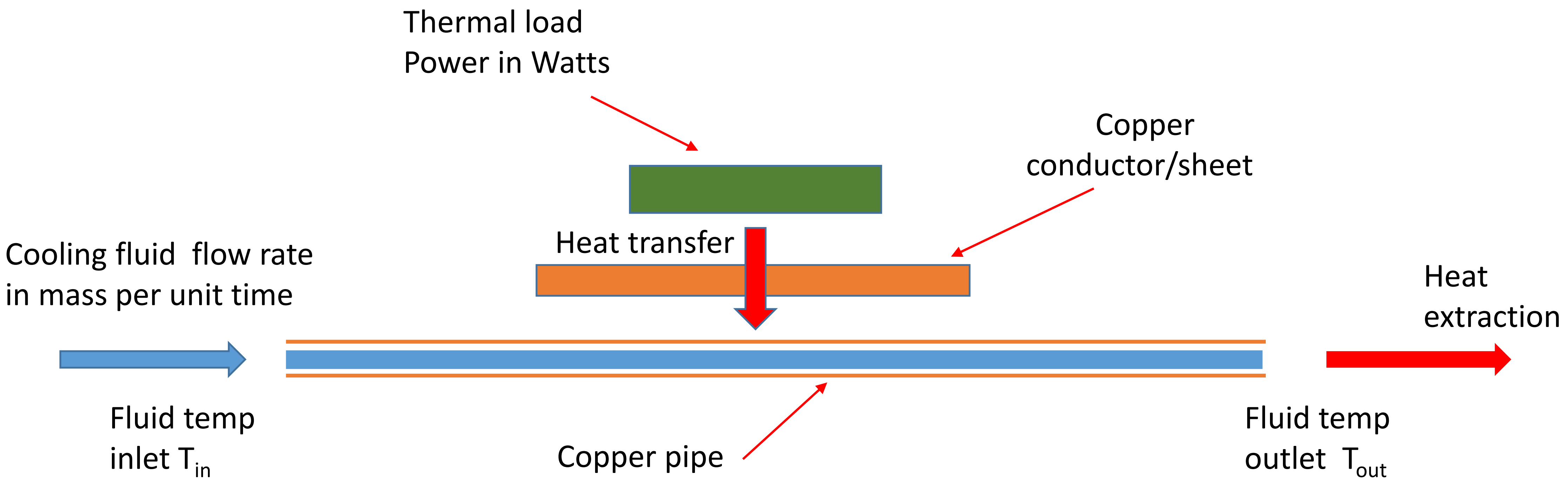
Compressed air cooling through FEB cooling circuit OR a leak free cooling system

Ian

31.08.21

Schematic of a thermal load and it's cooling circuit



There are 2 areas of interest of heat transfer.
From the load through the copper sheet, a thermal resistance. See I.Bagatori
And the heat that is extracted from the area by the flowing fluid .
Equilibrium is reached when heat generation = ALL heat losses.
Resultant temperatures of each element are established.
The latter case is looked at below.

Fluid mass
flow rate
[kg/s]

Temperature difference,
between inlet & outlet
[degree C]

$$\dot{Q} = \dot{M} * Cp * \Delta T$$

Dissipated
Power
[Watts]

Thermal
capacity
of fluid
[kJ/kg.K]

Parameters to play with;

- Power is 25W per FEB
- Mass flow rate can be varied.
- Thermal capacity is either that of water or air
- Delta T will vary along the length of the cooling system .
- The absolute entry temp is important .

The higher the fluid temp. the lower the power extracted from the FEB.

There are 3 orders of magnitude of difference in heat extraction capability between Water and Air ! This will not be easy.

Calculate the flow for air to achieve an acceptable delta T.
CMS RE cooling 2 litre H_2O/min

For water

$\dot{Q} = \dot{M} * Cp * \Delta T$

Q dot [watts]	50 [W]		
M dot [kg/s]	2 [litres/min]		
Cp Heat Capacity of water = 4.184 [kJ/kg.degC]			
Calculate Delta T [degC]	=	0.362 [degC]	basically no gradient along the cooling circuit
If only 0.2 [litres/min]	=	3.62 [degC]	
Or 0.1 [litres/min]	=	7.24 [degC]	perhaps an acceptable gradient

For Air

$\dot{Q} = \dot{M} * Cp * \Delta T$

Q dot [watts]	50 [W]	
M dot [kg/s]	To be found [litres/min]	
Cp Heat Capacity of Air [kJ/kg.degC]	= 1.0035 [kJ/kg.degC]	
Assume Delta degC	= 10 [degC]	Similar gradient to above
Calculated mass flow rate of air	= 4.98 [g/s]	
Air density	= 1.225 [kg/m3] @ 15[degC]	
Volume flow rate	= 14.6 [m3/hr]	

