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Thermal-Fluid Dynamic FEM Simulation of Advanced Water Cold Plates for Power Electronics

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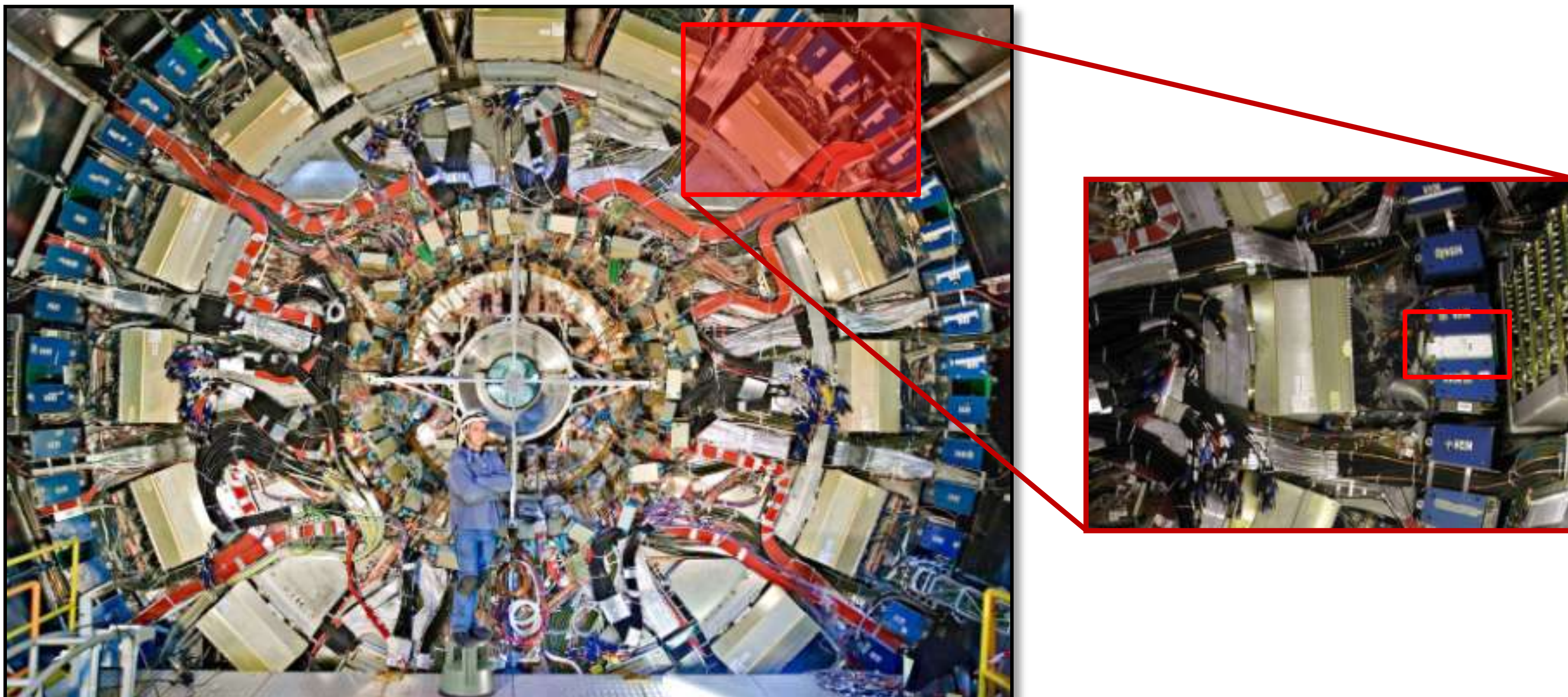
Purpose of the work

Thermal design of power supplies for application in high energy physics experiments: cold plate optimization

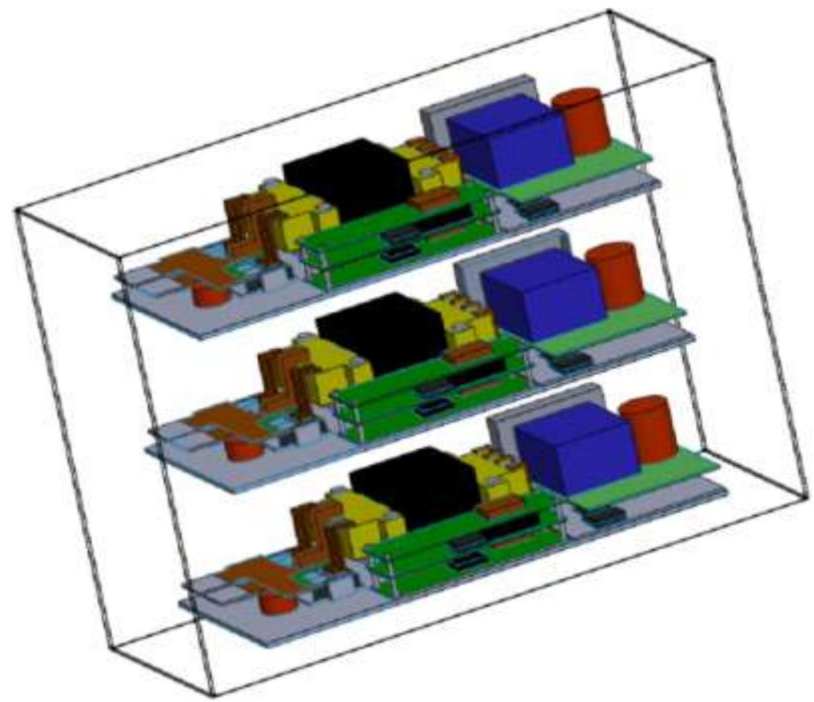


CERN, Genève (CH) LHC - ATLAS

System thermal constraints

DC-DC main converter: 280-12 V, P_{out} = 3 kW

3 modules 1.5 kW each
Redundancy 2+1:
- nominal condition: 3 x 1 kW
- one module failed: 2 x 1.5 kW



