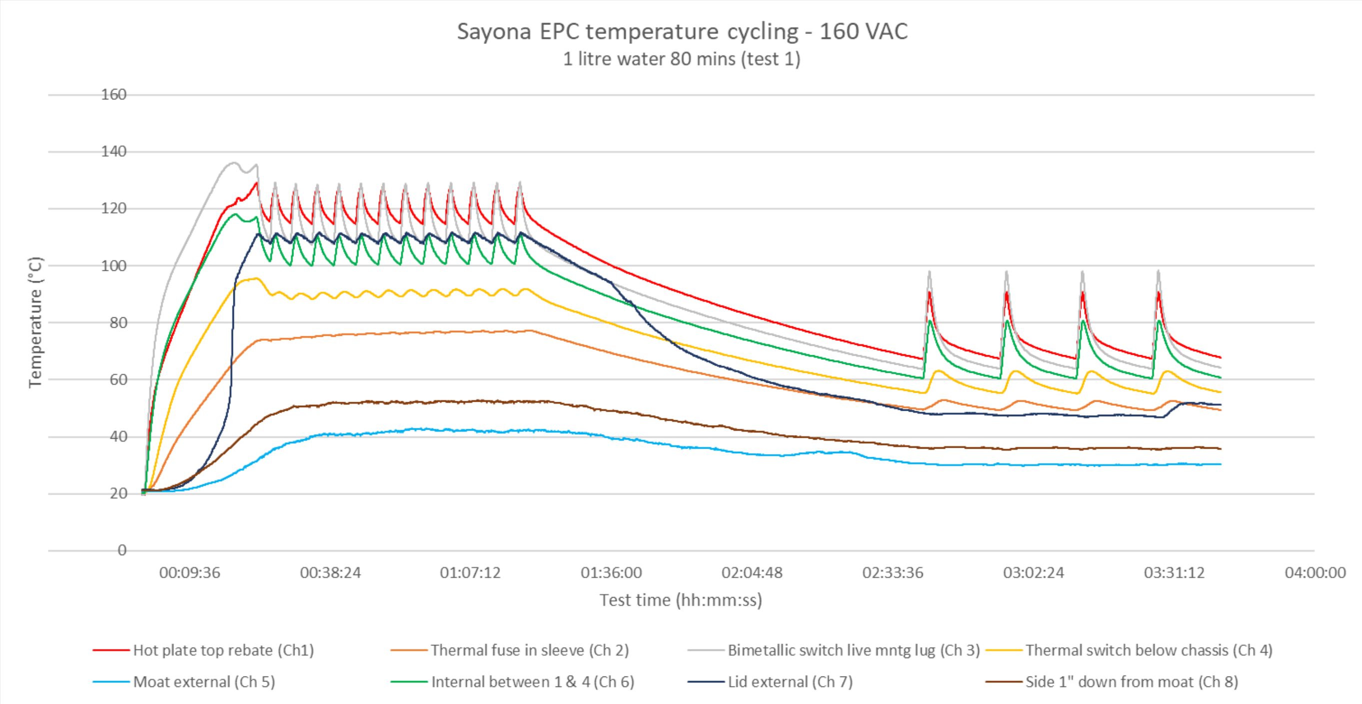
Appendix 2. Temperature and power test results graphs and analysis – reduced power @ 120, 160 VAC.

