



GREENCOOL



A new Micro-scale Cooling Solution for Macro-scale Energy Efficiency

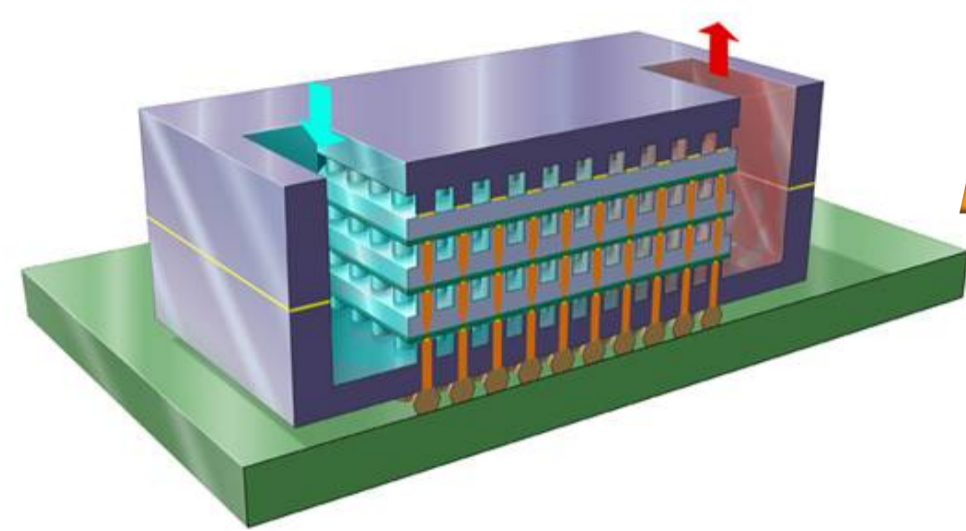
Arvind Sridhar, Mohamed M. Sabry, David Atienza
Embedded Systems Laboratory, EPFL

Liquid Cooling

... the next frontier in thermal packaging of electronics

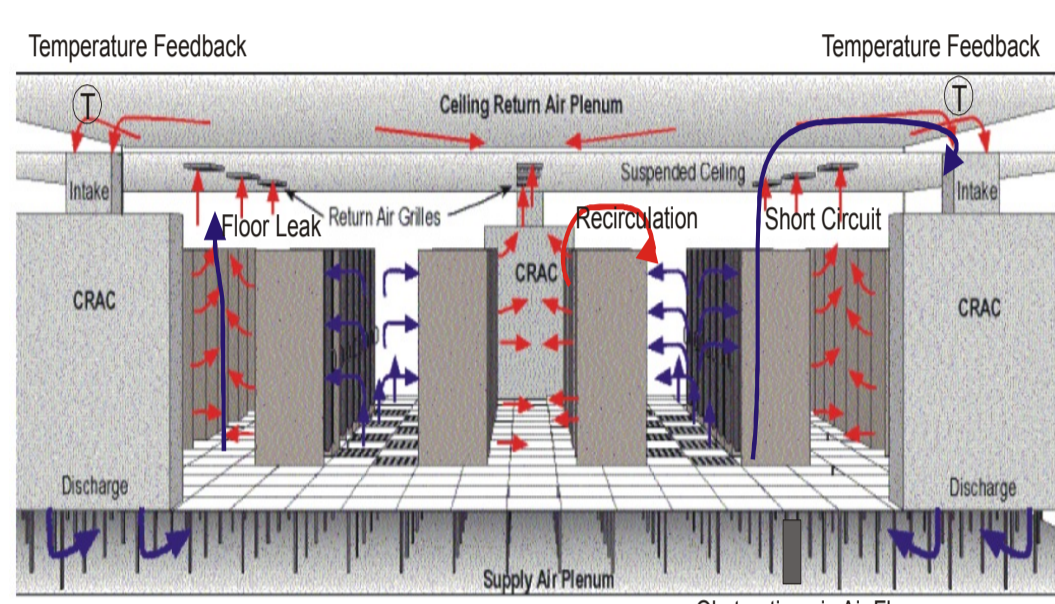
Energy Efficiency in Data Centers

... an unexpected gift!