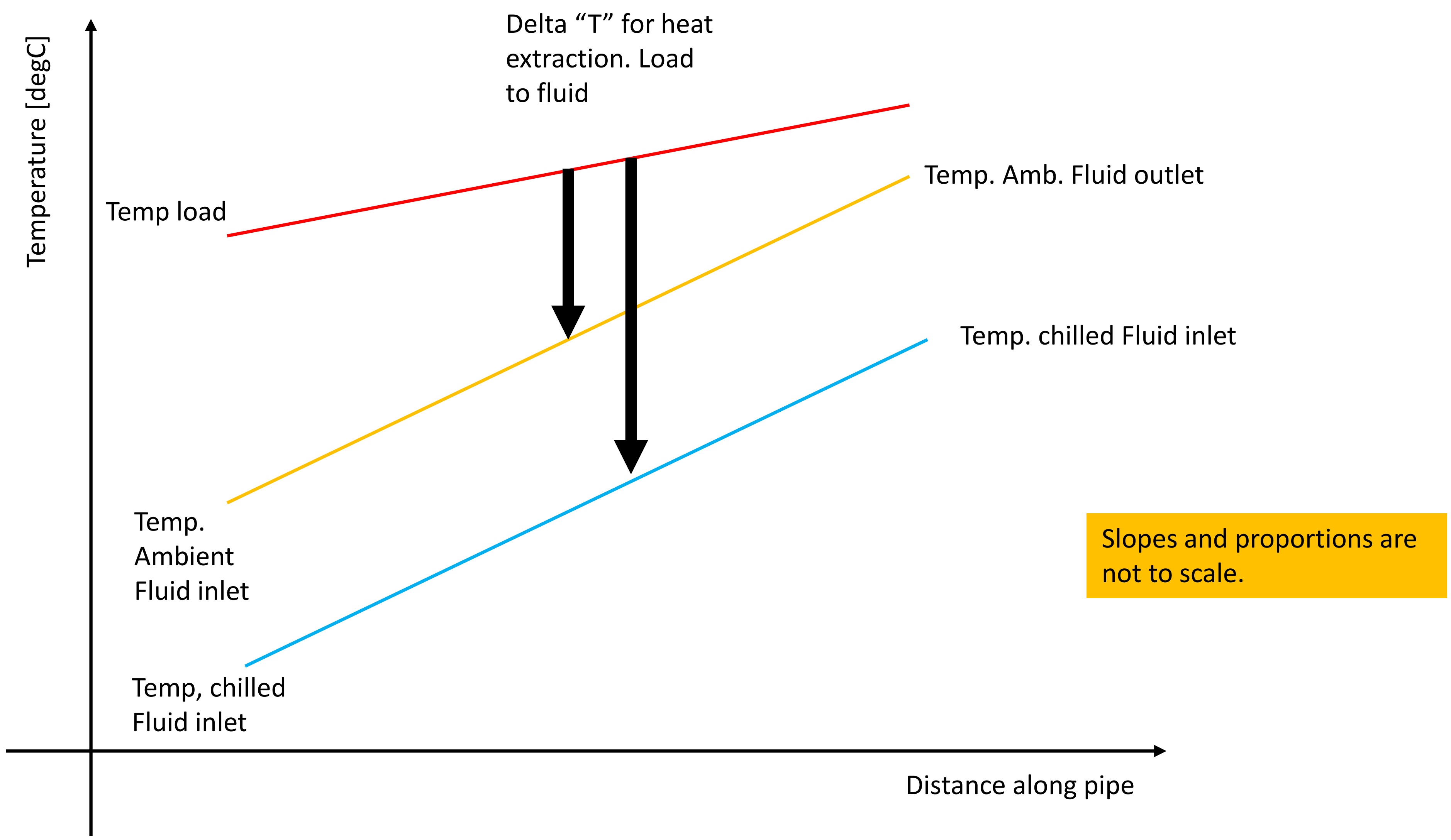
The flow of air in the pipe will result in heat extraction from the load (resistance). This heat extraction will be a function of the temperature difference between the cooling fluid and the resistance at each point along the pipe.

This extraction of heat will produce a gradient along the length of the pipe.

Additional heat can be extracted by increasing the former temperature difference by taking the inlet fluid below ambient, meaning a chiller !