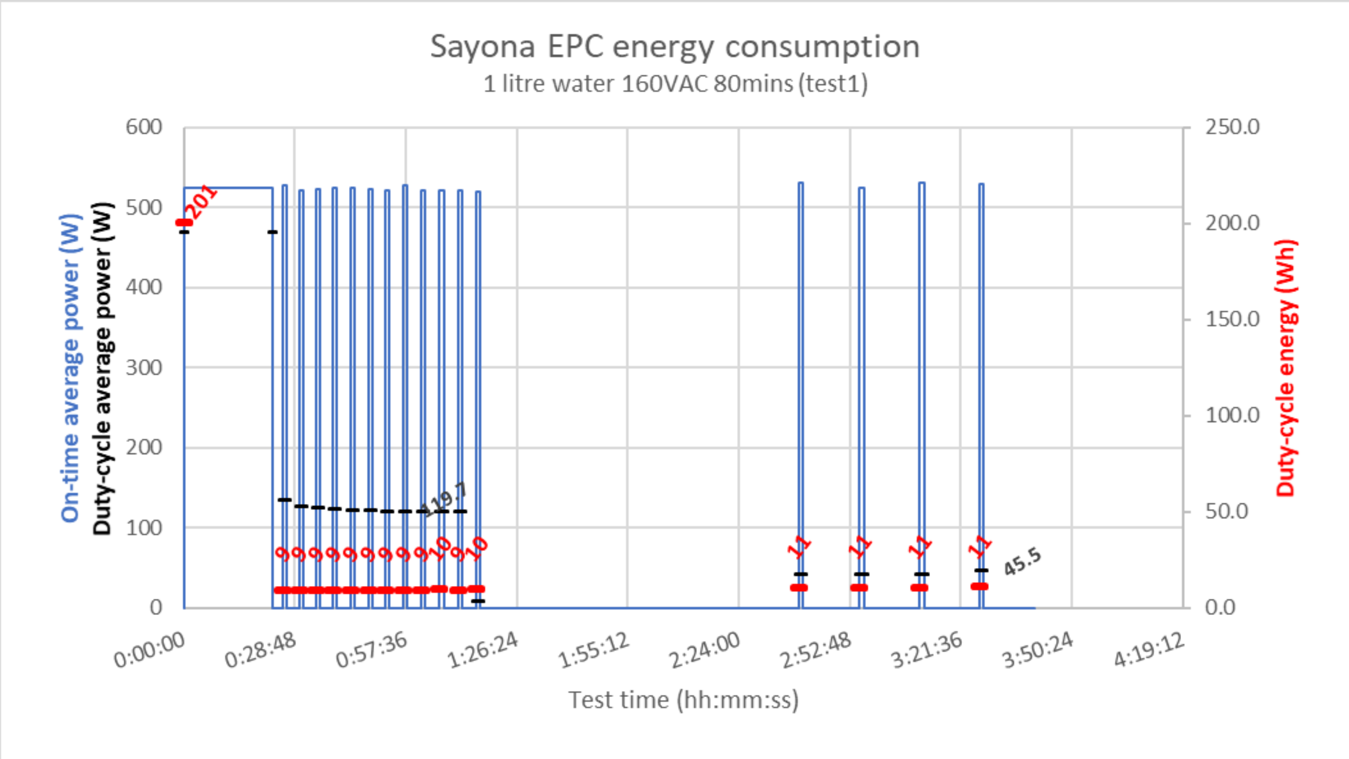


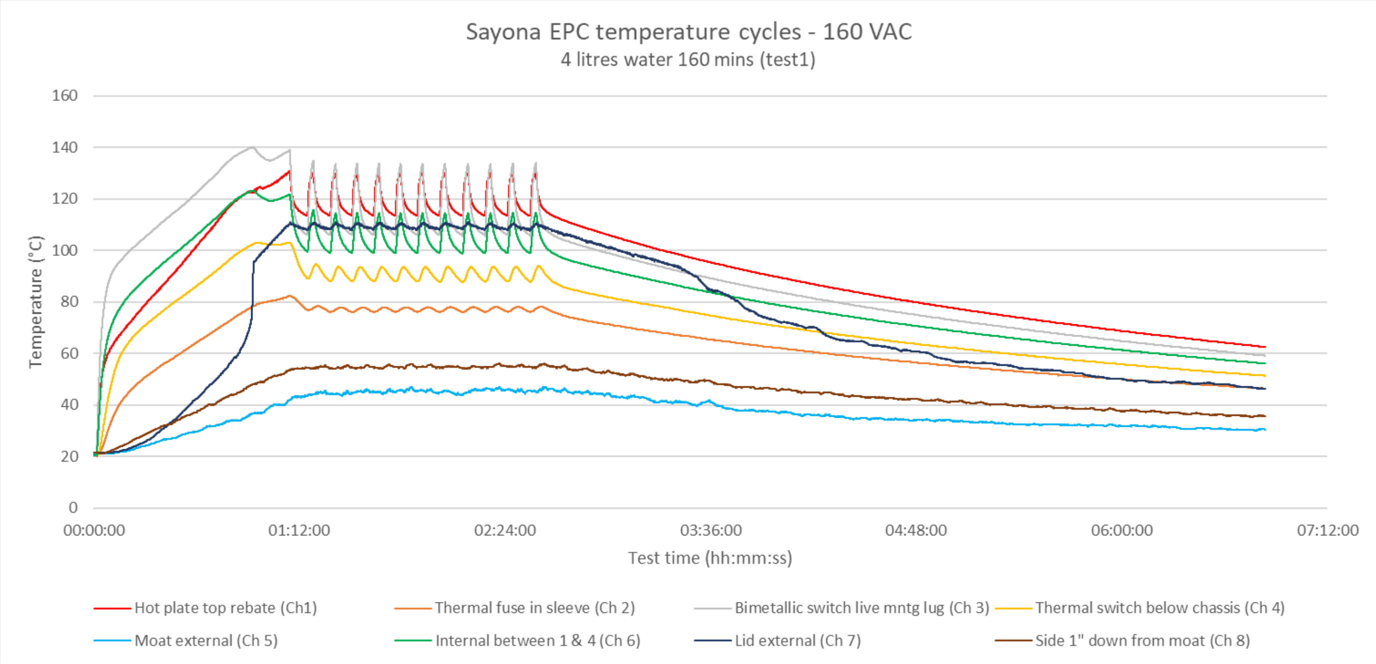



Sayona EPC temperature cycling - 120 VAC
4 litres water 200 mins (test 1)
Temperature (°C)
140
120
100
80
60
40
20
0
0:00:00
1:12:00
2:24:00
3:36:00
4:48:00
6:00:00
7:12:00
8:24:00
9:36:00
Test time (hh:mm:ss)
Hot plate top rebate (Ch1)
Thermal fuse in sleeve (Ch 2)
Bimetallic switch live mntg lug (Ch 3)
Thermal switch below chassis (Ch 4)
Moat external (Ch 5)
