Rack cooling studies at the TIF (bldg 186)

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10 May 2022 - 17th xTCA Interest Group Meeting

Motivations

- By design, racks at P5 (CMS cavern) have a **10kW limitation** (6-7 kW nominal)
- Check at the max allowed power if the rack design works properly
  - Check if the **inlet temperature** in each shelf is optimal
  - Check if the amount of **heat leakage**
- Understand if the **TIF setup needs improvements**
- Check the adopted configuration **solutions**

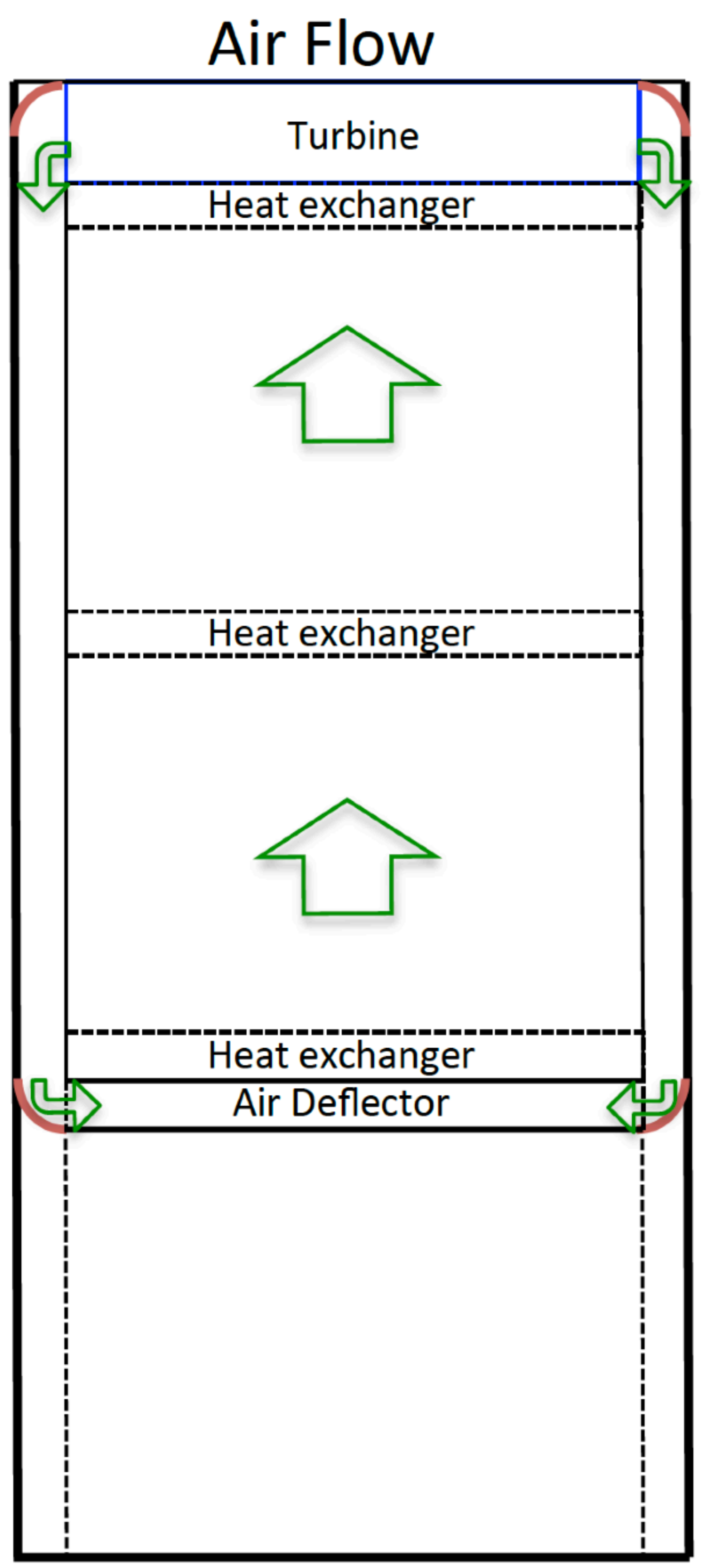
Bldg 186 : TIF

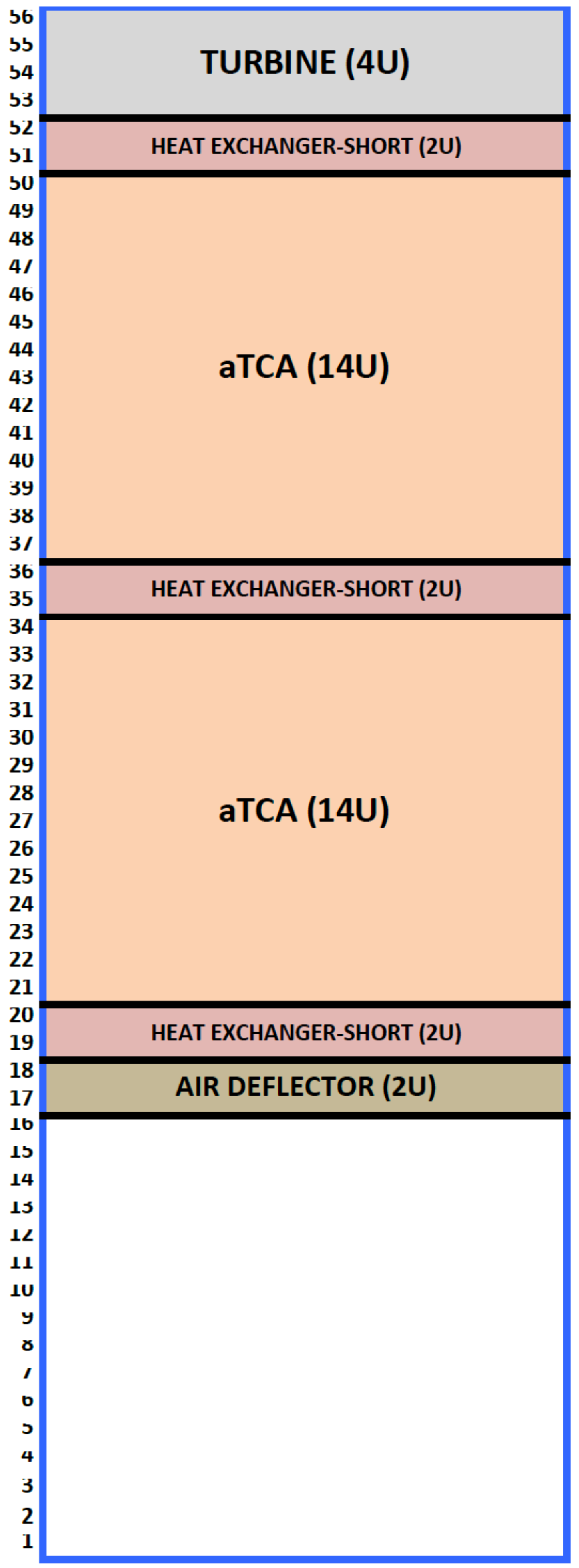
A16 TIF rack

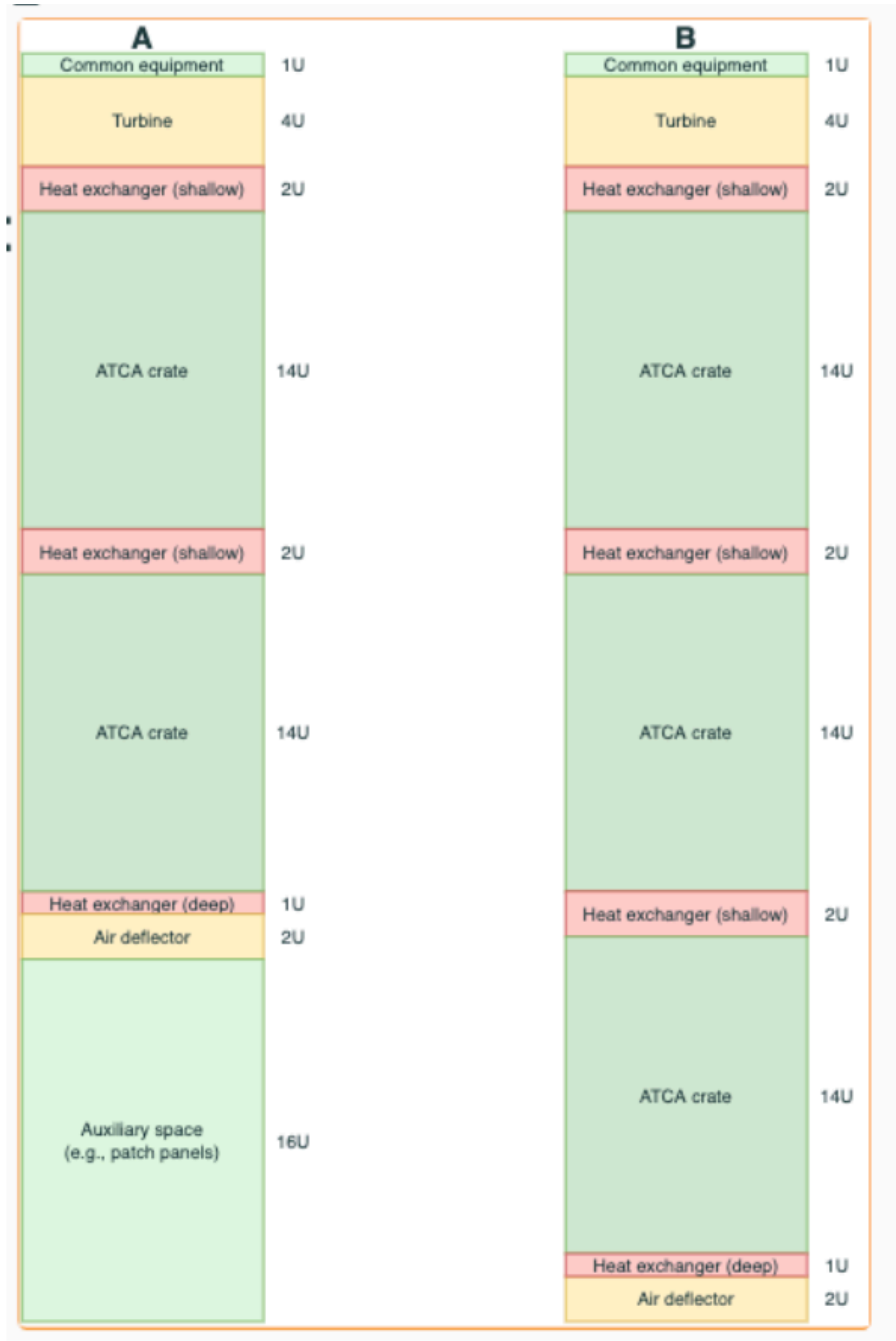
Heater board (200 to 800W configurable)

Some boards were left inserted but not activated

Setup







Top Shelf

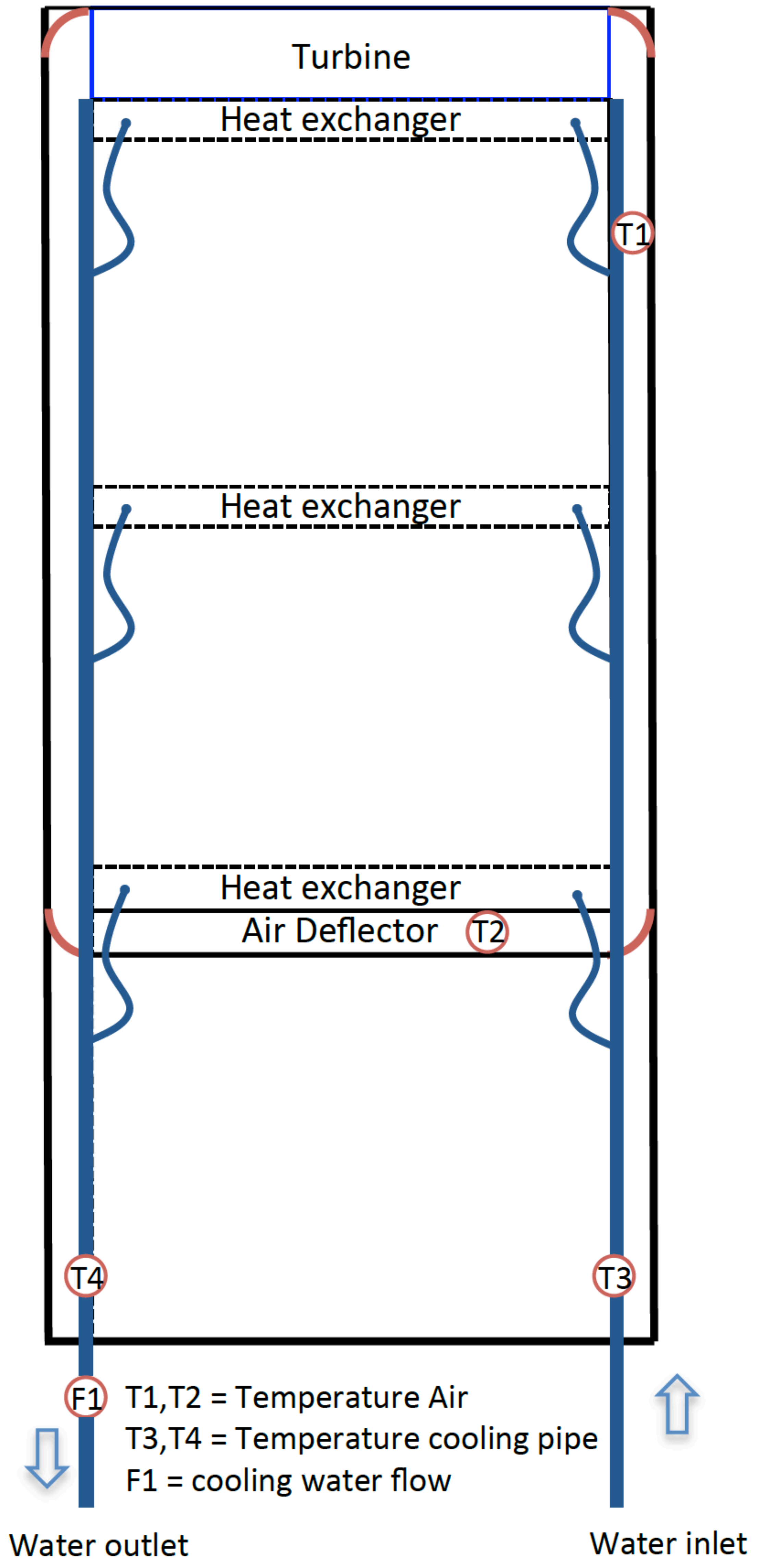
Bottom Shelf

- Shelf fan speed kept constant 10/15 (500W per shelf)
- 2U bottom heat exchanger at TIF while 1U in the current CMS proposal

Sensors

- Hall air temperature
- External rack temperature
- Rack water flow
- Air loop temperature
- Inlet/outlet water temperature
- Fan tray temperatures (left/center/right) x4
- PSU temperature
- PEM temperature
- Power @PSUs and before them
- More…

