Topology optimisation of heat sinks for instantaneous chip cooling:
using a transient pseudo-3D thermofluid model

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IJHMT 2020 154:119681
doi:10.1016/j.ijheatmasstransfer.2020.119681

2

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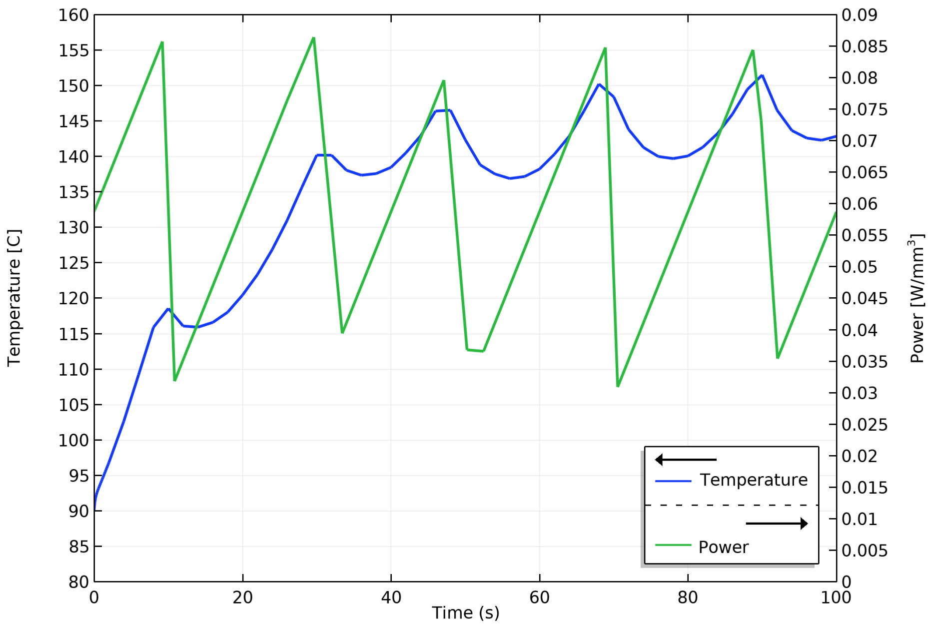
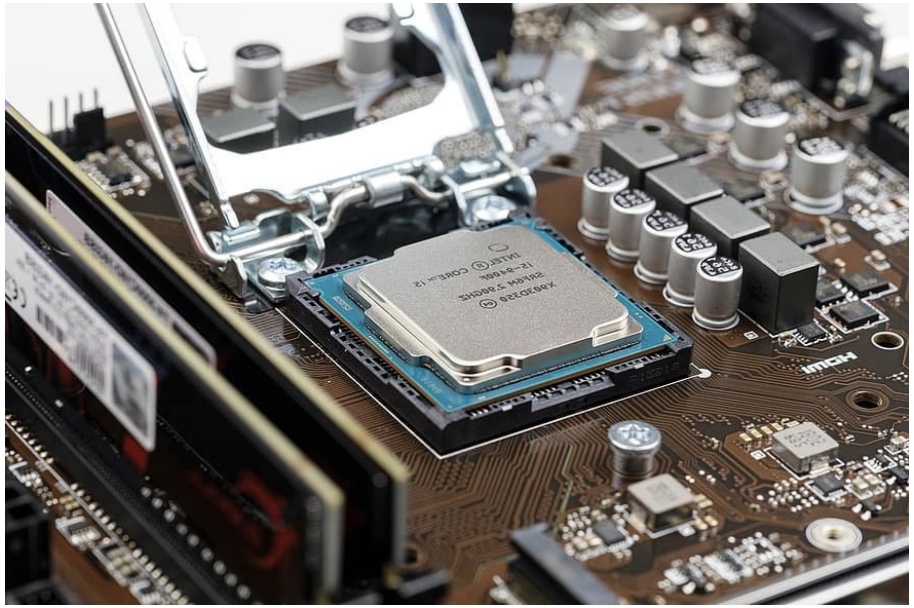
Motivation

- → Increasing power density of electronics
  - → Smaller and more powerful
  - → Serious thermal management issues

- → Electronics is inherently transient
  - → Varying thermal power output
  - → Needs fast response for sudden peak in load





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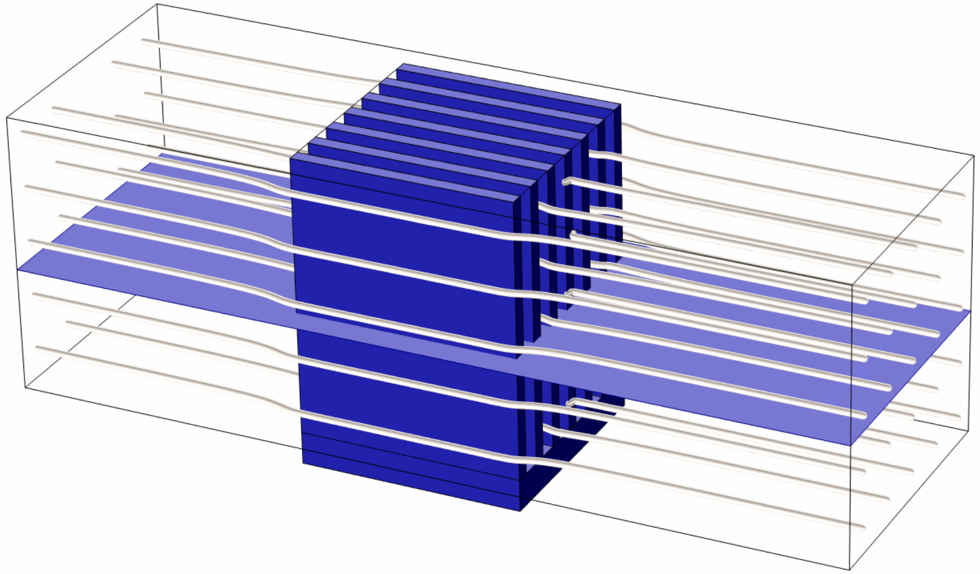

