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Performance evaluation of a solar heating plant in Ellös.

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Abstract

A performance evaluation on a newly built solar heating plant in Ellös municipality was carried out. The plant generates heat for a district heating network via a boiler system (4MW), 1000m^2 of solar collector arrays (700kW) and utilises a hot water storage tank (200m^3). Logged plant operational data for May, June and July 2011, was analysed for correct system operation. The return network temperature to the plant was noted to be too high. This high temperature limited the solar collectors contribution to the storage tank to operating temperatures above 60.6°C. Further data analysis, indicated that the distribution network substations may be contributing to this high return temperature through incorrect settings or faulty equipment. Four major stations were pinpointed for inspection, Hallberg Rassy boat manufacturing yard, Strandgärden retirement home, Ellös School and Sjogården hotel. A simplified model of the plants current operation settings was created in POLYSUN. The network piping was modelled as a yearly constant forward (74.6°C) and return (60.6°C) temperature, along with having a variable hourly flowrate of hot water drawoff equating to 344,000m^3. These inputs were calculated from the logged summer months data and monthly substation data available. The model was comparable with the summer month's logged data under hot water being demanded, boiler heat being supplied and solar heat being supplied. Simulations were run to optimize the plant operation. It is recommended to increase the plants solar collectors to 2000m^2, and reduce the return temperature to 50°C, which results in an annual 7% fuel saving for the boiler.

Key words:

Solar heating, District heating networks, Solar collectors,

A special thanks to Jan-Olof my supervisor for taking me under his wing for this project. His guidance, knowledge, and sense of humour made the project work rewarding and enjoyable.

The staff at Chalmers within the Energy and Environment department were always on hand to provide Fika and chat for the needed breaks in work. The staff within the Ellos plant were always helpful during visits and providing plant information. Thanks to all.

Thanks to Simon and Bengt for examining the project in Denmark, and to my Family for not disowning me after telling them I'm quitting my job in Ireland and going back to school in Scandinavia.

Table of Contents

List of Symbols

Symbol	*Parameter*	*Unit*
P	Power	W
T	Temperature	°C
Δ	Delta	difference
m_f	Flow rate of glycol fluid	m^3/s
m_w	Flow rate of water	m^3/s
C_f	Heat capacity of glycol fluid	J/kg.K
C_w	Heat capacity of glycol water	J/kg.K
ρ_f	Density of glycol fluid	Kg/m^3
ρ_w	Density of glycol water	Kg/m^3

List of Abbreviation

Abbreviation	*Meaning*
GWh	Giga watt hour
MWh	Mega watt hour
kWh	Kilo watt hour
HEX	Heat exchanger
GT	Temperature sensor
SV	Valve
VVX	Heat exchanger (schematic)

1 Introduction

1.1 Background

Within Orust municipality, a solar heating plant was built and has been in operation since spring 2009. This plant was built to provide heat to a district heating network which was built the same year. This network extends to the nearby town of Ellös supplying heat to various customers, ranging from residential areas, a hotel, a school and a boat manufacturing yard.

The plant itself generates heat through various sources, a 4MW wood chip boiler with exhaust gas heat recovery, a solar collector array (about 700kW, 1000m^2), and an auxiliary oil boiler. The plant also utilises a large hot water storage tank. This storage tanks purpose is to act as buffer for the wood chips boiler and the solar collector array when the heat demand in the district network is less than the boiler and collector operation.

1.2 Technologies

A solar heating plant consists of an array of solar collectors connected to a heat generating plant. This plant generates heat through burning fuel in a boiler to heat up water. The collectors absorb solar radiation from the sun and transfer this heat to a fluid which passes through them. This fluid is then sent to the plant were it contributes its heat to the hot water that is being sent to the customers. The plant is connected to a network of pipes which connects to the customers who desire the hot water. The amount of hot water that is supplied by the plant depends on how much the customers demand. This demand is typically quoted in GWh (equal to 1,000,000 kWh). The plant at Ellös supplies typically 4-5GWh per year. The city of Göteborg demands around 4000GWh per year. The largest solar plant in Sweden at Kungälv supplies 100GWh per year. This plant has 5 times the solar collector area and storage tank capacity as the plant in Ellös.

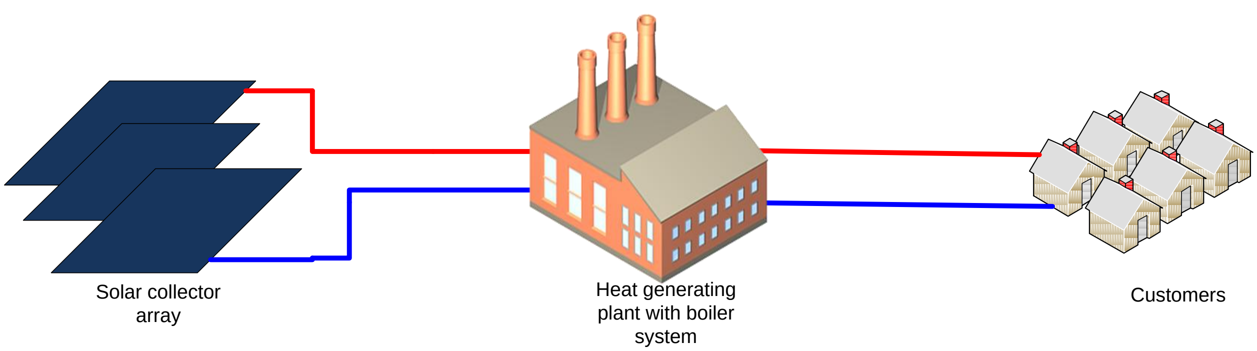


Figure 1 - Typical district heating network with solar heating plant

1.3 Problem formulation

A performance evaluation on the plant is required due to the grant conditions the project is partly financed with. The plant is (at present) designed for a 4MW load, but is typically operating at a lower heating load of about 1-2MW. The minimum operating load for the wood chip boiler is 1MW. Hence, there is often excess heat needed to be transferred to the storage tank, which results in it being full more often than not. As a result of this the solar heat is generated at high operating temperatures when solar heat becomes available.

An investigation will be performed on the plant operation through logged data and computer simulations. Data detailing the plant operation has been logged for 3 months, from which any patterns of inefficient operation can be checked. A simplified model of the plant will be created in POLYSUN, a well-known solar thermal simulation software. Simulations will be run with similar conditions and operating loads as in reality to see how the model performs in comparison. Also simulations will be run to find the optimal operational conditions of the plant.

2 Current plant

2.1 System components and operation

The plant consists of a closed solar and storage tank loop, hot water storage tank, boiler system and network piping which are connected by heat exchangers and valves. The solar loop connects the solar collectors with the storage tank via a heat exchanger. The storage tank piping connects the storage tank with the network piping. Lastly the network piping is connected to the boiler system, and supply's/receives water from the district network.

The flat plate solar collectors were model HT-ARCON, and had each a 12.5m^2 aperture area. Together there were 80 collectors amounting to 1000m^2. The storage tank was a 200m^3 capacity which was constructed onsite. The piping dimensions within the plant varied between 125mm and 300mm internal diameter, with steel piping and rigid insulating foam being used. Table 4 on page 21 details the lengths and widths of piping within each loop. The boiler system has a 5MW capacity of which 4MW from a woodchip boiler, 1MW from an auxiliary oil boiler, and there existed another oil boiler as backup. Jan Forshaun is the manufacturer operation designer of the boiler system. This boiler system was operating as unit independent of individual component control.

The following subsections describe each section of the plant and how they operate together. Whilst reading this system description Figure 2 should be consulted to understand equipment sensor referencing. The sensors within the Figure 2 follow a labelling pattern; (GT) indicates temperature sensor, (SV) indicates a valve, (VMM) indicates a power meter, (P) indicates a pump, and (VVX) indicates a heat exchanger. The power meters measure the power between two temperature sensors labelled with a blue sensor instead of the default yellow sensor. Hot flow is symbolized by a red pipe and cold flow by a pink pipe. In addition to this (VP) indicates the particular loop the sensor is located within. If no (VP) is labelled before a sensor, this sensor belongs to the storage loop. This particular labelling system has been omitted from this report. The real plant also contains a heat recovery system on the boiler systems exhaust gases as shown in the original system schematic. To simplify explanations and future model simulations this element of the plant was omitted.

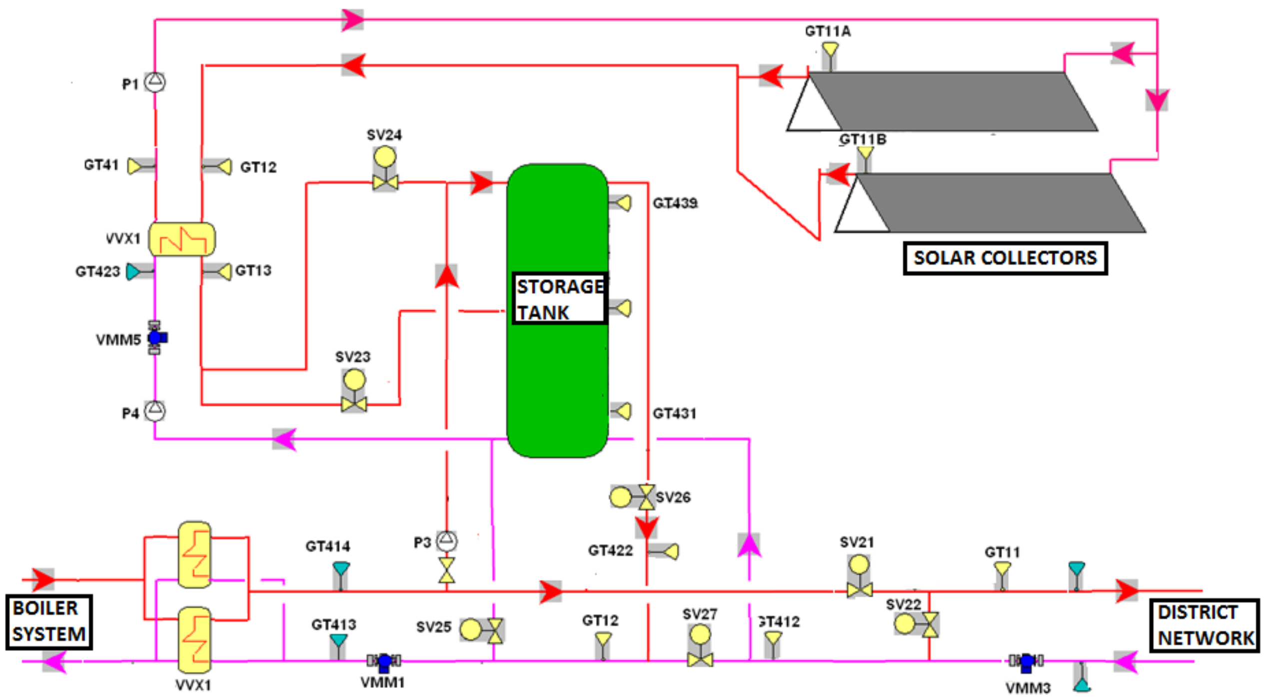


Figure 2 - Plant layout with data measuring sensors labelled

2.1.1 Solar and storage tank loops

The solar collectors transfer heat from the sun to the fluid passing through them. When the temperature is high enough in the solar collector fluid at sensor (GT11A/B) the pump (P1) is signalled to pump the fluid around the solar loop. Pumping the fluid around the loop allows heat to be transferred through the solar heat exchanger (VVX1) to the water filled storage tank loop.

There exist two temperature sensors at the collectors (GT11A) and (GT11B). One of these sensors is backup in case one breaks, as this temperature reading is important and being located outside is exposed to the elements. The pump (P1) starts to pump the hot fluid from the collectors towards the solar HEX when a temperature of at least 25°C is reached in the collectors, and this operation is stopped once it drops below 23°C. The maximum temperature which the collector fluid is allowed to reach is 110°C, at this point pump P4 of the storage tank loop stops operating. This prevents any more heat being exchanged from the solar loop and the storage tank loop.

There are predefined set points, which determine when it is the best time to turn pump P4 on and circulate water from the storage tank loop towards the solar loop heat exchanger to utilize the solar heat. When the forward temperature in the solar loop (GT12) is at least 5°C warmer than the bottom tank temperature (GT 431), the pump (P4) is turned on. This pump operation is ceased when the temperature difference is less than 2°C.

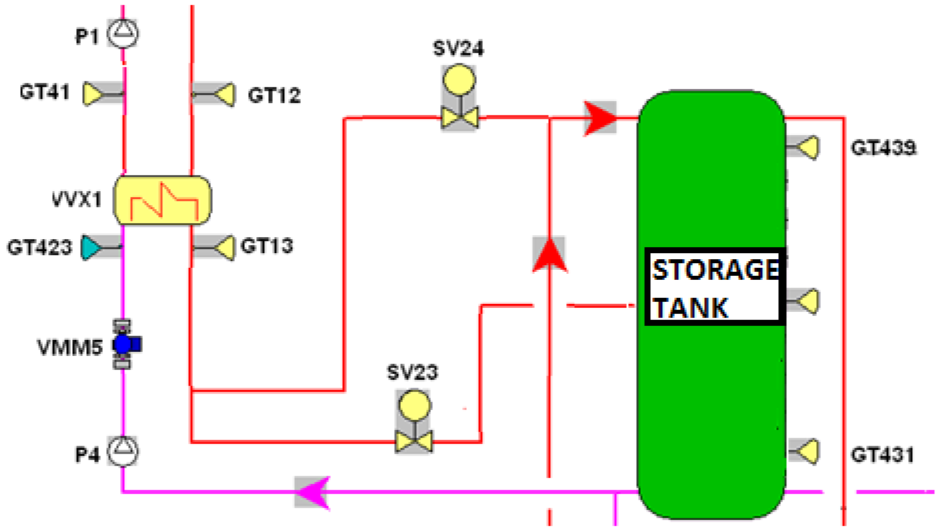


Figure 3 - Solar HEX (VVX1) position and associated sensors within the storage tank loop

There exists a 3-way switching valve for charging the storage tank with the solar heat. The tank can be charged either in the middle layer of the tank or top layer, depending on how hot the water temperature is after the Solar HEX (GT13). When the water temperature after the Solar HEX is higher than the average top tank temperature layers, the water is sent to charge the top of the tank. This causes (SV24) to open and (SV23) to close. The middle of the tank gets charged when this is not the case, hence (SV24) gets closed and (SV23) is made open.

2.1.2 Boiler system

There exists a boiler system to heat up the water returning from the district network to a set temperature, before it leaves the plant. Three boilers of different operating capacity and purpose exist within this system. A 4MW firewood boiler with 1MW minimum operating load is used typically in the higher hot water demanding winter months. There is also a 1MW oil boiler, with low minimum operating capacity and start-up which is always in operation. Lastly, a backup large oil boiler for when there is problem with the firewood boiler.

There exist no temperature settings within the plant manual, which detail temperatures the boiler system cuts in and heats up the return network flow. Common sense assumes that the boiler system must be related to the return network temperature (GT413) and the forward network temperature (GT11). The boiler must cut in at a set temperature level to ensure that the forward network temperature is at the supply set point temperature.

The boiler system is referred to VP01 within the plant schematic and manual. The boiler system has been designed with it’s owe independent controlling system, which is not in sync with the controlling system of the rest of the plant. Hence, the boiler will operate as it has been instructed to by the initial design, and doesn’t factor in the possibility of utilizing the buffer storage tank as much as it could.

2.1.3 Storage loop

There exist three valves (SV25), (SV26) and (SV27) which control the charging, discharging and non-discharging to the storage tank. They work together as follows as shown in Figure 4 to Figure 6.

Charging:

The storage tank is used as a buffer for covering load demand, when the demand is less than minimum operating load of the boiler system (0.8MW). However, when the buffer is needed and the tank is not fully loaded from the solar collector's contribution, the boiler will be triggered to charge it. The storage tank is charged by the boiler through the operation of pump (P3) .Valve (SV25) is used to create a hydraulic water balance whenever the P3 is used to pump water from the hot water from the forward network with the aim of charging the storage tank. In normal plant operation (SV26) is open allowing the storage tank to discharge hot water into the return network piping, and (SV25) is closed. When the storage tank requires to be recharged by the boiler (SV26) closes and (SV25) opens, which allows charging of the tank. The amount of power being discharged from tank is power meters (VMM3) – (VMM1).

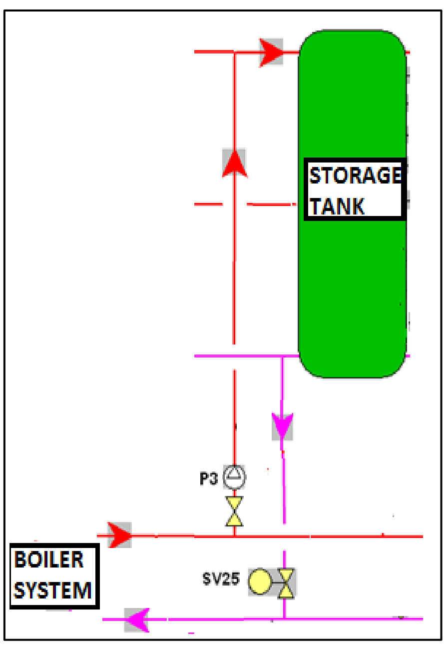


Figure 4 - Charging of the storage tank with boiler system

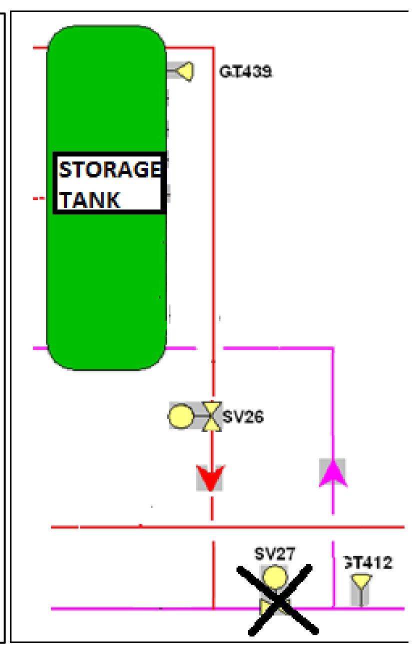


Figure 5- Discharging of the storage tank

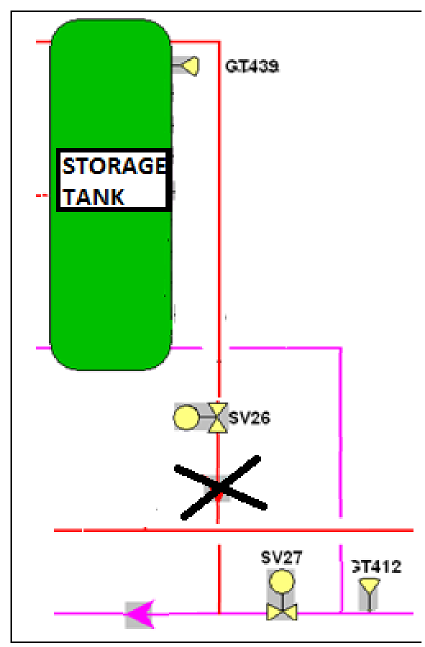


Figure 6 -Non - Discharging of the storage tank

Discharging:

When the top tank temperature (GT439) is at least 3°C greater than the return network temperature (GT412), the storage tank will discharge. This means (SV26) is open and (SV27) is closed. Normal plant operation has (SV26) open, hence default discharging. Discharged stops when the temperature in the top of the tank (GT439) has reached the return network temperature (GT412).

Non-discharging

Default operation of the plant has (SV27) open at 10% always, this is due to some control issue. Whenever the return network temperature (GT412) equals the top storage tank temperature (GT439), (SV27) is opened completely (At the same time (SV26) is closed) to allow the return network flow through. (SV27) remains open until the discharging set point of top tank temperature is reached. This causes (SV27) to return back to default operation as (SV26) opens and commences discharging.

2.1.4 Network piping

The return network comes back from the customers and is monitored at (GT412). When the temperature at (GT412) is lower than the top of the storage tank (GT439), the tank begins discharging into the return side of the network as previously mentioned. This combined cool return network and discharged storage tank water is sent to towards the boiler system heat exchanger. At this point, the temperature of the water is checked (GT413) to see if it satisfies the set point temperature to be supplied to the network. If it is not, the boiler system is called for assistance and to increase the temperature of the forward network. After the boiler HEX the temperature is checked (GT414), where if the water is hotter than the supply set point, it is cooled down via mixing with the cooler return network water. This is done with the mixing valves (SV21) and (SV22). Finally, a reading of the temperature being supplied to the network is recorded at (GT11). This process is illustrated in Figure 7.

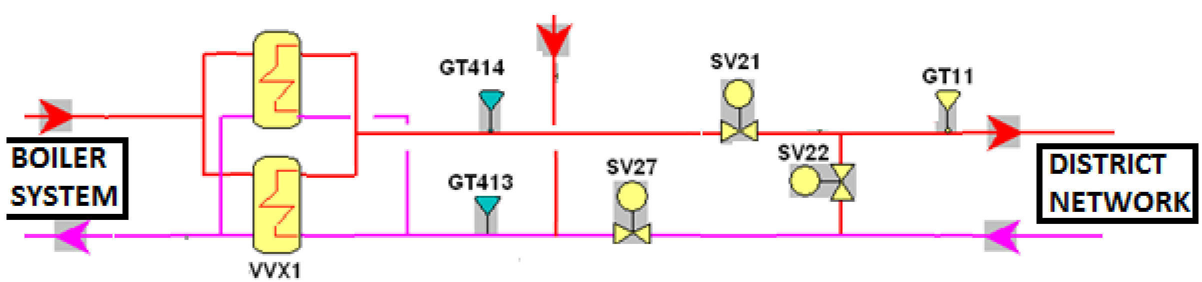


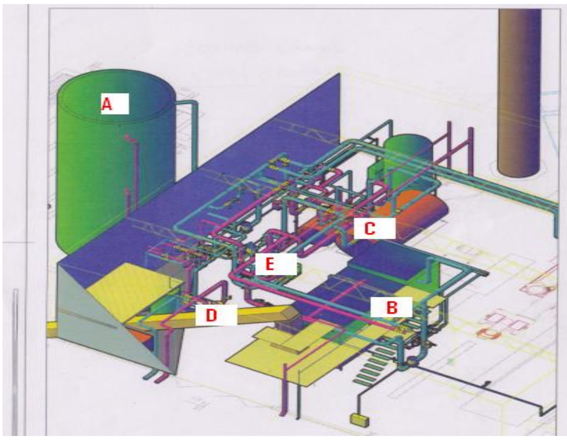
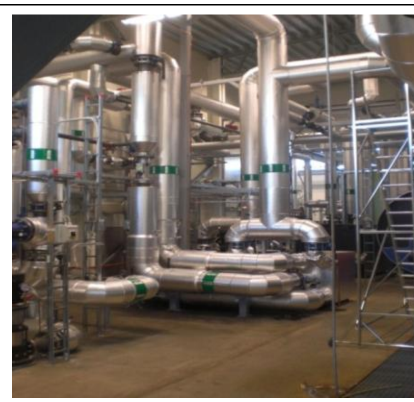
Figure 7 - Network piping operation

The district heating network extends to the town of Ellös, of around 1000 households and buildings. The major consumer within this network is a ship building company “Hallberg and Rassy”. This company uses the network heat directly to dry the paint being applied to the ships, and requires the heat to be at approximately 70°C. This temperature determines the minimum set point of supply network temperature from Ellös plant. The supply temperature to this network is also influenced by the outside ambient temperature, however this minimum value for the boat company must be met.

2.1.5 Plant photographic survey

The plant was visited on three separate occasions during March, April and May 2010. During this period, measured data was retrieved from plant operators (Section 2.2), and photos of the plants equipment and site layout was taken.

 Figure 8 - Interior plant schematic	A Storage tank B Wood chip boiler C Auxillary Oil boilers (x2) D Solar HEX E Boiler system HEX's
 Figure 9 - Wood chip boiler	 Figure 10 - Wood chip boiler
 Figure 11 - Solar Hex and Solar loop forward/return pipes	 Figure 12 - Boiler system HEX's

2.2 Measured Data

2.2.1 Plant operational data

Ellös plant records daily "reports" of sensors within the plant. These sensors include the temperatures (GT), power (VMM) and valve position (SV). There were 5 separate reports "Acktank", "Solfangare", "Urladdning", "Utg_natning", "Vmm1_5". The data within "Acktank" and "Vmm" had sensor reading in 5 minute intervals. The remaining reports had data in hourly intervals. . For this projects study, the content of these reports were requested.

The reports format was Excel worksheets. Each daily report had to be altered and complied into one large continuous worksheet in order for the data to be plotted. There were three stages of processing the raw data into a graph-able continuous format, as shown in Figure 13. Each daily report had several sensors which were stacked on top of each other like separated rows as shown in stage 1. Each sensors reading were copied and pasted into a side by side column format as seen in stage 2. Next the altered daily report was pasted into a worksheet, so that all the data was time continuous as shown in stage 3. A "date&time" column was inserted to allow Excel to show the timeline. Now the data could be easily graphed.

Related sensors were compiled into the same graph to aid understanding of the plants operation. Six graphed series were developed, A- Storage tank, B – Forward Collector loop, C- Solar HEX with tank, D – Tank discharging, E- Network and boiler HEX, F – Power Meters, and H – Heat usage. Within each series, 4 different time periods were plot for visual understanding, an OVERVIEW (3 months), APR/MAY, JUNE, JUL/AUG. All this graphs are included in the Appendix.

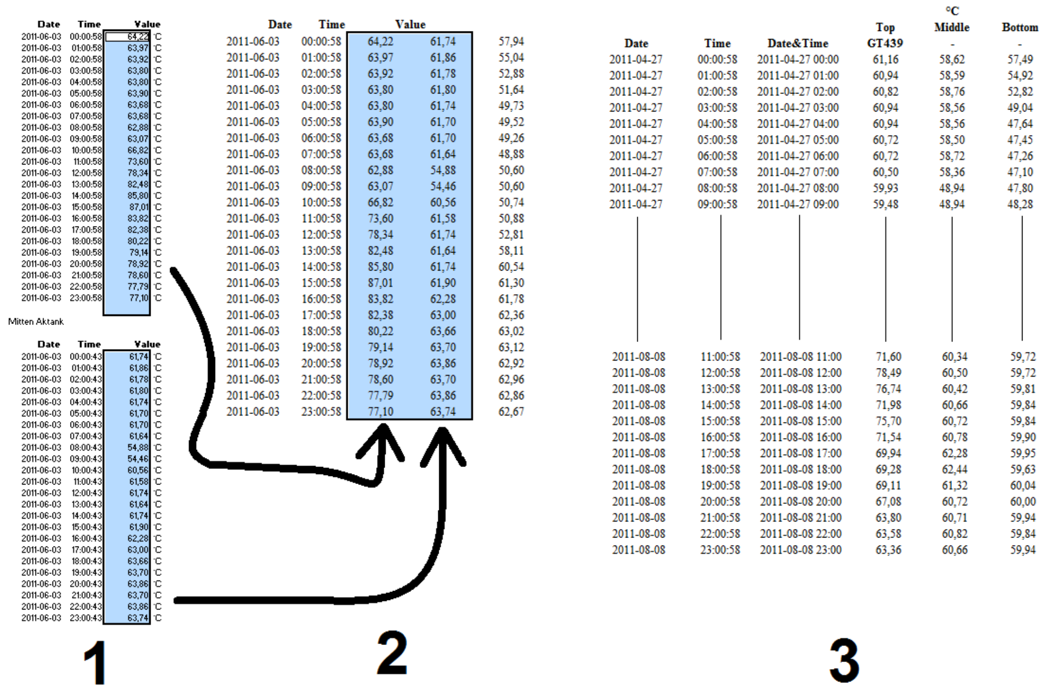
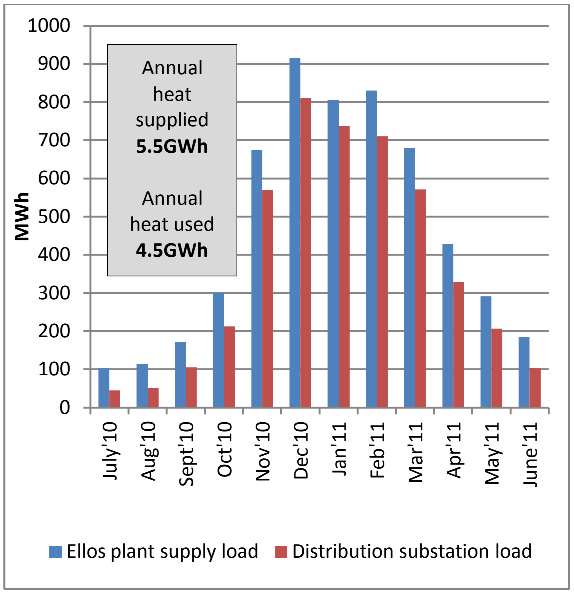


Figure 13 - Data processing technique for received rapports

2.2.2 Substation data

Since the plant has been in operation the heating loads have been recorded at the networks distribution substations. This data which also includes the supply load of the plant during the same monthly periods, has been attained in printed format and compiled into a worksheet format. This is important for this study as previously only the data from 3 months (May 2011 to August 2011) was known in detail. These additional monthly heat load values can help see how the accuracy of the model simulations compare, and in particular help develop a load profile for the year as explained in Section 3.5. From Figure 14, it can be seen the total heat being supplied to the network by the plant is 5.5GWh, of which 4.5GWh is being utilized by the customers. This equates to 19% of heat being lost through distribution losses.