Monitoring

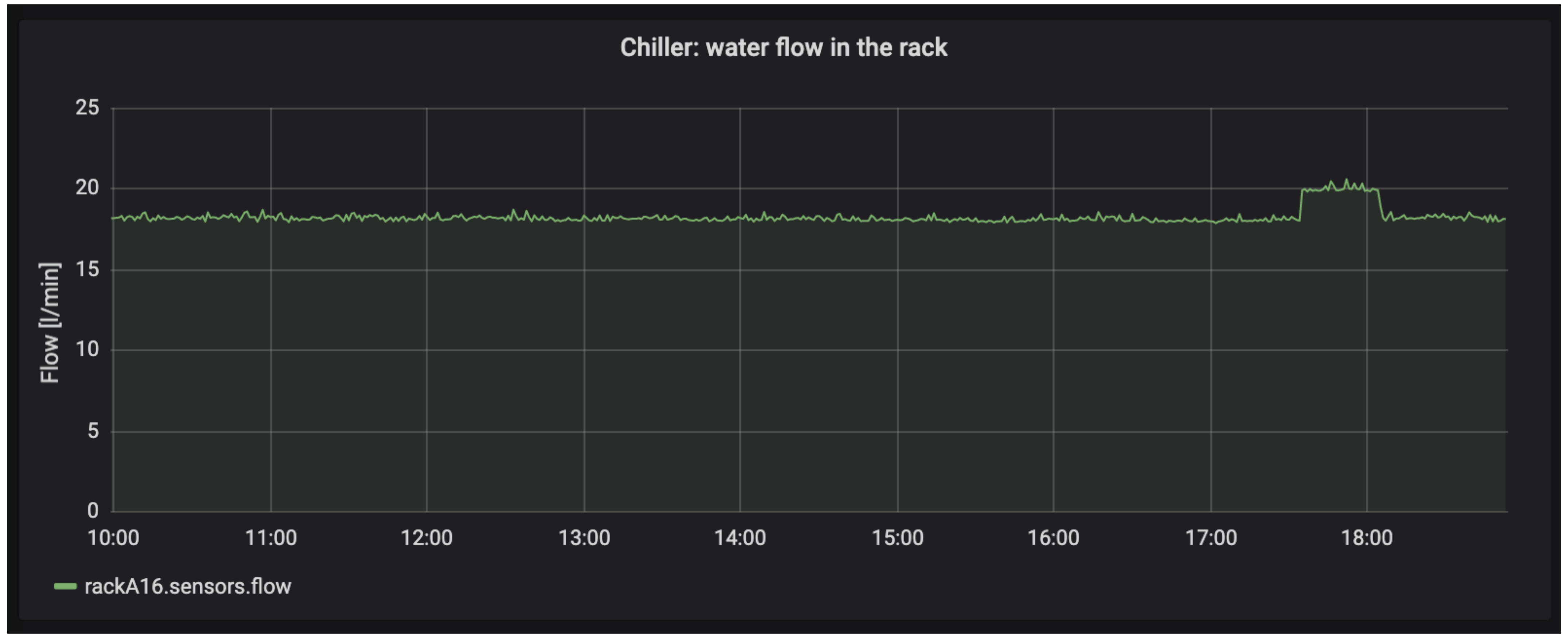


T3: temperature sensor

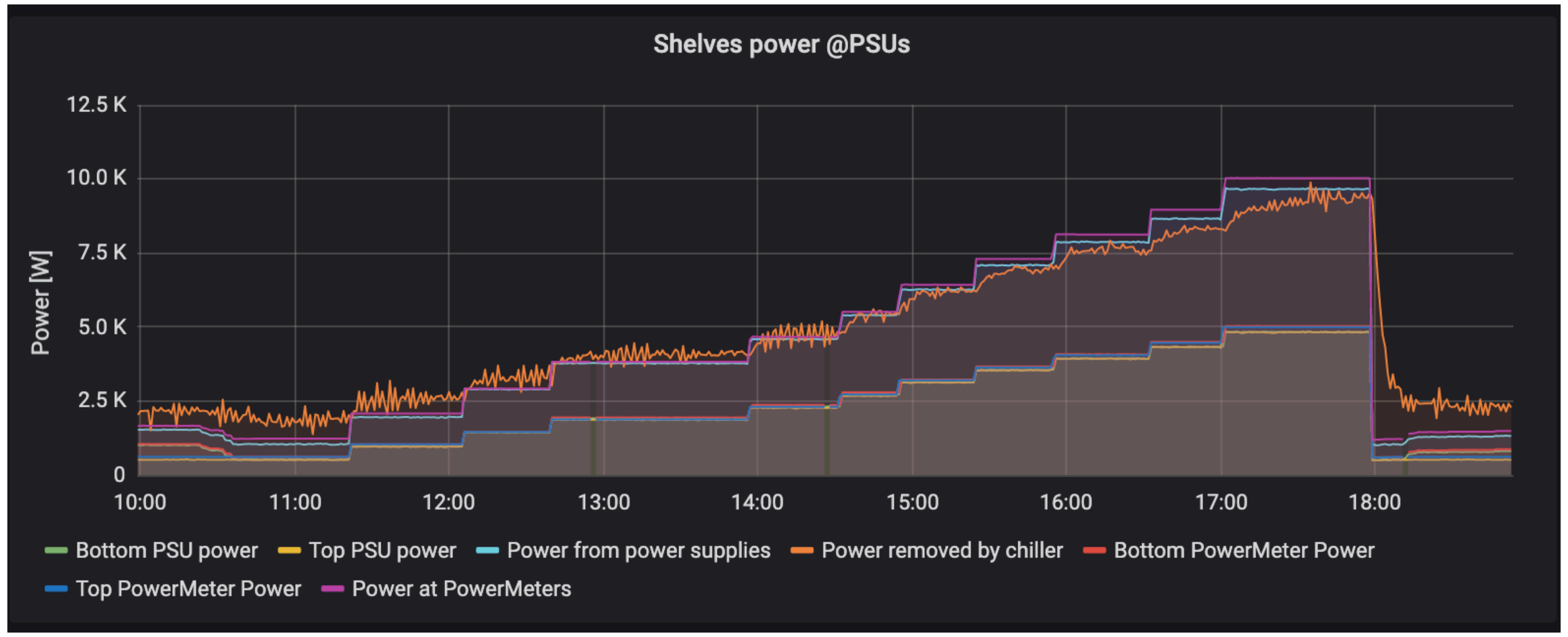
Power meters

Monitoring power

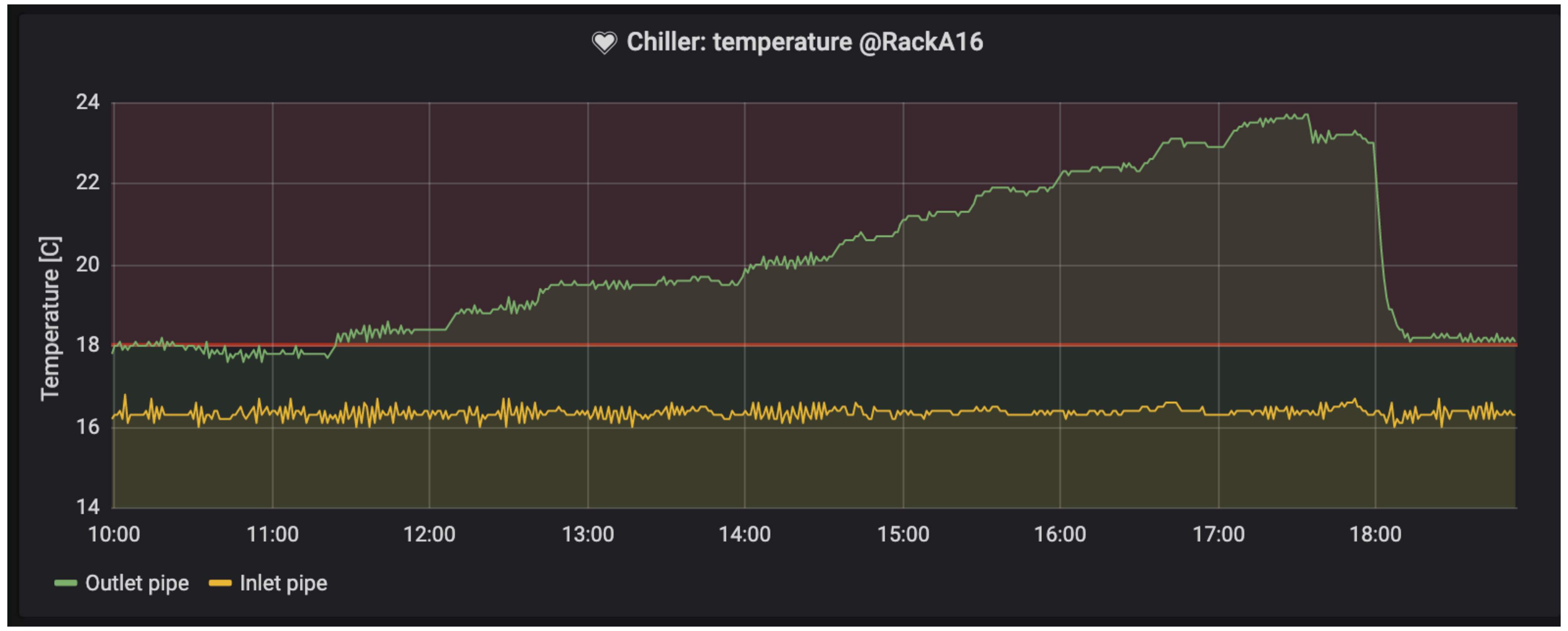
Water flow in our rack



Powers



Water temperature (inlet/outlet)

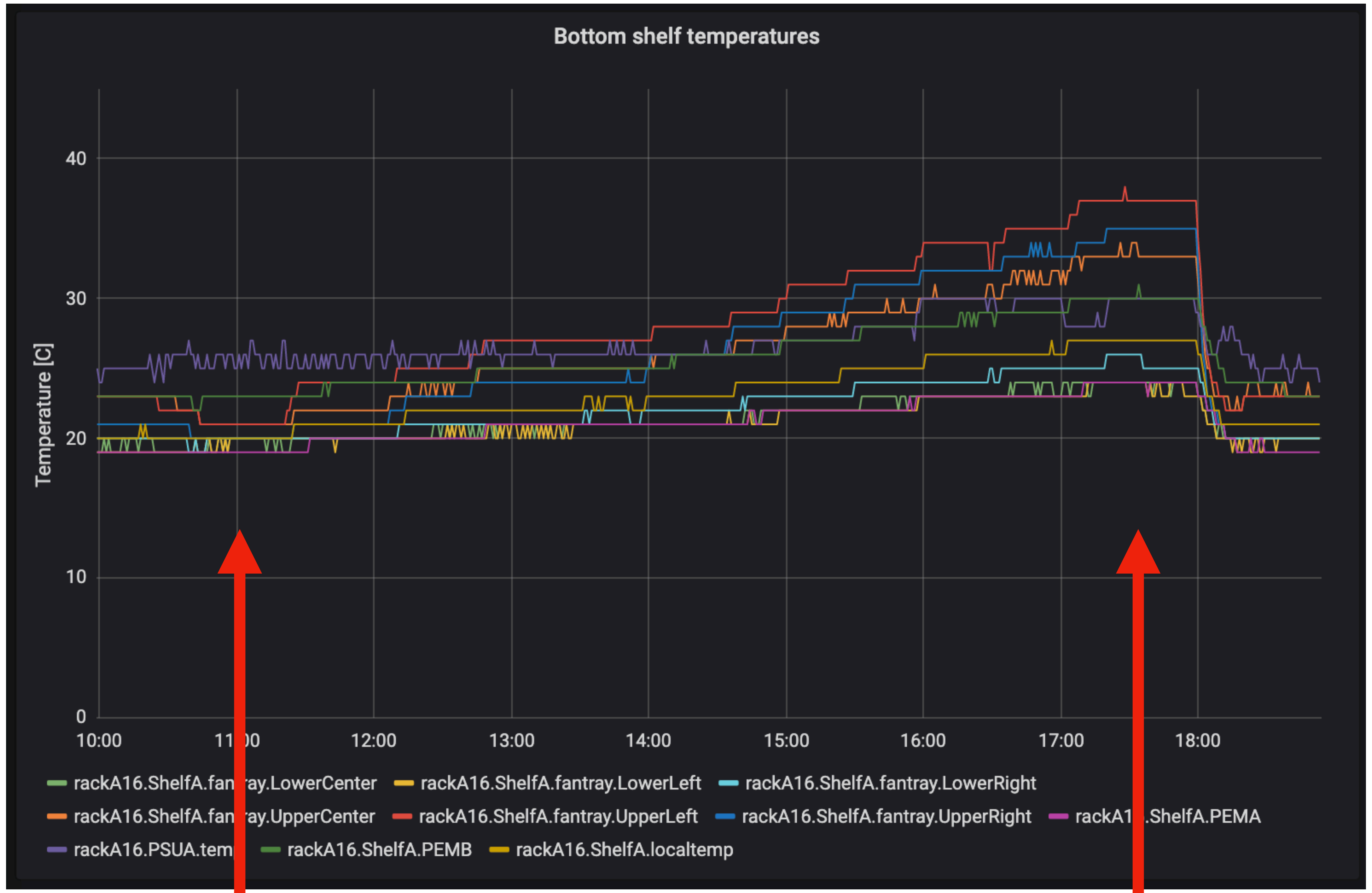


- Data is sent to a Graphite/Grafana monitoring system
- Shelves power plot shows the PSUs, power meters, total injected power, and the calculated extracted power by using the information from the left hand side plots
- Test have been done gradually increasing the power from 1.2kW to 10kW (about 800W increment)
- At max power we tried to increase the water flow by closing the circuit for two unused racks