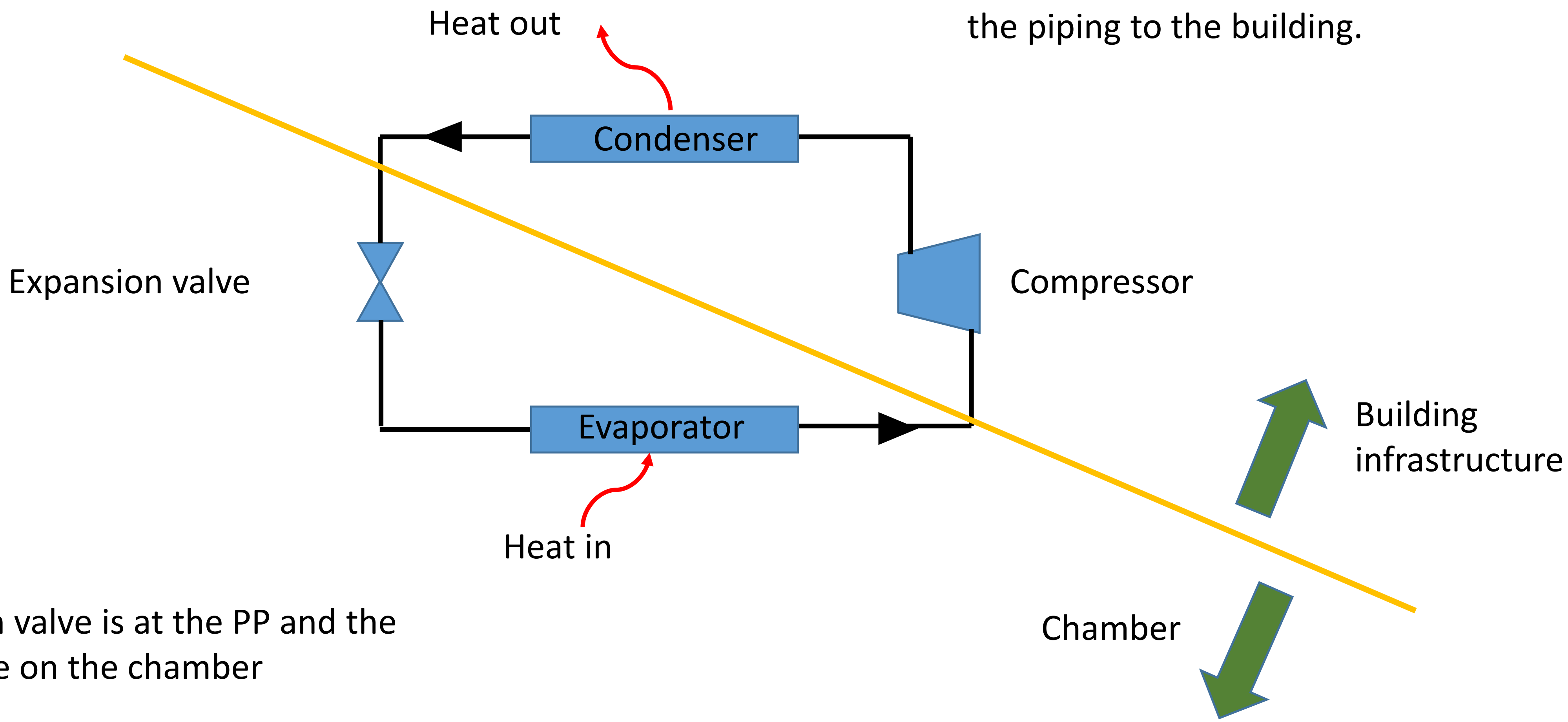
Can a chiller be built at the entry and onto the chamber ?

The principle values of interest and the importance of sub ambient fluid inlet temp.



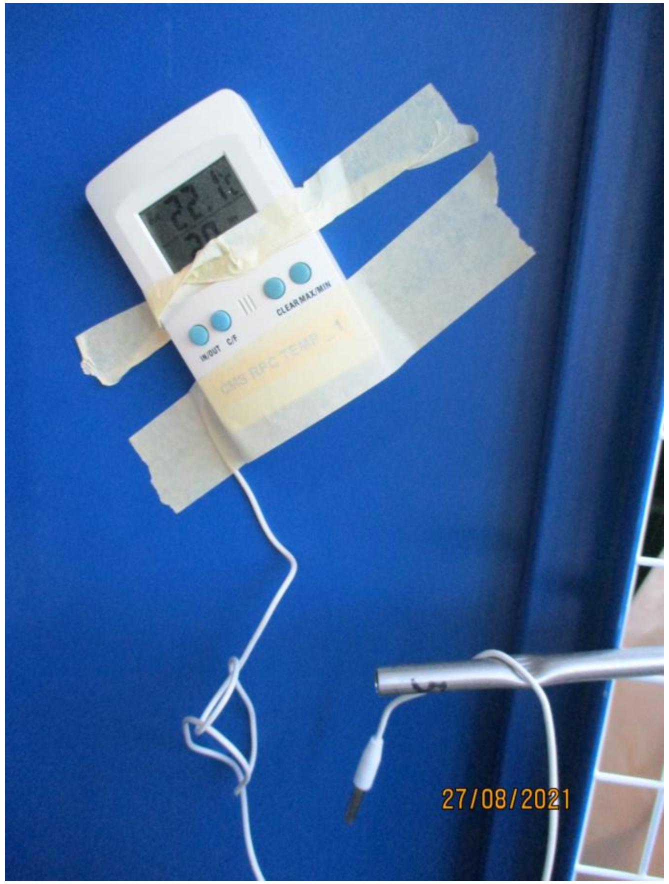
The air, in this case, can be chilled before the entry to the chamber.
A thermodynamic refrigeration cycle is required. In this case the circuit is not closed on a “local” scale.

The infrastructure at CERN can be used for the compressor and the condenser is the piping to the building.