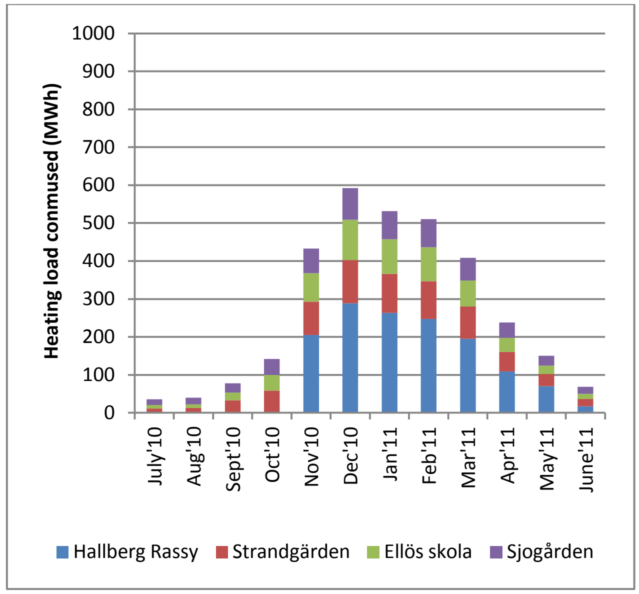


Figure 14 - Supply/use of load to distribution substations.

Figure 15 - Major distribution stations contribution to monthly heating load

There exist 15 substations which contribute to the 4.5GWh consumed. Two of these, “Friborgsvägen 2” and the boat painting yard “Hallberg Rassy”, came into substation operation during December 2010 and November 2010 respectively. In a pie chart within the Appendix showing how much heating load was recorded at each substation over the year period (July 2010 to June 2011), it can be seen that 75% of the load is from 4 major consumers; Hallberg Rassy, Sjogården, Strandgärden, and Ellös skola. Hallberg Rassy is a boat manufacturer at the harbour front. Sjogården is a hotel with conference centre and spa, Strandgärden is an old person’s retirement home in the centre of the town which has 50 housing units, and Ellös skola is the local school. The location of these substations relative to the plant is shown in Figure 16.

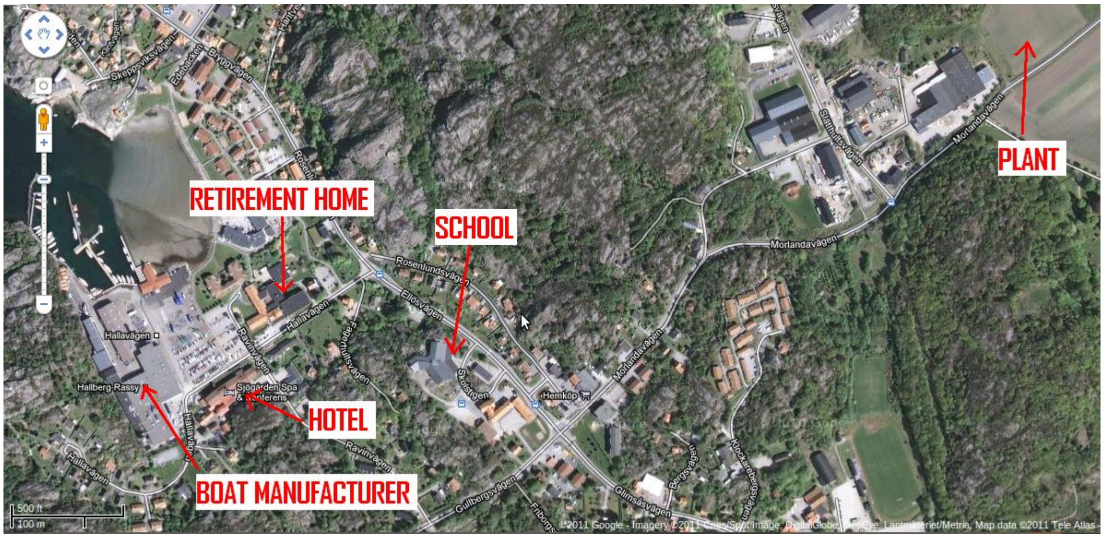


Figure 16 - Proximity of major distribution substations to Ellös plant

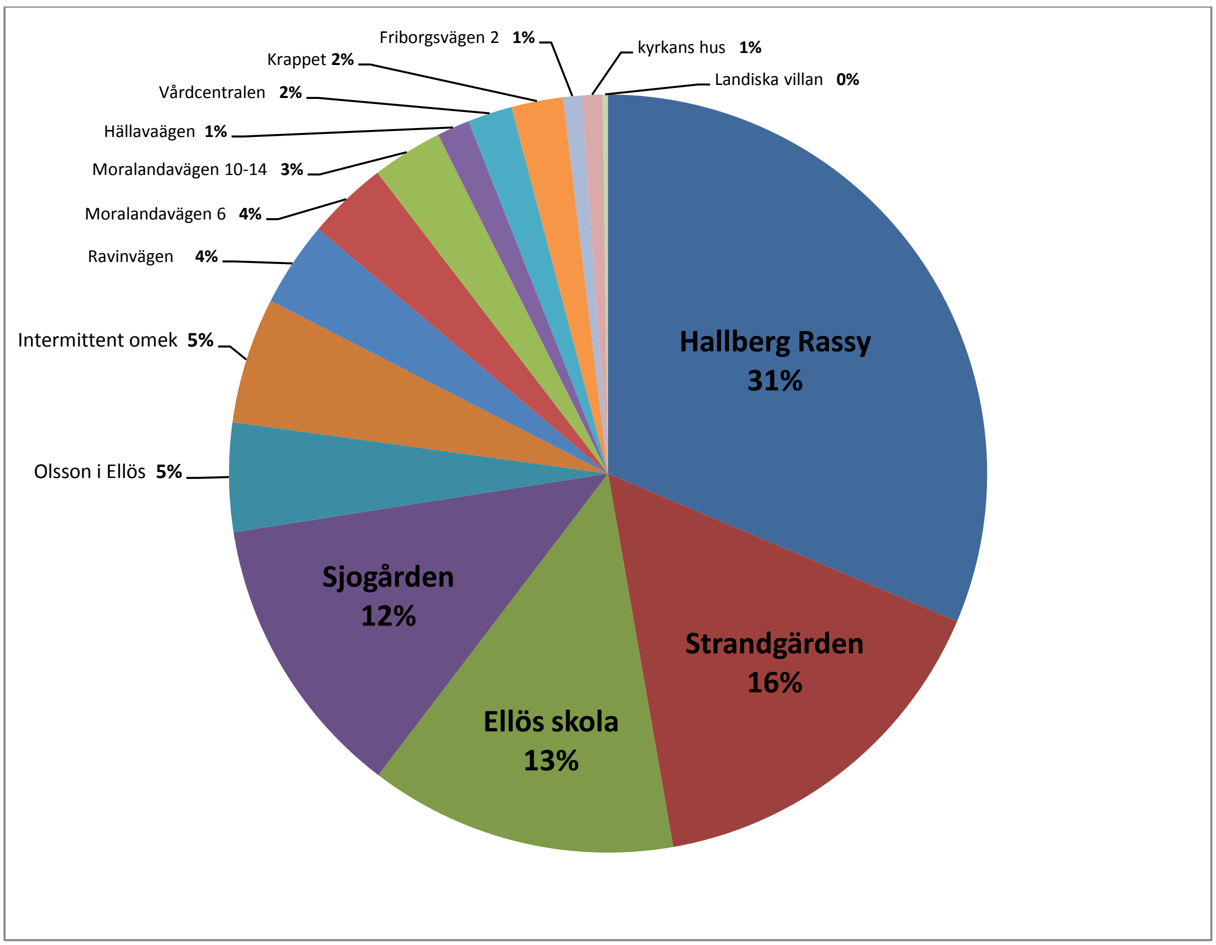


Figure 17 - Consumer contribution to substation yearly load

3 Model Development

3.1 Methodology

The current plant needed to be simplified to its basic operation before modelling could begin. Figure 18 shows this simplification. The solar and storage loop remains the same. The return network supplied cool water directly to the storage tank bottom. The forward network is drawn directly from the top of the storage tank. A temperature controller checks this top tank temperature to see if it satisfies the supply setting to the network. If not, the boiler system is called upon, and transfers heat to the forward network via a heat exchanger. There is also a system recovering heat from the boiler systems exhaust gases, and contributes to the cooler return network piping.

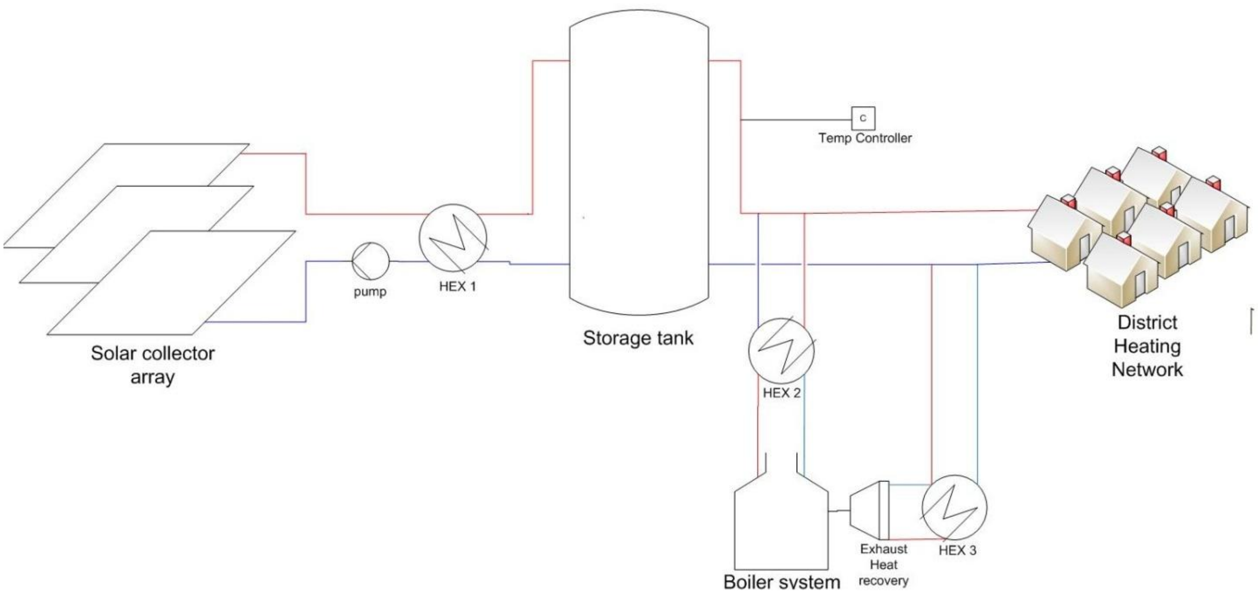


Figure 18 - Simplified schematic of Ellös plant operation

Next, a program to model this simplification was required. Polysun is a solar thermal simulation software. Roughly 200 templates of solar thermal systems are available within Polysun. These range from a simple boiler heating up a hot water storage tank, to including several storage tanks, various types of heat pumps, pool heating, heat exchangers, photovoltaic's , process systems, boilers and cooling systems. There exists a template which was well suited to the simplified Ellös plant system schematic of Figure 18. The difference between the schematic and template is a hot water return and supply network. Currently the template is set up for space heating of a building and has no hot water draw off, as shown in Figure 19.

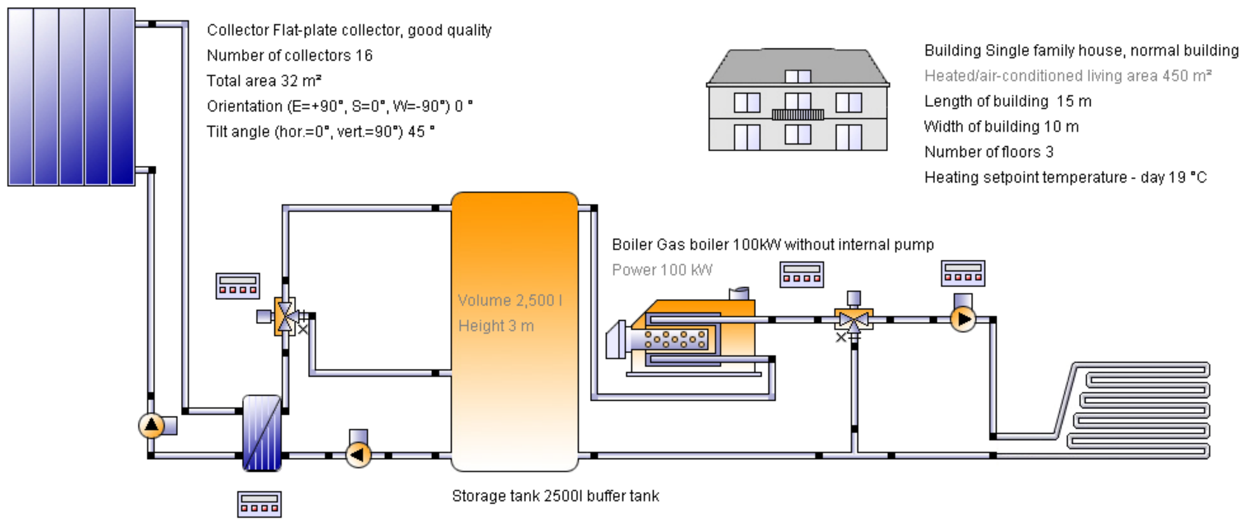


Figure 19 - Initial system template 13A within POLYSUN

The plan was to systematically change the component sizes and controller settings of this existing template, whilst bringing it closer to the Ellös plant system layout and operation. This method ensured that the model would run without any major simulation problems.

Firstly, the operation of the initial 13A template Polysun model had to be understood fully. Next, the required Ellös plant operating component size and controller settings were extracted from the plant designers operating manual (Sneider, 2011).The following subsections explain how each component of the system was developed according to the real Ellös plant.

3.2 Weather and location

Within Polysun there exists a meteorological database of locations around the world. The nearest town to Ellös in Polysun which is included in its meteorological database is Gothenburg. Table 1 shows this data, which has been averaged over historical data from the period 1960 -1990. Polysun generates hourly values based on these monthly inputs. Of greatest importance in these inputs is the global radiation (kWh/m^2). This yearly sum of 940KWh/m^2 is typical for the global radiation on a flat surface for this region.

Table 1 - Meterological data for Gotenborg within Polysun

	Yearly	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec
Global radiation (KWh/m2)	**940.9**	11.5	25.2	57.9	104.8	152.8	160.9	164.5	124.6	77	38	15.9	7.8
Outdoor temperature (°C)	**7.6**	0.02	0.1	1.5	6.3	10.7	14.1	16.5	16.8	12.9	8.1	3.9	0.4
Wind speed (m/s)	**3.82**	4.2	4.6	3.9	3.6	3.7	3.8	3.4	3.2	3.6	4	3.9	3.9

3.3 Solar loop and storage tank loop

Within the real plant, both the solar collector loop and storage tank had independent pumps regulating them with specific control settings. Within the Polysun model, a controller was defined for each loop operation. The solar loop was controlled by “Solar loop pump”. It operated and pumped fluid around the loop when the temperature in the collector was above 25°C, and stopped when this temperature was below 23°C. The storage tank loop was controlled by “Storage loop pump”, it operated and pumped water around the loop when the forward collector temperature was at least 6°C greater than the bottom tank temperature, and stopped when this difference was below 2°C. Both loops were connected via a heat exchanger, which transferred heat from the collector fluid to the tank’s water. Figure 20 illustrates the directional flows within each loop indicated by arrows, and temperatures within each loop indicated by light (hot) and dark (cold) colours.

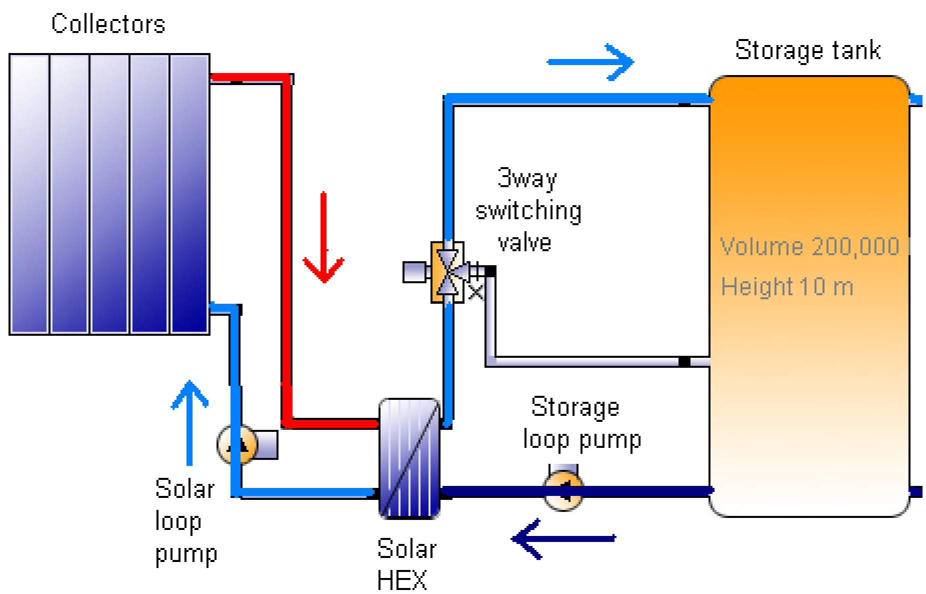
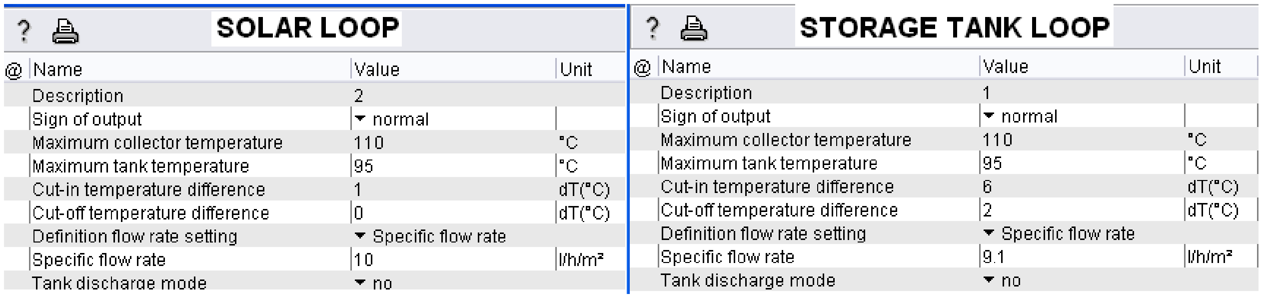


Figure 20 - Solar and storage loop components

Next the flowrates of the fluid and water in each respective loop had to be determined. The flowrate calculations performed on the measured plant data, retrieved the flowrate for the storage tank loop which circulates water. The solar loop has a 40% propylene glycol fluid mixture. For the solar HEX (Heat exchanger) to operate efficiently the heat capacity rate over the HEX must be balanced. Since the glycol fluid mixture has a higher heat capacity (3.8KJ/kg.K) compared to water (4.2KJ/kg.K), the flow rate in the fluid loop must be higher than the water loop. Section 4.1.7 details how the flow rates were calculated from the summer months measured data. The flowrate in the solar loops pump is defined with 19926 L/h (10l/h/m^2). The flowrate within the storage tank loops pump is set to 9.1 l/h/m2. Literature suggests, the collector fluid flowrate to be at 15l/h/m^2 (Furbo, DTU Solar Heating course 11116, 2010).The respective pumps for each loop were ensured to have the capacity to pump at these rates. No reference to a maximum storage tank temperature set point exists within the Plant manual, but a value of 95°C was taken from literature (Furbo, Solar heating course 11116, exercise 1., 2010). The collector was set to be available all year round. These values were inputted into the model as shown in Figure 21.



SOLAR LOOP

Name	Value	Unit
Description	2	
Sign of output	normal	
Maximum collector temperature	110	°C
Maximum tank temperature	95	°C
Cut-in temperature difference	1	dT(°C)
Cut-off temperature difference	0	dT(°C)
Definition flow rate setting	Specific flow rate	
Specific flow rate	10	l/h/m²
Tank discharge mode	no	

STORAGE TANK LOOP

Name	Value	Unit
Description	1	
Sign of output	normal	
Maximum collector temperature	110	°C
Maximum tank temperature	95	°C
Cut-in temperature difference	6	dT(°C)
Cut-off temperature difference	2	dT(°C)
Definition flow rate setting	Specific flow rate	
Specific flow rate	9.1	l/h/m²
Tank discharge mode	no	

Figure 21 - Solar loop and storage loop pump controller settings

In the Ellös plant there exists a 3-way switching valve for charging the storage tank. The tank can be charged either in the middle layer of the tank or top layer, depending on how hot the water temperature is after the Solar HEX. When the water temperature after the Solar HEX is higher than the average top tank temperature layers, the water is sent to charge the top of the tank. The middle of the tank gets charged when this is not the case. Logically this is shown in Table 2, and this is how it is formulated into Polysun by using a 3way switching valve for the solar loop. The two inputs for the controller are the temperatures directly after the Solar HEX and layer 9 of the storage tank. The output of the controller is logical 1 (charge the top tank layer) or logical 0 (charge the middle tank layer).

Table 2 - 3way switching valve of solar loop controller settings within the model

IF	output	Notes:
GT13 (pipe 25) > Average top layers temp	1	Top of the storage tank is charged
GT13 (pipe 25) < Average top layers temp	0	Middle of storage tank is charged

The buffer tank consisted of a 200,000L tank with rigid foam insulation on the sides, top and bottom being 400mm, 800mm and 200mm respectively. Within the real plant, it was possible to charge the storage through the boiler system. For simplification reasons this was not included.

3.4 Boiler system

The boiler system for the Ellös plant consists of a primary wood chip boiler, and auxiliary small oil boiler and a backup large oil boiler. The wood chip boiler has a capacity of 4MW and a minimum running level of 1MW, and the small oil boiler has a 1MW capacity. For simplification reasons one boiler was chosen to operate within Polysun to represent this boiler system. One firewood fuelled boiler with 5MW capacity and 78% operating efficiency was chosen for the model.

Within the real plant, the boiler system transfers heat via closed loop and heat exchanger to the supply network piping (Figure 18). For simplification reasons the boiler was included directly in series with the network supply loop in the model. The boilers inlet was connected directly to the top of the storage tank. The outlet was directly before the 3way mixing valve as shown in Figure 25. The boiler was set to cut in when the temperature coming from the top of the storage tank was 1°C below the hot water demand set point temperature, and cut out when this temperature was 1°C higher than the same set point.

3.5 Network loop

Hot water demand and cold water supply were used to model the real plants forward and return network. Within Polysun it is possible to create a hot water consumption profile based on the quantity of water drawn off per hour OR the temperature of that hot water at each hour. Both inputs are not possible. Hence, the quantity of water being drawn off each hour most accurately modelled the hot water demand and this was used for the profile input. This profile had to detail the exact quantity of water being drawn off in each particular hour for the whole year. These hourly values were achievable from the measured summer month's data using equation (1) in section 4.1.7 (where ΔT is fixed = forward – return temperature and Power = measured load) but only for those months. To create a profile for the remaining 9 months of the year, the measured "sub-station data" between July 2010 and July 2011 was used (Section 2.2.2). Within this data, the monthly load supplied by the plant in May 2011 was known. Knowing this, and already having the measured hourly hot water profile for May 2011 (section 2.2.1), it would be possible to create an hourly hot water profile of the year based on a scaling of May's hot water profile, and average ΔT. To achieve this, first each month of the year was given a scaling value based on May, as shown in Figure 22. Next, the hourly hot water consumption for each month was multiplied by this scaled factor. Then finally each month was compiled to create an hourly list of hot water being drawn off for the year. This list was inputted in a ".csv" format, were the two values listed the year in hours and an associated hot water draw off in litres/hour. Figure 23 shows a sample of the file.

Load factor relative to May	Month
0,4	July'10
0,4	Aug'10
0,6	Sept'10
1,0	Oct'10
2,3	Nov'10
3,1	Dec'10
2,8	Jan'11
2,8	Feb'11
2,3	Mar'11
1,5	Apr'11
1	May'11
0,6	June'11

Figure 22 - Scaled monthly load factors relative to May

Second	Litres	CSV input profile (L/h)
0	31087	0;31086,9724605068
3600	31087	3600;31086,9724605068
7200	29584	7200;29583,866099779
10800	33205	10800;33204,9838337108
:	:	:
31521600	12810	31521600;12809,801070437
31525200	17701	31525200;17700,8177008177
31528800	21583	31528800;21582,5759685409
31532400	21194	31532400;21194,4001417685

Figure 23 - Hourly hot water quantity profile for Polysyun (.CSV file)

Having created the hot water quantity profile, next the hot water temperature and cold water supply had settings to be inputted. These values equated to both the networks forward and return temperatures, which needed to be given a yearly estimation. This estimation was based on the measured summer month's average forward and return network temperatures as shown in Table 3.

Hence, hot water was supplied at 74.6°C and cold water was received at 60.6°C in the model. The hot water demand settings are inputted in the "Domestic hot water" dialogue box in Polysun, as shown in Figure 24. This also includes the annual demand of hot water (344000m3) and the maximum flowrate of hot water drawn off in any hour over the year (293000 L/h). These values were calculated from the previously developed hourly hot water quantity profile. The cold water supply was set to 60.6°C within the systems location settings.

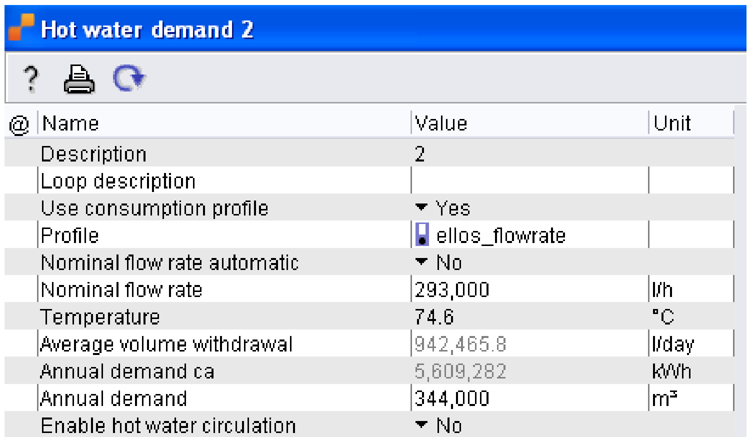


Figure 24 - Forward network hot water demand model settings

Table 3 - Average measured monthly network temperatures.

	Forward network	Return network	ΔT
May	79.3	56.8	22.4
June	72.3	63.1	9.2
July	71.8	62.5	9.4
Averaged	**74.6**	**60.6**	13.6

To achieve the correct hot water temperature supply in the model, a 3 way mixing valve was inserted. This ensured that if the hot water being sent from the boiler outlet was higher than 74.6°C, it would allow cold supply water to mix with it to achieve the correct temperature before supplying to the customers. Figure 25 shows the previously described network loop, including how the boiler, 3 way mixing valve, forward network outlet and return network inlet are all positioned relative to each other. The light blue piping entering the boiler and red piping exiting the boiler indicate the heating of the hot water. The dark blue piping returning/being supplied to the model indicates this is cold water relatively speaking.

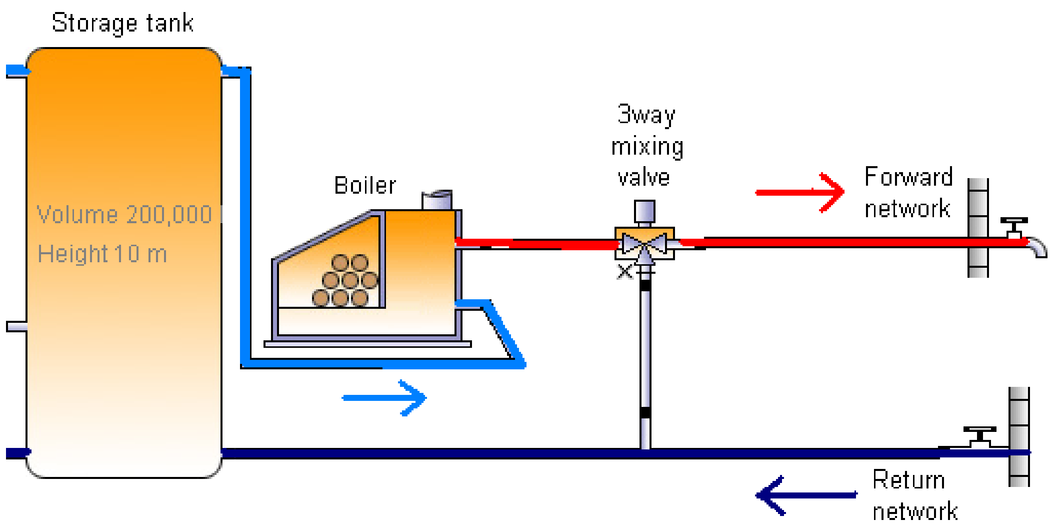


Figure 25 - Network loop with Boiler in series

The piping of the systems loops had also to be taken into account. There are three categories of piping to be modelled. The solar loop, the storage tank loop, and the network loop. On a plant visit photos had been taken of the piping outside and the exact pipe dimensions noted of the solar loop as DN 125/250. For the dimensioning of the storage and network piping, also the photos taken inside the plant were consulted and best guessed, along with the lengths of the piping. The length of the piping for the network is only considered within the plant. Hence, this study does not take into the account the network pipe losses through the distribution network piping. Table 4 shows a summary of piping dimensioning.