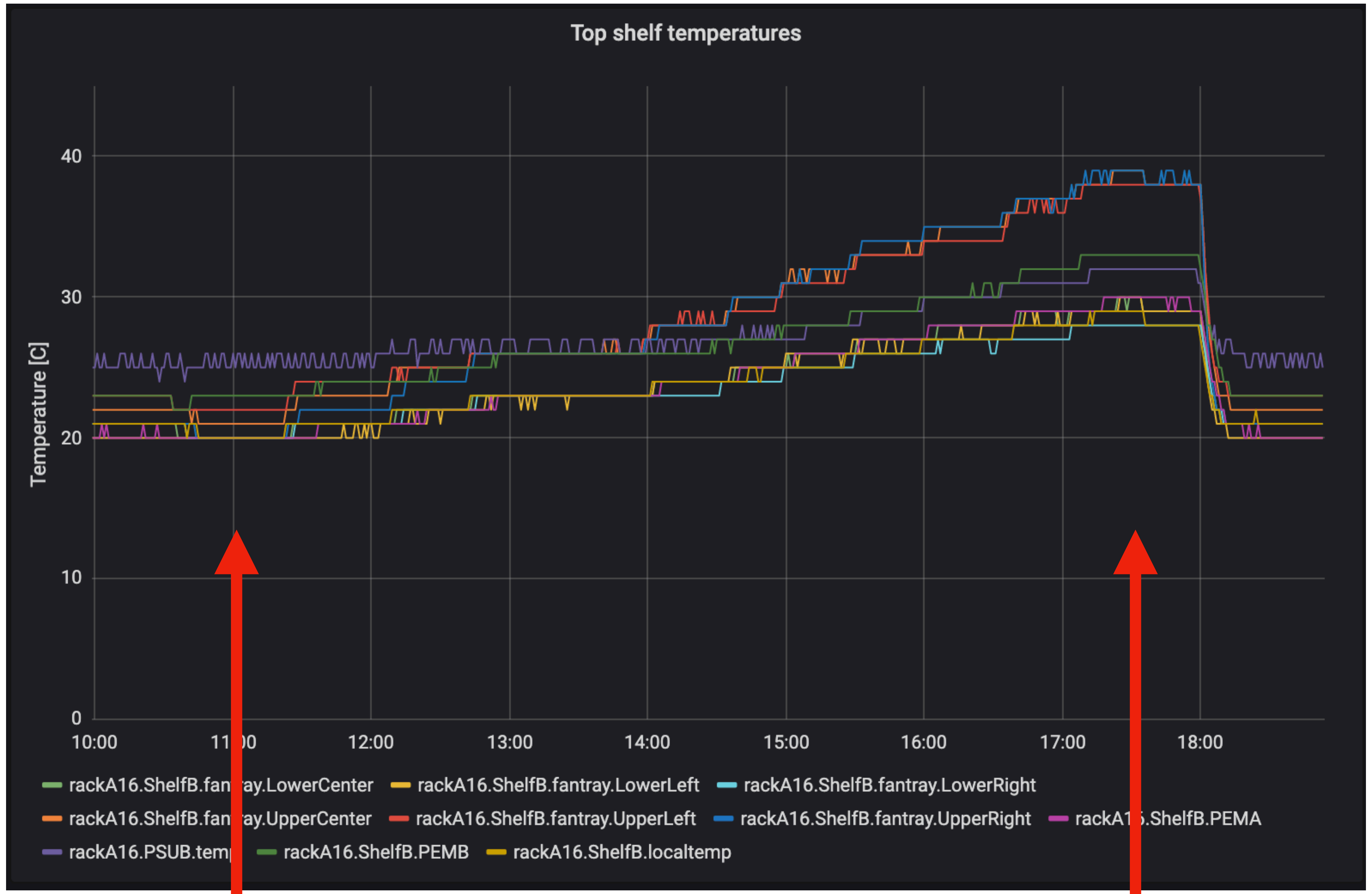
Ref

Monitoring temperatures

Bottom shelf temperatures



Top shelf temperatures



Test begin: 1.2kW

Test end: 10.0kW

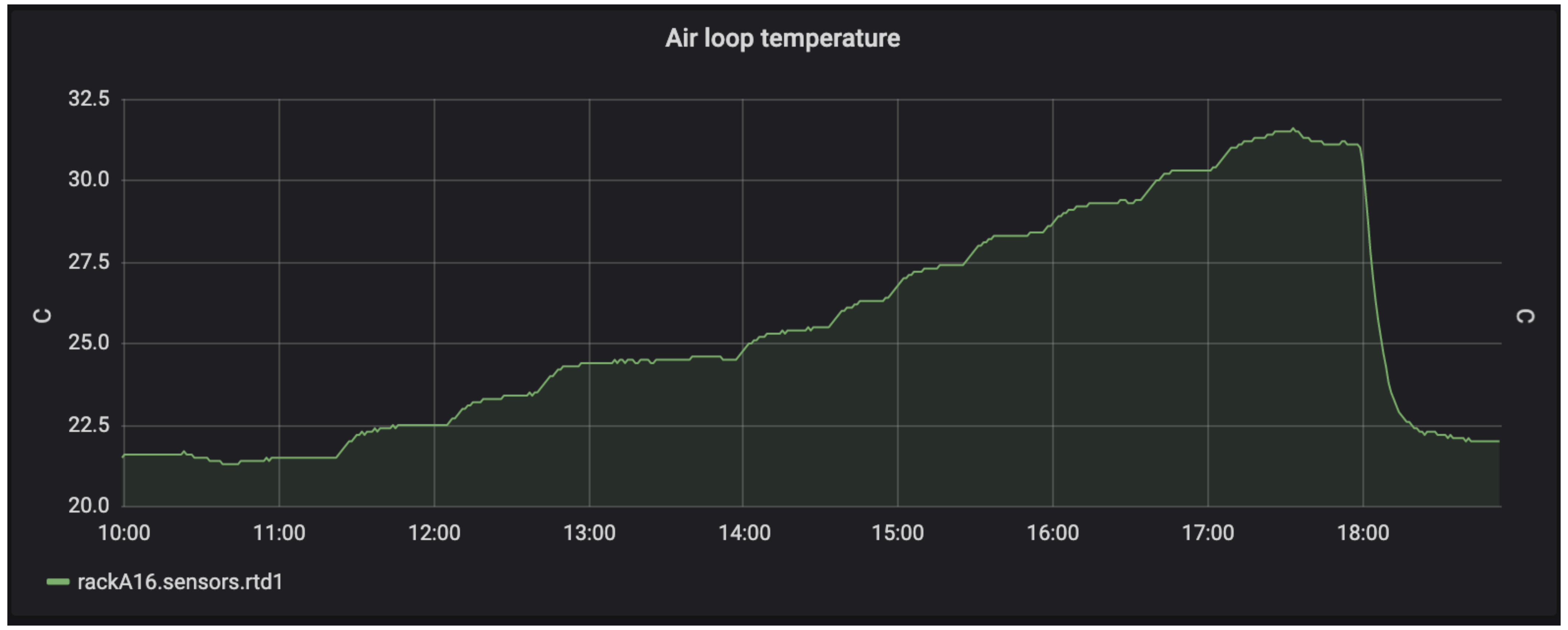
Test begin: 1.2kW

Test end: 10.0kW

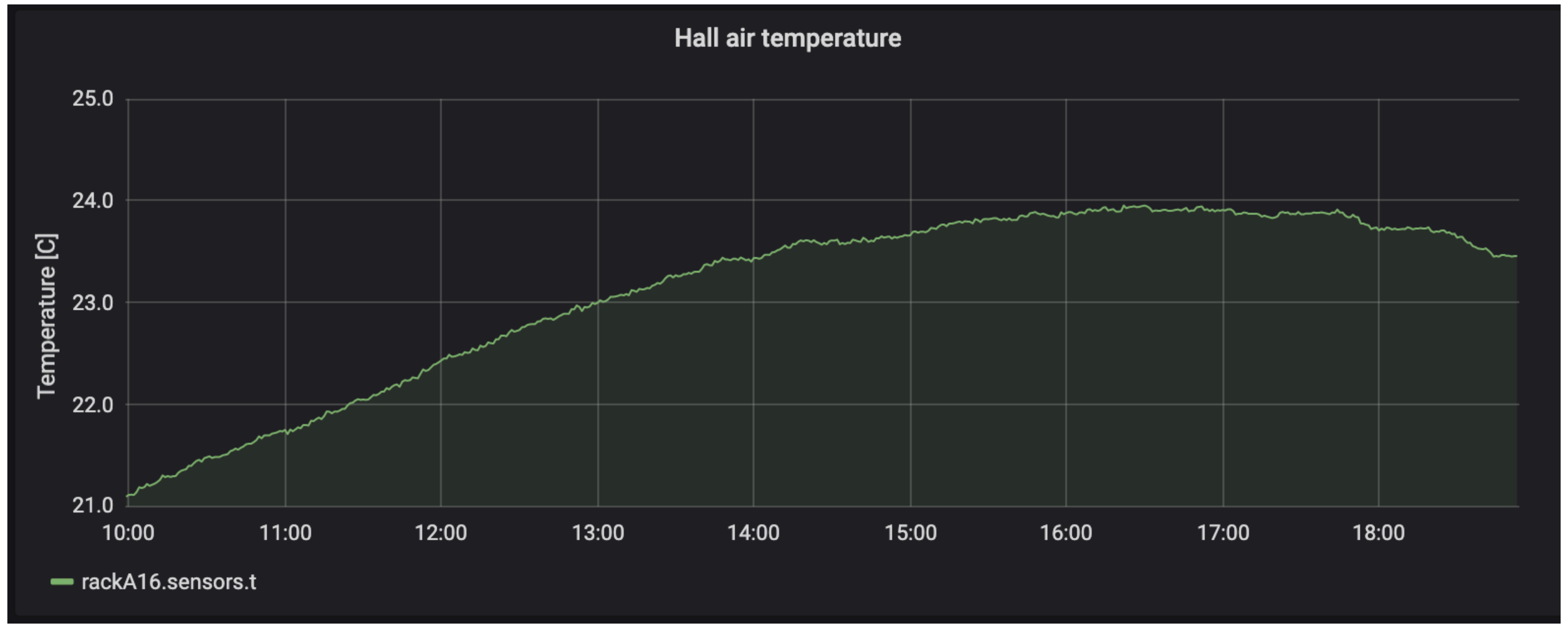
See next slides for more insights

Air temperatures

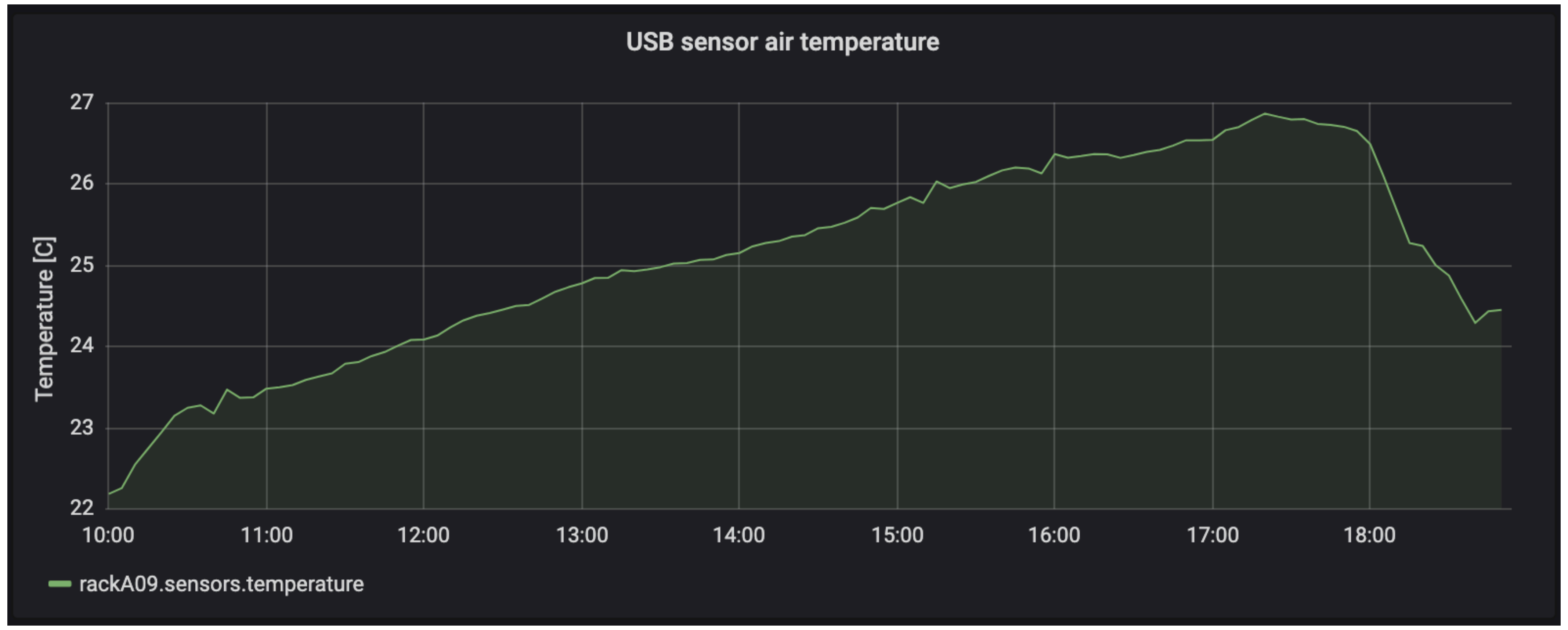
Air loop temperature



Ambient temperature



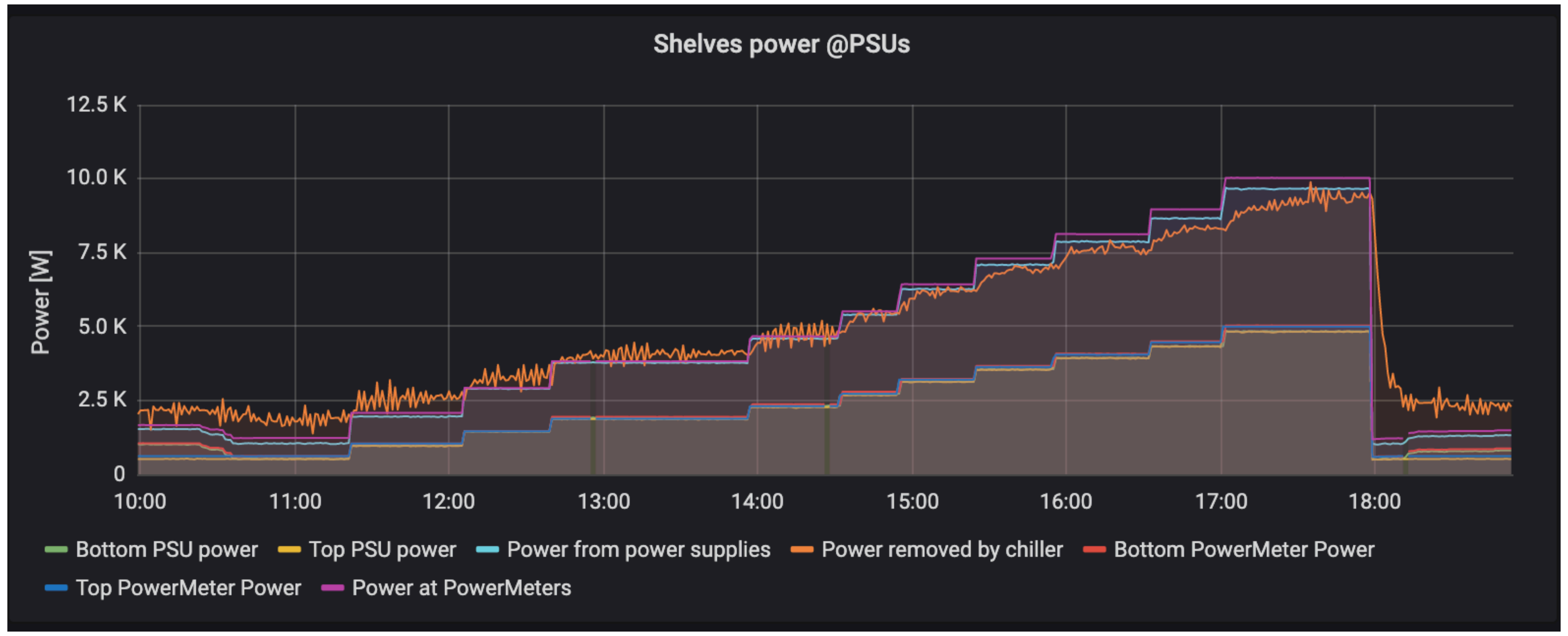
Rack external temperature



- Air temperatures in the rack loop, just outside the rack, and the temperature of the TIF hall
- We used this if info to try to model the rack-ambient heat exchange

Data analysis

- Data imported from graphite db (TIF monitoring system) to pandas dataframe
- Inputs averaged on stable periods (GMT time)

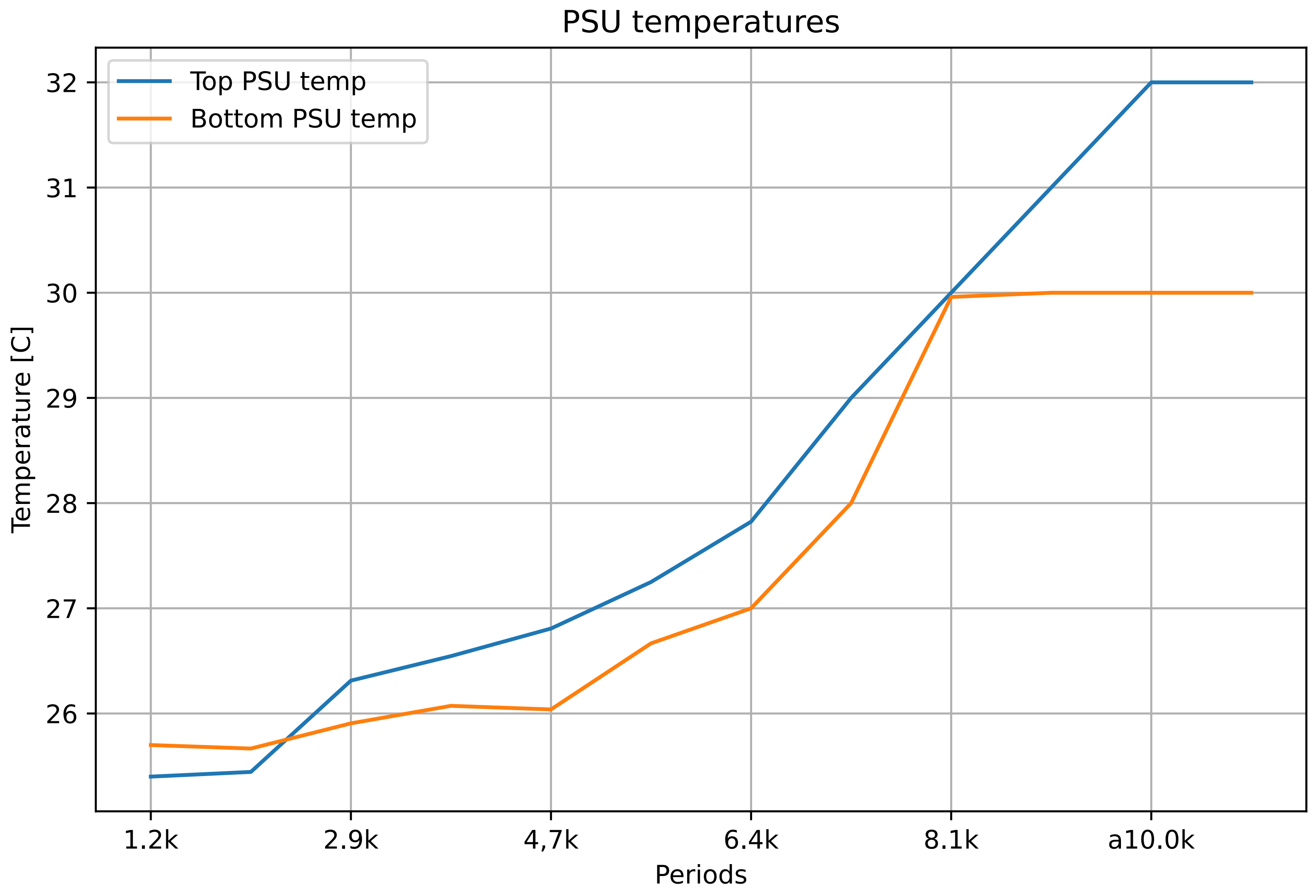



```
stable_ranges = {
    "1.2k" : ["2022-02-09 9:50","2022-02-09 10:19"],
    "2.1k": ["2022-02-09 10:37","2022-02-09 11:03"],
    "2.9k": ["2022-02-09 11:07","2022-02-09 11:38"],
    "3.8k": ["2022-02-09 12:00","2022-02-09 12:54"],
    "4,7k": ["2022-02-09 13:05","2022-02-09 13:30"],
    "5.5k": ["2022-02-09 13:42","2022-02-09 13:53"],
    "6.4k": ["2022-02-09 14:06","2022-02-09 14:22"],
    "7.3k": ["2022-02-09 14:37","2022-02-09 14:54"],
    "8.1k": ["2022-02-09 15:06","2022-02-09 15:30"],
    "9.0k": ["2022-02-09 15:43","2022-02-09 15:59"],
    "a10.0k": ["2022-02-09 16:27","2022-02-09 16:34"],
    "b10.0k": ["2022-02-09 16:44","2022-02-09 16:56"]
}
```

