Dynamic modeling of a Two-Phase On-Chip Cooling System for Multiple High Performance Microprocessors in Parallel

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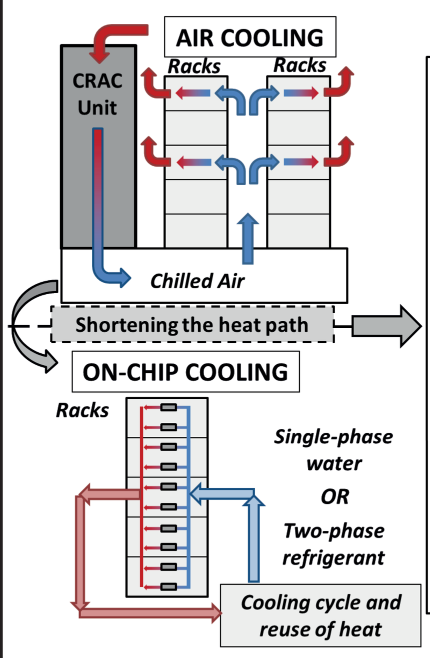
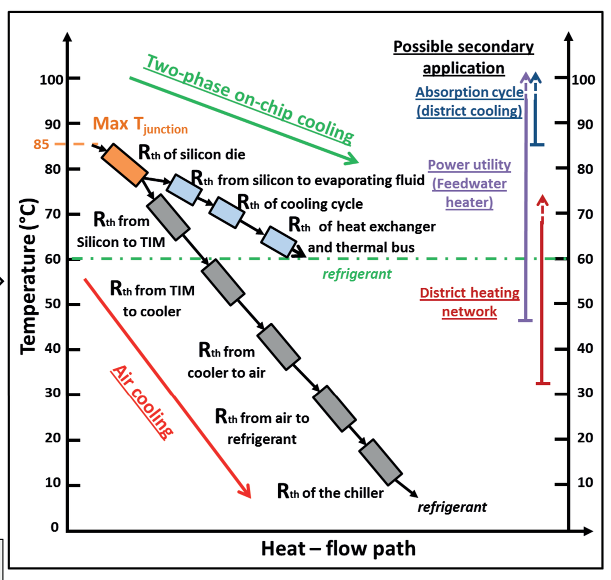
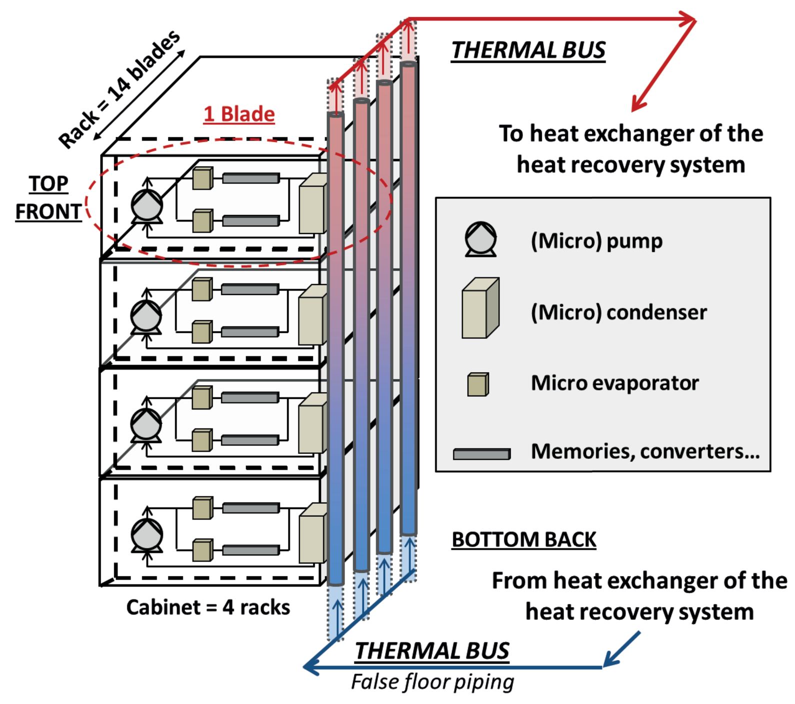
Context and Motivation