Table 4 - Systems piping dimensions

Piping category	pipe/insulation diameter (mm)	Pipe/insulation material	Length (m)
Solar loop	125/250	Steel/rigid foam	40/40/2/2 = 84
Storage tank loop	150/300	Steel/rigid foam	5/5/5/5/5 = 25
Network loop	150/300	Steel/rigid foam	5/5/5/5/5/5 = 30

3.6 Model system layout and parameters

Figure 26 shows the overall layout of the operating model. It can be seen how the components are connected and the flows are within the solar loop, storage loop and network loop.

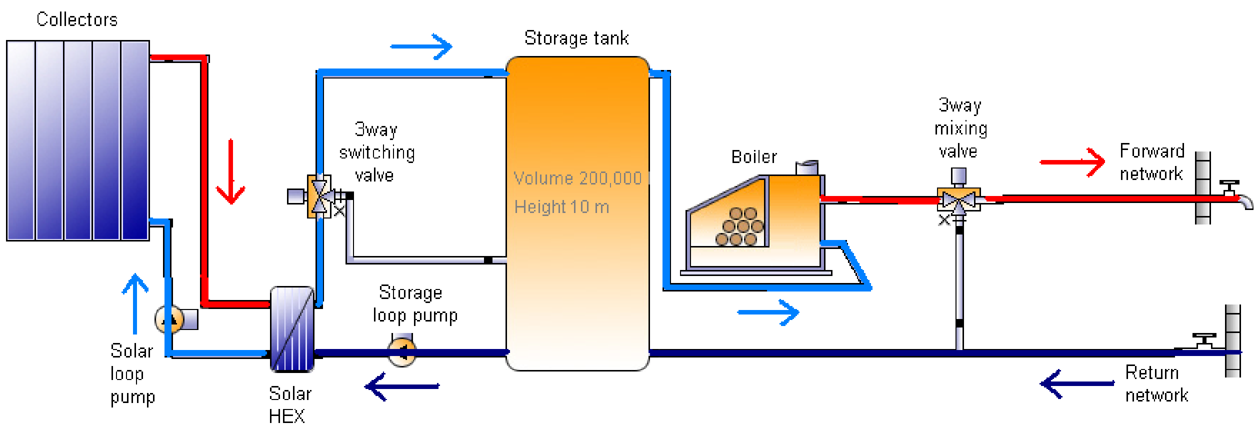


Figure 26 - Operating model layout

4 Analysis

4.1 Measured data system operation verifications

Whilst reading the following section, the graphed Appendix and Figure 2 should be consulted.

4.1.1 Received data errors.

The data received on Mays power readings had some missing values, everyday at midnight and the last 15 hours of the month. It was decided to fill in these values with representative numbers as even though this error occurs in May, through the scaling (Section 3.5) this error would be mirrored for each month of the year, which might not be true. The midnight hours where calculated based on the average of the hour before and after midnight. The final 15 hours of May (9am to 22pm), where copied from the 15 hours (9am to 22pm) values from the previous day (30th of May). Also, for June and July, the same midnight hour missing power meter value occurred, a similar averaging technique was used to create a complete hot water profile file for input into Polysun. The Author is assuming the missing data is an output error, and the plant still operates during this one hour period.

4.1.2 Solar and storage loop

The collector's temperatures of sensors GT11A and B should be the same. They are intended to measure the same temperature of the fluid in the collector. One sensor is used as backup to ensure that there is no problem in the measuring of this temperature. It can be seen from Figure 27, that the forward collector temperature (GT12) plateaus during cool fluid temperatures indicating the solar loop pump is cutting in at 25°C and out at 23°C as expected. Looking at graph series B and H within the Appendix, the month of May seems to be having higher than normal solar irradiance. The solar collector loop is in operation everyday of May and the summed solar heat to the system is around 70KWh/m^2, which is very good for May. Typically the annual heat generated from these collectors is 400KWh/m^2.

Referring to graph series C within the Appendix, the temperature profiles around the solar heat exchanger seem normal. On closer examination during noon in Figure 28, the collector fluid arrives to the HEX at 83°C, and leaves at 60°C, whilst heating up the water in the storage tank loop from below mid- 60°C to mid-70°C.

The solar collector loop pump is only triggered to send fluid via solar HEX when the forward collector fluid is 5°C warmer than the bottom tank temperature. However, the bottom tank temperature is averaging at 60°C over the summer months (Table 3) hence the collector fluid is only being utilized when it is above 65°C. This causes the collector to operate at high temperatures all the time. Therefore the collector is transferring heat to the storage tank only between the hours of 10am and 6pm during the summer months.

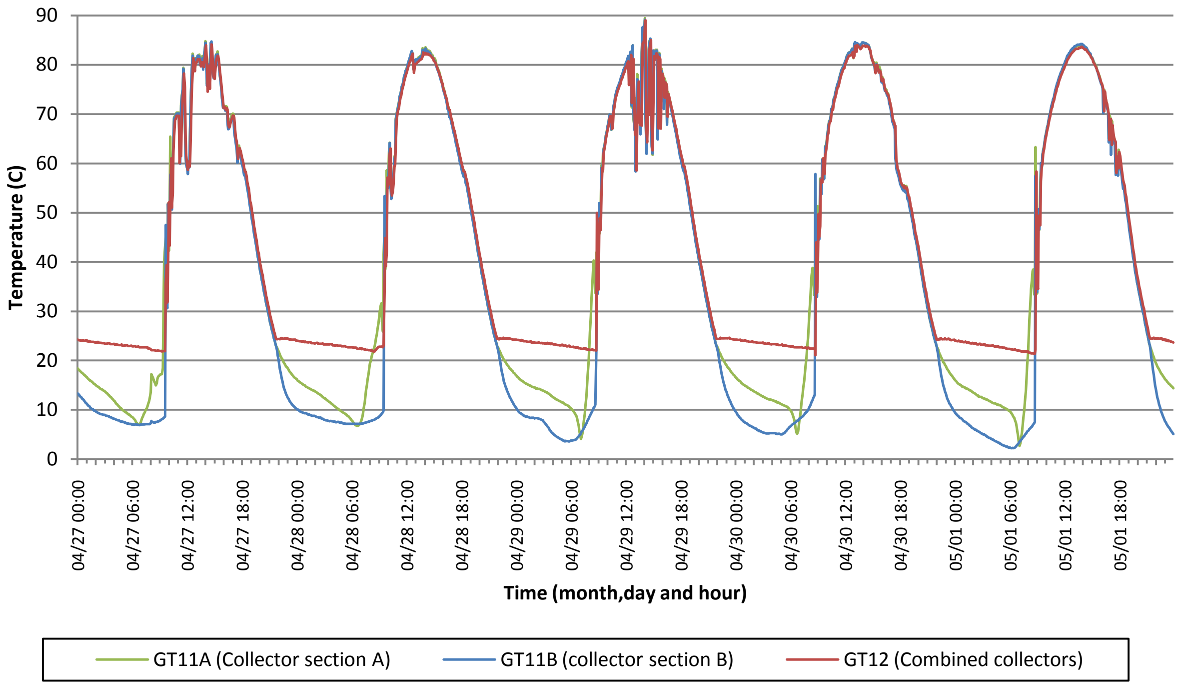


Figure 27 - Solar collectors outflow temperatures

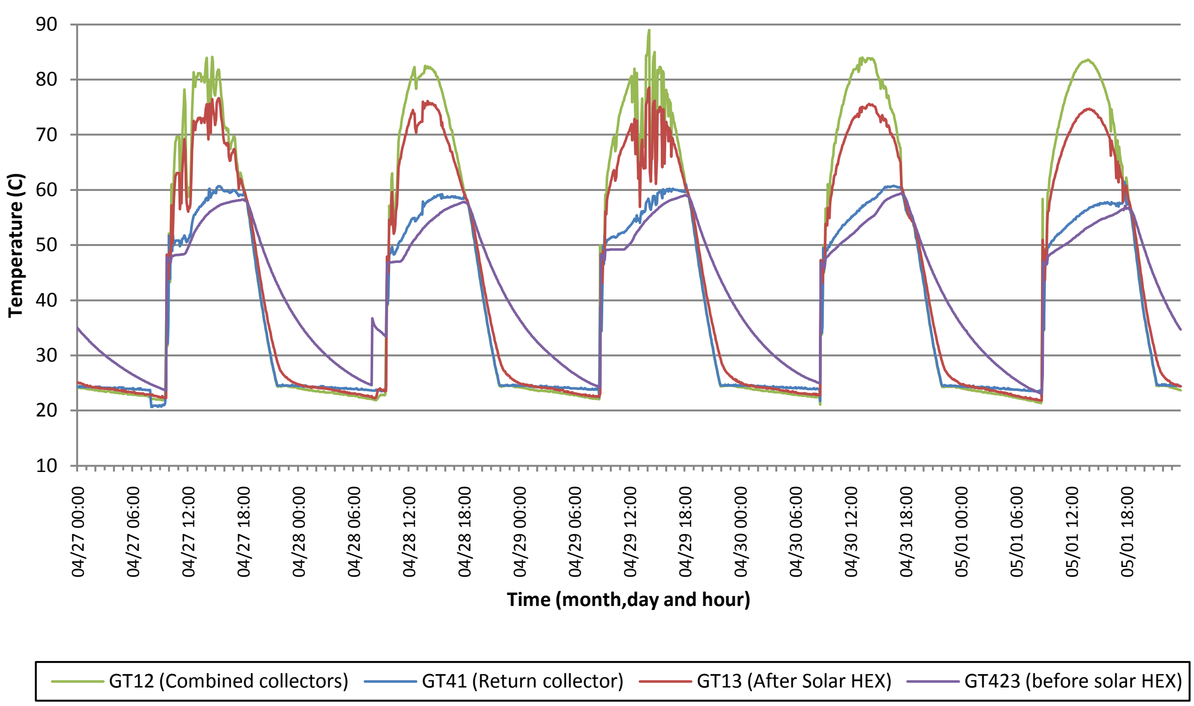


Figure 28 - Temperatures surrounding Solar HEX

4.1.3 Storage tank

The storage tank is set to not reach a top tank temperature above 95°C. Referring to Figure 29 it can be seen that this does not occur. However, the most significant element of this graph is the bottom tank temperature at the end of April which was fluctuating between 45°C and 60°C, and then by the end of July it had plateaued to a steady 60°C. This temperature is too high for the storage tank, from which the return network temperature is directly responsible. This has an adverse effect on the amount of solar heat being contributed to the tank, as the collector fluid will only be used at high operating temperatures.

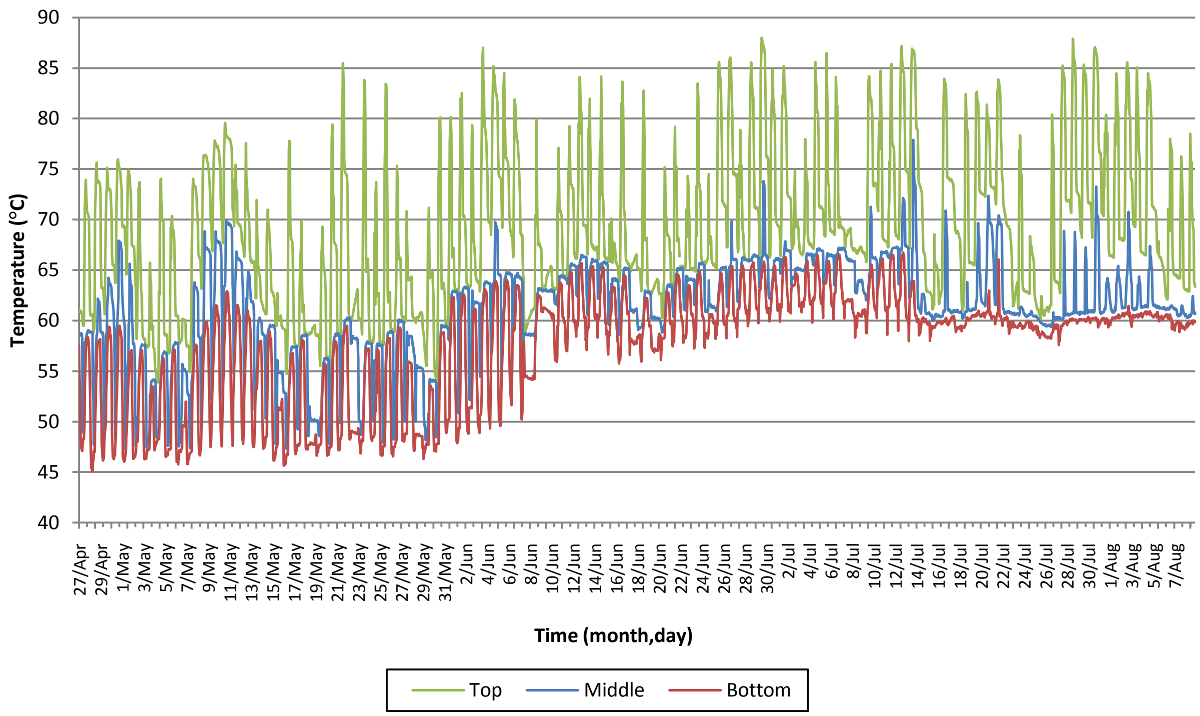


Figure 29 - Overview of storage tank temperatures during summer

4.1.4 Discharging of storage tank

As long as the top tank temperature (GT439) is greater than the return network (GT412), the storage tank will discharge, as shown in Figure 30. As soon as these temperatures roughly equal each other (in fact <3°C difference), the valve on the return network piping (SV27) opens fully and flows through, whilst the tank discharging valve (SV26) is closed. When this temperature difference is >3°C, that is the red line greater than the blue line, the valves switch positions and default discharging commences. Referring to graph series D within the Appendix, this discharging pattern can be seen of the 3 summer months.

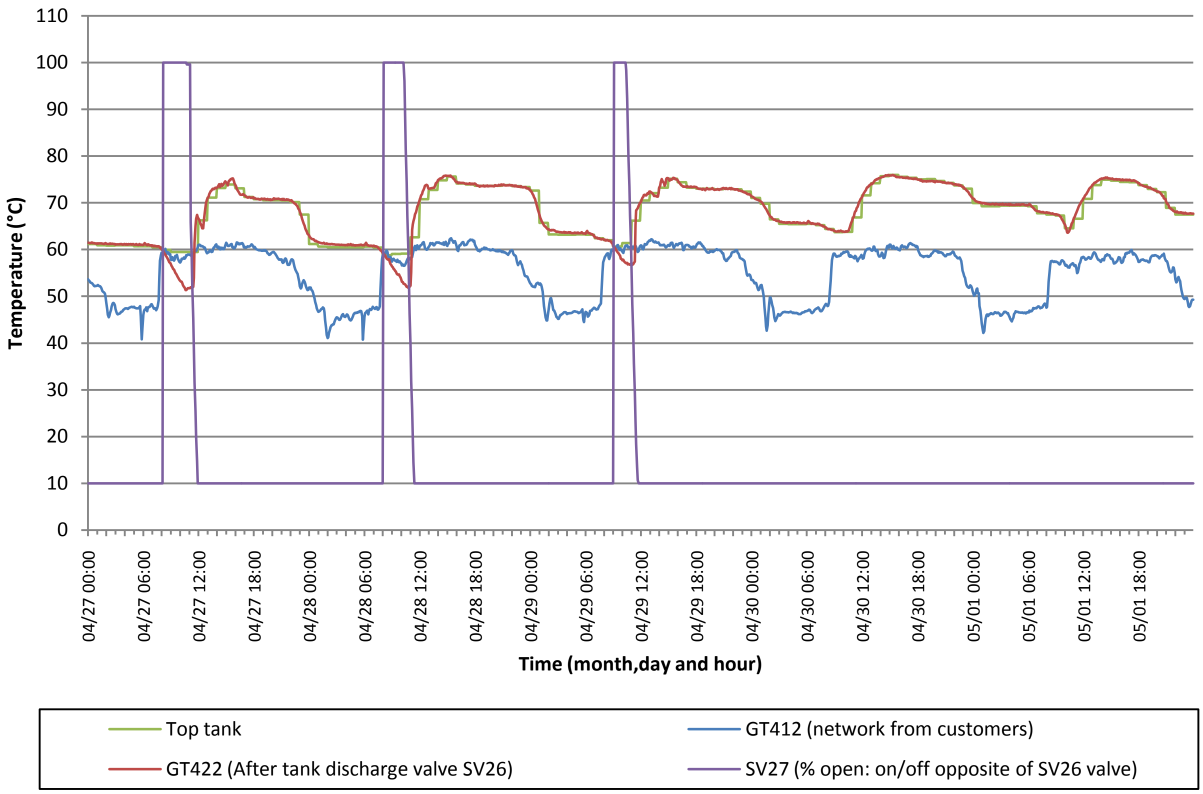


Figure 30 - Storage tank discharging into the return network

4.1.5 Network return and supply temperature

The district network returns its used hot water at temperature sensor (GT412). Looking at Figure 31, this value has a fluctuating daily profile with the night temperature being lower. The storage tank discharges into this returning flow, as the midday peaks in sensor (GT413) suggest. This flow continues towards the boiler where the temperature is increased to (GT412), a temperature which is consistently 10-30°C higher than the hot water supply set point. Hence, the 3 way value is constantly utilised to cool down before sending out to the customer network. It can be said there does not seem to be much coordination with the boiler system and network temperatures, as these high boiler temperatures suggest.

Referring to Figure 32, the varying profiles of the return and forward network temperatures over the summer months can be seen. The difference between both temperatures is not consistent over the summer months. During May the max storage tank temperature does not reach the forward network supply temperature (GT11) on enough occasions. Having a high hot water supply temperature of 83°C is the culprit. This means that the storage tank discharge temperature will never be sufficient which requires the boiler to be in operation all the time. At the start of June this supply set point was reduced to a more reasonable 70°C.

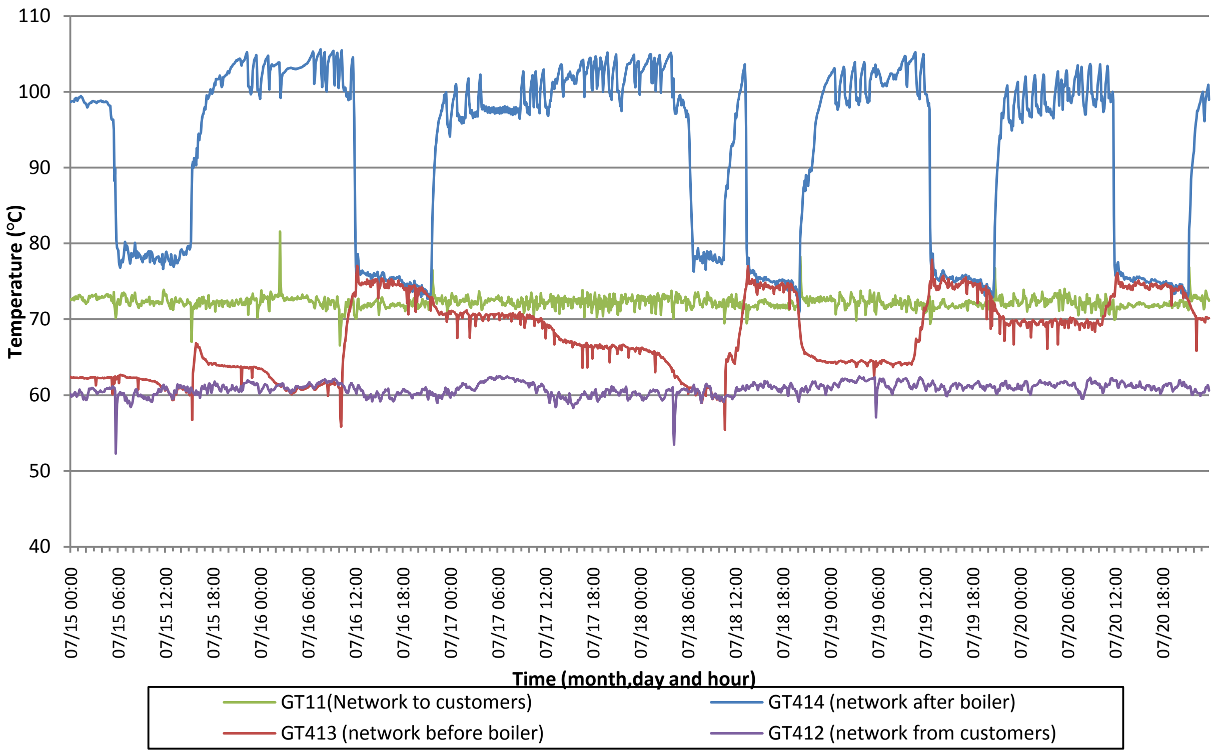


Figure 31 - Network piping temperatures during a week in July

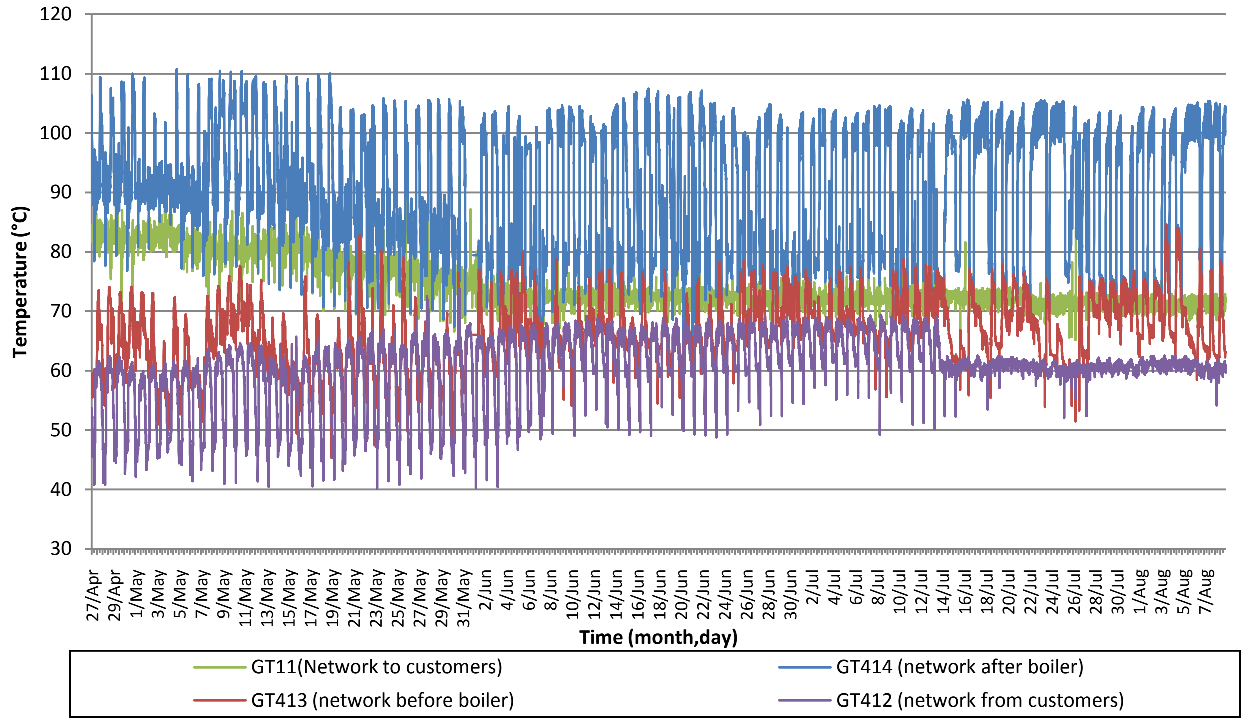


Figure 32 - Network temperatures over the summer months

As mentioned in the storage tank section, the return network temperature profile is too high. This can be explained by looking at a substation HEX schematic between the supply and distribution sides of the network as shown in Figure 33. The distribution side (C) requires water at 80°C for customers. A temperature sensor is connected to the supply side. It senses the forward supply temperature (A) and regulates how fast it needs the flow rate to be to achieve the 80°C at (C). If the forward supply temperature (A) is too high (say 90°C) and/ or the return distribution side (D) temperature is too high (say 60°C), the return supply side (B) temperature becomes high. Not much heat is required to be transferred through the HEX, hence a fast flow rate is regulated on the supply side. This ensures the return supply side temperature will be high.

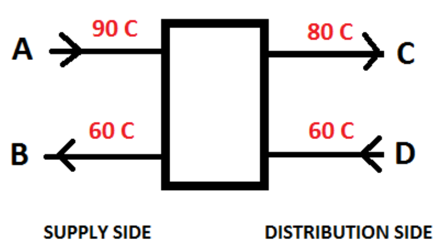


Figure 33 - Potential operation of network substation heat exchangers

4.1.6 Heating demanded and supplied

Referring to Figure 34, the amount of heat being demanded by the customers, supplied by the boiler, supplied by the solar collectors, and discharged by the storage tank per summer month is shown. The sum of the measured months solar heat supply is around 160MWh, which is good considering a typical yearly yield of 400MWh for 1000m^2 of solar collectors. The storage tank discharge is expected to be similar to the solar heat being transferred to the tank, and this is observed.

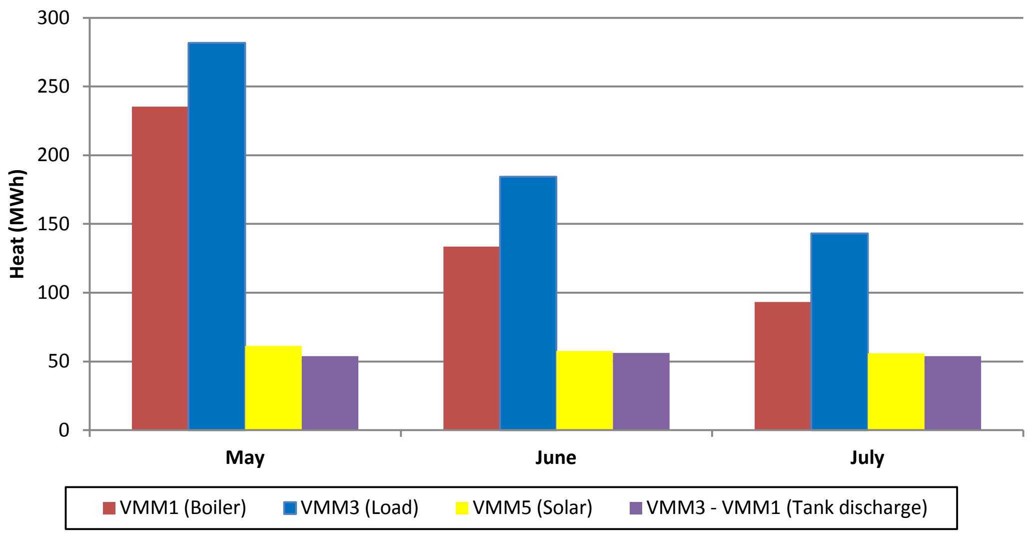


Figure 34 - Monthly heat and demand supplied during summer months

4.1.7 Flowrates for Solar and storage tank loops

The heat transfer shown in equation (1) was used to calculate the actual flowrate within the solar collector loop, based on real plant data. The raw data used was the power meter reading for the solar loop (VMM5), the forward collector fluid temperature (GT13), and the bottom tank temperature (GT423). ΔT was the difference in these two temperatures. This data was recorded on the storage tank loop as shown in Figure 3. The calculated flowrate of water within the loop, m_w, is

$$m_w = \frac{P}{\Delta T.\rho_w.C_w} \qquad (1)$$

Therefore to calculate the actual flow rate of the glycol fluid in the collector loop, m_f, on the other side of the solar HEX, a heat capacity balancing calculation had to be performed across the solar heat exchanger.

$$m_f = \left(\frac{C_w}{C_f}\right) * m_w \qquad (2)$$

The power meter has taken reading between 10am and 6pm on good solar radiation days. The current plant settings allow the solar pump to be in operation when the temperature in the forward collector fluid is 5°C warmer than the bottom tank temperature. With the bottom tank temperature being between 55°C and 64°C, the collector fluid had to reach a high temperature before its heat was utilized by the solar heat exchanger.