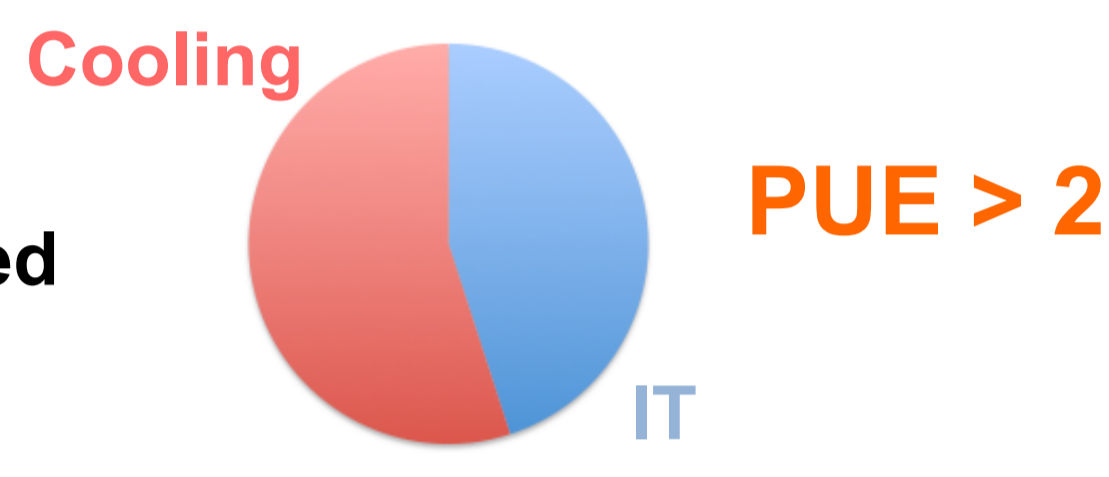


Power Usage Effectiveness (ideally =1)

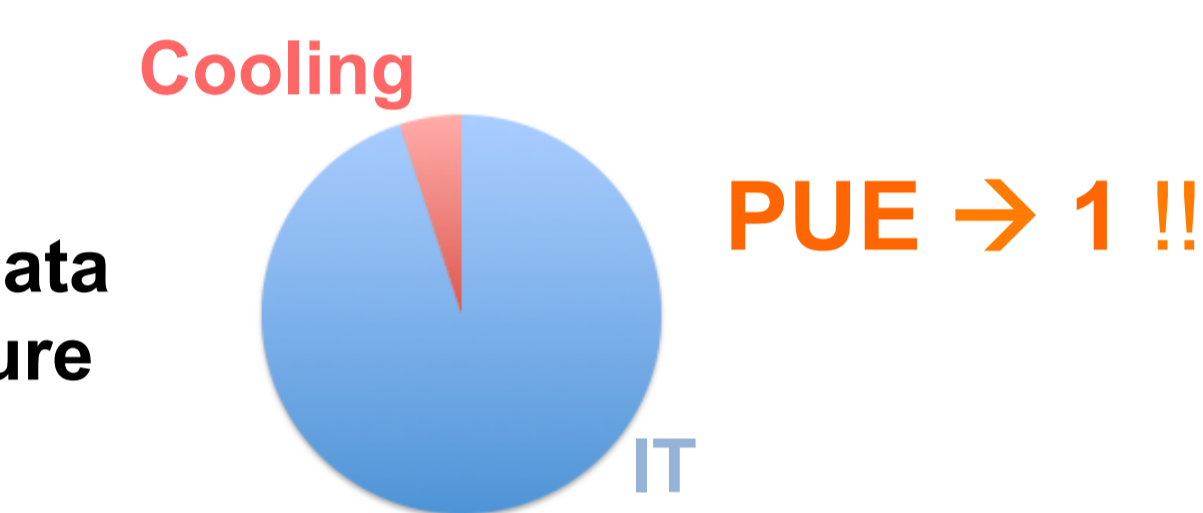
$$PUE = \frac{\text{Total Power Spent}}{\text{Power spent on the IT equipment}}$$



Modern Air-Cooled Data Centers



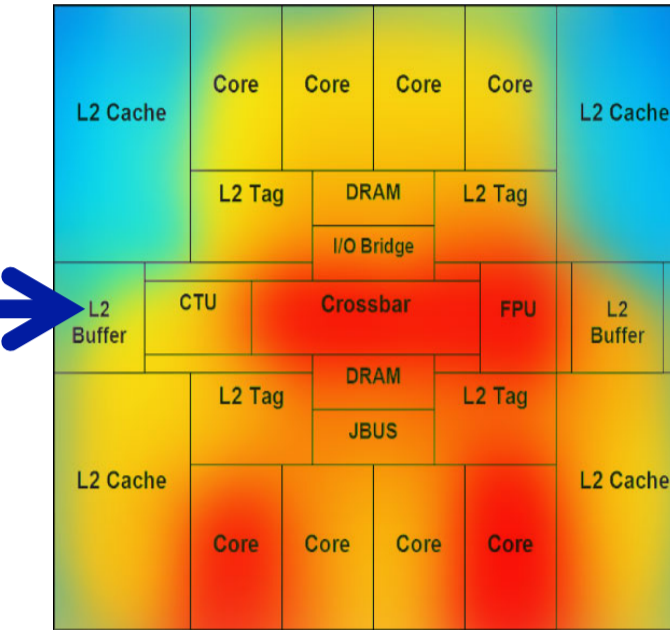
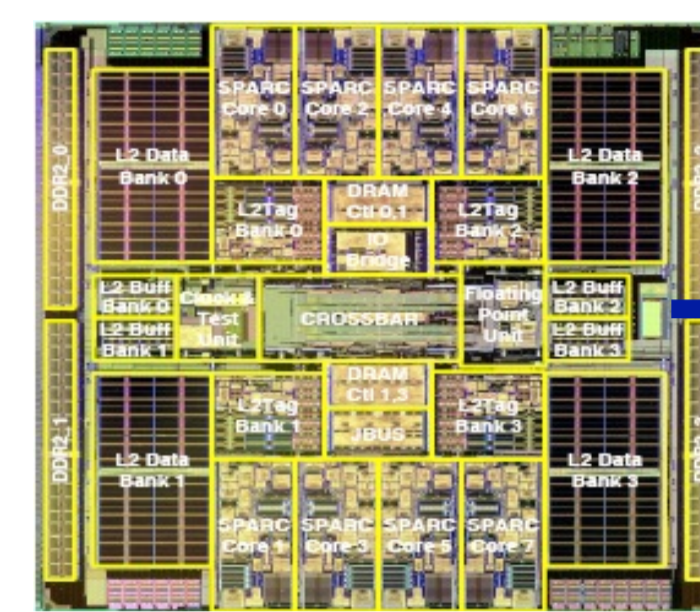
Hot water-cooled Data Centers of the Future



