



Central Bank Mini® (P58) Application Guide

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Summary

This document must be used in conjunction with the latest version of the Central Bank Mini (P58) thermal battery manual (document D0077). This manual can be downloaded from the Sunamp website www.sunamp.com

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



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1 Introduction

1.1 Definitions & symbols

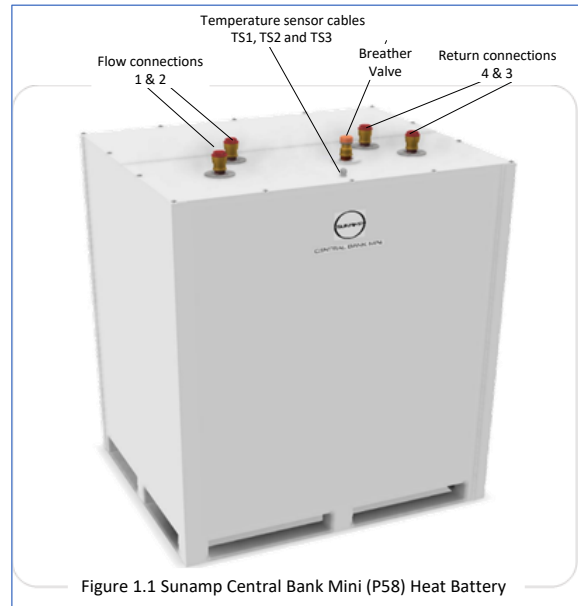
- **Central Bank Mini (P58):** Central Bank Mini® filled with P58 Phase change material
- **PCM:** Phase change material
- **TES:** Thermal Energy Storage
- **BOP:** Balance of plant – Consisting of pumps, control and isolating valves; pressure and temperature control sensors and devices; over pressure and over temperature control devices and system controller
- **PRV:** Over pressure safety relief valve
- **OHT:** Over temperature safety cut-off device (usually requiring manual resetting)
- **CV01:** Flow control valve number 1
- **T02:** Temperature sensor number 2
- **P03:** Pressure sensor number 3
- **Cell:** The inner containment vessel holding the phase change material and heat exchanger
- **HPC-1:** High power Central Bank Mini (P58) hydronic circuit – 1 (connections 1 & 3)
- **LPC-2:** Low power Central Bank Mini (P58) hydronic circuit – 2 (connections 2 & 4)

	Isolating valve - 2 way		Temperature sensor		Expansion vessel
	Circulation pump		Isolating valve - 3 way		Pressure sensor
	Non-return/Check valve		Drain valve		Flow rate sensor
	Air vent		Inline filter		Pressure regulator
	3-Port modulating mixing control valve		Pressure gauge		Low loss header
	2-Port modulating control valve		Pressure relief safety valve		Plate heat exchanger

1.2 Central Bank Mini (P58) heat battery

The Central Bank Mini range of thermal batteries, shown in figure 1.1 are designed to be charged by an external heat source. They are used for storing thermal energy for a wide range of process and space heating applications. The Central Bank Mini (P58) model is supplied with Sunamp phase change material (PCM) P58 which has operating temperature range from 5°C to 80°C (41°F - 176°F).

The Central Bank Mini® (P58) model has two hydronic circuits for storing and discharging the thermal energy. The maximum working pressure for these circuits is 16 Bar (232 PSI). For further technical specifications please refer to the product installation manual.



1.3 Application of Central Bank Mini® (P58) heat battery

For application and system integration, this heat battery should be considered as a Thermal Energy Store (TES). It uses phase change material to store thermal energy, and the thermal energy is then transferred, to and from, the PCM storage media via the heat exchanger(s). Therefore, for applications and system integration, the Central Bank Mini® (P58) as shown in figure 1.2, can be compared to an open-vented hot water based TES, which is heated and discharged via heat exchanger(s) as shown schematically in figure 1.3. Therefore, the balance of plant (BOP) equipment required for system integration would be similar.

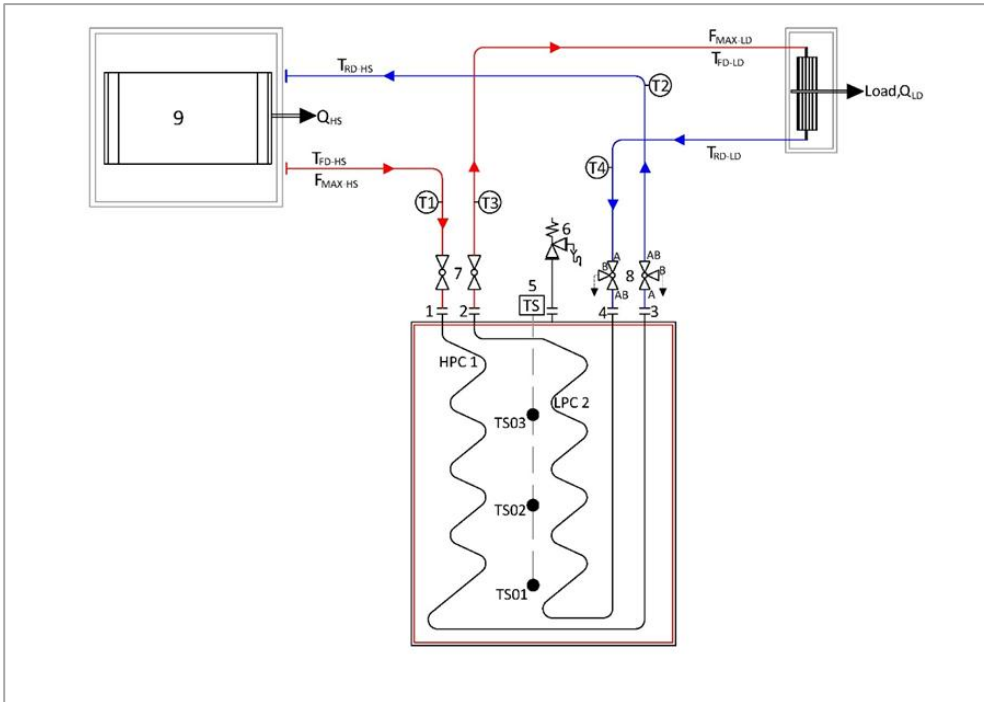


Figure 1.2: Typical connection arrangement Central Bank Mini (P58)

Key to figures 1.2 and 1.3	
1	High power circuit – 1 flow connection (1¼" Male threaded)
2	Low power circuit – 2 flow connection (1¼" Male threaded)
3	High power circuit – Return connection (1¼" Male threaded)
4	Low power circuit – return connection (1¼" Male threaded)
5	Heat battery temperature sensor cables (TS01, TS02 & TS03, 3-wire RTD PT100)
6	Heat battery cell breather / safety pressure relief valve
7	Heat battery isolating valve (2 – port)
8	Heat battery isolating valve (3 – port, AB - B is open, when AB - A is closed)
9	Hot water TES Feed and expansion cistern
10	Hot water TES Vent pipe (equivalent to item 6 on the heat battery)
11	Hot water RES feed pipe
12	Hot water TES Cistern overflow pipe (equivalent to discharge from item 6 on the heat battery)
13	Hot water TES heat exchanger drain valve
14	Hot water TES drain valve

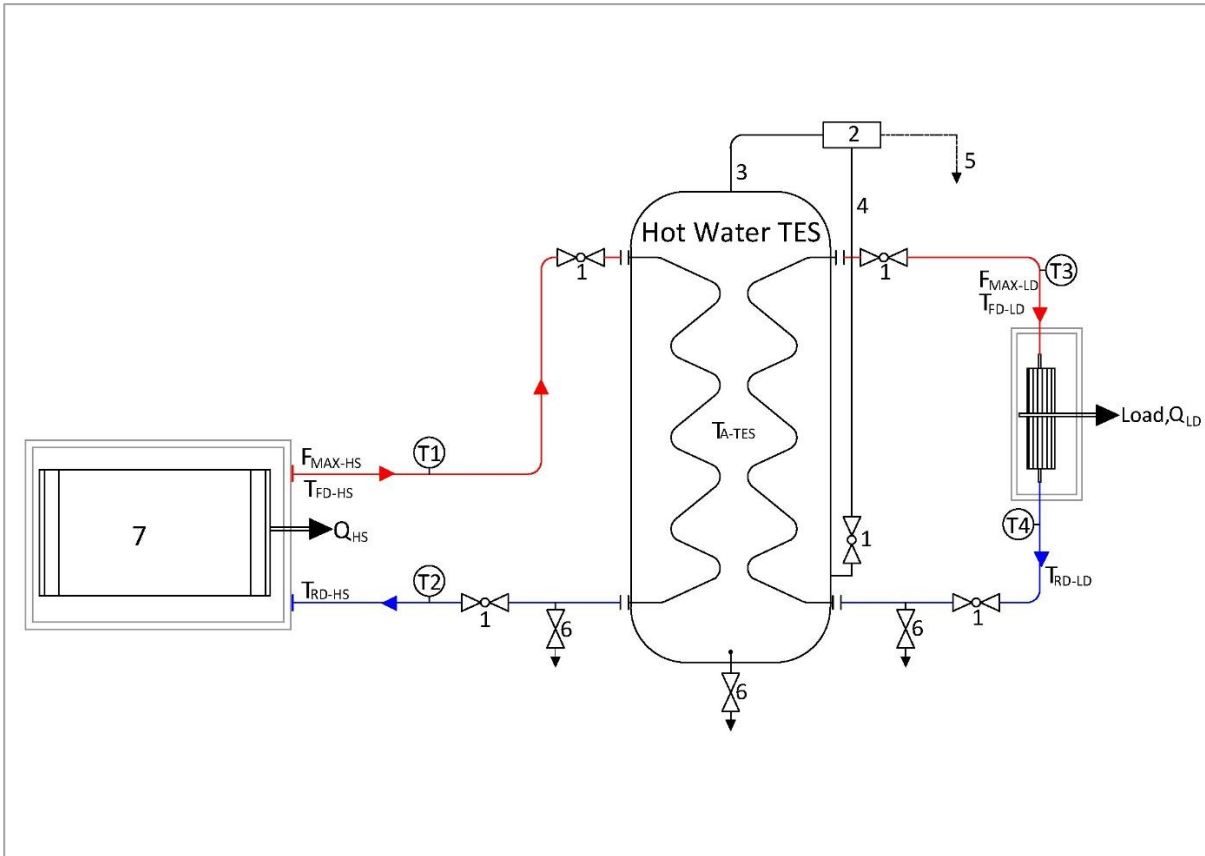


Figure 1.3: Typical connection arrangement of an indirect open vented hot water-based system TES

The key differences between the Central Bank Mini® (P58) heat battery connection arrangement (figure 1.2), and the open-vented indirect hot water TES vessel connection arrangement (figure 1.3), are:

- The Central Bank Mini (P58) heat battery is not fitted with heat exchanger hydronic circuit fluid drain valves, (number 13 in the Key to figures 1.2 and 1.3). Therefore, if the heat battery is isolated from the main system, the residual heat in the heat battery can heat the fluid in the heat exchanger – possibly resulting in overpressure, which could damage the heat exchanger.

Therefore, one of the Central Bank Mini (P58) heat battery isolating valves must be 3-port type, shown in figure 1.2. With this type of valve, the heat exchanger hydronic circuit will be open to atmosphere when the heat battery is isolated from the main system.

- Unlike a hot water TES, the Central Bank Mini (P58) does not require an expansion cistern, as one is integrated in the heat battery cell which opens to the atmosphere via the pressure safety relief valve (number 6 in the key to figures 1.2 and 1.3). The setting of this PRV is 0.5 Bar (7.25 PSI). Therefore, the pressure vessel directive and the sealed (i.e. closed) vessel directives do not apply to Central Bank Mini (P58).

- c) Assuming that for the hot water TES, the design temperature difference, δt_{HE1} , across the TES charging heat exchanger is 2°C, and design temperature difference, δt_{HE2} , across the TES discharging heat exchanger is 3°C, then:

$$\text{TES temperature, } T_{A-TES} = T_{FD-HS} - \delta t_{HE1}$$

$$\text{Load flow temperature, } T_{FD-LD} = T_{A-TES} - \delta t_{HE2}$$

Therefore, for the example case, the load design supply temperature, T_{FD-LD} , will be approximately 5°C/9°F lower than the heat source design supply temperature, T_{FD-HS} .

The design load supply temperature, T_{FD-LD} , for the Central Bank Mini (P58) heat battery is 53°C/127°F with a heat source charging temperature band from 65°C/149°F to 80°C/176°F. Therefore, for Central Bank Mini (P58), load flow temperature can be 12°C/22°F - 27°C/49°F lower than the heat source design flow temperature. **Note:** The Central Bank Mini (P58) heat battery is not fitted with a PCM drain valve. Sunamp should be consulted before undertaking the draining any PCM from the Central Bank Mini (P58).

2 Central Bank Mini (P58) Hydronic Connection Arrangement

The heat exchanger in the Central Bank Mini (P58) heat battery has two independent high and low power interleaved hydronic circuits - as shown schematically in figures 2.1 – 2.3. This heat exchanger is immersed in the phase change material and transfers the thermal energy between the PCM inside the cell and the fluid flowing in the two hydronic circuits.

- a) **High power circuit 1 (HPC-1):** The thermal power rating of this circuit reaches 70% of the total thermal power rating of the heat battery, in both charging and discharging modes. The HPC-1 connection ports/pipes have 1¼" male threaded fittings and are labelled 1 and 3.
- b) **Low power circuit 2 (LPC-2):** The thermal power rating of this circuit reaches 30% of the total thermal power rating of the heat battery, in both charging and discharging modes. The LPC-2 connection ports and pipes have 1¼" male threaded fittings and are labelled 2 and 4.
- c) Although the power ratings of the two hydronic circuits, HPC-1 and LPC-2, are different, both circuits address the full design storage capacity of the Central Bank Mini (P58) heat battery when it is either charging or discharging. Therefore, depending upon the relative thermal power rating of the heat source and the heating load, either circuit can be used for charging and discharging the Central Bank Mini® (P58) heat battery as shown in figures 2.1 and 2.2.
- d) The direction of flow through the circuits and ports is important for efficient operation and storage capacity of the Central Bank Mini (P58) heat battery.
- e) The Central Bank Mini (P58) heat battery heat exchanger hydronic circuits are not fitted with fluid drain valves. Therefore, if the heat battery is isolated from the main system, the residual heat in the heat battery can heat the fluid in heat exchanger, which could result overpressure that could damage the heat exchanger.

It is therefore recommended the Central Bank Mini (P58) heat battery should be connected to the system using either (1 ¼" / DN32) flat face union connectors or flanges and 2 and 3 port isolating valves, as shown schematically in figures 2.1, 2.2 and 2.3. With this arrangement, when the heat battery is isolated for service or inspection, the heat exchanger hydronic circuits will be open to the atmosphere.

- f) The Central Bank Mini (P58) can be integrated with the heating system and/or plant to provide either simultaneous charging and discharging function, or to provide maximum charging and discharging power at discrete charging and discharging times. These connection arrangements are discussed in sections 2.1 and 2.2. The technical performance specifications of the Central Bank Mini® (P58) are summarised in table 2.1 and for further information please refer to the product installation manual.

Phase transition temperature of Central Bank Mini		°C / [°F]	58 / [136]
Maximum charging circuit flow temperature, T_{F-HS}		°C / [°F]	80 / [176]
Minimum charging circuit flow temperature, T_{F-HS}		°C / [°F]	65 / [149]
Minimum charging circuit return temperature for 100% charge, T_{R-HS}		°C / [°F]	63 / [145] ^[1]
Charging circuit design flow temperature, T_{F-LD}		°C / [°F]	53 - 55 / [127 - 131]
Discharging circuit inlet temperature, T_{R-LD}		°C / [°F]	46 / [115] ^[2]
Maximum charging or discharging hydronic circuit flow rates ^[3]	HPC-1	L/min / [gpm]	95 / [25.1]
	LPC-2	L/min / [gpm]	44 / [11.6]
	HPC-1 & LPC-2 in parallel	L/min / [gpm]	139 / [36.7]
Maximum charging or discharging power rating of hydronic circuits ^[4]	HPC-1	kW / [btu/hr]	65 / [221,789]
	LPC-2	kW / [btu/hr]	16 / [54,594]
	HPC-1 & LPC-2 in parallel	kW / [btu/hr]	81 / [276,383]
Notes			
1) In the product manual, this value is 63°C which is desirable. For field applications this could be reduced to 61°C.			
2) In the product manual, this value is 50°C. For product application, this has been reduced to 45°C. With 50°C value, the load circuit will have to be designed for 3°C temperature difference.			
3) Based on about 10°C design temperature difference for charging and discharging circuits			
4) Based on about 10°C design temperature difference for charging and discharging circuits			

2.1 Heat source (charging) circuit

The minimum heat source flow temperature, T_{F-HS} , required to charge the Central Bank Mini (P58) heat battery is 65°C and the minimum return temperature, T_{R-HS} , required to ensure that the heat battery is charged to its design storage capacity is 63°C, although in practice 61°C would be acceptable. The heat source flow temperature, T_{F-HS} , should not exceed 80°C during the heat battery charging cycle or the battery will be degraded. These boundary conditions apply to all three connection arrangements shown in figures 2.1 and 2.3. Therefore, any heat source connected to the Central Bank Mini (P58) for charging must abide by the following considerations:

- The heat source should be capable of delivering flow temperature, T_{F-HS} , between, 65°C/149°F and 80°C/176°F, when the return temperature, T_{R-HS} , is $\geq 61^\circ\text{C} / 142^\circ\text{F}$, without on/off cycling.
- If the design flow temperature of the heat source is $>80^\circ\text{C} / 176^\circ\text{F}$, then, the heat battery charging circuit must be fitted with appropriate temperature control devices to limit the charging flow temperature to 80°C / 176°F maximum.
- The design charging circuit flow rate, F_{HS} , should not exceed the maximum value for the selected circuit specified in table 2.1 or the product installation manual.
- The charging circuit design and operating pressures should not exceed the relevant values specified above in table 2.1, and in the product installation manual.