Table 5, shows the calculated flowrates. For each month, at least 2 sunny days were selected and averaged for that month. Literature recommends the collector flowrate to be 0.2l/min/m2 of collector area (Furbo, DTU Solar Heating course 11116, 2010). The result for the current plant operation during these summer months is at 0.17l/min/m2, which is slightly below the recommendation but acceptable

Table 5 - Solar collector loop flowrate calculations

Date	*Flowrate (l/h/m2)*	*Flowrate (l/min/m2)*	*Collector fluid(°C)*	*Bottom tank(°C)*
April (27,28,29)	*11.44*	*0.19*	*67*	*54*
May (21,25)	*7.82*	*0.13*	*77*	*54*
June (28,29)	*10.61`*	*0.18*	*80*	*64*
July(13,14)	*10.71*	*0.18*	*80*	*64*
August (1,2)	*9.13*	*0.15*	*74*	*61*
AVERAGE	***9.96***	*0.17*	*76*	*60*

4.2 Model Comparison with measured data

4.2.1 Heating demand and supply

Through model simulates it was possible to satisfy the hot water energy demand over the year. In other words, the quantity of hot water demanded at a set temperature was being provided ever hour. The network demanded 5.5GWh of heat to be supplied to the network and this was provided with a solar fraction contribution of 6.2% amounting to 348MWh. This solar contribution is typical for a solar heating plant of this size.

The summer months were the only comparable measured data months. Figure 35 shows the comparison under the categories of load demanded, boiler heat supplied and solar heat supplied. It can be seen the load demanded only differs between 3-5% over the months. This accuracy was expected as the load profile created for the simulations was based on the actual summer's months. Figure 36 shows that the yearly demand profile is as accurate as these summer months. The models boiler system provides between 14-40% more heat than the real plant over the summer months. This extra heat supplied could be explained by the lack of heat recovery system being modelled in the simulations. Heat loss to the plants indoor environment is 1.6GWh through simulations over the year, and between 50-90MWh per summer month. Hence, if a percentage of this could be recovered the boiler would not have to supply so much. The solar results are comparable with May and July being 10% larger and 4% smaller in simulations, but July was 18% smaller through simulations. This could be from the actual global solar radiation for those months being better or worse for each month in comparison to the library catalogue within Polysun. The actual solar radiation values for these months were not on hand during this study, so this can only be speculated.

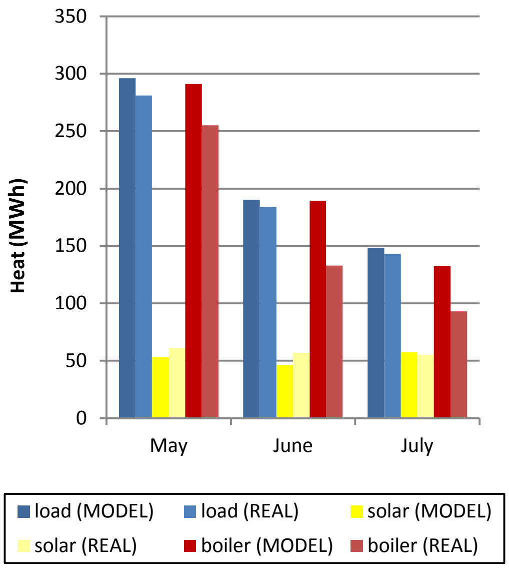


Figure 35 - Comparison of simulated and measured results for summer months. Polysun outputs: Load =Qdem, Boiler = Qaux, Solar = Qsol, Supplied =Qsol + Qaux.

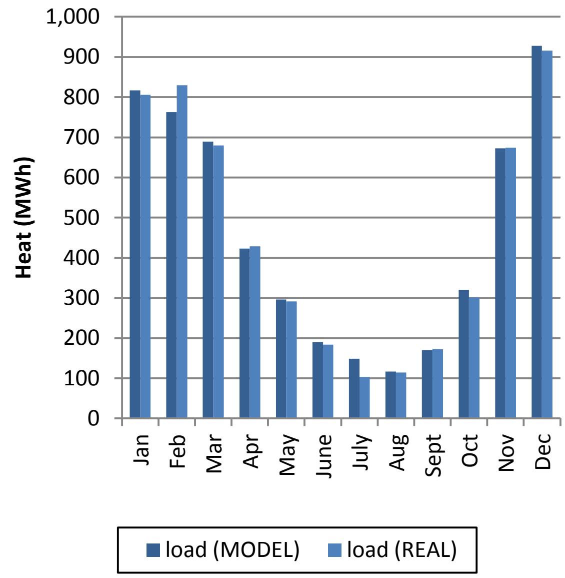


Figure 36 - Comparison of scaled and simulated yearly heating demand results

Overall, the solar and load results were comparable but the boiler was not. If a heat balance is performed on the plant, as shown in Figure 37, the inputs of solar and boiler heat into the system should equal the load being outputted. From the model results, the solar input and load output are correct, therefore the boiler should also be correct. Hence the definition of Polysun's boiler heat contribution must be questioned. The output result of "Qaux" is being taken as the boilers heating contribution to network load and is defined as "Energy transferred by the fuel powered heat generator to the fluid". According to this definition, the model and real plant results shown be comparable. An investigation into how Polysun calculates this figure should be carried out, but for the time scale of this report, it was unable to be performed.

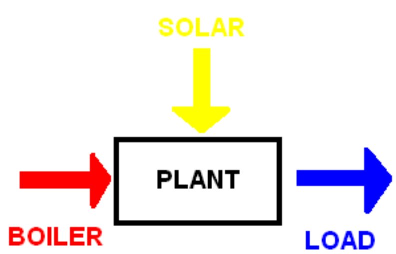


Figure 37 - Heat balance on the operating plant

In an attempt to include waste heat recovery into the models boiler system, the boilers efficiency was increased from the default 78% to 90%. Increasing the boilers operating efficiency means the boiler will use less fuel in providing the same heat, which is similar to the waste heat recovery principle. This resulted in 6.1GWh of energy required by the boiler to supply the demanded 5.5GWh of heat. This equates to a 9% saving of energy in comparison to the 6.7GWh of energy required by the boiler when the efficiency was 78%.

4.2.2 Solar collector temperatures

Figure 38 shows a comparison between the solar collectors outflow temperatures. The location of the temperature sensor for the measured data is just before it enters the solar HEX. Within the model the same location was taken for the temperature values. A week period during the start of July was chosen as it was in the middle of summer and solar radiation levels could be high enough to see the collectors operate on a good day. It can be seen that the measured profile is cut at the bottom during the night periods, this is because the collector pumps only operates when the 25°C is reached across the collectors. Both the measured and model profiles follow this. The rate of increase and decrease in temperature is similar to both profiles, and the time period at which they occur are again the same, indicating the solar loop pump in the model has the correct settings. The models daily temperature peaks are generally higher than the measured values. The peaks of the measured data indicate that clouds have come across the sky as the temperature fluctuates and levels out.

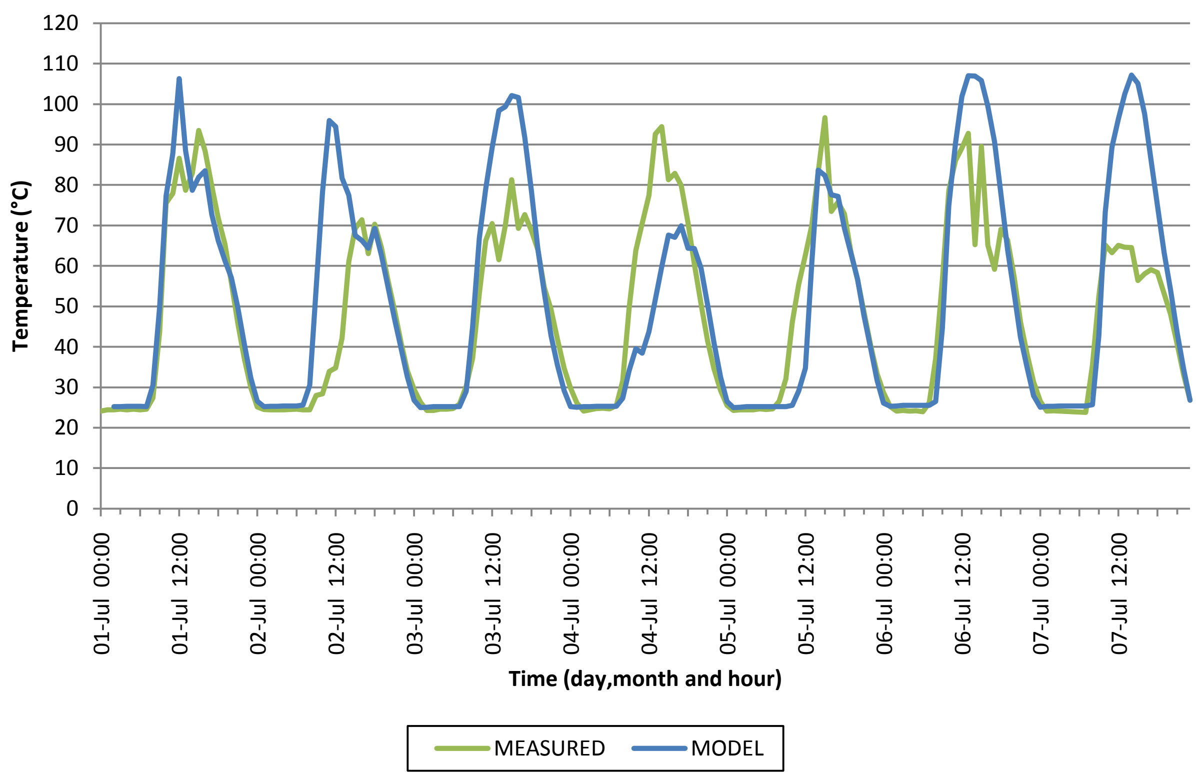


Figure 38 - Comparison of Solar collector outflow temperatures

4.2.3 Storage tank temps

The same comparison period in July as the collector outflow temperatures was chosen, so as to aid with understanding the levels of temperatures reached in the tank as shown in Figure 39. No date of the top tank temperatures have a very accurate comparison, but the 1st, 2nd 3rd and 6th all have similar shapes with varying maximum temperatures. Looking at the 6th, the outflow of the collector for the model reached 105°C which resulted in a top tank temperature of 90°C, whereas the measured results reached 92°C and 83°C respectively. The bottom tank temperatures reflect a similar night time temperature, however during the day the measured data increases towards a midday peak. The high returning network temperature is the contributing factor to this. The models constant temperature profile shows the constant temperature setting for the return network within the model.

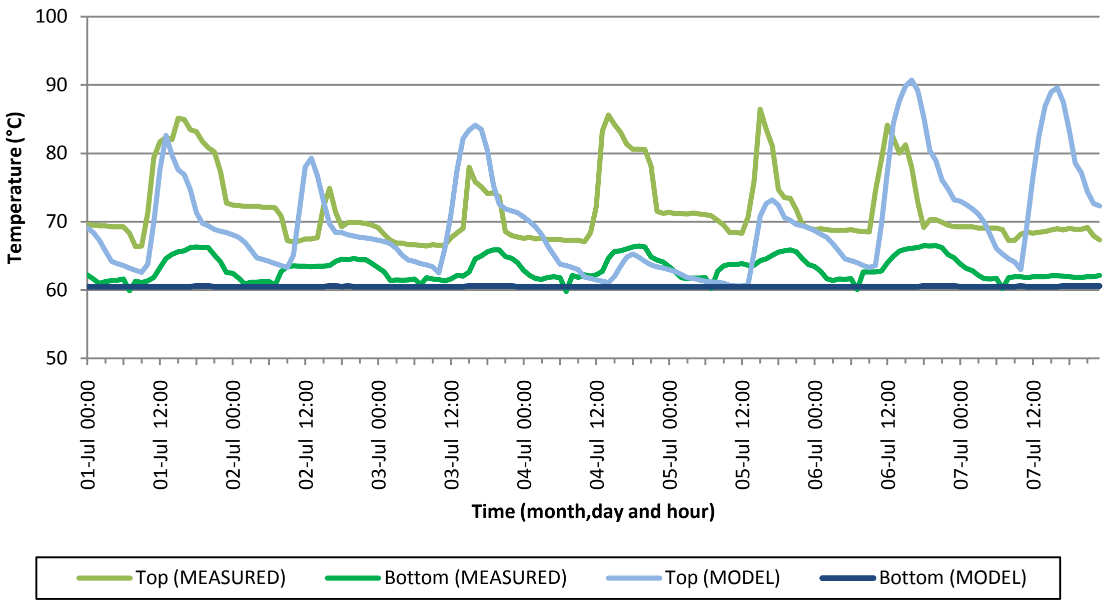


Figure 39 - Comparison of storage tank temperatures

4.2.4 Solar loop Heat exchanger

The solar heat exchanger transfers the heat from the solar collectors to the storage tank. Looking at Figure 40, the collector loop provides the hot "supply in" and receives the cold "supply out". The storage tank loop provides the cold "demand in" and receives the hot "demand out". The model is run with an ideal heat exchanger (transfer capacity of 1000000 W/K) with very little loses while transferring heat between the supply and demand side.

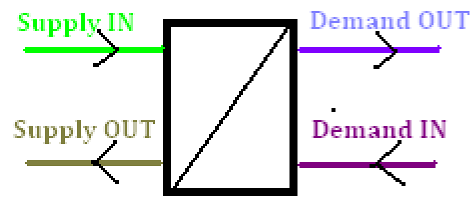


Figure 40 - Solar Heat exchanger layout

Looking at Figure 41, the ideal HEX shows all of the heat from the collector fluid has been transferred the storage loop. The water leaving the HEX "demand out" is the same temperature as the collector fluid entering the HEX "Supply in". The same model was run with a more realistic HEX (transfer capacity of 30,000 W/K), which show a difference between supply in and demand out temperatures. The measured data reflects the same temperature profiles of the realistic HEX.

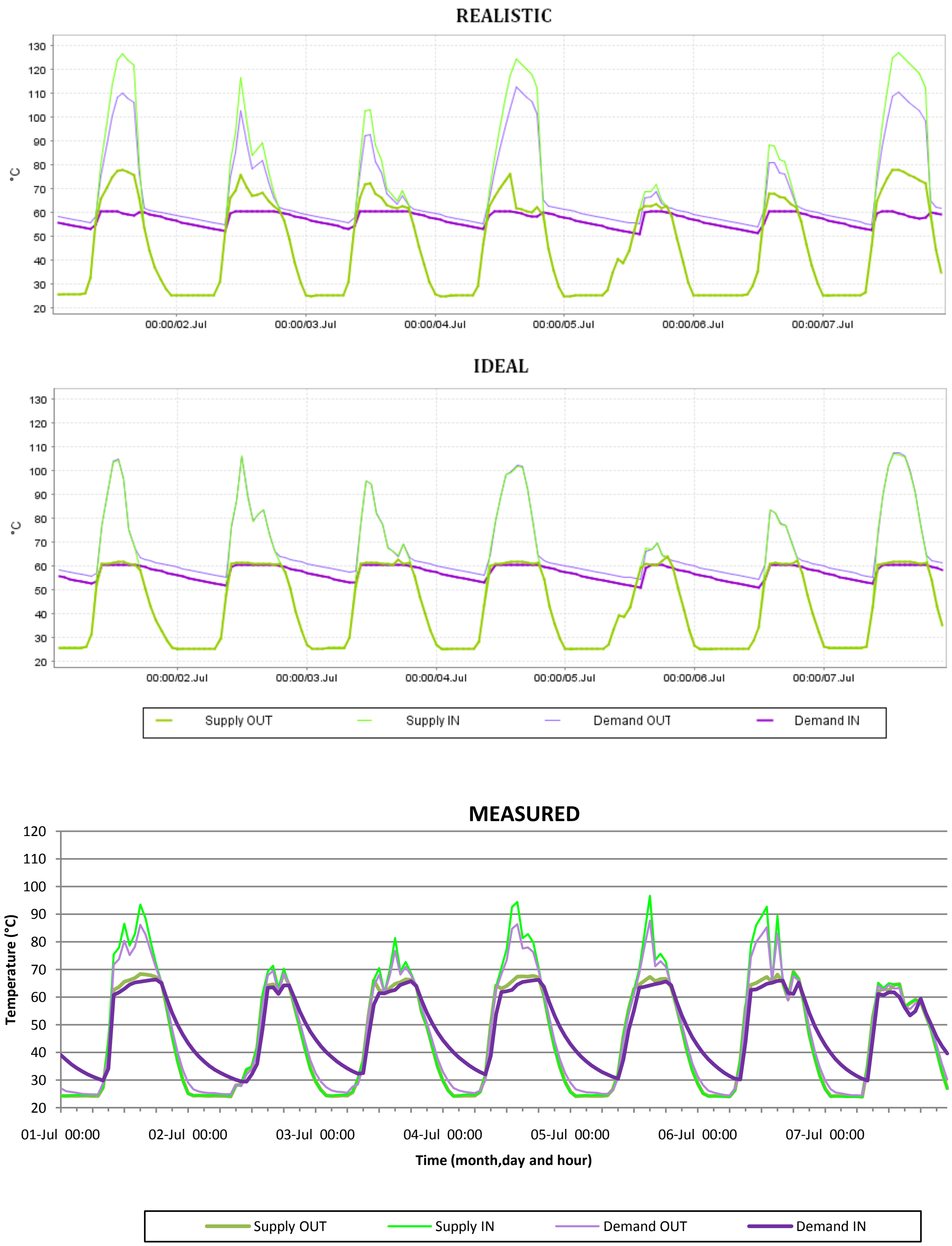


Figure 41 - Solar heat exchanger comparisons

4.2.5 Network temperatures

A correct comparison of the forward and return temperatures cannot be expected between the model and measured data because of their temperature settings. Within the model forward and return temperatures were set to 74.6°C and 60.8°C. For the real plant, the temperature settings was not known, but the measured forward and return temperatures are recorded over the 3 summer months and vary as shown in Table 3. Looking at the same week in July, from Figure 42, it can be seen the model provides the hot water between 75°C and 80°C, with the odd hour of high water quantity demand bringing the temperature down to 68°C. The fluctuations are from the 3 way mixing value cooling the high storage tank temperature down to the outlet setting. A yearly view of the hot water being supplied to the customers is shown in the Appendix, showing the summer months supply temperature slightly higher than the winter months. As expected the models return network temperature, which is in fact the cold water supply to the system, is at a set 60.6°C. However, the return networks measured values have a profile which is indicating that little of the forward network heat is being utilized during the daytime period by the customers. This is to be expected during a summer day.

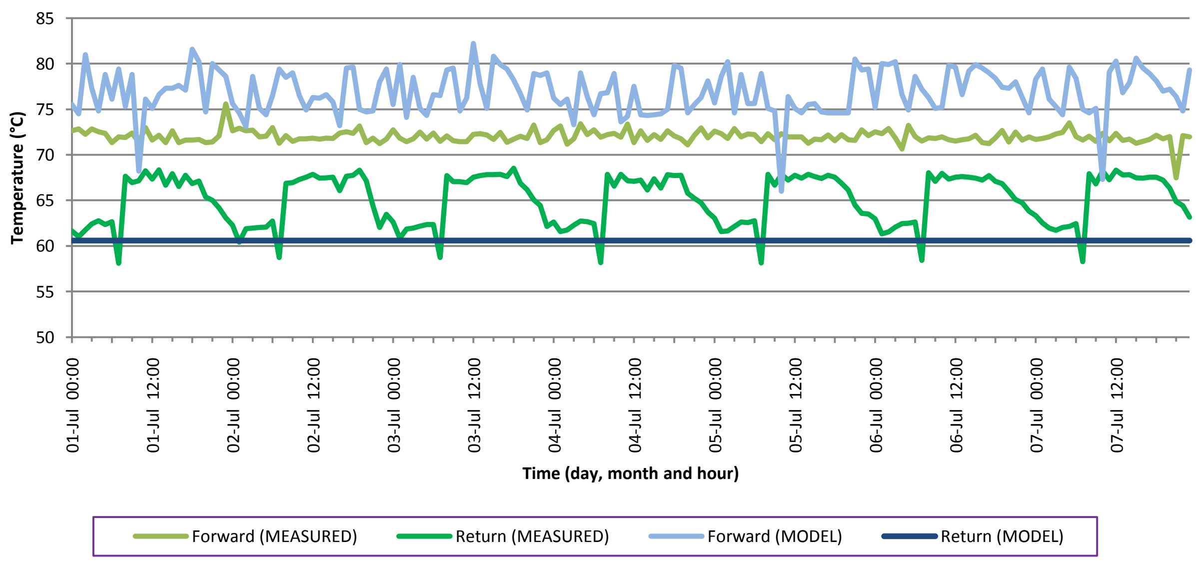


Figure 42 - Network temperatures comparison

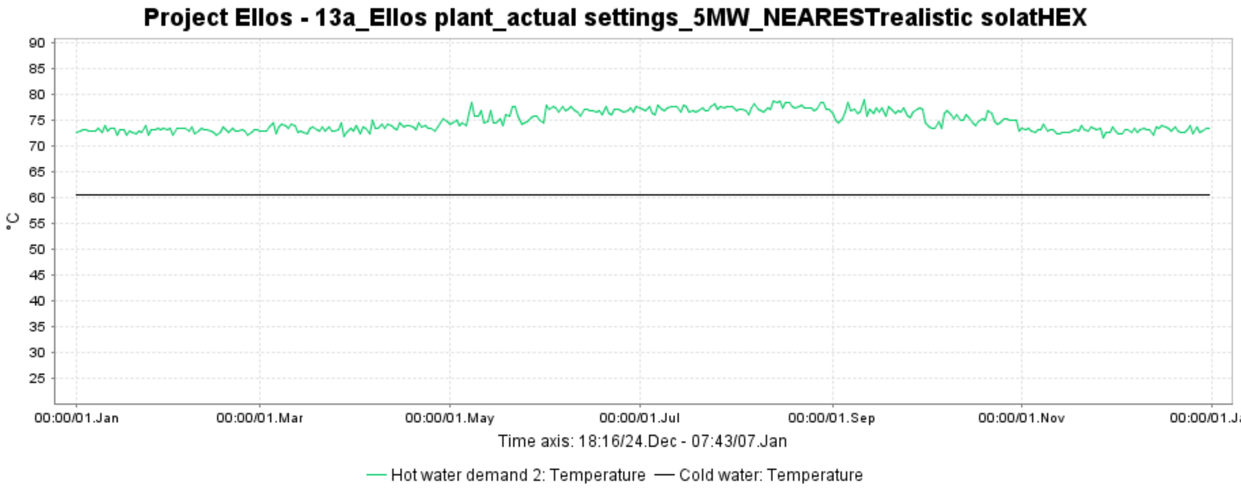


Figure 43 - Yearly Forward and return network temperatures of the model

4.3 Model sensitivity analysis

From measured data analysis the most significant finding was the high return temperature from the network entering the plant, and its potential negative impact on the plants performance. Currently it is being returned at 60°C. For a sensitivity analysis, it would be worthwhile to investigate the performance of the plant when this temperature was reduced, to 40°C and 50°C.

The plant had been designed with 1000m^2 of solar collector panels installed. There are future plans of increasing this instalment, based on the plants performance over the first year or two among other things. Hence, the sensitivity analysis will also include increasing the plants solar collector area to 2000m^2.

4.3.1 Collectors expansion and return network temperature reduction

Whenever the return network temperature is changed, this has a large knock on effect for input requirements in the Polysun model. Most significantly the hot water quantity draw off profile had to be developed again. The explanation of how this was developed is detailed in section 3.1. Following from this, the annual hot water demand per year (m^3) and the maximum draw off of hot water in any one hour of the year (L/h) was required to be recalculated and both of these then inputted into the "Domestic hot water dialogue box". Lastly, the return network temperature setting had to be changed, which is in fact the cold water supply to the system. As the return network temperature decreases, ΔT within equation (1) in section 4.1.7 also increases. This results in a smaller flow rate of hot water being demanded per hour with the same hourly power supply. This reduction in flow rate and resultant annual hot water demand can be seen in Table 6.

Table 6 - Revised hot water demand model inputs for each return temperature setting

	40°C	50°C	60°C
Annual hot water demand (m3)	139,390	196,283	344,000
Nominal flow rate (L/h)	117,983	166,139	293,000

The same heating demand & supply results as in section 4.2.1 were used as the model output data for comparison. These included hot water demand (MWh), boiler system heat supplied (MWh) and solar energy supplied to the tank (MWh). The previous model settings created to reflect the real plant settings were used as the base scenario in comparisons. That is 1000m^2 solar collectors and return network temperature at 60°C.

The collector area variation has no impact on the annual hot water demand quantity. This demand changes overall by only 0.5% and 0.4% between return temperatures 40° and 50°C annually. This was expected as the same power being supplied by the plant is being used for each return temperature case. Only the balance between ΔT and flow rate change.

The boiler and solar heat being supplied to the system change significantly relative to the base plant scenario, as shown in Figure 44 and Figure 45. This figures shown the relative gain or reduction in heat being supplied for each scenario.

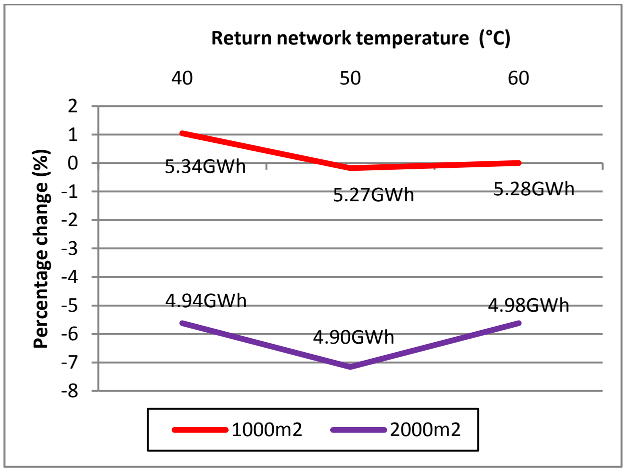


Figure 44 - Percentage change in annual Boiler heating supply

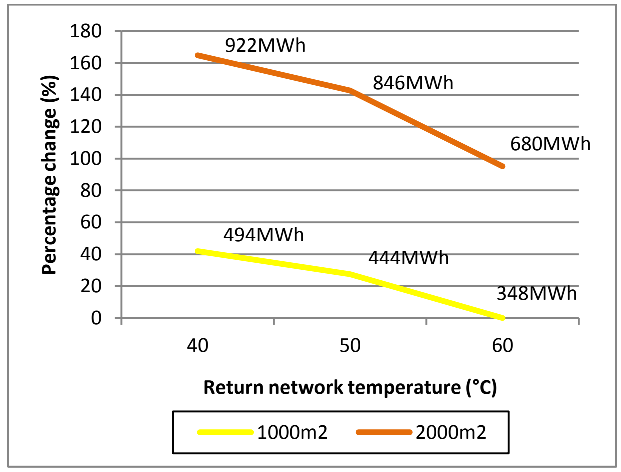


Figure 45 - Percentage change in annual Solar heating supply

When the collectors remain at 1000m^2, the solar heat contribution to the system steadily increases as the return temperature decreases. A maximum 40% (146MWh) increase in solar heat contribution can be achieved. With the return network going directly into the bottom of the tank at 40°C, the solar loops fluid can contribute to the tank heat at lower collector fluid temperatures. Figure 46 shows the top and middle storage tank temperatures for both 40°C and 50°C return temperature. Similar profiles are followed, however the maximum temperatures achieved per day in the top layer are averaging 5°C lower in the 40C return case. The middle temperatures daily peaks are similar. The same cannot be said with the boiler heat being supplied. Infact the boiler must contribute 1% more energy at 40°C. Even though more heat is being supplied from the solar collector to the tank, the top tank temperature is still lower than the 60°C case, and results in the boiler needed to do more work.

Figure 46 - Top and middle storage tank temperatures at varying network return temperatures

When the collectors are increased to 2000m^2, a similar improvement in solar heat contributing to the system can be seen but on a larger scale. An extra 574MWh, or 160% increase relative to the base scenario can be seen for the 40°C case. The boiler has 6% (297MWh) less heat to supply as the collector area is increased under current return temperature conditions. The most optimal boiler usage reduction occurs when the return temperature is at 50°C, which results in a 7% heat supply saving.

5 Conclusion

Through measured data analysis of the plant, the correct operation of plant settings was verified according to plant design manual. Collector loop pump cut in and out at set 25°C, storage tank discharging valves were operating as they should, and 3way mixing valves ensured a constant hot water supply temperature to the network. However, one major issue was the high return temperature of the network, averaged at 60.6°C. This causes the collector temperatures to operate at a very high temperature in order to contribute to the heating load demanded. When the collector operates at these high temperatures it decreases its operating efficiency.

Related to first point is the operation of the heat exchangers at the distribution networks substations. They are not transferring heat to the consumer loop, as the return temperature to the plant is too high. The substations need to be checked for equipment operation and the control settings. Around three quarters of load is consumed at 4 substations (Hallberg Rassy, Sjogården, Ellös Skola and Strandgärden). It is recommended to tackle these stations as a priority.

A model with the correct operating settings as the real plant was created. The forward and return network piping was modelled by hot water demand and cold water supply. A constant hot water setting of 74.6°C and cold water supply of 60.6°C was based on summer months measured data. A hot water demand profile for the year was developed based on the scaling of 3 measured months of hourly data. The scaling was created from monthly heating loads supplied to network substations for the whole year, where May 2011 was used as the base. The model outputs of hot water demand, boiler heat supplied and solar heat supplied were compared with May, June and July measured plant data. The hot water demand was accurate, the boiler heat supplied varied between 14-40% larger, and the solar heat supplied between 4-18% larger. The models application has been useful in finding what is required to model real district heating networks when measured data is available. Having the capability to input multiple hourly profiles of power, supply temperature, return temperature and hot water drawoff quantity would be required for accurate comparison results.