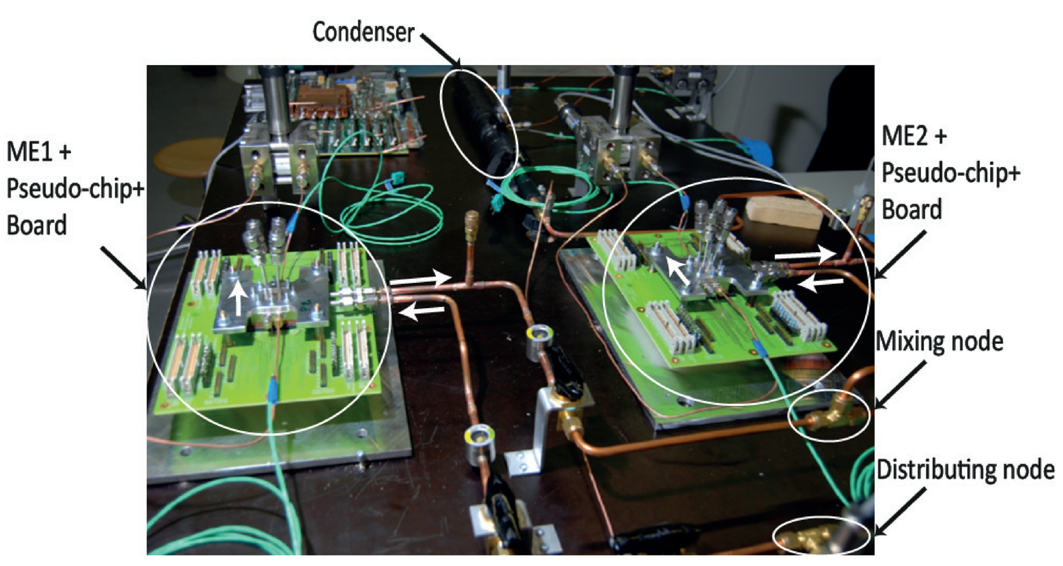


Switching **from air cooling to on-chip two-phase cooling** in datacenter:
- Reduce the power consumption
- Allow the reuse of the large amount of evacuated heat

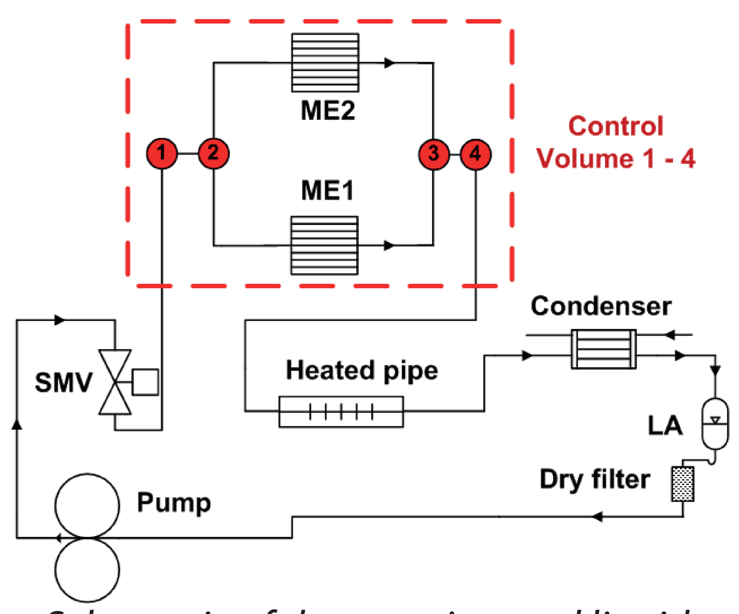
Need to **describe dynamically the cooling process** to track the quality of the recovered heat with the time.

Cooling System Description

The components of the system are **2 parallel microevaporators** (ME) assembled on the top of microprocessors (experimentally mimicked by pseudo-chips composed of 35 heaters and temperatures sensors), a **heated pipe** to emulate memories and AC/DC converters normally found in blade server boards, a **condenser** for heat recovery, a **liquid accumulator** (LA) to ensure that only liquid flow to the pump, a dry filter, a **liquid pump** and a **stepper motor valve** (SMV) to modulate the mass flow rate.