← Two measurements done with the same power but different water flow

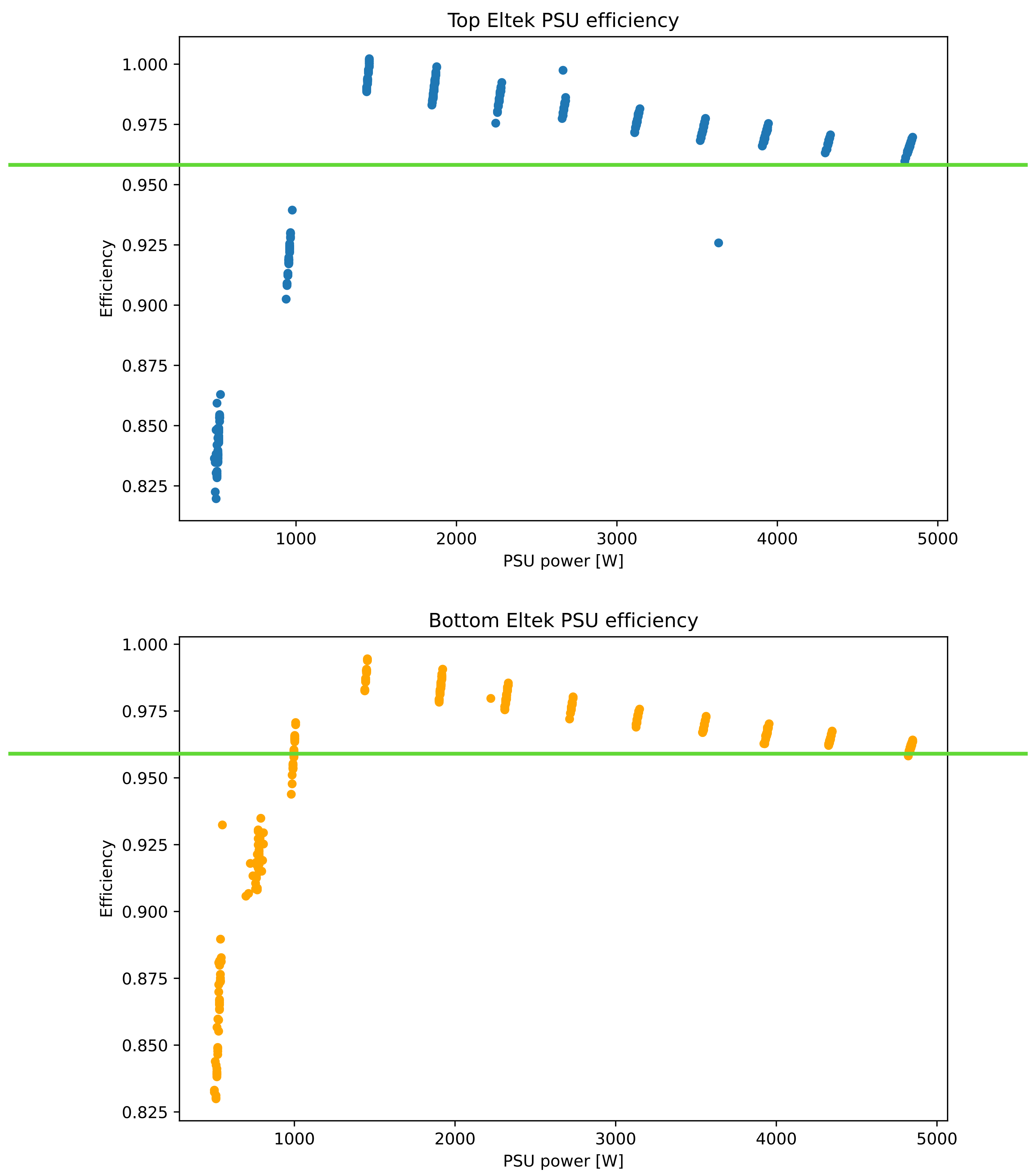
Checking Eltek PSU

Temperature of the PSUs



- Installing the PSU on the back part of the rack doesn't create any temperature issue
- PPSU efficiency is pretty high and the heat that leaks from the rack doesn't seem to be a problem

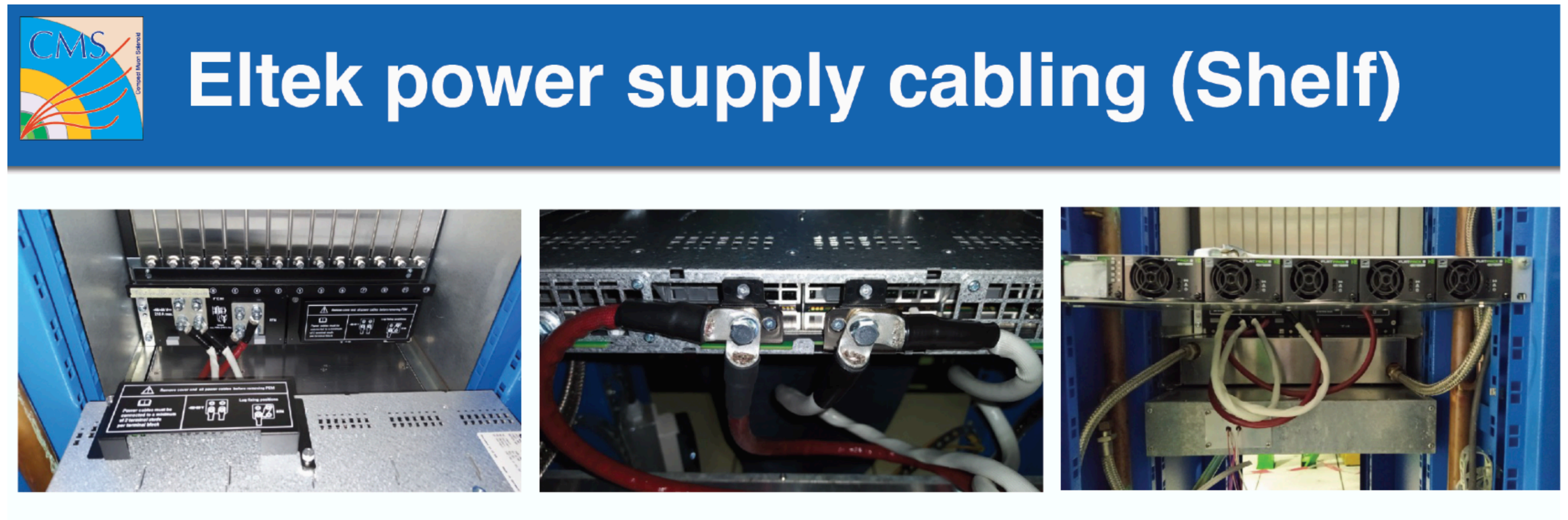
PSU Efficiencies

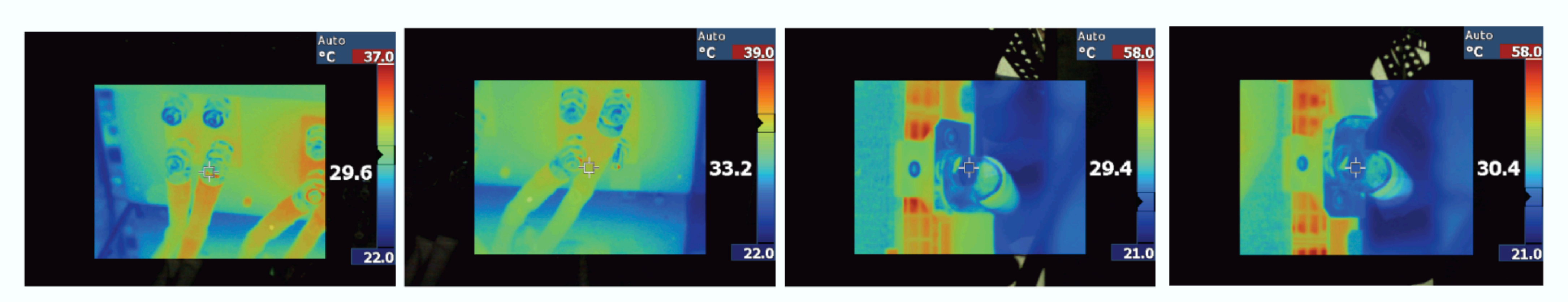


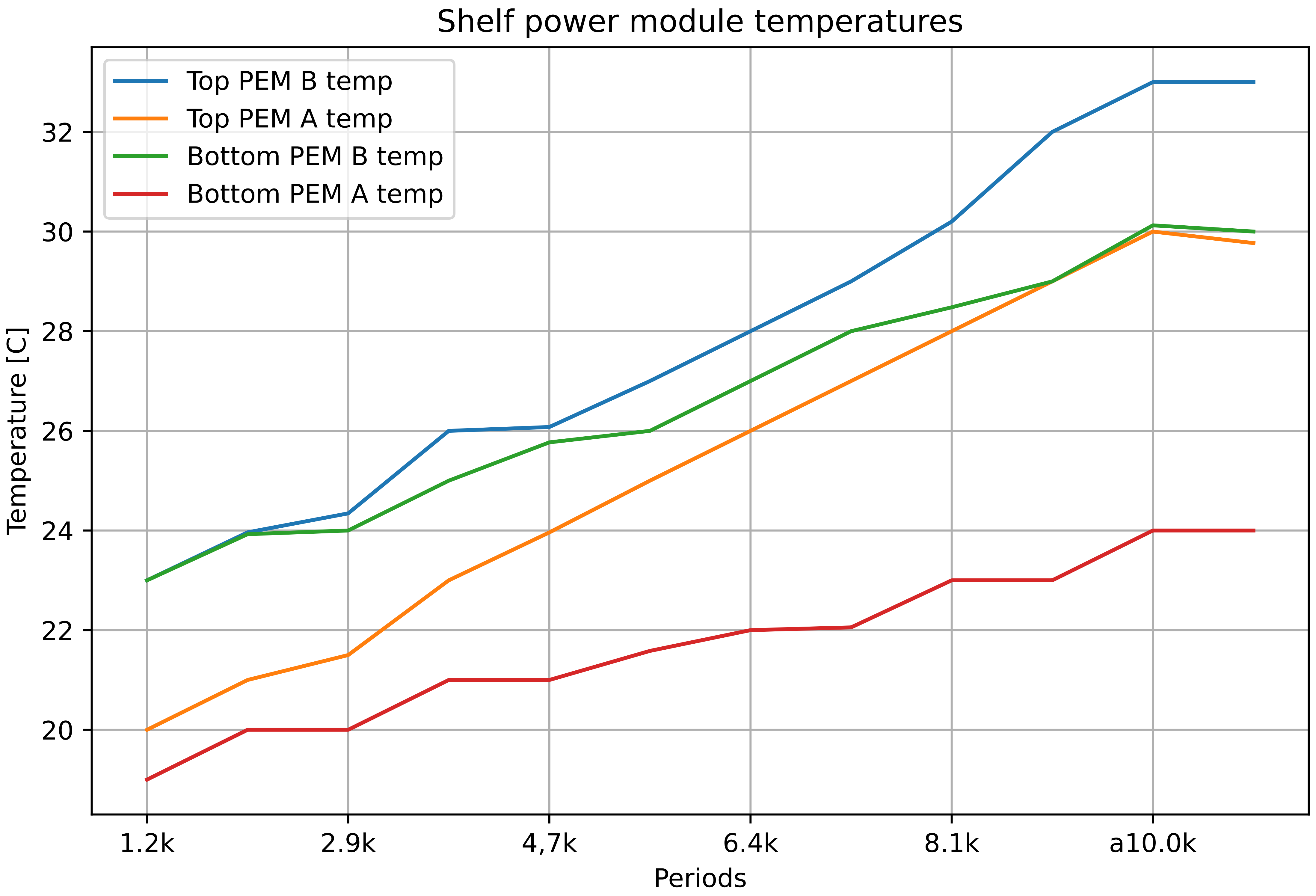
Eltek module specifications

OUTPUT DATA		
Voltage (default)	53.5 V_{DC}	
Voltage (adjustable range)	43.5 - 57.6 V_{DC}	
Power (maximum) @ nominal input	1000 W	1800 W
Power @ 85 VAC	420 W	700 W[2)]
Current (maximum) @ nominal input	20.9 A (@V_{OUT} < 48V_{DC})	37.5 A (@V_{OUT} < 48V_{DC})
Hold up time, maximum output power	>20ms; output voltage > 41 V_{DC}	>10ms; output voltage > 42 V_{DC}
Current sharing (10 - 100% load)	±5% of maximum current from 10 to 100% load	
Static Voltage regulation (10 - 100% load)	±0.5%	
Dynamic Voltage regulation	±5.0% for 10-90% or 90-10% load variation, regulation time < 50ms	
Ripple	< 150 mV_{PP} , 30 MHz bandwidth	
Protection	ORing FET, Short circuit proof, High temperature protection, Over voltage Shutdown	
OTHER SPECIFICATIONS		
Efficiency	Up to 95.5 %	Up to 95.8 %