A sensitivity analysis on the return network temperature (40°C, 50°C, 60°C) and possible future solar collector expansion (2000m^2) were performed. Reducing the return temperature has a positive effect on the plant performance and in particular its solar heating contribution. Little impact is made at 50°C and negative impact at 40°C for boiler heat being supplied, however up to 50% more solar heat can be achieved with the current plant collector capacity of 1000m^2. An upgrade of the solar collectors to 2000m^2 is feasible with positive saving effects on boiler heat being supplied. It is recommended to increase the plants solar collectors to 2000m^2, and reduce the return temperature to 50°C, which results in an annual 7% fuel saving for the boiler.

6 Works Cited

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Sneider, E. (2011). *"Ellös fjärrvärmeverk funktionsbeskrivning" Ellos plant opearting manual.* Gotenborg, Sweden: Sneider Electric.

Solaris, V. (2011). *Polysun user manual.* Switzerland: Vela Solaris.

7 Appendix

7.1 Sneider Plant operating manual

Sneider Plant operating manual settings summary (Sneider, 2011)

Setting values for the Solar loop

VP02-P4	Start VP03-GT12>VP02-GT431	> +5°C
VP02-P4	Stopp VP03-GT12<VP02-GT431	< +2°C
VP02-P4	Snabbstopp VP03-GT12	> +110°C
GT11A/B	Medelvärde start P1	> 25 °C
GT11A/B	Medelvärde stopp P1	< 23 °C
GT11A/B	Högtemperatur	110 °C

Charging the tank with boiler

Whilst charging the boiler, the forward network directly after the boiler system HEX (GT 414A) is not allowed to fall 5C below the supply temperature set for the customers at GT11. Charging of the tank stops, when the temperature difference between the forward network after the boiler system (GT414A) and the return network (with newly charged storage tank discharge contribution) has fallen below 10C.

Laddningen upphör inte förrän differanstemperaturen (10°C) mellan GT421 och GT414A understigs.
Stop charging until differanstemperaturen (10 ° C) between the GT421 and GT414A fall.

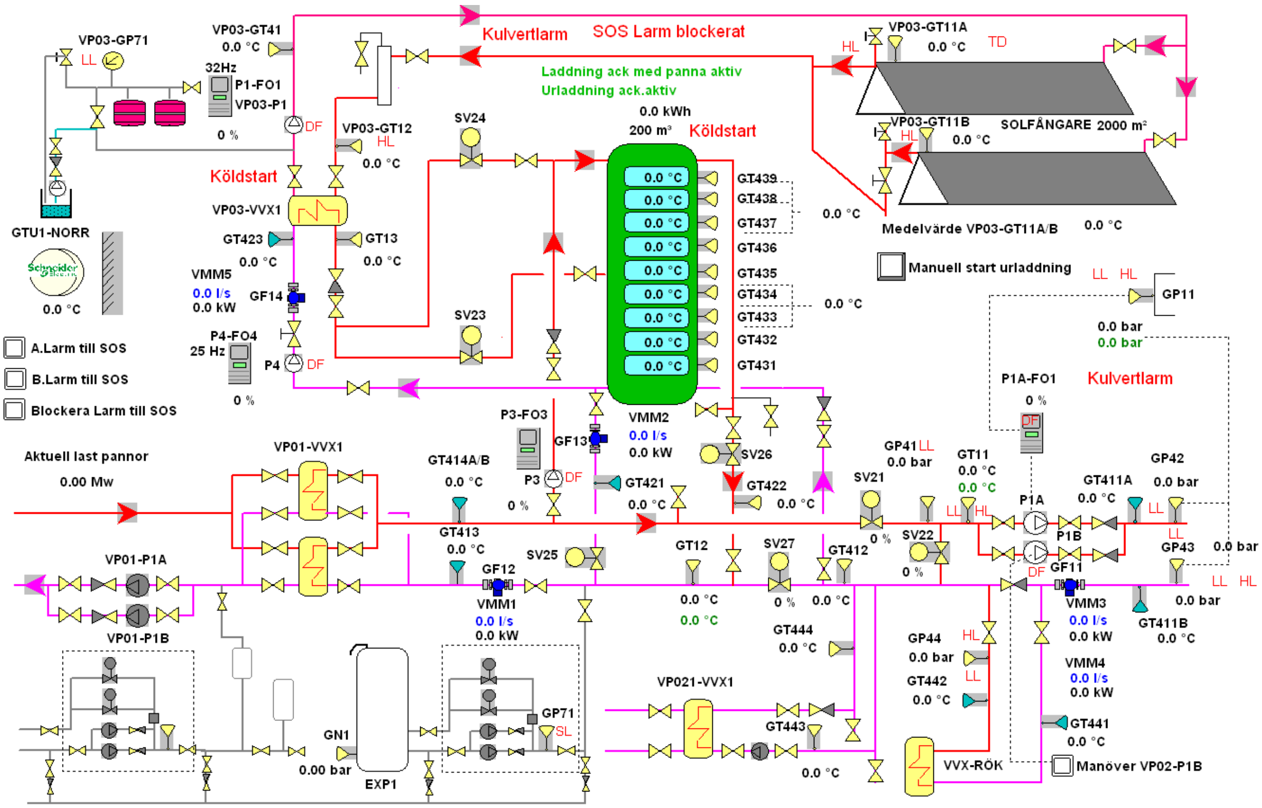
Temperaturen vid GT414A får inte understiga börvärdet för VP02-GT11 med mer än 5°C.
The temperature at GT414A may not fall below the set point for VP02-GT11 with more than 5 ° C.

Tank discharging

Also, the boiler must also be in operation with a load greater than 1.5MW, for discharging to commence

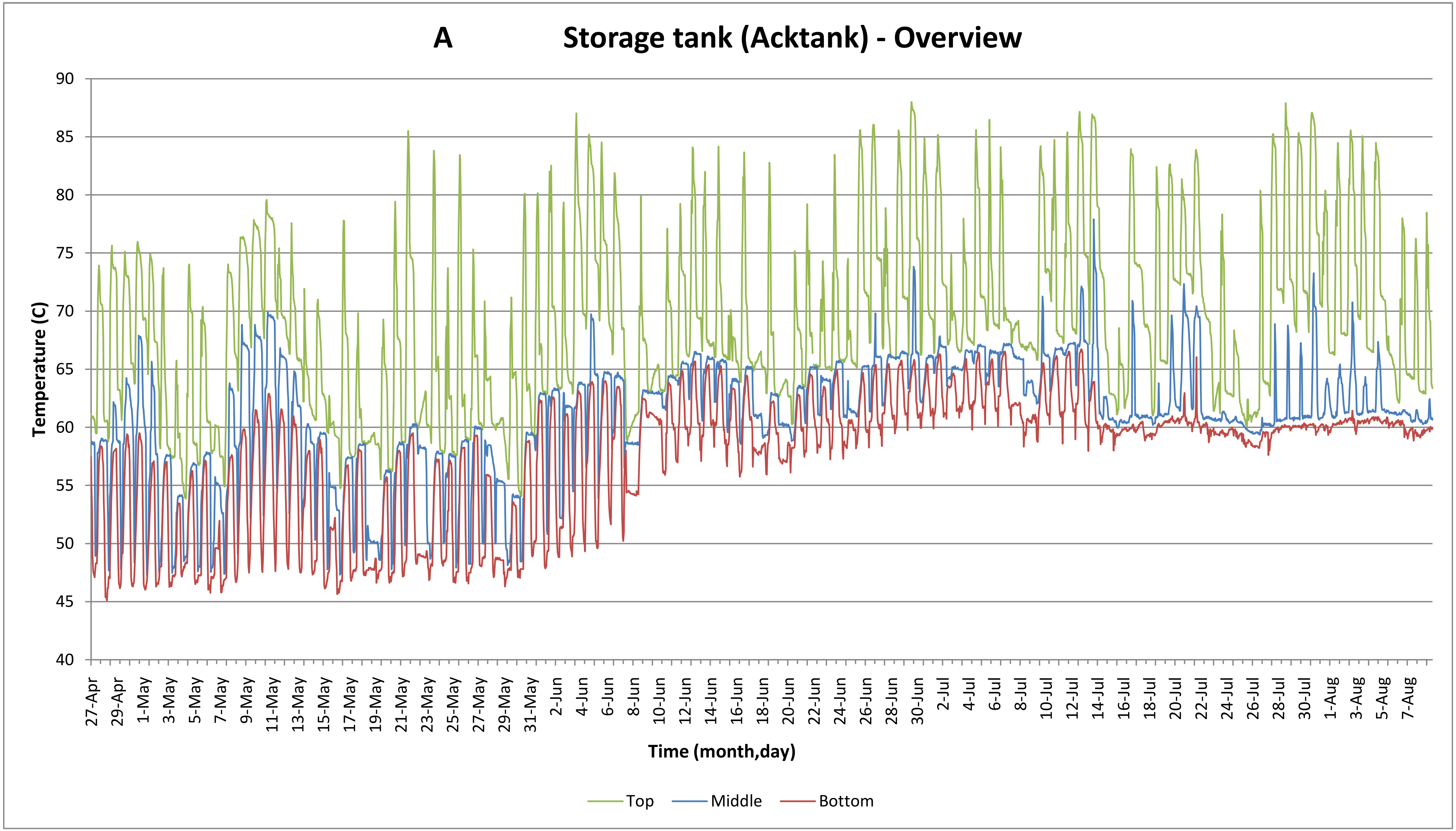
VP02-GT12	Börvärde urladdning acktank *Setpoint discharge acc tank*	VP02-GT11+2°C

Urladdningen stoppas då temperaturen vid VP02-GT439 uppnår samma ärvärde som VP02-GT412.
The discharge is stopped when the temperature at the VP02-GT439 achieve the same actual value as VP02-GT412.

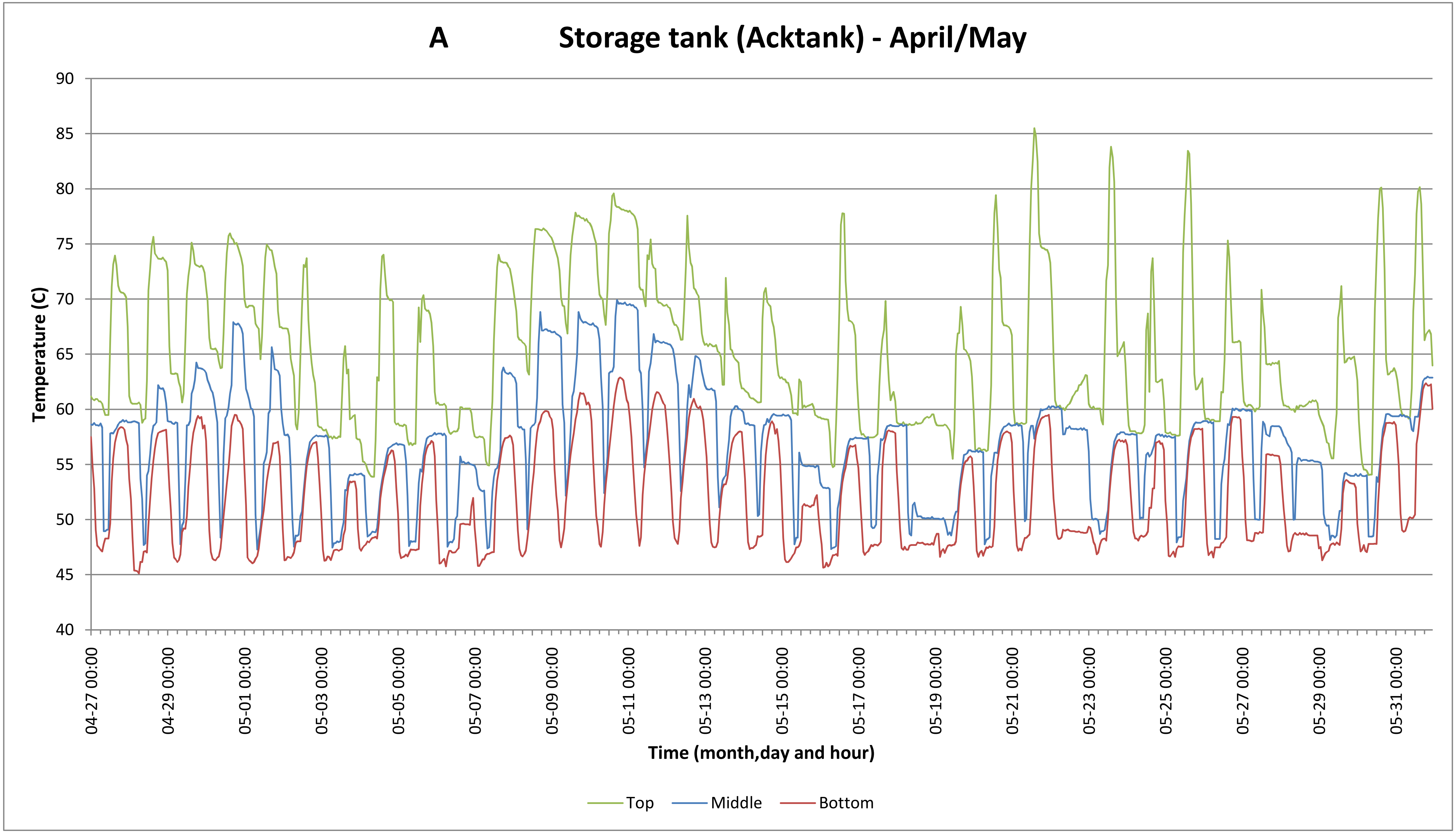


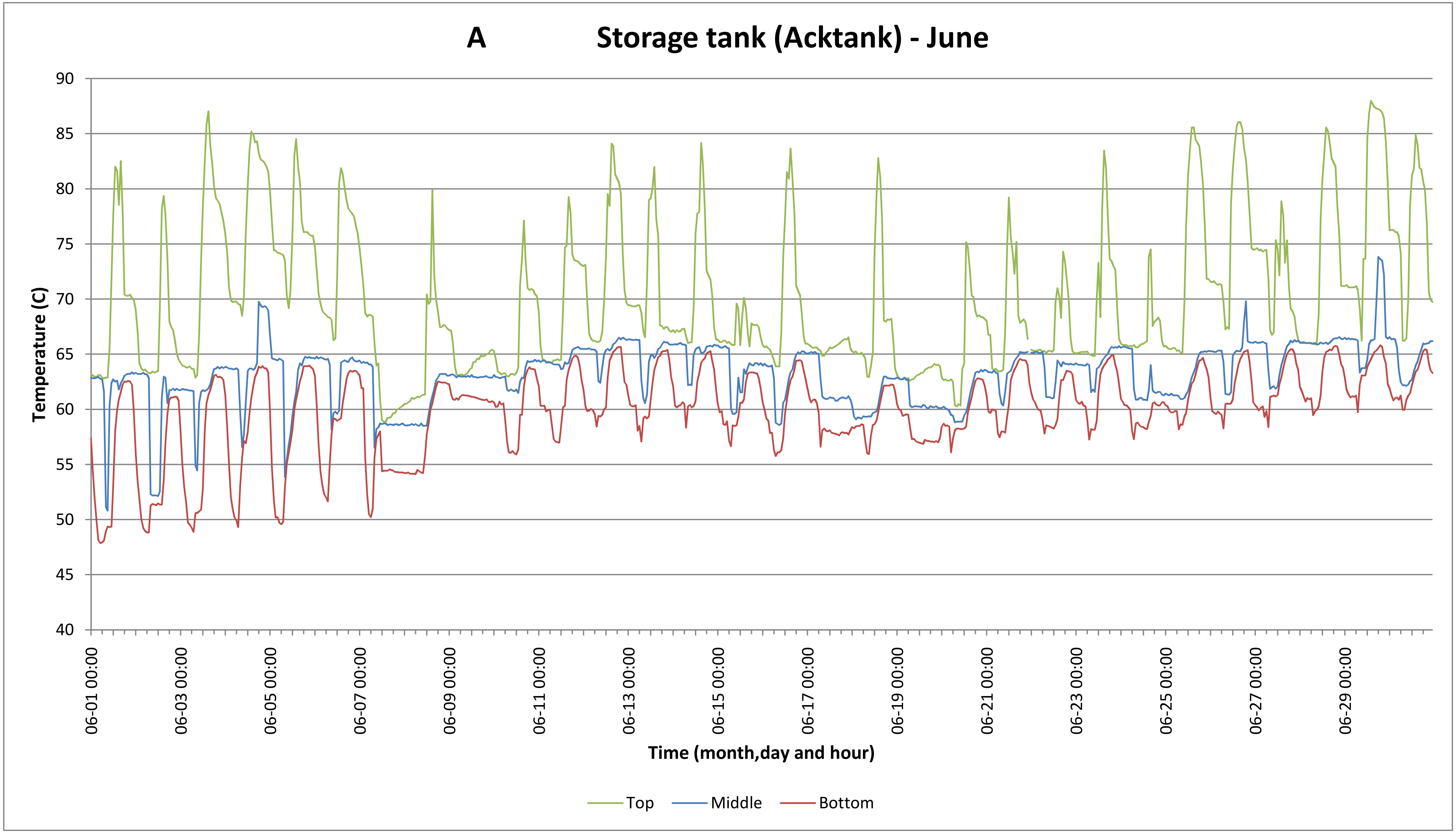
Kulvertlarm
SOS Larm blockerat
Laddning ack med panna aktiv
Urladdning ack.aktiv
0.0 kWh
200 m³
Köldstart
SOLFÅNGARE 2000 m²
Medelvärde VP03-GT11A/B
Manuell start urladdning
A.Larm till SOS
B.Larm till SOS
Blockera Larm till SOS
Aktuell last pannor
0.00 Mw
VP01-VVX1
VP01-P1A
VP01-P1B
VP021-VVX1
VVX-RÖK
Manöver VP02-P1B
EXP1
GTU1-NORR

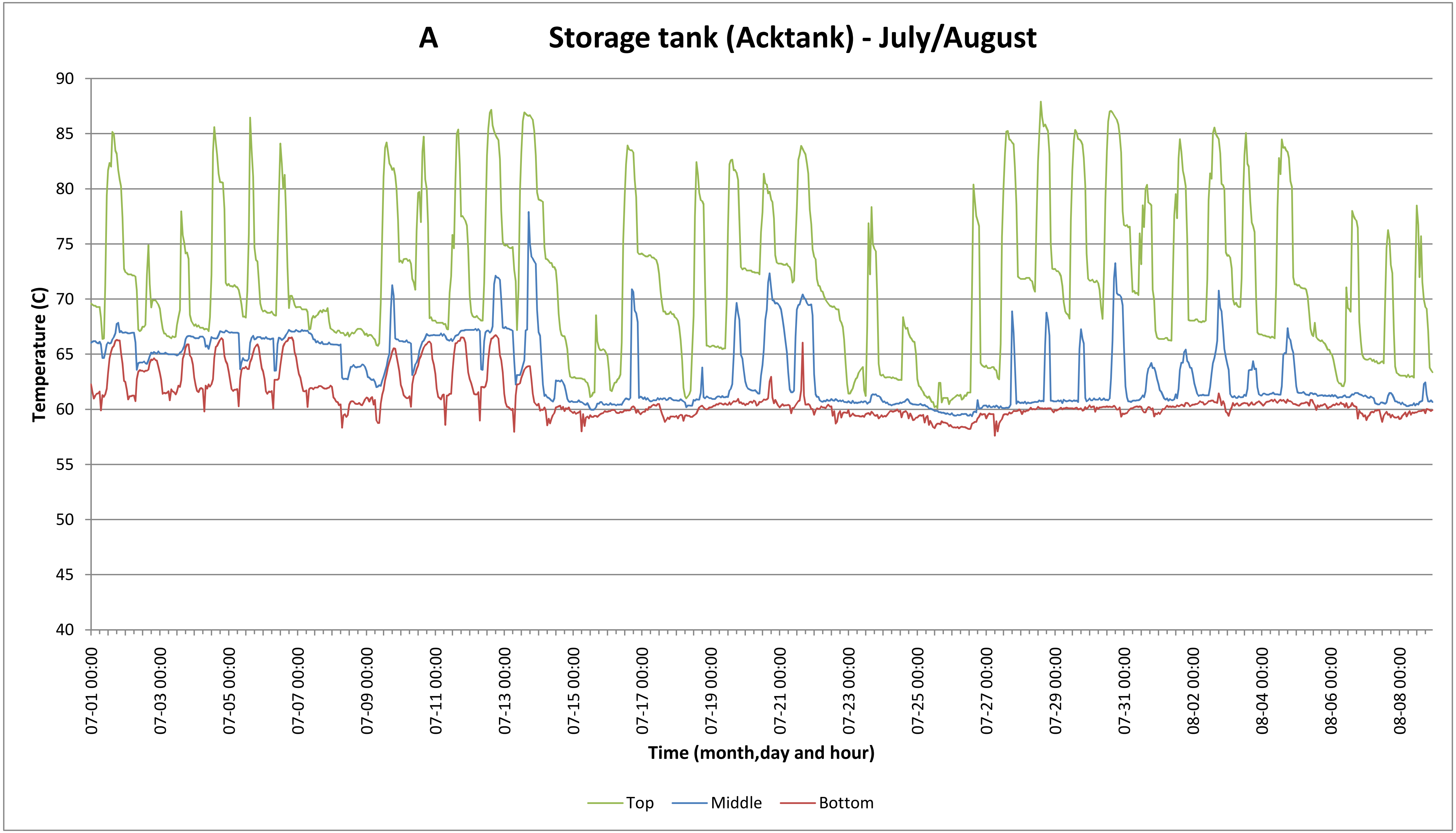
7.2 Graphed Appendix

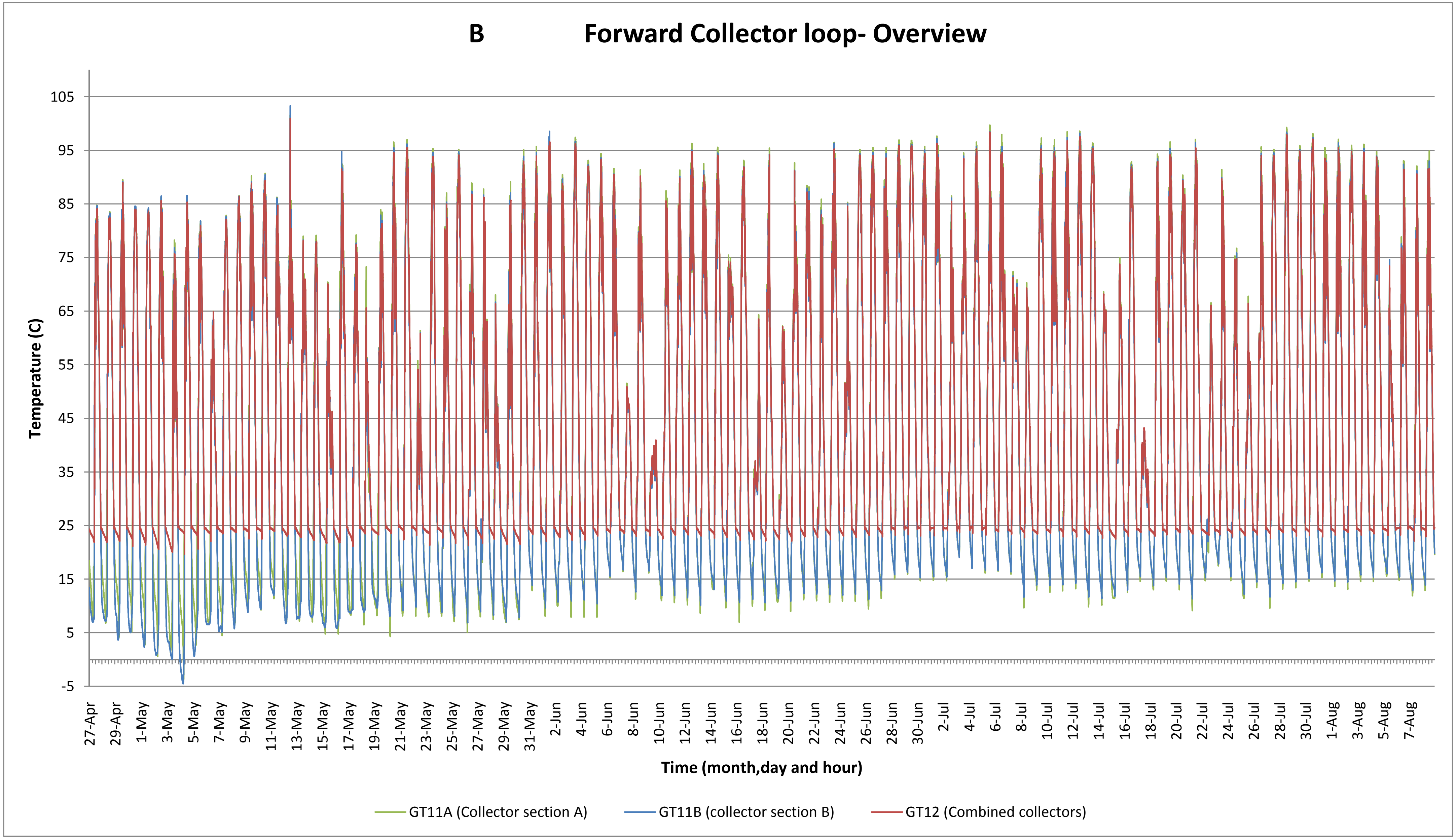


A
Storage tank (Acktank) - Overview
90
85
80
75
70
65
60
55
50
45
40
Temperature (C)
27-Apr
29-Apr
1-May
3-May
5-May
7-May
9-May
11-May
13-May
15-May
17-May
19-May
21-May
23-May
25-May
27-May
29-May
31-May
2-Jun
4-Jun
6-Jun
8-Jun
10-Jun
12-Jun
14-Jun
16-Jun
18-Jun
20-Jun
22-Jun
24-Jun
26-Jun
28-Jun
30-Jun
2-Jul
4-Jul
6-Jul
8-Jul
10-Jul
12-Jul
14-Jul
16-Jul
18-Jul
20-Jul
22-Jul
24-Jul
26-Jul
28-Jul
30-Jul
1-Aug
3-Aug
5-Aug
7-Aug
Time (month,day)
Top
Middle
Bottom

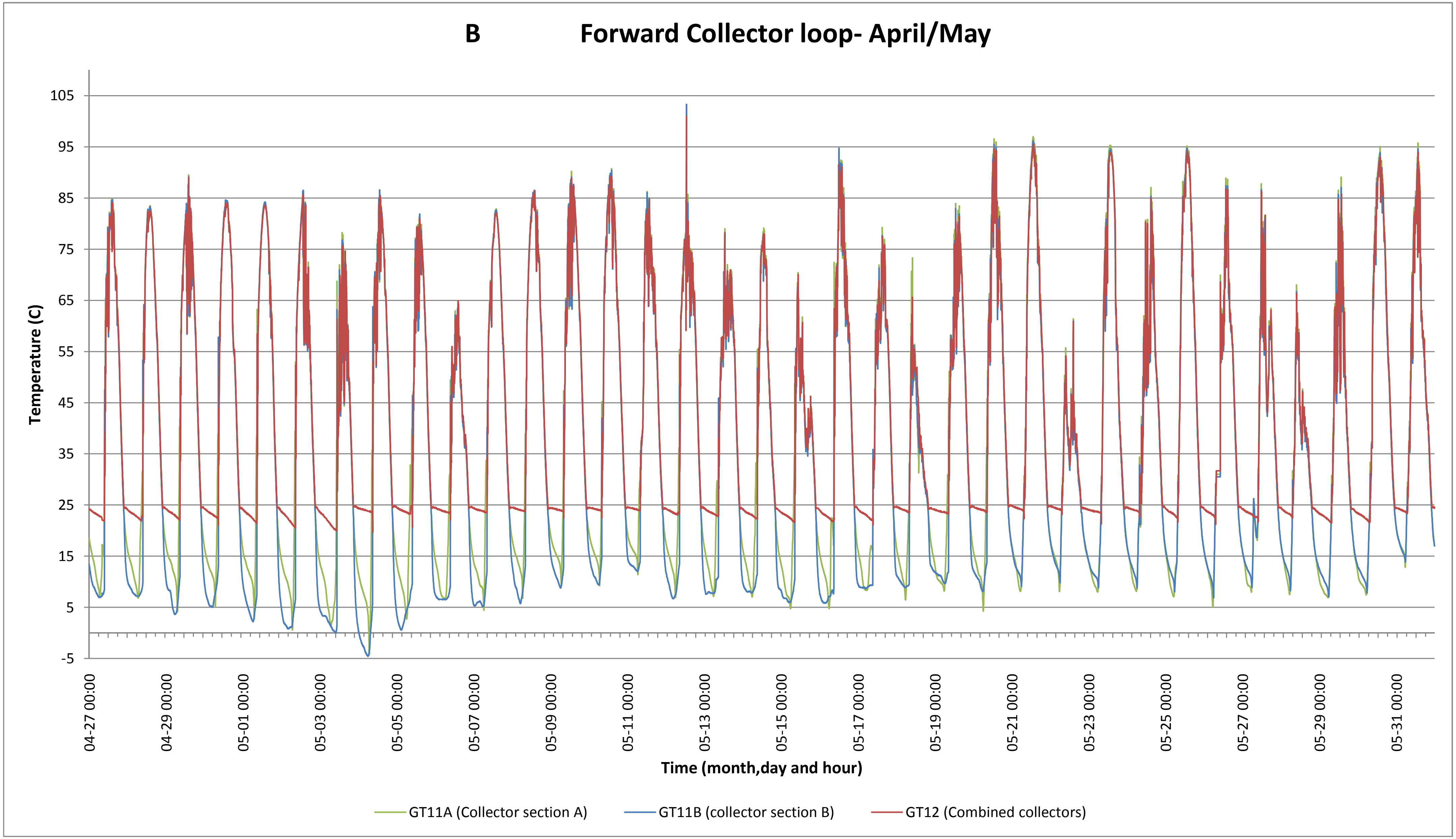

A
Storage tank (Acktank) - April/May
Temperature (C)
90
85
80
75
70
65
60
55
50
45
40
04-27 00:00
04-29 00:00
05-01 00:00
05-03 00:00
05-05 00:00
05-07 00:00
05-09 00:00
05-11 00:00
05-13 00:00
05-15 00:00
05-17 00:00
05-19 00:00
05-21 00:00
05-23 00:00
05-25 00:00
05-27 00:00
05-29 00:00
05-31 00:00
Time (month,day and hour)
Top
Middle
Bottom