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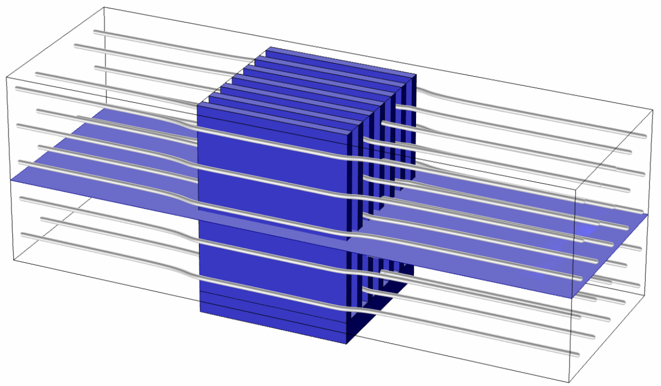
Instantaneous cooling

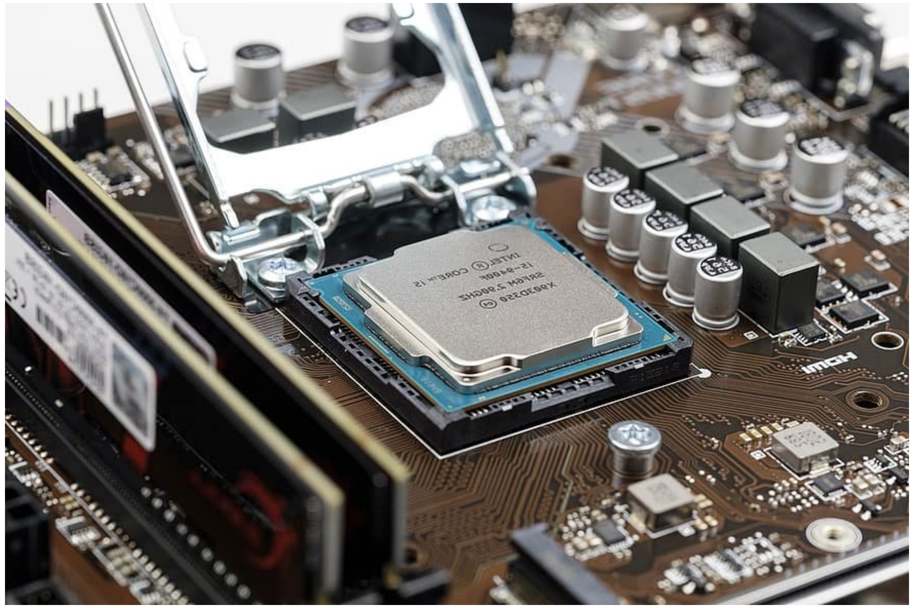
[**Zeng, …, Alexandersen** – doi:10.1016/j.ijheatmasstransfer.2020.119681]

- → CPU chip: maximum temperature limit
  - → Above limit, speed is throttled down (worse performance)
  - → Critical case: turn on cooling system when limit is reached

- → Goal: lower temperature fast!
  - → Not ***long*** time frame: steady state performance
  - → ***Short*** time frame: instantaneous performance

- → Requires time-dependent simulation model
  - → Computationally expensive!
  - → Simplified model to make each time step cheaper?





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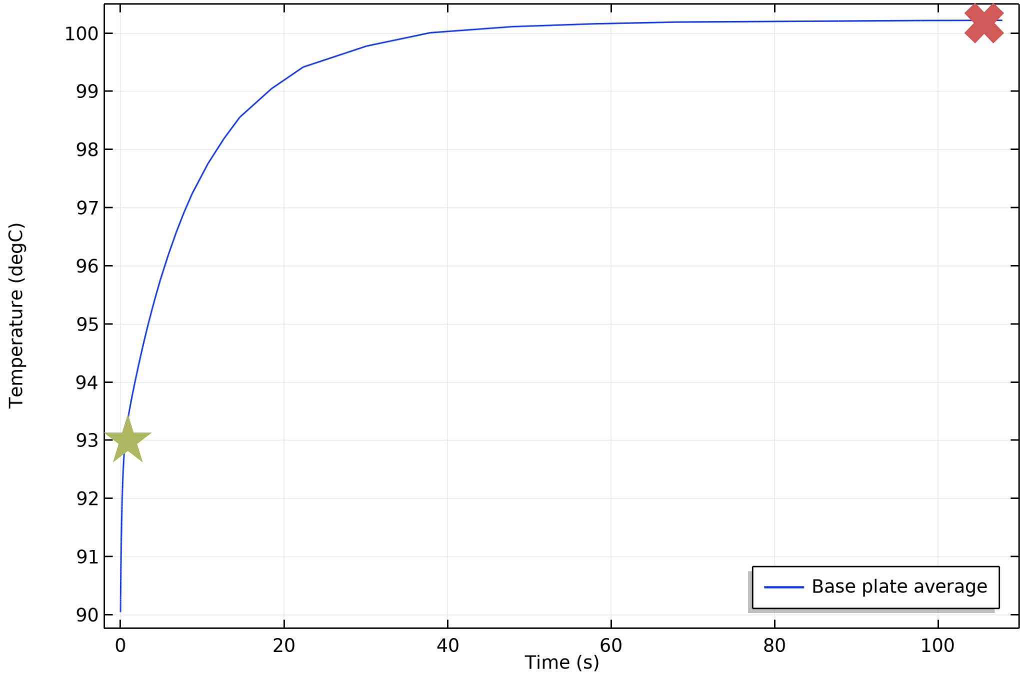

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Transient flow-based problems

→ Recent review of topology optimisation of flow-based problems:
  → showed that only 7% of 186 papers treated transient problems!