Courtesy: IBM Research, Zurich

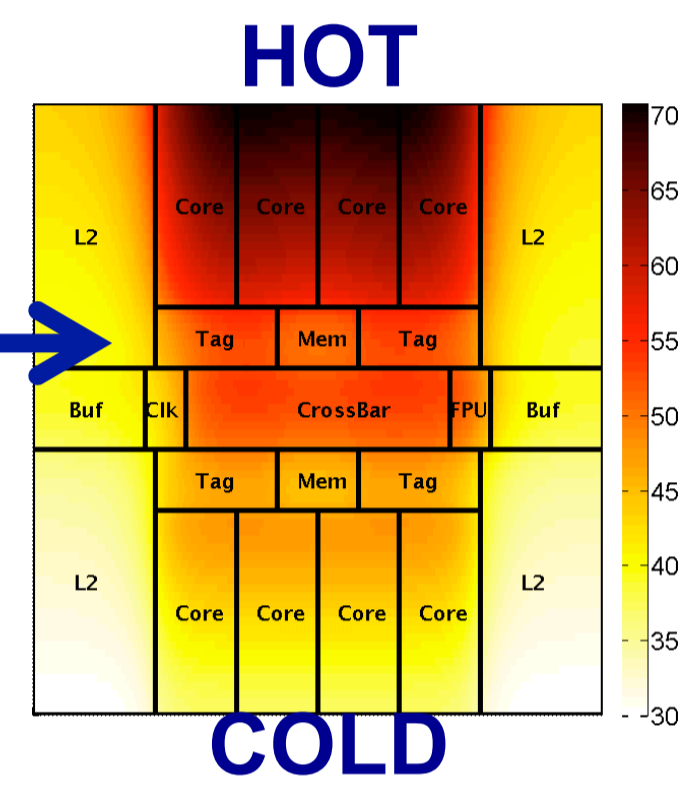
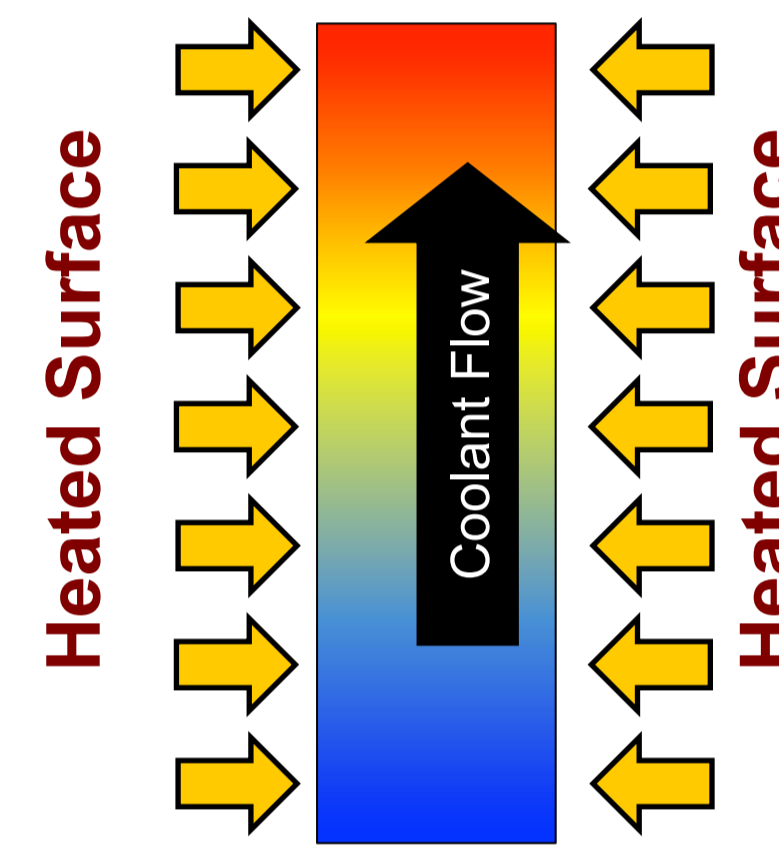
Challenges with Liquid-Cooling Efficiency

CHALLENGE #1



Non uniform heating of complex microprocessors
→ Non uniform temperatures!