A
Storage tank (Acktank) - June
Temperature (C)
90
85
80
75
70
65
60
55
50
45
40
06-01 00:00
06-03 00:00
06-05 00:00
06-07 00:00
06-09 00:00
06-11 00:00
06-13 00:00
06-15 00:00
06-17 00:00
06-19 00:00
06-21 00:00
06-23 00:00
06-25 00:00
06-27 00:00
06-29 00:00
Time (month,day and hour)
Top
Middle
Bottom

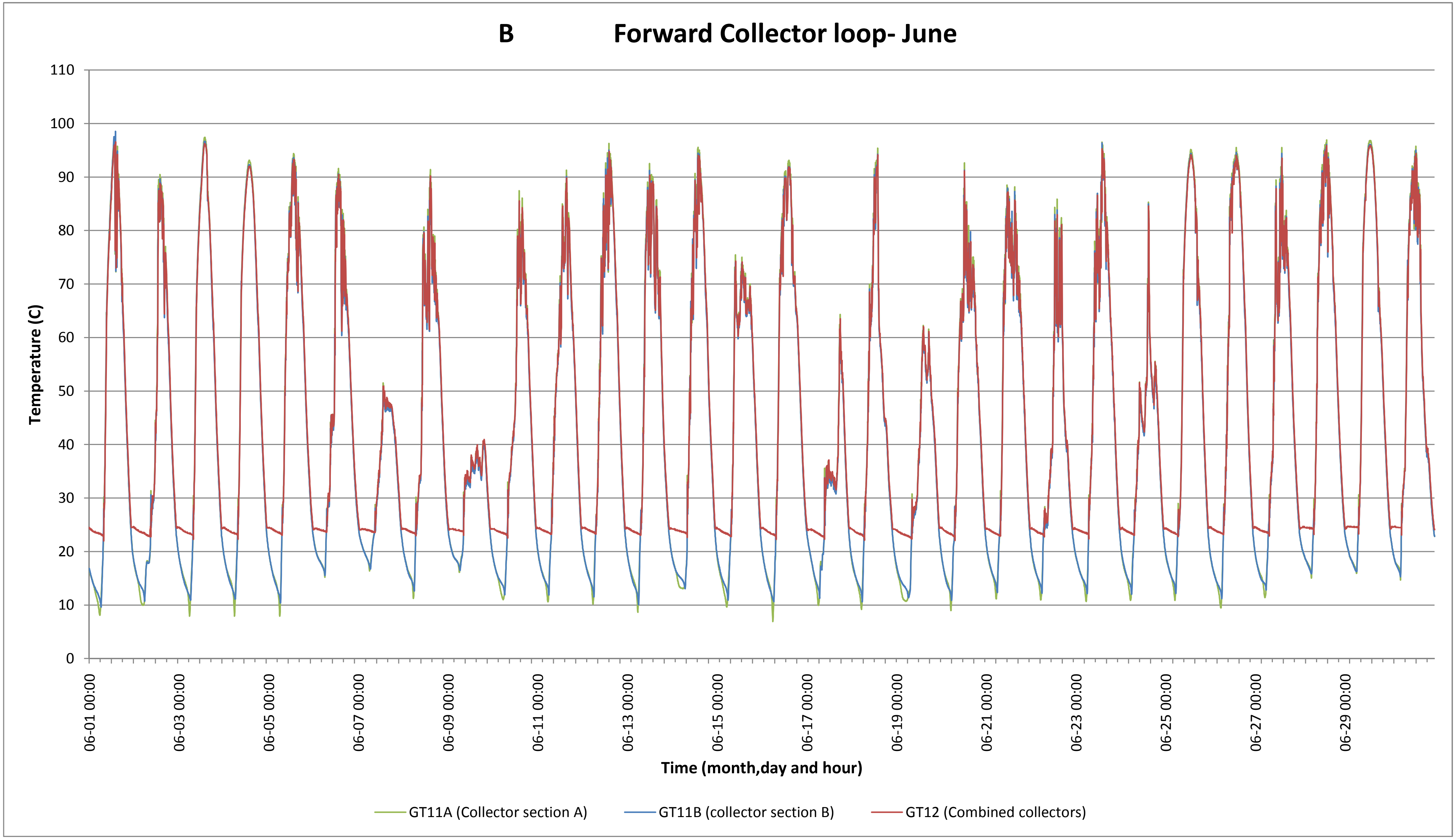

A
Storage tank (Acktank) - July/August
Temperature (C)
Time (month,day and hour)
90
85
80
75
70
65
60
55
50
45
40
07-01 00:00
07-03 00:00
07-05 00:00
07-07 00:00
07-09 00:00
07-11 00:00
07-13 00:00
07-15 00:00
07-17 00:00
07-19 00:00
07-21 00:00
07-23 00:00
07-25 00:00
07-27 00:00
07-29 00:00
07-31 00:00
08-02 00:00
08-04 00:00
08-06 00:00
08-08 00:00
Top
Middle
Bottom

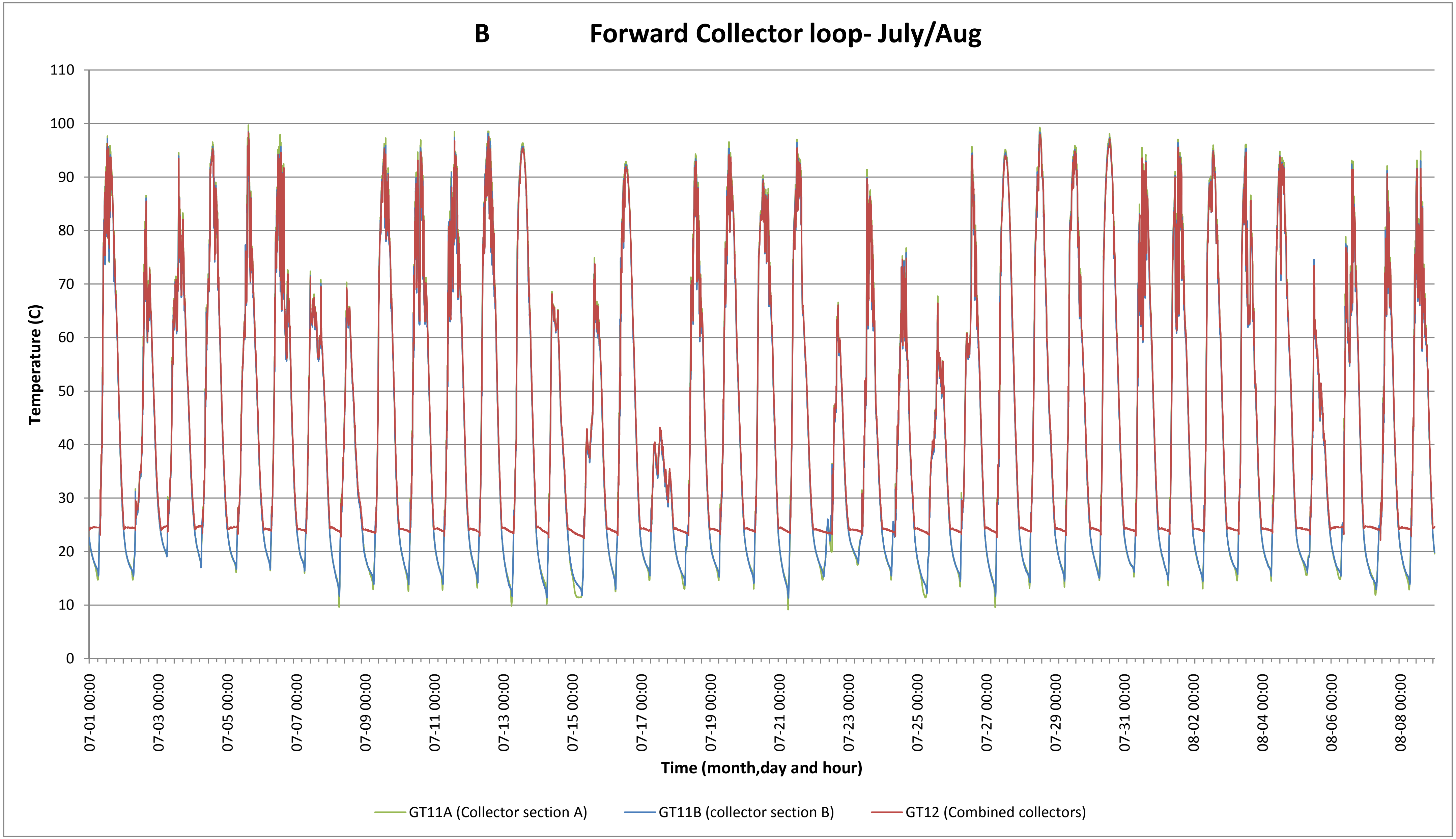


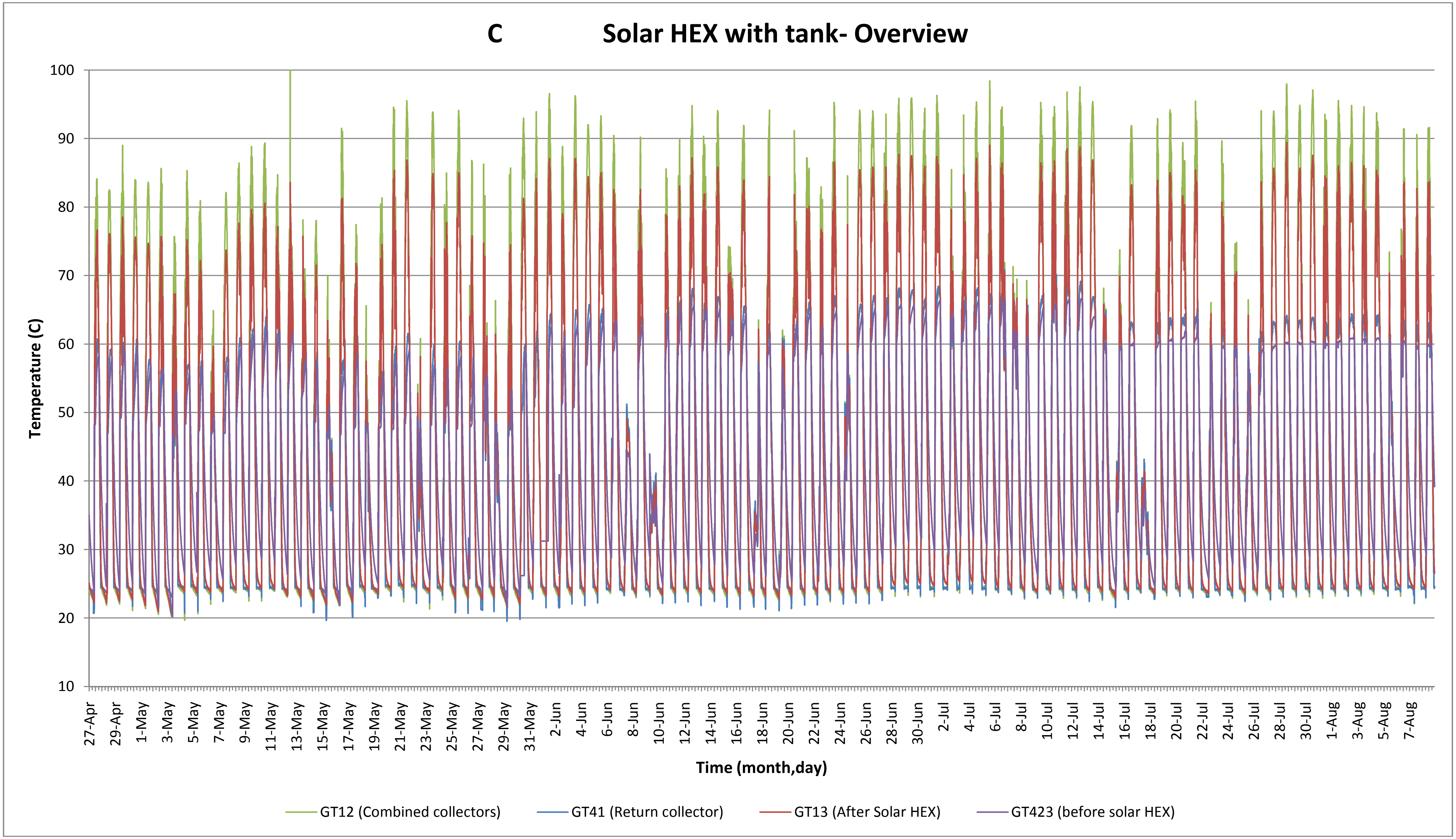
B
Forward Collector loop- Overview
Temperature (C)
105
95
85
75
65
55
45
35
25
15
5
-5
27-Apr
29-Apr
1-May
3-May
5-May
7-May
9-May
11-May
13-May
15-May
17-May
19-May
21-May
23-May
25-May
27-May
29-May
31-May
2-Jun
4-Jun
6-Jun
8-Jun
10-Jun
12-Jun
14-Jun
16-Jun
18-Jun
20-Jun
22-Jun
24-Jun
26-Jun
28-Jun
30-Jun
2-Jul
4-Jul
6-Jul
8-Jul
10-Jul
12-Jul
14-Jul
16-Jul
18-Jul
20-Jul
22-Jul
24-Jul
26-Jul
28-Jul
30-Jul
1-Aug
3-Aug
5-Aug
7-Aug
Time (month,day and hour)
GT11A (Collector section A)
GT11B (collector section B)
GT12 (Combined collectors)

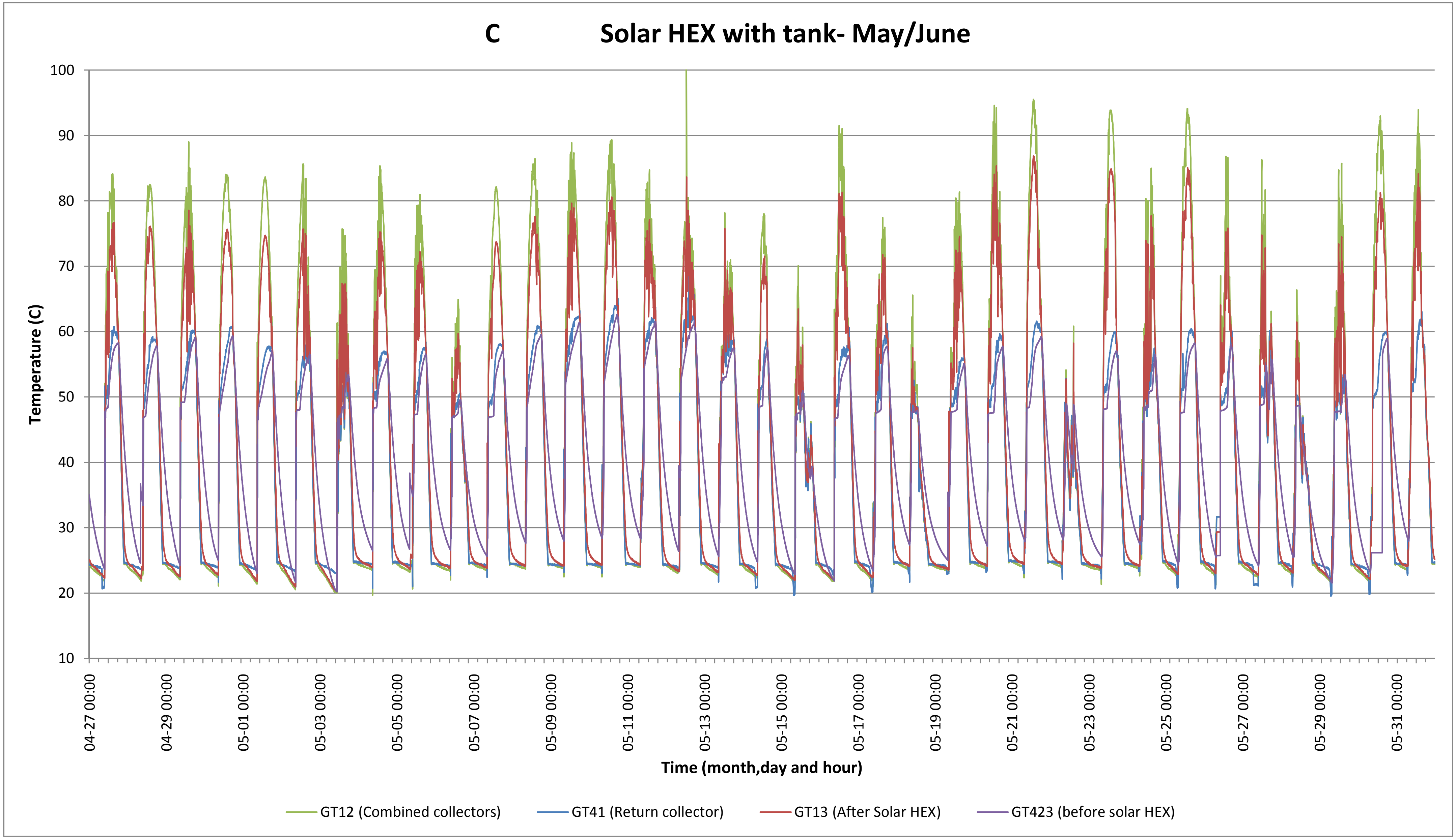


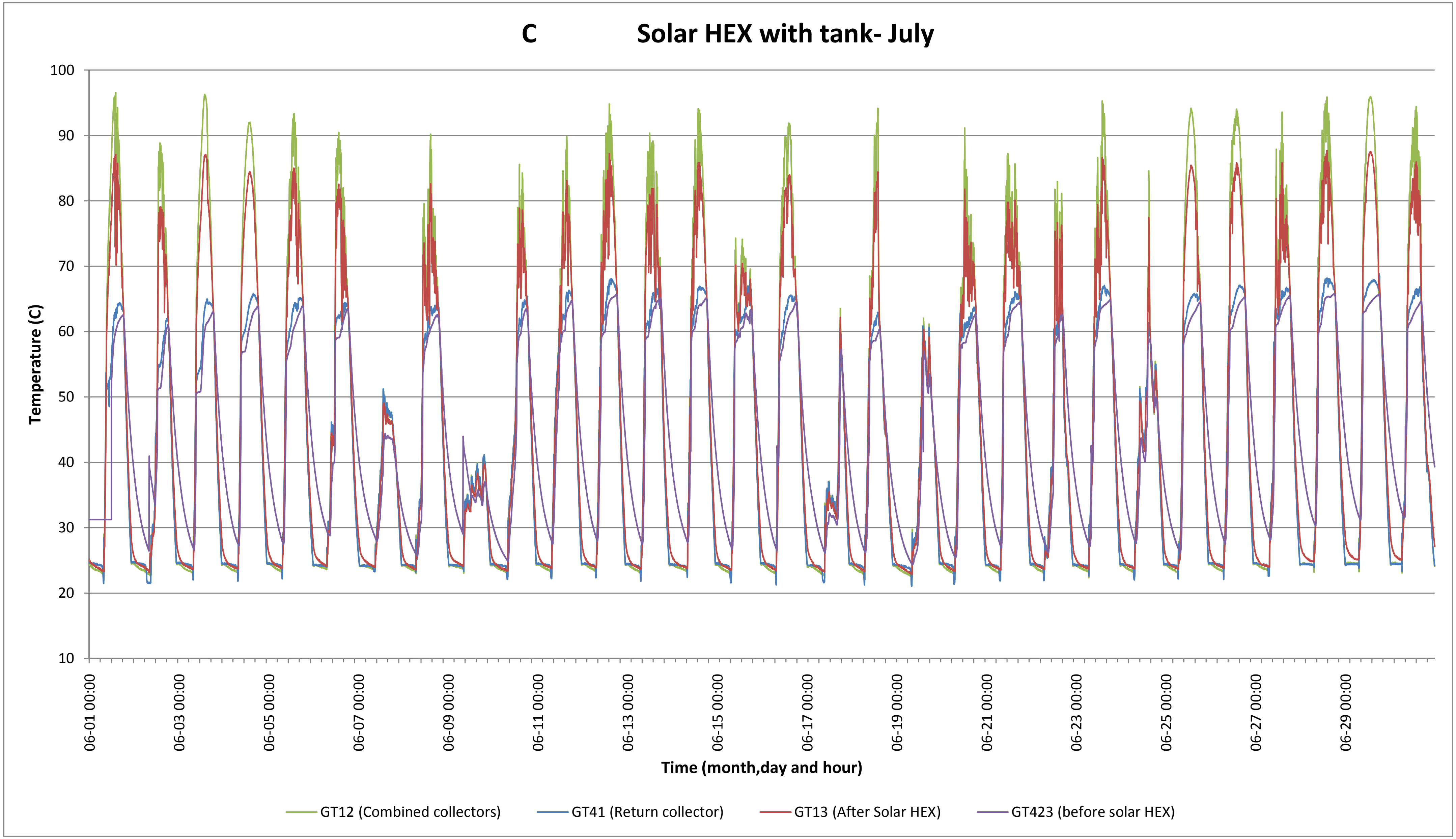
B
Forward Collector loop- April/May
Temperature (C)
105
95
85
75
65
55
45
35
25
15
5
-5
04-27 00:00
04-29 00:00
05-01 00:00
05-03 00:00
05-05 00:00
05-07 00:00
05-09 00:00
05-11 00:00
05-13 00:00
05-15 00:00
05-17 00:00
05-19 00:00
05-21 00:00
05-23 00:00
05-25 00:00
05-27 00:00
05-29 00:00
05-31 00:00
Time (month,day and hour)
GT11A (Collector section A)
GT11B (collector section B)
GT12 (Combined collectors)

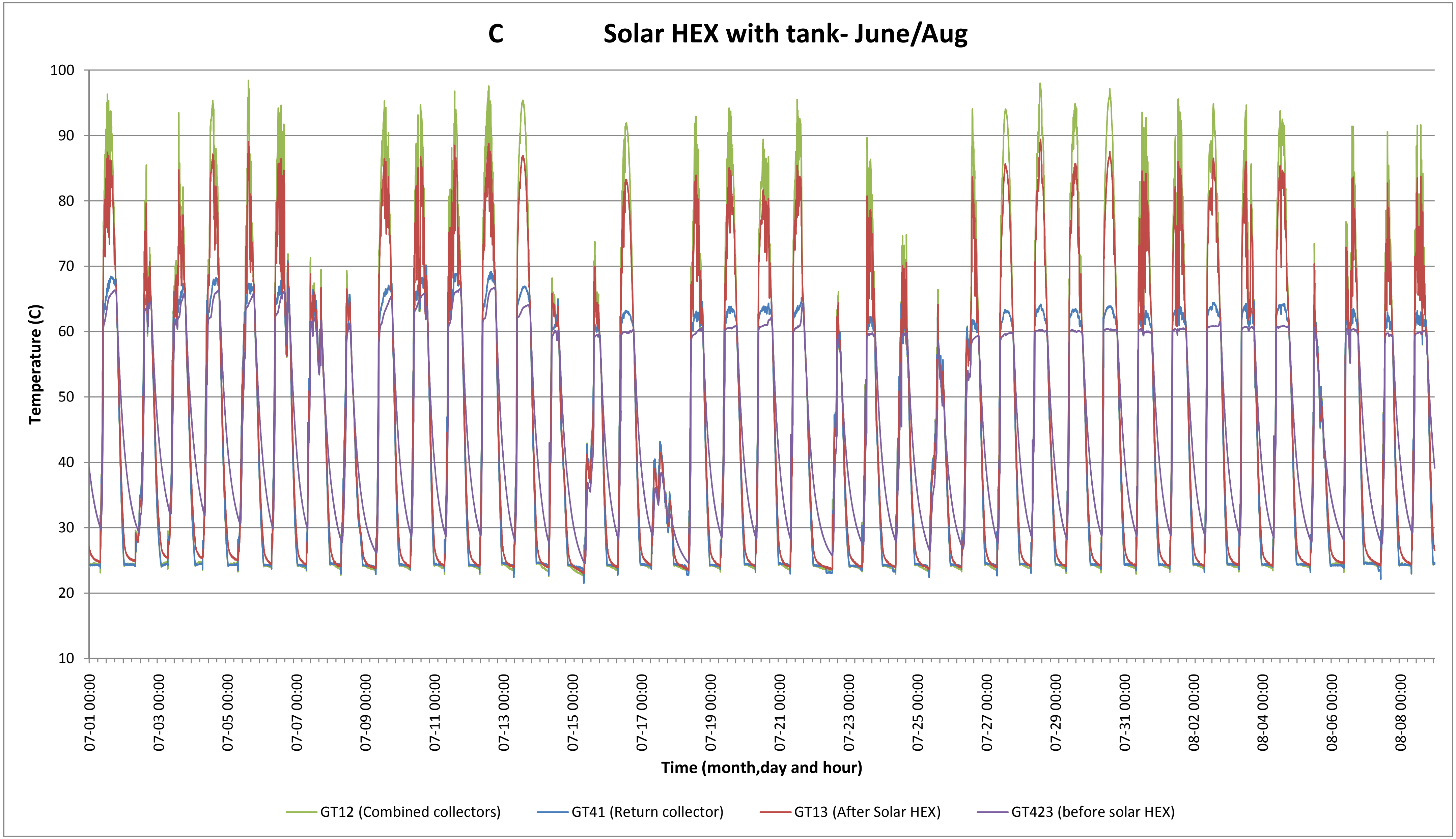

B
Forward Collector loop- June
Temperature (C)
110
100
90
80
70
60
50
40
30
20
10
0
06-01 00:00
06-03 00:00
06-05 00:00
06-07 00:00
06-09 00:00
06-11 00:00
06-13 00:00
06-15 00:00
06-17 00:00
06-19 00:00
06-21 00:00
06-23 00:00
06-25 00:00
06-27 00:00
06-29 00:00
Time (month,day and hour)
GT11A (Collector section A)
GT11B (collector section B)
GT12 (Combined collectors)

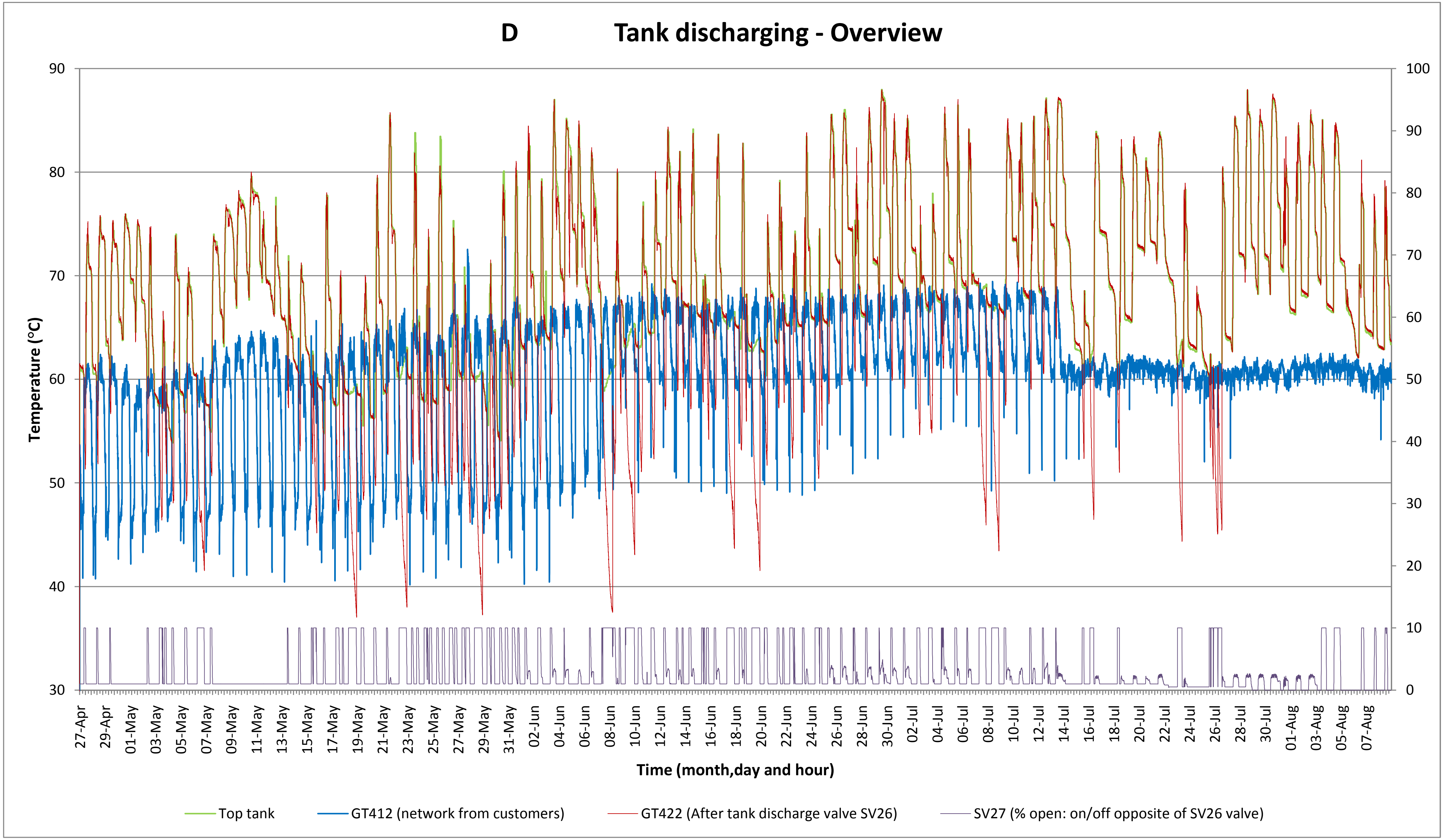

B
Forward Collector loop- July/Aug
Temperature (C)
110
100
90
80
70
60
50
40
30
20
10
0
07-01 00:00
07-03 00:00
07-05 00:00
07-07 00:00
07-09 00:00
07-11 00:00
07-13 00:00
07-15 00:00
07-17 00:00
07-19 00:00
07-21 00:00
07-23 00:00
07-25 00:00
07-27 00:00
07-29 00:00
07-31 00:00
08-02 00:00
08-04 00:00
08-06 00:00
08-08 00:00
Time (month,day and hour)
GT11A (Collector section A)
GT11B (collector section B)
GT12 (Combined collectors)