Checking shelf power modules

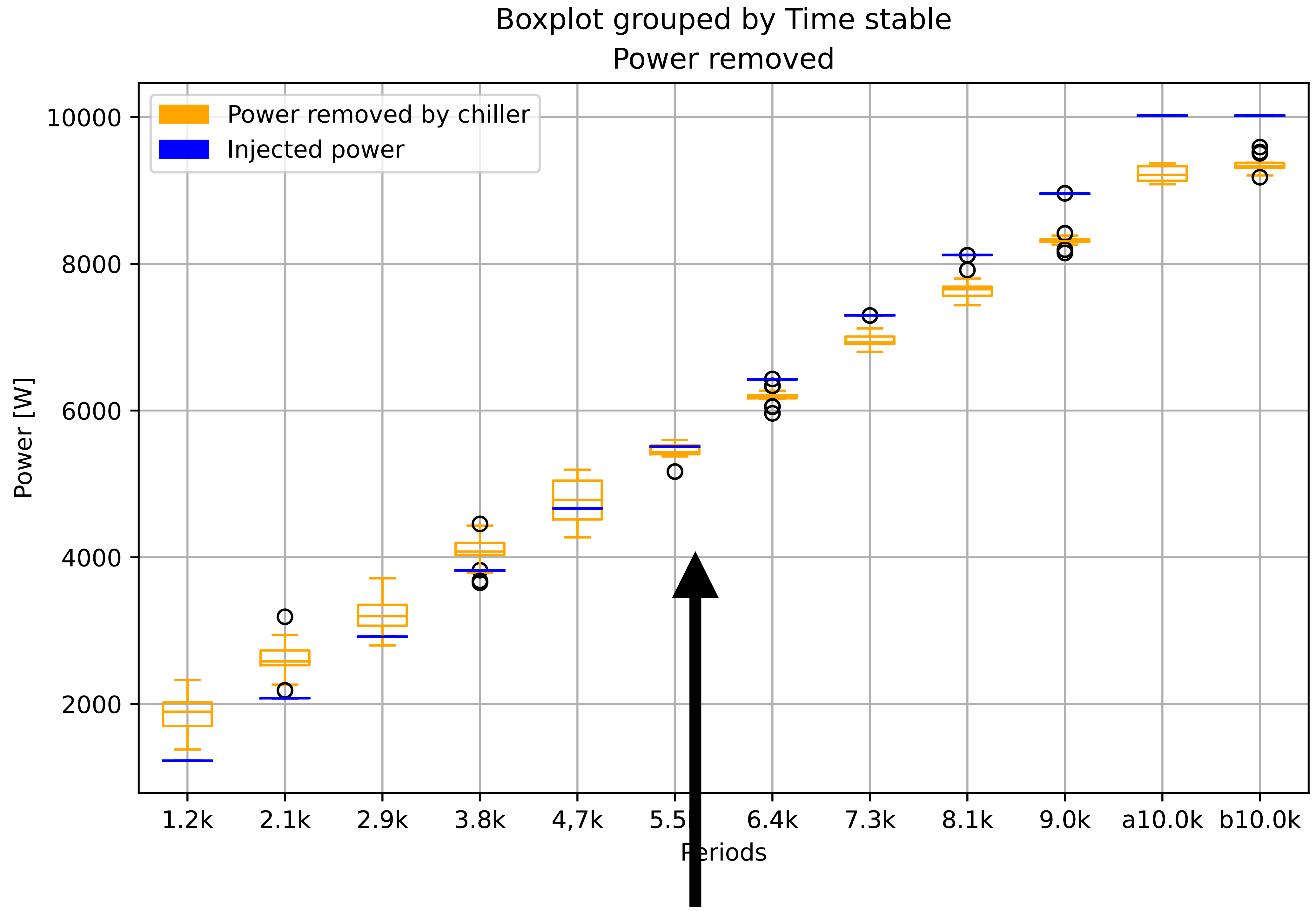


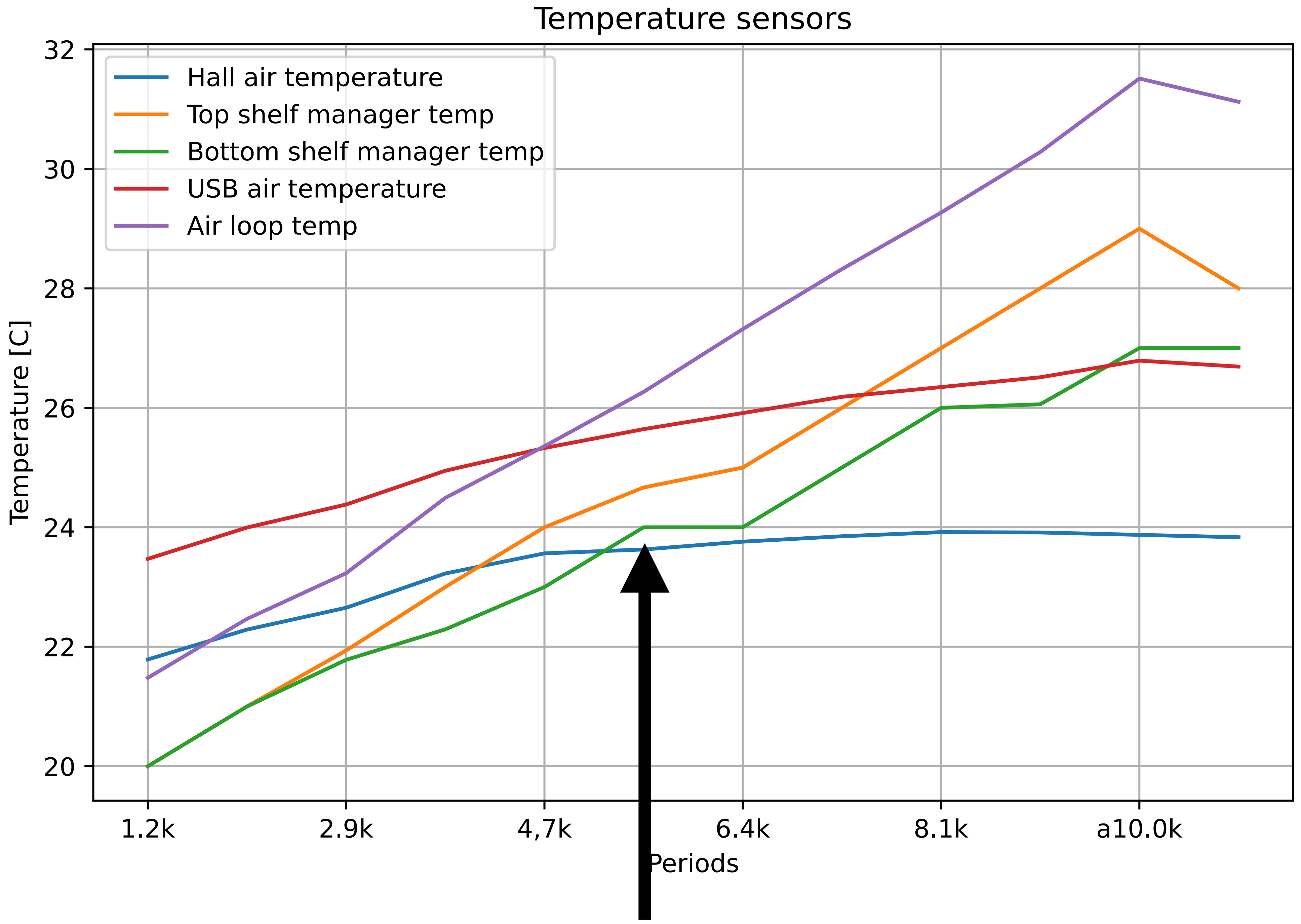




- Shelf power modules are not overheating

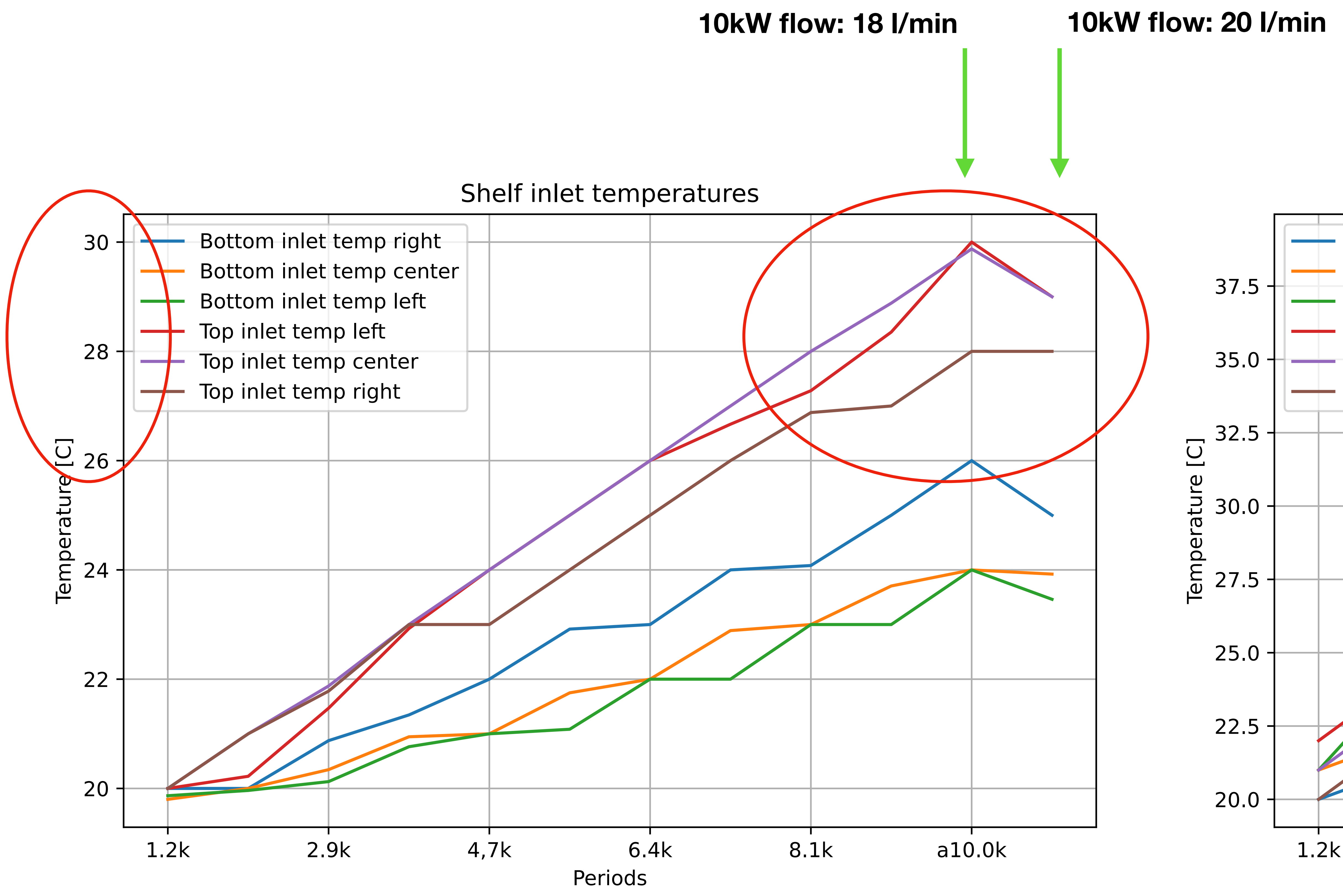
Rack thermal equilibrium

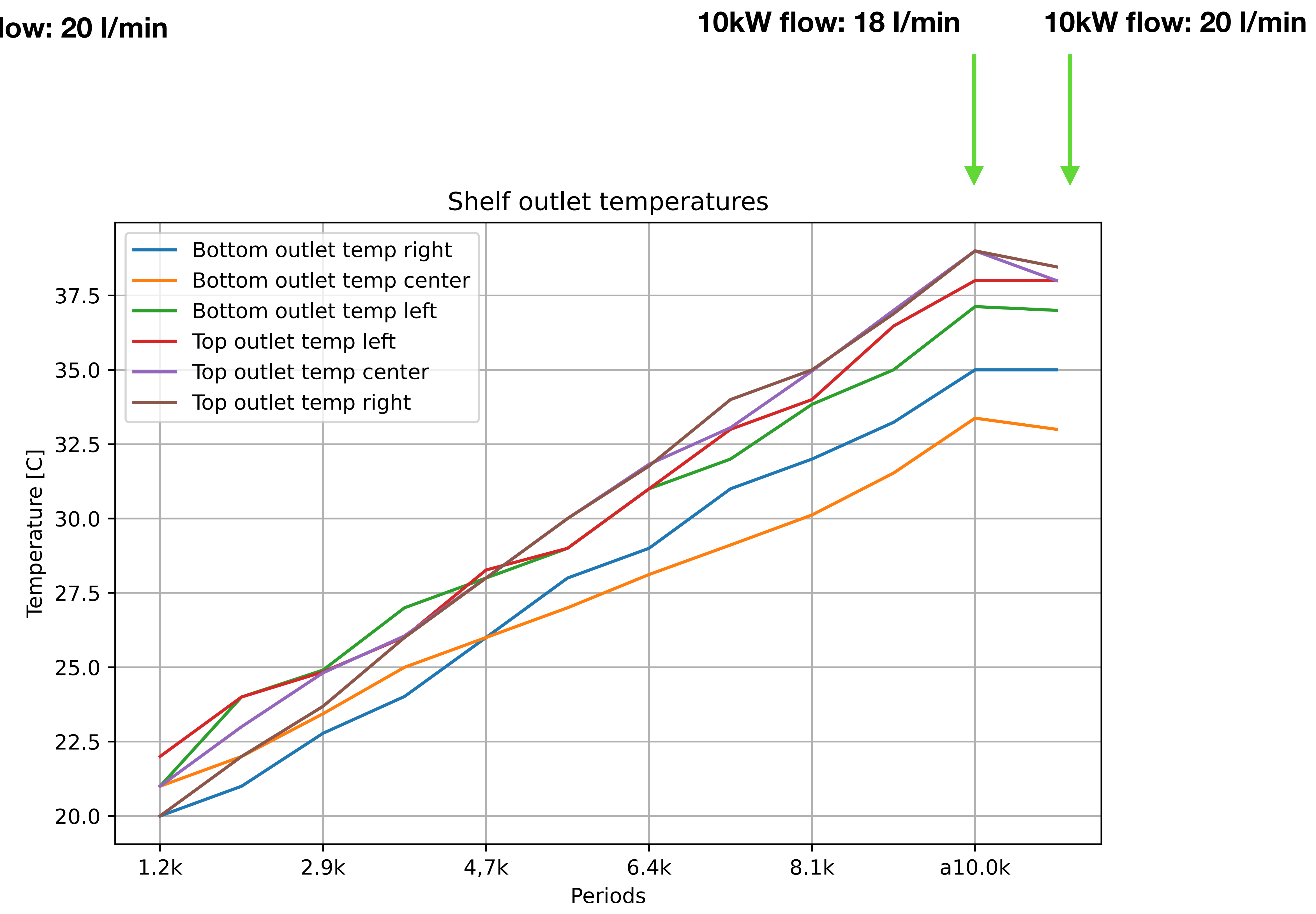




- Left hand side plot shows the total injected power measured at the power meters versus the power removed by the chiller.
- The power removed exceeds the injected power at low power and viceversa at high power
- The two equal around 5kW, a similar equilibrium is found between the ambient temperature and the shelf temperature measured in the shelf manager
  - This suggests that there is a non-negligible radiative component