Internal between 1 & 4 (Ch 6)
Lid external (Ch 7)
Side 1" down from moat (Ch 8)

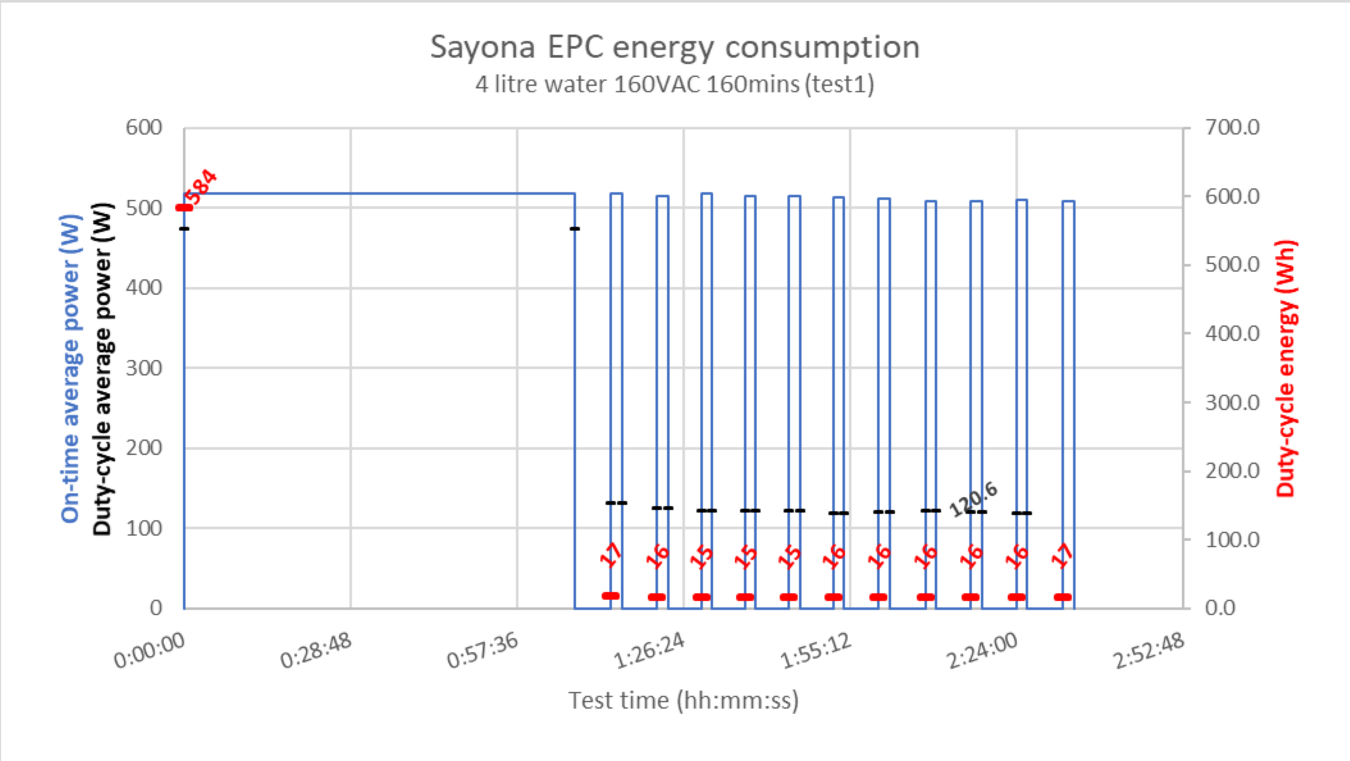

Sayona EPC energy consumption
4 litre water 120VAC 200mins (test1)
On-time average power (W)
Duty-cycle average power (W)
Duty-cycle energy (Wh)
350
300
250
200
150
100
50
0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
659
122.7
18
18
19
21
0:00:00
0:28:48
0:57:36
1:26:24
1:55:12
2:24:00
2:52:48
3:21:36
3:50:24
4:19:12
Test time (hh:mm:ss)