2.2 Heat load (discharging) circuit

The design supply temperature from the Central Bank Mini (P58) to the heating load, T_{F-LD} , is about 53°C / 127°F. Although at the start of the heat battery discharge, the supply temperature T_{F-LD} , can be as high as the charging supply temperature T_{F-HS} , over 70% of the stored thermal energy will be supplied at about 53°C / 127°F. The recommended maximum design return temperature from the load to the heat battery, T_{R-LD} , is 46°C / 115°F. These design boundary conditions apply to all three connection arrangements shown in figures 2.1 – 2.3. Therefore, any discharging circuit heating load, Q_{LD} , connected to the Central Bank Mini (P58) must abide by the following:

- a) The design discharging circuit flow rate, F_{LD} , should not exceed the maximum value for the selected circuit specified above in table 2.1 or the product installation manual.
- b) If design heating load circuit flow temperature, T_{R-LD} , is lower than 53°C, or if a higher temperature transient flow temperature from the heat battery is not acceptable, then a mixing valve should be fitted in the discharge circuit to control the supply temperature at the required value.
- c) The discharging circuit design and operating pressures should not exceed the relevant values specified above in table 2.1 and the product installation manual.

2.3 Central Bank Mini (P58) system configuration for simultaneous charging and discharging

For simultaneous charging and discharging applications, the heat source for charging and the heating load for discharging the Central Bank Mini (P58) are connected to their dedicated HPC-1 and LPC-2 circuits, respectively, as shown in figures 2.1 and 2.2. The main characteristics of this connection arrangement are:

- a) The Central Bank Mini (P58) heat battery can be both charged and discharged simultaneously. When the charging and discharging circuits are simultaneously activated, then:
 - If the power rating of the heat source, Q_{HS} , is greater than the power rating of the heating load, Q_{LD} , then charge state of the Central Bank Mini (P58) heat battery will increase at $(Q_{HS} - Q_{LD})$ rate. When the heat battery is fully charged, the controller will switch off the heat source.
 - If the power rating of the heat source, Q_{HS} , is less than the power rating of the heating load, Q_{LD} , then charge state of the Central Bank Mini (P58) heat battery will decrease at $(Q_{LD} - Q_{HS})$ rate. When the heat battery is fully discharged, the supply power rating of the heating load, Q_{LD} , will be approximately same as the power rating of the heat source, Q_{HS} , and heating load supply temperature, T_{FD-LD} , will be between 4 – 8°C

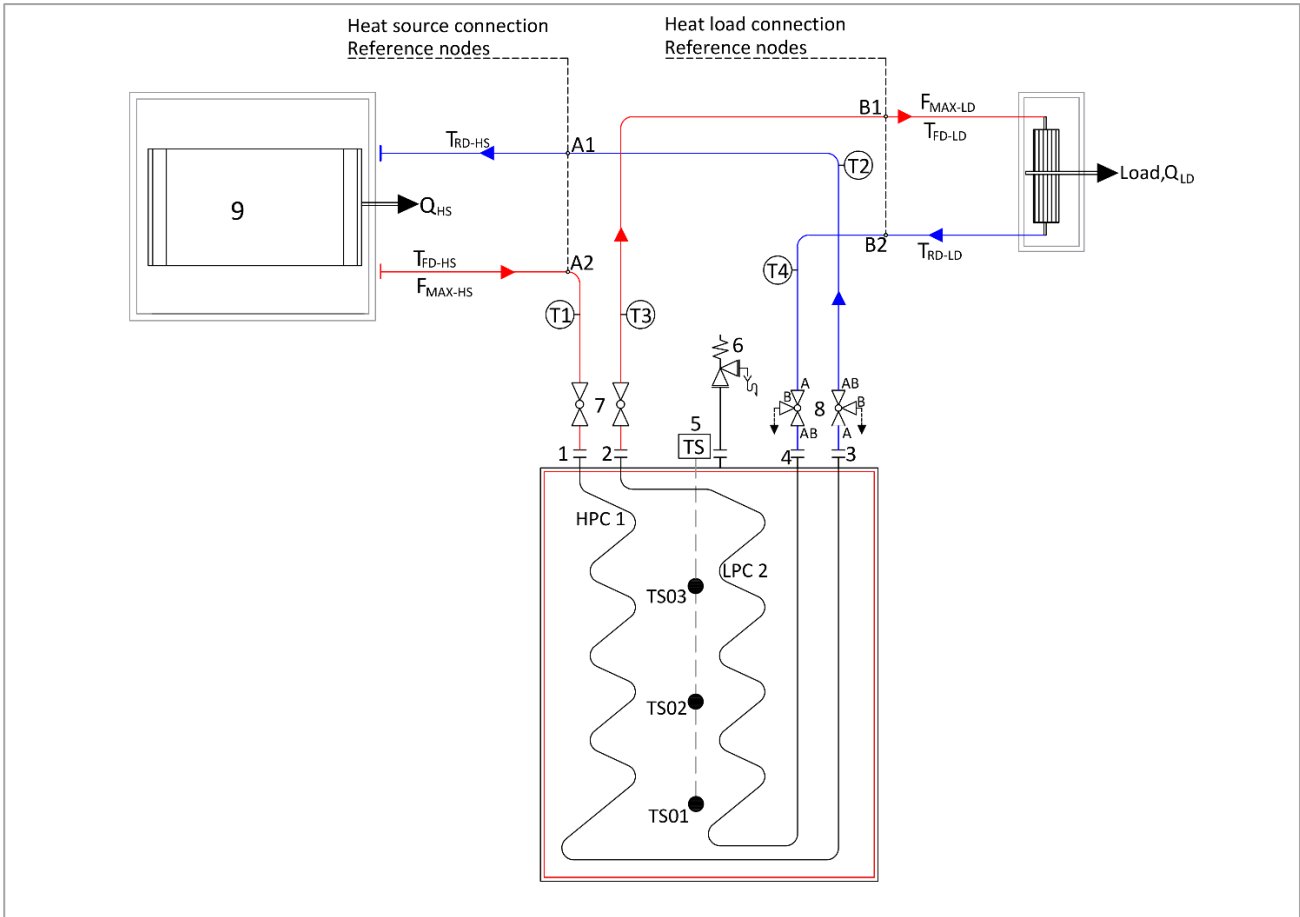
lower than the heat source supply temperature, T_{FD-HS} , In this circumstance the Central Bank Mini (P58) heat battery will function like a plate heat exchanger.

- b) Because there is no hydronic connection between HPC-1 and LPC-2 circuits, the charging and discharging circuits can have different fluids and can be designed to operate at different pressures below the maximum specified limits (see table 2.1).

2.4 Central Bank Mini (P58) system configuration for non-simultaneous maximum charging and discharging power

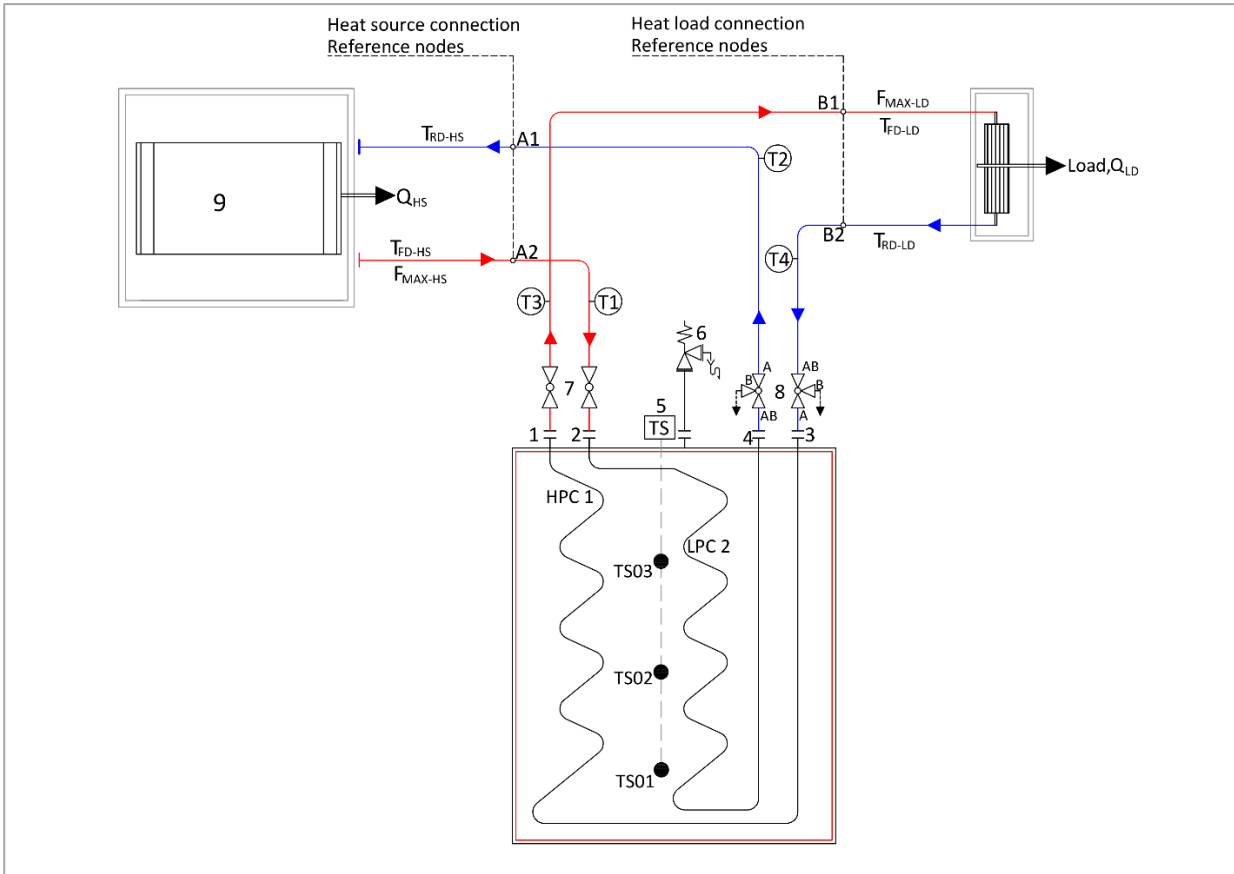
For maximum charging and discharging power applications, the heat source for charging and the heating load for discharging the Central Bank Mini (P58) heat batteries are connected to common flow and return headers. The heat battery hydronic circuits HPC-1 and LPC-2 are also connected in parallel with the flow and return headers as shown in figure 2.3. The main characteristics of this connection arrangement are:

- a) The Central Bank Mini (P58) heat battery cannot be charged or discharged simultaneously; therefore, this TES configuration is generally used for load shifting during the 24h period.
- b) The design operating pressures and circuit fluids will be same for both heat source charging and heating load discharging circuits.
- c) Both charging and discharging powers can be higher than the configuration described in section 2.3 for the same design operating temperatures.



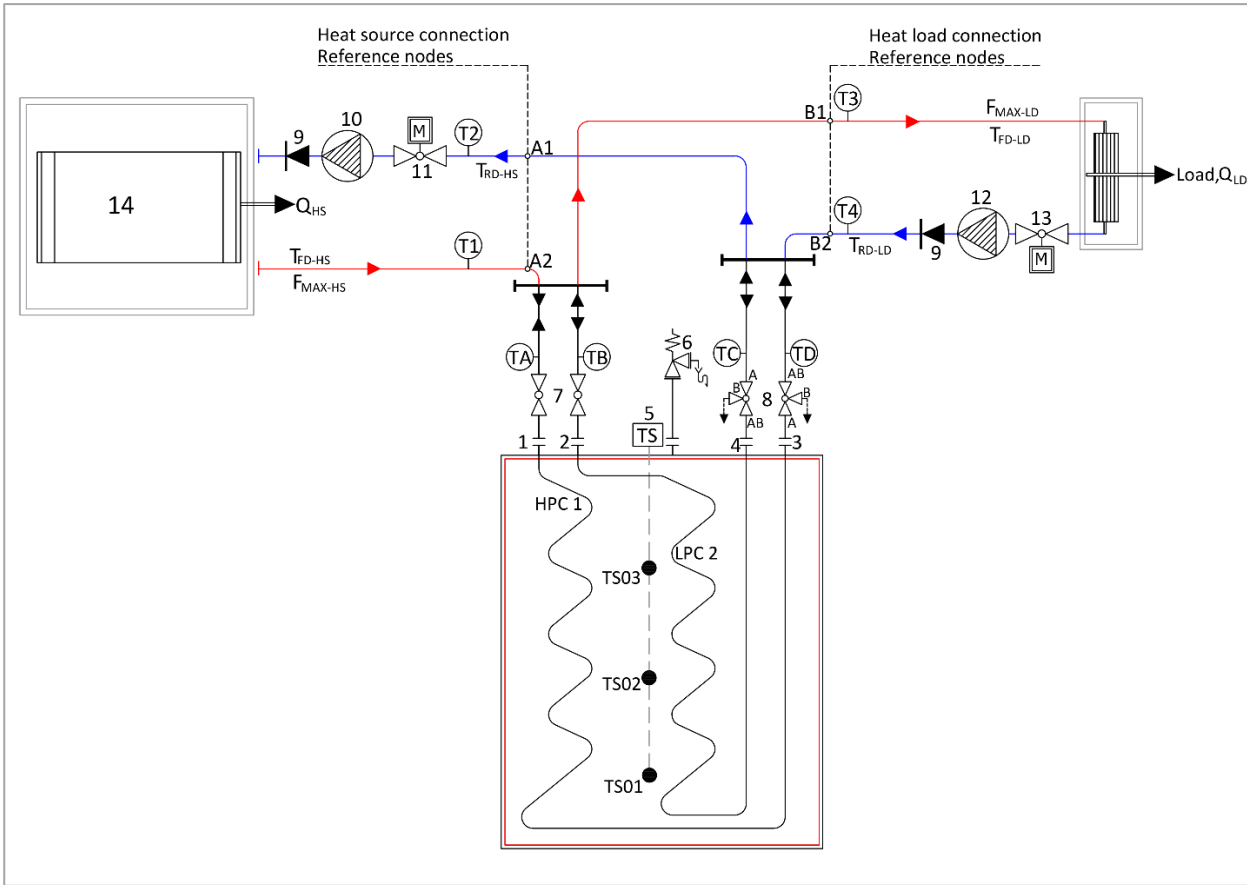
Key Figures 2.1: Central Bank Mini (P58) Hydronic connection arrangement - 1, Charging via HPC-1 and Discharging via LPC-2

1	High power circuit - Flow connection.
2	Low power circuit - Flow connection.
3	High power circuit - Return connection.
4	Low power circuit - Return connection.
5	Heat battery temperature sensor cables (TS01, TS02 & TS03 - 3 wire RTD PT100).
6	Pressure relief valve.
7	Isolating valve (2-port).
8	Isolating valve (3-port).
9	Heat source.



Key Figures 2.2: Central Bank Mini (P58) Hydronic connection arrangement - 2, Charging via LPC - 2 and Discharging via HPC - 1

1	High power circuit - Heating load flow connection.
2	Low power circuit - Heat source flow connection.
3	High power circuit - Heating load return connection.
4	Low power circuit - Heat source return connection.
5	Heat battery temperature sensor cables (TS01, TS02 & TS03 - 3 wire RTD PT100).
6	Pressure relief valve.
7	Isolating valve (2-port).
8	Isolating valve (3-port).
9	Heat source.



Key Figures 2.3: Central Bank Mini (P58) Hydronic 1, HPC-1 and LPC-2 Connected in parallel

1	High power circuit - Heat source and heating load flow connection
2	Low power circuit - Heat source and heating load flow connection
3	High power circuit - Heat source and heating load return connection
4	Low power circuit - Heat source and heating load return connection
5	Heat battery temperature sensor cables (TS01, TS02 & TS03 - 3 wire RTD PT100).
6	Pressure relief valve
7	Isolating valve (2-port)
8	Isolating valve (3-port)
9	Pump non-return / check valve
10	Heat source circuit pump
11	Heat source circuit control valve
12	Heating load circuit pump
13	Heating load circuit control valve
14	Heat source.

3 Central Bank Mini (P58) Hydronic Circuit Design and Selection

As discussed in previous sections, the two hydronic circuits of the Central Bank Mini® (P58) heat battery can be configured to suit the application and the characteristics of the heat source and the heating load. The maximum power ratings of the circuits, HPC-1 and the LPC-2, at different flow and return temperatures are summarised in table 3.1. The data in table 3.1, is based on maximum flow rates specified for the high-power circuit HPC-1 and low power circuit LPC-2 of the Central Bank Mini (P58) and the boundary conditions specified in table 2.1.