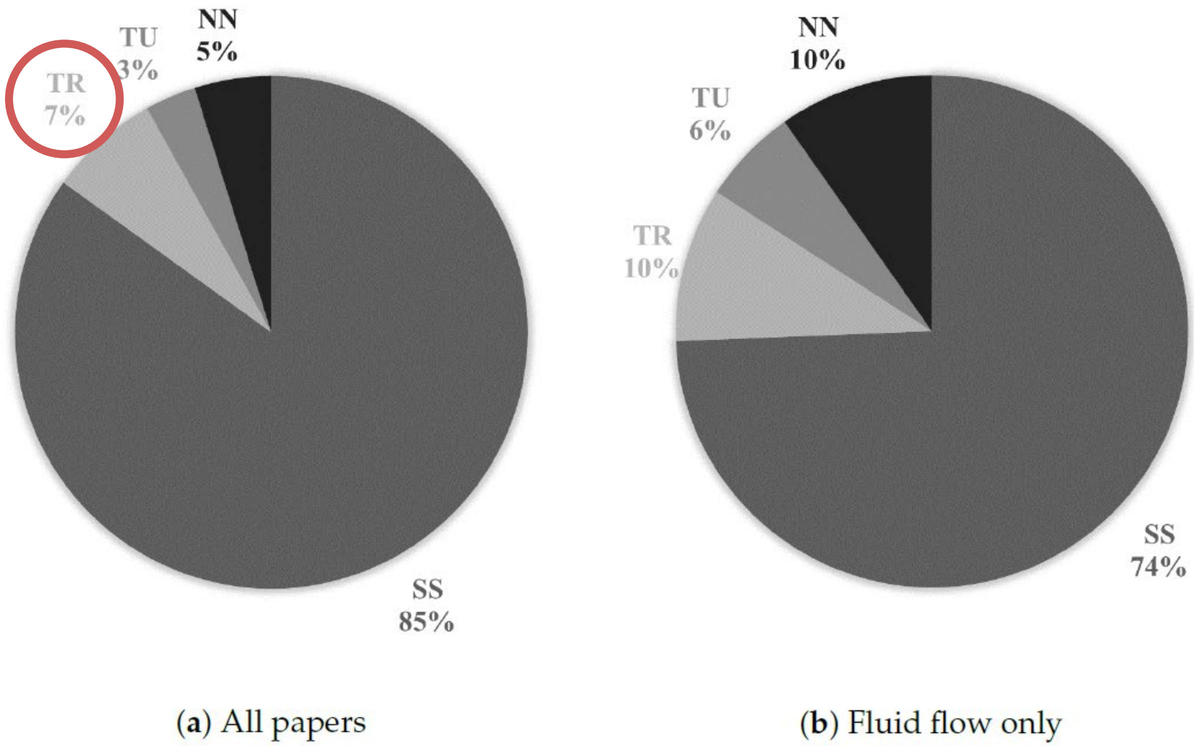

Figure 8. Distribution of papers for fluid model type: SS = steady-state laminar flow; TR = transient laminar flow; TU = turbulent flow; NN = Non-Newtonian fluid.

[**Alexandersen** & Andreasen – doi:10.3390/fluids5010029]

Heat sink design

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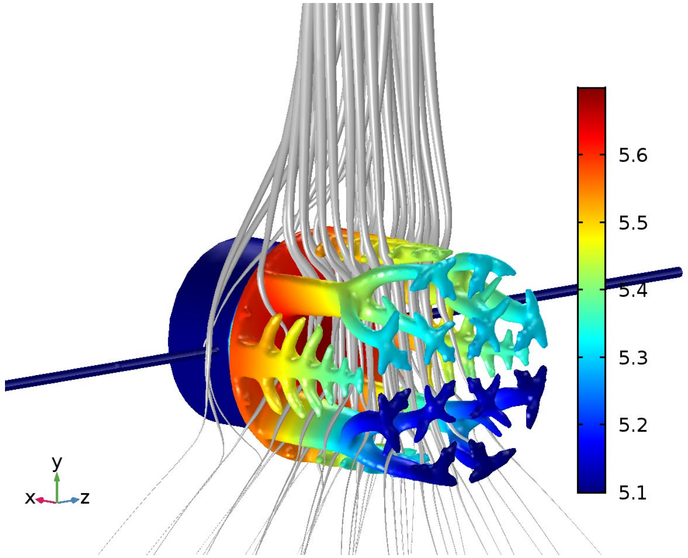
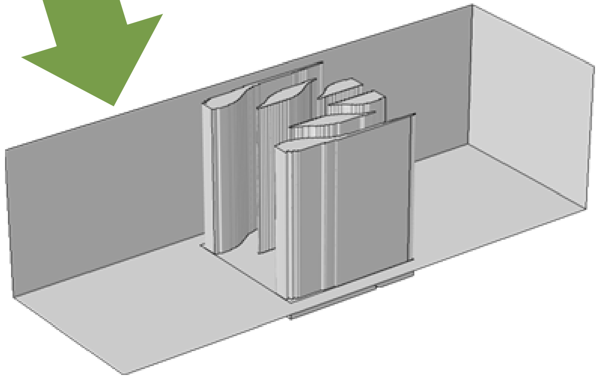
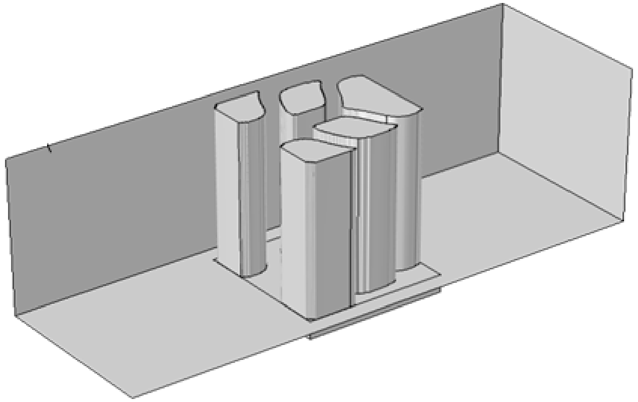