Sayona EPC temperature cycling - 160 VAC
1 litre water 80 mins (test 1)
Temperature (°C)
Test time (hh:mm:ss)
Hot plate top rebate (Ch1)
Thermal fuse in sleeve (Ch 2)
Bimetallic switch live mntg lug (Ch 3)
Thermal switch below chassis (Ch 4)
Moat external (Ch 5)
Internal between 1 & 4 (Ch 6)
Lid external (Ch 7)
Side 1" down from moat (Ch 8)


Sayona EPC energy consumption
1 litre water 160VAC 80mins (test1)
On-time average power (W)
Duty-cycle average power (W)
Duty-cycle energy (Wh)
Test time (hh:mm:ss)
201
119.7
45.5

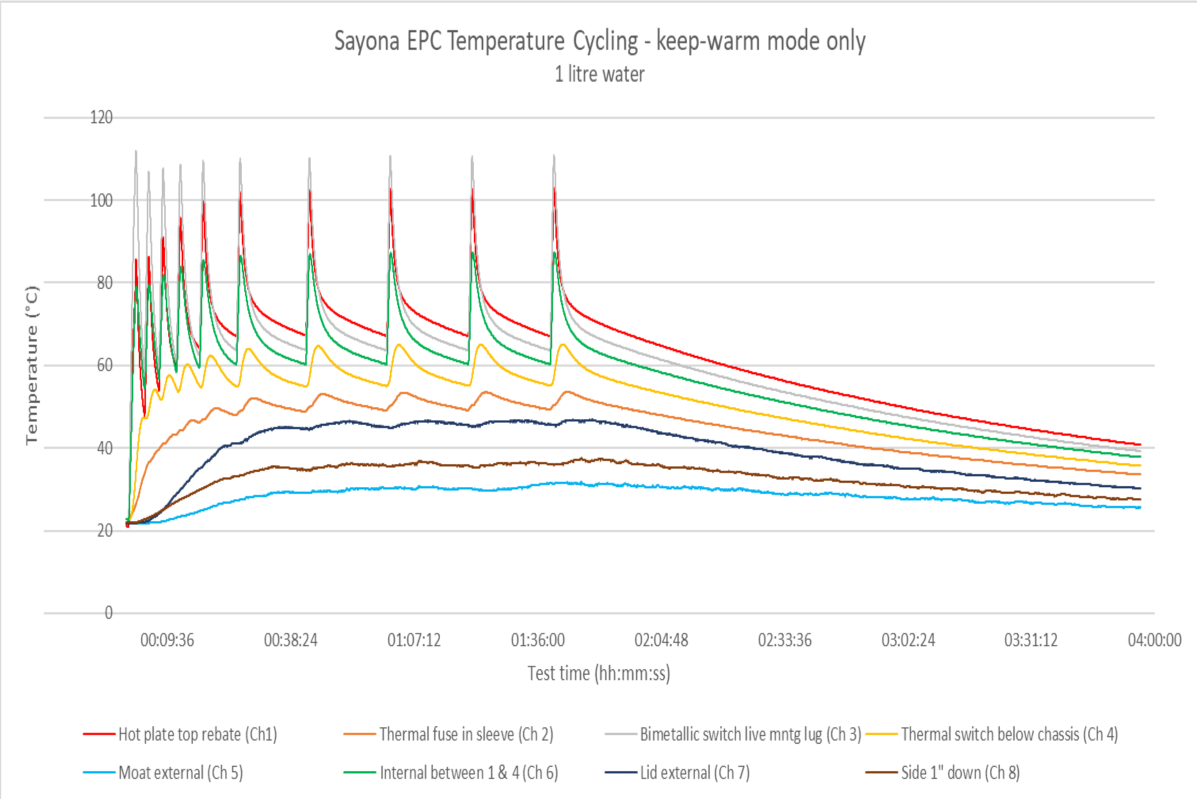


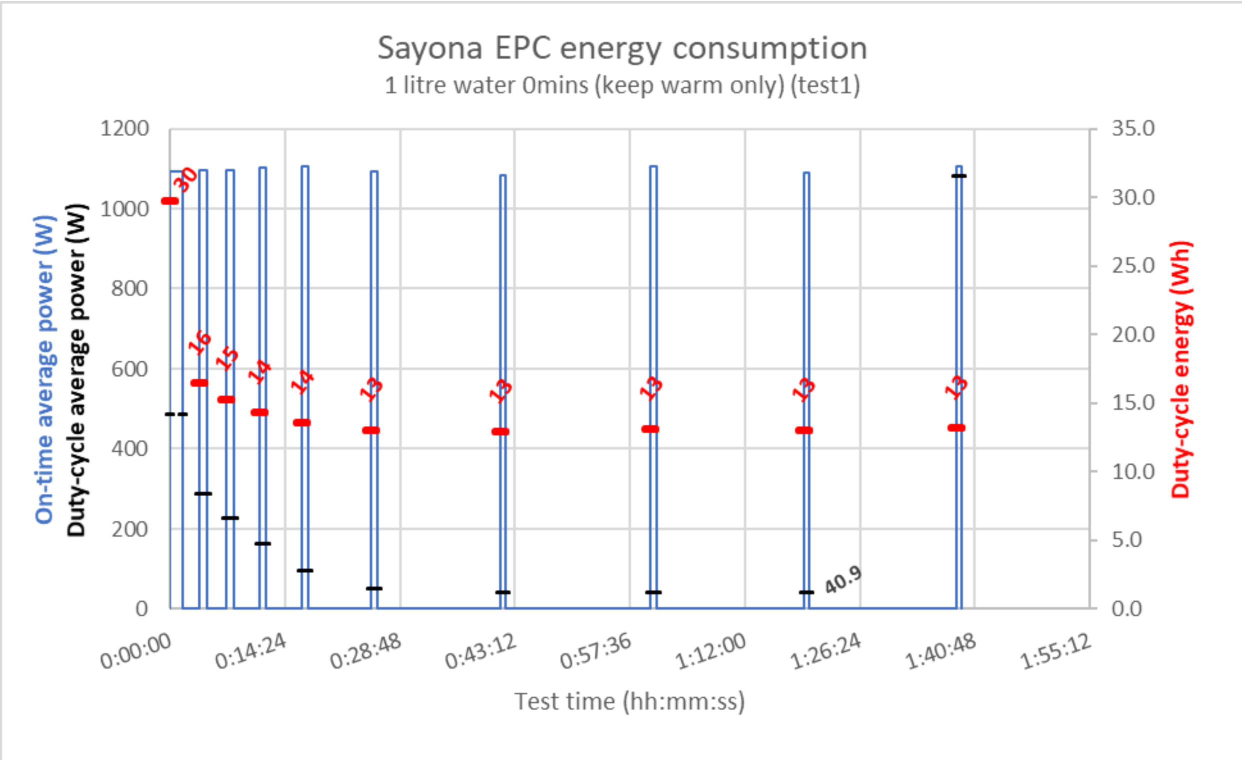
Sayona EPC temperature cycles - 160 VAC
4 litres water 160 mins (test1)
Temperature (°C)
Test time (hh:mm:ss)
160
140
120
100
80
60
40
20
0
00:00:00
01:12:00
02:24:00
03:36:00
04:48:00
06:00:00
07:12:00
Hot plate top rebate (Ch1)
Thermal fuse in sleeve (Ch 2)
Bimetallic switch live mntg lug (Ch 3)
Thermal switch below chassis (Ch 4)
Moat external (Ch 5)
Internal between 1 & 4 (Ch 6)
Lid external (Ch 7)
Side 1" down from moat (Ch 8)



Sayona EPC energy consumption
4 litre water 160VAC 160mins (test1)
On-time average power (W)
Duty-cycle average power (W)
Duty-cycle energy (Wh)
Test time (hh:mm:ss)
600
500
400
300
200
100
0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
0:00:00
0:28:48
0:57:36
1:26:24
1:55:12
2:24:00
2:52:48
584
120.6
17
16
15
15
15
16
16
16
16
16
17

Appendix 3. Temperature and power test results graphs and analysis without pre-heat, continuous-power period.