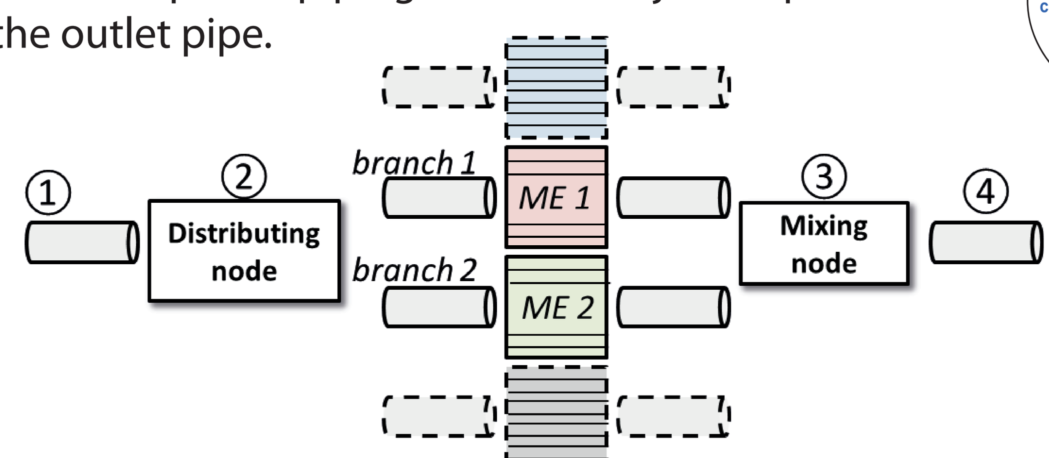
Microevaporators in parallel flow on the experimental two-phase cooling loop

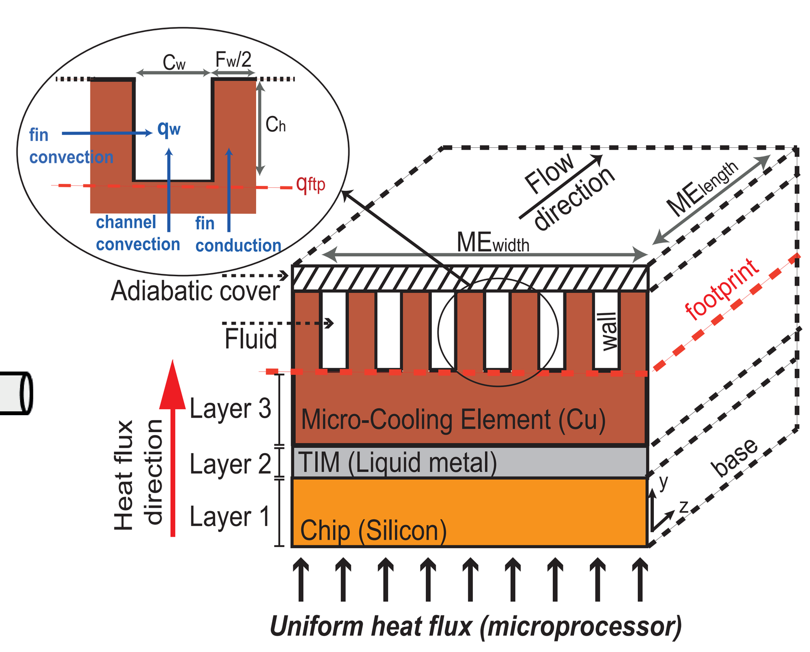


Schematic of the experimental liquid pumping cycle

Mathematical model

The liquid refrigerant flows through the inlet piping, is then split into two pipes feeding the cold plates and exits in separate piping. The flows rejoin to proceed in the outlet pipe.





- Overall steady state momentum balance -

$$\frac{\partial P}{\partial z} = \frac{\partial}{\partial z}\left[(1-\varepsilon)\cdot\rho_l\cdot u_l^2 + \varepsilon\cdot\rho_v\cdot u_v^2\right] - \left(\frac{\partial P}{\partial z}\right)_f - \left[(1-\varepsilon)\cdot\rho_l + \varepsilon\cdot\rho_v\right]\cdot \sin\theta\cdot g$$

- Transient energy balance for the microevaporators -

$$\frac{dh}{dt} = \frac{1}{[(1-\varepsilon)\cdot\rho_l + \varepsilon\cdot\rho_v]}\cdot\left(\frac{\dot{q}_{wall}\cdot d_{heat}}{A_{channel}} - \frac{\dot{m}}{A_{total}}\cdot\frac{\partial h}{\partial z} - (UA)_{T_{mean}}\frac{T_{mean}-T_{amb}}{S_{tot} * ME_{length}}\right)$$