[**Alexandersen et al.** - IJHMT (2018) 122:138-149]

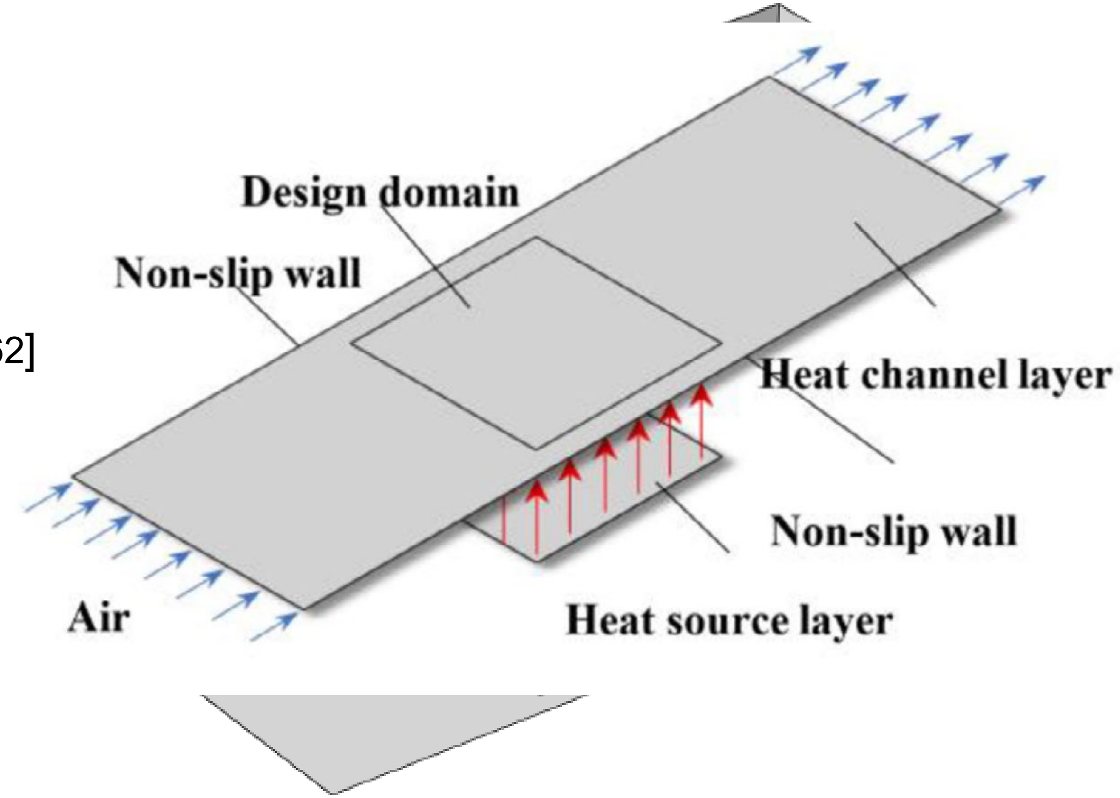




Pseudo-3D: 2 layer model

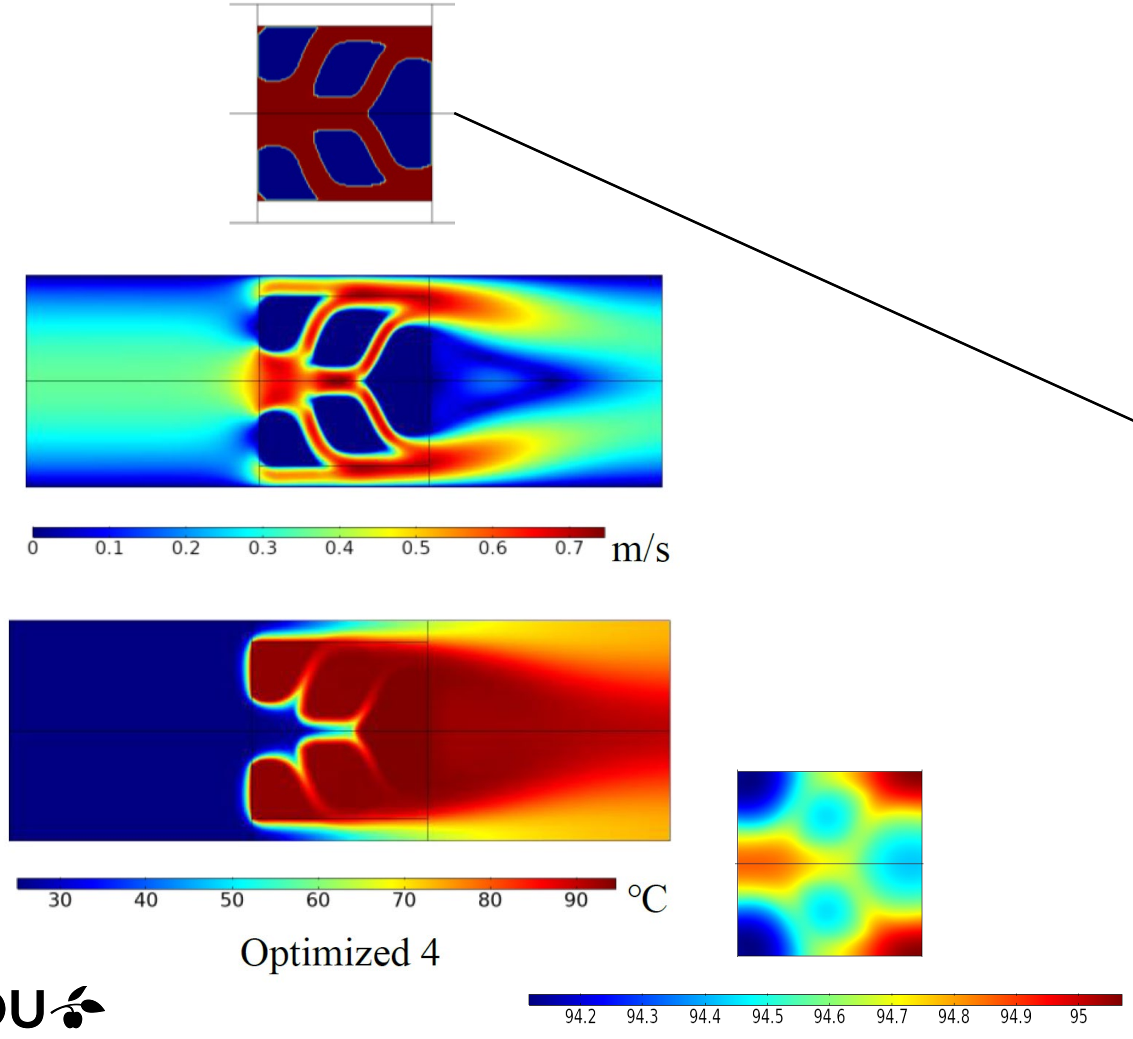
[**Zeng, …, Alexandersen** – doi:10.1016/j.ijheatmasstransfer.2020.119681]