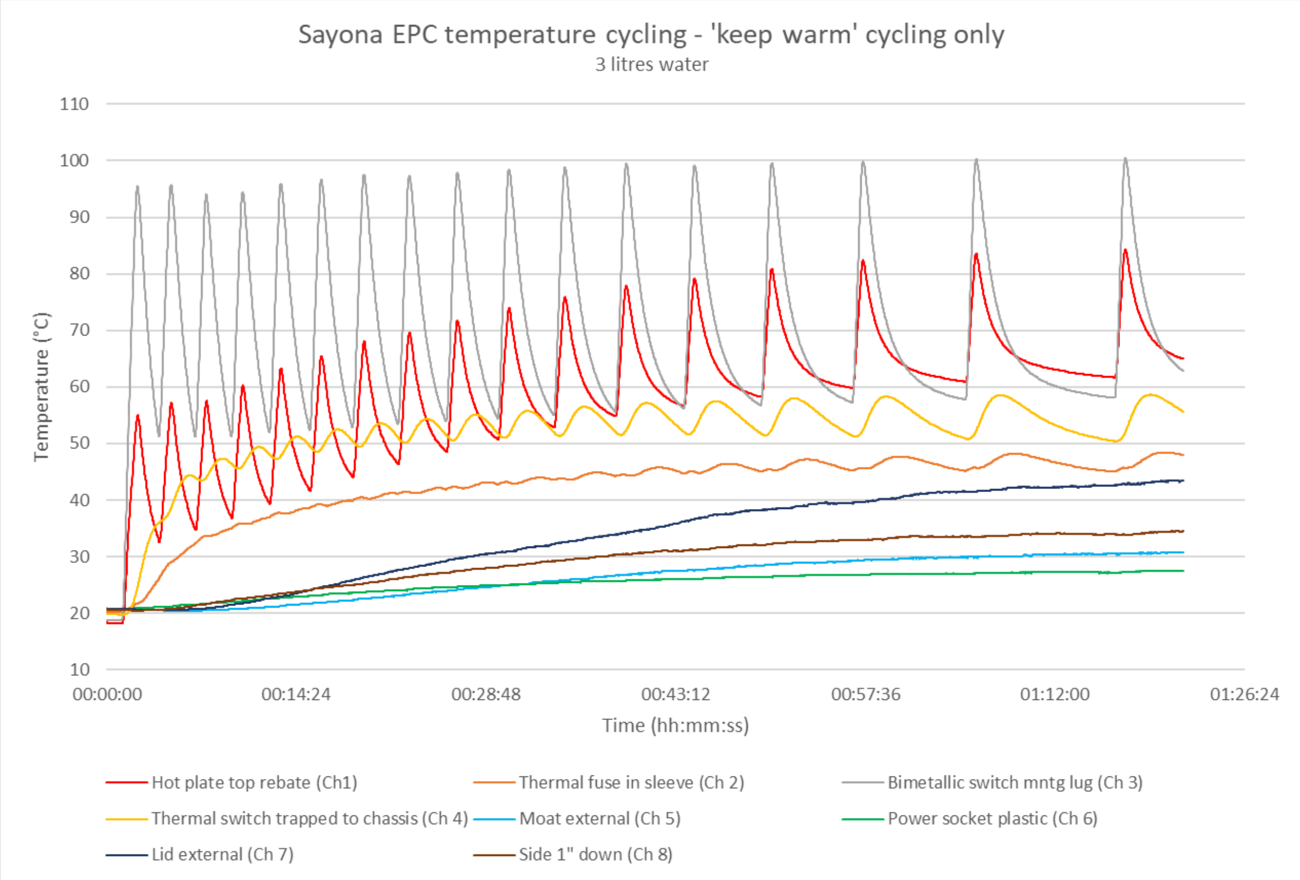


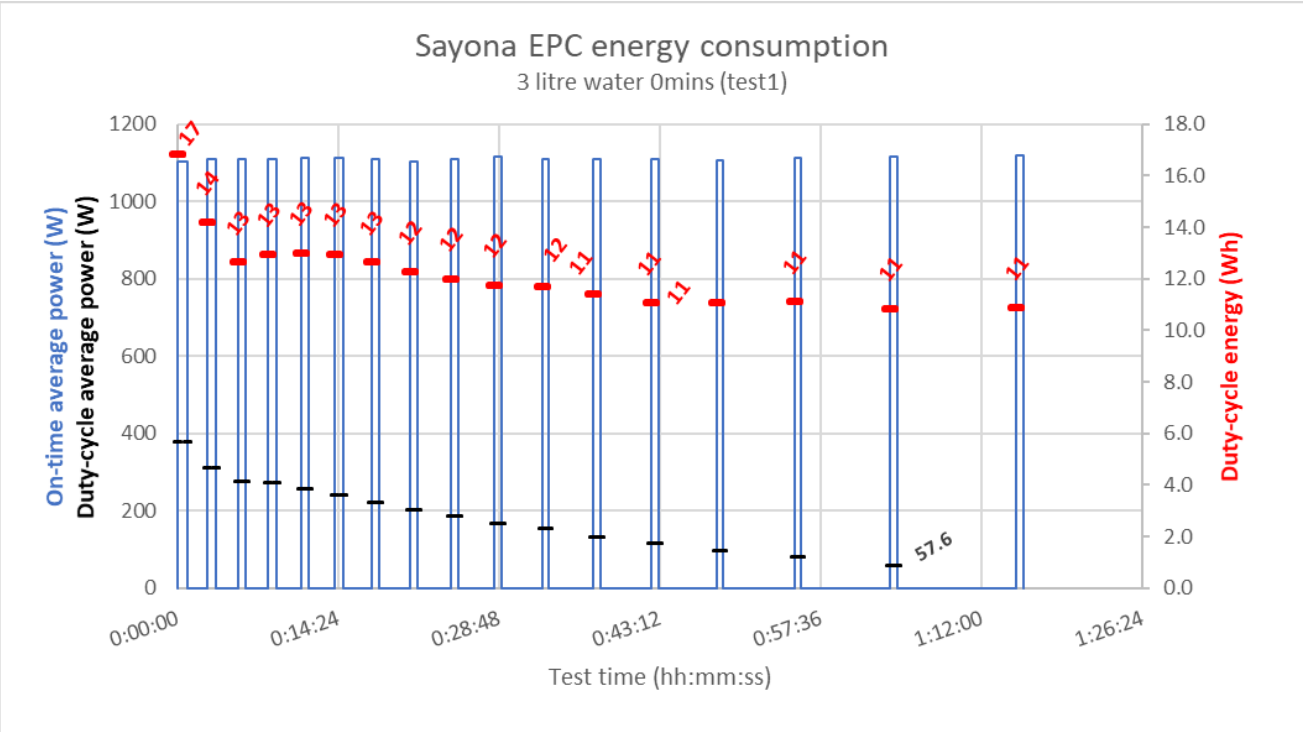


1 litre water, keep-warm mode only. This is an attempt to test whether the EPC can bring a load up to temperature using the keep-warm part of the switching circuitry. The tests are repeated for 1, 3 and 4 litre loads (water). Power is switched via the thermostat mounted on the lug monitored by Ch3.

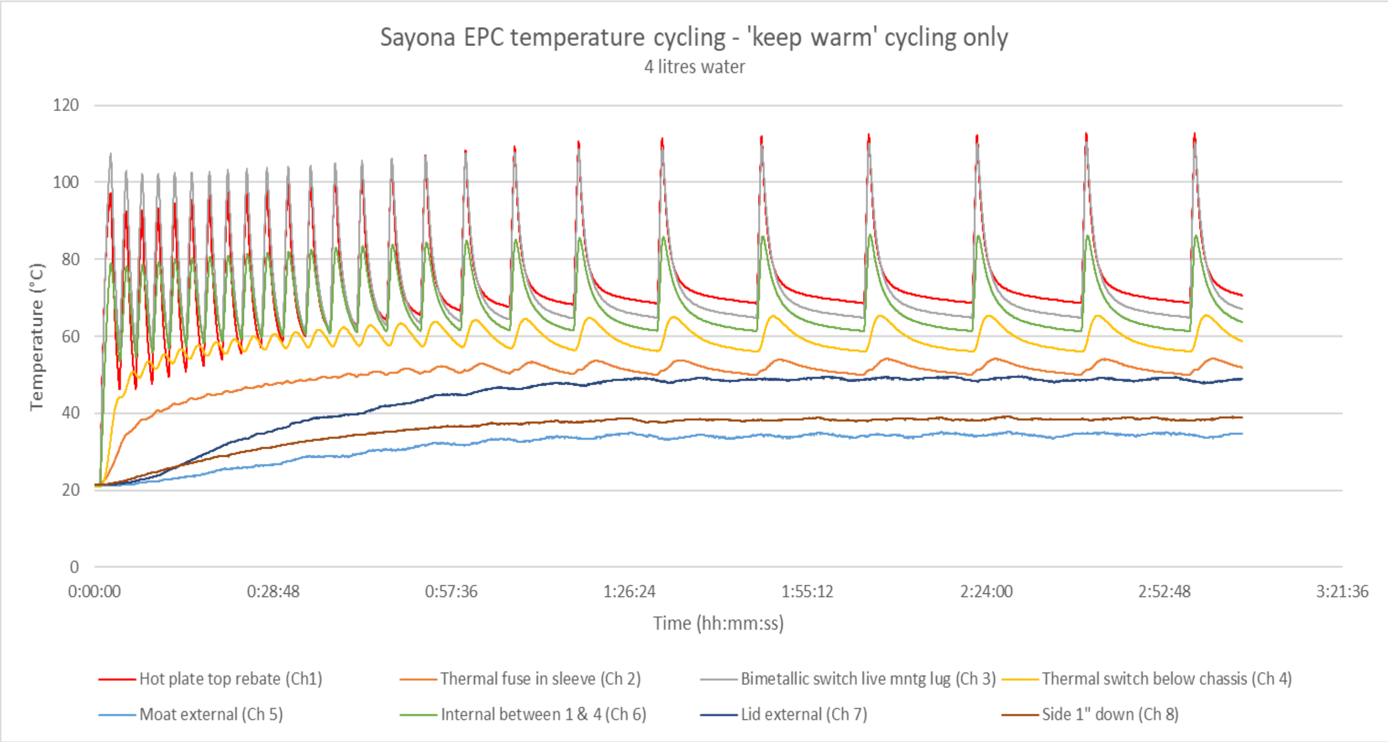
The closest thermocouple temperature to the water temperature is Ch1 between the hotplate and pan. This can be seen to rise rapidly when power is on but only reaches >100°C for a few seconds, then cools rapidly as the excess heat is diffused into the water, bringing the difference back down. It is likely the local water temperature adjacent to the hotplate is approximately 72°C after a power pulse but then drops back to approximately 68°C before the subsequent power pulse. However, the lid external temperature Ch 7 remains below 50°C which indicates either there is a significant stratification – plausible because heat is applied at the base – or that there is little steam to effectively transfer heat to the lid material from the water surface approximately 10cm below.