CHALLENGE #2



Water absorbs heat, inlet hotter than outlet
→ Temperature Gradients!

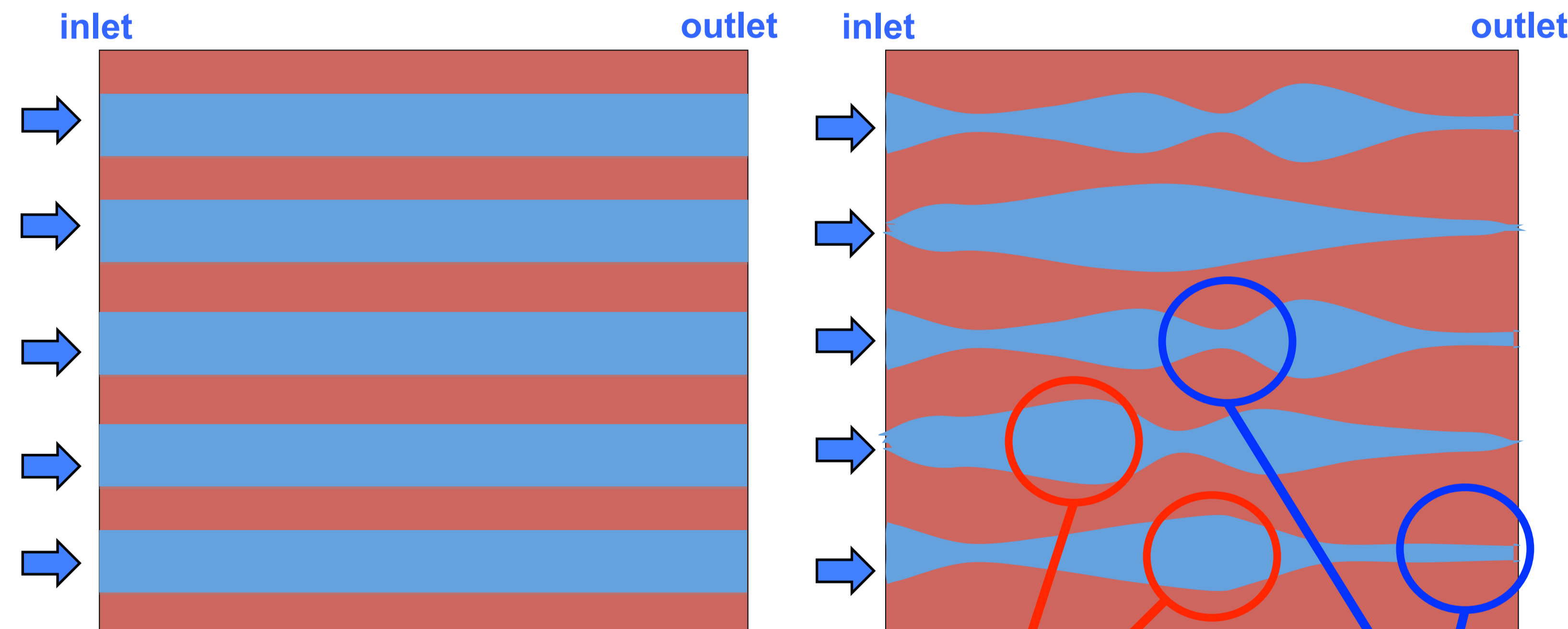
Design determined by "worst case"

→ hottest spot governs cooling effort

Channel Modulation : a novel idea !

Tweaking the Physics of the problem

What if we "locally" customize the cooling effort for an IC?