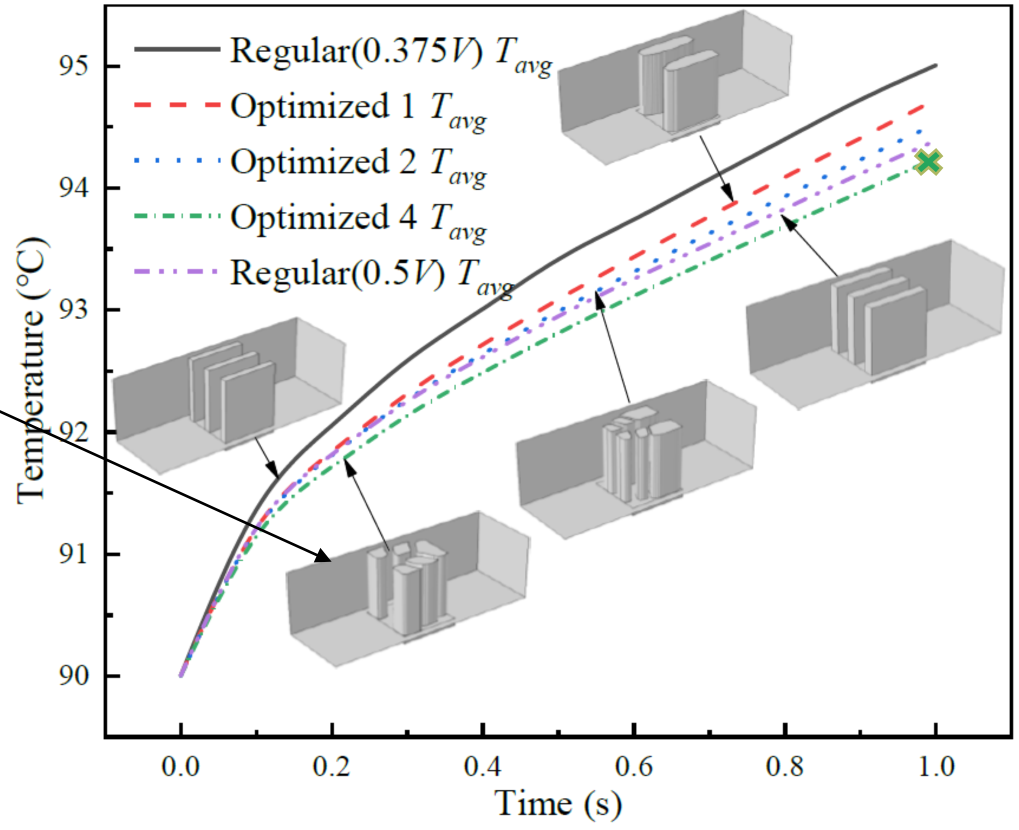
- → Pseudo-3D model by Haertel et al. [doi:10.1016/j.ijheatmasstransfer.2018.01.078]
  - → Extruded heat sink geometry with base plate (heat source)
  - → Cut-plane through channel and heat sink
  - → Channel layer is then coupled to base plate layer
  - → *Heuristic coupling heat transfer coefficient*
- → Zeng et al. – [doi:10.1016/j.ijheatmasstransfer.2018.01.039]
  - → Calculate coupling coefficient from reference geometry
- → Alternative: Yan et al. – [doi:10.1016/j.ijheatmasstransfer.2019.118462]
  - → Analytical derivation based on assumptions



Instantaneous performance

[**Zeng, …, Alexandersen** – doi:10.1016/j.ijheatmasstransfer.2020.119681]

