TESSe2B
the smart energy storage

Thermal Energy
Storage Systems
for energy efficient building an integrated solution for residential building energy storage by solar and geothermal resources

Control and monitoring system for high energy and cost efficiency

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European Commission

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WP5 Objectives:

- Development of a database with usage profiles and technical data for required equipment and components.

- Definition of a hydraulic scheme for the demo-sites

- Selection of measurement units, e.g. temperature/flow/power sensors and actuators for the Tesse2b prototypes

- Design, optimize and parameterize a system-wide control system which optimally coordinates the interaction of the various subsystems to achieve high energy and cost efficiency

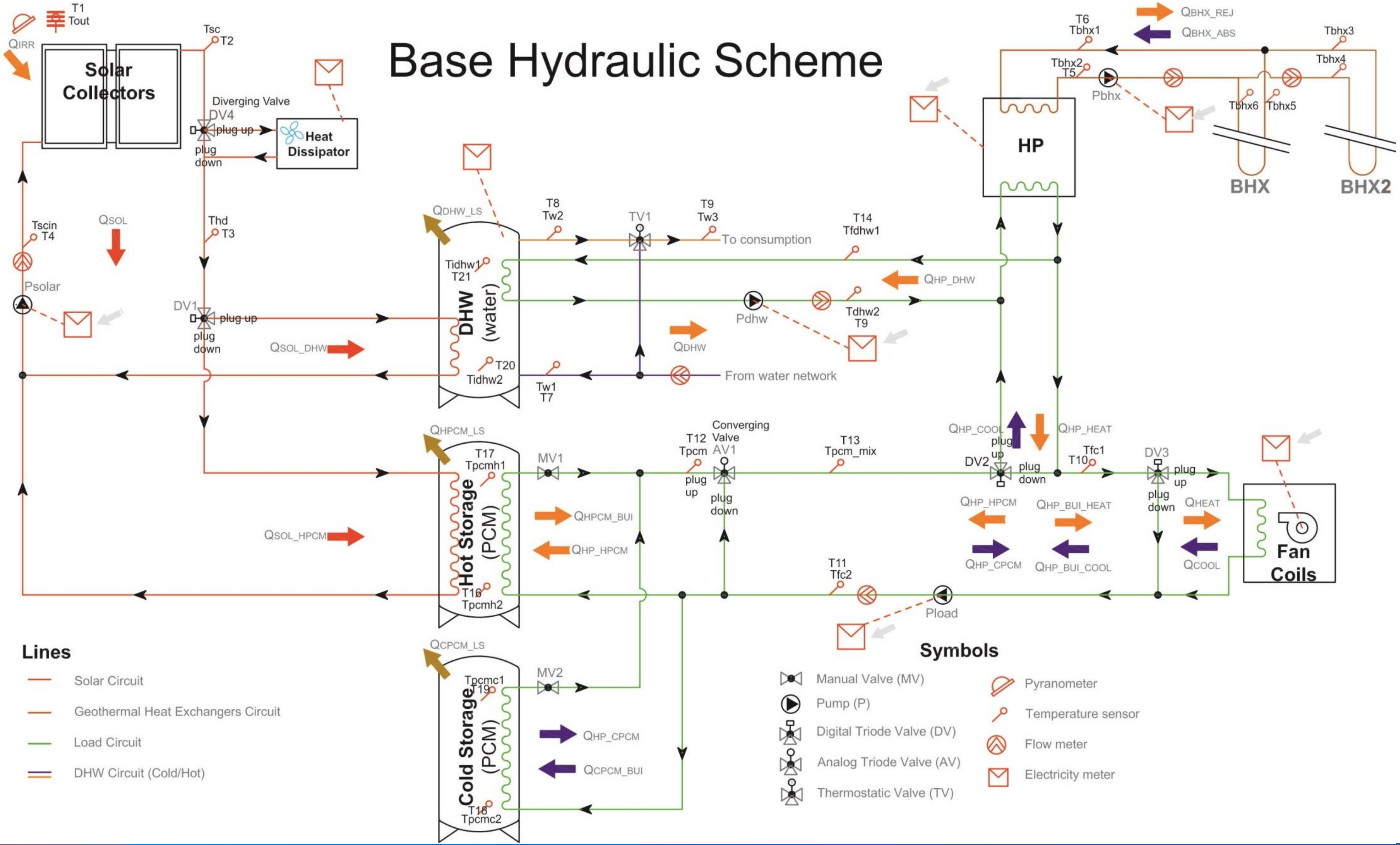
Operation mode & hydraulic scheme

Different operation modes and system configurations suggested by partners.

Final operation modes suggested based on the following criteria:

- Contribution to the overall energy efficiency of the system
- Purchase cost of the system (devices, hydraulic connections, actuators, sensors)
- Technical effort for the control system (e.g. additional inputs/outputs from sensors/actuators, complex software)
- Installation complexity and cost
- Service & maintenance

Base Hydraulic Scheme



Selected Operation modes

Operation modes					
Description	**Operation Symbol**	**MODE**	**From**	**To**	**Flow chart symbol**
DHWboiler charging by Solar Collectors	SC_DHWB	DHW	SC	DHWB	OM_S1
DHWboiler charging by Heat Pump	HP_DHWB	DHW	HP	DHWB	OM_L1
DHWboiler charging by Backup Heater	BUH_DHWB	DHW	BUH	DHWB	OM_L9
DHWboiler charging by BUH for Legionella Protect.	BUH_DHWB_LEG	DHW	BUH	DHWB	OM_L10
Hot PCM charging by Solar Collectors	SC_HPCM	Heating	SC	HPCM	OM_S2
Hot PCM charging by Heat Pump	HP_HPCM	Heating	HP	HPCM	OM_L2
Building heating by HPCM	HPCM_BLU	Heating	HPCM	BLU	OM_L6
Building heating by HPCM and Heat Pump	HPCM-HP_BLU	Heating	HPCM & HP	BLU	OM_L7
Building heating by Heat Pump	HP_BLU_H	Heating	HP	BLU	OM_L4
Overheating prevention	SC_HD	Heating	SC	HD	OM_S3
Cold PCM charging by Heat Pump	HP_CPCM	Cooling	HP	CPCM	OM_L3
Building cooling by CPCM	CPCM_BLU	Cooling	CPCM	BLU	OM_L8
Building cooling by CPCM and Heat Pump	CPCM-HP_BLU	Cooling	CPCM & HP	BLU	OM_L13
Building cooling by Heat Pump	HP_BLU_C	Cooling	HP	BLU	OM_L5
Building cooling by Heat Pump & Dehumidification	HP_BLU_C_DEH	Cooling	HP	BLU	OM_L13
Idle State: No heat transfers	IDLE	-	-	-	OM_S0
Holiday Mode (to be defined if needed)	HOLIDAY	-	-	-	OM_L11
Service Mode (to be defined if needed)	SERVICE	-	-	-	OM_L12

Symbols	
H	Heating
DHW	Domestic Hot Water
C	Cooling
HP	Heat Pump
SC	Solar Collectors
BUH	Backup Heater
CPCM	Cold PCM Storage
HPCM	Hot PCM Storage
DHWB	Boiler of DHW
BLU	Building Terminal Units
HD	Heat Dissipater

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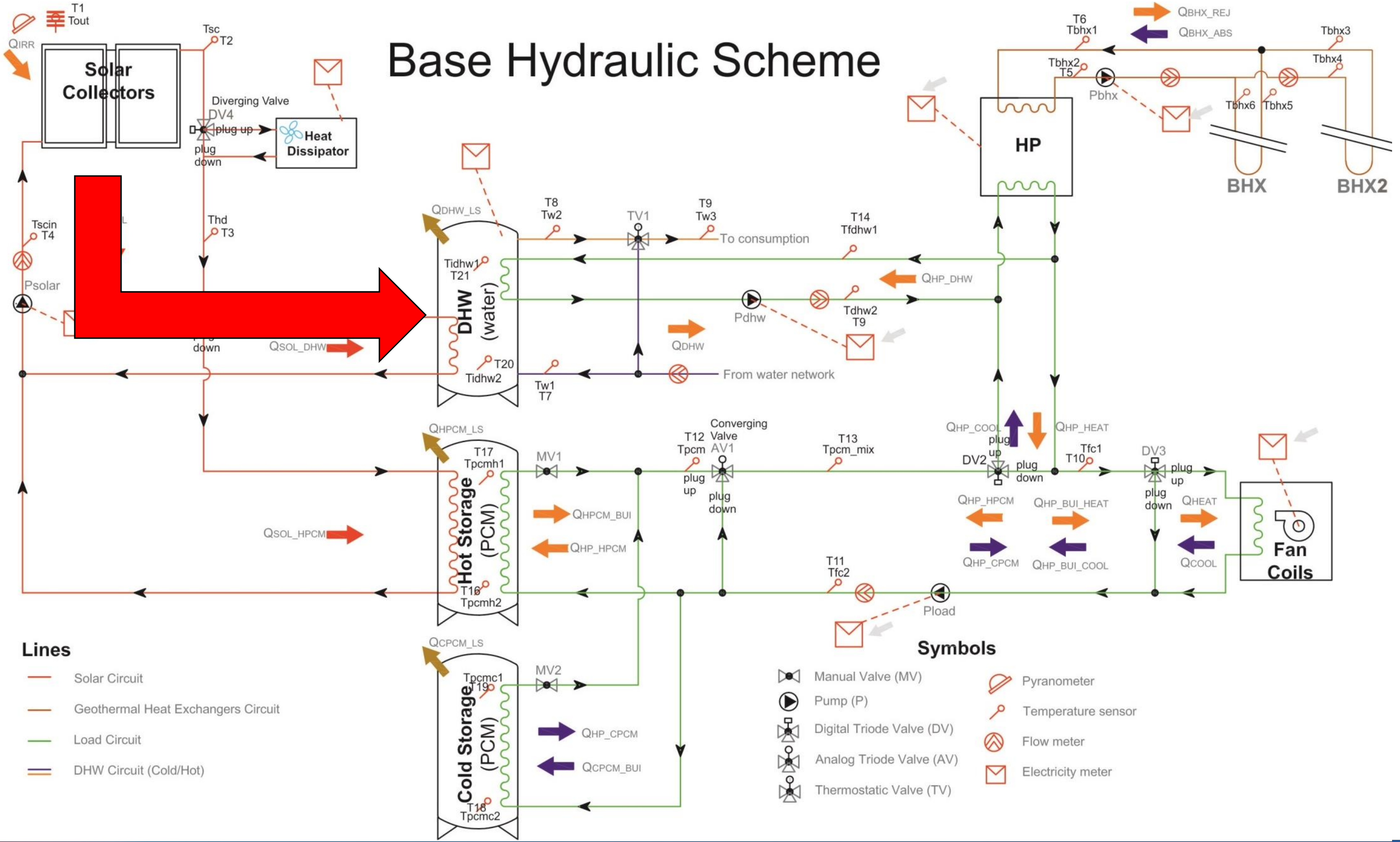