C
Solar HEX with tank- Overview
Temperature (C)
100
90
80
70
60
50
40
30
20
10
27-Apr
29-Apr
1-May
3-May
5-May
7-May
9-May
11-May
13-May
15-May
17-May
19-May
21-May
23-May
25-May
27-May
29-May
31-May
2-Jun
4-Jun
6-Jun
8-Jun
10-Jun
12-Jun
14-Jun
16-Jun
18-Jun
20-Jun
22-Jun
24-Jun
26-Jun
28-Jun
30-Jun
2-Jul
4-Jul
6-Jul
8-Jul
10-Jul
12-Jul
14-Jul
16-Jul
18-Jul
20-Jul
22-Jul
24-Jul
26-Jul
28-Jul
30-Jul
1-Aug
3-Aug
5-Aug
7-Aug
Time (month,day)
GT12 (Combined collectors)
GT41 (Return collector)
GT13 (After Solar HEX)
GT423 (before solar HEX)

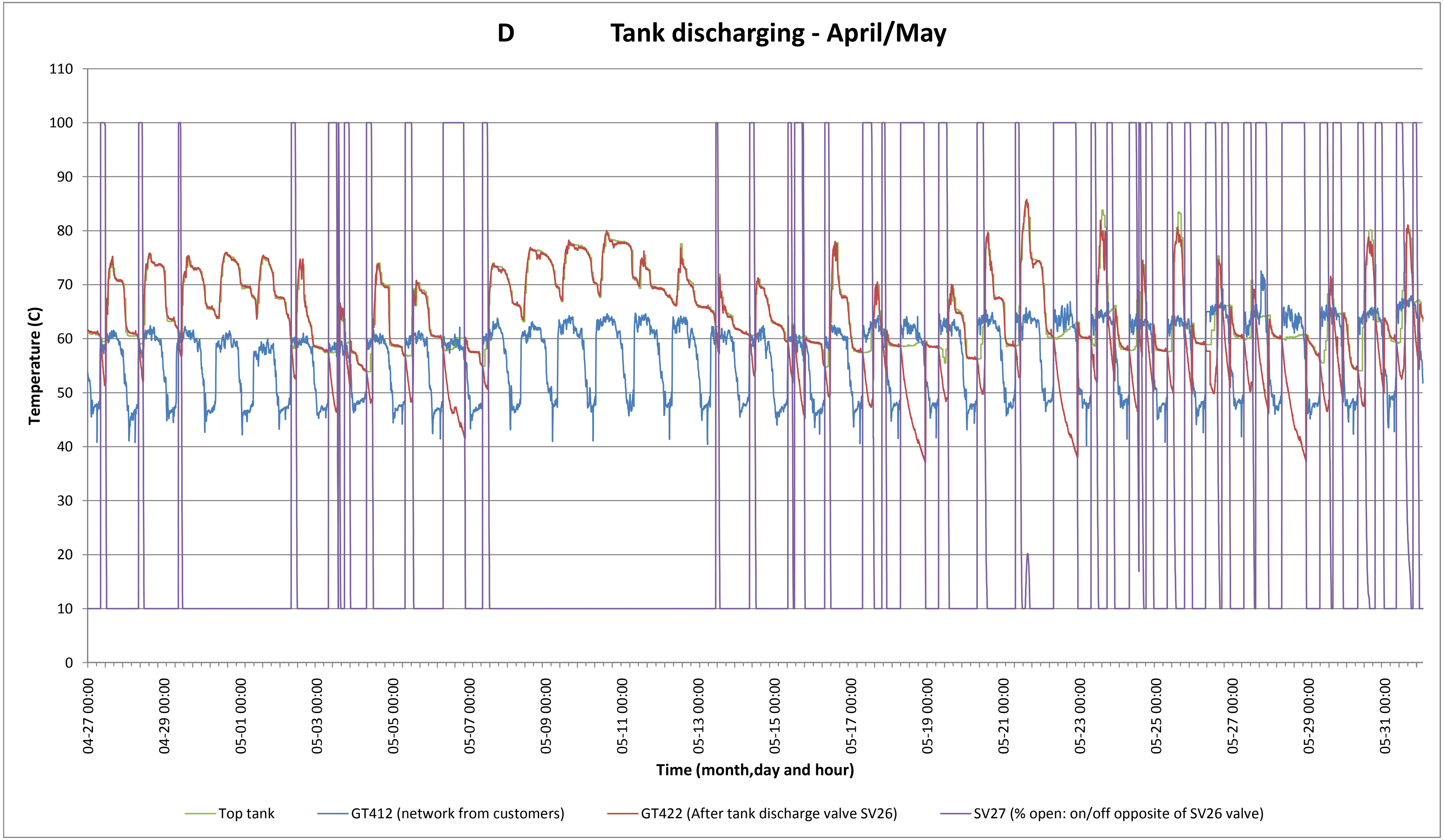

C
Solar HEX with tank- May/June
Temperature (C)
100
90
80
70
60
50
40
30
20
10
04-27 00:00
04-29 00:00
05-01 00:00
05-03 00:00
05-05 00:00
05-07 00:00
05-09 00:00
05-11 00:00
05-13 00:00
05-15 00:00
05-17 00:00
05-19 00:00
05-21 00:00
05-23 00:00
05-25 00:00
05-27 00:00
05-29 00:00
05-31 00:00
Time (month,day and hour)
GT12 (Combined collectors)
GT41 (Return collector)
GT13 (After Solar HEX)
GT423 (before solar HEX)

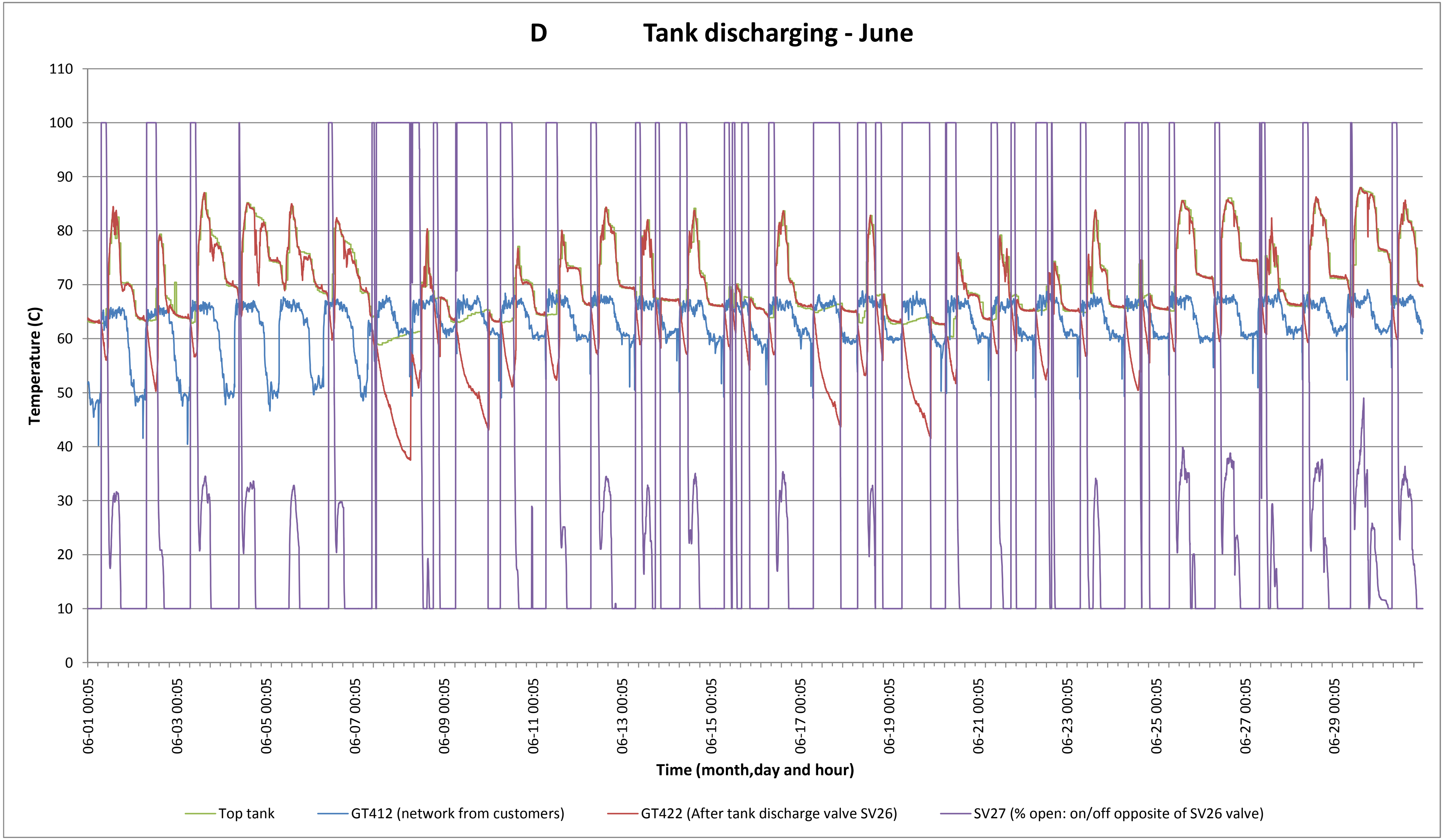

C Solar HEX with tank- July
Temperature (C)
100
90
80
70
60
50
40
30
20
10
06-01 00:00
06-03 00:00
06-05 00:00
06-07 00:00
06-09 00:00
06-11 00:00
06-13 00:00
06-15 00:00
06-17 00:00
06-19 00:00
06-21 00:00
06-23 00:00
06-25 00:00
06-27 00:00
06-29 00:00
Time (month,day and hour)
GT12 (Combined collectors)
GT41 (Return collector)
GT13 (After Solar HEX)
GT423 (before solar HEX)

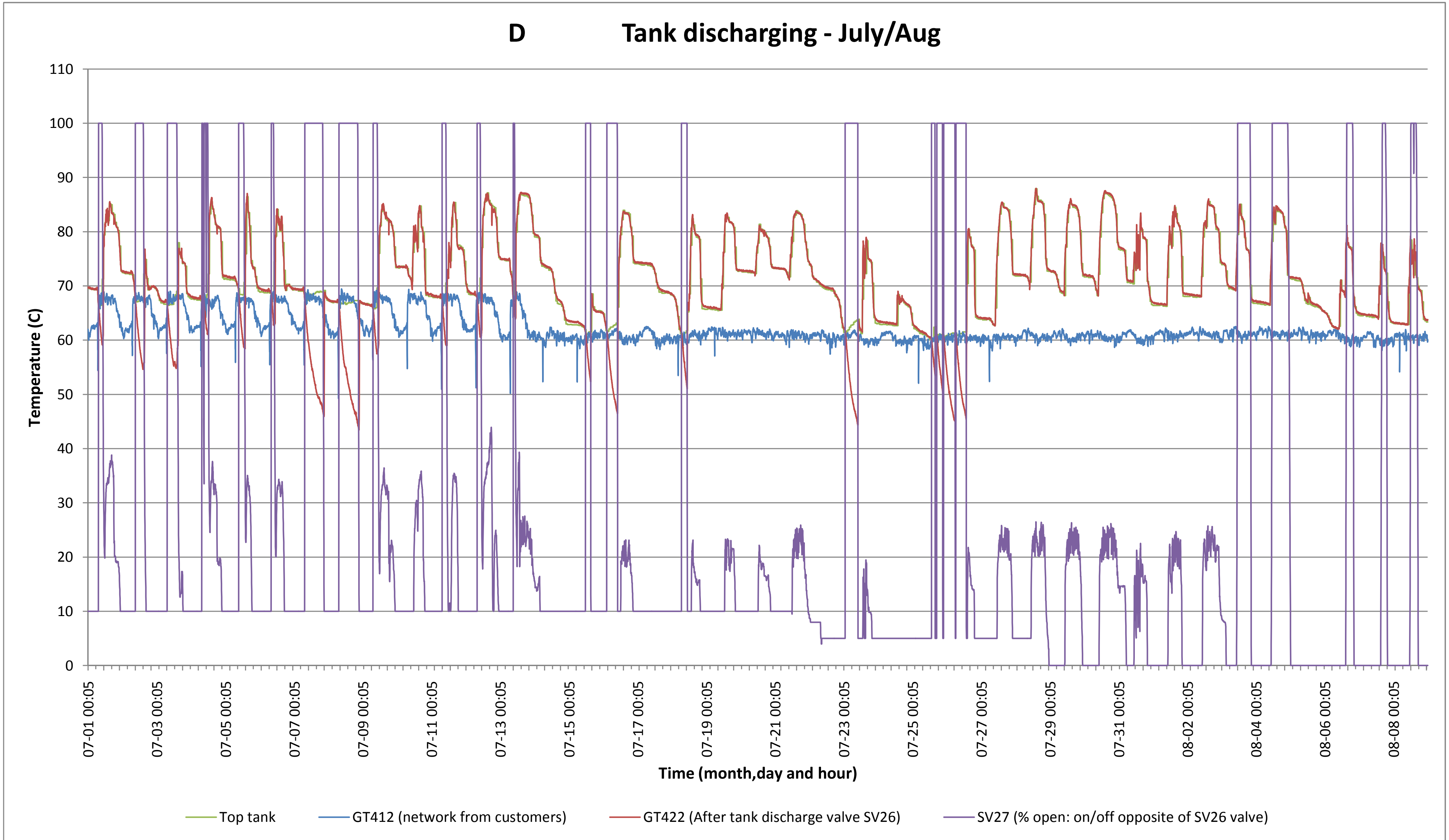

C Solar HEX with tank- June/Aug
Temperature (C)
100
90
80
70
60
50
40
30
20
10
07-01 00:00
07-03 00:00
07-05 00:00
07-07 00:00
07-09 00:00
07-11 00:00
07-13 00:00
07-15 00:00
07-17 00:00
07-19 00:00
07-21 00:00
07-23 00:00
07-25 00:00
07-27 00:00
07-29 00:00
07-31 00:00
08-02 00:00
08-04 00:00
08-06 00:00
08-08 00:00
Time (month,day and hour)
GT12 (Combined collectors)
GT41 (Return collector)
GT13 (After Solar HEX)
GT423 (before solar HEX)



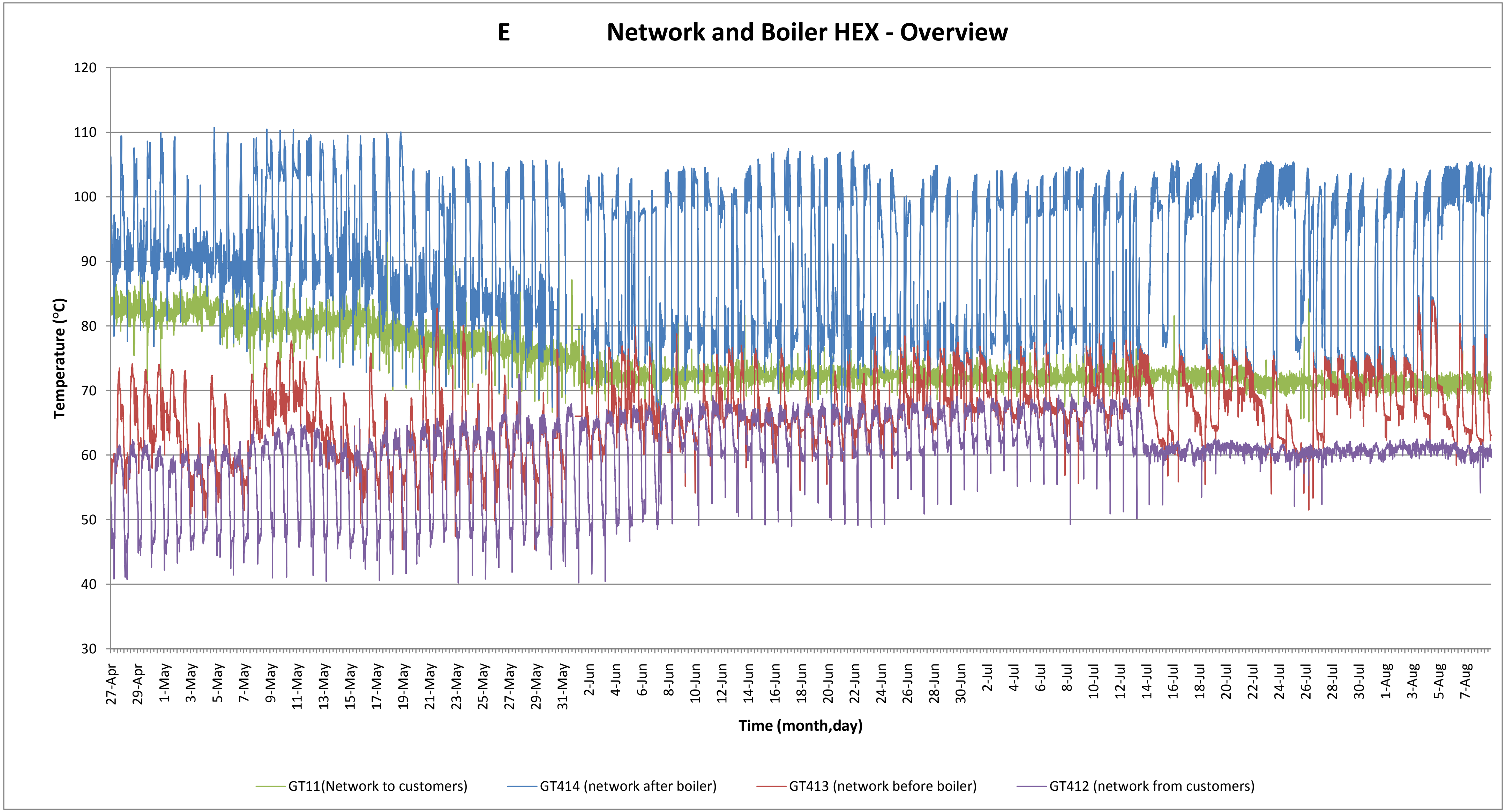
D
Tank discharging - Overview
Temperature (°C)
90
80
70
60
50
40
30
100
90
80
70
60
50
40
30
20
10
0
27-Apr
29-Apr
01-May
03-May
05-May
07-May
09-May
11-May
13-May
15-May
17-May
19-May
21-May
23-May
25-May
27-May
29-May
31-May
02-Jun
04-Jun
06-Jun
08-Jun
10-Jun
12-Jun
14-Jun
16-Jun
18-Jun
20-Jun
22-Jun
24-Jun
26-Jun
28-Jun
30-Jun
02-Jul
04-Jul
06-Jul
08-Jul
10-Jul
12-Jul
14-Jul
16-Jul
18-Jul
20-Jul
22-Jul
24-Jul
26-Jul
28-Jul
30-Jul
01-Aug
03-Aug
05-Aug
07-Aug
Time (month,day and hour)
Top tank
GT412 (network from customers)
GT422 (After tank discharge valve SV26)
SV27 (% open: on/off opposite of SV26 valve)

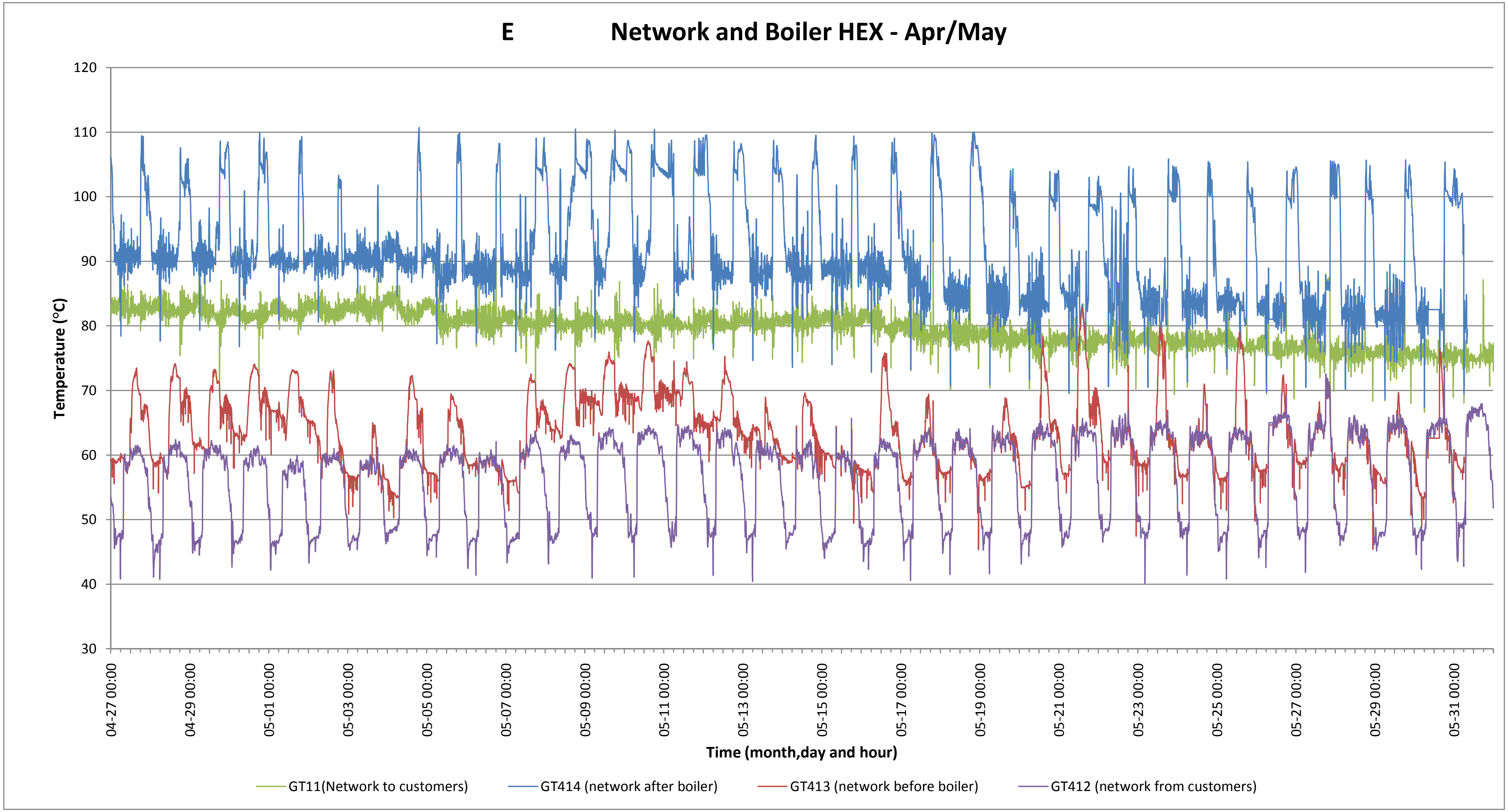

D
Tank discharging - April/May
Temperature (C)
110
100
90
80
70
60
50
40
30
20
10
0
04-27 00:00
04-29 00:00
05-01 00:00
05-03 00:00
05-05 00:00
05-07 00:00
05-09 00:00
05-11 00:00
05-13 00:00
05-15 00:00
05-17 00:00
05-19 00:00
05-21 00:00
05-23 00:00
05-25 00:00
05-27 00:00
05-29 00:00
05-31 00:00
Time (month,day and hour)
Top tank
GT412 (network from customers)
GT422 (After tank discharge valve SV26)
SV27 (% open: on/off opposite of SV26 valve)

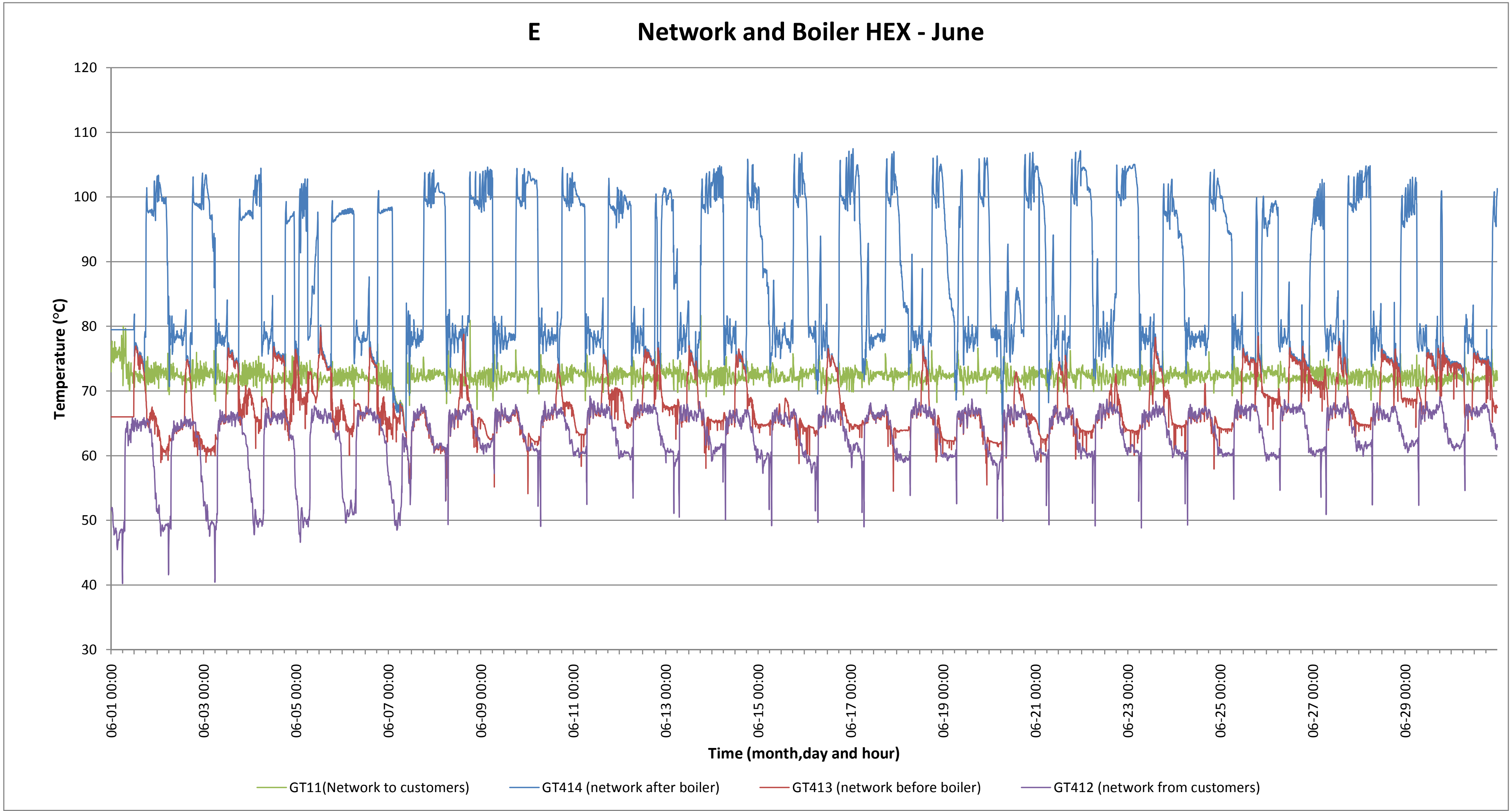

D
Tank discharging - June
Temperature (C)
110
100
90
80
70
60
50
40
30
20
10
0
06-01 00:05
06-03 00:05
06-05 00:05
06-07 00:05
06-09 00:05
06-11 00:05
06-13 00:05
06-15 00:05
06-17 00:05
06-19 00:05
06-21 00:05
06-23 00:05
06-25 00:05
06-27 00:05
06-29 00:05
Time (month,day and hour)
Top tank
GT412 (network from customers)
GT422 (After tank discharge valve SV26)
SV27 (% open: on/off opposite of SV26 valve)