- Transient energy balance for the piping -

$$\frac{dh}{dt} = \frac{1}{[(1-\varepsilon)\cdot\rho_l + \varepsilon\cdot\rho_v]}\left(4\cdot h_{loss}\cdot\frac{D_{ext}}{D_{int}^2}\cdot\left(T_{amb}-T_{fl}(z)\right) - \frac{4\cdot\dot{m}}{\pi\cdot D_{int}^2}\cdot\frac{\partial h}{\partial z}\right)$$

- 2D transient conduction scheme in the microevaporators -

$$\left.\frac{dT_p}{dt}\right|_{k,y,z} = \frac{1}{[\rho_k\cdot cp_k\cdot\Delta y_k\cdot\Delta z]}\cdot[BC]\cdot[HF]$$

- Mixing vapor quality controller -

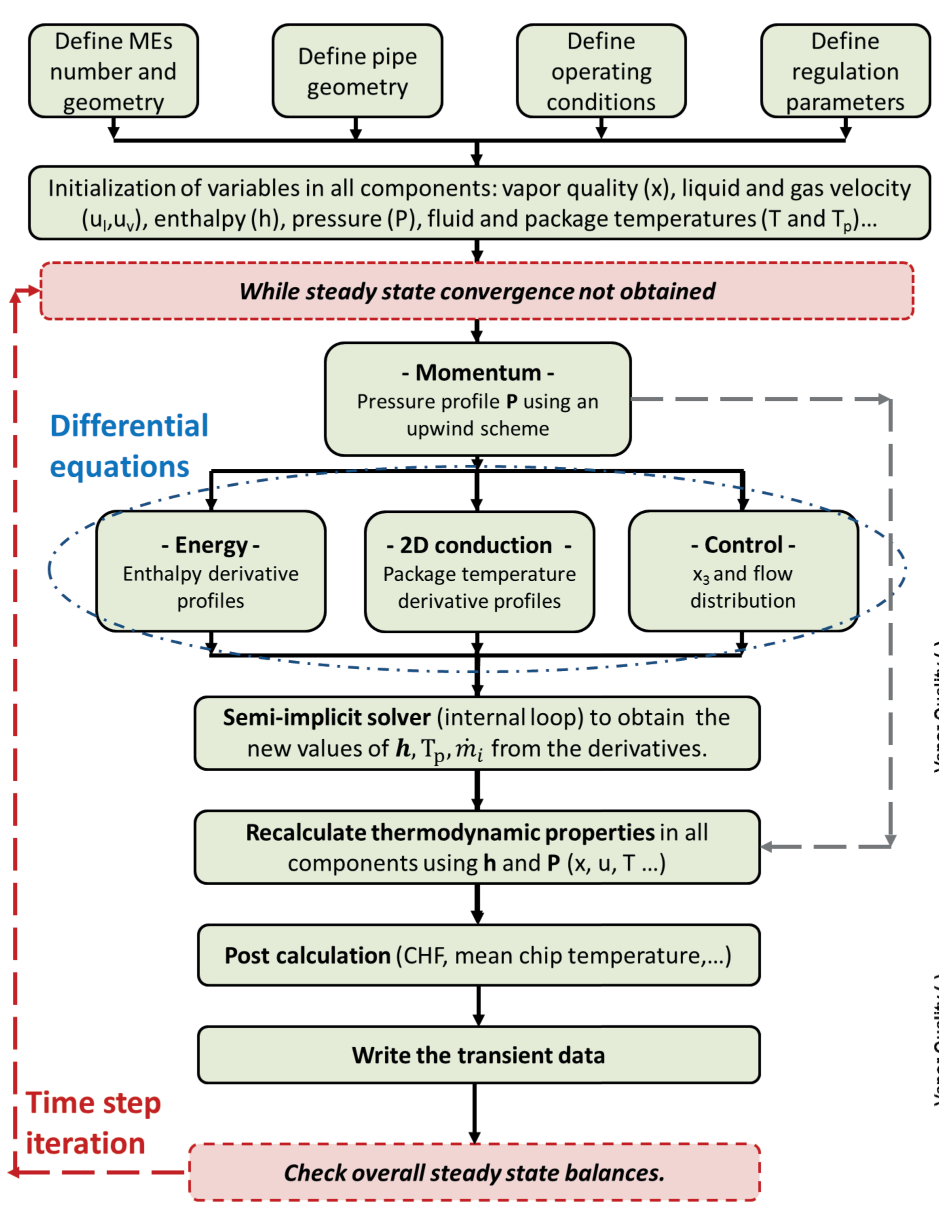
$$\frac{d\dot{m}_{tot}}{dt} = \left(K_i\,(x_3 - x_{set}) + K_c\frac{dx_3}{dt}\right)$$