Discharging circuit design flow temperature, T_{F-LD}		°C	53	53	53	53	53	53	53
		[°F]	[127.4]	[127.4]	[127.4]	[127.4]	[127.4]	[127.4]	[127.4]
Discharging circuit δt		°C	7	10	15	20	25	30	40
		[°F]	[44.6]	[50]	[59]	[68]	[77]	[86]	[104]
Discharging circuit design return temperature, T_{R-LD}		°C	46	43	38	33	28	23	13
		[°F]	[114.8]	[109.4]	[100.4]	[91.4]	[82.4]	[73.4]	[55.4]
Maximum discharge circuit power rating	High power circuit - 1, (1 - 3)	kW	46.33	66.18	99.27	132.37	165.46	198.55	264.73
		[btu/hr]	[158319]	[226170]	[339255]	[452340]	[565425]	[678510]	[904680]
	Low power circuit - 2, (2 - 4)	kW	21.46	30.65	45.98	61.30	76.63	91.96	122.61
		[btu/hr]	[73332]	[104760]	[157140]	[209520]	[261900]	[314280]	[419040]
	Combined circuits 1 & 2, (1&2 - 3&4)	kW	67.78	96.84	145.25	193.67	242.09	290.51	387.34
		[btu/hr]	[31651]	[330930]	[96395]	[661860]	[827325]	[992790]	[1323720]
Charging circuit design return temperature, T_{R-HS} (For charging heat battery up to design storage capacity)		°C	61	61	61	61	61	61	61
		[°F]	[141.8]	[141.8]	[141.8]	[141.8]	[141.8]	[141.8]	[141.8]
Charging circuit δt		°C	6	10	15	19	19	19	19
		[°F]	[10.8]	[18.0]	[27.0]	[34.2]	[34.2]	[34.2]	[34.2]
Charging circuit flow temperature, T_3		°C	67	71	76	80	80	80	80
		[°F]	[152.6]	[159.8]	[168.8]	[176.0]	[176.0]	[176.0]	[176.0]
Maximum charge circuit power rating	High power circuit - 1, (1 - 3)	kW	39.70	66.18	99.27	125.74	125.74	125.74	125.74
		[btu/hr]	[135702]	[226170]	[339255]	[429723]	[429723]	[429723]	[429723]
	Low power circuit - 2, (2 - 4)	kW	18.39	30.65	45.97	58.23	58.23	58.23	58.23
		[btu/hr]	[62856]	[104760]	[157140]	[199044]	[199044]	[199044]	[199044]
	Combined circuits 1 & 2, (1&2 - 3&4)	kW /	58.10	96.83	145.25	183.98	183.98	183.98	183.98
		[btu/hr]	[198558]	[330930]	[496395]	[628767]	[628767]	[628767]	[628767]
Notes:									

As shown in table 3.1, the maximum power rating of a Central Bank Mini (P58) heat battery hydronic circuit depends upon the circuit design temperature difference, δt , and its function i.e. charging or discharging. Therefore, assignment of a hydronic circuit for charging or discharging function will depend upon the relative power ratings and the circuit temperature difference.

Typical Central Bank Mini (P58) applications are defined and discussed in section 4 of this document. Some rules of thumb for assigning charging or discharging function to the heat battery hydronic circuit are listed below:

- a) For potable hot water production, the high-power circuit should be connected to a hot water station and low power circuit connected to the heat source. This is because the power required for generating potable hot water would be significantly greater than the power rating of the heat source used for charging the heat battery.
- b) For heating load applications, in most cases, the charging and discharging power requirements would be similar. Therefore, if the heat source is designed to operate at a low temperature difference (e.g. a heat pump), then the heat source should be connected to a high-power circuit and heating load to a low power circuit.
- c) For thermal load shifting and balancing:
 - If simultaneous charging and discharging is required, then, if the power required during the charging phase is greater than the heat load, the high-power circuit should be connected to the heat battery charging source and low power circuit to the heat load as shown in system configurations figures 2.1 and 2.2.
 - If simultaneous charging and discharging is **NOT** required, then the high-power circuits and low power circuits should be connected in parallel and charging heat source and the heating load circuits are connected to the Central Bank Mini (P58) as shown schematically in figure 2.3.

4 Central Bank Mini (P58) Example Applications and System Configurations

The system integration and application of the Central Bank Mini (P58) heat battery primarily depend upon the main functional requirements listed below. These basic functional requirements are used for designing and sizing the system configuration and apply to applications of both single Central Bank Mini (P58), and multiple Central Bank Mini (P58) based TES systems:

- a) Is simultaneous charging and discharging of the Central Bank Mini (P58) TES required? For example, for hot water production.
- b) Is hydronic separation of the Central Bank Mini (P58) TES heat source charging and heating load discharging circuits is required? For example, different fluids or different operating pressures in charging and discharging circuits.
- c) Are both simultaneous charging and discharging of the Central Bank Mini (P58) TES and the hydronic separation of charging and discharging circuits not required? For example, where for heat load balancing at higher power ratings is not needed.

4.1 Central Bank Mini (P58) Applications requiring simultaneous charging and discharging plus hydronic separation between heat source and heating load circuits.

In these types of applications, the design, configuration, and controls of the Central Bank Mini (P58) charging and discharging circuits can be optimised when configured independent of each other. Typical applications of these configurations are listed below in table 4.1 and described in the following sections.

Table 4.1: Example system configurations		
Function / Application	Figure	Section
a) Potable hot water heating – Central Bank Mini (P58) charged by a heat source (e.g. heat pumps, gas or electric boilers)	4.1	4.1.1
b) Space or process water heating – Central Bank Mini (P58) charged by a heat source (e.g. heat pumps, gas or electric boilers)	4.2 & 4.3	4.1.2
c) Space or process water heating – Central Bank Mini (P58) charged by process waste or recaptured heat	4.4	4.1.2
d) Waste heat recovery from hot gas streams e.g. flue gases, drying ovens etc.	4.4A	4.1.3

4.1.1 Hot water heating with Central Bank Mini (P58) heat battery

Potable Cat 1 hot water cannot be heated directly by this Central Bank Mini® (P58) model as it would become Cat 2. Therefore, potable water must not be connected to either the high power HPC-1, or the low power LPC-2, hydronic circuit. An indirect hot water heating station, shown schematically in figure 4.1. should be used for generating potable Cat 1 hot water. A plate heat

exchanger based potable hot water production station can be constructed from individual components on site or pre-packaged unit can be connected to the high-power circuit of Central Bank Mini (P58) as shown in figure 4.1.

The hot water production station controller (item 10 in figure 4.1) senses the hot water demand and flow rate with flow sensor, FS. When the demand is present, it switches on the pump (item 9 in figure 4.1), which then modulates its speed with relation to hot water flow temperature sensor, TC, to control the hot water supply temperature at a pre-set value (between 45 – 51°C / °F). The thermal performance specification of the Central Bank Mini (P58) TES, for a hot water generating station is listed in table 4.2. The controller, 10, in addition to normal control of hot water heating, may also include other functions, for example:

- a) A plate heat exchanger warming cycle to increase responsiveness of the system.
- b) Hot water recirculation loop in buildings as shown schematically in figure 4.1.

The heat source for charging the Central Bank Mini (P58) TES, for this application is connected to the low power circuit LPC-2 via a low loss header as shown in figure 4.1. The TES system controller, 8, manages the operation of the Central Bank Mini (P58) heat battery, and the example control logics are described in section 6 of this document.

It is important for efficient charging and storage capacity utilisation of the Central Bank Mini (P58) TES, that the heat source design flow temperature, T_{FD-HS} , is $\geq 65^{\circ}\text{C}$ and it will continue to run without on/off cycling when the return temperature, T_{RD-HS} , is $\geq 61^{\circ}\text{C}$, until the TES is fully charged.

It is recommended that a heat source (e.g. heat pump, gas or electric boiler) is connected to the charging circuit of the Central Bank Mini (P58) via a low loss header as shown schematically in figure 4.1. This is because it will decouple the heat source design flow rate from the Central Bank Mini (P58) charging design flow rate and facilitate efficient design and operation of space heating circuit.

If the heat source design supply temperature is greater than 80°C , then, a 3-port mixing valve should be fitted to regulate the Central Bank Mini (P58) charging temperature, T_{FD-HS} , to between 65°C and 80°C .

Table 4.2: Performance specification of hot water generating station and heat source (Figure 4.1)			
Hot water heating circuit			Notes
Design maximum primary circuit flow rate, F_{MAX-LD}	L/min / [GPM]	50 [13.2]	
Design primary circuit flow temperature, T_{FD-LD}	$^{\circ}\text{C}$ / [$^{\circ}\text{F}$]	53 [127.4]	
Recommended plate heat exchanger δT_{PH}	$^{\circ}\text{C}$ / [$^{\circ}\text{F}$]	≤ 2 [3.6]	
Design hot water flow temperature, T_{HW}	$^{\circ}\text{C}$ / [$^{\circ}\text{F}$]	51 [123.8]	Based on $\delta T_{PH} = 2^{\circ}\text{C}$
Design primary circuit return temperature, T_{RD-LD}	$^{\circ}\text{C}$ / [$^{\circ}\text{F}$]	12 [53.6]	Cold water supply temperature, $T_{CW} = 10^{\circ}\text{C}$
Calculated primary circuit power, Q_{T-LD}	kW / [btu/hr]	142 [484,524]	
Design hot water production rate, F_{HW}	L/min / [GPM]	50 [13.2]	When primary & secondary flow rates are similar
Heat source charging circuit			
Design heat source circuit flow rate, F_{MAX-HS}	L/min / [GPM]	22 [5.8]	
Heat source circuit charging power at ($T_{FD} - T_{RD} = 7^{\circ}\text{C}$)	kW / [btu/hr]	10.5 [35,827]	
Heat source circuit charging power at ($T_{FD} - T_{RD} = 12^{\circ}\text{C}$)	kW / [btu/hr]	18.0 [61,418]	

4.1.2 Space or process water heating with Central Bank Mini (P58) heat battery

In these applications, the Central Bank Mini (P58) heat battery TES is charged by either by a dedicated heat source (e.g. heat pump and electric boiler powered by renewable energy) or by process waste heat recovery. The Central Bank Mini (P58) TES is then discharged into the local heat distribution headers during peak demand and/or to replace percentage of the thermal energy generated by the existing heat source with cheaper and/or low carbon renewable energy.

Table 4.3: Design parameters for Central Bank Mini (P58) for applications shown in figures 4.2 and 4.3.		
Maximum design heating load circuit flow temperature, T_{FD-LD}	°C / [°F]	53 / [127.4]
Maximum design load circuit return temperature, T_{RD-LD}	°C / [°F]	≤ 46 / [114.8]
Minimum heat source return temperature for charging, T_{RD-HS}	°C / [°F]	61 / [141.8]
Maximum heat source flow temperature for charging, T_{FD-HS}	°C / [°F]	65 - 80 / [149 - 176]
Design HPC-1 flow rate	L/min / [GPM]	50 / [13.2]
HPC-1 Pressure loss at maximum flow rate, δP_{CBM}	kPa / [psi]	6.4 / [0.92]
Design LPC-2 flow rate	L/min / [GPM]	22 / [5.8]
LPC-2 Pressure loss at maximum flow rate, δP_{CBM}	kPa / [psi]	3.4 / [0.49]
Heating load connected to HPC-1 and the heat source connected to LPC-2		
Maximum heating load (Discharging) power at ($T_{FD-LD} - T_{RD-LD} = 7^{\circ}\text{C}$)	kW / [btu/hr]	24.37 / [83286]
Maximum heating load (Discharging) power at ($T_{FD-LD} - T_{RD-LD} = 12^{\circ}\text{C}$)	kW / [btu/hr]	41.78 / [142776]
Maximum heat source (Charging) power at ($T_{FD-HS}-T_{RD-HS} = 7^{\circ}\text{C}$)	kW / [btu/hr]	10.71 / [36666]
Maximum heat source (Charging) power at ($T_{FD-HS}-T_{RD-HS} = 12^{\circ}\text{C}$)	kW / [btu/hr]	18.36 / [62856]
Heating load connected to LPC-2, and the heat source connected to HPC-1		
Maximum heating load (Discharging) power at ($T_{FD-LD} - T_{RD-LD} = 7^{\circ}\text{C}$)	kW / [btu/hr]	10.71 / [36666]
Maximum heating load (Discharging) power at ($T_{FD-LD} - T_{RD-LD} = 12^{\circ}\text{C}$)	kW / [btu/hr]	18.36 / [62856]
Maximum heat source (Charging) power at ($T_{FD-HS}-T_{RD-HS} = 7^{\circ}\text{C}$)	kW / [btu/hr]	24.37 / [83286]
Maximum heat source (Charging) power at ($T_{FD-HS}-T_{RD-HS} = 12^{\circ}\text{C}$)	kW / [btu/hr]	41.78 / [142776]

The main design and performance parameters for the space and/or process water heating with Central Bank Mini (P58) are summarised in table 4.3. The example system configurations for space and/or process water heating with Central Bank Mini (P58) heat battery TES are shown in figures 4.2, 4.3 and 4.4.

In figures 4.2 and 4.3, the low power circuit, LPC-2, of the Central Bank Mini (P58) is connected to a dedicated heat source (e.g. heat pump, gas or electric boiler) and the high-power circuit, HPC-1, is connected to the heating load. Depending upon the relative design charging, Q_{HS} , and discharging thermal power, Q_{LD} , requirements, the connection arrangement can be reversed.

In figure 4.4, the Central Bank Mini (P58) TES is charged by process waste heat, with the process waste heat circuit decoupled from the Central Bank Mini (P58) TES charging circuit through a plate heat exchanger, 13. In this example application, Central Bank Mini (P58) TES is charged via the low power circuit, LPC-2, and discharged via the high power circuit, HPC-1. Depending upon the relative design charging, Q_{HS} , and discharging thermal power, Q_{LD} , requirements, the connection arrangement can be reversed.

The design discharge i.e. heating load flow temperature, T_{F-LD} , for the Central Bank Mini (P58) heat battery TES, is 53°C and the maximum design heating load return temperature, T_{R-LD} , is

46°C. Therefore, the process / building heating return temperature, T_{RP} , must not be greater than 46°C for the Central Bank Mini® (P58) TES to function efficiently.

If the building/process design heating return temperature, T_{RP} , is $\leq 46^\circ\text{C}$, and the building/process design supply temperature, T_{FP} , is $\leq 53^\circ\text{C}$, then, the Central Bank Mini (P58) discharge circuit is connected to the heat distribution header as shown in figure 4.2. The Central Bank Mini (P58) TES will function as another heat source connected in parallel with the existing heat generators.

If the building/process design heating return temperature, T_{RP} , is $\leq 46^\circ\text{C}$, and the building/process design supply temperature, T_{FP} , is $> 53^\circ\text{C}$, then the Central Bank Mini (P58) discharge circuit is connected to the heat distribution header as shown in figure 4.3. The CBM (P58) TES will then function as pre-heater to the existing heat generators.

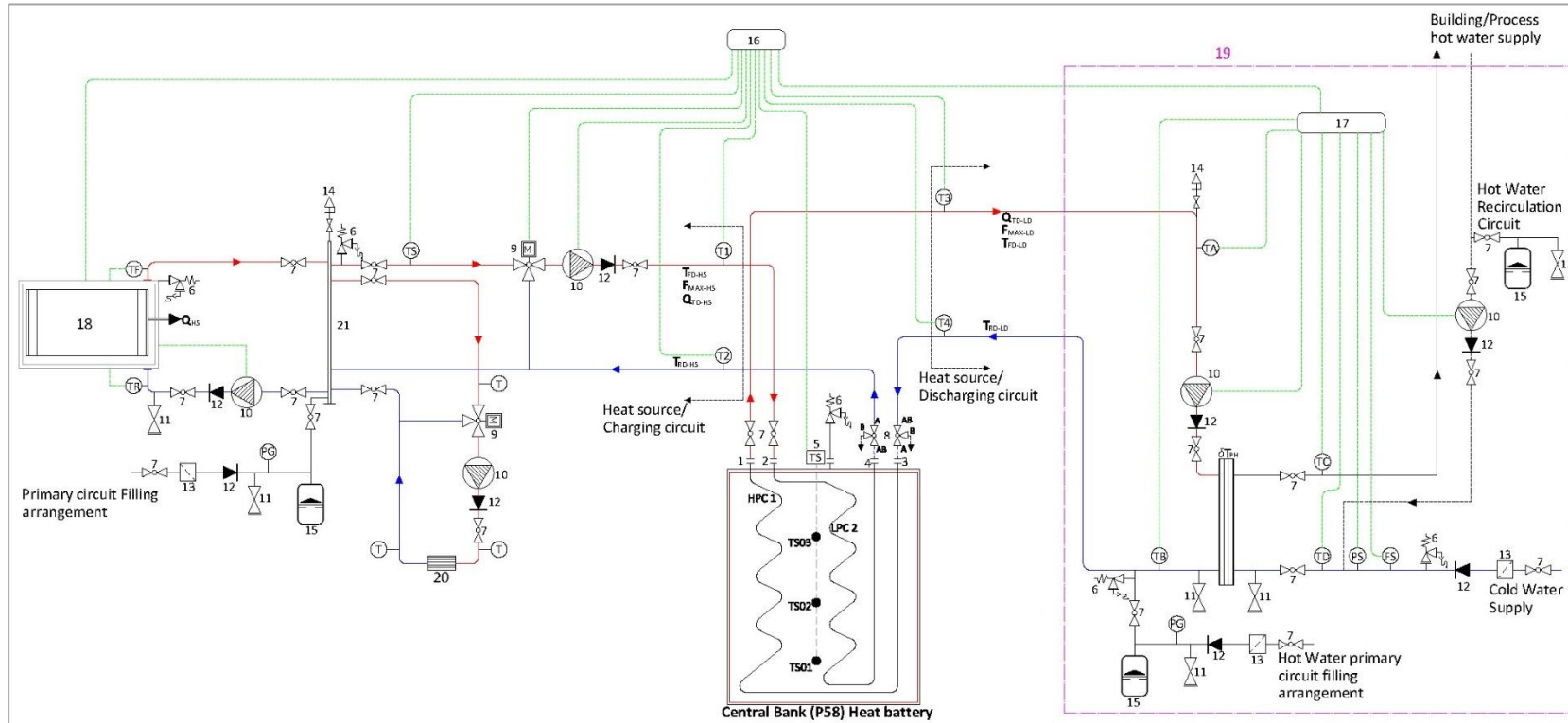
A PLC based controller, 8, can be used to control the operation of the Central Bank Mini® TES subsystem as shown schematically in figures 4.2, 4.3 and 4.3. The high-level control logics for typical applications are described in section 6 of this document.