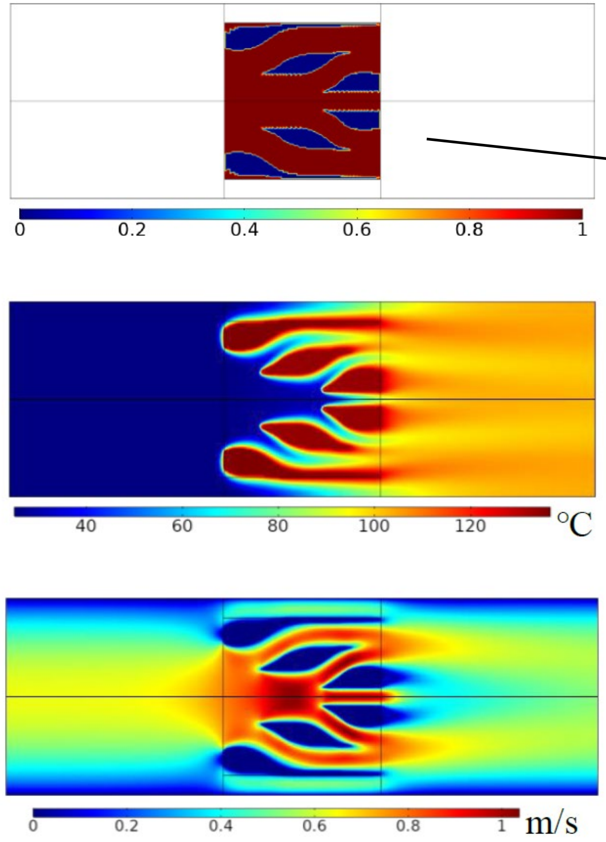




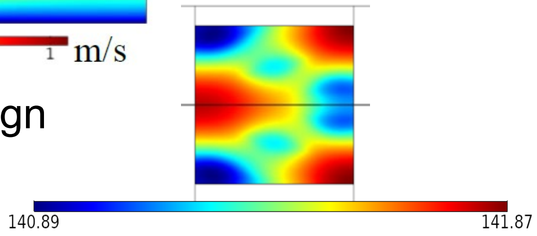
→Chip temperature after 1 second is improved compared to regular designs

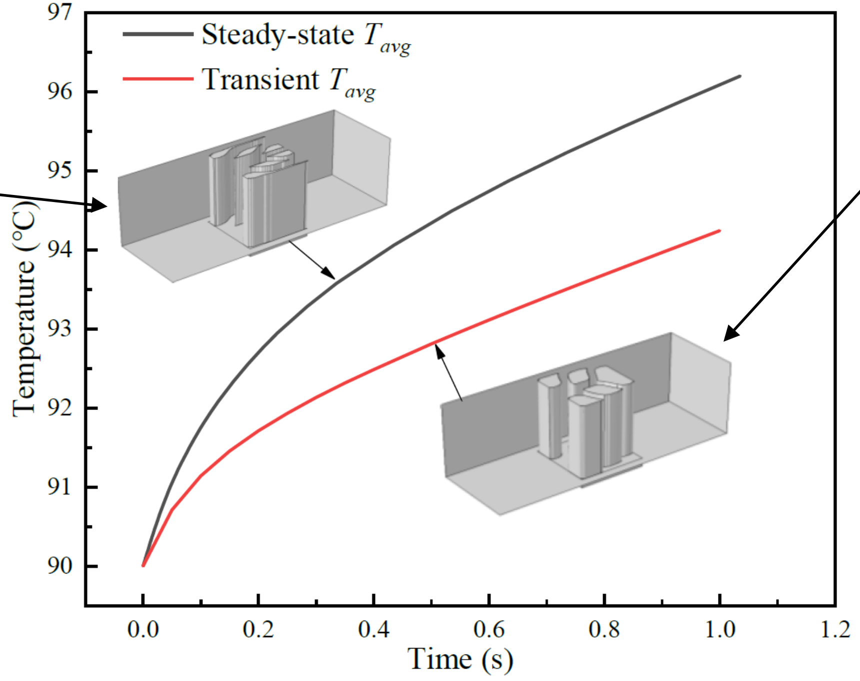
Steady-state performance

[**Zeng, …, Alexandersen** – doi:10.1016/j.ijheatmasstransfer.2020.119681]

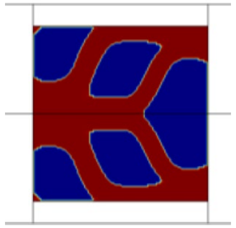


Steady-state design

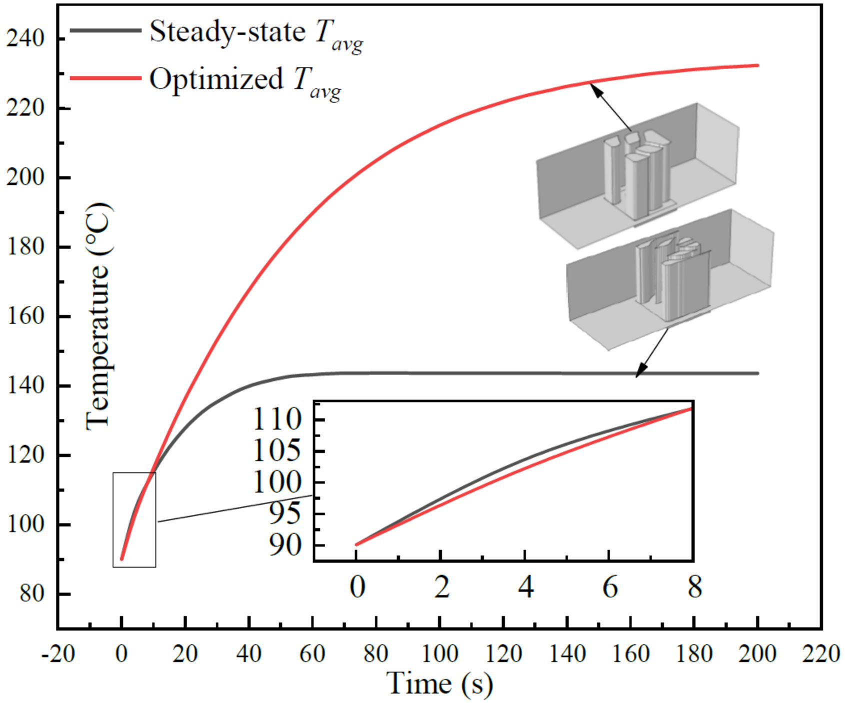




Transient design outperforms steady-state design for instantaneous cooling!



But steady-state design outperforms transient design for long term cooling!