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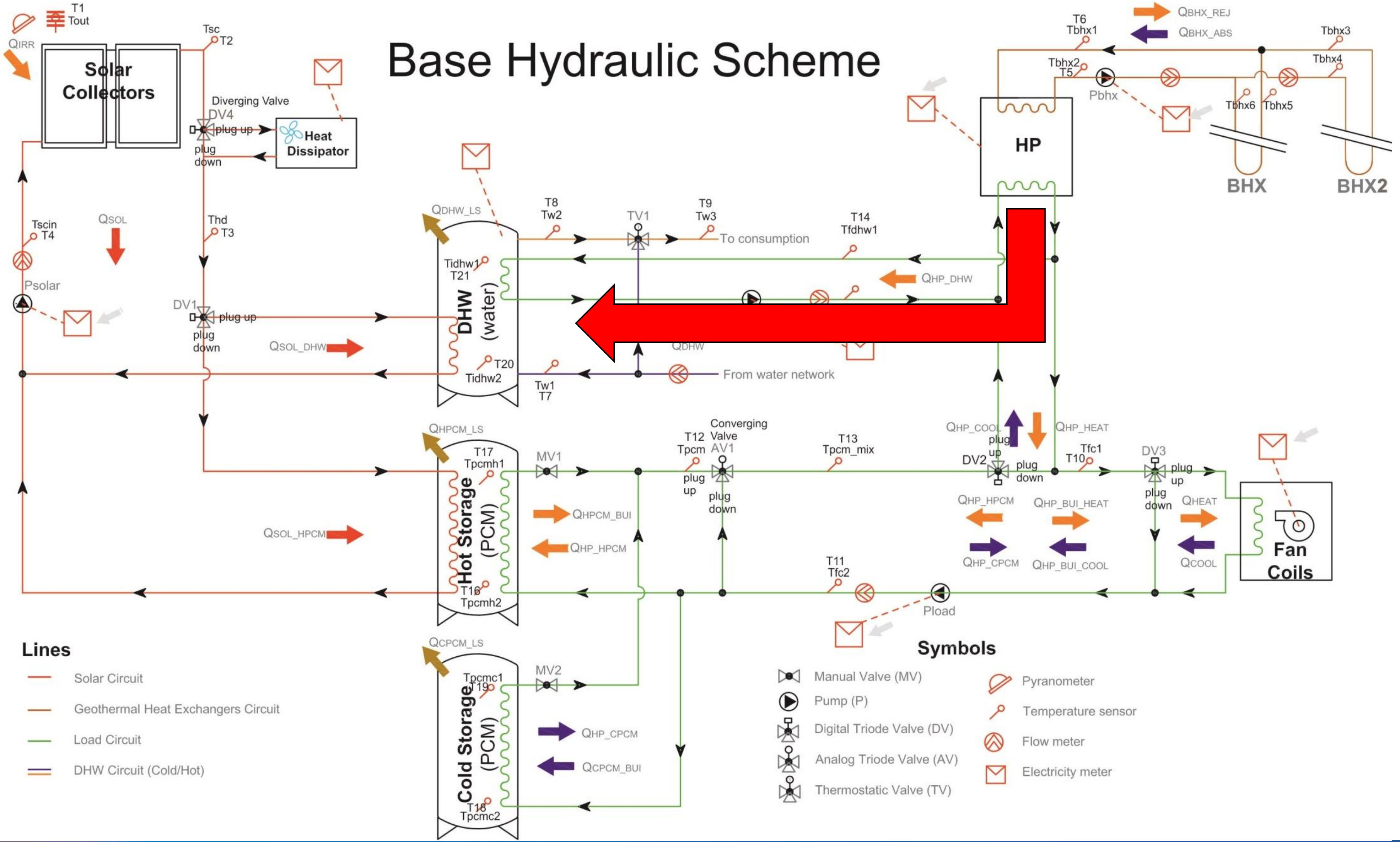

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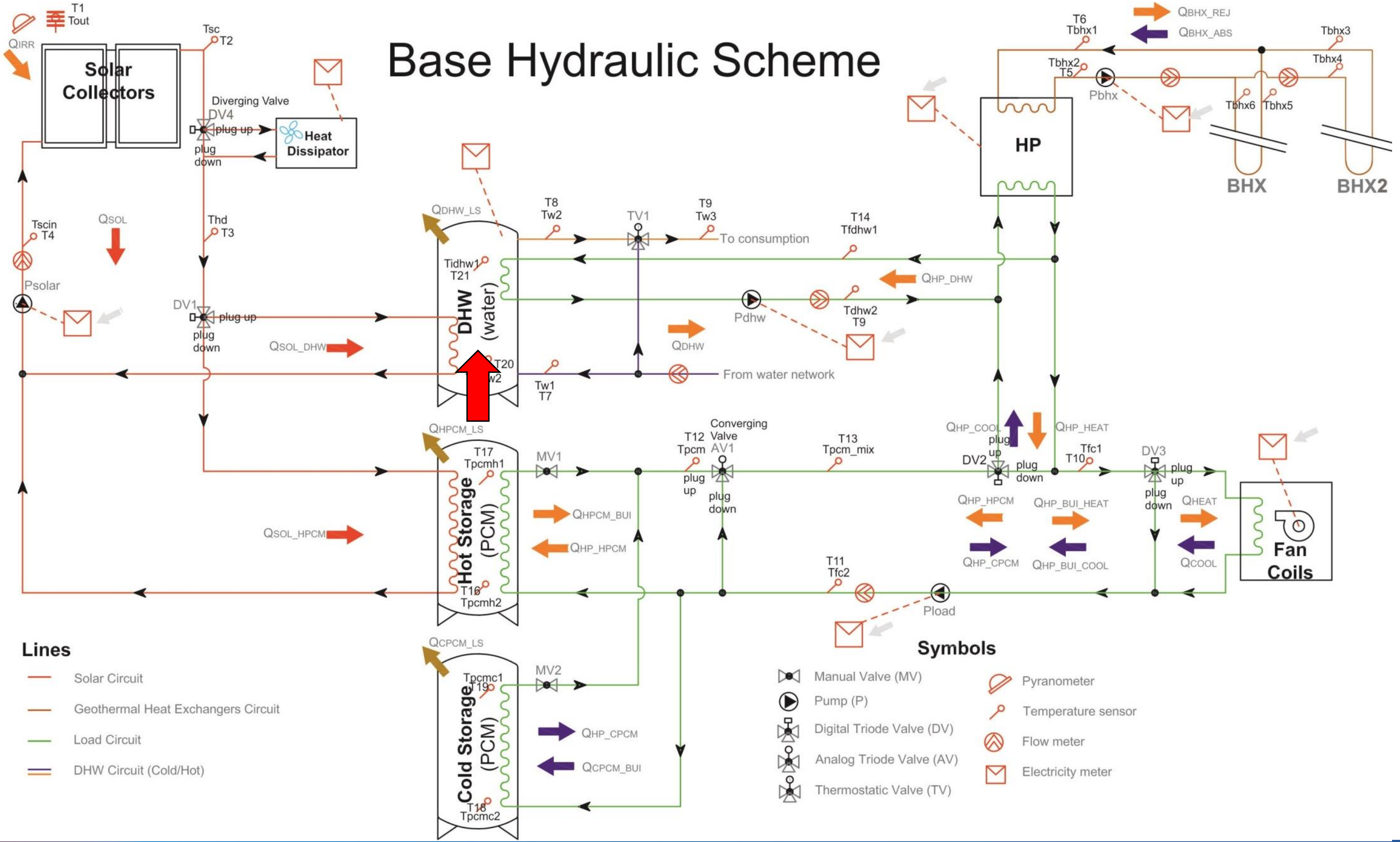

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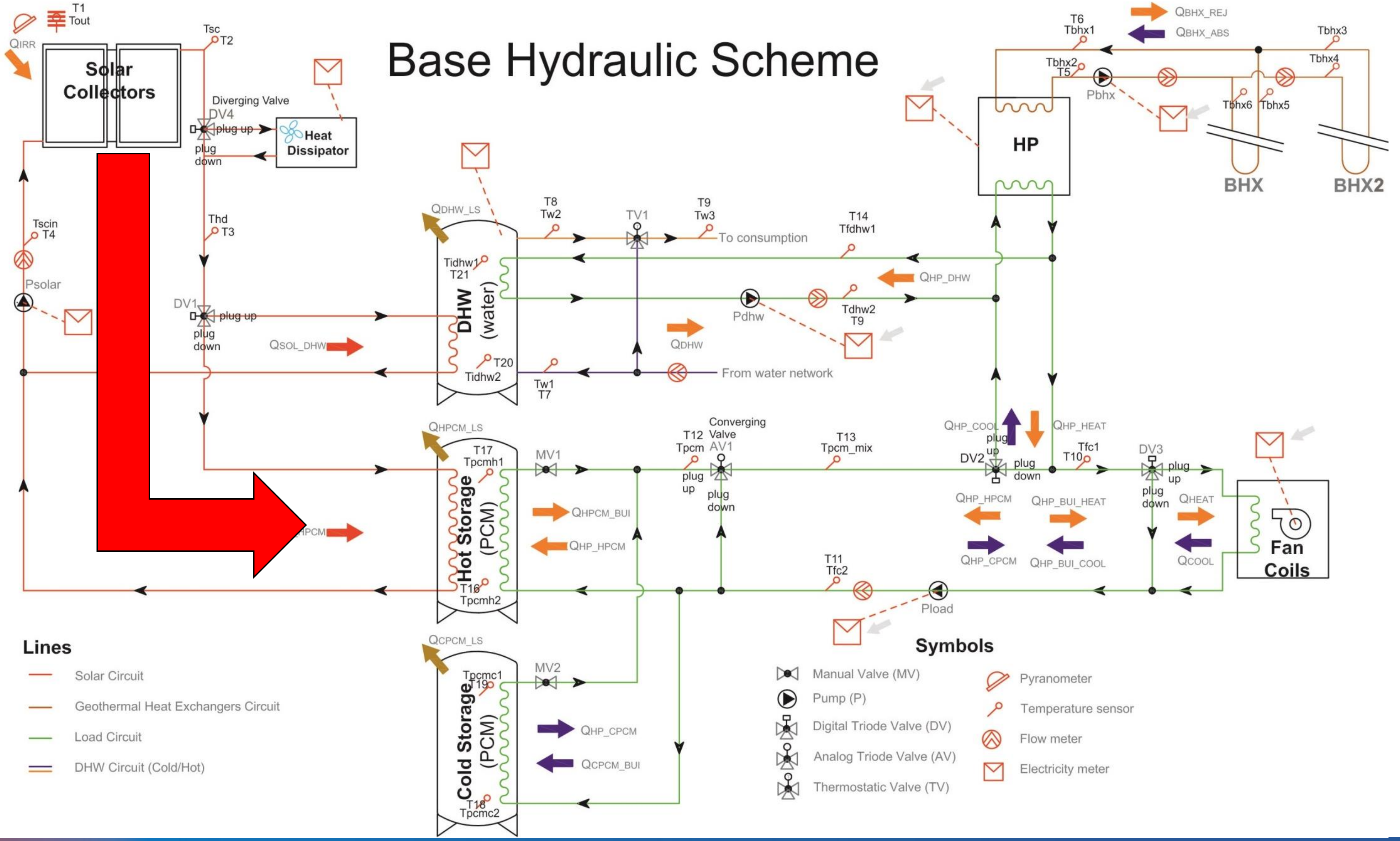