- Mass flow distribution controller -

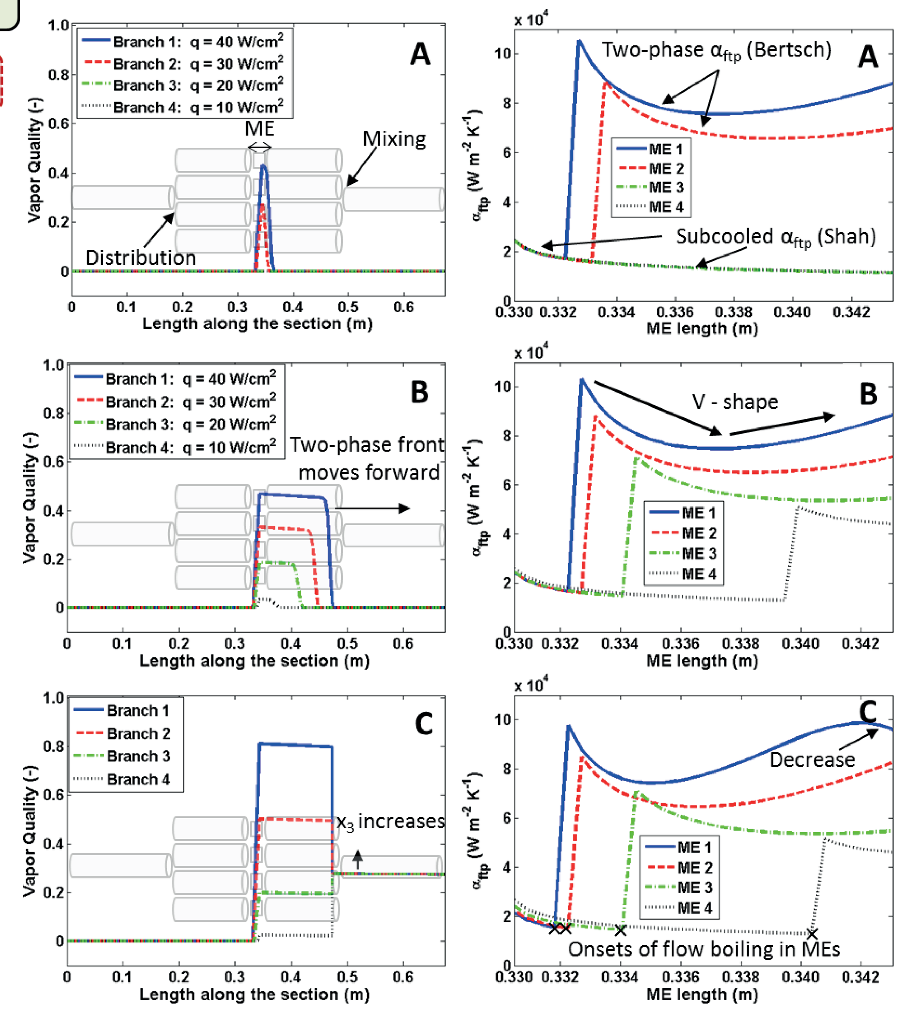
$$\frac{d\dot{m}_i}{dt} = K_{distri}\,(\Delta P_i - \Delta P_{i+1})$$