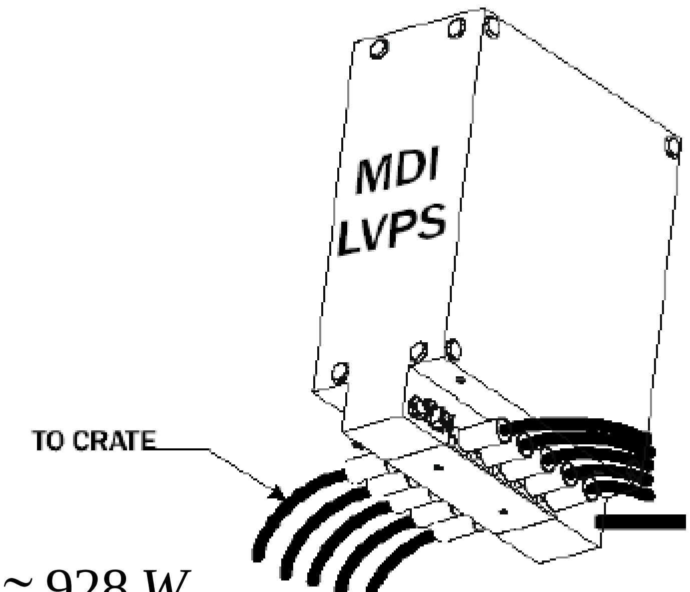
Worst case efficiency: η = 79%
Dissipated power = 800 W
- nominal condition: 3 x 267 W
- one module failed: 2 x 400 W

Each module cooled by its own water heat sink

System thermal constraints

DC-DC main converter: 280-12 V, P_{out} = 3 kW

- **Case**: 150 x 402 x 285 mm^3, steel 1510
- **Water cooling system**:
  - *delivery* = 1.9 l/min,
  - $\Delta p \leq 350$ mbar
  - T_{inlet} = 18 °C ; $T_{outlet} \leq$ 25 °C
- Maximum heat flux:



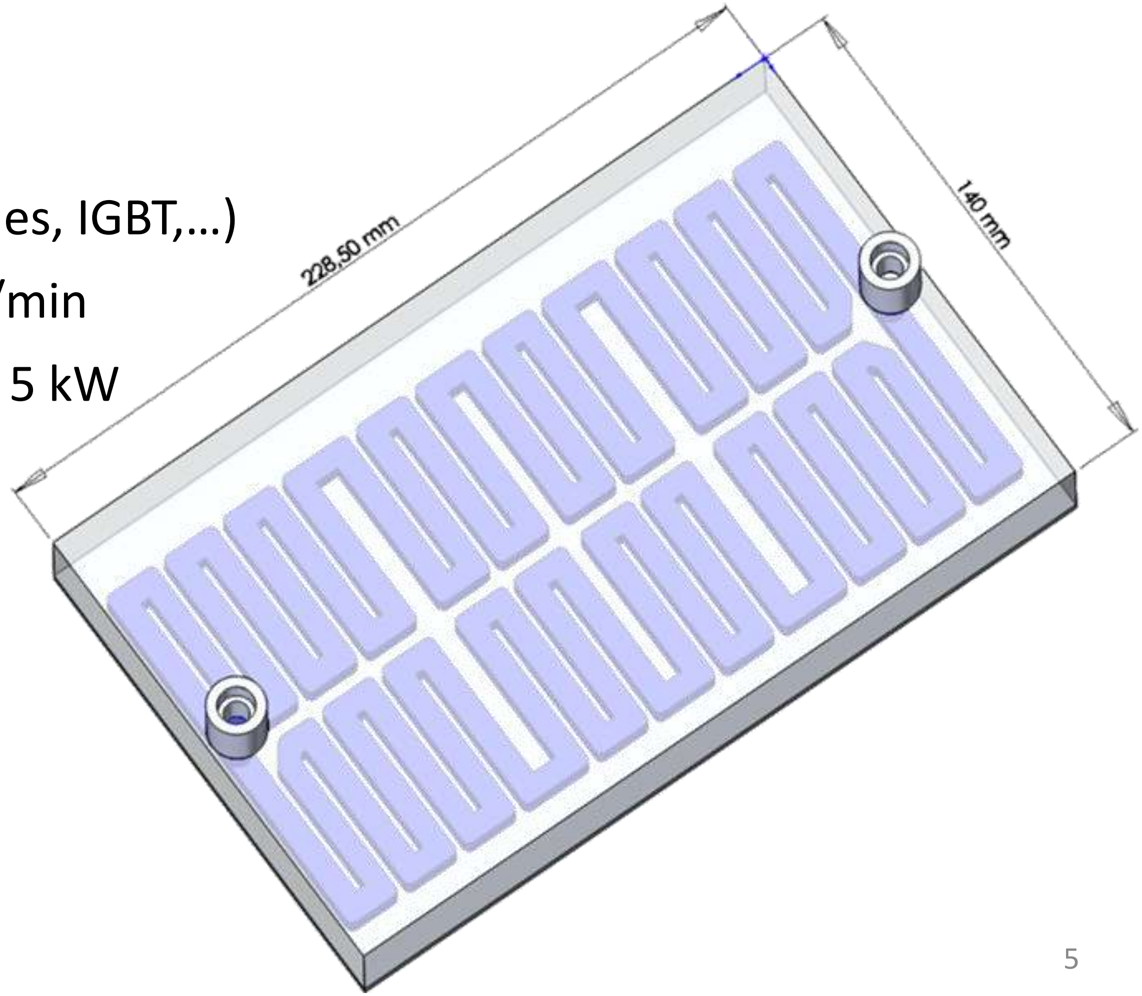
$$Q_{H_2O\,flow} = C_p \cdot \Delta T \cdot delivery = 4186 \cdot 7 \cdot \frac{1.9}{60} \cong 928\ W$$