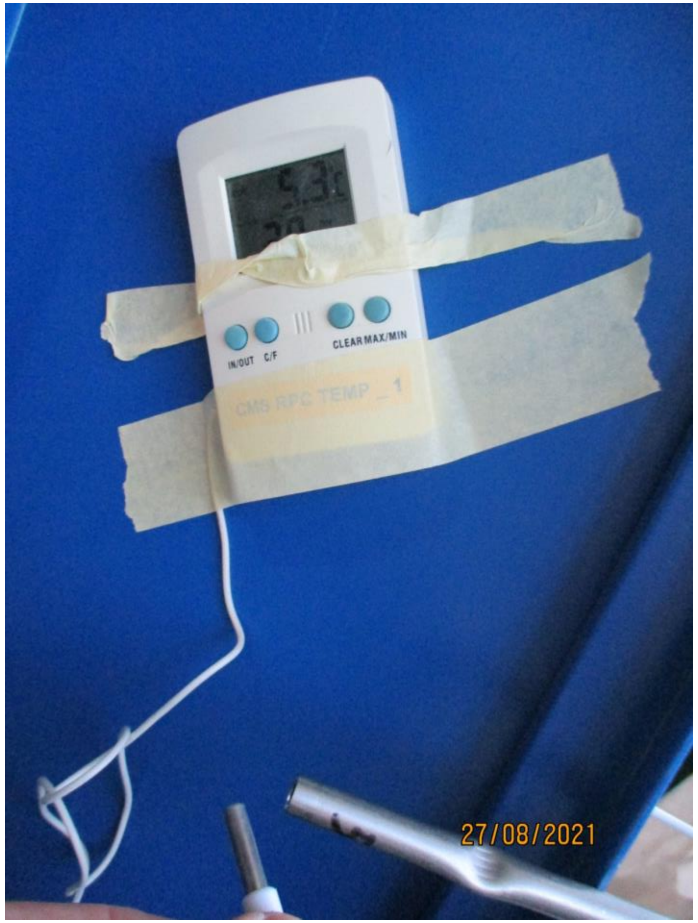


The expansion valve is at the PP and the evaporator are on the chamber

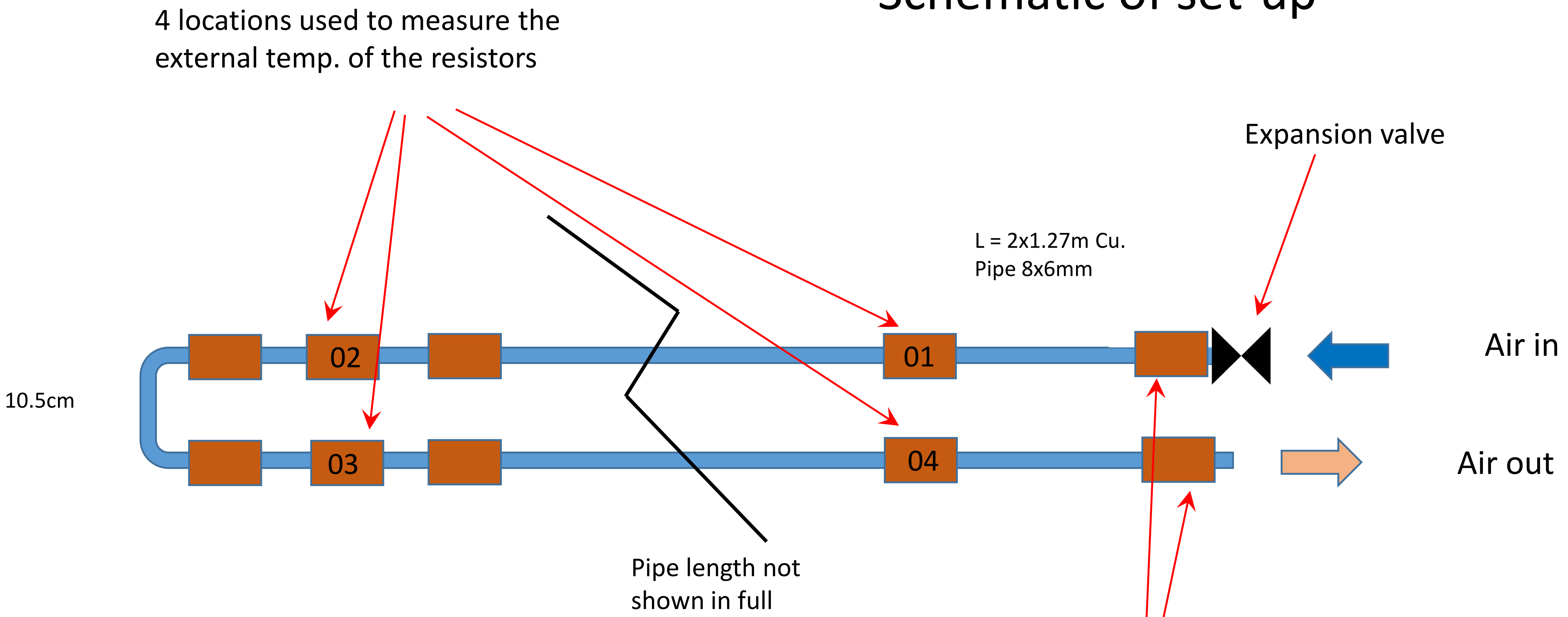
Illustration of passive cooling of ambient compressed air.
Sub zero temperatures can be obtained.



Temperature reduction of 17 degC through the first attempt with expansion valve. No optimisation



Schematic of set-up

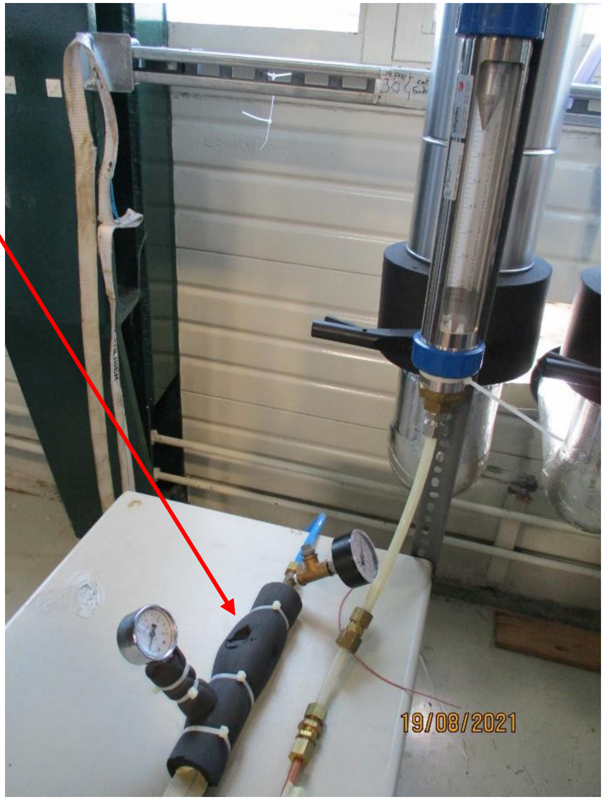


Cu pads 13 on each length = 26.
22 pads equipped with 100 Ohm resistors
Cu. Pads 50 x 30 x 3mm pitch between ~100mm