$$\dot{m}(n) = \dot{m}_{tot} - \sum_{1}^{n-1}\dot{m}_i$$

Flow diagram and Case study

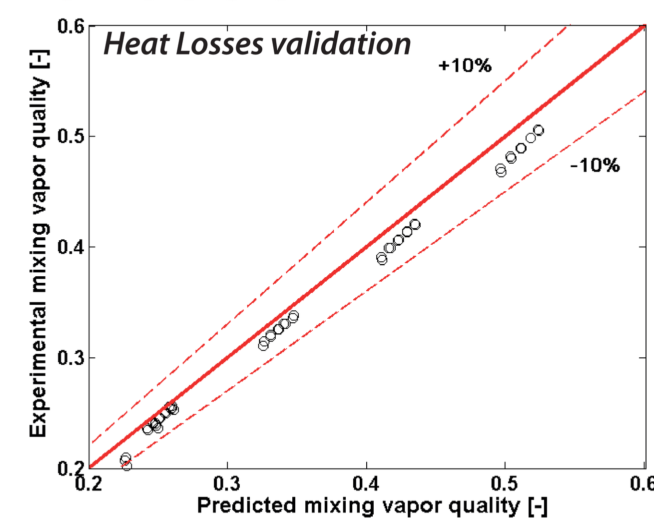


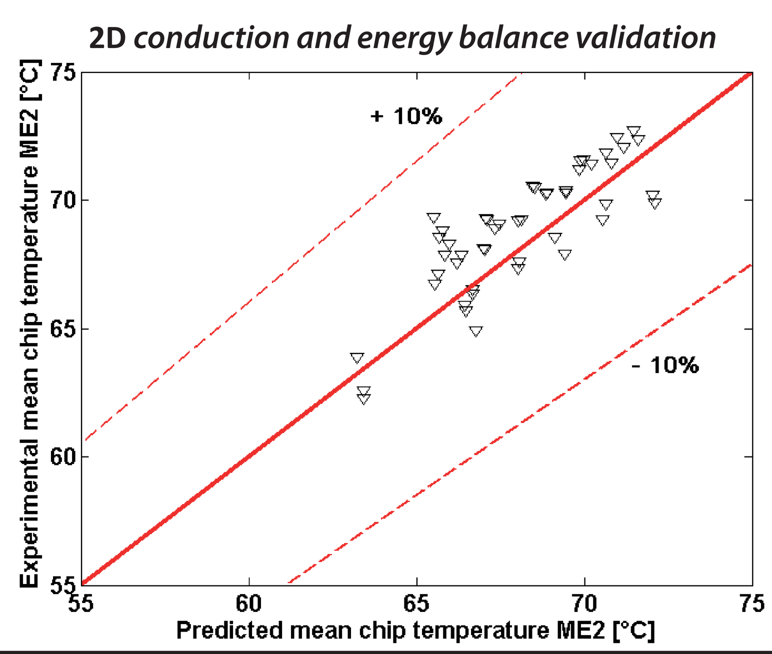
- 4 MEs (40, 30, 20 and 10 W.cm^{-2})
- P=16 bar
- Subcooling of 3K
- x_{set} of 30%

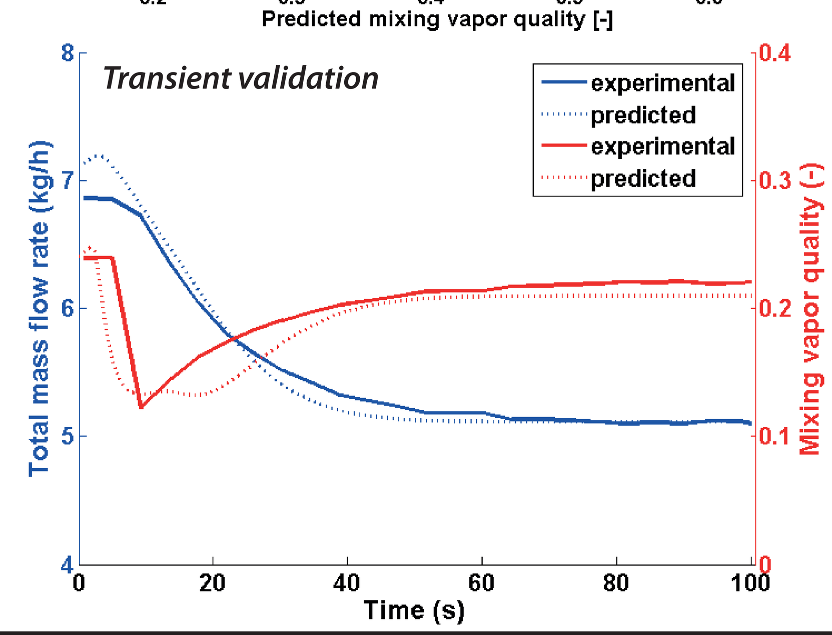


Simulation Code Validation

- 49 steady states
- 6 transients
- Unbalanced/Balanced heat loads
- Heat loads from 18 to 30 W.cm^{-2}
- Mixing vapor quality set point from 20 to 60%
- Pressure from 16 to 18 bar
- Mass flow rate between 4 and 9 kg/h
- Fluid HFC134a