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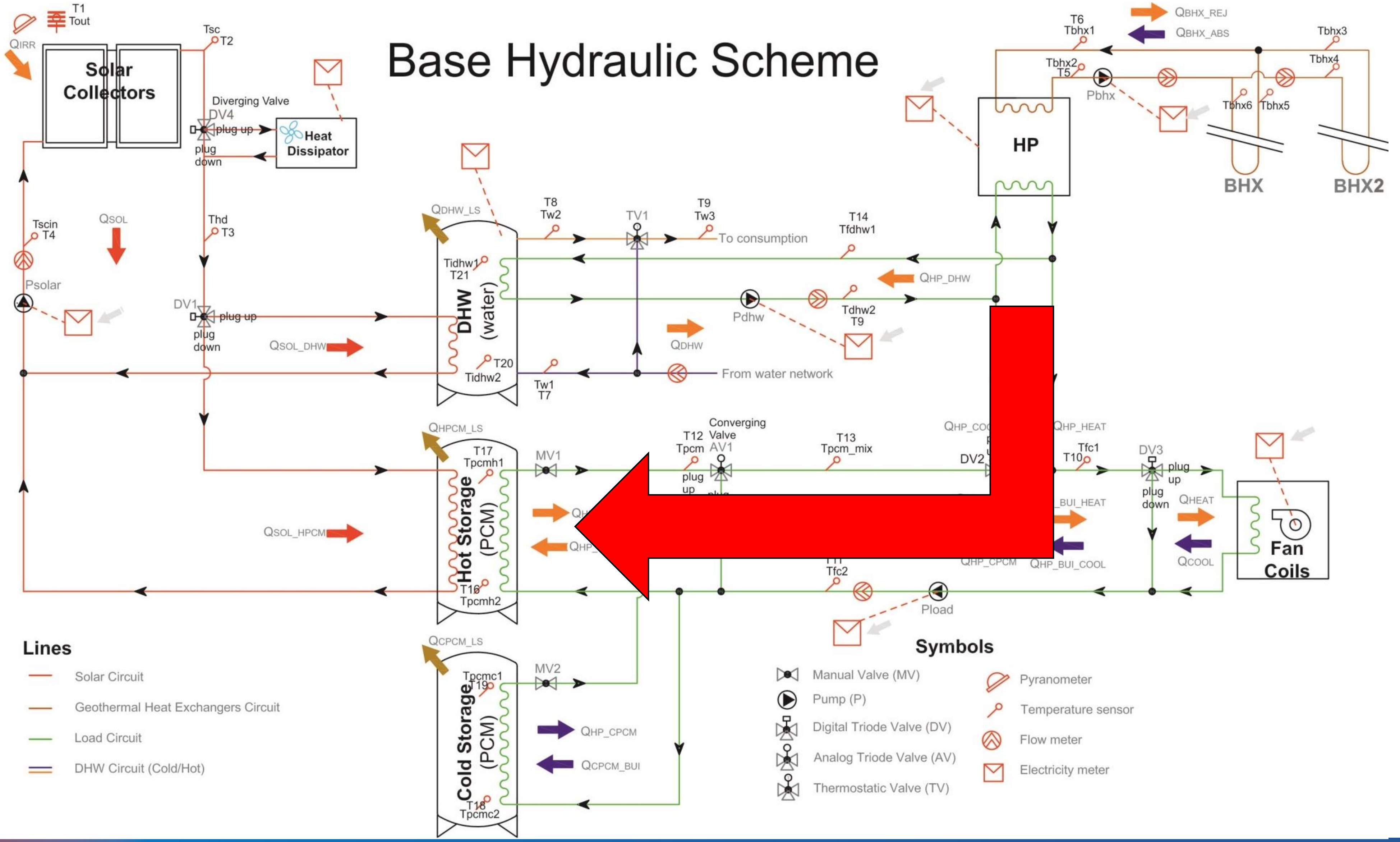

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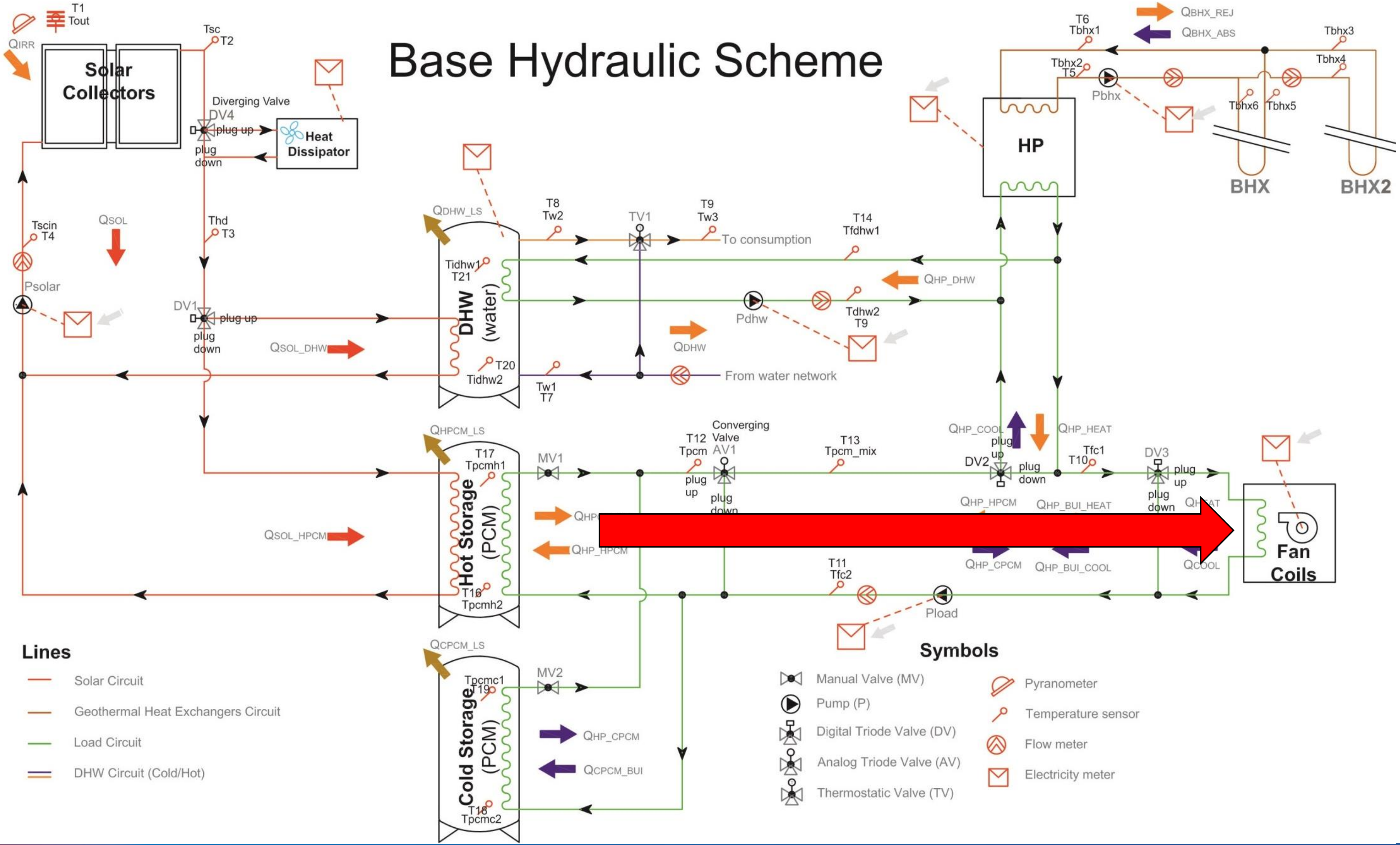

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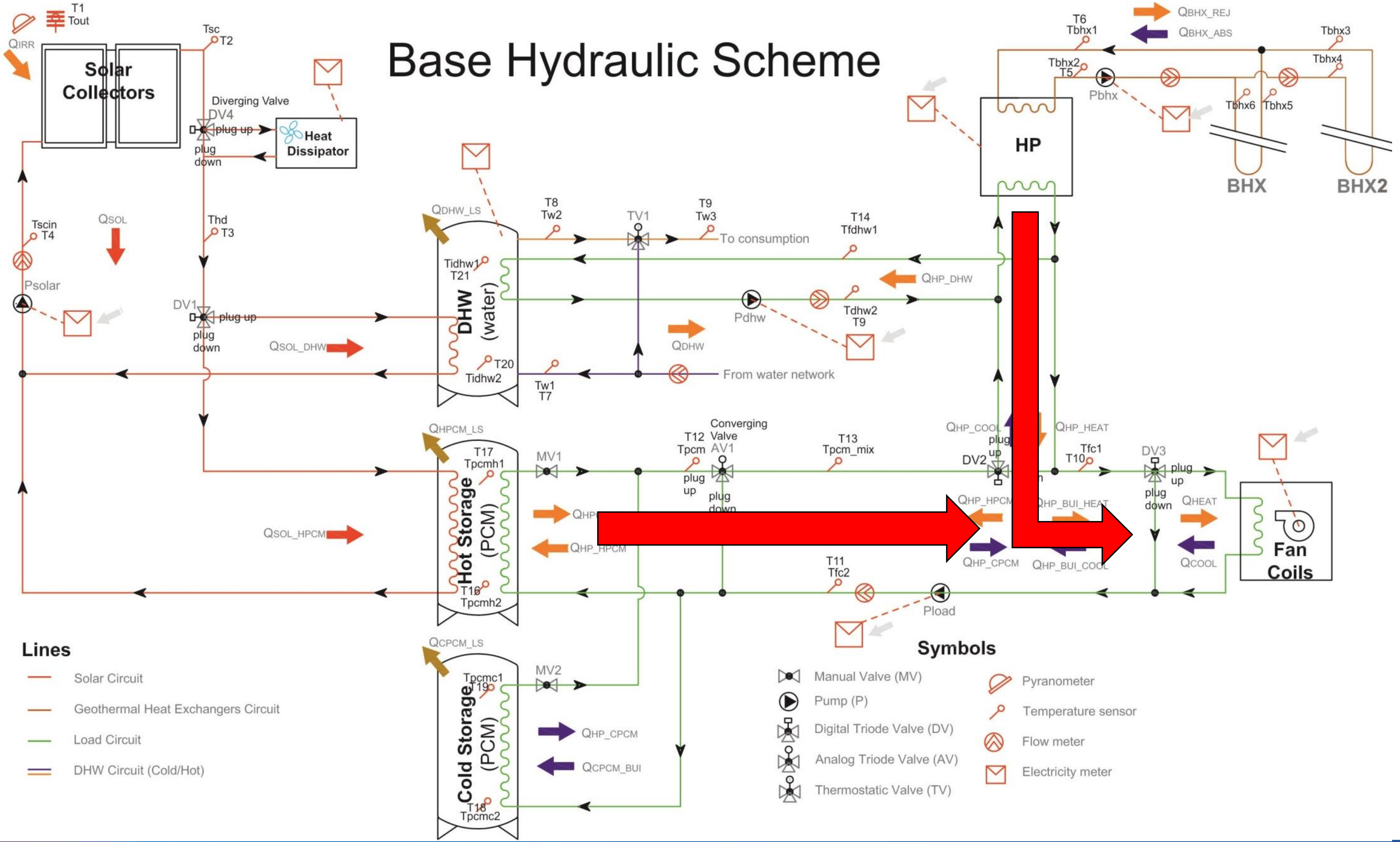