Air temperature in the shelves

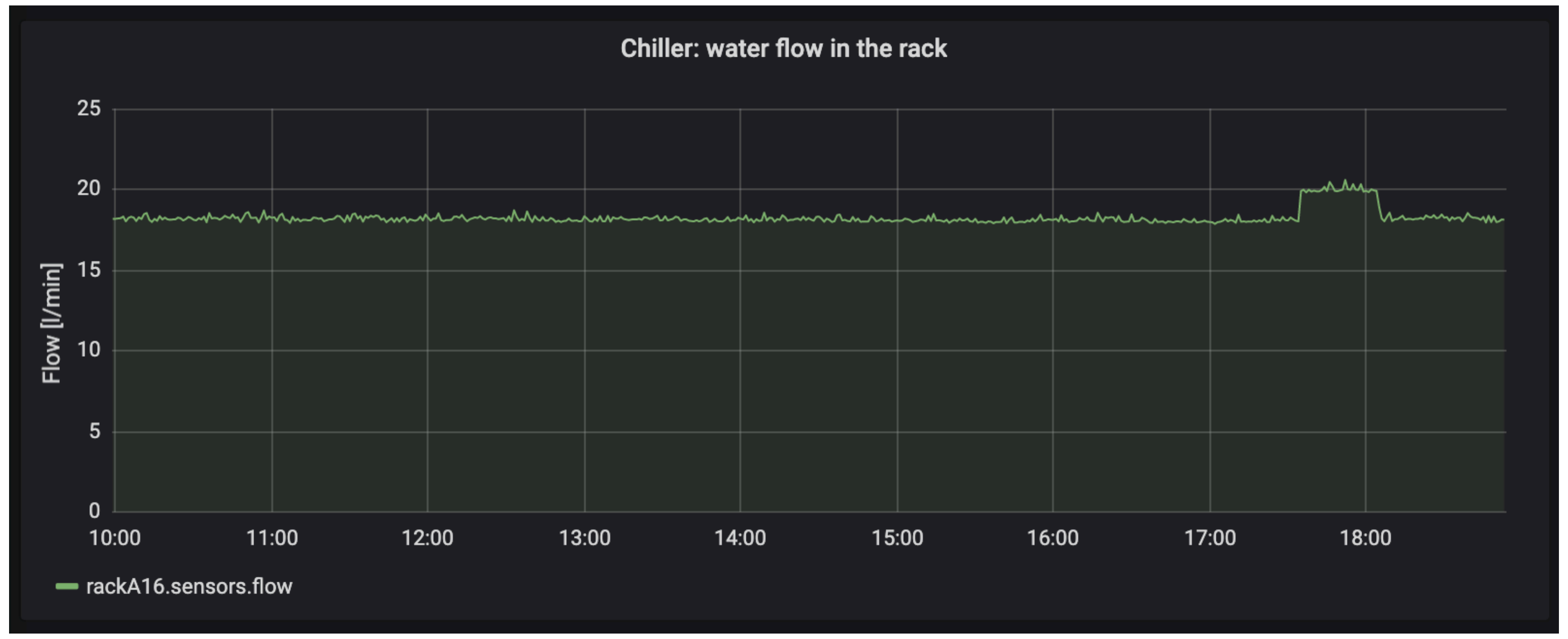




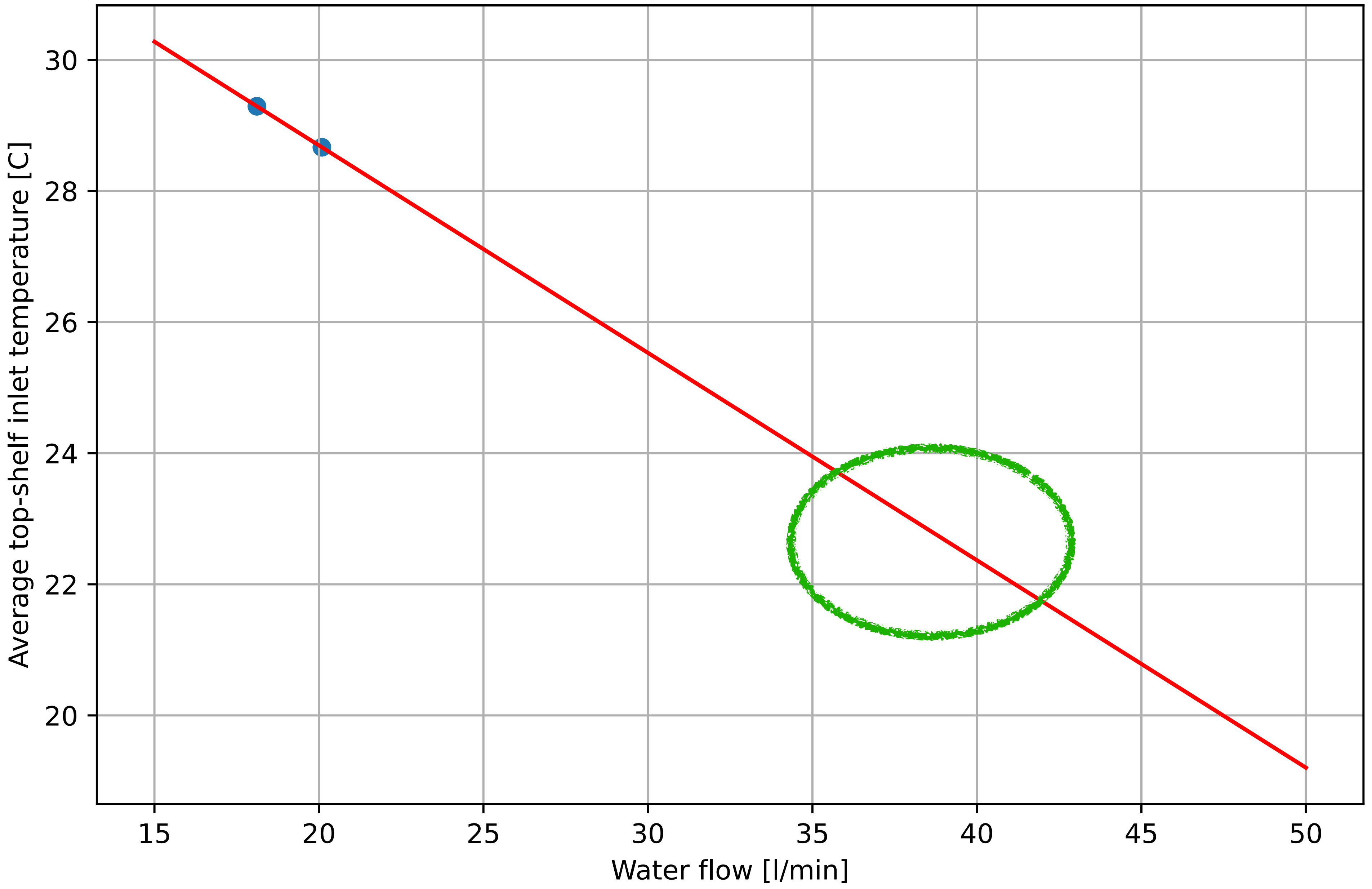
- Inlet and outlet temperatures measured at the fan trays in three positions: left, center, right
- Each shelf has a bottom and a top fan tray
- We care about the inlet temperature because it could jeopardise the ATCA board cooling
- At the TIF the inlet temperature reaches 30C which is not optimal

Extrapolations

Water flow rate in our rack



Water flow extrapolation



Increase of water flow rate

- Last two measurements done at 10kW
  - One with 18 l/min flow
  - One with 20 l/min flow
- Here we try to extrapolate the **top shelf inlet temperature as function of the water flow**
- The extrapolation is affected by non-negligible uncertainties and the assumption of linearity
- It looks like we should **double the water flow rate** to have more inlet temperature values

Decrease of water temperature

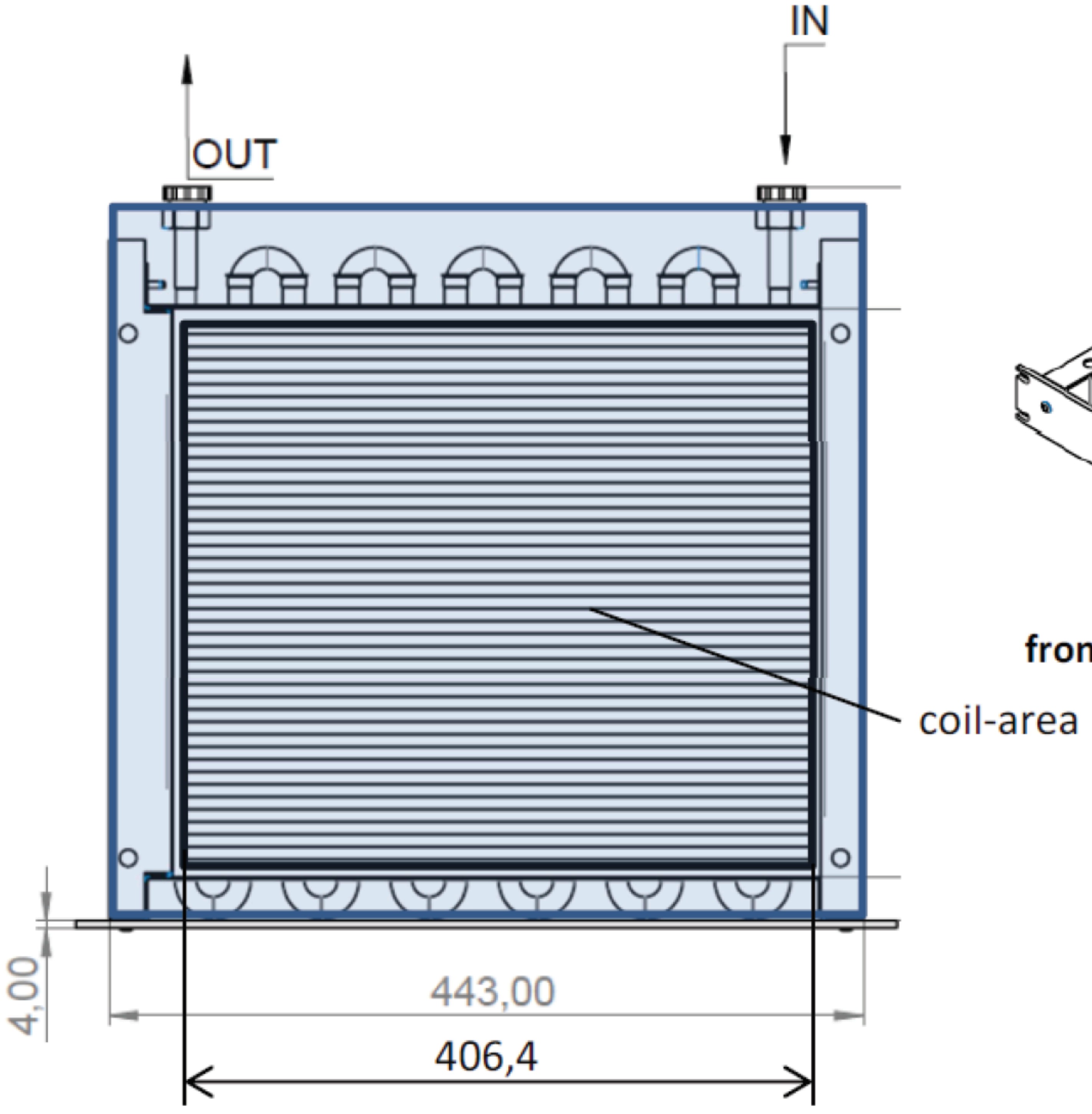
- Another leverage for improvements is the **water temperature** from the chiller. 16C during this test. It can be lowered by 1-2C depending on the condensation issue.
- Cannot be lowered at TIF, but it might be done in P5 USX

Conclusions

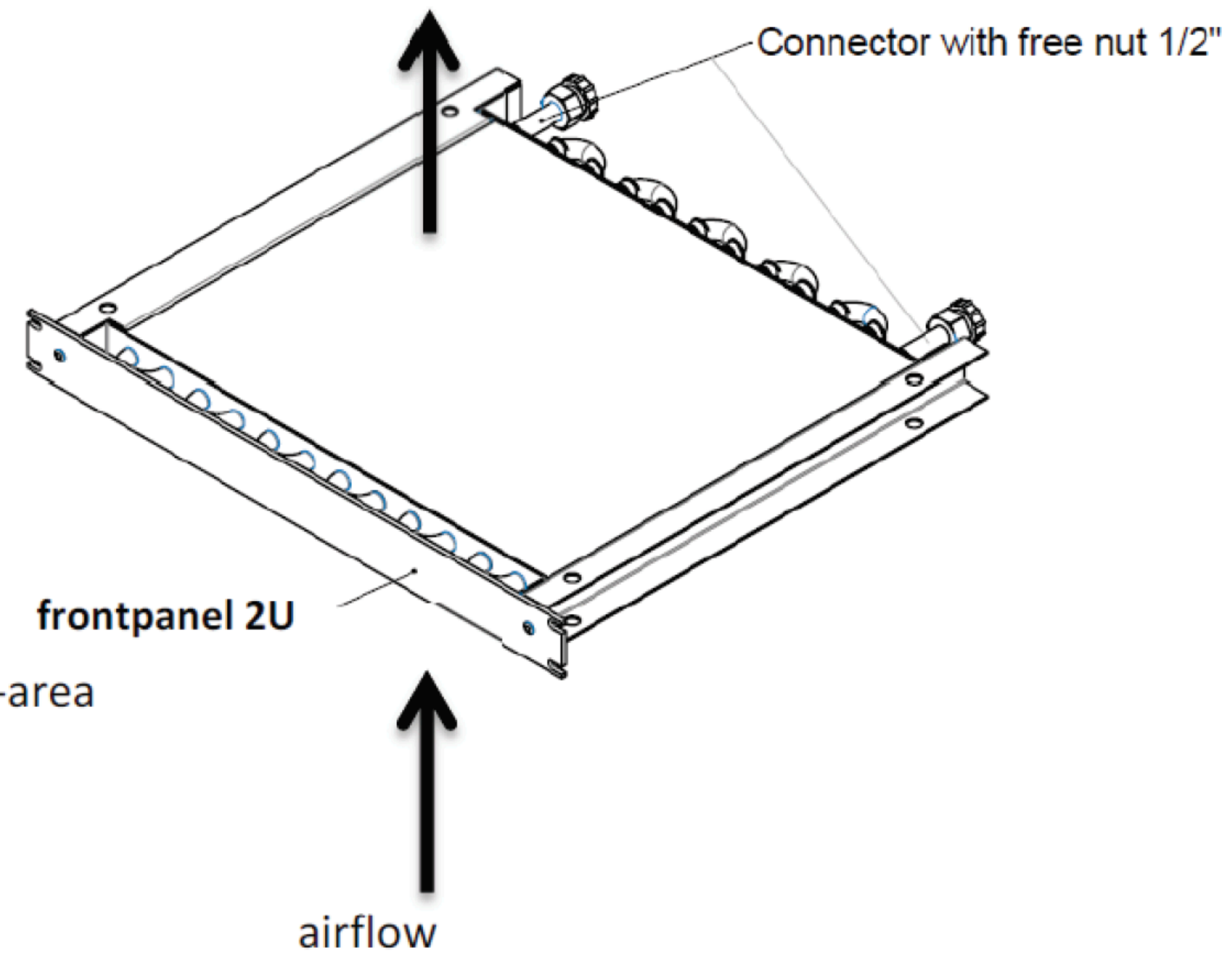
- General rack design is validated
  - PSU configuration ok
  - 48V cabling ok
- But an higher water flow is needed If we want to reach the max power 10kW to guarantee an optimal **board cooling performance**
- TIF A16 looks ok up to 5kW then we have to be aware that **cooling is underperforming**
- Rack **heat leaking** might not be negligible, but it depends on the cavern temperature

Heat exchangers

Top-view with complete 19"-rack-mount-frame:



View without frame (coil only):



20 l/min = 1.20 m3/h
18 l/min = 1.08 m3/h

ENERGY BALANCES @ 7KW

$$P[W] = \dot{m} * c_p * \Delta T = \rho * \dot{V} * c_p * \Delta T$$

$$\dot{V} = \frac{P}{\rho * c_p * \Delta T}$$

$$c_{p,water} = 4.23 \frac{kJ}{kg * K} \qquad c_{p,air} = 1.0 \frac{kJ}{kg * K}$$

$$\rho_{water} = 1007 \frac{kg}{m^3} \qquad \rho_{air} = 1.17 \frac{kg}{m^3}$$

ΔT_{water} [K]	$\dot{V}_{water}$ $[m^3/h]$
5	1,18
6	0,99
7	0,85
8	0,74
10	0,59
12	0,49
15	0,39

ΔT_{air} [K]	$\dot{V}_{air}$ $[m^3/h]$
5	4165
8	2603
10	2083
12	1736
15	1388
18	1157
20	1041

WATER COIL CALCULATIONS

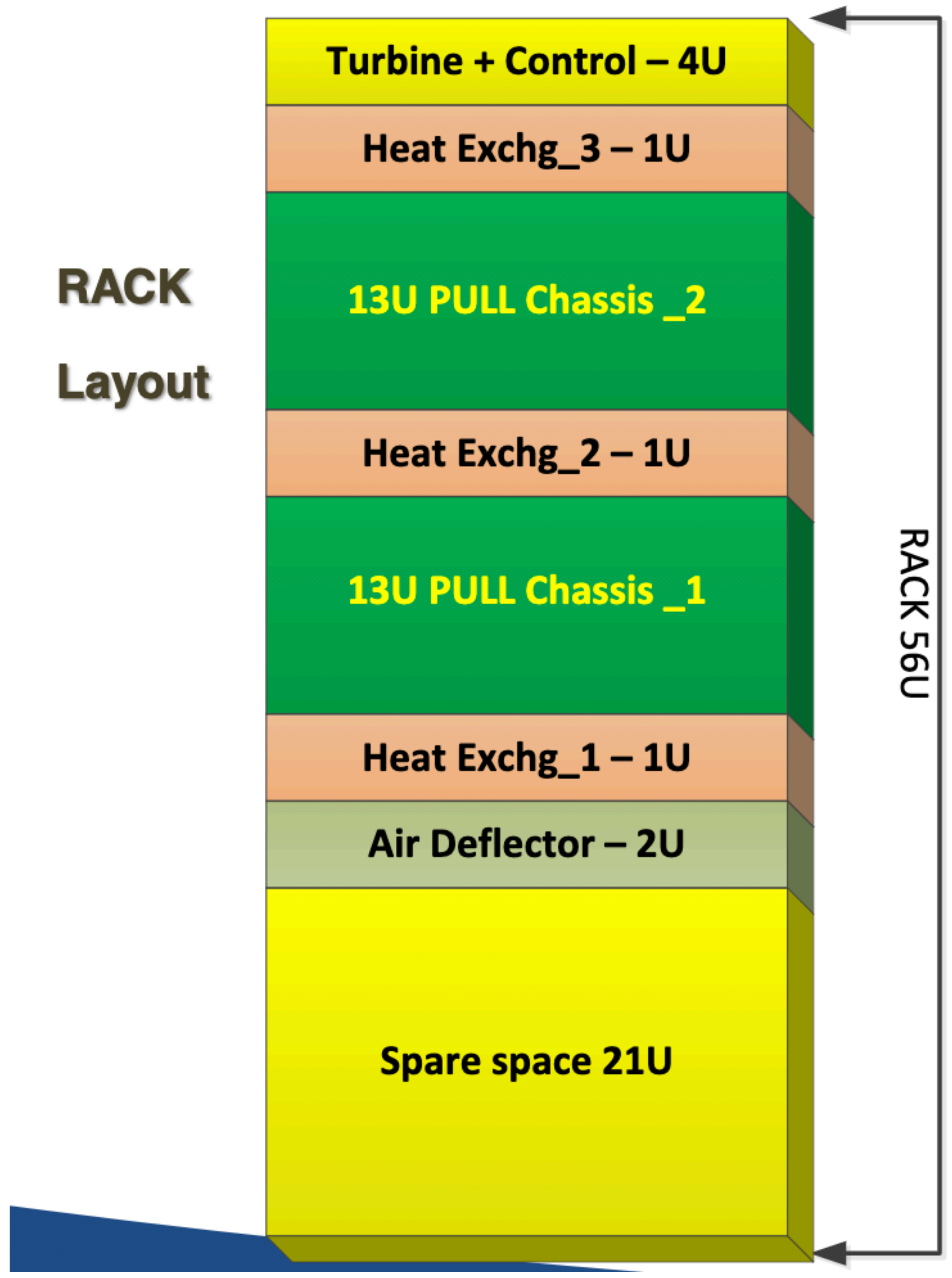
	@ 7 kW	@ 7 kW	@ 7.7 kW	@ 7 kW
Water Flow [m³/h]	0,9	1,0	0,9	1,0
Air Flow [m³/h]	2080	2080	2080	2080
Cold Air Temp. [°C]	24,5	24,2	25,4	25,1
Hot Air Temp. [°C]	35	35	37,1	37,1
Supply Water Temp. [°C]	15	15	15	15
Return Water Temp. [°C]	21,7	21,2	22,4	21,8
Cooler Power [W]	7000	7170	7700	7900
Air Side Pressure Drop [Pa]	95	95	95	95
Water Side Pres. Drop [kPa]	47	57	47	56