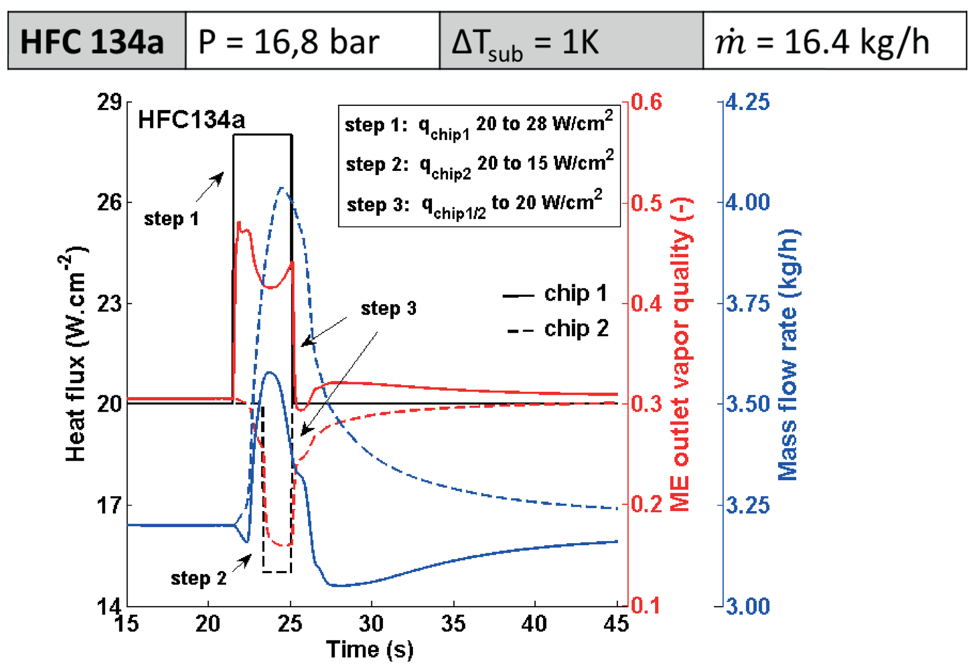


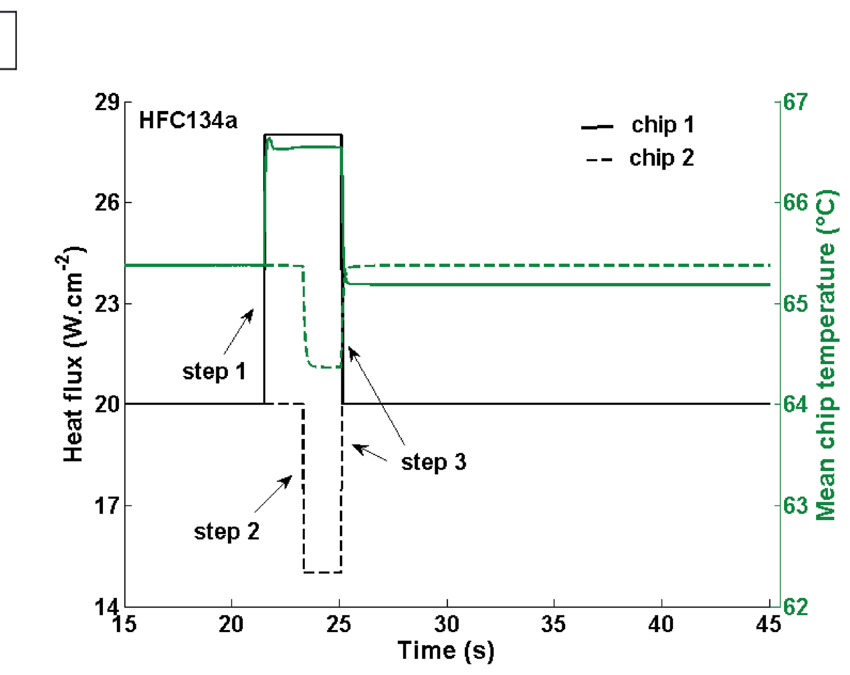




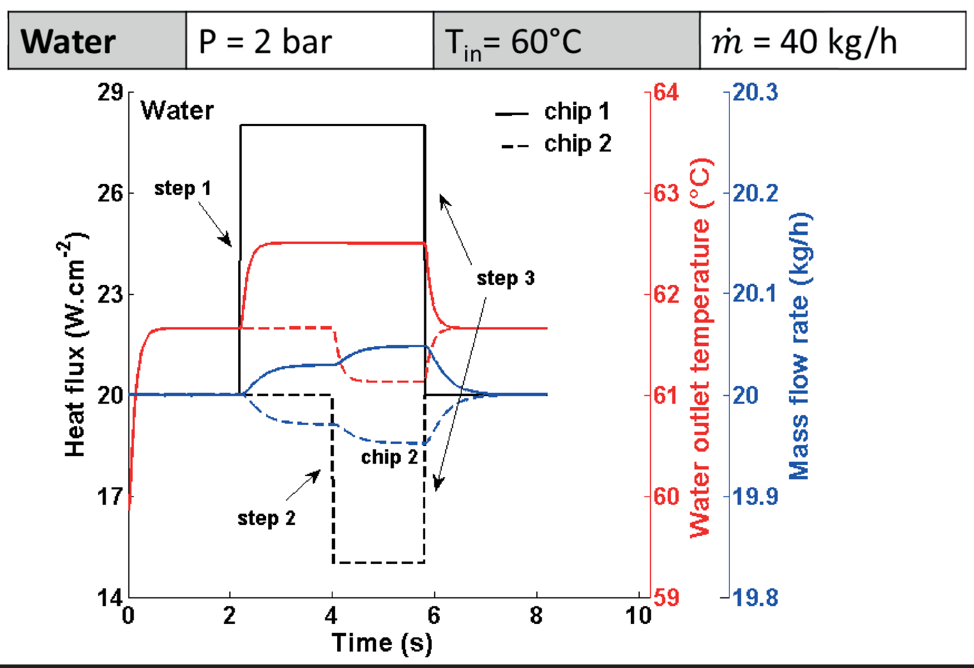
Transient Heat Load Simulation

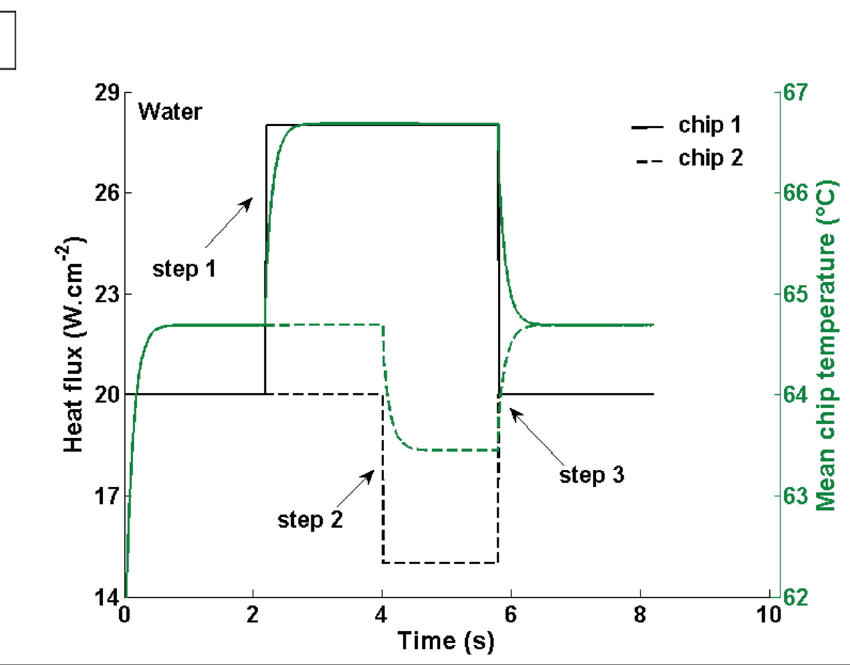
HFC 134a	P = 16,8 bar	ΔT_{sub} = 1K	$\dot{m}$ = 16.4 kg/h





Water	P = 2 bar	T_{in} = 60°C	$\dot{m}$ = 40 kg/h





On-Going Activities

- ***Simulation code:*** Condenser and Thermal bus modeling
- ***Validation:*** Pressure drop and chip temperature profiles
- ***Experimental campaign:*** Performance maps of the cooling system for unbalanced heat loads

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