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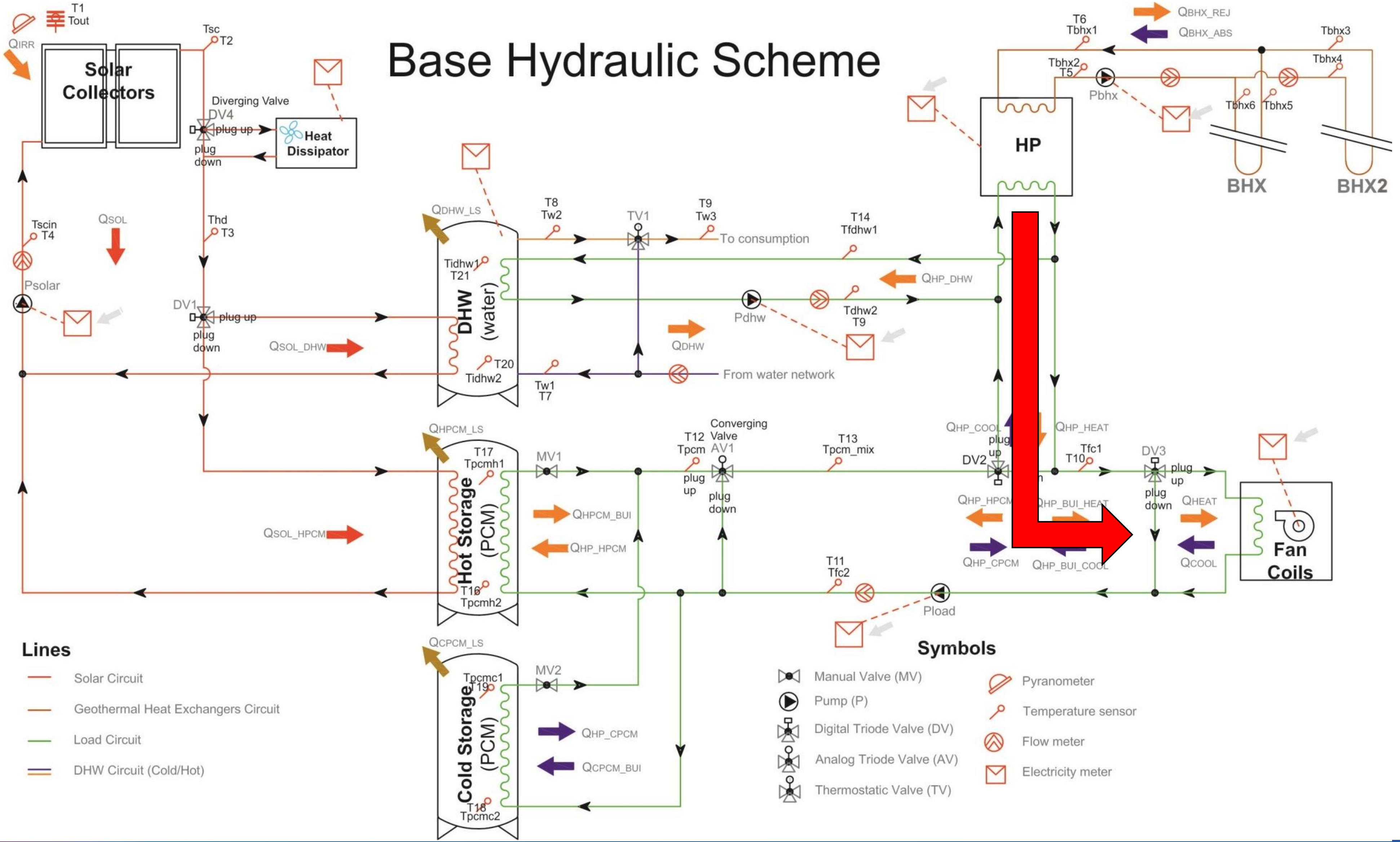

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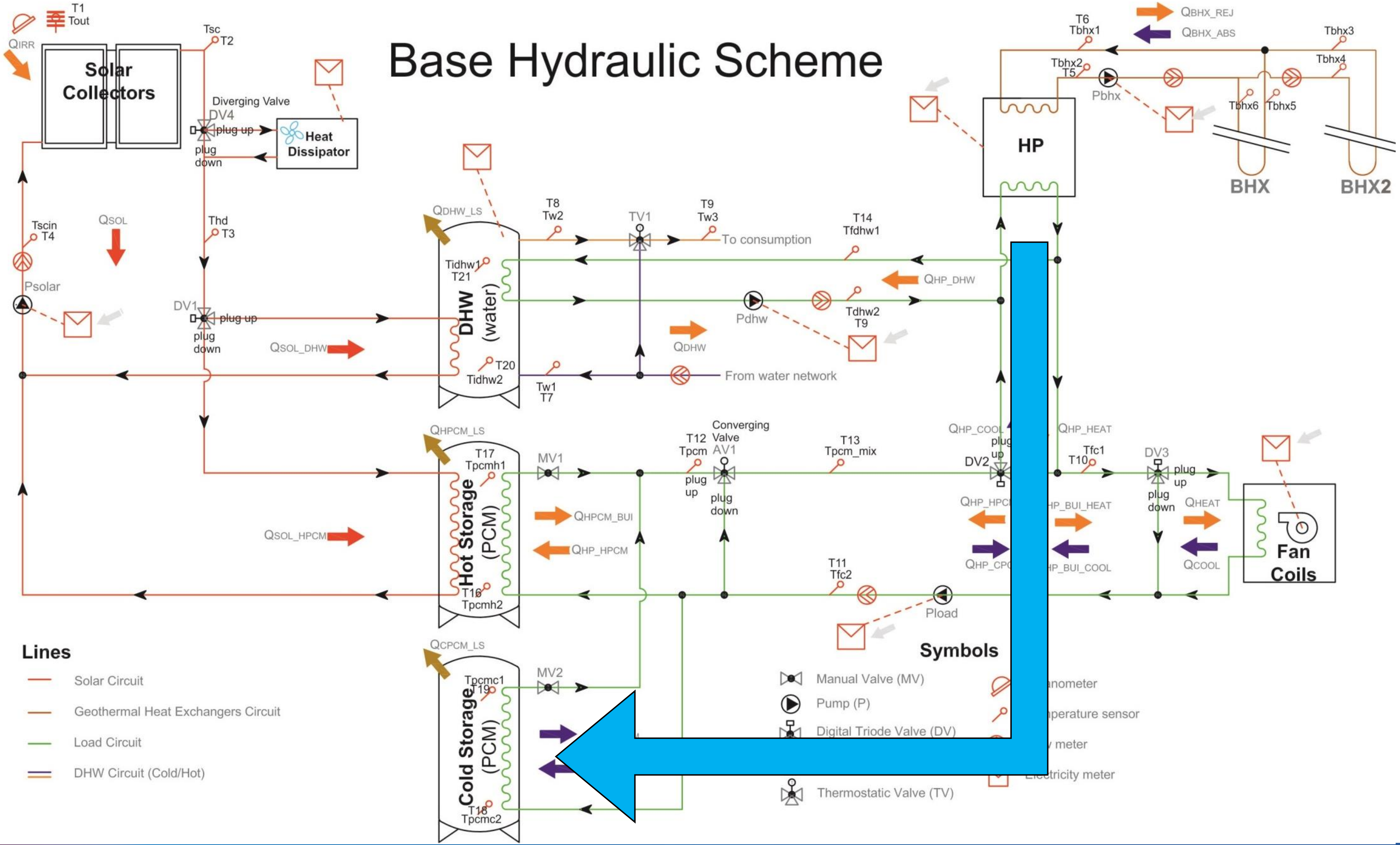

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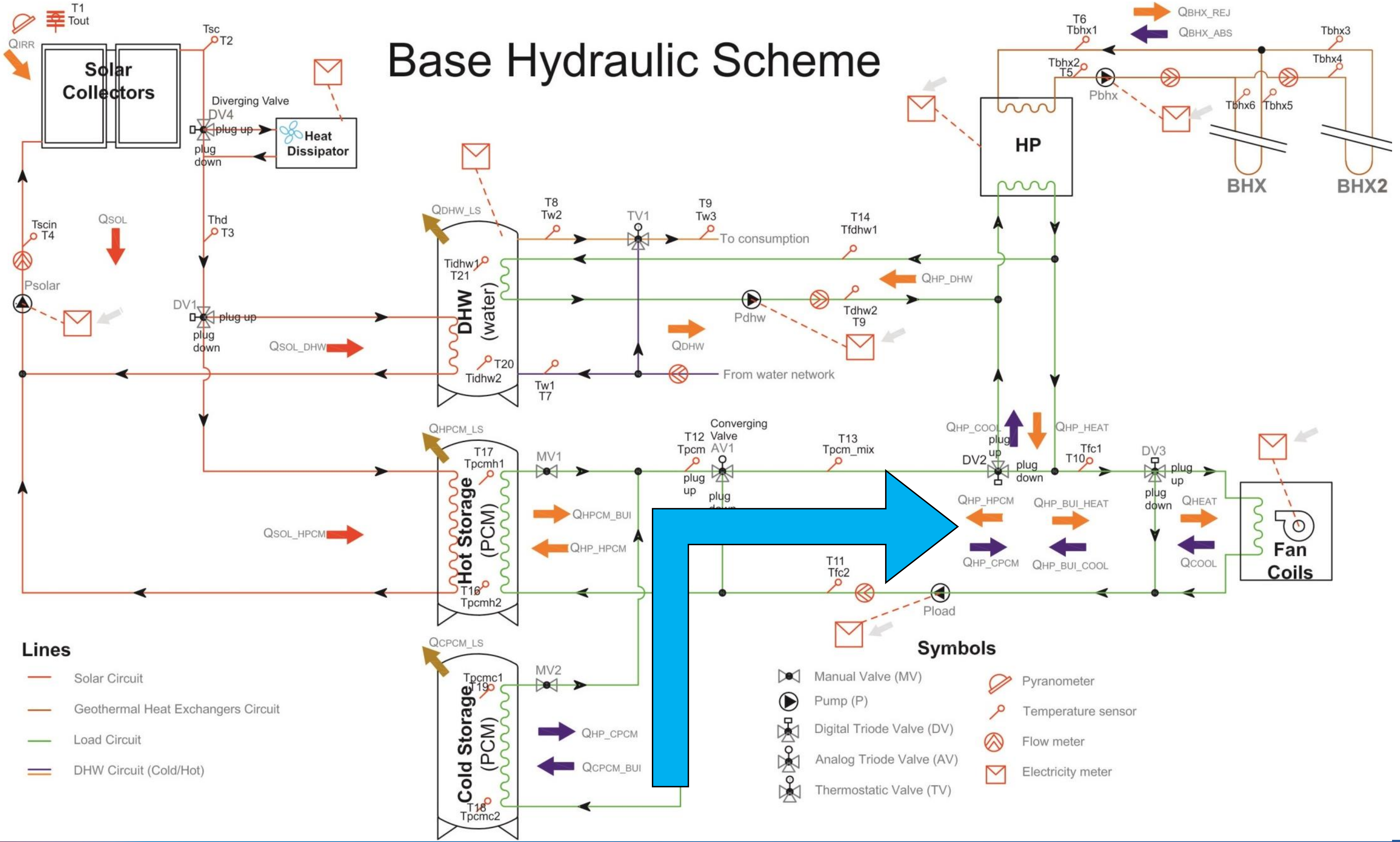