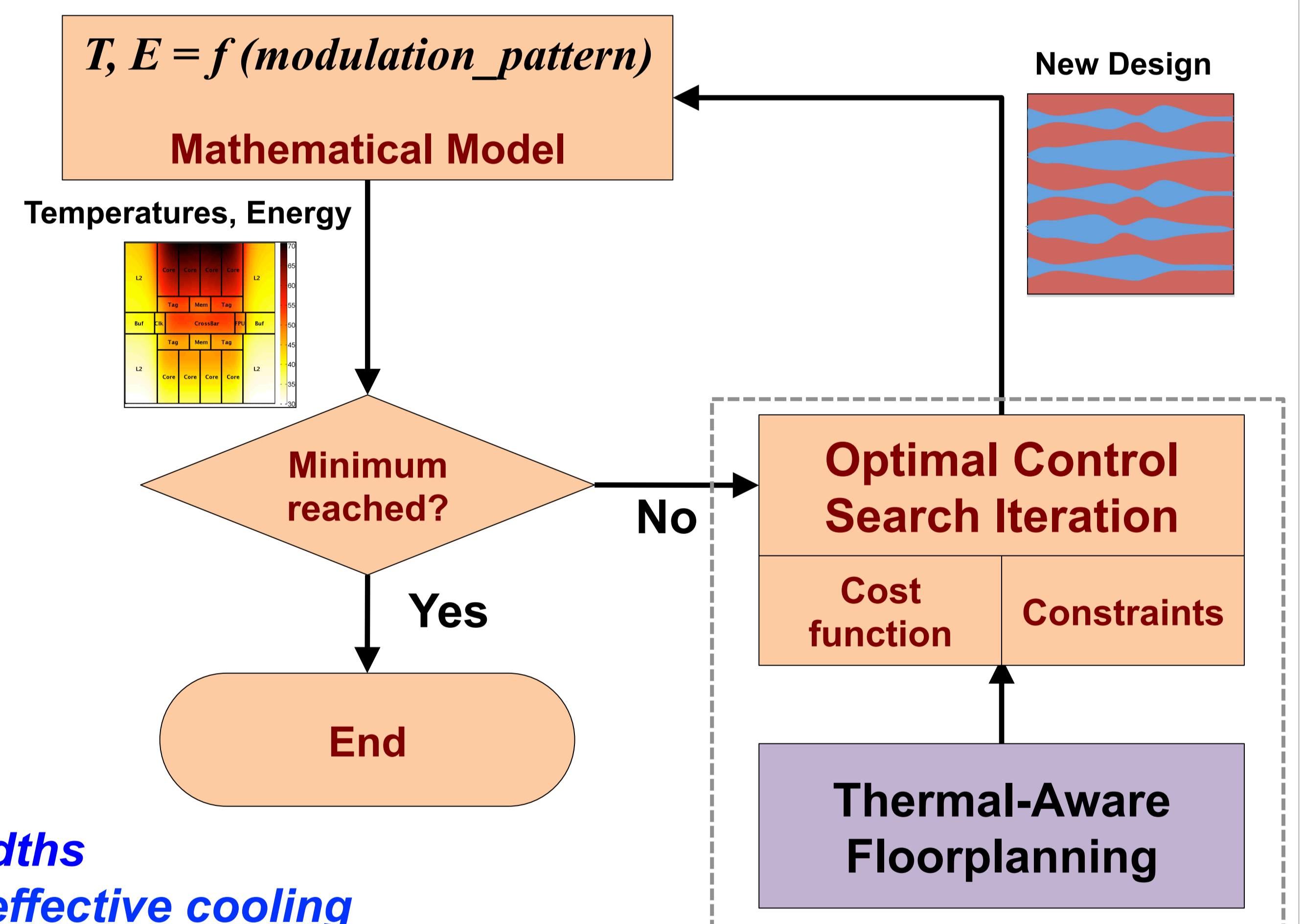


Uniform Widths
→ Uniform cooling effectiveness
→ Large Thermal Gradients