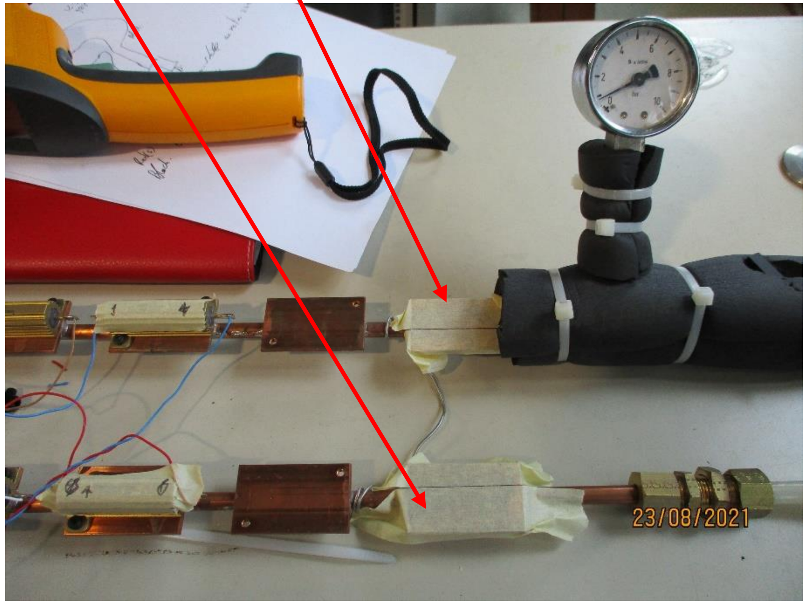
2 pads for entry air
and exit
temperatures
measurements
with IR Fluke pistol