- Room temperature = 18 °C
- Maximum case external temperature: 20 °C, stable

Modeling validation

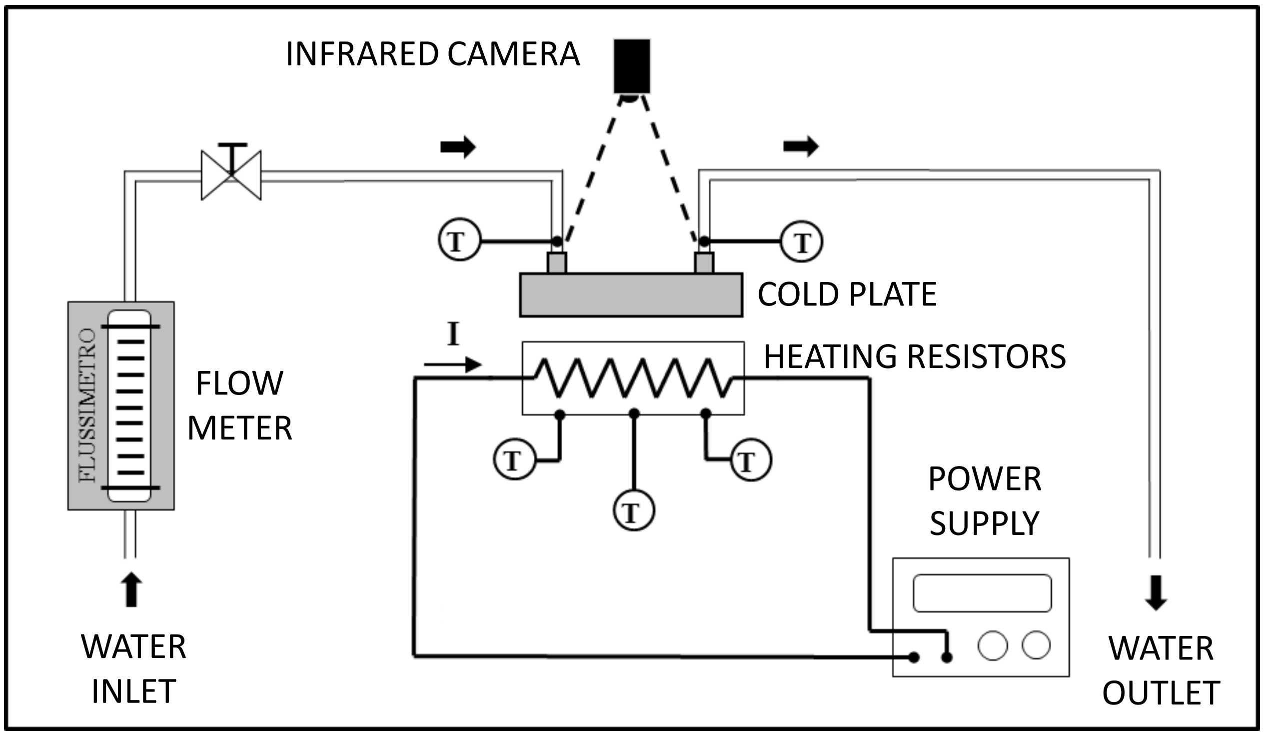
POSEICO AWCH_L228W140T28

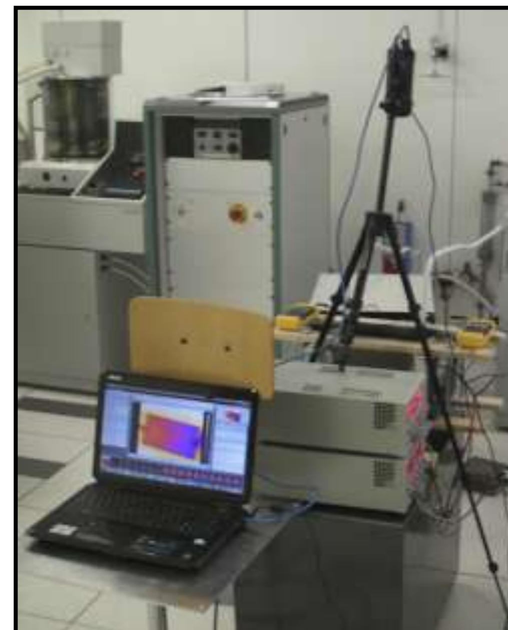
- Aluminum cold plate
- Coolant: water
- Power devices (PiN diodes, IGBT,…)
- Maximum flow rate: 9 l/min
- Dissipated power: up to 5 kW



Modeling validation

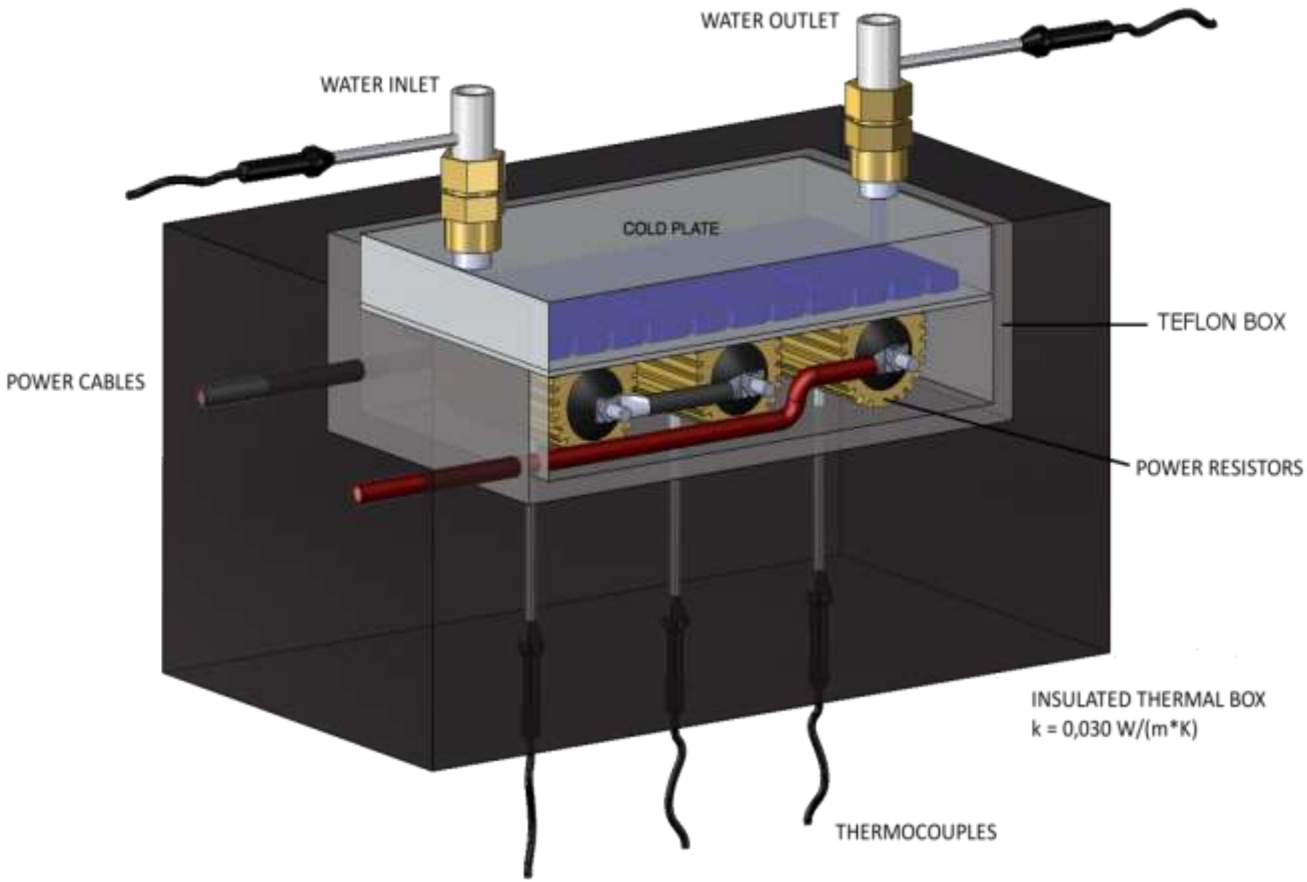
Experimental characterization: test bench