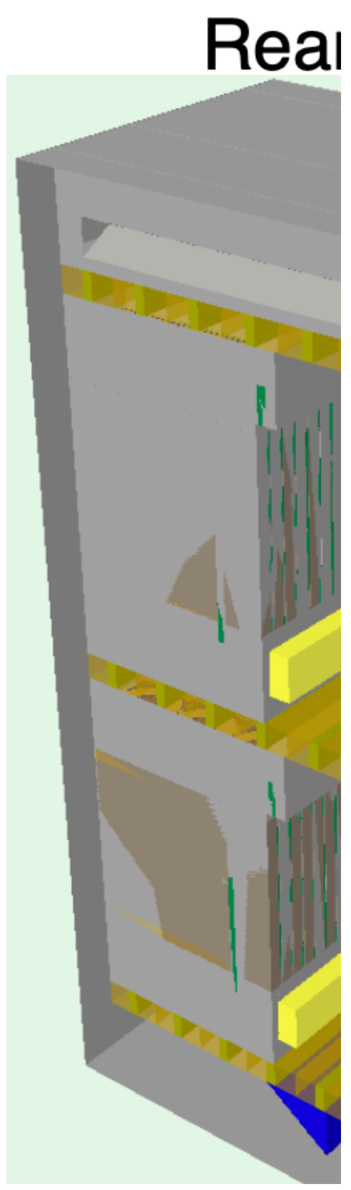
Simulations

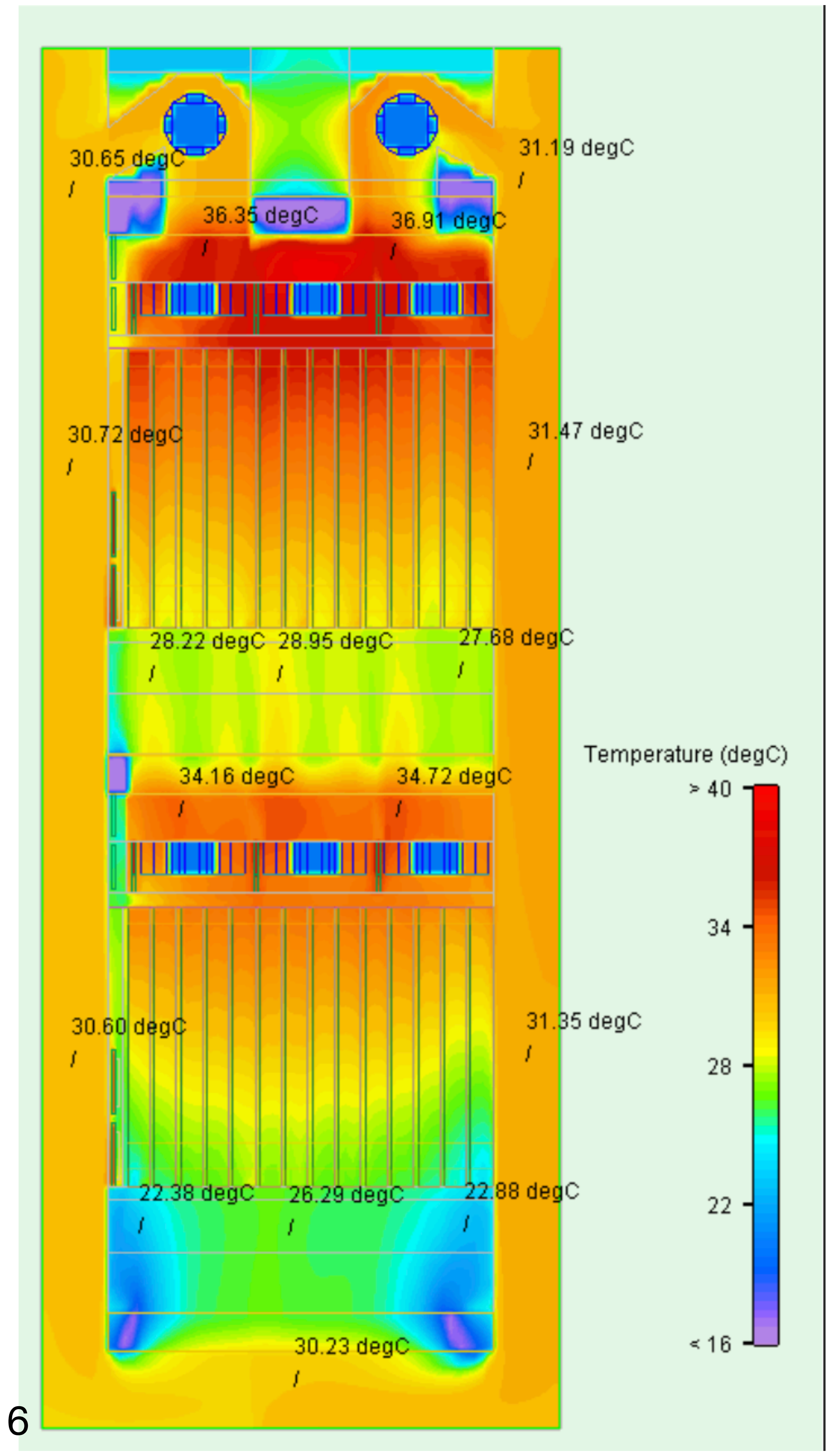
- From: https://indico.cern.ch/event/489996/contributions/2289631/attachments/1345278/2028007/xTCA_IG_Sep2016_ATCA_specs.pdf

1. First simulation run

- 2 x 13U Asis Chassis.
- Chassis air flow bottom up.
- Up to 400W per blade, and 50W RTM
- Heat Exchange 1U, water cooling 16 C







A slide shows that without the turbine, is it better?

Shelf airflow

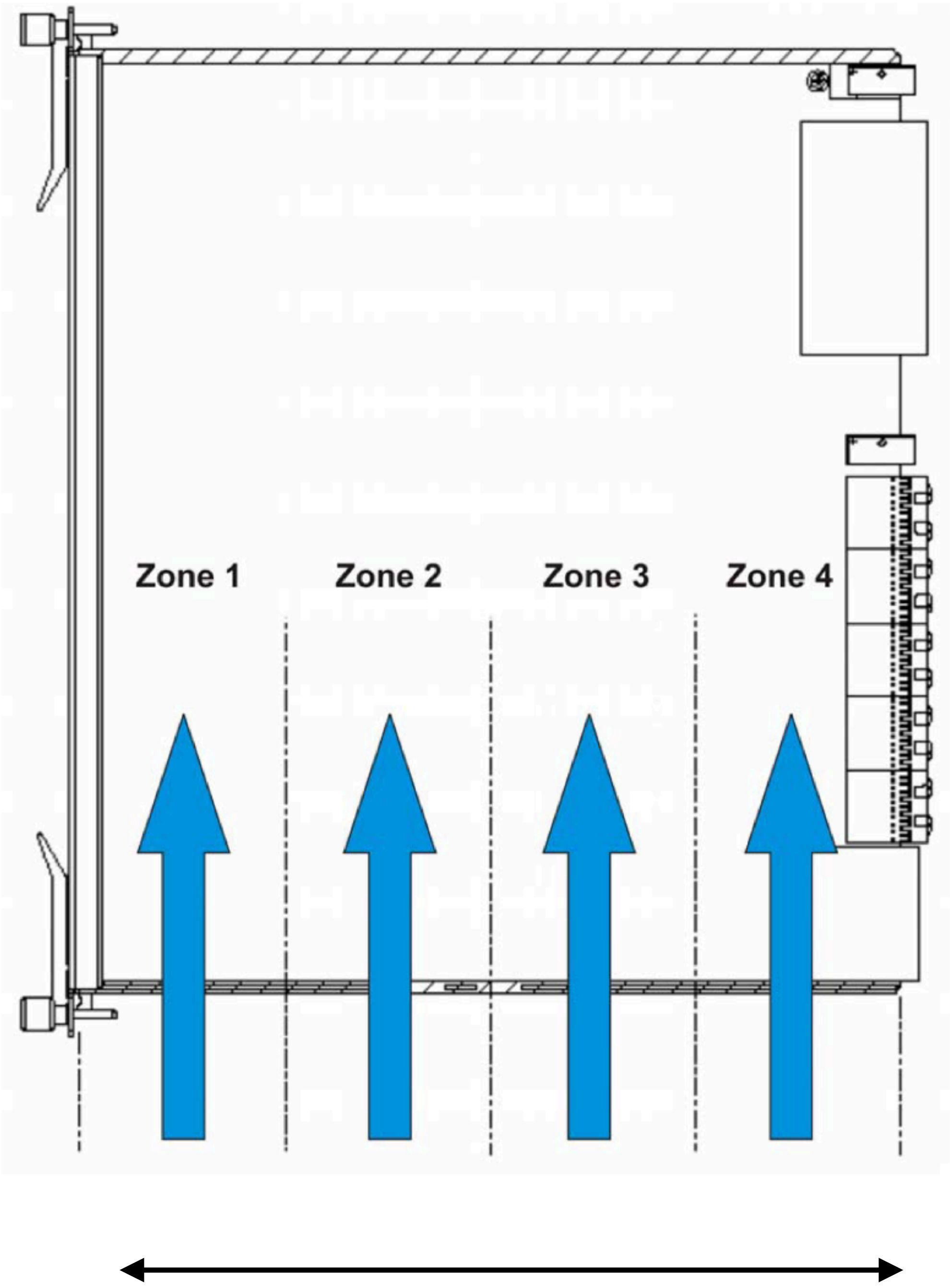


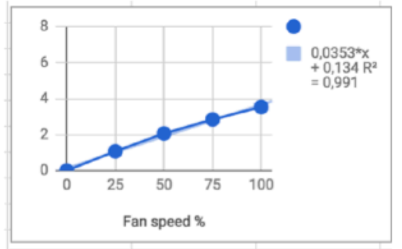
Figure 20: Front Board Air Flow 11990-190

	Zone 1 [m³/h]	Zone 2 [m³/h]	Zone 3 [m³/h]	Zone 4 [m³/h]	∑ [m³/h]	∑ [cfm]
Slot 1	37,4	34,2	33,7	36,3	**141,5**	**83,3**
Slot 2	37,0	31,8	36,6	34,7	**140,1**	**82,4**
Slot 3	39,0	35,6	34,1	25,7	**134,4**	**79,1**
Slot 4	43,4	40,0	34,4	29,4	**147,2**	**86,6**
Slot 5	42,2	37,4	32,1	36,1	**147,7**	**86,9**
Slot 6	40,2	38,6	34,9	39,6	**153,3**	**90,2**
Slot 7	36,1	31,9	37,8	32,7	**138,4**	**81,4**
Slot 8	41,9	38,4	34,7	28,0	**143,0**	**84,1**
Slot 9	42,4	40,3	35,5	33,8	**152,0**	**89,4**
Slot 10	41,6	38,2	33,7	37,6	**151,0**	**88,8**
Slot 11	39,9	37,5	39,6	42,6	**159,6**	**93,9**
Slot 12	37,0	34,3	39,5	32,4	**143,1**	**84,2**
Slot 13	43,3	40,9	37,5	29,4	**151,1**	**88,9**
Slot 14	42,1	39,4	35,4	31,9	**148,9**	**87,6**
∑	**563,5**	**518,3**	**499,5**	**470,1**	**2051,4**	**1206,7**

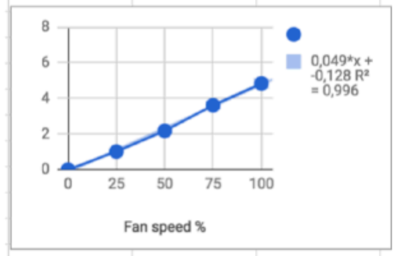
Anemometer: testo 425
Accuracy: ~5%
Measured inside the ATCA shelf
Board setup: like picture

Air speed [m/s] Vs. Fan speed for bottom part

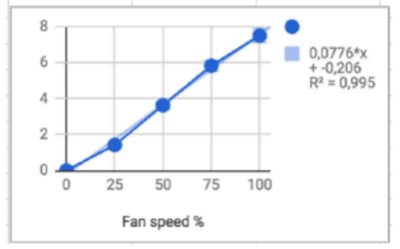
Front



Middle



Rear



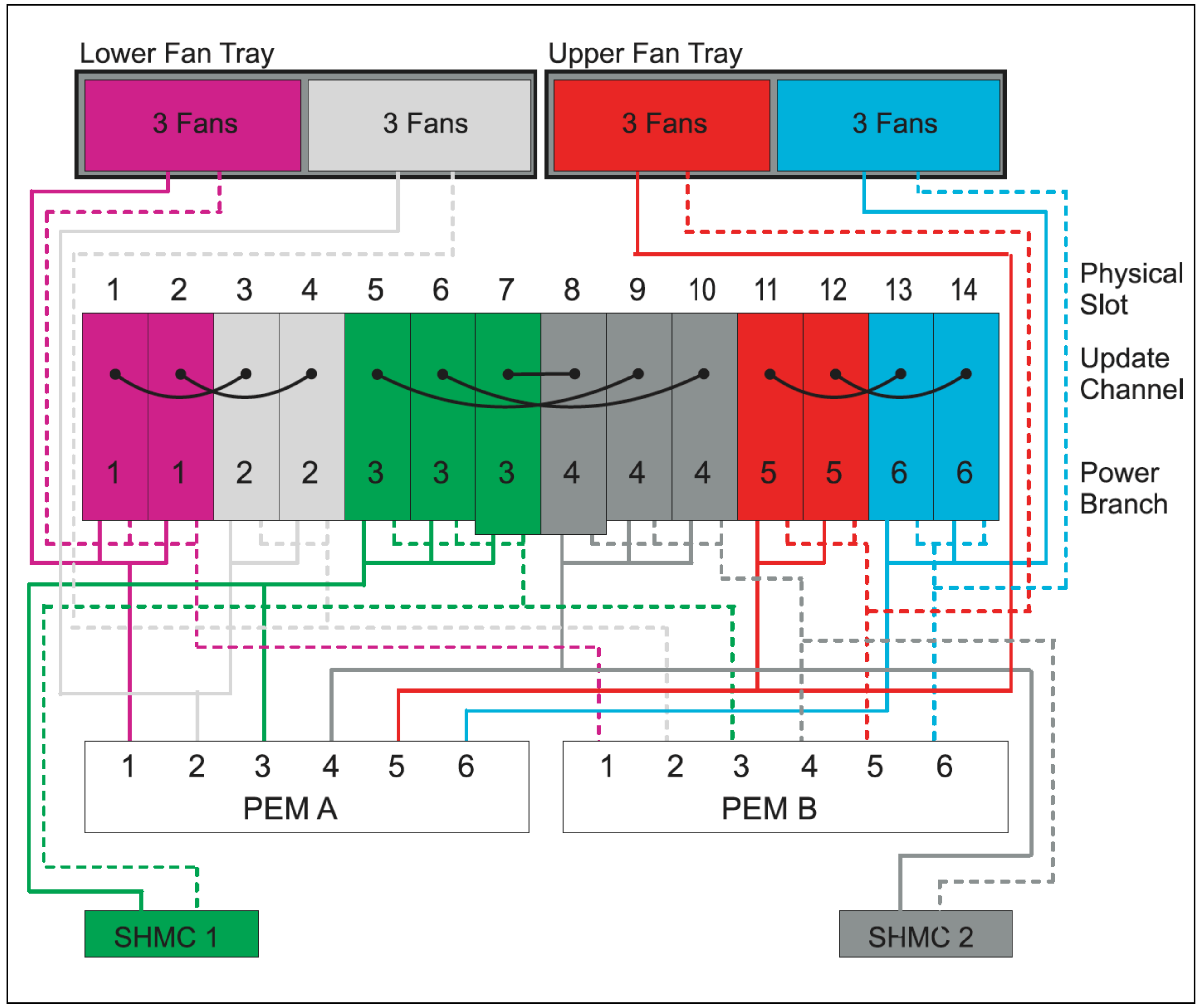
Bottom line: fairly linear, reproducible measurements

- Target shelf fan speed is 10/15 for our racks
- The linearity of the air flow Vs fan speed has been measured in a Comtel shelf -> assume 2/3 of air flow for this validation -> 1350 m3/h as total air flow

Shelf power rails

Manager. This topology is used to keep the max. current per branch less then 35 A.