Layout of copper pipe and 22 resistors

Air entry with expansion valve, and exit with flow meter

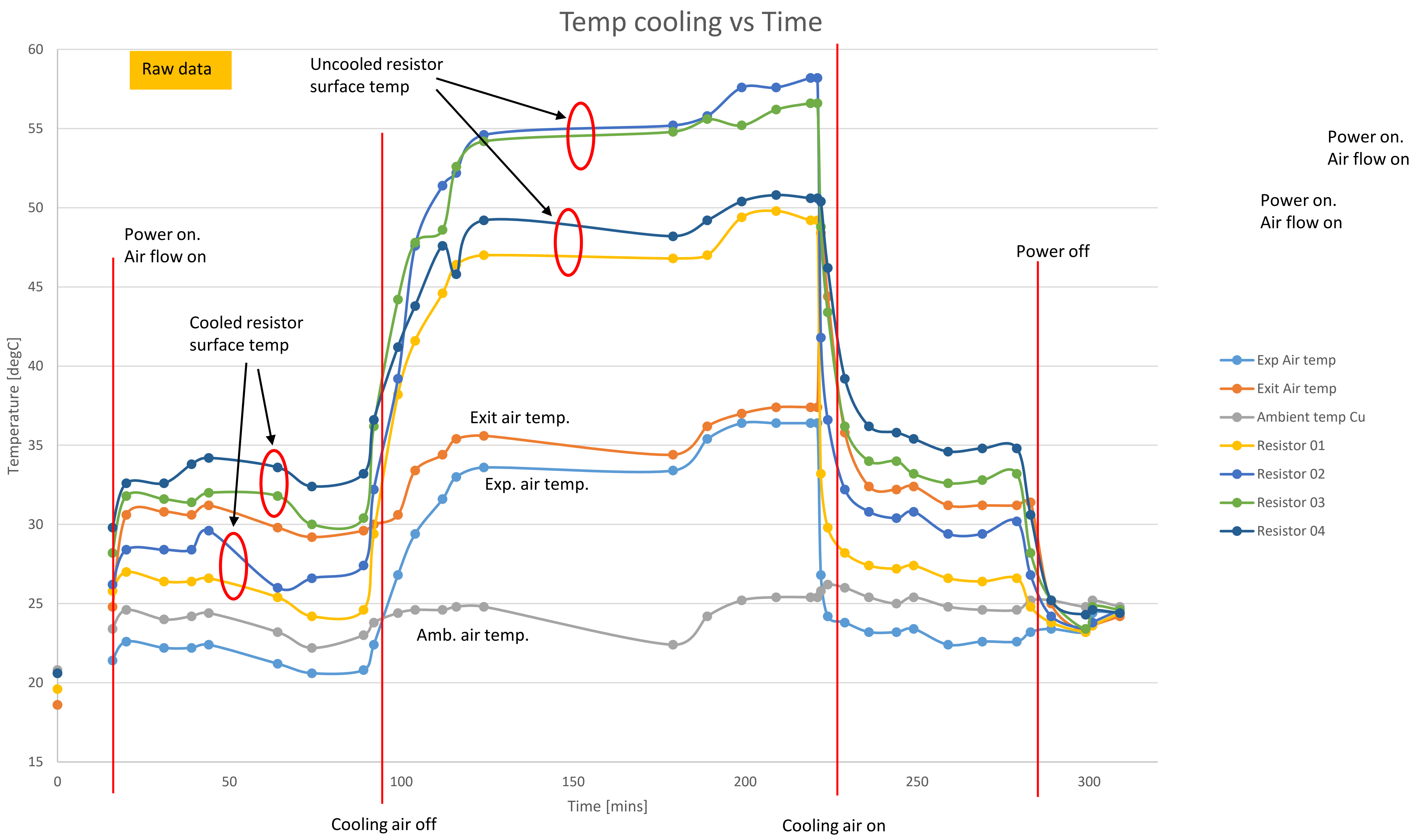


Temperature measurement points. Using IR pistol
Entry temp.
Exit temp.

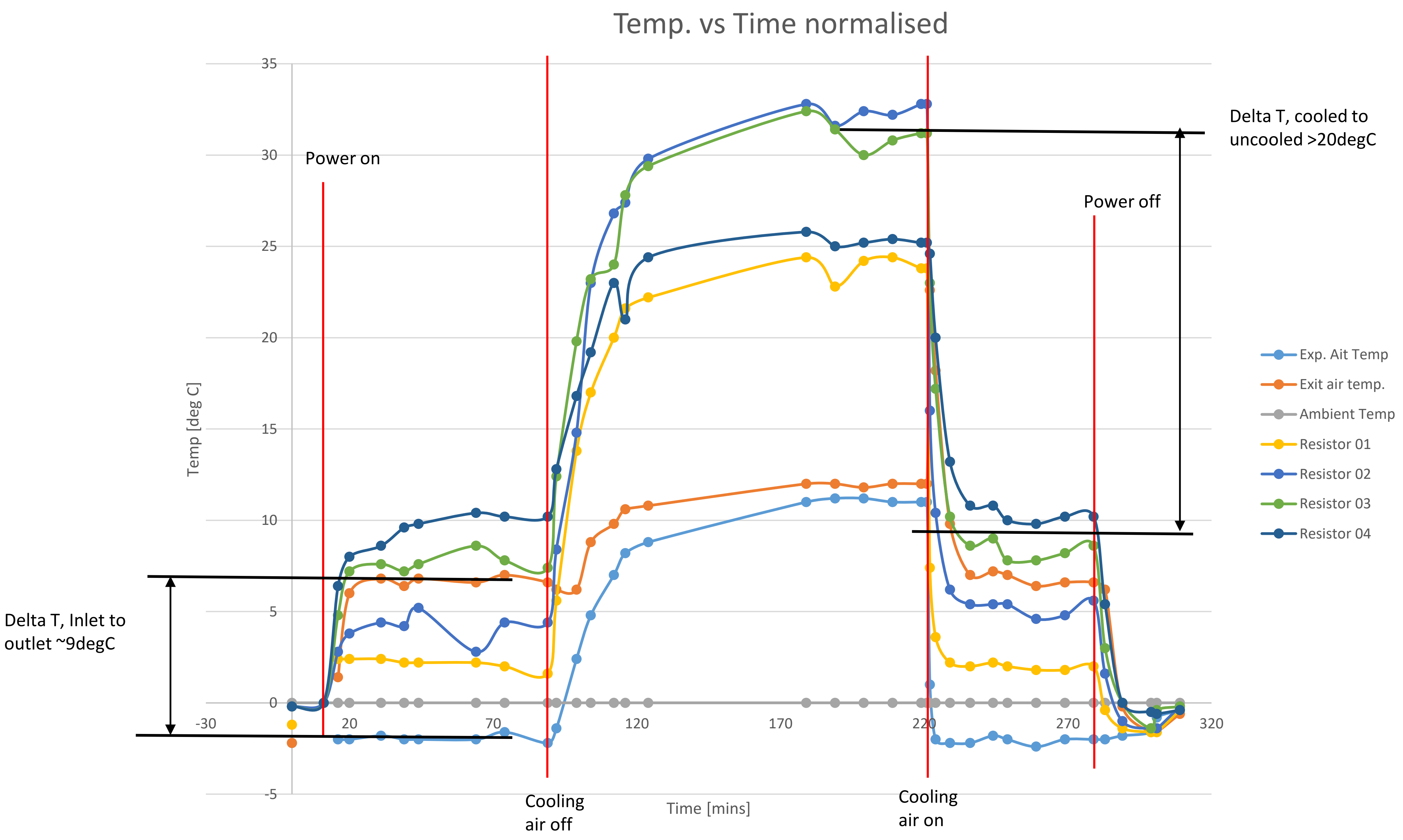


Air flow meter [m3/hr]

Power supply and manual DAQ



Temp cooling vs Time
Raw data
Uncooled resistor surface temp
Cooled resistor surface temp
Power on. Air flow on
Power on. Air flow on
Power on. Air flow on
Power off
Exit air temp.
Exp. air temp.
Amb. air temp.
Cooling air off
Cooling air on
Temperature [degC]
Time [mins]
60
55
50
45
40
35
30
25
20
15
0
50
100
150
200
250
300
Exp Air temp
Exit Air temp
Ambient temp Cu
Resistor 01
Resistor 02
Resistor 03
Resistor 04