Modeling validation

Experimental characterization: heating set up



Heat sources

- 3 Power resistors
- R = 0.1 Ω (200 W)
- P_{max} = 600 W

Insulation

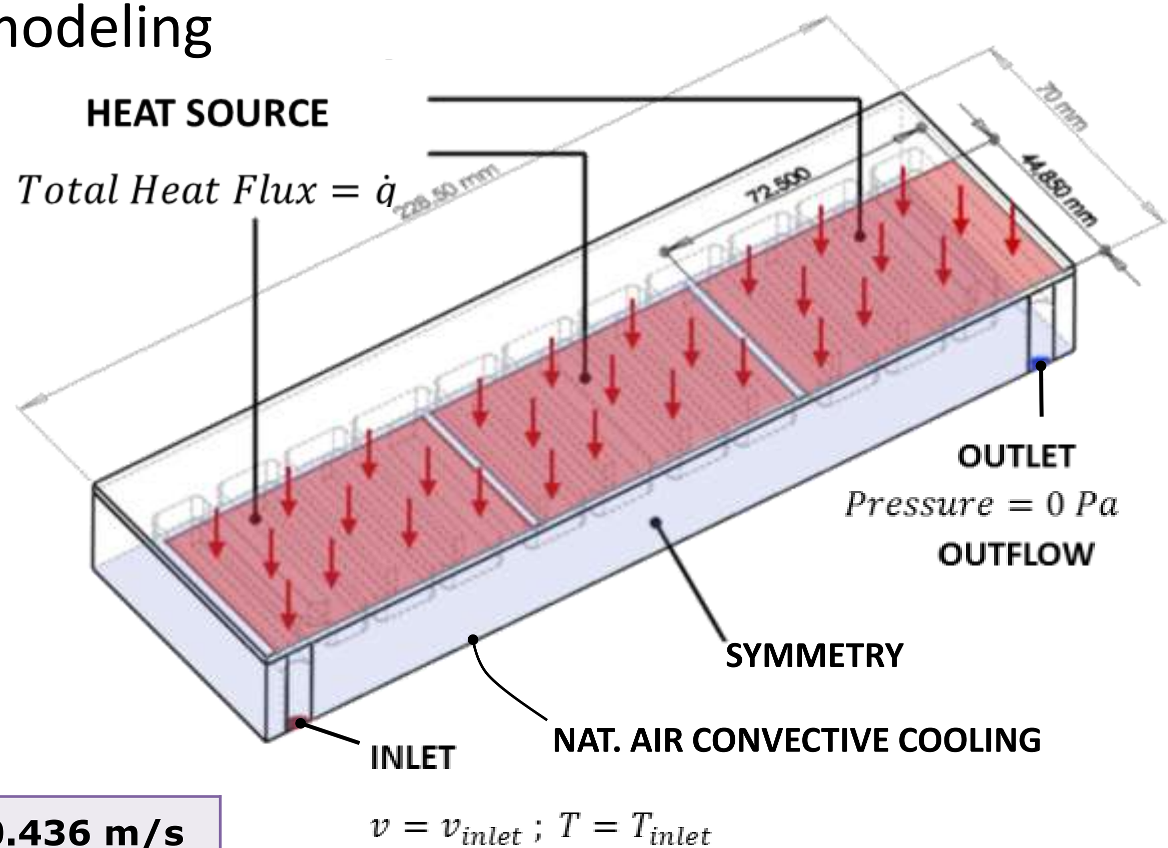
- Teflon-Polystyrene insulator box
- P_{loss} < 2 W