Water-cooled design

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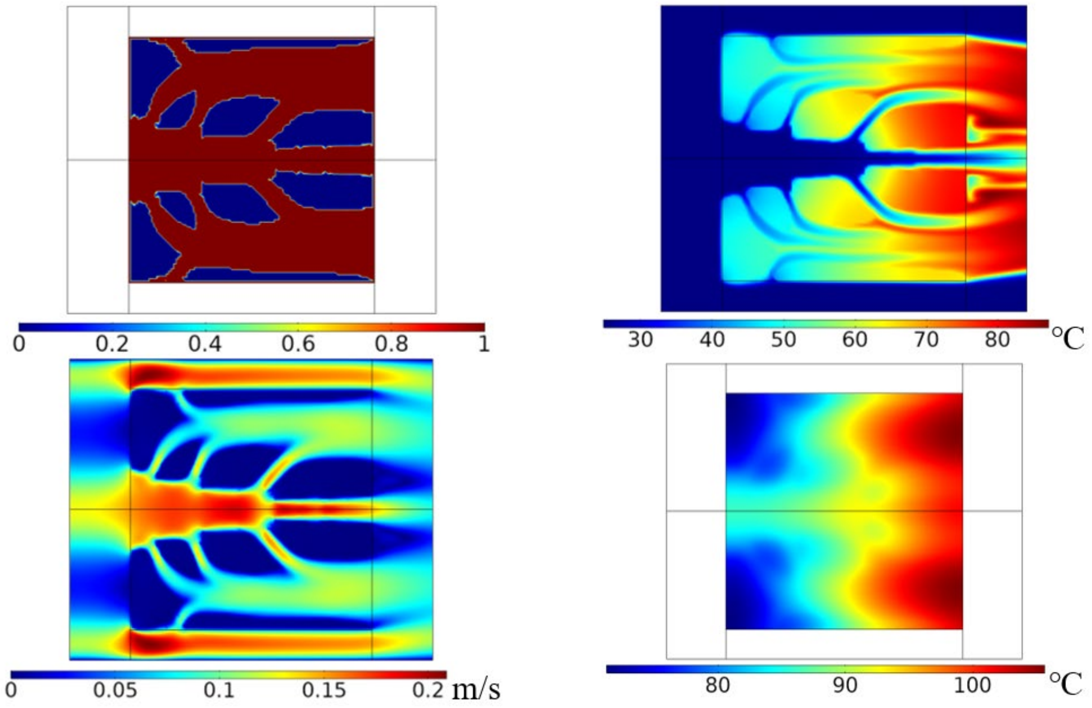