Temp. vs Time normalised
Temp [deg C]
Time [mins]
35
30
25
20
15
10
5
0
-5
-30
20
70
120
170
220
270
320
Power on
Cooling
air off
Cooling
air on
Power off
Delta T, cooled to
uncooled >20degC
Delta T, Inlet to
outlet ~9degC
Exp. Ait Temp
Exit air temp.
Ambient Temp
Resistor 01
Resistor 02
Resistor 03
Resistor 04

Calculated extracted heat from test installation

$\dot{Q}$ = $\dot{M}$ * Cp * ΔT

Cp Heat Capacity of Air [J/kg.degC]	= 1.0035 [kJ/kg.degC]
Air density	= 1.225 [kg/m3]
Air entry temp.	= 22 [deg C]
Exit air temp	= 31 [deg C]
Vol. flow rate	~ 10 [m3/hr]
Calculated mass flow	= 3.4 [g/s]
Removed heat @ Delta T of 9 degC	= 30.7 [W]

The remaining 20W is convected and radiated away.

Nota. The inlet & outlet temperatures are NOT the fluid temperatures

Conclusions

Compressed air cooling through the cooling circuit reduces the temperature of the resistors, from 55degC, by >20degC

The use of the compressed air circuit available through out CERN, not dry air, can cool tens of watts of heat load with a delta T of around 10 degrees for free.

Optimisation of the expansion valve opening will produce better results, only one setting tried as the flow meter dynamic range was insufficient.

Compressed air can be cooled by > 17degC

Measure the flow rate with more appropriate flow meter.

The inlet & outlet air temperature should be established.

The noise level is similar or less than an average rack when the exhaust is “silenced” and vented outside.

The cooling due to uncooled comp air should be measured to establish the cooled air component of the heat extraction.

Notes

Notes

Look at delta air on and air off >20degC

Repeatable results before and after air on , off

Illustrate cooling using nozzle , try and obtain freezing ! Partially done

explain temp increase around circuit

Outlet temp jumps UP when cooling comes back on !

Impact of airflow to cool hot uncooled resistors

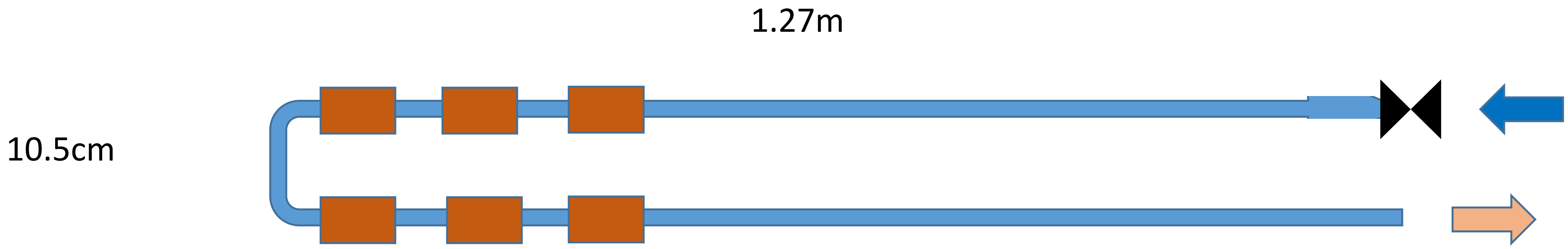
Air quality on cooling.

Long time , >60mins, to stabilise with no cooling.

Or use the expansion of the air after an obstruction to obtain sub ambient cooling as in the pressure released from a tyre valve !

OR

We squirt it directly onto the FEB through some nozzles, forced air convective cooling !!



Cu pads 13 on each length = 26.
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Ian Crotty - Outlook Web App | Relative Magnetic Permeability - | Files - CERNBox: the CERN Cloud | Flow meters for compressed air -

ifm.com/de/en/category/070/070_020/070_020_010#!/S/BD/DM/1/D/0/F/0/T/24

Selector

Product designation

- Compressed air meter (33)
- Flow rate meter for gases (4)
- industrial gas counter (7)

Media

- Argon (Ar) (9)
- carbon dioxide (CO2) (9)
- compressed air (38)
- helium (2)
- nitrogen (N2) (9)

Measuring range min. (l/min)

0.80 – 40.00

Final value of the measuring range (l/min) (l/min)

83.40 – 11670.00

Measuring range min. (m/s)

0.10 – 0.60

Final value of the measuring range (m/s) (m/s)

13.30 – 143.90

Flow meters for compressed air

- Measurement to ISO 2533 and DIN 1343
- For compressed air in industrial use as well as argon (Ar), carbon dioxide (CO2), nitrogen (N2)
- Large measuring range up to 700 Nm³/h
- Fast response time and high response sensitivity
- With volumetric flow quantity, total quantity and temperature indication

https://www.ifm.com/de/en/category/070/070_020/070_020_010#!/S/BD/DM/1/D/0/F/0/T/24