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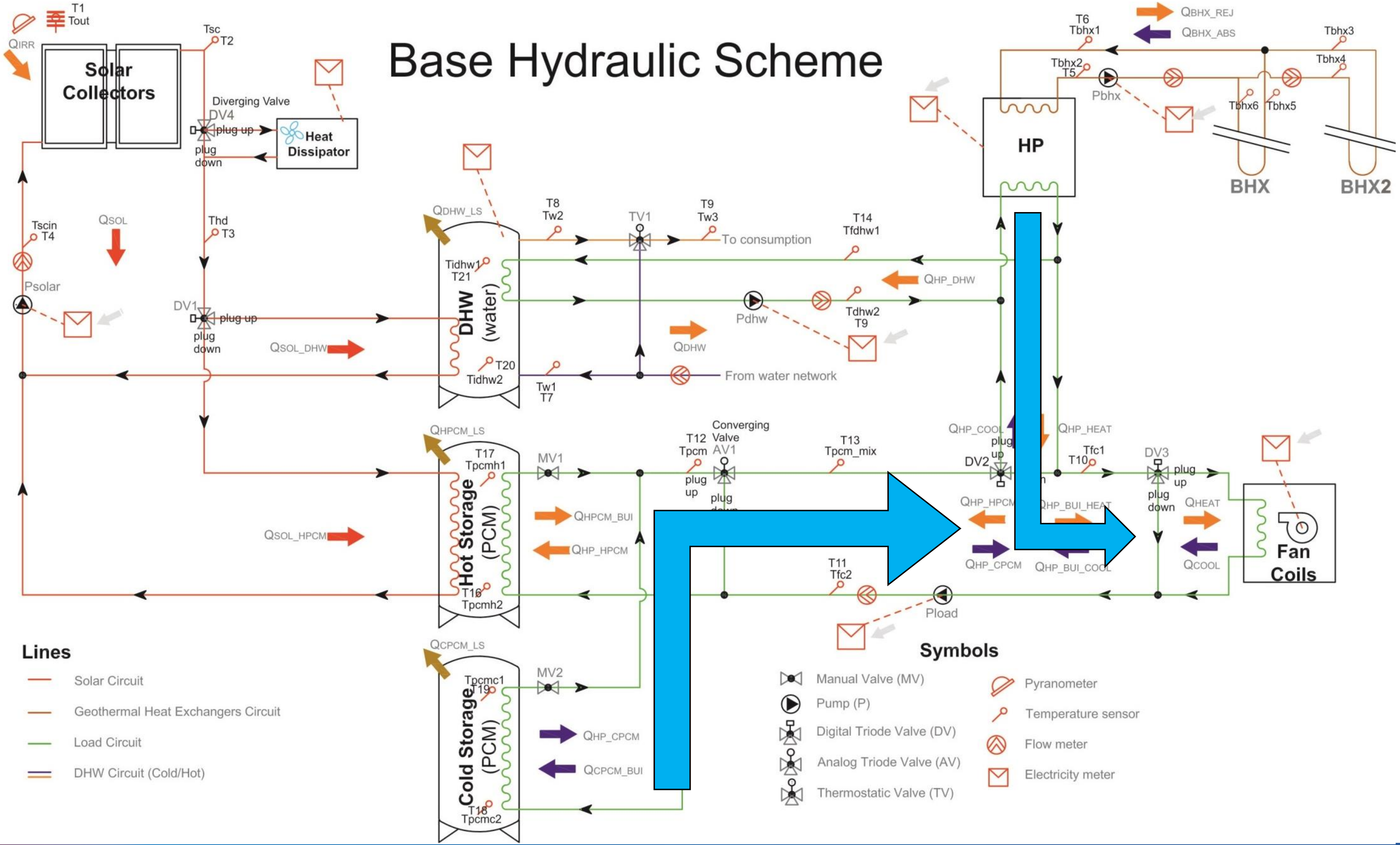

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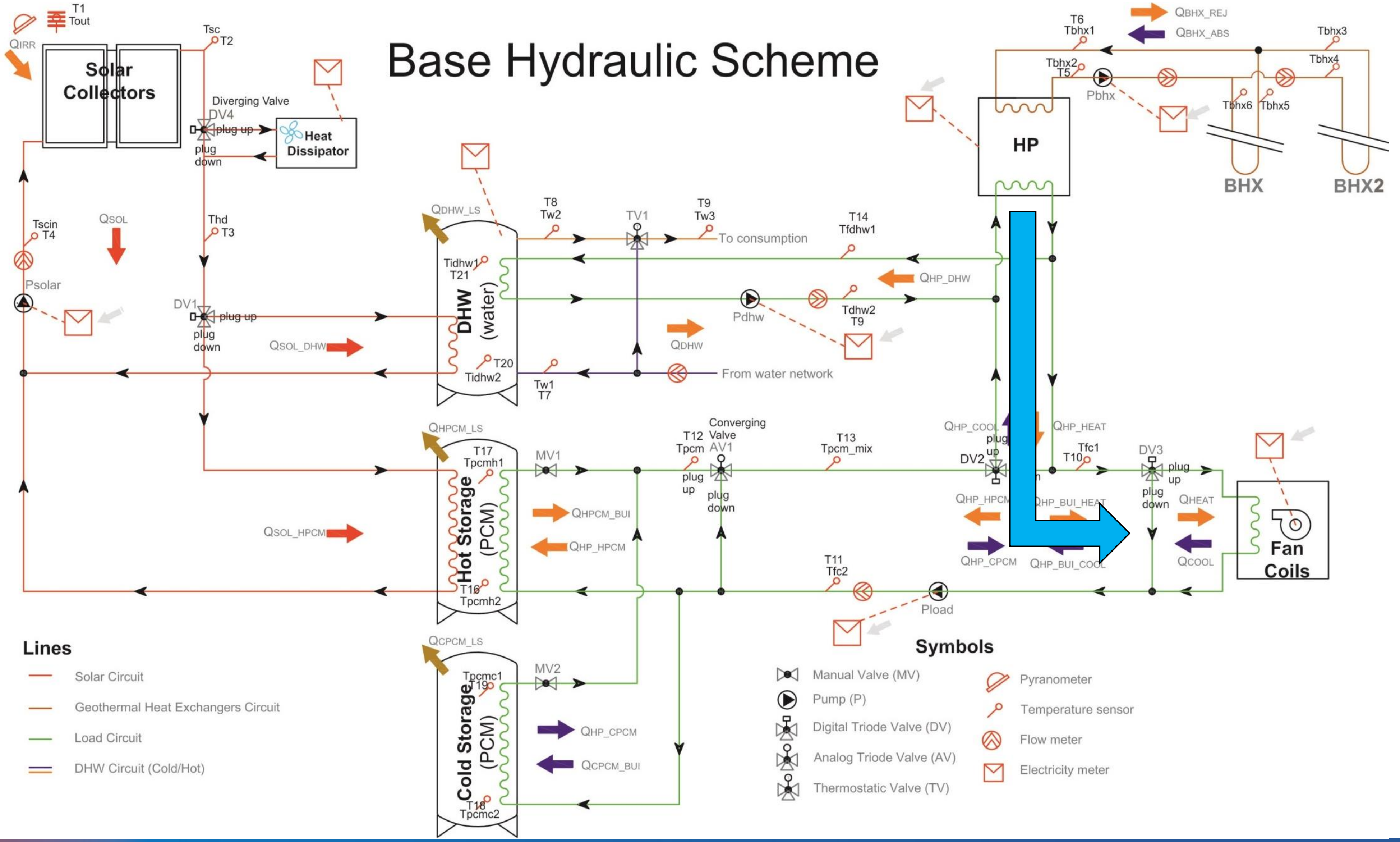