4.1.3 Waste heat recovery hot gas streams with Central Bank Mini (P58) heat battery

In these applications, the Central Bank Mini (P58) heat battery TES is charged by indirectly transferring heat from hot gas waste stream as shown schematically in figure 4.4A. The gas to water heat exchanger compatible with the waste gas stream and the hydronic circuit fluid properties, is interposed between waste hot gas stream discharge duct and the hydronic circuit is connected to the Central Bank Mini (58) as shown schematically in figure 4.4A.

The main design and operating parameters for this application are listed below.

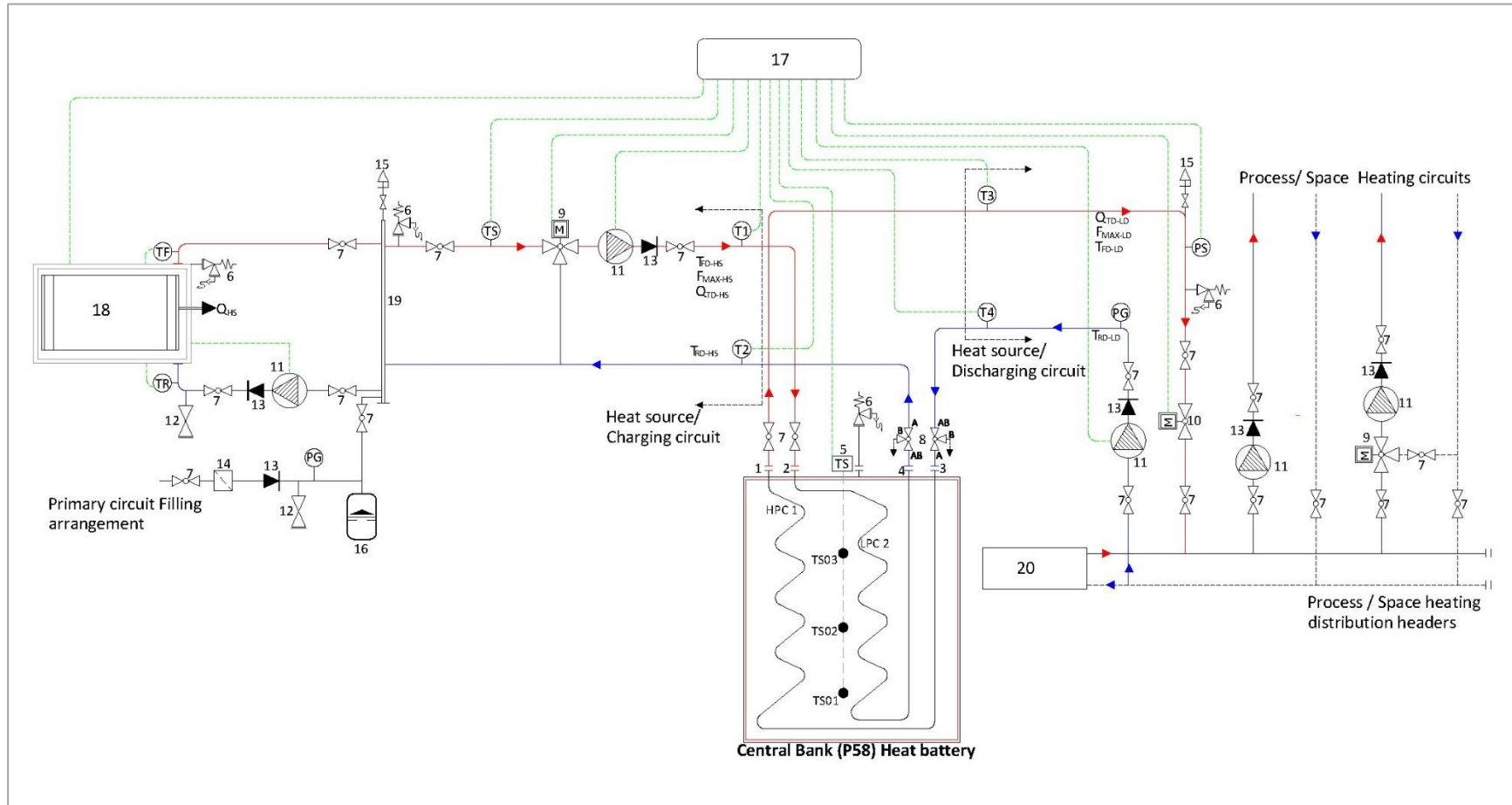
- a) The waste gas stream temperature must be greater than 70°C, because the minimum charge temperature for the Central Bank Mini (P58) is 65°C. This will allow up to 5°C temperature drop across the air to water heat exchanger.
- b) If the design hydronic circuit flow temperature, T_5 , from the air to water heat exchanger is greater than 95°C, then, the hydronic circuit fluid with boiling point greater than 100°C (e.g. water glycol mixture, heat transferred fluid) should be used.
- c) The air to water heat exchanger return temperature, T_2 , can be below 50°C and therefore temperature of the waste gas stream after the heat exchanger will be of the order of 55°C. During the design phase, the effect of this on condensation in gas stream should be investigated.



Key Figures 4.1: Indirect potable hot water heating with Central Bank Mini (P58) heat battery TES via plate heat exchanger based packaged hot water production station.

1	High power circuit - Heating load flow connection
2	Low power circuit - Heat source flow connection
3	High power circuit - Heating load return connection
4	Low power circuit - Heat source return connection
5	Heat battery temperature sensor cables (TS01, TS02 & TS03 - 3 wire RTD PT100).

Key Figures 4.1: Indirect potable hot water heating with Central Bank Mini (P58) heat battery TES via plate heat exchanger based packaged hot water production station.	
6	Pressure relief valve.
7	Isolating valve (2-port)
8	Isolating valve (3-port)
9	3 Port motorised mixing valve.
10	Circulation pump
11	Drain valve
12	Non return / check valve
13	Inline filter
14	Automatic air vent
15	Expansion vessel
16	Central Bank Mini (P58) system controller
17	Hot water production station controller
18	Heat source
19	Packaged hot water production station
20	Space / Process heat loads
21	Low loss header

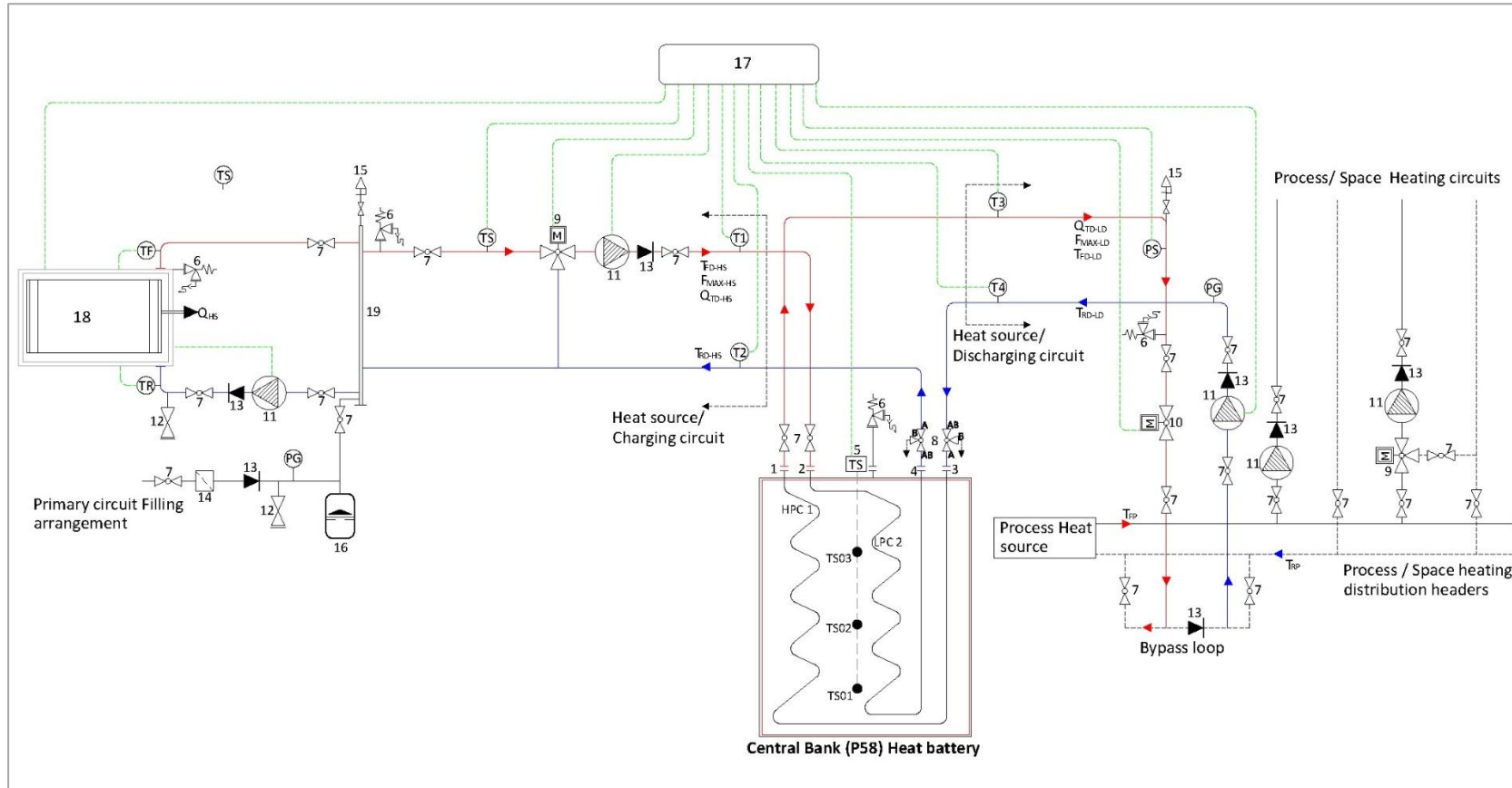


Key Figures 4.2: Central Bank Mini (P58) TES is charged by a dedicated heat source, and the discharge circuit is connected to the main heat distribution headers. Therefore, the TES acts as another heat source for peak demands or utilisation of renewable energy

1	High power circuit - Heating load flow connection
2	Low power circuit - Heat source flow connection
3	High power circuit - Heating load return connection
4	Low power circuit - Heat source return connection

Key Figures 4.2: Central Bank Mini (P58) TES is charged by a dedicated heat source, and the discharge circuit is connected to the main heat distribution headers. Therefore, the TES acts as another heat source for peak demands or utilisation of renewable energy

5	Heat battery temperature sensor cables (TS01, TS02 & TS03 - 3 wire RTD PT100).
6	Pressure relief valve.
7	Isolating valve (2-port)
8	Isolating valve (3-port)
9	3 Port motorised mixing valve
10	Discharge circuit control valve
11	Circulation pump
12	Drain valve
13	Non return / check valve
14	Inline filter
15	Automatic air vent
16	Expansion vessel
17	Central Bank Mini (P58) system controller
18	Heat source
19	Low loss header
20	Process heat sources

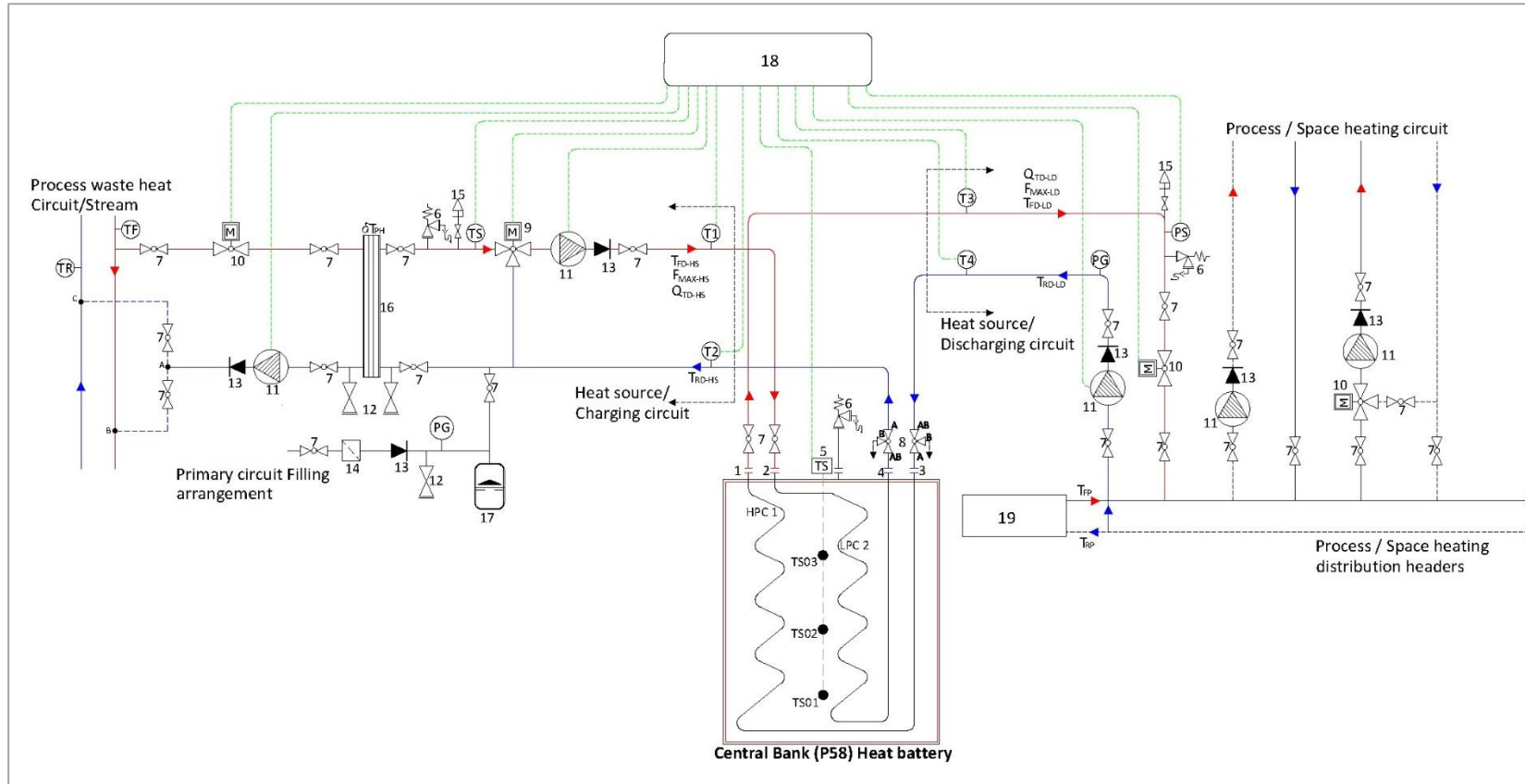


Key Figures 4.3: Central Bank Mini (P58) TES is charged by a dedicated heat source, and the discharge circuit is connected to the main return pipe to the heat sources. Therefore, the TES acts as a pre-heater to the main heat sources e.g. during peak demands or utilisation of renewable energy

1	High power circuit - Heating load flow connection
2	Low power circuit - Heat source flow connection
3	High power circuit - Heating load return connection
4	Low power circuit - Heat source return connection
5	Heat battery temperature sensor cables (TS01, TS02 & TS03 - 3 wire RTD PT100).