Modeling validation

Numerical analysis: FE modeling

HT+CFD fully coupled model

Re < 4300 ☞ Laminar Flow



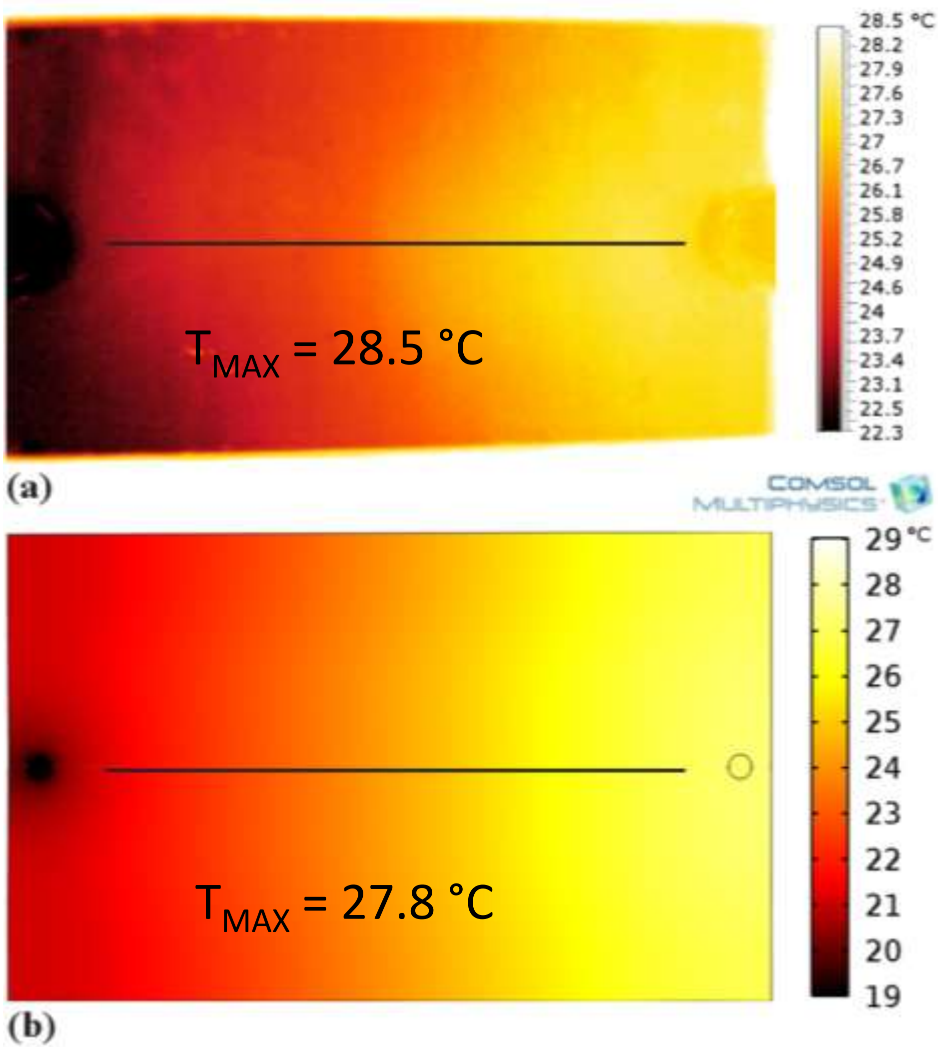
Boundary conditions

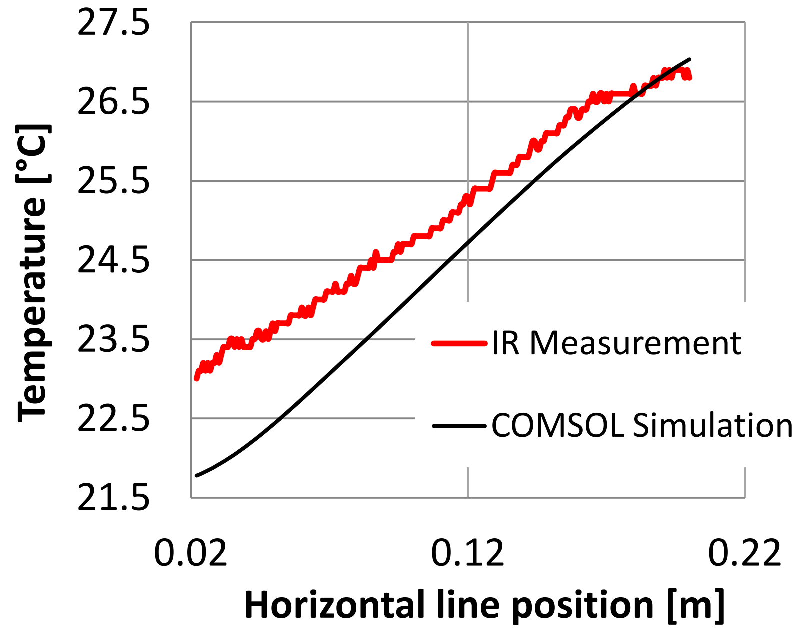
Mean Inlet Velocity	v_{inlet}	**0.436 m/s**
Inlet Temperature	T_{inlet}	18.8 °C
Total Heat Flux	T_{inlet}	28600 W/m^2
External Temperature	T_{amb}	31 °C