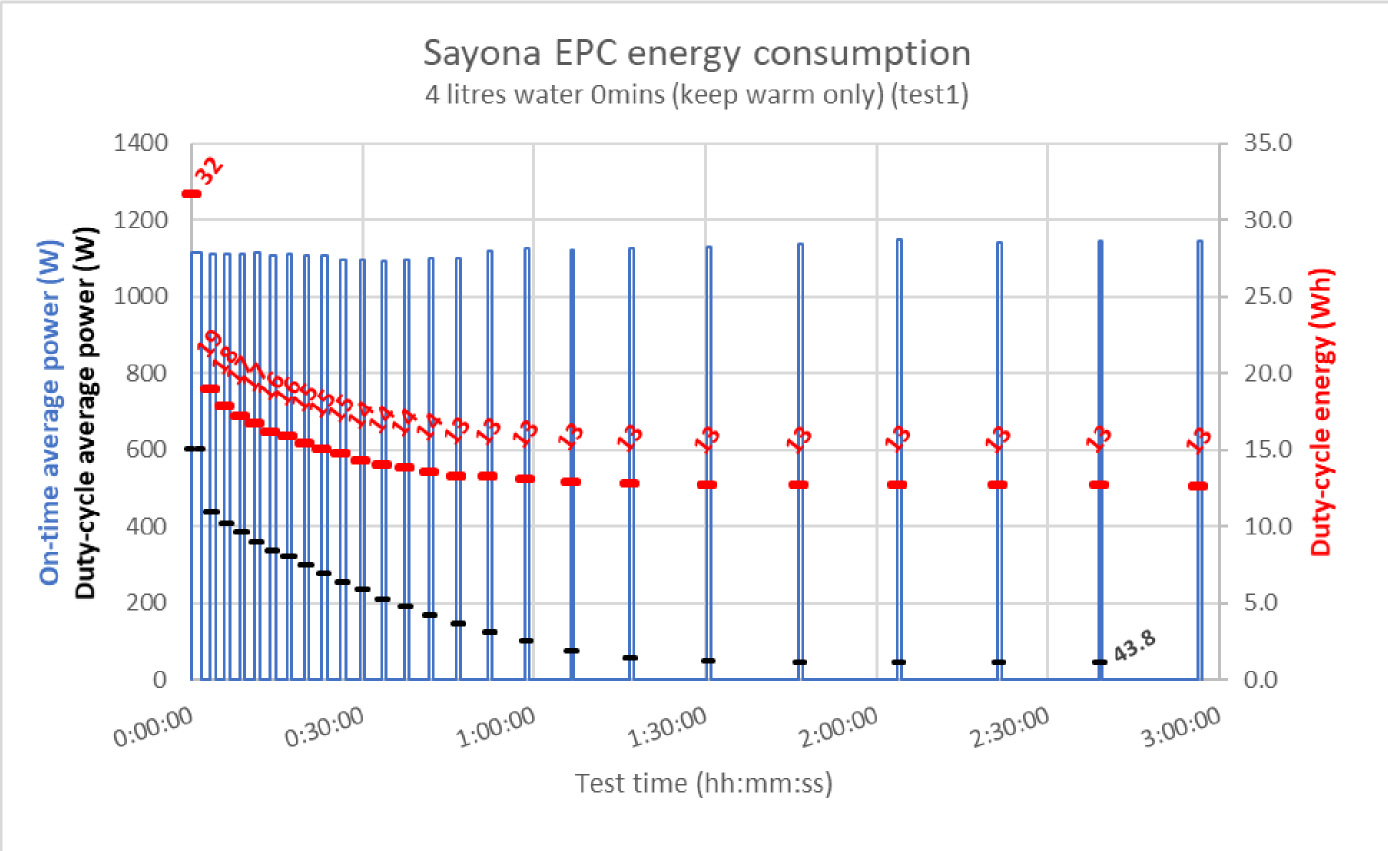
The tests were suspended when the temperature cycles were stable. Boiling temperature and therefore pressurisation cannot be achieved. The final average power input 40.9W, depite the lower cooker temperatures, does not exceed the average heat dissipation. Thus the average temperatures cease to increase.





3 litres water, keep warm mode only. The greater mass of water stabilises the hotplate more effectively so that the temperature cycle band is narrower. The test did not reach stability; the average power input was continuing to fall.





4 litres water keep warm mode only. This test was allowed to reach stability and indicates a similar final average power input as the 1 litre test, 43.8W.