Key Figures 4.3: Central Bank Mini (P58) TES is charged by a dedicated heat source, and the discharge circuit is connected to the main return pipe to the heat sources. Therefore, the TES acts as a pre-heater to the main heat sources e.g. during peak demands or utilisation of renewable energy

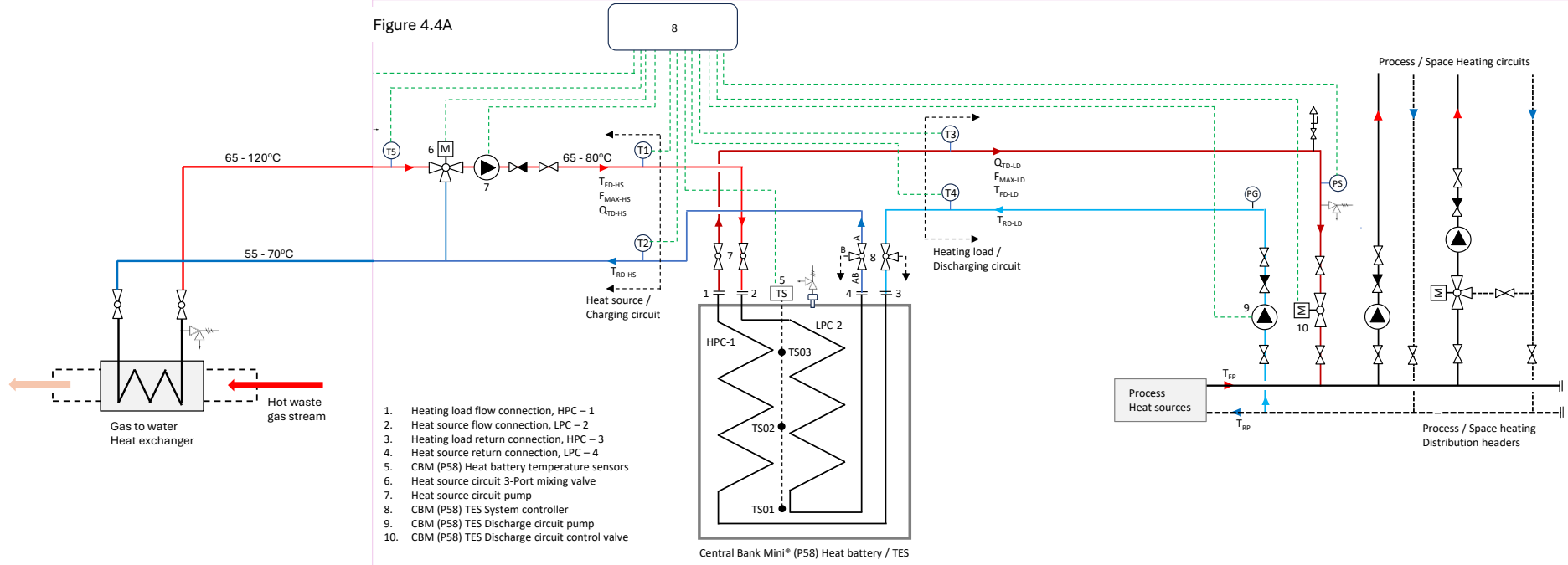
6	Pressure relief valve.
7	Isolating valve (2-port)
8	Isolating valve (3-port)
9	3 Port motorised mixing valve
10	Discharge circuit control valve
11	Circulation pump
12	Drain valve
13	Non return / check valve
14	Inline filter
15	Automatic air vent
16	Expansion vessel
17	Central Bank Mini (P58) system controller
18	Heat source
19	Low loss header



Key Figures 4.4: Typical arrangement for connecting waste heat recovery circuit to Central Bank Mini (P58) TES

1	High power circuit - Heating load flow connection
2	Low power circuit - Heat source flow connection
3	High power circuit - Heating load return connection
4	Low power circuit - Heat source return connection
5	Heat battery temperature sensor cables (TS01, TS02 & TS03 - 3 wire RTD PT100).
6	Pressure relief valve
7	Isolating valve (2-port)
8	Isolating valve (3-port)

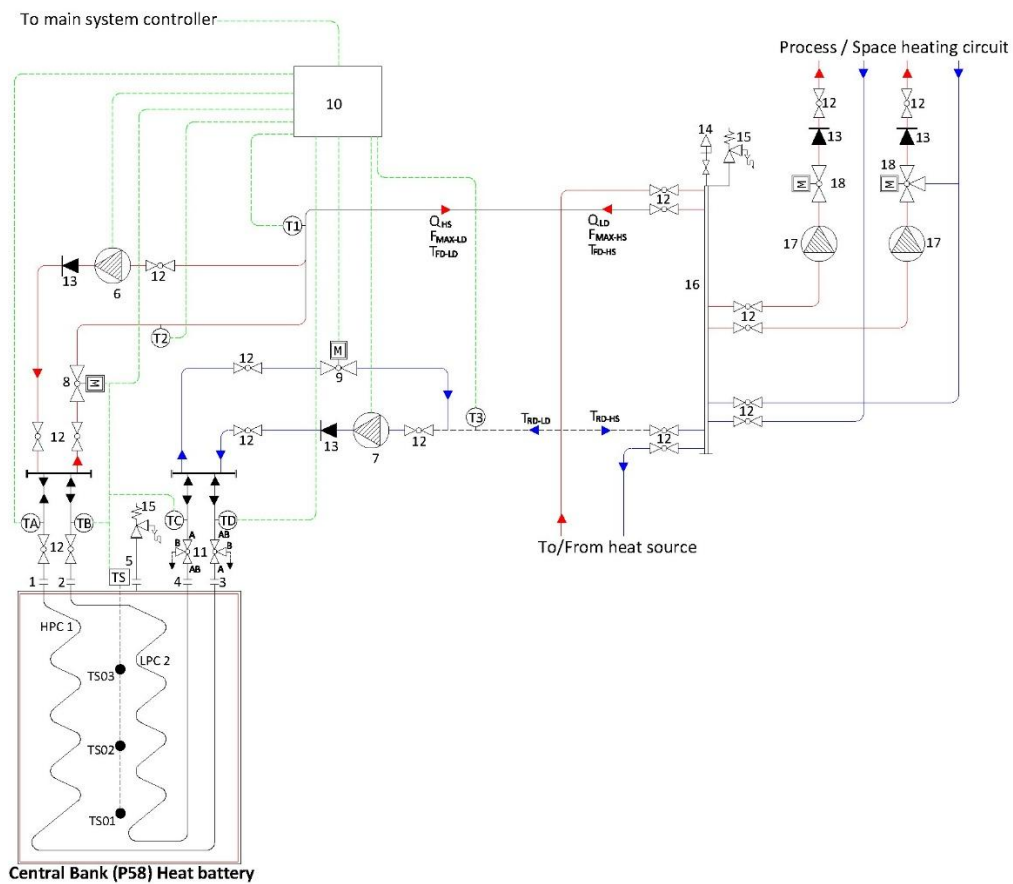
Key Figures 4.4: Typical arrangement for connecting waste heat recovery circuit to Central Bank Mini (P58) TES	
9	3 Port motorised mixing valve
10	2 Port mixing valve
11	Circulation pump
12	Drain valve
13	Non return / check valve
14	Inline filter
15	Automatic air vent
16	Plate heat exchanger
17	Expansion vessel
18	Central Bank Mini (P58) system controller
19	Process heat source



4.2 Applications for Central Bank Mini (P58) which require no simultaneous charging and discharging or hydronic separation between heat source and heating load circuits.

Generally, for thermal load balancing or time shifting and for improving the efficiency of the heat generators by increasing the load factor, a TES system is usually charged by the existing process and/or building heat generators. Therefore, a TES is normally interposed between the heat generators and heating loads i.e. the heat demands.

Unlike the traditional water-based TES, the Central Bank Mini (P58) heat battery cannot be interposed between the generators and the heating load demands. Therefore, for these applications, the LPC-2 and HPC-1 of the Central Bank Mini (P58) heat battery is connected in parallel to maximise the charging and discharging power heat battery. The Central Bank Mini (P58) is then interfaced with the building/process heating system by a low loss header as shown schematically in figures 4.5.



Key Figures 4.5: Central Bank Mini (P58) TES is charged by local heat source from heat distribution main header and discharges back into the same distribution headers

1	High power circuit – Heat source and heating load flow connection
2	Low power circuit – Heat source and heating load return connection
3	High power circuit – Heating source and heating load flow connection

Key Figures 4.5: Central Bank Mini (P58) TES is charged by local heat source from heat distribution main header and discharges back into the same distribution headers	
4	Low power circuit - Heat source and heating source return connection
5	Heat battery temperature sensor cables (TS01, TS02 & TS03 - 3 wire RTD PT100).
6	Charging circuit pump
7	Discharging circuit pump
8	Control valve
9	Control valve
10	TES system controller
11	Isolating valve (3-port)
12	Non return / check valve
13	Non return / check valve
14	Automatic air vent
15	Pressure relief valve
16	Low loss header
17	Circulation pump
18	3 Port motorised mixing valve

The main design parameters for this application and configurations are summarised in table 4.3. This application and connection arrangement is only feasible, when:

- Hydronic separation between charging and discharging circuits is not required.
- Heating system fluid and operating pressures are compatible with the Central Bank Mini (P58) heat battery hydronic circuits (see product manual for details).
- When the Central Bank Mini (P58) TES is scheduled to charge, the heat generator flow temperature, T_{FD-HS} , is $\geq 65^{\circ}\text{C}$ and the heat generator will continue to run without on/off cycling when the return temperature, T_{RD-HS} , is between 61°C and 62°C .
- When the Central Bank Mini (P58) TES is scheduled to discharge, the load return temperature, T_{RD-LD} , is $\leq 46^{\circ}\text{C}$ and the load supply temperature, T_{FD-LD} , of 53°C from the TES, is acceptable for meeting the heating demands.

Table 4.3: Design parameters for Central Bank Mini (P58) for applications shown in figures 4.5 - 4.7		
Design charging flow temperature limits, T_{FD-HS}	$^{\circ}\text{C} / [^{\circ}\text{F}]$	65 - 80 / [149 - 176]
Design charging minimum return temperature, T_{RD-HS}	$^{\circ}\text{C} / [^{\circ}\text{F}]$	61 / [141.8]
Design Discharging flow temperature limits, T_{FD-LD}	$^{\circ}\text{C} / [^{\circ}\text{F}]$	53 / [127.4]
Design Discharging maximum return temperature, T_{RD-LD}	$^{\circ}\text{C} / [^{\circ}\text{F}]$	46 / [114.8]
Design Maximum charging and discharging flow rate, F_{MAX-HS} , F_{MAX-LD}	L/min / [GPM]	72 / [19.0]
Design Pressure loss at maximum flow rate	kPa / [PSI]	5.1 / [0.74]
Maximum heating load (Discharging) power at ($T_{FD-LD} - T_{RD-LD} = 7^{\circ}\text{C}$)	kW / [btu/h]	35.11 / [119952]
Maximum heating load (Discharging) power at ($T_{FD-LD} - T_{RD-LD} = 12^{\circ}\text{C}$)	kW / [btu/h]	60.19 / [205632]
Maximum heat source (Charging) power at ($T_{FD-HS} - T_{RD-HS} = 7^{\circ}\text{C}$)	kW / [btu/h]	35.11 / [119952]
Maximum heat source (Charging) power at ($T_{FD-HS} - T_{RD-HS} = 12^{\circ}\text{C}$)	kW / [btu/h]	60.19 / [205632]

For optimum performance of the heat battery in this configuration, it is important to design and install flow balanced Central Bank Mini (P58) header systems such that:

- a) When the heat battery is charging, the heat battery return temperatures from high and low power circuits (TD & TC), are similar (i.e. the temperature difference between, TD, and TC, is less than 1.5°C).
- b) When heat battery is discharging, the heat battery flow temperatures from high and low power circuits (TA & TB), are similar (i.e. the temperature difference between, TA, and TC, is less than 1.5°C.)

For example, a PLC based controller, can be used to control the operation of the Central Bank Mini TES subsystem as shown schematically in figure 4.5. The high-level control logics for typical applications are described in section 6 of this document. Typical high level system functionality is described below.

- a) When the Central Bank Mini (P58) TES is in charging mode:
 - The charging circuit pump, 6, is switched on and the control valve, 9, is opened.
 - The discharging circuit pump, 7, is switched off and the control valve, 8, is closed.
 - The pump, 6, and/or the control valve, 9, modulate to control the charging thermal power and heat source return temperature, T_{RD-HS} , at pre-set values.
- b) When the Central Bank Mini (P58) TES is in discharging mode:
 - The charging circuit pump, 6, is switched off and the control valve, 9, is closed.
 - The discharging circuit pump, 7, is switched on and the control valve, 8, is opened.
 - The pump, 7, and/or the control valve, 8, modulate to control the discharging thermal power and the heating load flow temperature, T_{FD-LD} , at pre-set values.
- c) When the Central Bank Mini (P58) TES is in standby mode:
 - The charging circuit pump, 6, is switched off and the control valve, 9, is closed.
 - The discharging circuit pump, 7, is switched off and the control valve, 8, is closed.

This Central Bank Mini (P58) heat battery can also be used when it is charged by dedicated heat source (e.g. heat pump, electric boiler) for higher thermal power requirements as shown in figures 4.6 and 4.7.

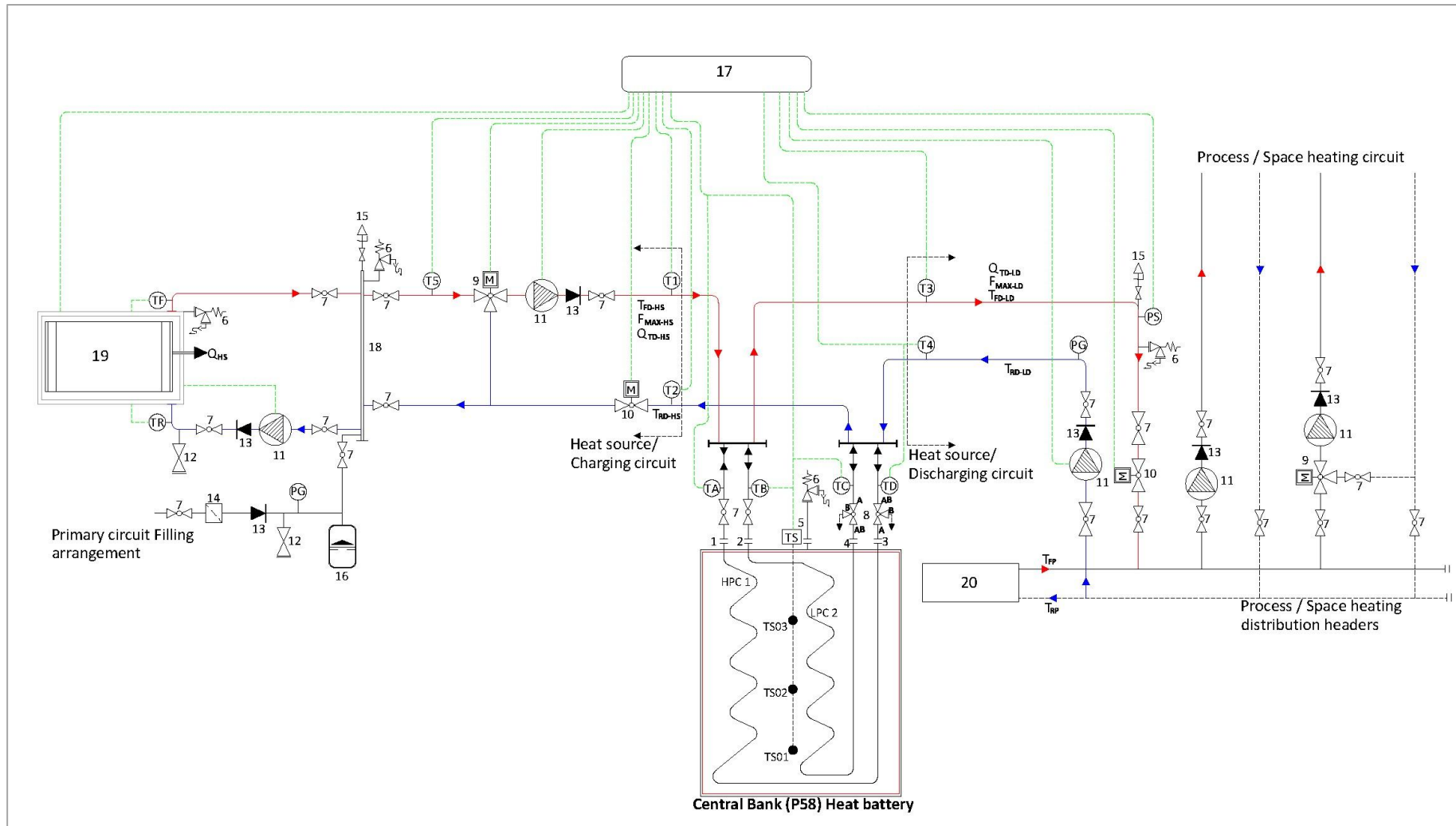


Figure 4.6: Central Bank Mini (P58) TES is charged by its dedicated heat source and discharge circuit is connected to the main distribution headers. Therefore, the TES acts as another heat source for peak demands or utilisation of renewable energy. With this arrangement the TES **cannot** be simultaneously charged and discharged

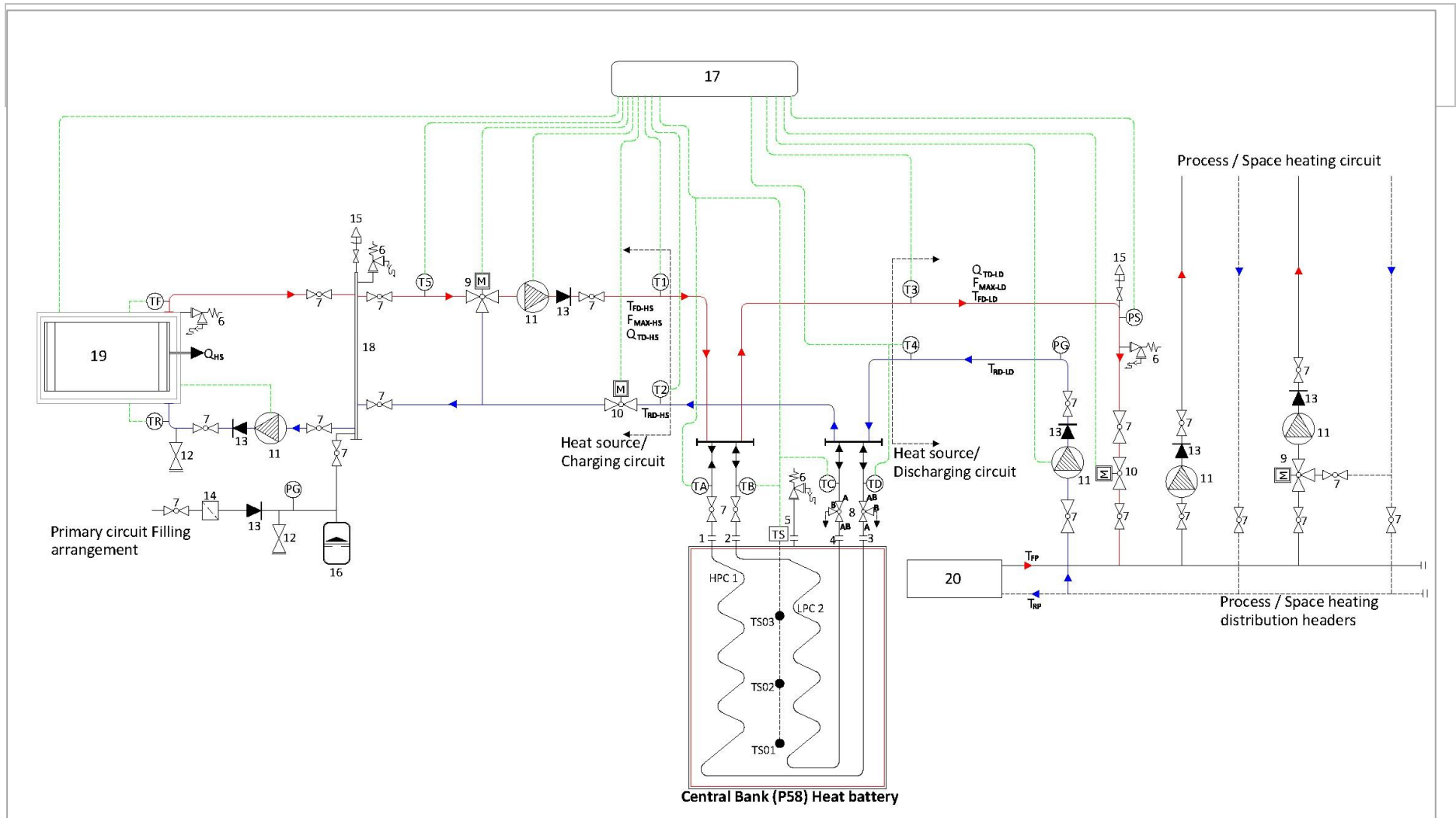


Figure 4.7: Central Bank Mini (P58) is charged by its dedicated heat source and discharge circuit is connected to the main heat distribution headers. Therefore, the TES acts as another heat source for peak demands of utilisation of renewable energy. With this arrangement the TES cannot be simultaneously charged and discharged.