558 W

Modeling validation

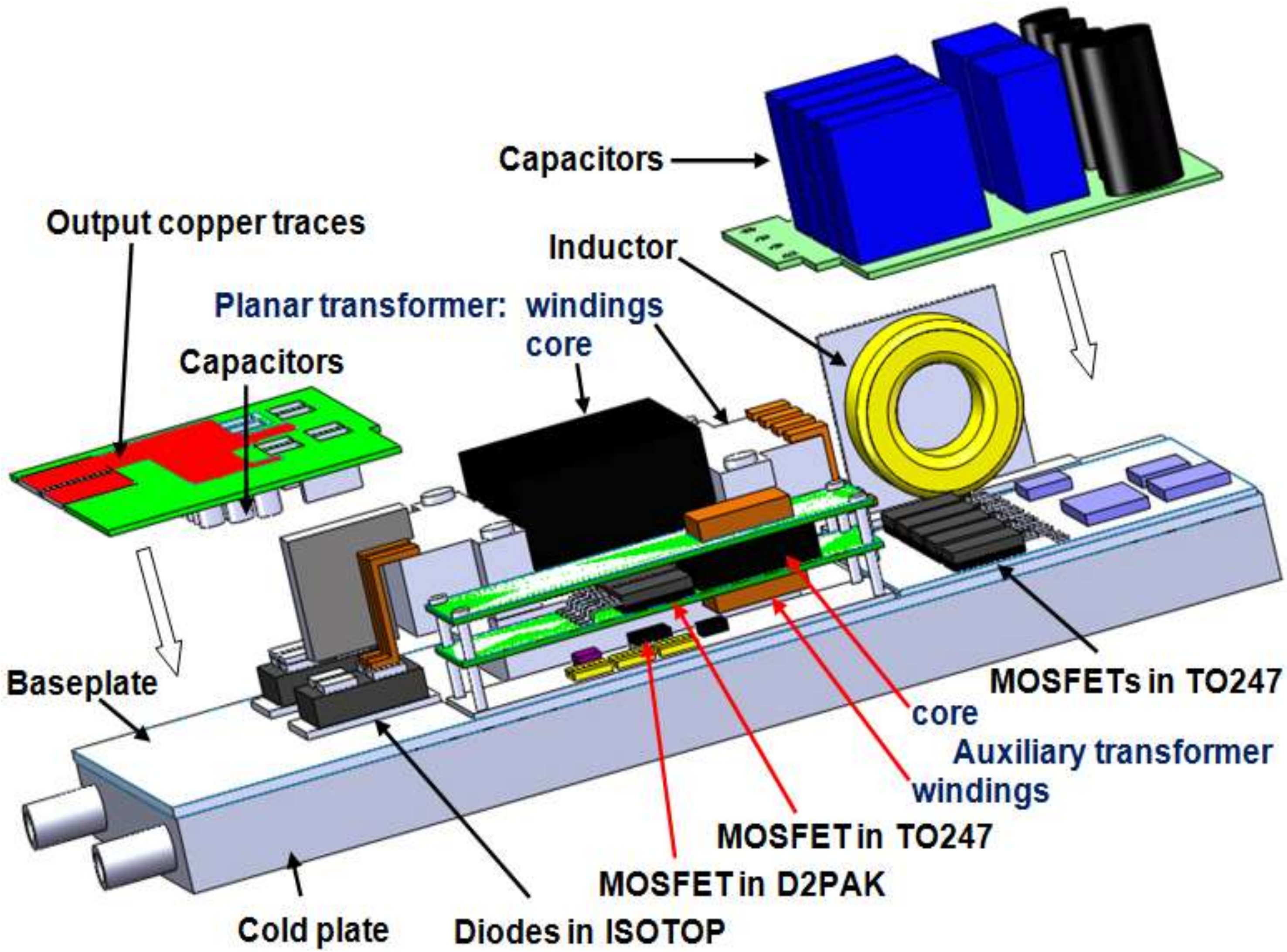
Simulations vs. Measurements





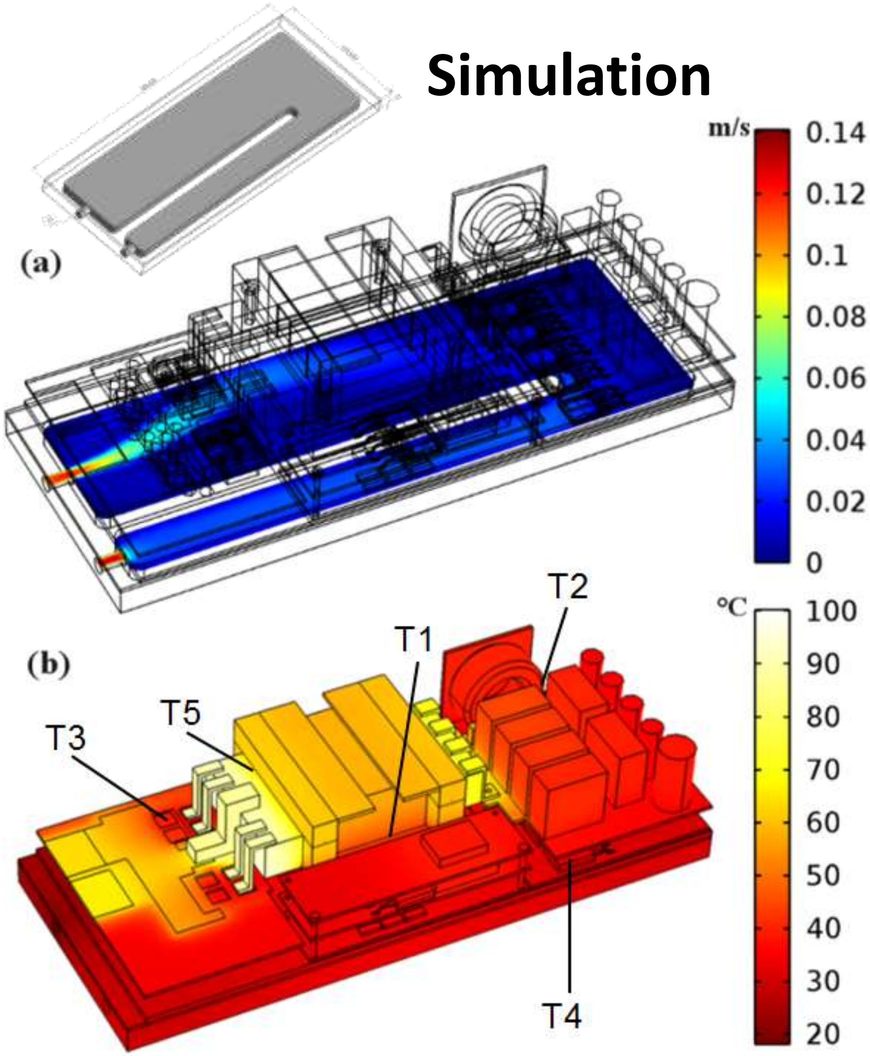
	T_{inlet}	T_{outlet}	ΔT
Thermocouple	18.8 °C	24.8 °C	6.0 °C
COMSOL	18.8 °C	25.6 °C	6.8 °C

Power module thermal modeling



Power module thermal modeling

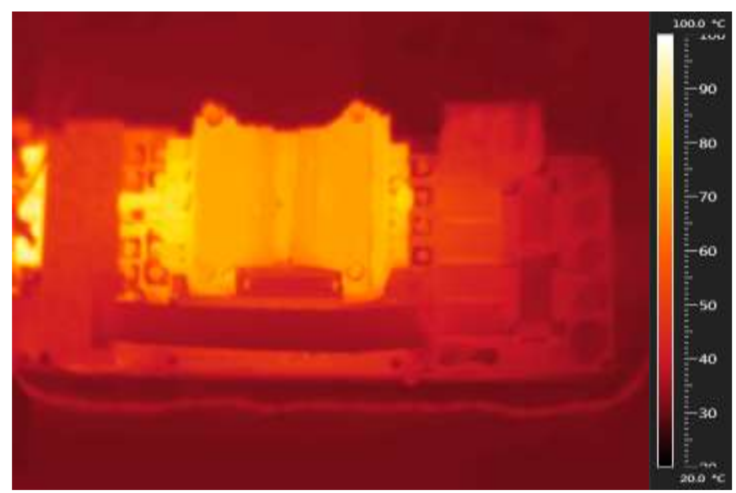
Simulation



P_{out} = 1.2 kW P_d = 240 W

	Thermocouple	COMSOL
T1	35.1 °C	37.8 °C
T2	36.7 °C	37.3 °C
T3	37.5 °C	38.4 °C
T4	40.0 °C	39.1 °C
T5	77.2 °C	75.7 °C