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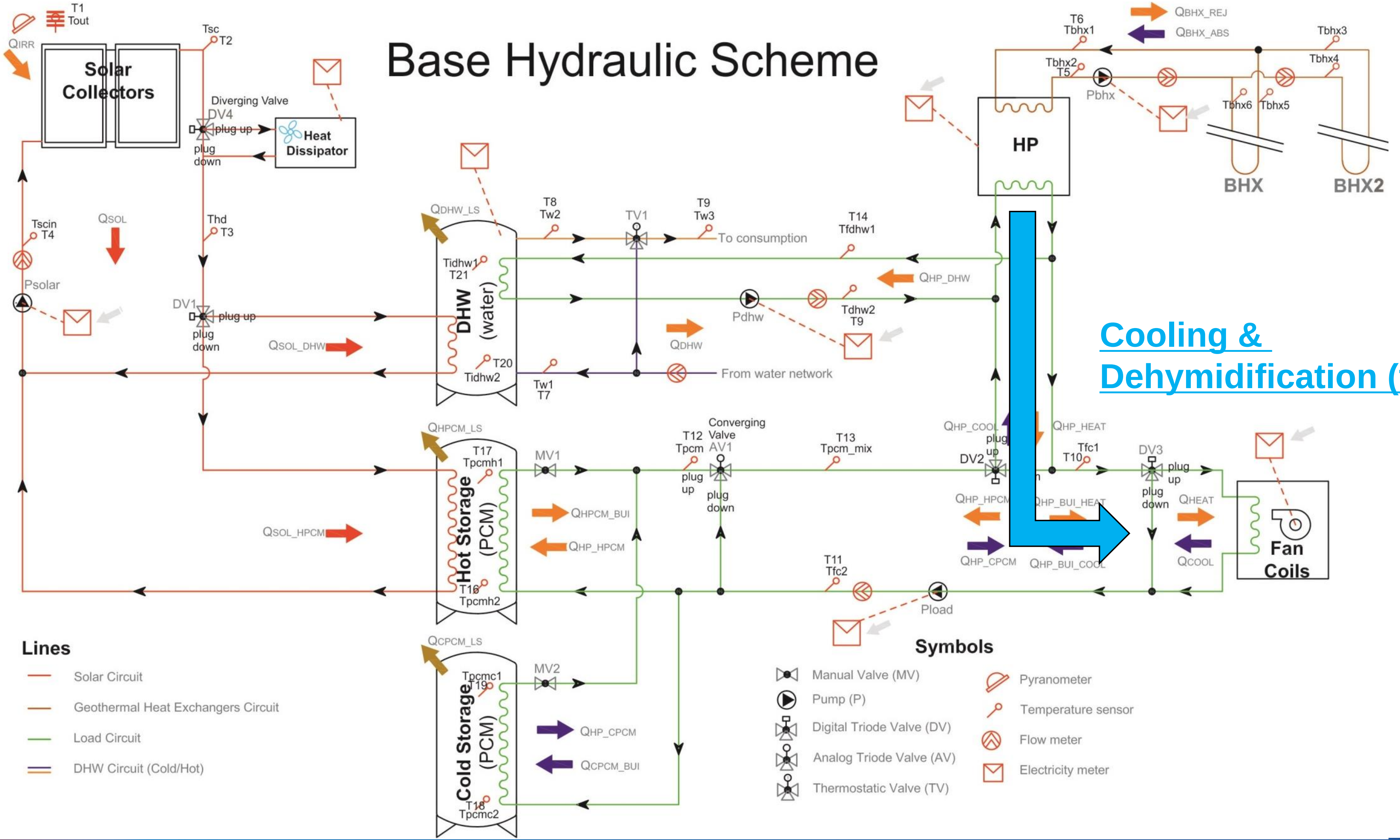
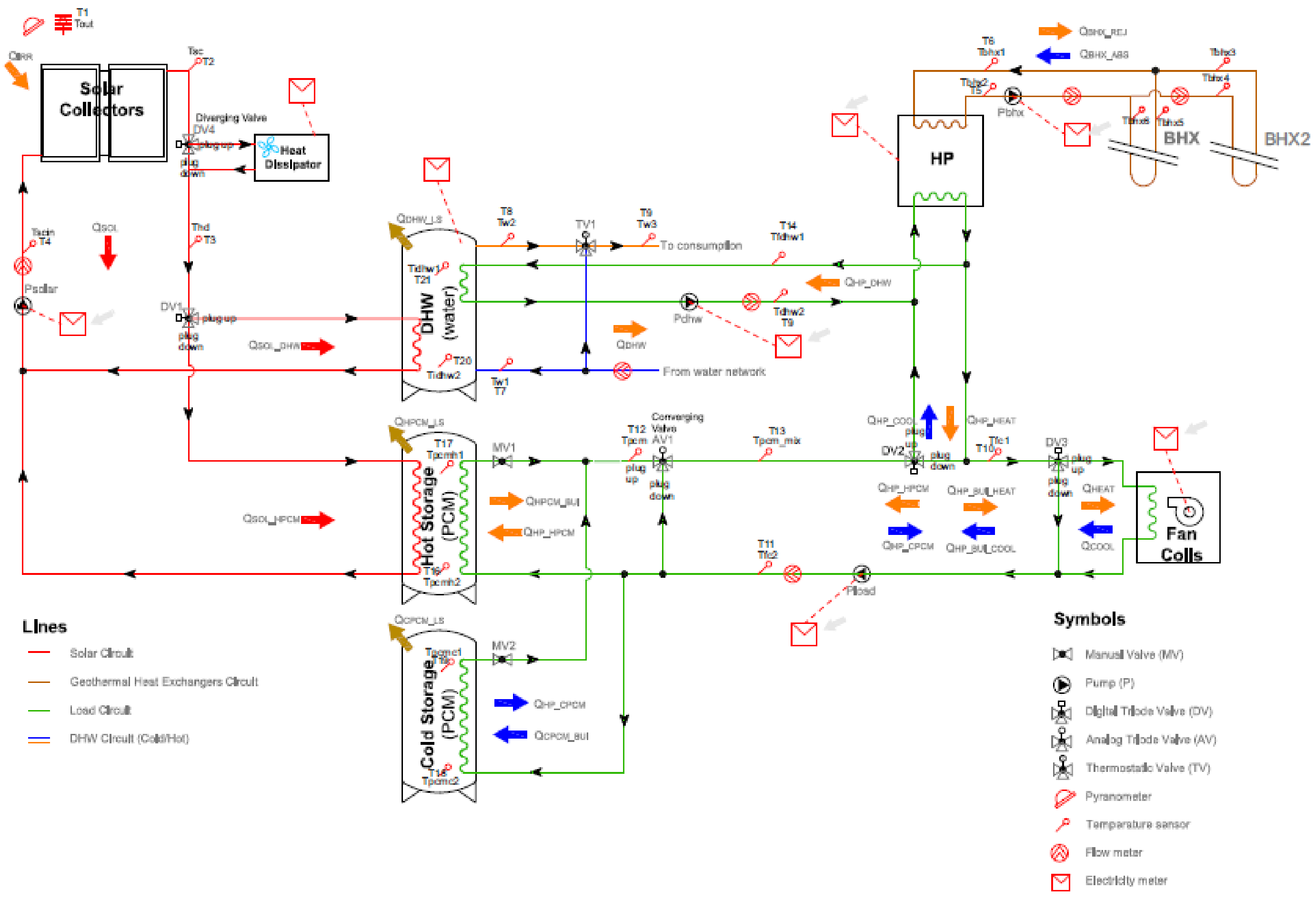


Cooling & Dehymidification (fan-coisl)

Controlled devices

- Valves:
  - Digital valves
  - Analog mixing valves
- Circulator pumps:
  - solar loop pump
  - load loop
  - DHW loop
- Geothermal heat pump (on/off)
- DHW backup heater (on/off)
- Heat dissipater fan speed (analog)



Sensors signals for control

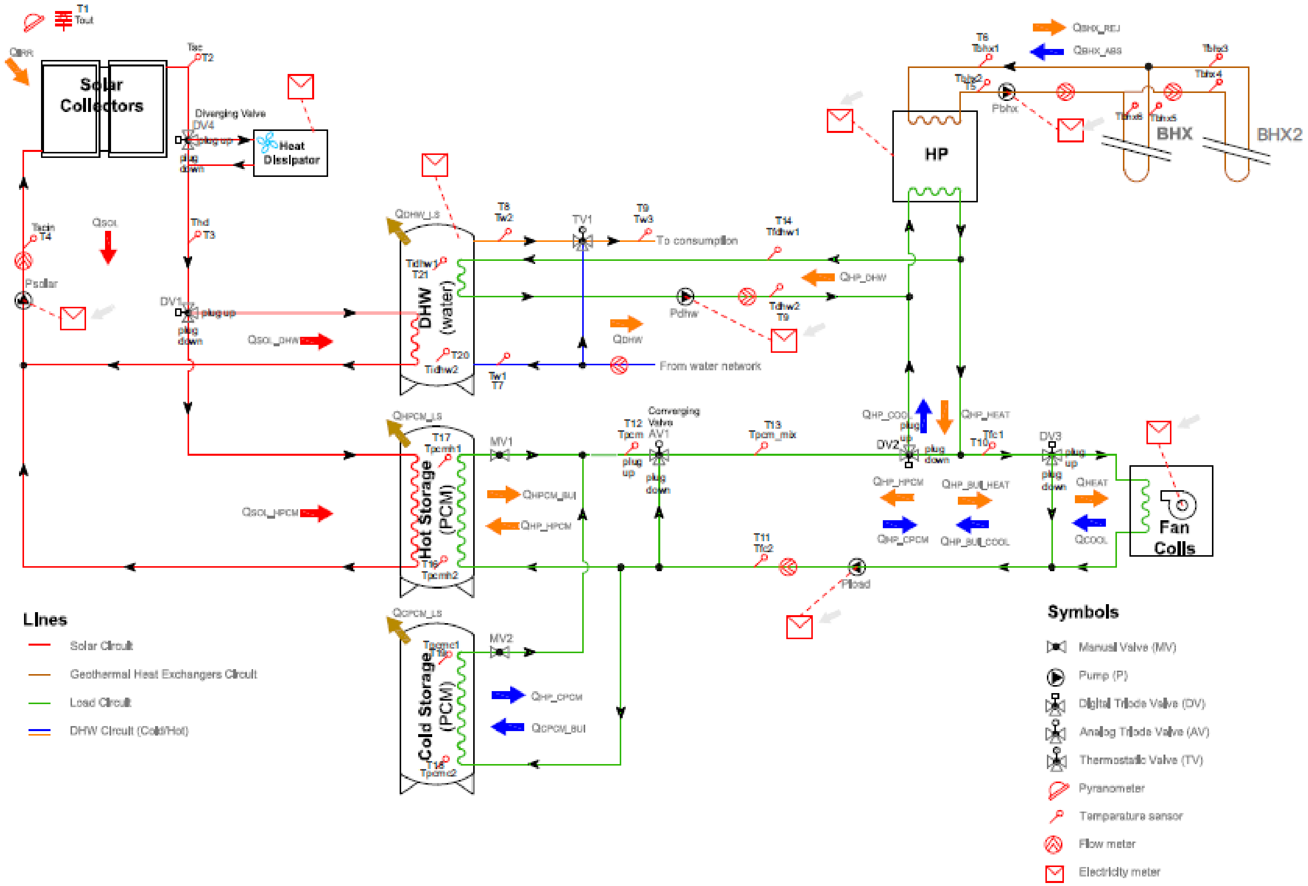
- Temperature sensors

Decentralised equipment

- Decentralised room thermostats for individual room temperature control (user selected desired temp).
  - E.g. on fan coils

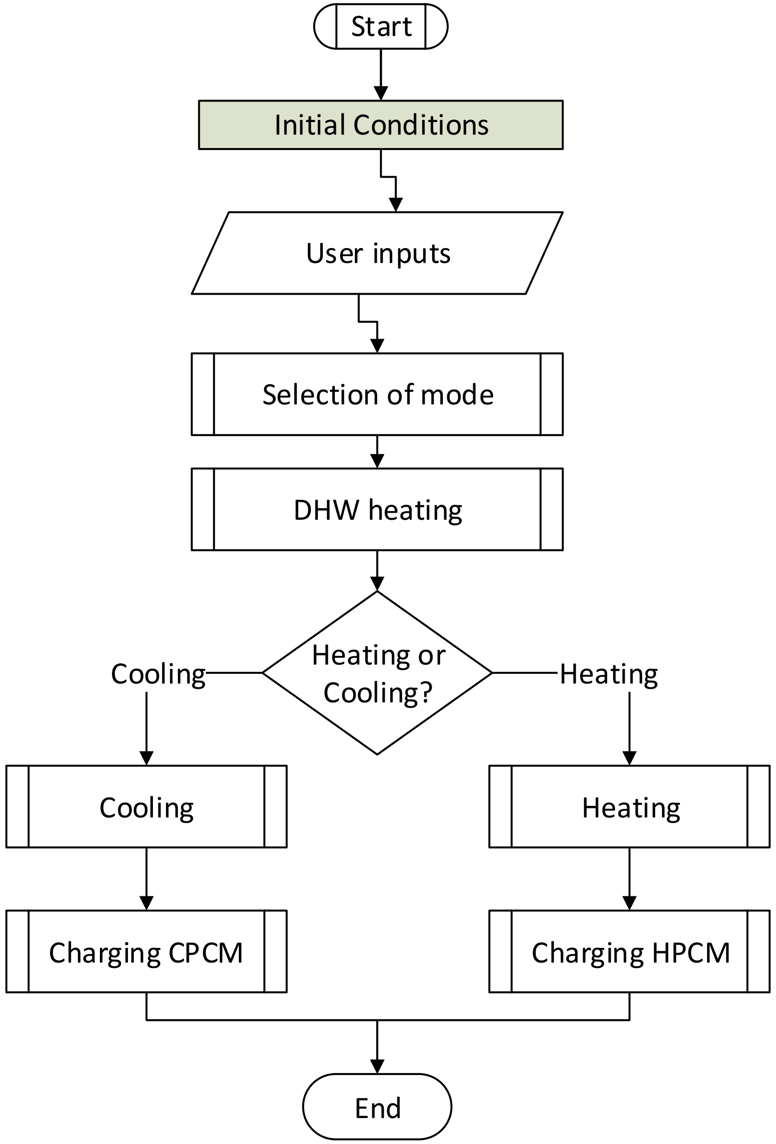
- Internal control of commercially heat pump control

- All other equipment will be controlled by the central TESSe2b controller.