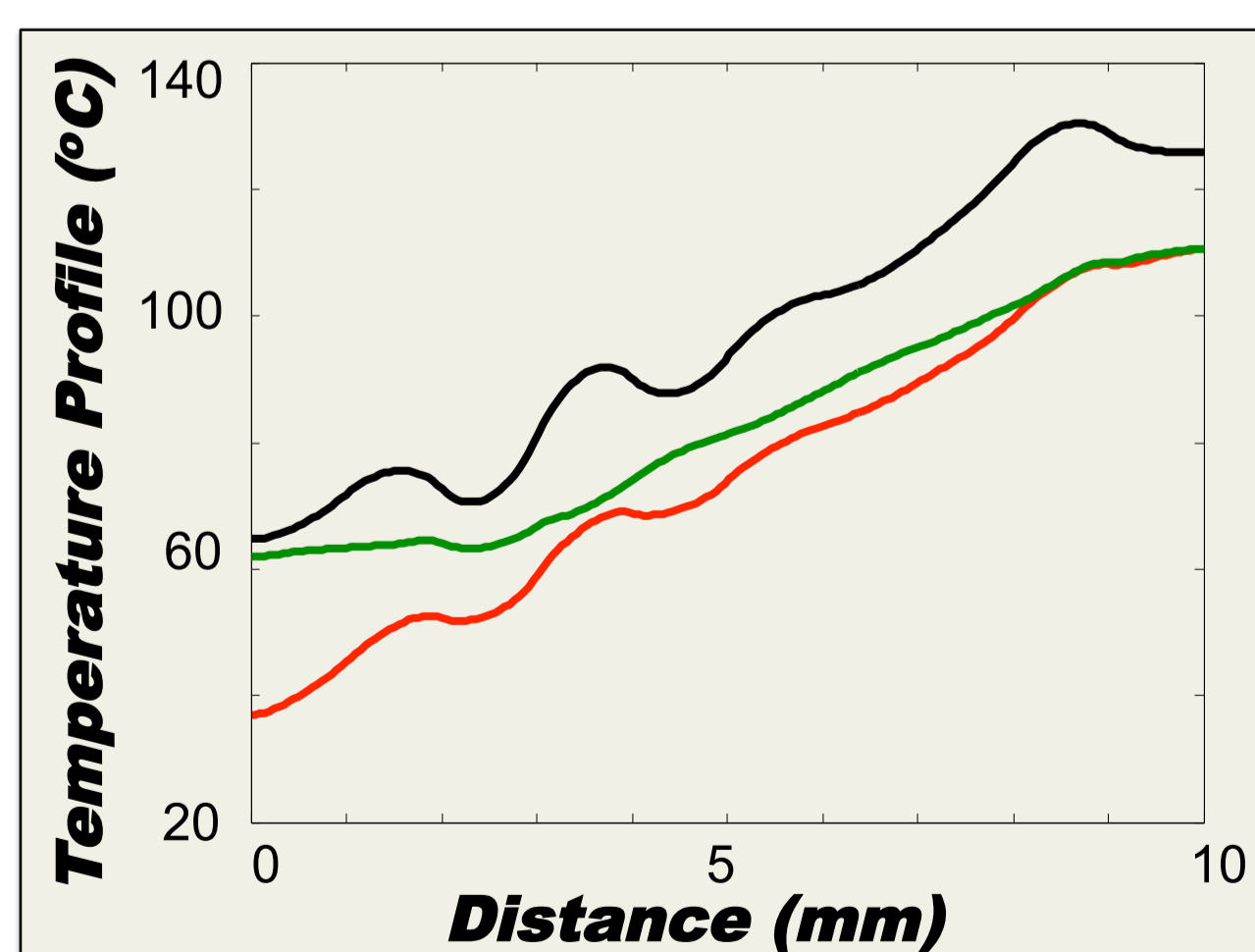
Large widths
→ Less effective cooling
→ Lower pumping effort