5 Configuring Multiple Central Bank Mini (P58) Heat Batteries

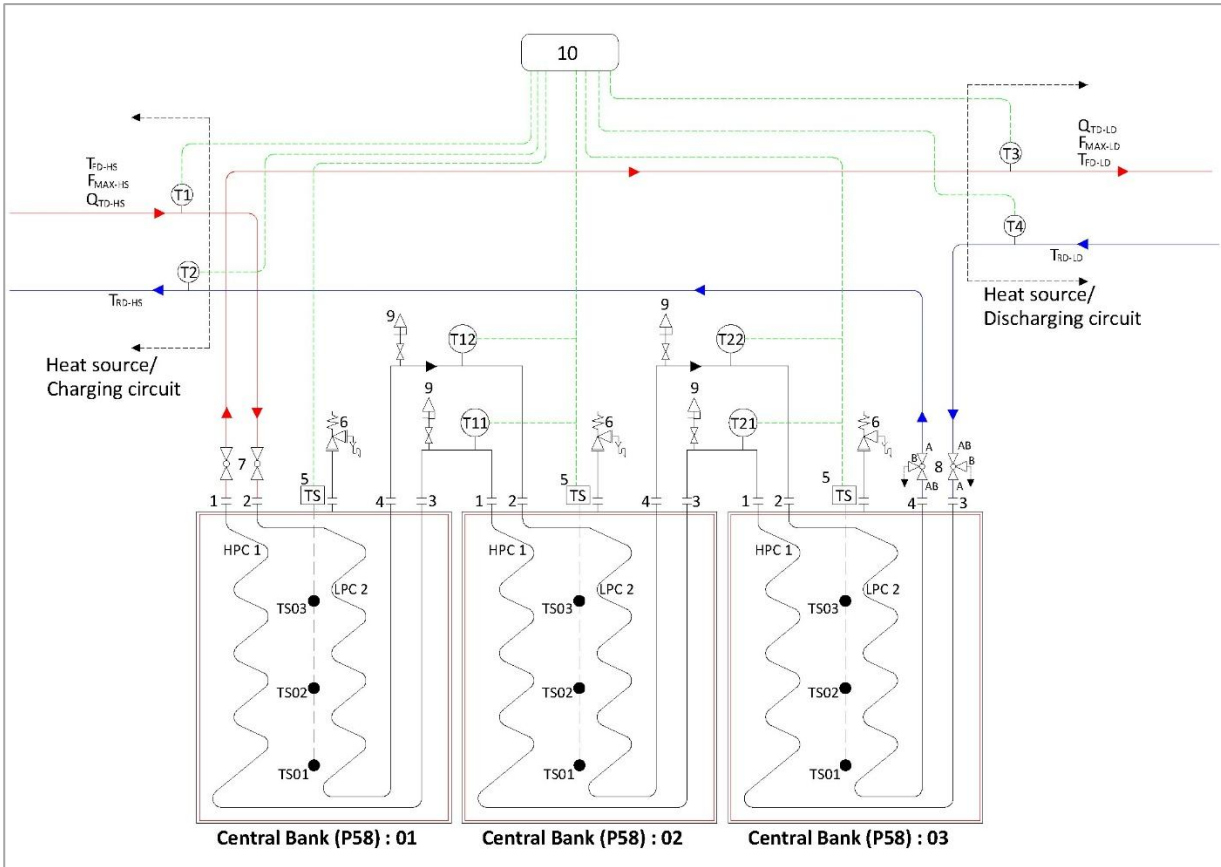
Multiple Central Bank Mini (P58) heat batteries can be connected in series, parallel or combination of these configurations, to meet the requirements for thermal storage capacities greater than 80kWh nominal rating for the single Central Bank Mini (P58) heat battery. A flow and return header of the TES system based on multiple Central Bank Mini (P58) heat batteries can be connected to the heat source and the heating loads in a similar configuration to a single heat battery as discussed in section 4 of this document.

The technical specifications of the TES systems based on multiple Central Bank Mini (P58) heat batteries described in the following sections, are based on the parameters listed in table 5.1.

Parameter	Unit	Value	Notes
Nominal storage capacity	kWh / [btu]	80.0 / [272,971]	
HPC-1 Design flow rate	L/min / [GPM]	50.0 / [13.2]	
LPC-2 Design flow rate	L/min / [GPM]	22 / [5.8]	
HPC-1 + LPC-2 in parallel: Maximum design flow rate	L/min / [GPM]	72 / [19.0]	
Kv Value of hydronic circuit HPC-1		11.9	
Kv Value of hydronic circuit LPC-2		7.2	
Kv Value of hydronic circuits HPC-1 + LPC-2		19.1	
HPC-1 Pressure loss at Design flow rate	kPa / [psi]	6.4 / [0.91]	
LPC-2 Pressure loss at Design flow rate	kPa / [psi]	3.4 / [0.49]	
HPC-1 + LPC-2 Pressure loss at maximum design flow rate	kPa / [psi]	5.1 / [0.74]	
In series storage capacity correction factor	%	8	When heat batteries are connected in series, the effective flow length of the heat exchanger increase. Therefore, the UA- Value increases
LPC-2 Maximum flow rate correction factor	%	6	
HPC-1 Maximum design flow rate correction factor	%	6	
connecting pipework pressure loss factor	%	15	

5.1 Central Bank Mini (P58) TES System with heat batteries connected in series WITH hydronic separation between charging and discharging circuits (HPC-1 & LPC-2)

The TES System with this configuration, the HPC-1 and the LPC-2 hydronic circuits of the Central Bank Mini (P58) heat batteries are connected in series as shown in figure 5.1. In figure 5.1, the heating load is connected to the high-power circuit, HPC-1, and heating source is connected to the low power circuit, LPC-2, of the TES system. Depending upon the relative design thermal power rating of the heating load, Q_{TD-LD} , and the heat source, Q_{TD-HS} , the connection arrangement can be modified. The technical specification of a TES system based on this heat battery connection arrangement is listed in table 5.2.



Key Figures 5.1: Three Central Bank Mini (P58) heat batteries connected in series with hydronic separation between the charging and discharging circuits. In this arrangement the heat batteries can be charged and discharged simultaneously

1	High power circuit - Heating load flow connection
2	Low power circuit - Heat source flow connection
3	High power circuit - Heating load return connection.
4	Low power circuit - Heat source return connection.
5	Heat battery temperature sensor cables (TS01, TS02 & TS03 - 3 wire RTD PT100).
6	Pressure relief valve
7	Isolating valve (2-port).
8	Isolating valve (3-port).
9	Automatic air vent
10	Central Bank Mini (P58) system controller

The main advantages of connecting heat batteries in series with hydronic separation between charging and discharging circuits are:

- a) The charging and the discharging circuits, (HPC-1 and LPC-2) of the TES system can have different fluids and design operating pressures to meet the requirements of the connected heating loads and heat sources.
- b) The TES system can be both charged and discharged simultaneously:
 - When the heating load, Q_{TD-LD} , is less than the heat source power, Q_{TD-HS} , the charge state of the heat battery, Q_{T-HB} , will increase at rate, $Q_{TD-HS} - Q_{TD-LD}$.

- When the heating load, Q_{TD-LD} , is greater than the heat source power, Q_{TD-HS} , the charge state of the heat battery, Q_{T-HB} , will decrease at rate, $Q_{TD-LD} - Q_{TD-HS}$.
- c) This connection arrangement increases the thermal utilisation and storage capacity of the heat batteries and the balancing of low rates between heat batteries (i.e. using balancing valves and a header), is not required.
- d) This arrangement is suitable for configuring a TES system with heat batteries containing different phase change materials (PCM).

The main disadvantages of connecting heat batteries in series with hydronic separation between the HPC-1 and LPC-2 charging and discharging circuits are:

- a) As shown in table 5.2, although the storage capacity of TES system increases with the number of heat batteries, the charging and discharging thermal power ratings do not significantly change when compared with a single heat battery TES system.
- b) The pressure loss values presented for the Central Bank Mini (P58) represent the pressure drop across the heat battery only. When designing the TES system, the designer must also account for additional pressure losses in the interconnecting pipework, headers, valves, and fittings between the Central Bank Mini (P58) units.
- c) As commonly seen in series connection systems, if one of the heat batteries develops a critical fault in the core of the battery, it cannot be isolated from the rest of the TES system. Therefore, a critical fault in one heat battery can result in a complete TES system shutdown unless multiple manual bypasses are installed.

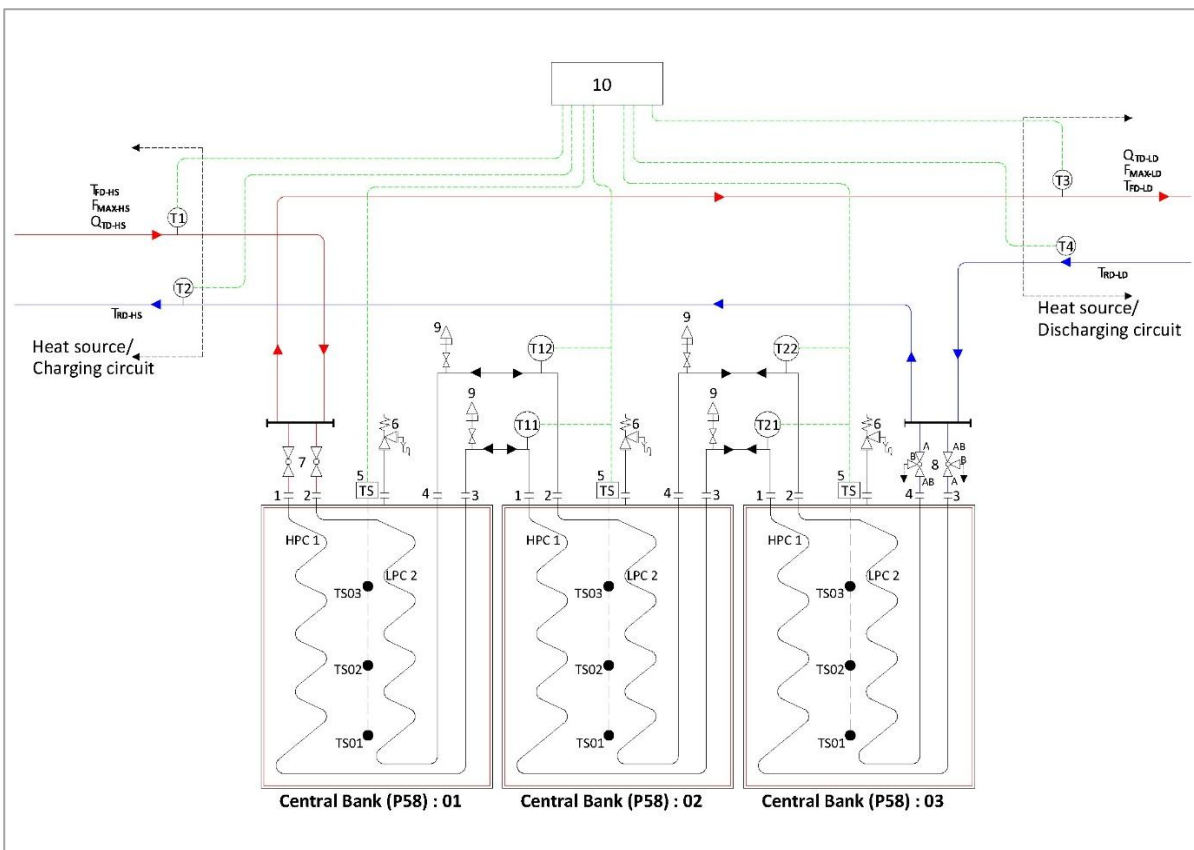
Table 5.2 : Technical specification of TES System with multiple Central Bank Mini (P58) heat batteries connected in series with hydronic separation (Figure 5.1)								
Number of Central Bank Mini (P58) connected in series (Figure 5.1)		2	3	4	5	6	7	8
Nominal storage capacity	kWh	166	253	339	426	512	598	685
	btu	567,780	862,589	1,157,398	1,452,207	1,747,016	2,041,825	2,336,633
HPC-1 Maximum design flow rate	L/min	53.0	56.0	59.0	62.0	65.0	68.0	71.0
	GPM	14.0	14.8	15.6	16.4	17.2	18.0	18.8
LPC-2 Maximum design flow rate	L/min	23.3	24.6	26.0	27.3	28.6	29.9	31.2
	GPM	6.2	6.5	6.9	7.2	7.6	7.9	8.3
TES System: HPC-1 Circuit maximum power rating at 7°C / [12.8 °F]	kW	25.8	27.3	28.7	30.2	31.7	33.1	34.6
	btu/hr	86928	91848	96769	101689	106610	111530	116451
TES System: HPC-1 Circuit maximum power rating at 12°C / [21.6 °F]	kW	44.3	46.8	49.3	51.8	54.3	56.8	59.3
	btu/hr	146691	154994	163298	171601	179904	188208	196511
TES System: HPC-1 Circuit maximum power rating at 18°C / [32.4 °F]	kW	66.4	70.2	74.0	77.7	81.5	85.2	89.0
	btu/hr	220037	232492	244947	257402	269857	282312	294767
TES System: LPC-2 Circuit maximum power rating at 7°C / [12.8 °F]	kW	11.3	12.0	12.6	13.3	13.9	14.6	15.2
	btu/hr	38248	40413	42578	44743	46908	49073	51238
TES System: LPC-2 Circuit maximum power rating at 12°C / [21.6 °F]	kW	19.5	20.6	21.7	22.8	23.9	25.0	26.1
	btu/hr	64544	68197	71851	75504	79158	82811	86465
TES System: LPC-2 Circuit maximum power rating at 18°C / [32.4 °F]	kW	29.2	30.9	32.5	34.2	35.8	37.5	39.1
	btu/hr	96816	102296	107776	113257	118737	124217	129697
HPC-1 pressure loss at maximum design flow rate	kPa	7.14	7.97	8.85	9.77	10.74	11.76	12.82
	psi	1.04	1.16	1.28	1.42	1.56	1.70	1.86
	kPa	3.78	4.22	4.68	5.17	5.68	6.22	6.78

Table 5.2 : Technical specification of TES System with multiple Central Bank Mini (P58) heat batteries connected in series with hydronic separation (Figure 5.1)

Number of Central Bank Mini (P58) connected in series (Figure 5.1)		2	3	4	5	6	7	8
LPC-2 pressure loss at maximum design flow rate	psi	0.55	0.61	0.68	0.75	0.82	0.90	0.98
Total pressure loss of HPC-1 of TES system	kPa	14.28	23.91	35.4	48.85	64.44	82.32	102.56
	psi	2.08	3.48	5.12	7.1	9.36	11.9	14.88
Total pressure loss of LPC-2 of TES system	kPa	7.56	12.66	18.72	25.85	34.08	43.54	54.24
	psi	1.1	1.83	2.72	3.75	4.92	6.3	7.84

5.2 Central Bank Mini (P58) TES System with heat batteries connected in series WITHOUT hydronic separation between charging and discharging circuits (HPC-1 & LPC-2)

In a TES System with this configuration, the HPC-1 and the LPC-2 hydronic circuits of the Central Bank Mini (P58) heat batteries are connected in parallel before connecting it to the next heat battery, as shown in figure 5.2. Therefore, the heat batteries function as individual hydronic circuit devices. Therefore, the maximum TES charging flow rate, F_{MAX-HS} , and the TES discharging flow rate, F_{MAX-LD} , will be same, i.e. the maximum charging power, Q_{TD-HS} , and the discharging power, Q_{TD-LD} , will only depend upon the design temperature differences. The technical specification of a TES system based on this heat battery connection arrangement is listed in table 5.3.