General priorities for the control

1. Charge DHW tank
2. Space Heating / Space Cooling
3. Charge PCM tanks



Priorities for the control

DHW Loop

1. Charge DHW tank by solar collectors
2. Charge DHW tank by HP
3. Legionella Protection
4. Electric Heater (backup, if HP is in cooling mode)

Control-oriented Models in Matlab/Simulnk

Fast dynamic models developed in Matlab/Simulink by RUB and SGGW

•Test control algorithms by simulations

•Emulate dynamic behaviour of system components on the laboratory test-benches

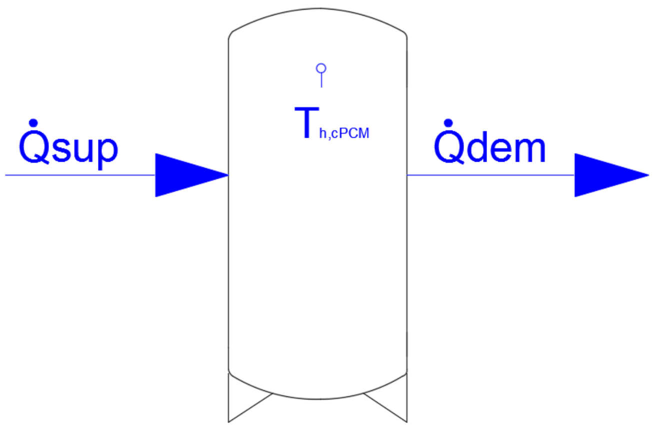
The model of hot and cold PCM storage tanks

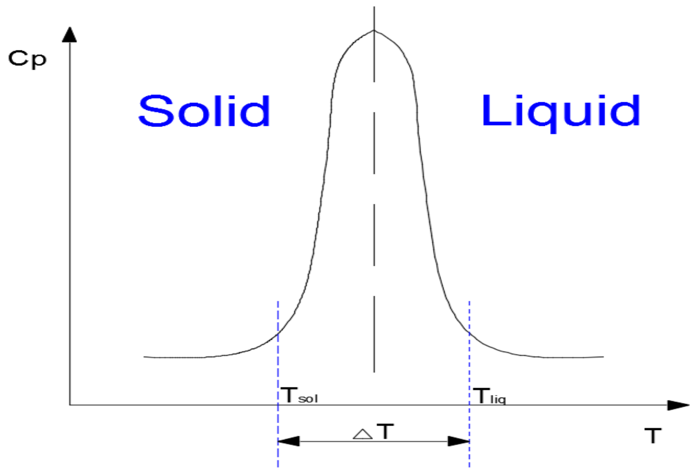
$$\frac{dT_{h,cPCM}(t)}{dt} = \frac{\dot{Q}_{sup}(t) - \dot{Q}_{dem}(t)}{C_{h,c\_PCM,}}$$

T_{h,c_PCM} – temperature in the PCM tank $[K]$
C_{h,c_PCM} – thermal capacity of the PCM tank $\left[\frac{J}{K}\right]$
$\dot{Q}_{sup}$ – thermal power received from the heat pump and (or) the solar installation $[W]$
$\dot{Q}_{dem}$ – thermal power supplied from the PCM tank to the building $[W]$

$$C_{h,c\_PCM} = M_{h,c,\_PCM} * cp_{h,c\_PCM}$$

$$cp_{h,c\_PCM} = \begin{cases} cp_{h,c\_PCM,sol} & T < T_{sol} \\ \dfrac{\left[\int_{T_{sol}}^{T_{liq}} cp_{h,c\_PCM}(T)dT + L_f\right]}{T_{liq} - T_{sol}} & T_{sol} < T < T_{liq} \\ cp_{h,c\_PCM,liq} & T < T_{liq} \end{cases}$$





T – temperature of the PCM $[K]$
T_{sol} – limit temperature of the solid phase $[K]$
T_{liq} – limit temperature of the liquid phase $[K]$
L_f – latente heat of PCM, solid – liquid $\left(\frac{J}{kg}\right)$

S. Arena: Modelling, design and analysis of innovative thermal energy storage systems using PCM for industrial processes, heat and power generation. Doktor work. Università degli Studi di Cagliari, 2015

The model of the solar thermal installation

$$\frac{dT_{out}(t)}{dt} = \frac{Q_s(t) - Q_{out}(t)}{C_{col}}$$

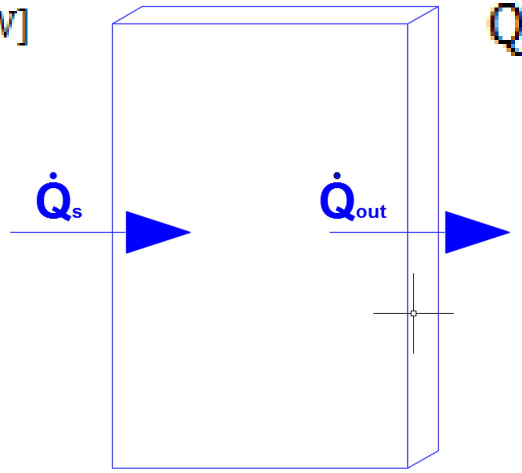
T_{out} – outlet temperature of working medium [^{0}C]
Q_{out} – thermal power output from the collector [W]
C_{col} – effective thermal capacity [$\frac{J}{K}$]

$$Q_s(t) = I(s) * A_{col} * F_R$$

F$_R$ - heat removal coefficient defined by equation

$$F_R = \frac{\dot{m}c_p}{A_c U_L}\left[1 - \exp\left(-\frac{A_c U_L F'}{\dot{m}c_p}\right)\right]$$

$\dot{m}$ – flow of working medium [l/s]
U_L – collector heat loss coefficient [W/m^{2}K]
c_p – specific heat of the working medium [J/kgK]
F' – coefficient of performance



$$Q_{out} = \dot{m}c_p * (T_{out} - T_{in}) + U_L * (T_{in} - T_{amb})$$

T_{amb} – ambient temperature [^{0}C]

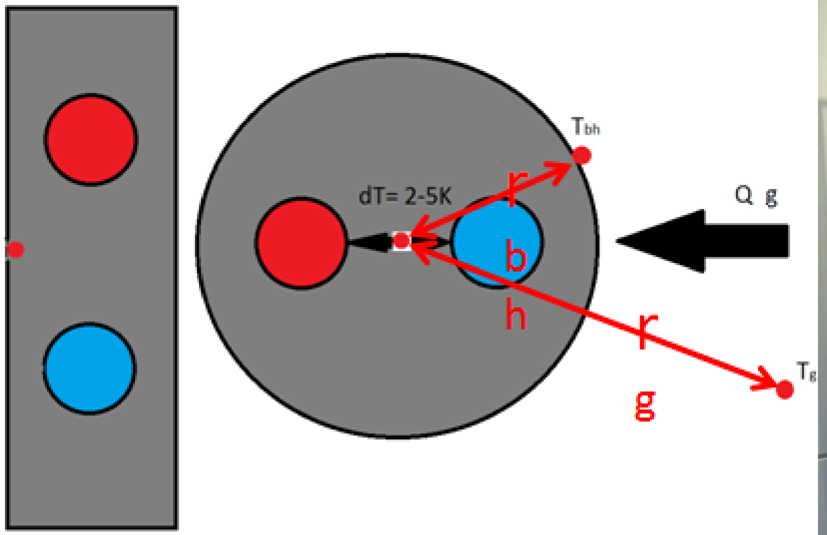
T_{out} – inlet temperature of working medium [^{0}C]

$$\frac{dT_{out}(t)}{dt} = \frac{I(t) * A_{col} * F_R - \dot{m}c_p * (T_{out}(t) - T_{in}(t)) - U_L * (T_{in}(t) - T_{amb}(t))}{C_{col}}$$

Duffie J. A., Beckman W. A.: Solar Engineering of thermal processes. John Wiley & Sons, United States of America, 1991

The vertical ground heat exchanger

$$Q_g = \frac{T_{bh} - T_f}{R_{bh}} \left[\frac{W}{m}\right]$$



Q_g – heating power per depth of the heat exchanger [W/m]
T_{bh} – average temperature of the borehole wall [K]
T_f – average temperature of an intermittent fluid in the borehole heat exchanger (BHE) [K]
R_{bh} – total thermal resistance of the borehole heat exchanger (BHE) [m*K/W]

$$T_g(t) - T_f(t) = Q_g * R_{bh} + Q_g * f(t)\ [K]$$

T_f – average temperature of the intermittent fluid in the sensor probe [K]
R_{bh} – total resistance of the borehole heat exchanger [Km/W]
f(t) – function determining variability of soil thermal resistance value at the time [7]

$$f(t) = \frac{1}{4\pi\lambda_g} * \left(ln\left(\frac{4\alpha t}{{d_{bh}}^2}\right) - \gamma\right)$$

λ_g – soil thermal conductivity [W/mK]
α – soil thermal diffusivity [m^2/s]
t – time [s]
d_{bh} – diameter of the borehole [m]
ϒ – Euler's constant = 0.5772