Small widths
→ More effective cooling
→ Higher pumping effort

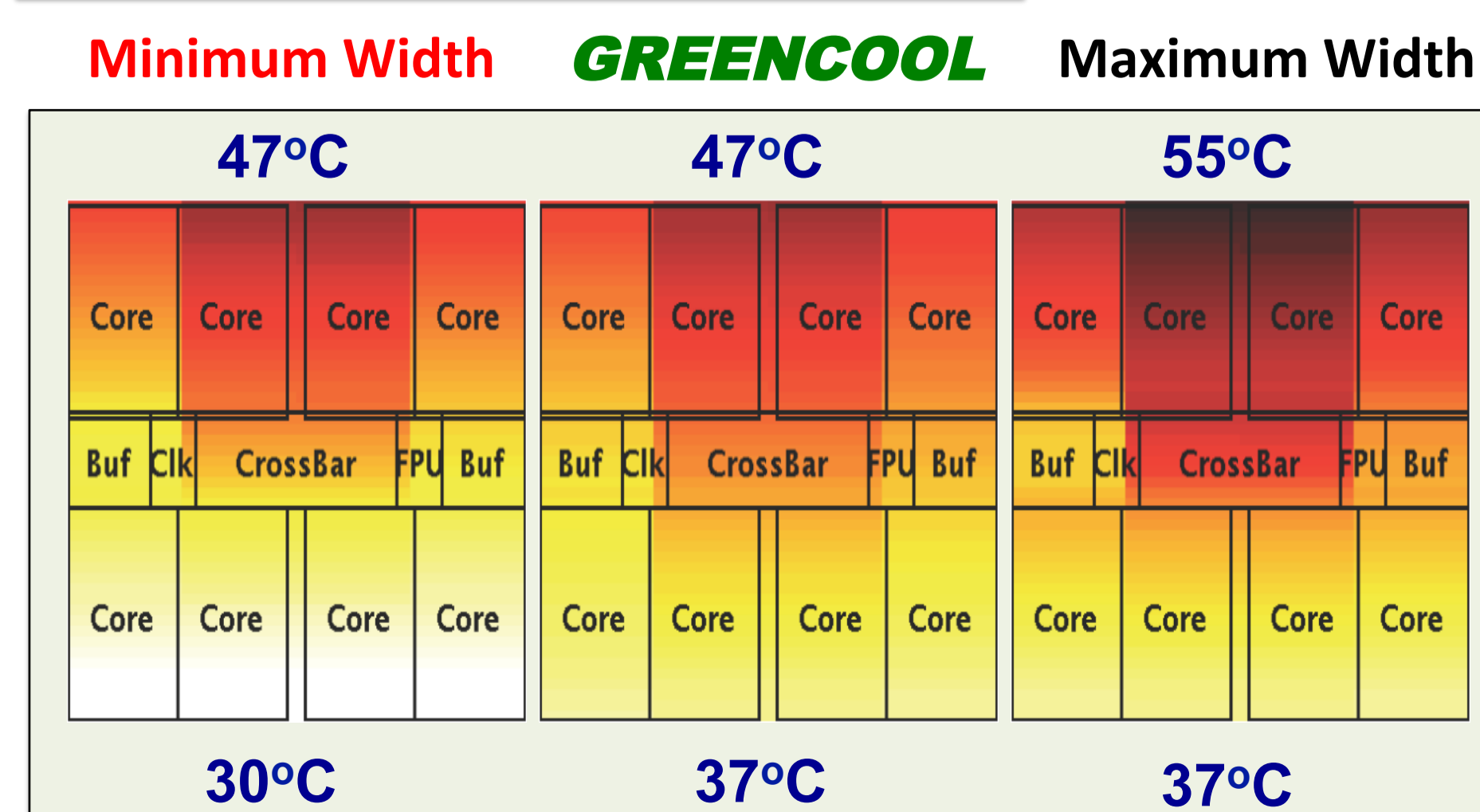
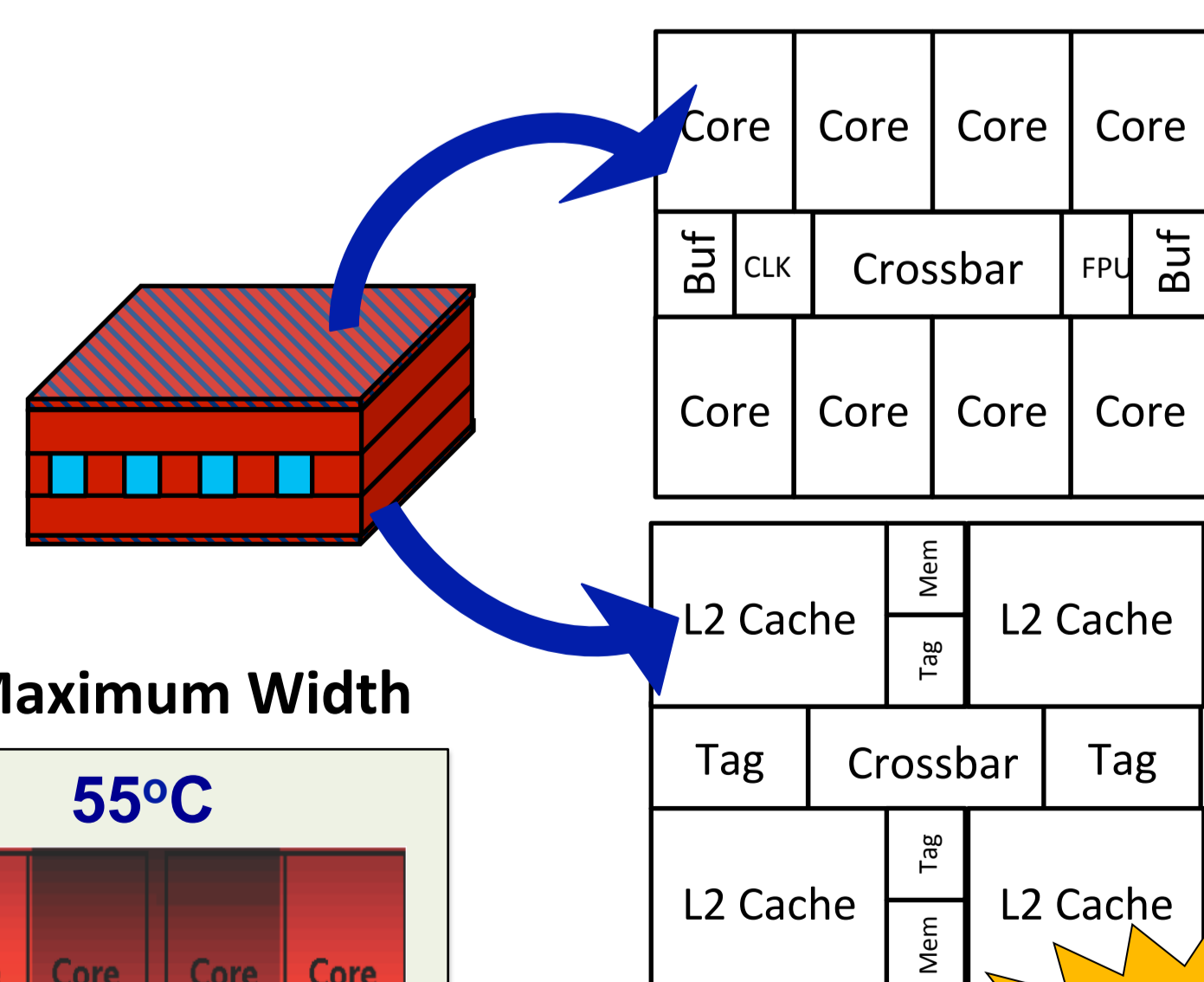
GREENCOOL methodology