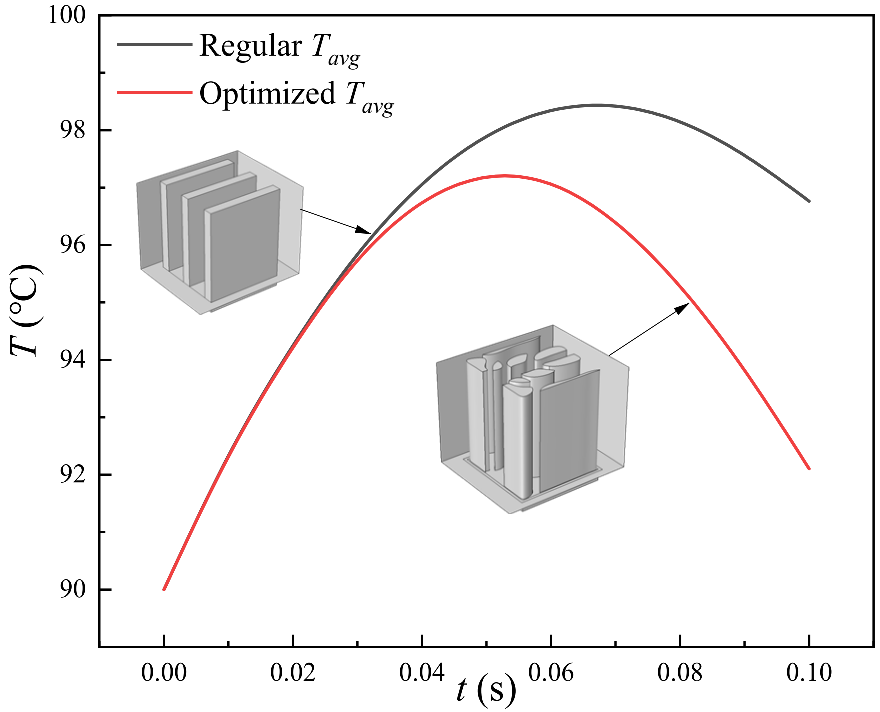

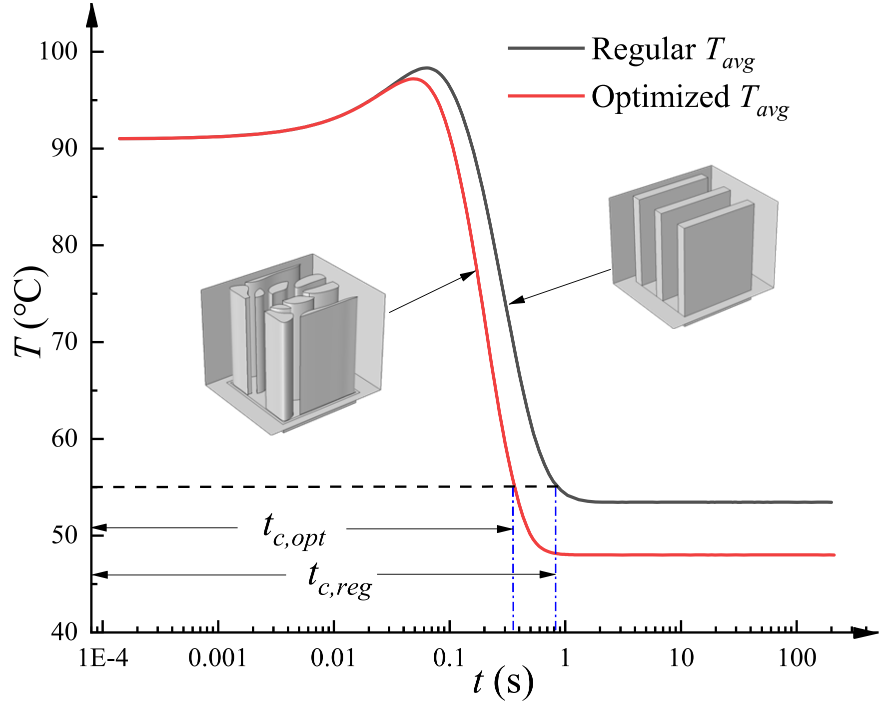

Water-cooled design: practical conditions

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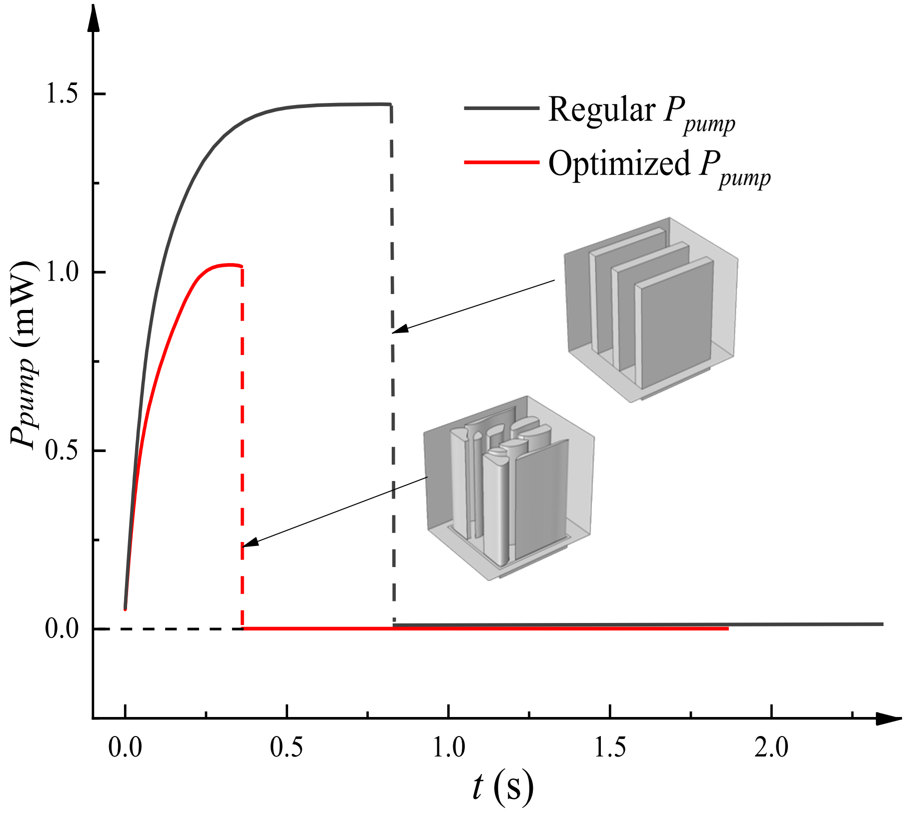

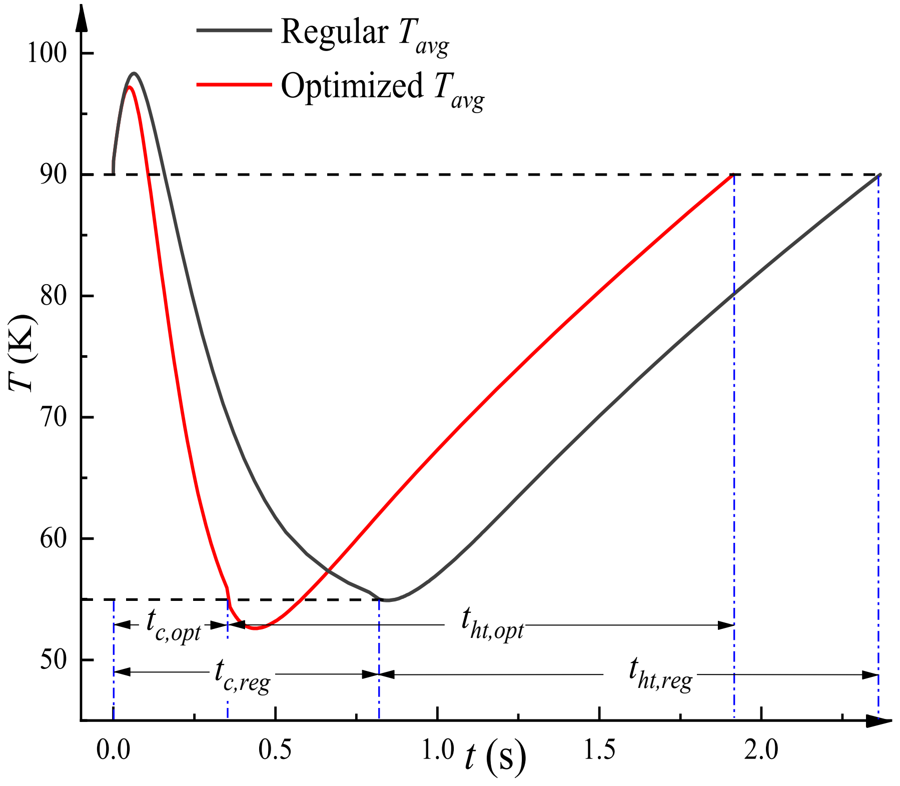

→ Hits 90°C, cooling system turned on
→ Reduced to 55°C, cooling system turned off

→ Pumping energy: 67% saved!

→ Time from 90 to 55 much faster!
→ Time from 55 back to 90 more or less the same

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Any questions?

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