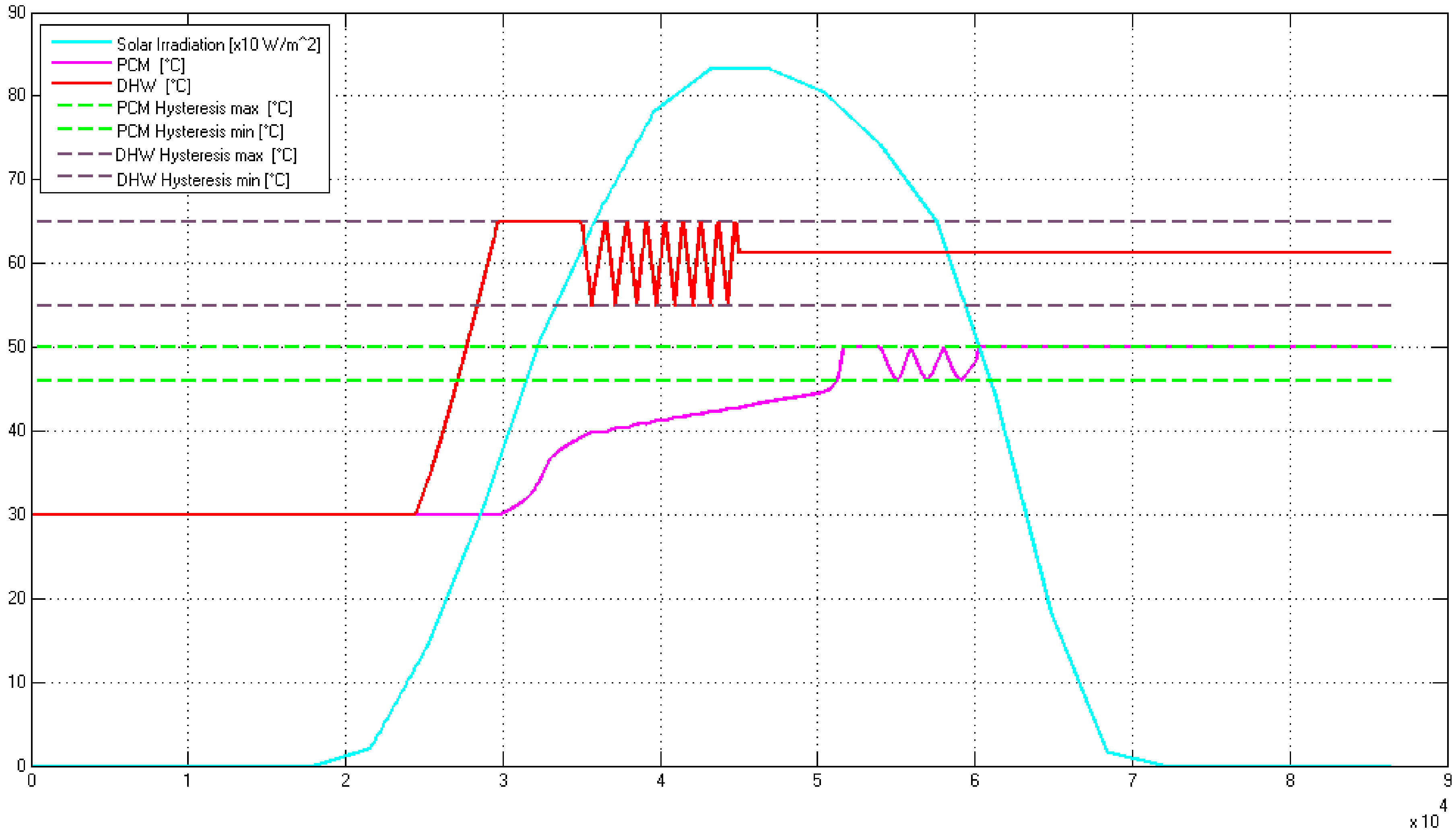
M. Wajman: Technical and Economical Analysis of Ground Source Heat Pump Systems with BHE in Poland. Master of Science Thesis in Energy Technology. 2011, Stockholm: KTH, Sweden

Example simulation of Solar loop

PCM A44:

Temperature Hysteresis control

Dynamic parameters must be adapted to demo sites

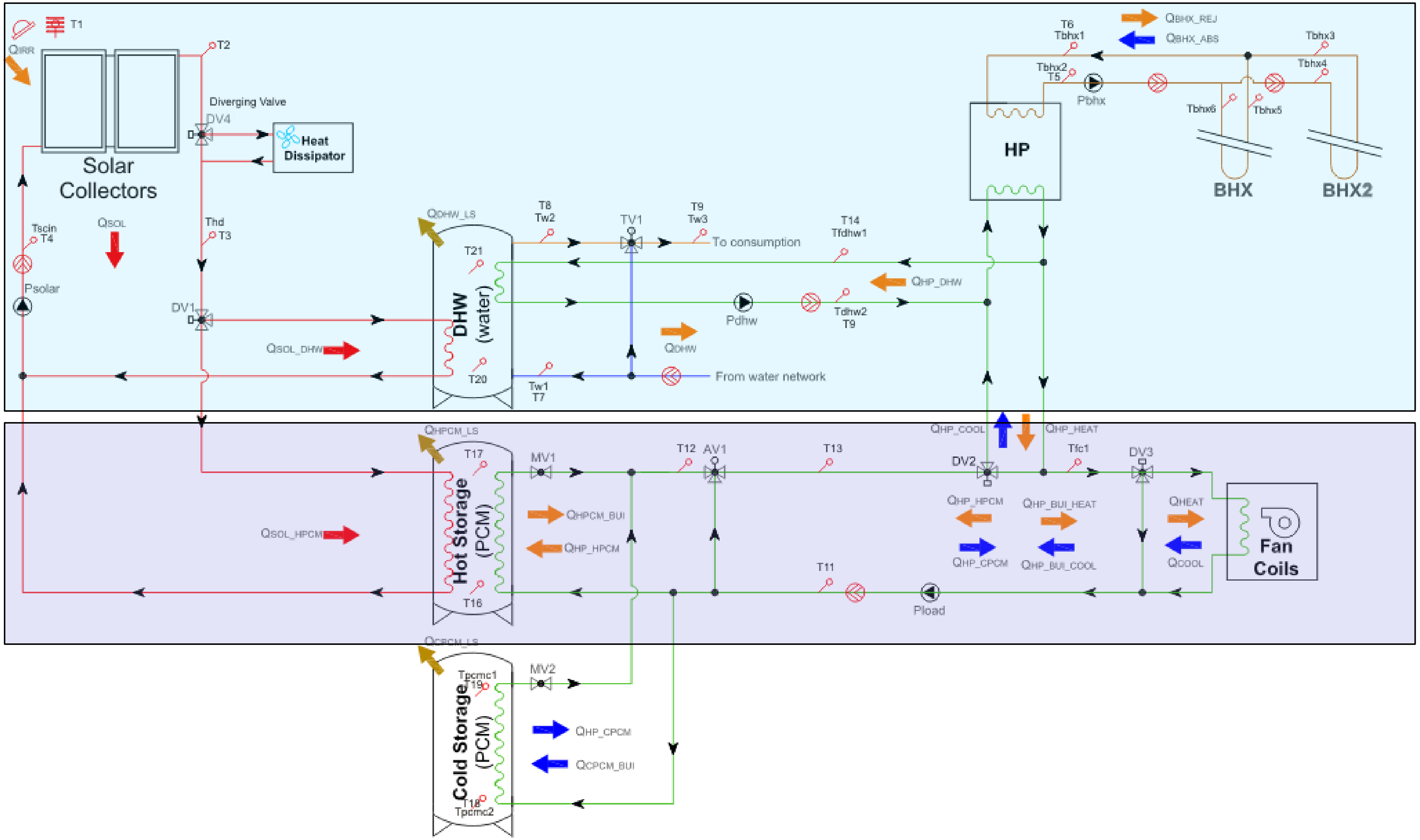


Laboratory test bench

Simplified hydraulic scheme is being built at RUB to test
-basic functions of control hardware and software
-performance of the hot PCM Tank with preliminary heat exchanger and paraffin (A44)

dSpace emulation system supported by a PC:

- Emulate operating behavior of solar collectors, HP, CPCM and load
- Fast implementation of control algorithms through Matlab/Simulink models
- Analog and digital inputs from sensors
- Analog, digital and PWM outputs for actuators
- Data acquisition & monitoring
- Hardware-in-the-loop tests for final control hadware and software



Emulated sub-systems:
-mathematical models
-heat sources
-mixing valves

Test-bench sub-systems

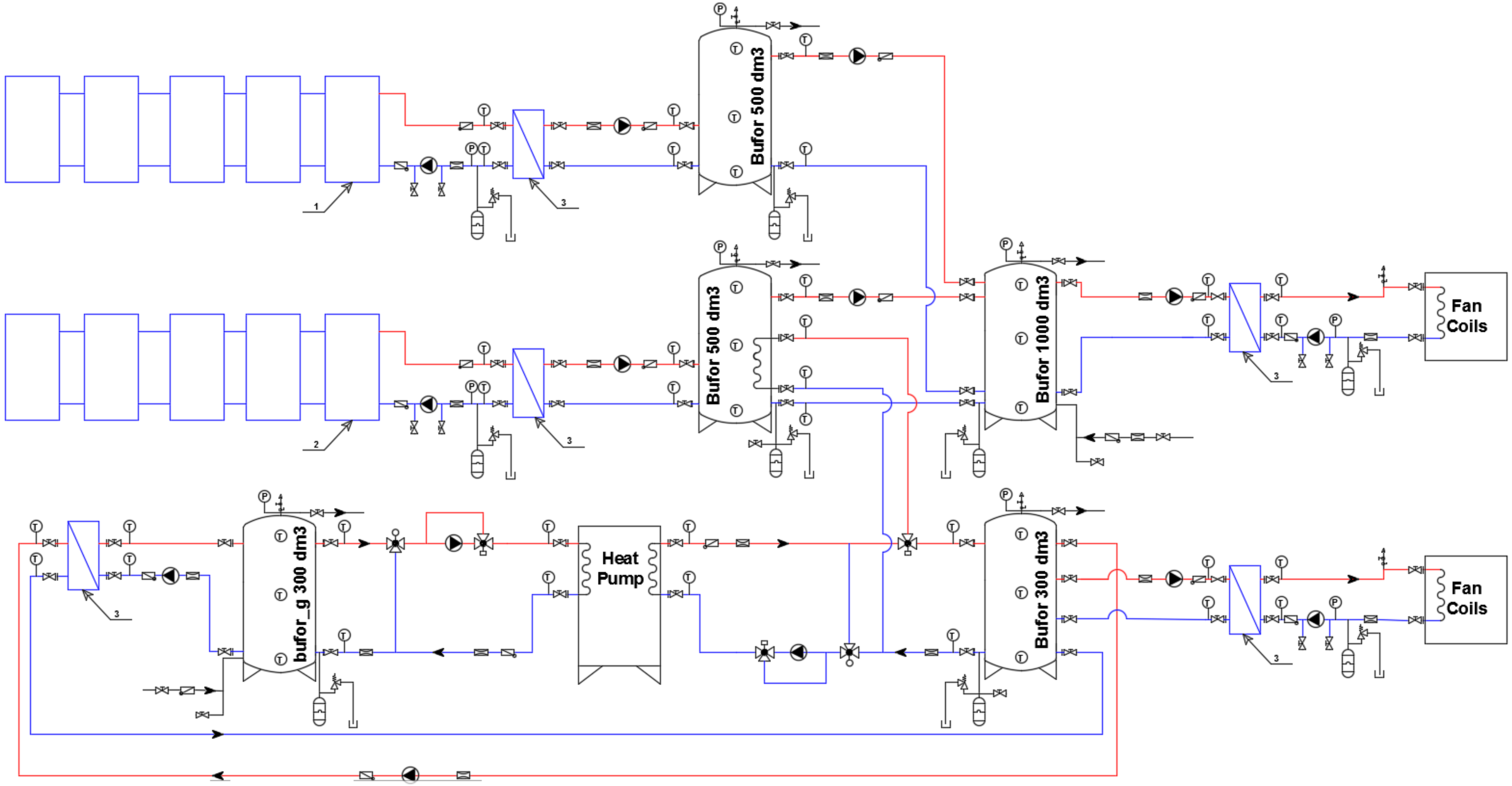
130 Liter

2 heat exchangers

6 circuits in each HE

150 Liter Tank with windows

SGGW test bench – under construction



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Thank for your attention

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