Figure 29: Power distribution of the 6 Power Branches within the Shelf



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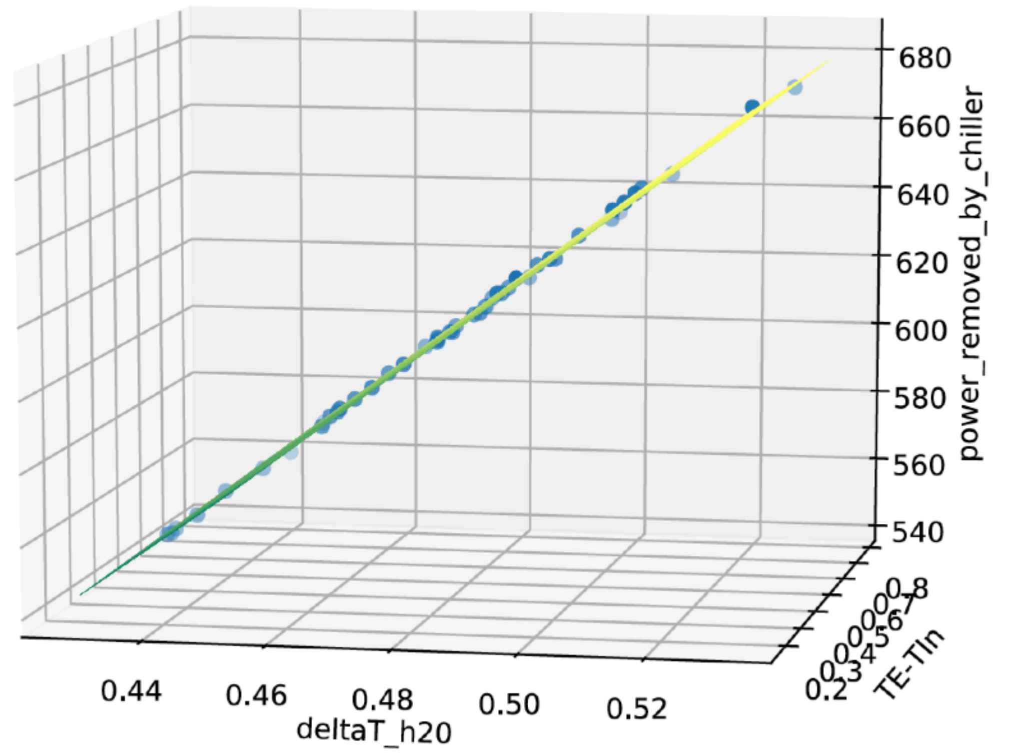
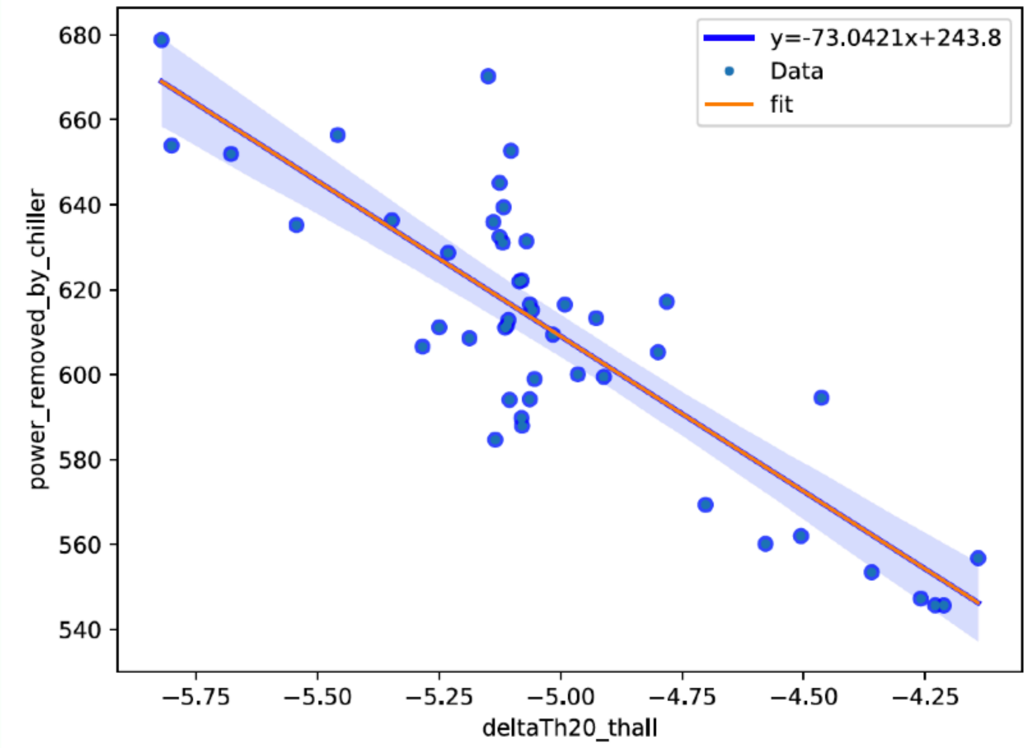
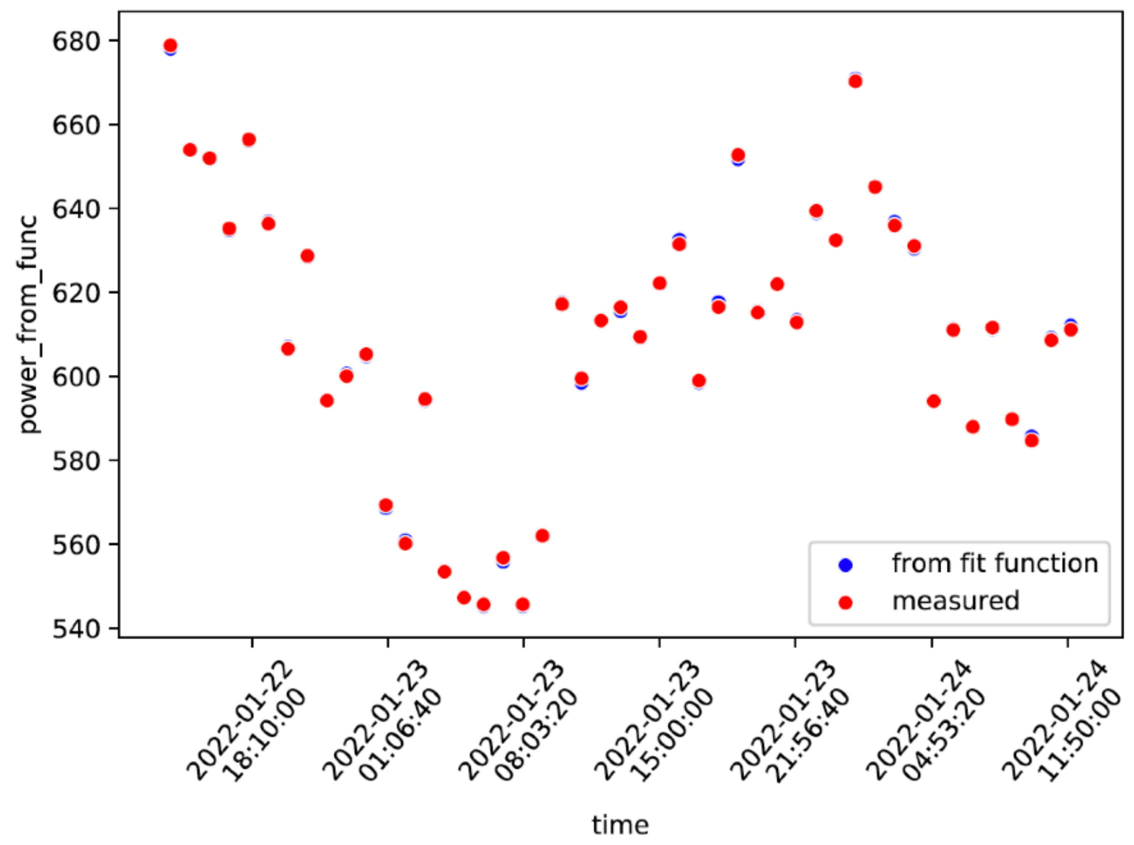
Rack thermal modelling



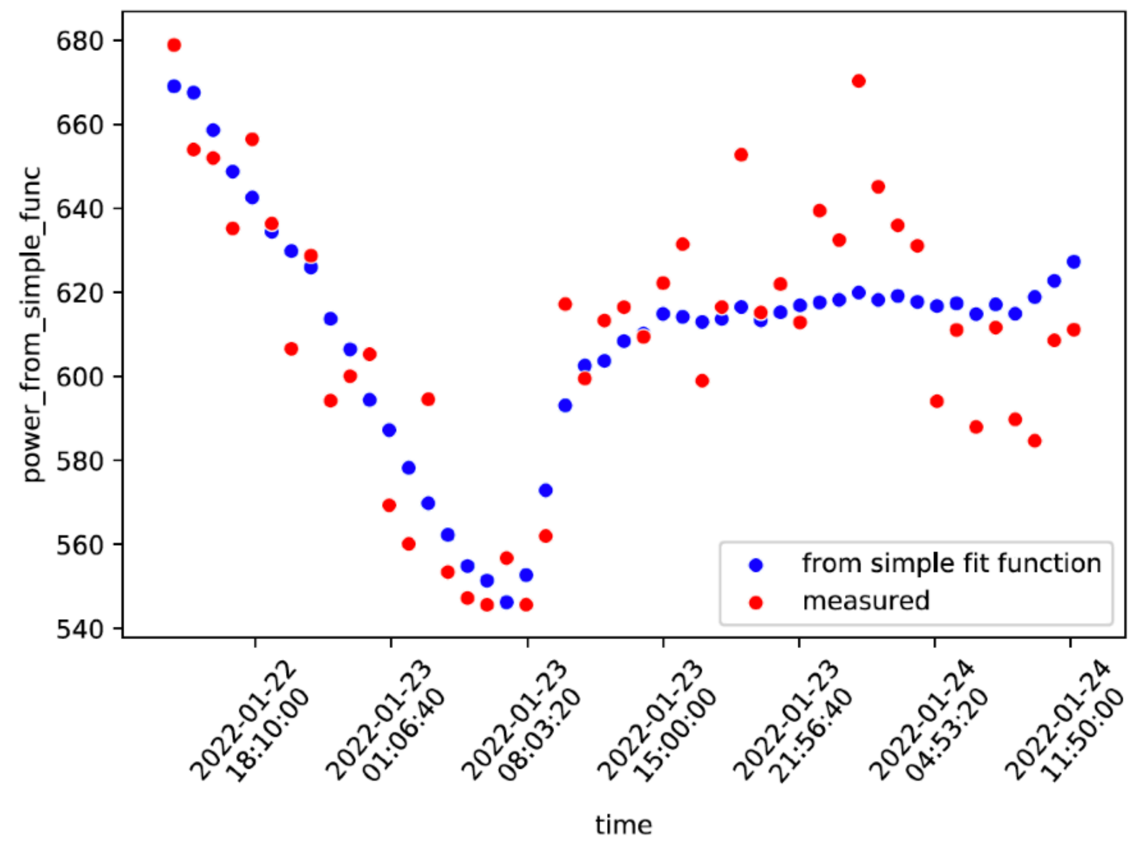
R^2: 0.9997



R^2 (simple model): 0.72

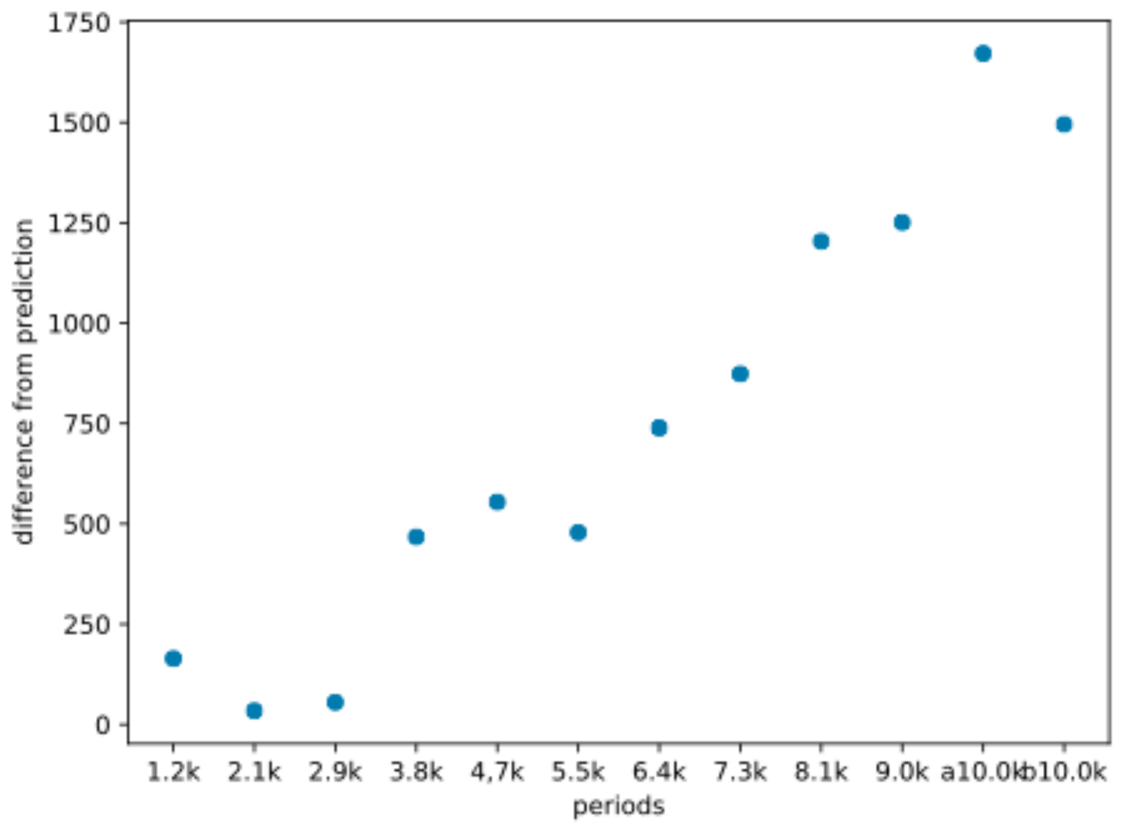


original model



simple model

- During a period where the shelves were off, data was collected to understand the cooling performance as function of different temperatures
- We tried two linear models, one which depends on air loop and external temperatures, and one which depends only on the difference between the water temperature and the ambient temperature
- Both models reproduced the data in case of shelves turned off, but failed reproducing the behaviour once the shelves were activated (injected power was taken into account)
- Linear model failure is another hint of radiative thermal exchange



Not easy to model, Google tells too https://deepmind.com/blog/article/deepmind-ai-reduces-google-data-centre-cooling-bill-40