Sort: Best results | Elements: 24 | Expand All | Page 1 of 2

Product	Installation length EL	Materials (wetted parts)	Electrical design	Process connection	Output function
SD6500		stainless steel (1.4301 / 304); stainless steel (1.4305 / 303); FKM; ceramics glass passivated; PPS GF40; Al2O3 (ceramics); acrylate	PNP/NPN	R 1/2 DN15	normally open / normally closed; (parameterisable); analogue
SD5500		EN AW-6082 (aluminium); stainless steel (1.4305 / 303); FKM; ceramics glass passivated; PPS GF40; Al2O3 (ceramics); acrylate	PNP/NPN	G 1/4 DN8	normally open / normally closed; (parameterisable); analogue
SD9500		stainless steel (1.4301 / 304); stainless steel (1.4305 / 303); FKM; ceramics glass passivated; PPS GF40; Al2O3 (ceramics); acrylate	PNP/NPN	R 1 1/2 DN40	normally open / normally closed; (parameterisable); analogue
SD8500		stainless steel (1.4301 / 304); stainless steel (1.4305 / 303); FKM; ceramics glass passivated; PPS GF40; Al2O3 (ceramics); acrylate	PNP/NPN	R 1 DN25	normally open / normally closed; (parameterisable); analogue
SD2500		stainless steel (1.4301 / 304); stainless steel (1.4305 / 303); FKM; ceramics glass passivated; PPS GF40; Al2O3 (ceramics); acrylate	PNP/NPN	R 2 DN50	normally open / normally closed; (parameterisable); analogue

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T-CDI-5200-10S Compressed Air Flow Meter (1 - 80 SCFM)

Reference T-CDI-5200-10S

Manufacturer: CDI Meters

- Easy to install
- No moving parts
- Weather resistant and surge protected (new with Rev. 3)
- Milliamp output
- Pulse output convertible to threshold output
- User-configurable scaling, filtering and units of measure
- Optional RS-485 output for networking

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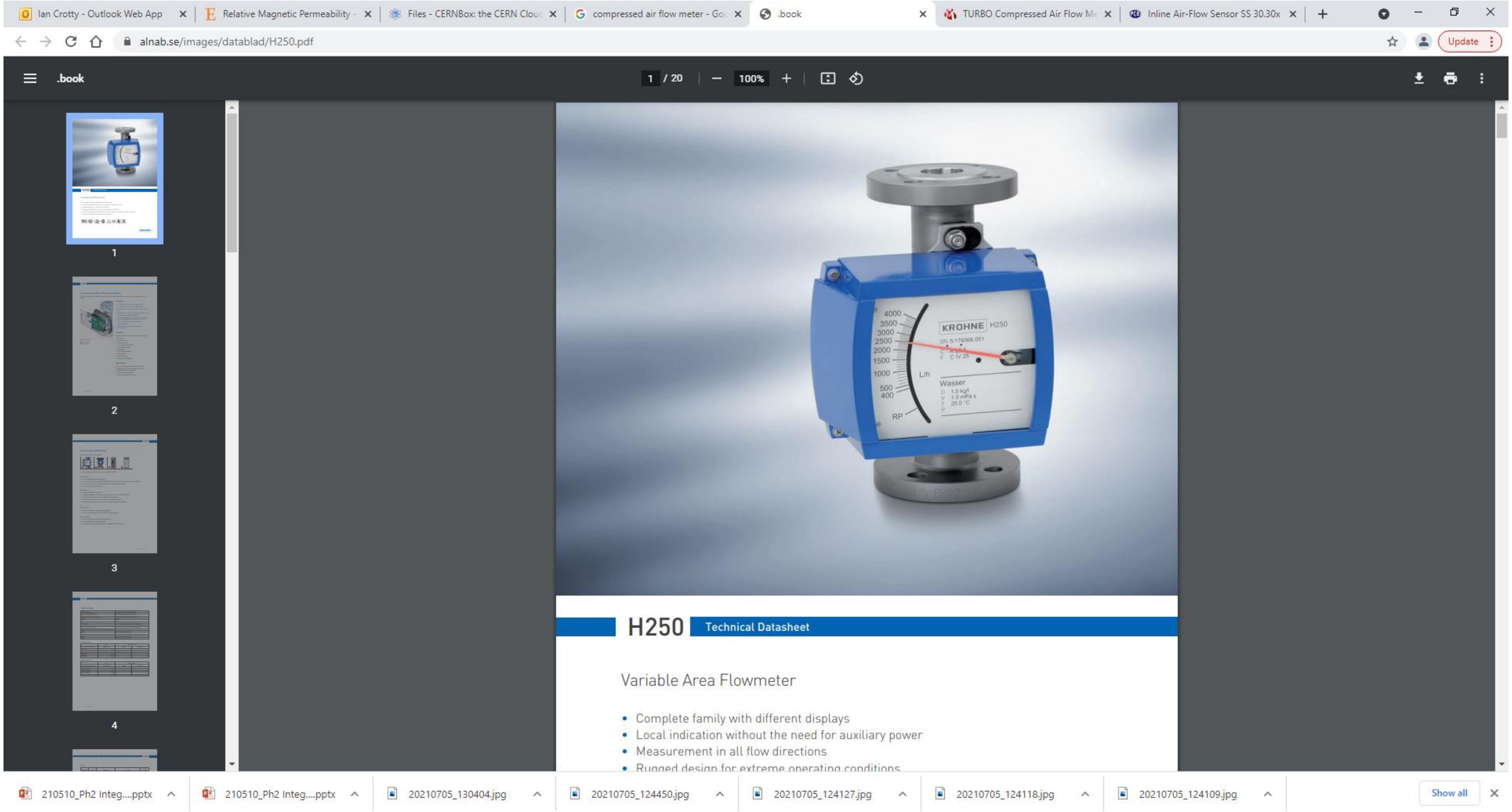
CHARACTERISTICS | DESCRIPTION | CATALOGS https://www.alnab.se/images/datablad/H250.pdf



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