IR measurement

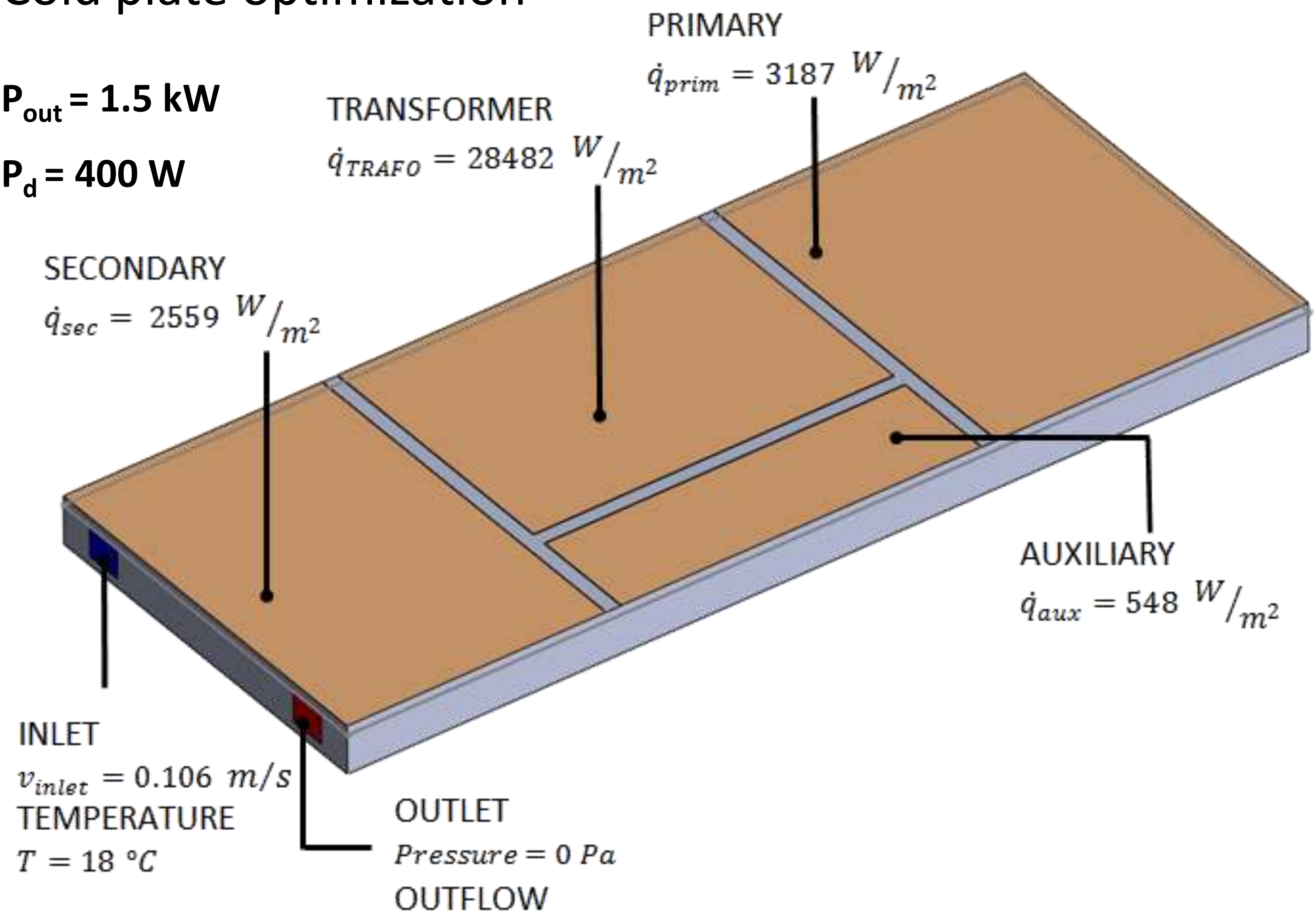


Power module thermal modeling

Cold plate optimization

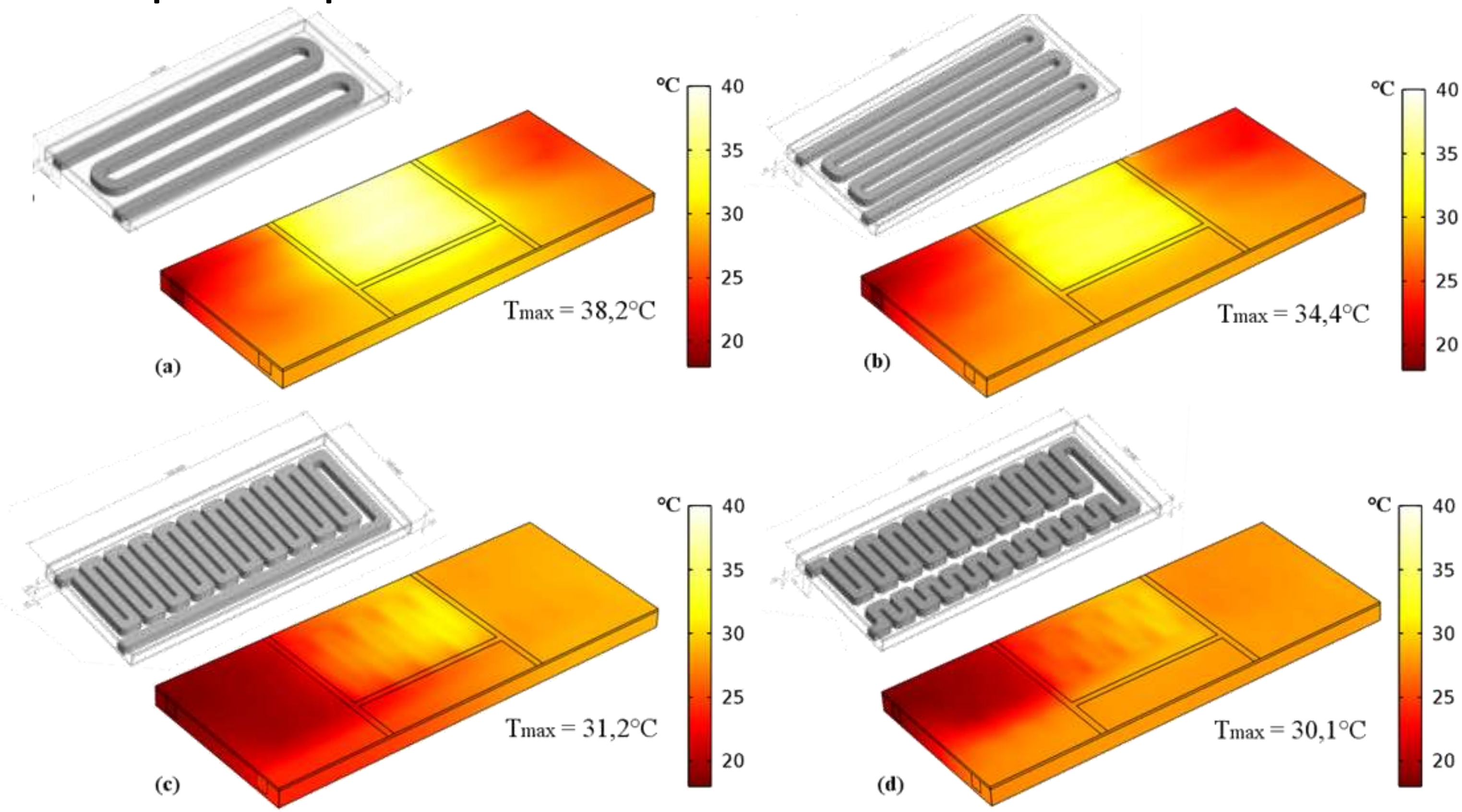
P_{out} = 1.5 kW

P_d = 400 W



Power module thermal modeling

Cold plate optimization



P_{out} = 1.5 kW

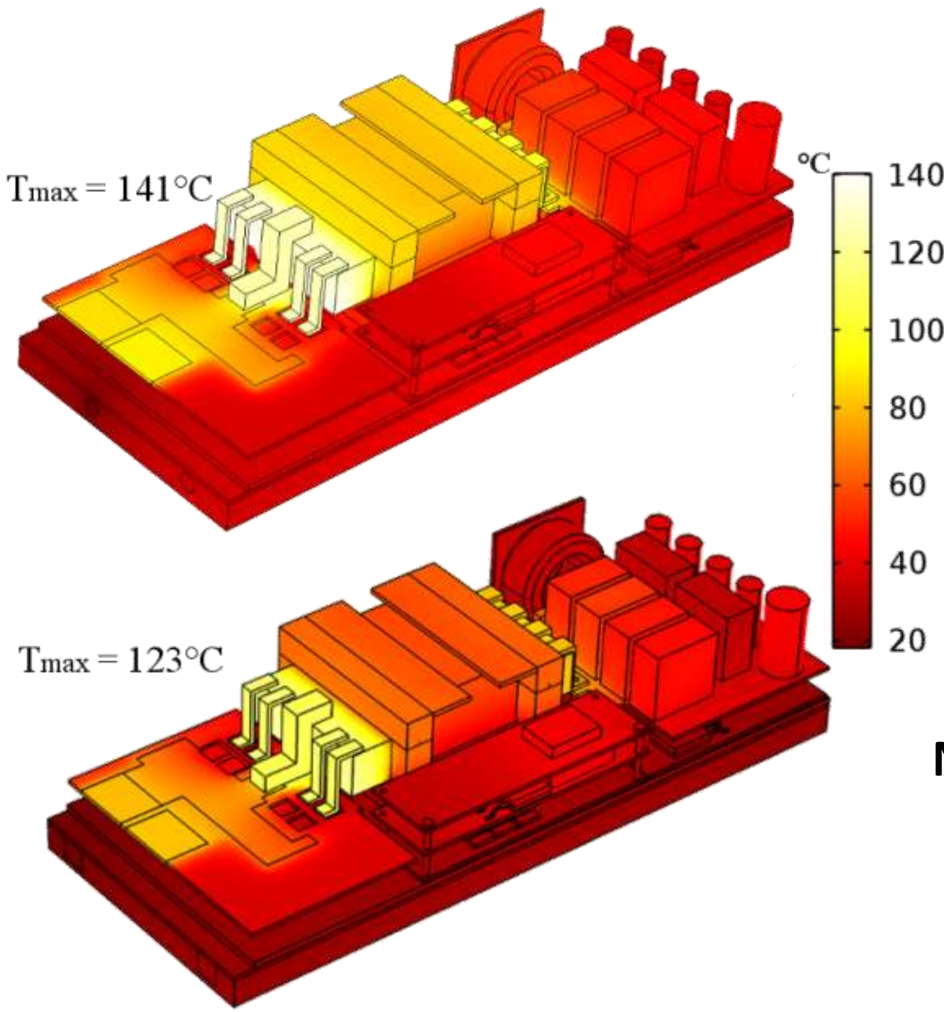
P_d = 400 W

Pattern	(a)	(b)	(c)	(d)
T_{outlet}	24.8 °C	27.4 °C	26.8 °C	27.2 °C

Power module thermal modeling

P_{out} = 1.5 kW

P_d = 400 W



"U shaped" cold plate

New cold plate type (a)

Conclusions

- FE simulations of a complex power converter with coupled HT-CFD solution has been shown.
- The approximations introduced to simplify the models without losing accuracy were validated with ad-hoc test bench and measurements.
- Searching for the optimum cold plate, has been found that for the current converter the power to dissipate is too much high.
- Improvement of the converter efficiency and further optimization of the cold plate are needed.

Thank you