Key Figures 5.2: Three Central Bank Mini (P58) heat batteries connected in series without hydronic separation between charging and discharging circuit (TES **cannot** be charged and discharged simultaneously).

1	High power circuit – Heating load flow connection
2	Low power circuit – Heat Source flow connection
3	High power circuit – Heating load return connection
4	Low power circuit – Heat source return connection
5	Heat battery temperature sensor cables (TS01, TS02 & TS03 - 3 wire RTD PT100)
6	Pressure relief valve
7	Isolating valve (2-port)
8	Isolating valve (3-port)
9	Automatic air vent
10	Central Bank Mini (P58) system controller

The main advantages of connecting heat batteries in series with no hydronic separation between charging and discharging circuits (HPC-1 and LPC-2), are:

- a) This connection arrangement increases the thermal utilisation and storage capacity of the heat batteries and the balancing of low rates between heat batteries (i.e. using balancing valves and headers) is not required.
- b) This arrangement is suitable for configuring TES system with heat batteries containing different phase change materials (PCM).

The main disadvantages of connecting heat batteries in series with no hydronic separation between charging and discharging circuits, (HPC-1 and LPC-2) are:

- c) The charging and the discharging circuits, (HPC-1 and LPC-2) of the TES system, in this connection arrangement are connected in parallel, therefore, the heat source and heating load circuits cannot contain different fluids and the design operating pressures for both circuits cannot differ.
- d) The TES system cannot be charged and discharged simultaneously. Therefore, TES System charging and discharging is an “either/or” operation only. As shown in table 5.3, although the storage capacity of TES system increases with the number of heat batteries, the charging and discharging thermal power ratings do not significantly change when compared with a single heat battery TES system.
- e) The pressure loss values presented for the Central Bank Mini (P58) represent the pressure drop across the heat battery only. When designing the TES system, the designer must also account for additional pressure losses in the interconnecting pipework, headers, valves, and fittings between the Central Bank Mini (P58) units.
- f) As commonly seen in series connection systems, if one of the heat batteries develops a critical fault, it cannot be isolated from the rest of the TES system. Therefore, one heat battery with a critical fault can result in a complete TES system shutdown unless multiple manual bypasses are installed.

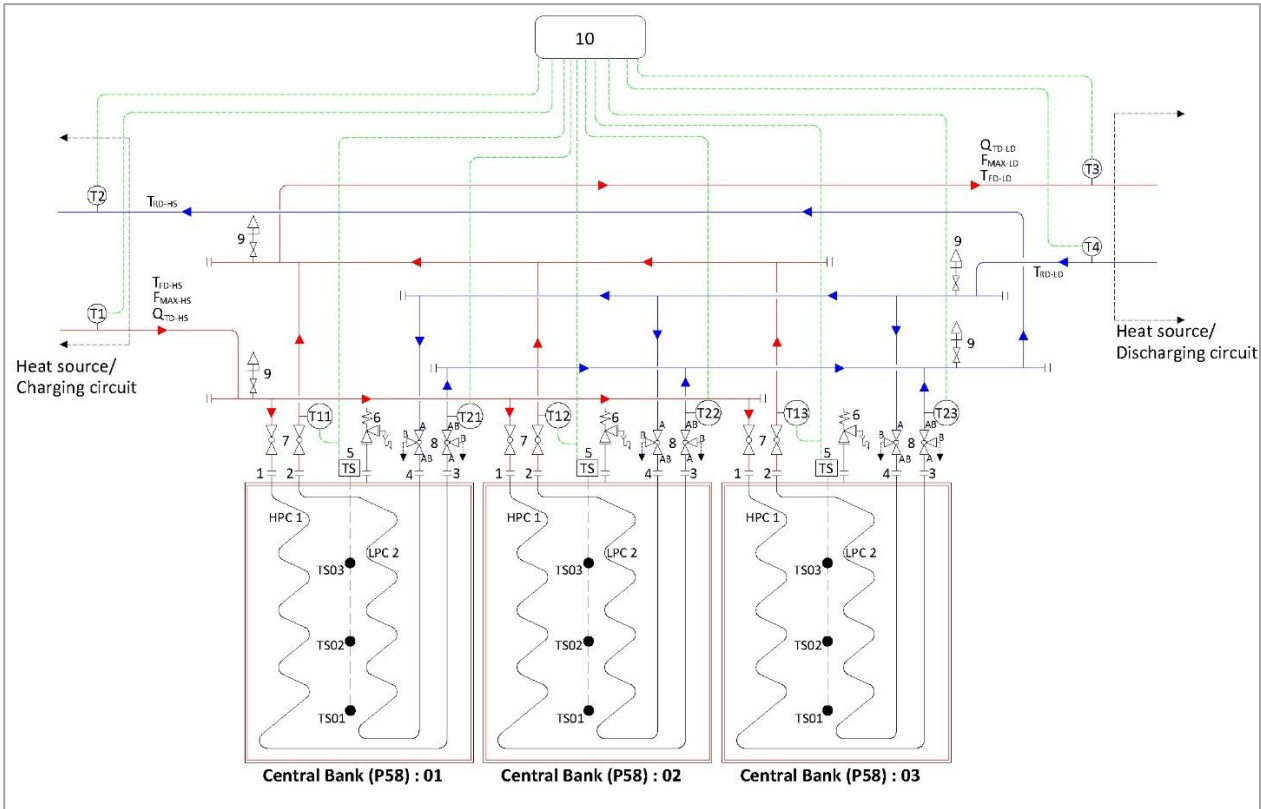
Table 5.3: Technical specification of TES System with multiple Central Bank Mini (P58) heat batteries connected in series without hydronic separation (Figure 5.2)

Number of Central Bank Mini (P58) connected in series (Figure 5.2)		2	3	4	5	6	7	8
Nominal storage capacity	kWh	166	253	339	426	512	598	685
	btu	567,780	862,589	1,157,398	1,452,207	1,747,016	2,041,825	2,336,633
Maximum flow rate (HPC + LPC in parallel)	L/min	76.3	80.6	85.0	89.3	93.6	97.9	102.2
	GPM	20.2	21.3	22.4	23.6	24.7	25.9	27.0
TES System: Maximum power rating at 7°C / [12.8 °F]	kW	36.47	38.54	40.60	42.67	44.73	46.80	48.86
	btu/hr	124,456	131,500	138,545	145,590	152,634	159,679	166,724
TES System: Maximum power rating at 12°C / [21.6 °F]	kW	62.53	66.07	69.61	73.15	76.68	80.22	83.76
	btu/hr	213,353	225,429	237,506	249,582	261,659	273,735	285,812
TES System: Maximum power rating at 18°C / [32.4 °F]	kW	93.79	99.10	104.41	109.72	115.03	120.34	125.64
	btu/hr	320,029	338,144	356,258	374,373	392,488	410,603	428,718
pressure loss (HPC + LPC in parallel)	kPa	5.75	6.42	7.12	7.87	8.65	9.46	10.32
	psi	0.83	0.93	1.03	1.14	1.25	1.37	1.50
Total TES Pressure loss	kPa	11.5	19.26	28.48	39.35	51.9	66.22	82.56
	psi	1.66	2.79	4.12	5.7	7.5	9.59	12

5.3 Central Bank Mini (P58) TES System with heat batteries connected in parallel WITH hydronic separation between charging and discharging circuits (HPC-1 & LPC-2)

The TES System with this configuration, the HPC-1 and the LPC-2 hydronic circuits of the Central Bank Mini (P58) heat batteries in parallel are connected to common heat source and heating load flow and return headers as shown schematically in figure 5.3.

In figure 5.3, the heating load is connected to the low power circuit, LPC-2, and the TES heating source is connected to the high-power circuit, HPC-1, TES headers. Depending upon the relative design thermal power rating of the heating load, Q_{TD-LD} , and the heat source, Q_{TD-HS} , the connection arrangement can be adjusted. The technical specification of a TES system based on this heat battery connection arrangement is listed in table 5.4.



Key Figures 5.3: Three Central Bank Mini heat batteries connected in series with hydronic separation between charging and discharging circuit (TES can be charged and discharged simultaneously).

1	High power circuit – Heating load flow connection
2	Low power circuit – Heat source flow connection
3	High power circuit – Heating load return connection
4	Low power circuit – Heat source return connection
5	Heat battery temperature sensor cables (TS01, TS02 & TS03 - 3 wire RTD PT100).
6	Pressure relief valve
7	Isolating valve (2-port)
8	Isolating valve (3-port).
9	Automatic air vent
10	Central Bank Mini (P58) system controller

Table 5.4 : Technical specification of TES System with multiple Central Bank Mini (P58) heat batteries connected in parallel with hydronic separation (Figure 5.3)

Number of Central Bank Mini (P58) connected in parallel (Figure 5.3)		2	3	4	5	6	7	8
Nominal storage capacity	kWh	160	240	320	400	480	560	640
TES System: HPC-1 Circuit maximum design flow rate	L/min	100	150	200	250	300	350	400
	GPM	26.4	39.6	52.8	66.0	79.3	92.5	105.7
TES System: LPC-2 Circuit maximum design flow rate	L/min	44	66	88	110	132	154	176
	GPM	11.6	17.4	23.2	29.1	34.9	40.7	46.5
TES System: HPC-1 Circuit maximum power rating at 7°C / [12.8 °F]	kW	47.79	71.69	95.58	119.48	143.37	167.27	191.17
	btu/hr	163,071	244,606	326,142	407,677	489,212	570,748	652,283
	kW	81.93	122.89	163.86	204.82	245.78	286.75	327.71

Table 5.4 : Technical specification of TES System with multiple Central Bank Mini (P58) heat batteries connected in parallel with hydronic separation (Figure 5.3)								
Number of Central Bank Mini (P58) connected in parallel (Figure 5.3)		2	3	4	5	6	7	8
TES System: HPC-1 Circuit maximum power rating at 12°C / [21.6 °F]	btu/hr	279,550	419,325	559,100	698,875	838,650	978,425	1,118,200
	kW	122.89	184.34	245.78	307.23	368.68	430.12	491.57
TES System: HPC-1 Circuit maximum power rating at 18°C / [32.4 °F]	btu/hr	419,325	628,987	838,650	1,048,312	1,257,975	1,467,637	1,677,300
	kW	21.03	31.54	42.06	52.57	63.08	73.60	84.11
TES System: LPC-2 Circuit maximum power rating at 7°C / [12.8 °F]	btu/hr	71,751	107,627	143,502	179,378	215,253	251,129	287,005
	kW	36.05	54.07	72.10	90.12	108.14	126.17	144.19
TES System: LPC-2 Circuit maximum power rating at 12°C / [21.6 °F]	btu/hr	123,002	184,503	246,004	307,505	369,006	430,507	492,008
	kW	54.07	81.11	108.14	135.18	162.22	189.25	216.29
TES System: LPC-2 Circuit maximum power rating at 18°C / [32.4 °F]	btu/hr	184,503	276,754	369,006	461,257	553,509	645,760	738,012
	kPa	6.4	6.4	6.4	6.4	6.4	6.4	6.4
TES System: HPC-1, total pressure loss (@50L/Min)	psi	1.06	1.06	1.06	1.06	1.06	1.06	1.06
	kPa	3.87	3.87	3.87	3.87	3.87	3.87	3.87
TES System: LPC-2, total pressure loss	psi	0.56	0.56	0.56	0.56	0.56	0.56	0.56
	kPa	3.87	3.87	3.87	3.87	3.87	3.87	3.87

The main advantages of connecting heat batteries in parallel with hydronic separation between the charging and the discharging circuits HPC-1 and LPC-2 in all heat batteries, are:

- a) The charging and the discharging circuits (HPC-1 and LPC-2 in individual heat batteries), of the TES system can have different fluids and design operating pressures to meet the requirements of the connected heating loads and heat sources.
- b) The TES system can be charged and discharged simultaneously:
 - When the heating load, Q_{TD-LD} , is less than the heat source power, Q_{TD-HS} , the charge state of the heat battery, Q_{T-HB} , will increase at rate, $Q_{TD-HS} - Q_{TD-LD}$.
 - When the heating load, Q_{TD-LD} , is greater than the heat source power, Q_{TD-HS} , the charge state of the heat battery, Q_{T-HB} , will decrease at rate, $Q_{TD-LD} - Q_{TD-HS}$.
- c) The hydronic circuit pressure drops between flow and returns headers does not significantly increase with the number of heat batteries connected in parallel.
- d) As shown in table 5.4, the total storage capacity of the TES system and the thermal power rating of the charging and discharging circuits, HPC-1 and LPC-2, are directly proportional to the number of heat batteries connected in parallel. Therefore, there is no theoretical limit to the number of heat batteries that can be connected in parallel.
- e) If one of the heat batteries in a TES system develops a fault, it can be isolated from the rest of the TES system. Therefore, a critical failure of one heat battery will not result in complete TES system shutdown.

The main disadvantages of connecting heat batteries in parallel with hydronic separation between the charging and the discharging circuits (HPC-1 and LPC-2 in all heat batteries), are:

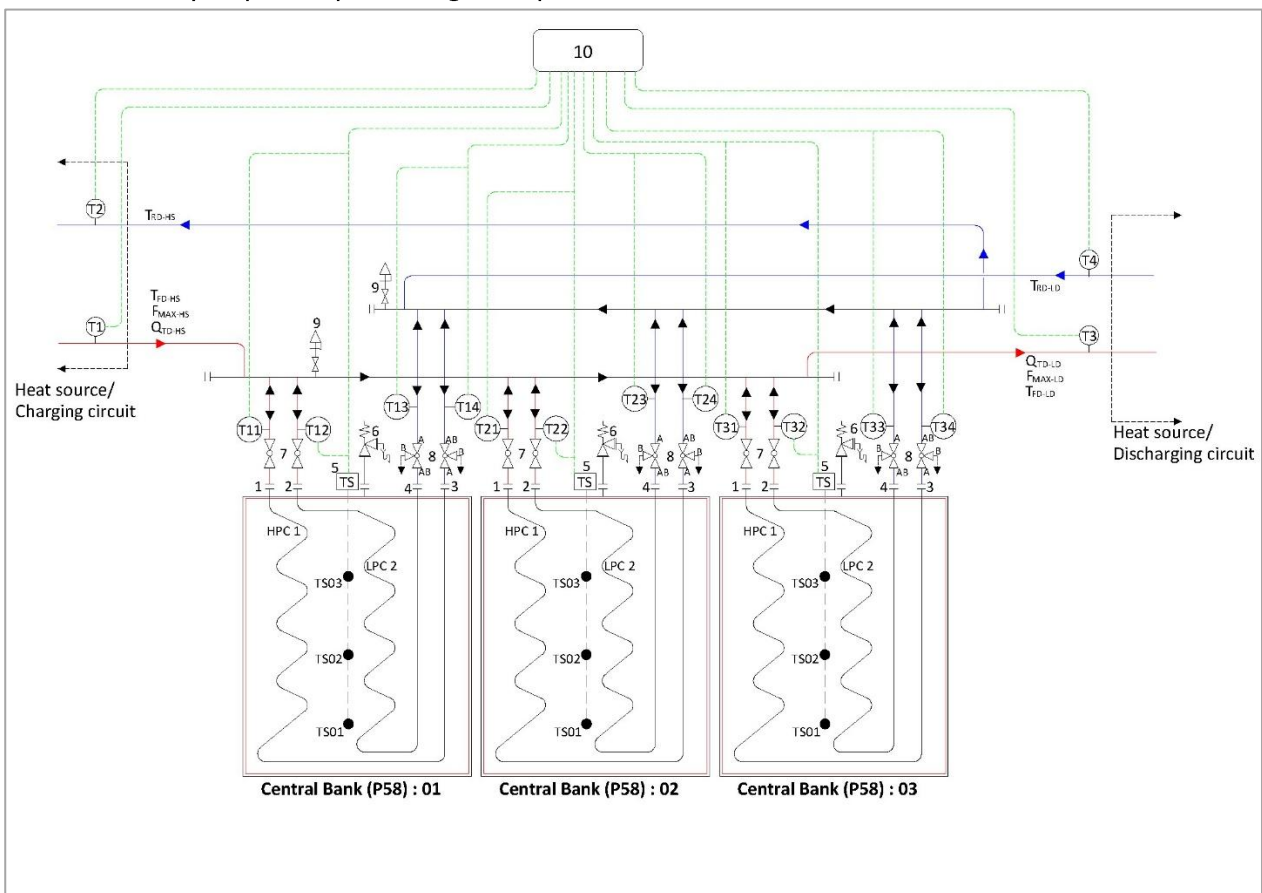
- a) The utilized storage capacity of the TES system will depend upon the uniform charging and discharging of each heat battery in TES system. Therefore, the flow and return

headers should be designed so that the design charging and discharging flow rates should be the same for the heat batteries connected in parallel. Therefore, flow balancing, regulating valves and Tichelman pipe configuration may be required to balance the flow rate.

- b) If one or more heat batteries fail, the performance of the TES system will be significantly reduced (e.g. heating load supply temperature). Therefore, the control system should be designed to detect heat battery failure and prompt automatic or manual isolation from the rest of the TES system.

5.4 Central Bank Mini (P58) TES System with heat batteries connected in parallel WITHOUT hydronic separation between charging and discharging circuits (HPC-1 & LPC-2)

The HPC-1 and the LPC-2 hydronic circuits of the Central Bank Mini heat batteries in this TES system configuration are connected in parallel to the same flow and return headers as shown schematically in figure 5.4. Therefore, the heat batteries function as single hydronic circuit devices. Therefore, the maximum TES charging flow rate, F_{MAX-HS} , and the TES discharging flow rate, F_{MAX-LD} , will be same, i.e. the maximum charging power, Q_{TD-HS} , and the discharging power, Q_{TD-LD} , will only depend upon design temperature differences.