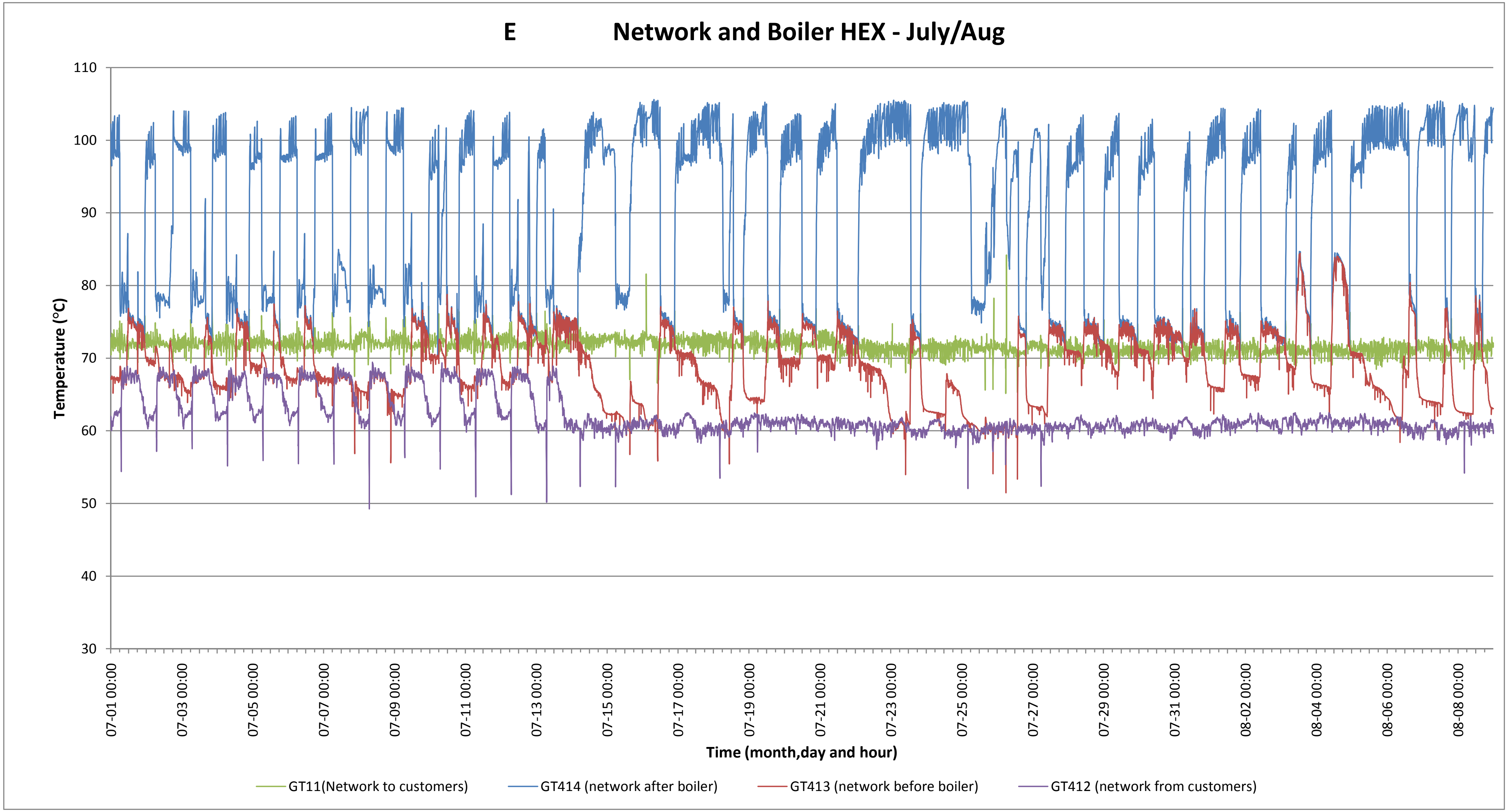


D
Tank discharging - July/Aug
Temperature (C)
110
100
90
80
70
60
50
40
30
20
10
0
07-01 00:05
07-03 00:05
07-05 00:05
07-07 00:05
07-09 00:05
07-11 00:05
07-13 00:05
07-15 00:05
07-17 00:05
07-19 00:05
07-21 00:05
07-23 00:05
07-25 00:05
07-27 00:05
07-29 00:05
07-31 00:05
08-02 00:05
08-04 00:05
08-06 00:05
08-08 00:05
Time (month,day and hour)
Top tank
GT412 (network from customers)
GT422 (After tank discharge valve SV26)
SV27 (% open: on/off opposite of SV26 valve)

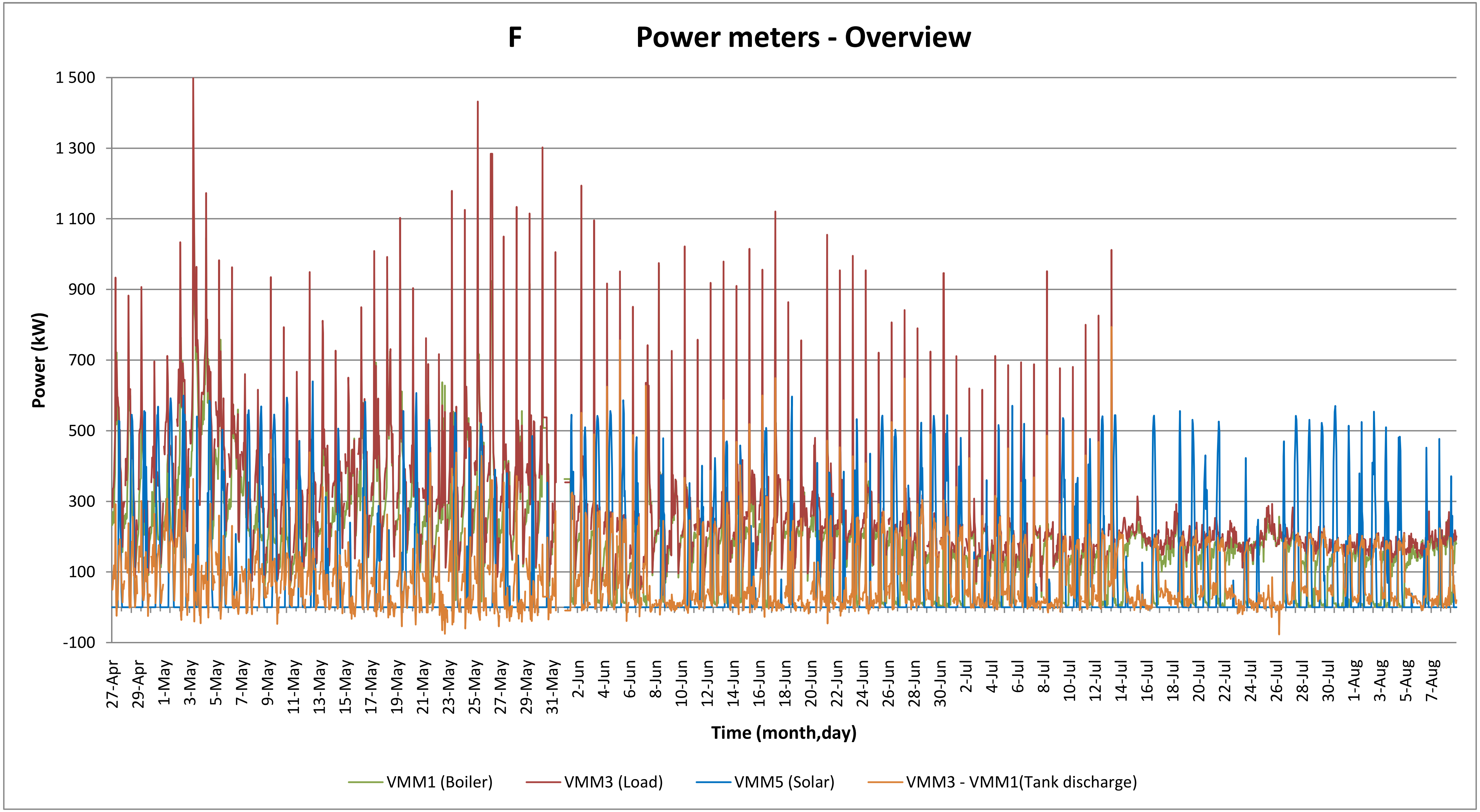

E Network and Boiler HEX - Overview
Temperature (°C)
120
110
100
90
80
70
60
50
40
30
27-Apr
29-Apr
1-May
3-May
5-May
7-May
9-May
11-May
13-May
15-May
17-May
19-May
21-May
23-May
25-May
27-May
29-May
31-May
2-Jun
4-Jun
6-Jun
8-Jun
10-Jun
12-Jun
14-Jun
16-Jun
18-Jun
20-Jun
22-Jun
24-Jun
26-Jun
28-Jun
30-Jun
2-Jul
4-Jul
6-Jul
8-Jul
10-Jul
12-Jul
14-Jul
16-Jul
18-Jul
20-Jul
22-Jul
24-Jul
26-Jul
28-Jul
30-Jul
1-Aug
3-Aug
5-Aug
7-Aug
Time (month,day)
GT11(Network to customers)
GT414 (network after boiler)
GT413 (network before boiler)
GT412 (network from customers)

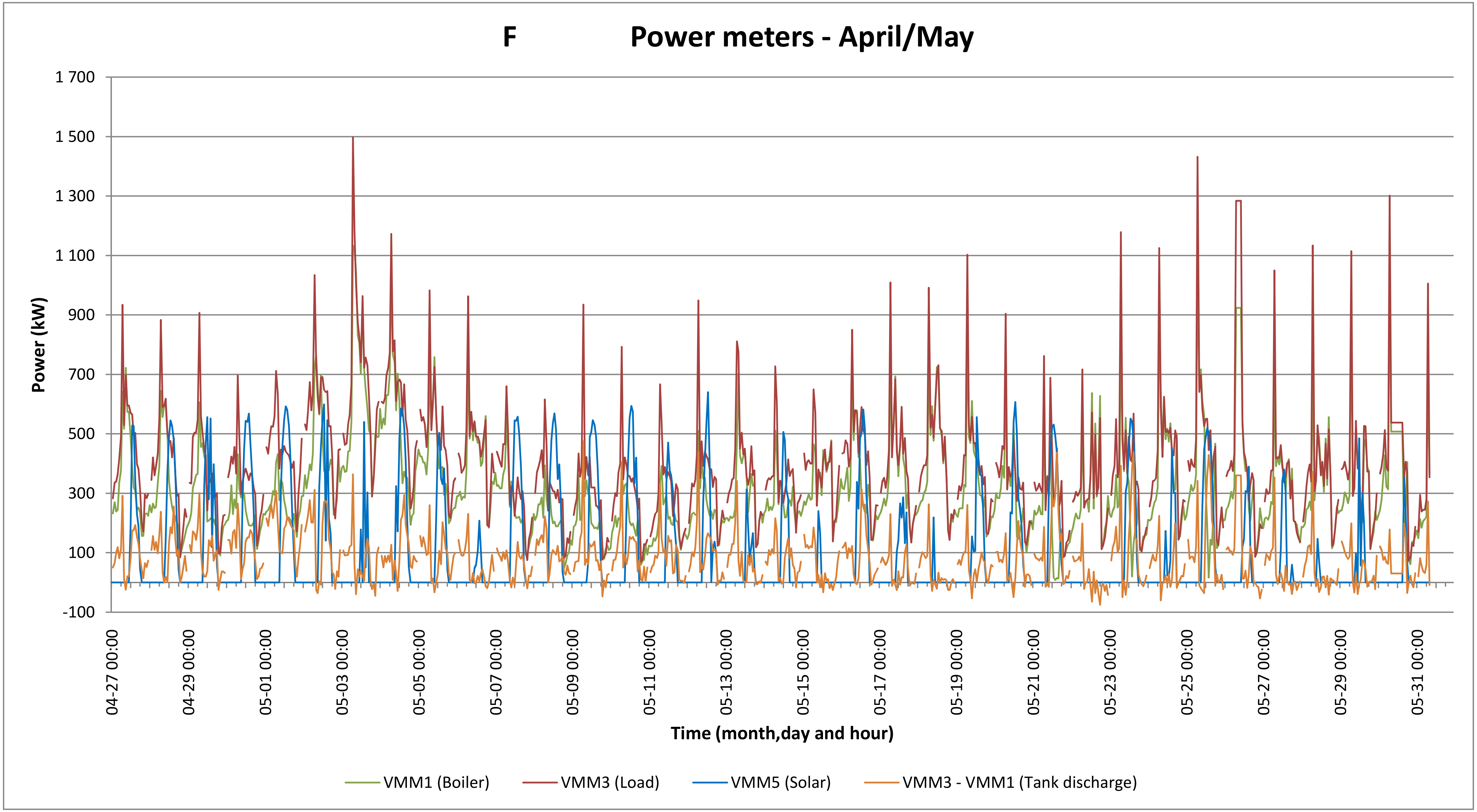

E
Network and Boiler HEX - Apr/May
Temperature (°C)
120
110
100
90
80
70
60
50
40
30
04-27 00:00
04-29 00:00
05-01 00:00
05-03 00:00
05-05 00:00
05-07 00:00
05-09 00:00
05-11 00:00
05-13 00:00
05-15 00:00
05-17 00:00
05-19 00:00
05-21 00:00
05-23 00:00
05-25 00:00
05-27 00:00
05-29 00:00
05-31 00:00
Time (month,day and hour)
GT11(Network to customers)
GT414 (network after boiler)
GT413 (network before boiler)
GT412 (network from customers)

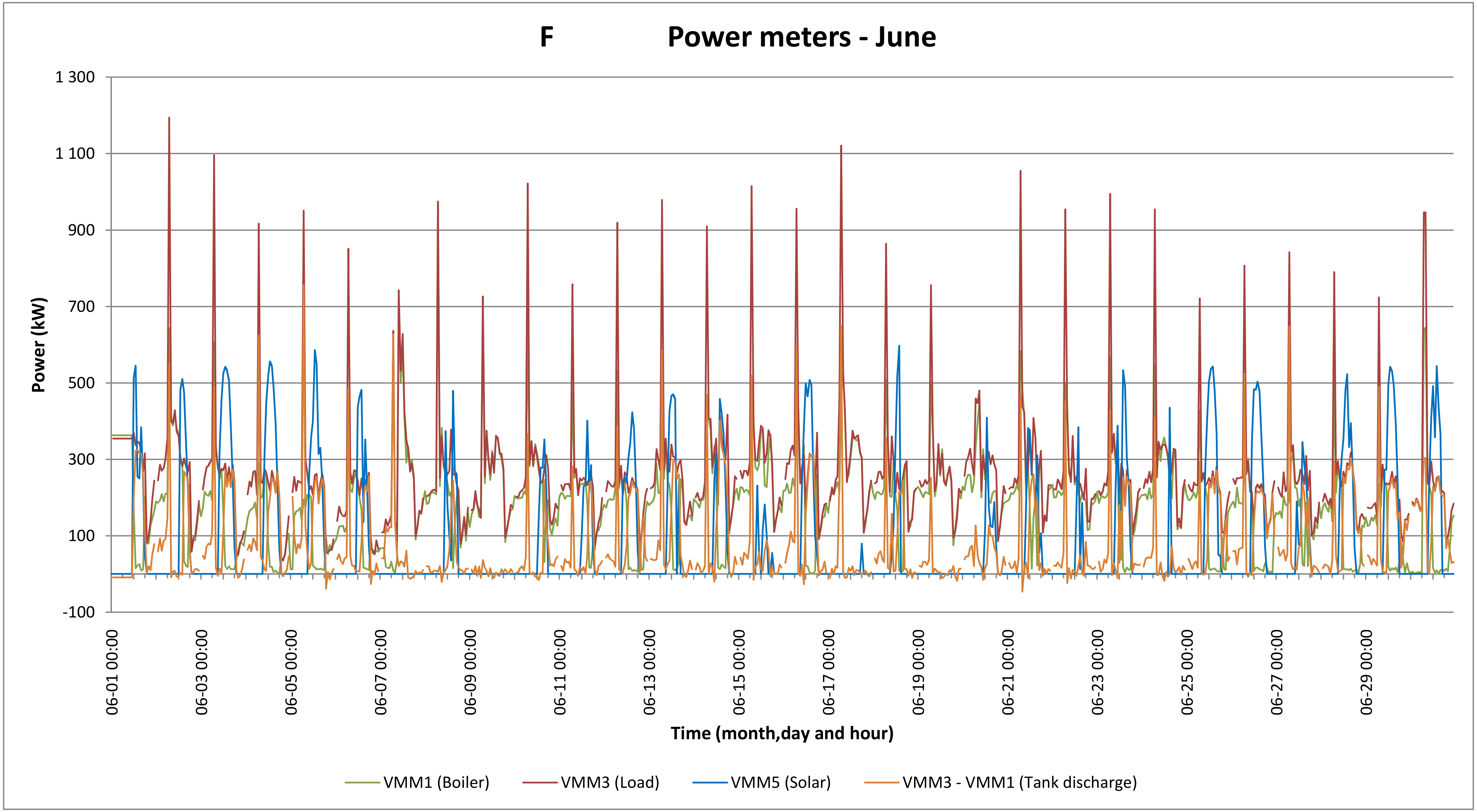

E Network and Boiler HEX - June
120
110
100
90
80
70
60
50
40
30
Temperature (°C)
06-01 00:00
06-03 00:00
06-05 00:00
06-07 00:00
06-09 00:00
06-11 00:00
06-13 00:00
06-15 00:00
06-17 00:00
06-19 00:00
06-21 00:00
06-23 00:00
06-25 00:00
06-27 00:00
06-29 00:00
Time (month,day and hour)
GT11(Network to customers)
GT414 (network after boiler)
GT413 (network before boiler)
GT412 (network from customers)

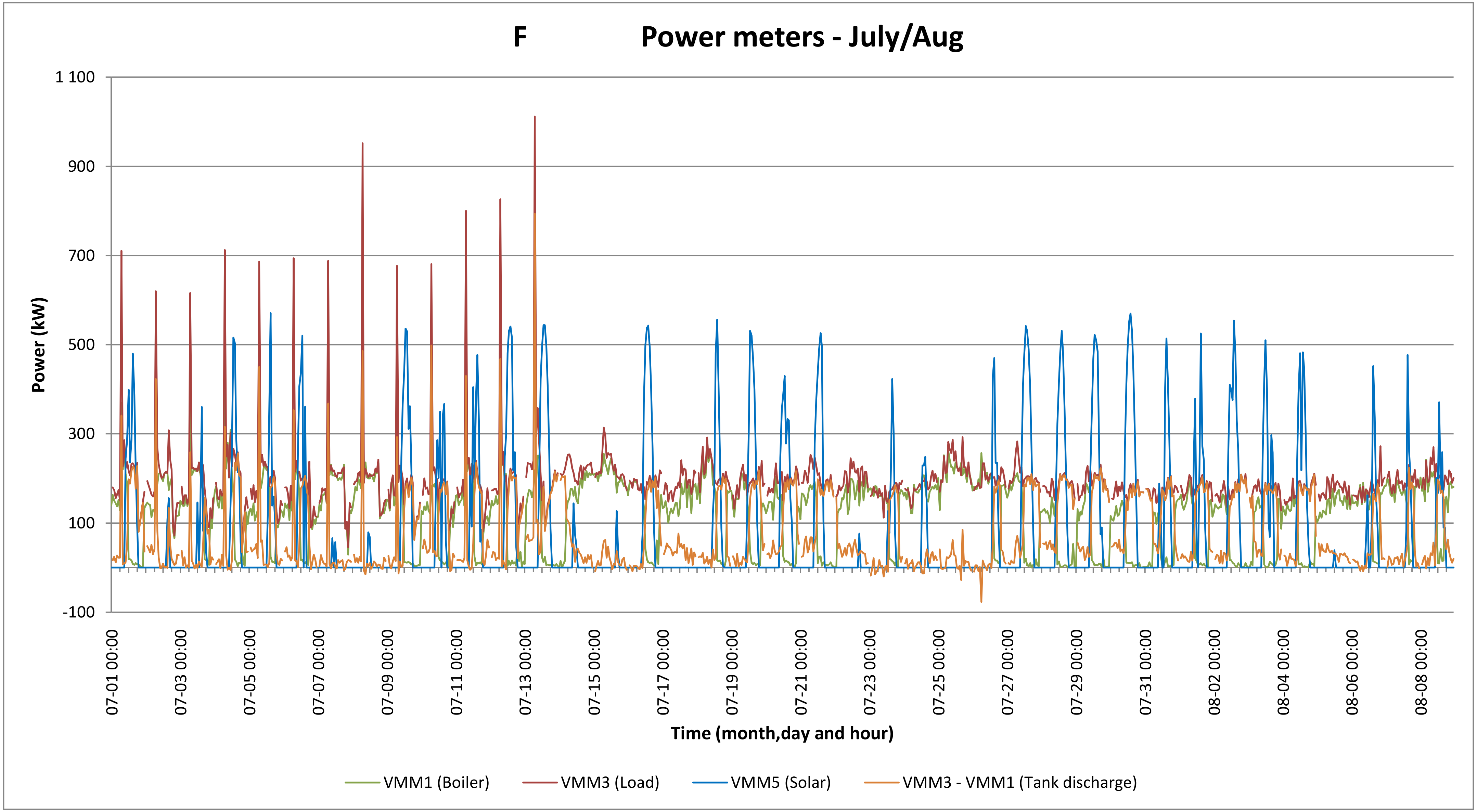


E Network and Boiler HEX - July/Aug
110
100
90
80
70
60
50
40
30
Temperature (°C)
07-01 00:00
07-03 00:00
07-05 00:00
07-07 00:00
07-09 00:00
07-11 00:00
07-13 00:00
07-15 00:00
07-17 00:00
07-19 00:00
07-21 00:00
07-23 00:00
07-25 00:00
07-27 00:00
07-29 00:00
07-31 00:00
08-02 00:00
08-04 00:00
08-06 00:00
08-08 00:00
Time (month,day and hour)
GT11(Network to customers)
GT414 (network after boiler)
GT413 (network before boiler)
GT412 (network from customers)

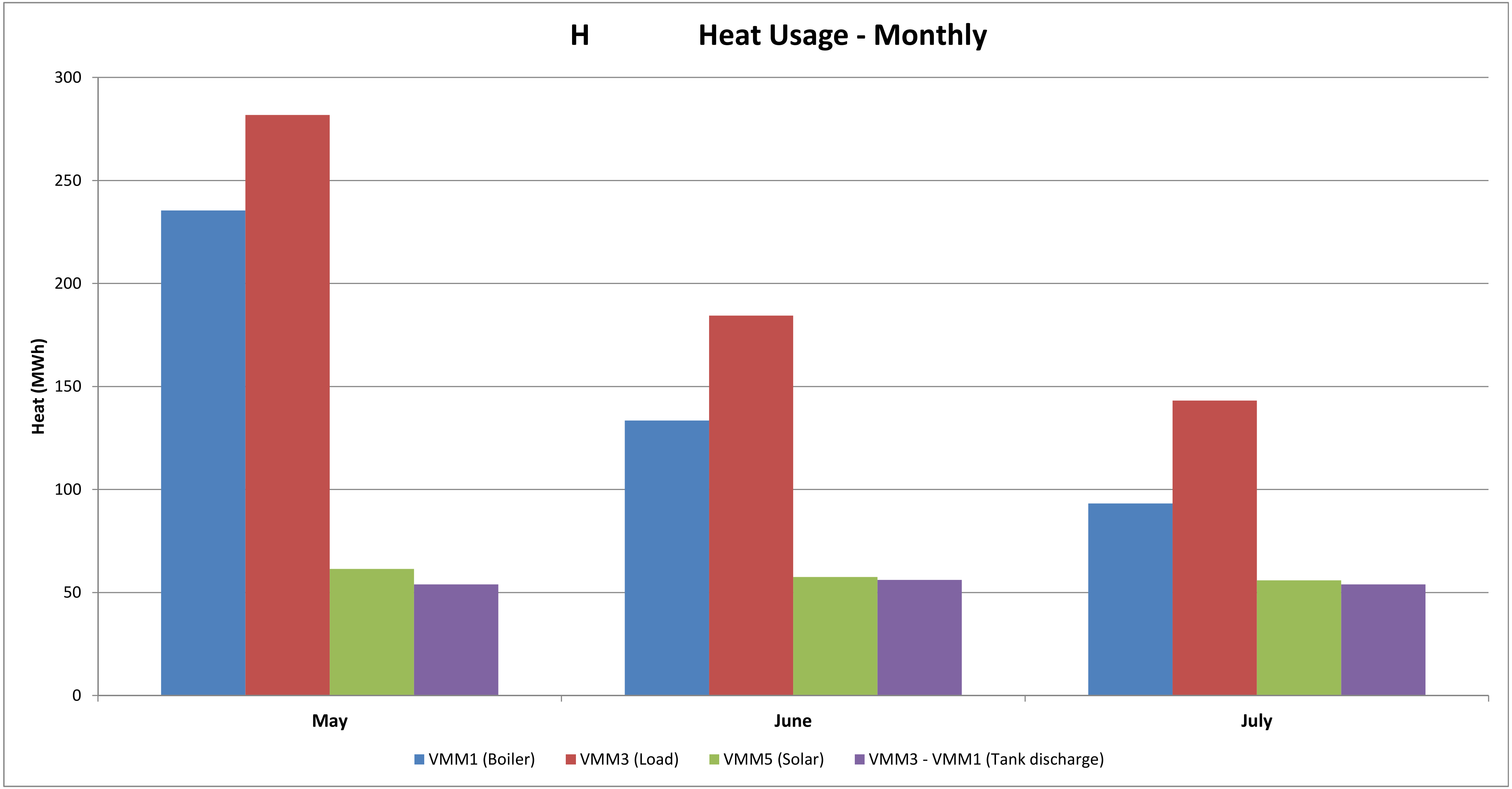

F
Power meters - Overview
Power (kW)
1 500
1 300
1 100
900
700
500
300
100
-100
Time (month,day)
27-Apr
29-Apr
1-May
3-May
5-May
7-May
9-May
11-May
13-May
15-May
17-May
19-May
21-May
23-May
25-May
27-May
29-May
31-May
2-Jun
4-Jun
6-Jun
8-Jun
10-Jun
12-Jun
14-Jun
16-Jun
18-Jun
20-Jun
22-Jun
24-Jun
26-Jun
28-Jun
30-Jun
2-Jul
4-Jul
6-Jul
8-Jul
10-Jul
12-Jul
14-Jul
16-Jul
18-Jul
20-Jul
22-Jul
24-Jul
26-Jul
28-Jul
30-Jul
1-Aug
3-Aug
5-Aug
7-Aug
VMM1 (Boiler)
VMM3 (Load)
VMM5 (Solar)
VMM3 - VMM1(Tank discharge)


F
Power meters - April/May
Power (kW)
1 700
1 500
1 300
1 100
900
700
500
300
100
-100
04-27 00:00
04-29 00:00
05-01 00:00
05-03 00:00
05-05 00:00
05-07 00:00
05-09 00:00
05-11 00:00
05-13 00:00
05-15 00:00
05-17 00:00
05-19 00:00
05-21 00:00
05-23 00:00
05-25 00:00
05-27 00:00
05-29 00:00
05-31 00:00
Time (month,day and hour)
VMM1 (Boiler)
VMM3 (Load)
VMM5 (Solar)
VMM3 - VMM1 (Tank discharge)


F
Power meters - June
1 300
1 100
900
700
500
300
100
-100
Power (kW)
06-01 00:00
06-03 00:00
06-05 00:00
06-07 00:00
06-09 00:00
06-11 00:00
06-13 00:00
06-15 00:00
06-17 00:00
06-19 00:00
06-21 00:00
06-23 00:00
06-25 00:00
06-27 00:00
06-29 00:00
Time (month,day and hour)
VMM1 (Boiler)
VMM3 (Load)
VMM5 (Solar)
VMM3 - VMM1 (Tank discharge)



F Power meters - July/Aug
1 100
900
700
500
300
100
-100
Power (kW)
07-01 00:00
07-03 00:00
07-05 00:00
07-07 00:00
07-09 00:00
07-11 00:00
07-13 00:00
07-15 00:00
07-17 00:00
07-19 00:00
07-21 00:00
07-23 00:00
07-25 00:00
07-27 00:00
07-29 00:00
07-31 00:00
08-02 00:00
08-04 00:00
08-06 00:00
08-08 00:00
Time (month,day and hour)
VMM1 (Boiler)
VMM3 (Load)
VMM5 (Solar)
VMM3 - VMM1 (Tank discharge)



H Heat Usage - Monthly
300
250
200
150
100
50
0
Heat (MWh)
May
June
July
VMM1 (Boiler)
VMM3 (Load)
VMM5 (Solar)
VMM3 - VMM1 (Tank discharge)