Key Figures 5.4: Three Central Bank Mini heat batteries connected in parallel without hydronic separation between charging and discharging circuit (TES **cannot** be charged and discharged simultaneously).

1	High power circuit – Heating load flow connection
2	Low power circuit – Heat source flow connection
3	High power circuit – Heating load return connection
4	Low power circuit – Heat source return connection
5	Heat battery temperature sensor cables (TS01, TS02 & TS03 - 3 wire RTD PT100).
6	Pressure relief valve
7	Isolating valve (2-port)
8	Isolating valve (3-port).
9	Automatic air vent
10	Central Bank Mini (P58) system controller

The overall performance of the Central Bank Mini (P58) heat battery-based TES system, configured as shown in figure 5.4, will be similar to the TES system discussed in section 5.3. Although, this system arrangement is simpler to install compared with the arrangement shown in figure 5.3, it has the following disadvantages:

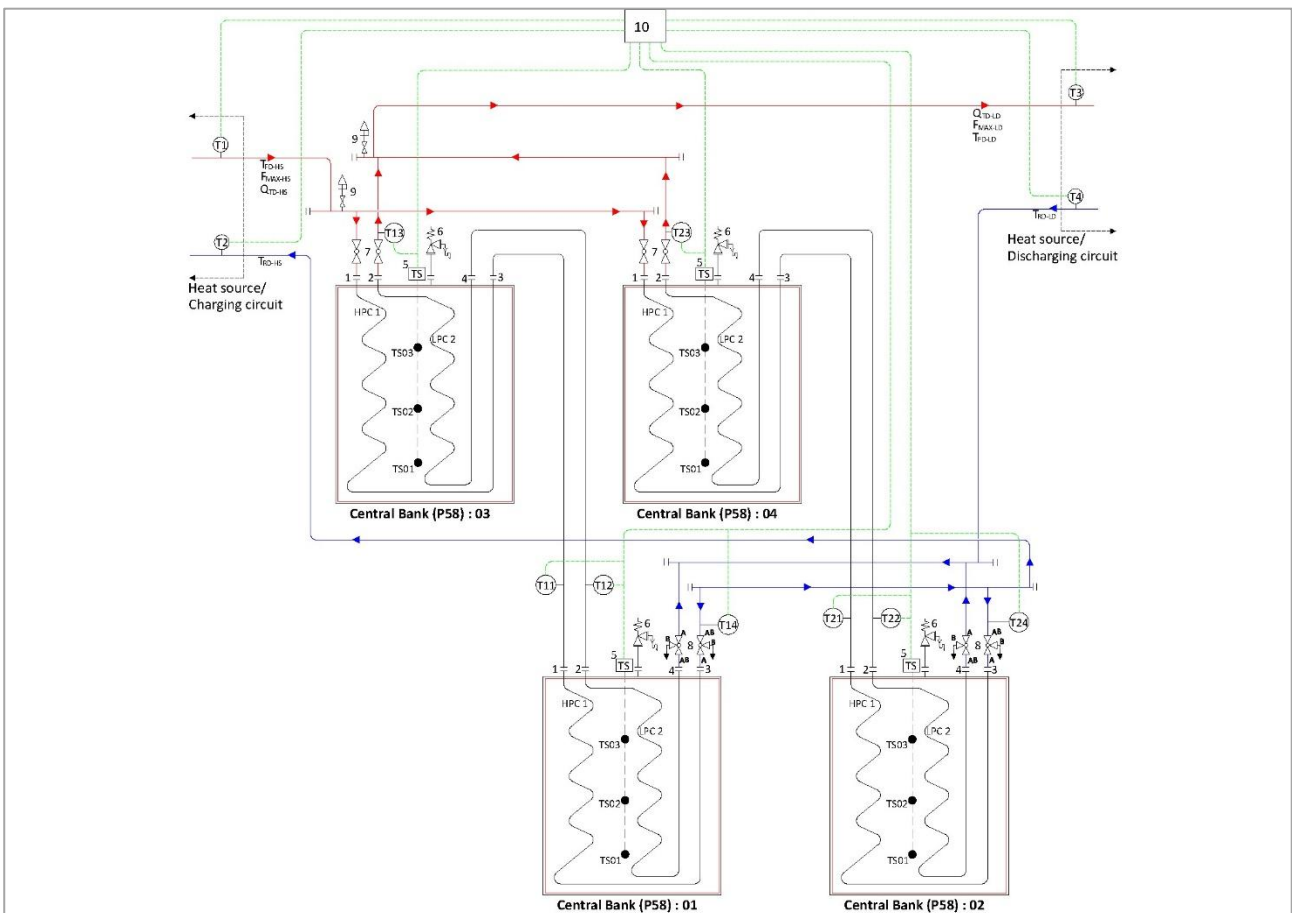
- a) The charging and the discharging circuits, (HPC-1 and LPC-2) of the TES system in this connection arrangement are connected in parallel, therefore, the heat source and heating load circuits cannot have different fluids and the design operating pressures for both circuits cannot differ.
- b) The TES system cannot be charged and discharged simultaneously. Therefore, this TES System arrangement is only suitable for applications where simultaneous charging and discharging is not required.

5.5 Central Bank Mini (P58) TES System with heat batteries connected in a serial and parallel connection matrix WITH hydronic separation between charging and discharging circuits (HPC-1 & LPC-2)

The series and parallel matrix connection arrangement for multiple Central Bank Mini (P58) heat batteries is shown schematically in figure 5.5. This arrangement has all the advantages for both in series and in parallel connection arrangements discussed above in sections 5.1 – 5.3.

For this type of configuration, the performance the TES can be calculated from the data in table 5.2 and 5.4. Typical example configurations arrangements are listed in table 5.5.

Total number Central Bank Mini (P58) units	4	6	8	10
Number of rows (Batteries in series)	2	2	2	2
Number of columns (Batteries in parallel)	2	3	4	5
Total storage capacity, kWh / [btu]	332 [1,135,560]	498 [1,703,340]	664 [2,271,120]	830 [2,838,900]



Key Figures 5.5: Two Central Bank Mini heat batteries connected in 2x2 parallel and series matrix with hydronic separation between charging and discharging circuit.

1	High power circuit – Heating load flow connection
2	Low power circuit – Heat source flow connection

Key Figures 5.5: Two Central Bank Mini heat batteries connected in 2x2 parallel and series matrix with hydronic separation between charging and discharging circuit.

3	High power circuit - Heating load return connection
4	Low power circuit - Heat source return connection
5	Heat battery temperature sensor cables (TS01, TS02 & TS03 - 3 wire RTD PT100).
6	Pressure relief valve
7	Isolating valve (2-port)
8	Isolating valve (3-port).
9	Automatic air vent
10	Central Bank Mini (P58) system controller

6 Central Bank Mini (P58) heat battery TES System controls and control algorithms

6.1 Central Bank Mini (P58) Temperature sensors and control temperature settings

The Central Bank Mini (P58) heat battery is fitted with 3 sets of temperature sensor strings as standard. Each string consists of 3 x 3-wire RTD PT100 sensors, at the bottom, middle and top of the heat exchanger. Each sensor in the string is labelled 1 = Bottom sensor, 2 = Middle sensor, and 3 = Top sensor. These sensors are connected to the TES system controller 8, as shown schematically in figure 6.1, and are used for controlling the charging and discharging of the heat battery.

The variables and set points used for controlling the charging and discharging of the heat, Central Bank Mini (P58), are defined below in tables 6.1 and 6.2.

Table 6.1: Heat battery temperature sensors and measurements (Example figure 6.1)

Heat battery temperature sensor: 3 Wire RTD, PT100	Sensor string number	1			2			3		
	Sensor number	1	2	3	1	2	3	1	2	3
	Measurement variable	TS11	TS12	TS13	TS21	TS22	TS23	TS31	TS32	TS33
	Measurement variable type	Real	Real	Real	Real	Real	Real	Real	Real	Real
	Measurement units	°C	°C	°C	°C	°C	°C	°C	°C	°C
	Measurement range	-40 ... 150	-40 ... 150	-40 ... 150	-40 ... 150	-40 ... 150	-40 ... 150	-40 ... 150	-40 ... 150	-40 ... 150

Table 6.2: Definition of variables and constants used in high level control algorithms (Example figure 6.1)

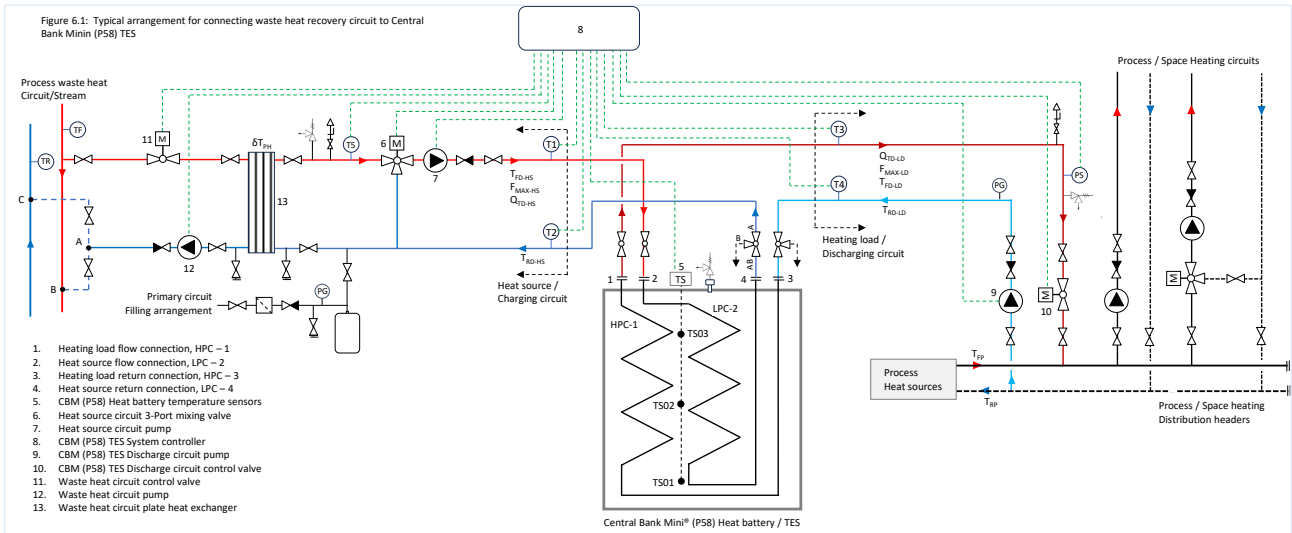
Variable	Description	Type	Units	Measured / Calculated / IO	
TSA1	Average heat battery temperature - Bottom	Real	°C	Calculated: $TSA1 = (TS11 + TS12 + TS13)/3$	
TSA2	Average heat battery temperature - Middle	Real	°C	Calculated: $TSA2 = (TS21 + TS22 + TS23)/3$	
TSA3	Average heat battery temperature - Top	Real	°C	Calculated: $TSA3 = (TS31 + TS32 + TS33)/3$	
TEMP_T1	Temperature measured by sensor, T1	Real	°C	Measured	
TEMP_T2	Temperature measured by sensor, T2	Real	°C	Measured	
TEMP_T3	Temperature measured by sensor, T3	Real	°C	Measured	
TEMP_T4	Temperature measured by sensor, T4	Real	°C	Measured	
TEMP_T5	Temperature measured by sensor, T5	Real	°C	Measured	
TEMP_T6	Temperature measured by sensor, T6	Real	°C	Measured	
Variable	Description	Type	Value	Units	Description
HB_TES_CM	Heat battery charging mode	Integer	1, 2	N/A	1 = Deep discharging 2 = Shallow discharging
HB_TES_CHG	Heat battery TES charging permit	Boolean	0, 1	N/A	0 = TES Charging is not permitted 1 = TES Charging is permitted
HB_TES_DCHG	Heat battery TES discharging permit	Boolean	0, 1	N/A	0 = TES Discharging is not permitted 1 = TES Discharging is permitted
TES_SOC	State of charge	Real	0 ... 100	%	

constant	Description	Type	Value	Units	Description
CBM_CHG	Needs adding Central Bank Mini charging demand status	Boolean	0, 1	N/A	0 = No charging demand, 1 = Charging demand active
TS01_ON1	Heat battery charging on setting_1 for sensor TS01	Real	To be determined	°C	Charging start threshold for bottom sensor in deep discharge mode
TS02_ON1	Heat battery charging on setting_1 for sensor TS02	Real	To be determined	°C	Charging start threshold for middle sensor in deep discharge mode
TS03_ON1	Heat battery charging on setting_1 for sensor TS03	Real	To be determined	°C	Charging start threshold for top sensor in deep discharge mode.
TS01_ON2	Heat battery charging on setting_2 for sensor TS01	Real	To be determined	°C	Charging start threshold for bottom sensor in shallow discharge mode.
TS02_ON2	Heat battery charging on setting_2 for sensor TS02	Real	To be determined	°C	Charging start threshold for middle sensor in shallow discharge mode.
TS03_ON2	Heat battery charging on setting_2 for sensor TS03	Real	To be determined	°C	Charging start threshold for top sensor in shallow discharge mode.
TS01_OFF1	Heat battery charging off setting_1 for sensor TS01	Real	To be determined	°C	Charging stop threshold for bottom sensor in deep discharge mode
TS02_OFF1	Heat battery charging off setting_1 for sensor TS02	Real	To be determined	°C	Charging stop threshold for middle sensor in deep discharge mode
TS03_OFF1	Heat battery charging off setting_1 for sensor TS03	Real	To be determined	°C	Charging stop threshold for top sensor in deep discharge mode.
TS01_OFF2	Heat battery charging off setting_2 for sensor TS01	Real	To be determined	°C	Charging stop threshold for bottom sensor in shallow discharge mode.
TS02_OFF2	Heat battery charging off setting_2 for sensor TS02	Real	To be determined	°C	Charging stop threshold for middle sensor in shallow discharge mode.
TS03_OFF2	Heat battery charging off setting_2 for sensor TS03	Real	To be determined	°C	Charging stop threshold for top sensor in shallow discharge mode.
SOC_MIN	Minimum state of charge of TES to supply demand	Real	10	%	Minimum TES state of charge required for discharging

The ensure the thermal battery is fully charge the bottom sensor TS01 across the three strings will have to achieve 63°C. The control logic for recharging the Central Bank Mini (P58) should be determined by the designer in relation to the application the battery is installed in.

6.2 Example system control algorithms

The following control algorithm example has been prepared for illustration purposes based on a use case of waste heat recapture and utilization, as shown in figure 6.1.



a) Read system control parameters

- Read system control settings (Constants) defined in table 6.2.
- Read system operational control parameters defined in table 6.2.

b) Read and calculate temperatures

- Read temperatures: TS11, TS12, TS13, TS21, TS22, TS23, TS31, TS32, TS33
- Read temperatures: TEMP_T1, TEMP_T2, TEMP_T3, TEMP_T4, TEMP_T5,
- Calculate: $TSA1 = (TS11 + TS12 + TS13)/3$
- Calculate: $TSA2 = (TS21 + TS22 + TS23)/3$
- Calculate: $TSA3 = (TS31 + TS32 + TS33)/3$

c) Central Bank Mini (P58) Heat battery charging demand.

```

IF ((HB_TES_CM = 1) & (CBM_CHG = 0))
    IF ((TSA1 ≤ TS01_ON1) & (TSA2 ≤ TS02_ON1))
        CBM_CHG = 1
    END IF
IF ((HB_TES_CM = 2) & (CBM_CHG = 0))
    IF ((TSA1 ≤ TS01_ON2) & (TSA2 ≤ TS02_ON2))
        CBM_CHG = 1
    
```

END IF

IF ((HB_TES_CM = 1) & (CBM_CHG = 1))

IF ((TSA1 > TS01_OFF1) & (TSA2 > TS02_OFF1) && (TSA3 > TS03_OFF1))

CBM_CHG = 0

END IF

IF ((HB_TES_CM = 2) & (CBM_CHG = 1))

IF ((TSA1 > TS01_OFF2) & (TSA2 > TS02_OFF2) && (TSA3 > TS03_OFF2))

CBM_CHG = 0

END IF

d) Central Bank Mini (P58) TES Charging control

IF ((HB_TES_CHG = 1) & (CBM_CHG = 1))

- Switch on TES Charging pump, 7.
- Modulate control valve, 6, to control the TES charging temperature, TEMP_T1, at preset value, TF_CHG.
- Switch on the heat source i.e. pump, 12, and the control valve, 11.

END IF

IF ((HB_TES_CHG = 0) OR (CBM_CHG = 0))

- Switch off TES Charging pump, 7.
- Close port, A, of Modulate control valve, 6.
- Switch off the heat source i.e. pump, 12, and the control valve, 11.

END IF

e) Central Bank Mini P58 TES Discharging control

IF ((HB_TES_DCHG = 1) & (TES_SOC ≥ SOC_MIN))

- Switch on TES discharging pump, 9.
- Switch on TES discharging control valve, 10, and modulate control valve, 10, to control the TES discharging power.

END IF

IF ((HB_TES_DCHG = 0) OR (TES_SOC < SOC_MIN))

- Switch off TES discharging pump, 9.
- Switch off TES discharging control valve, 10.

END IF

7 Decommissioning

Please refer to the manual

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