GREENCOOL 1.0* Minimizing Thermal Gradients



2-die SUN Niagara multi-core processor



30% gradient reduction

Theoretical Minimum Achieved

GREENCOOL 2.0 Maximizing Energy Efficiency

- > 2-die 16-core Multiprocessor with DRAM
- > Full microarchitecture exploration
- > Full software benchmark exploration
- > total of 360 experiments

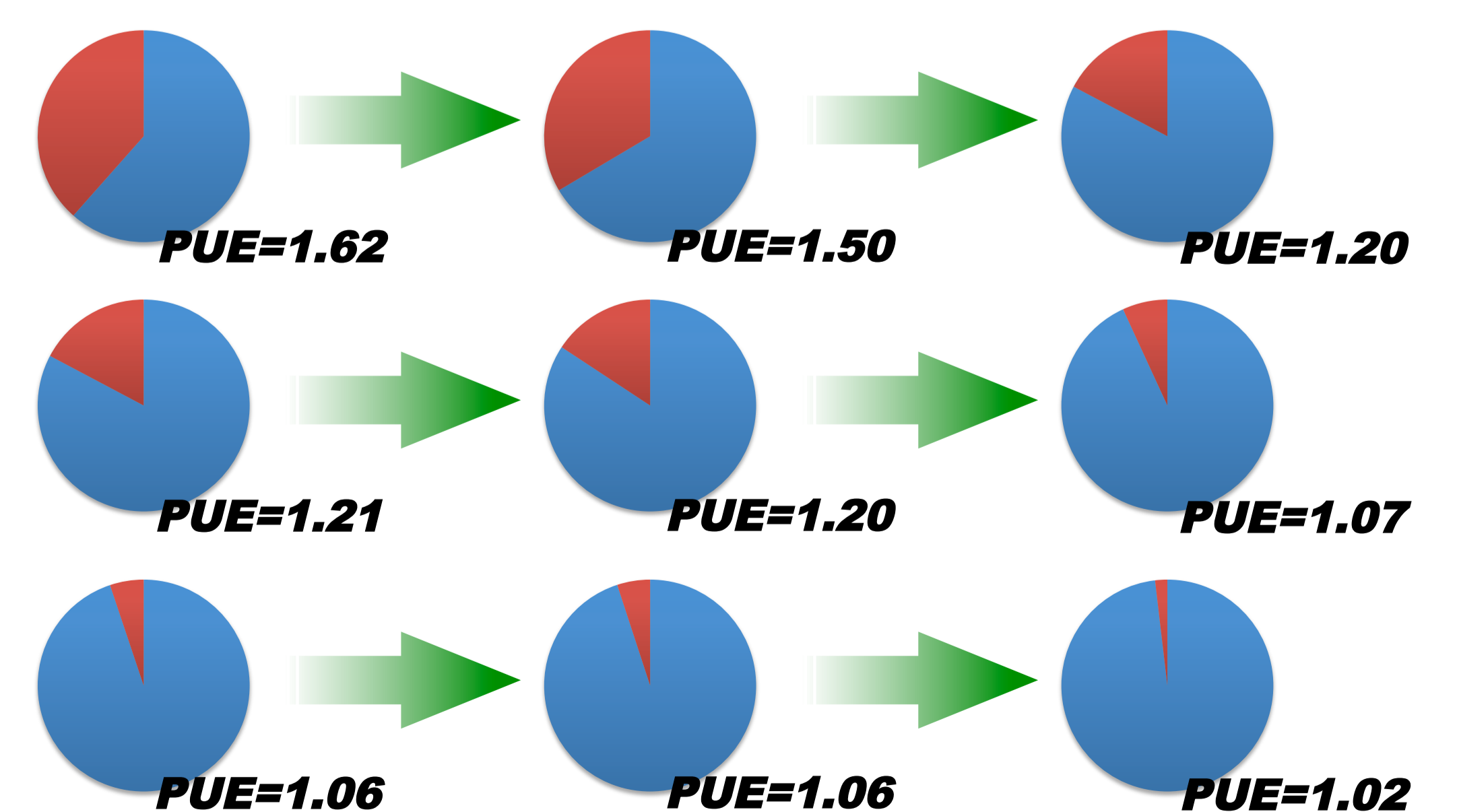
Up to 80% reduction in cooling energy

≤10°C

≤12°C

≤15°C

Peak Gradient



Maximum Width

GREENCOOL without modulation (uniform width)

GREENCOOL with modulation

*Sabry et al. "Thermal Balancing of liquid-cooled ICs using Channel modulation", DATE 2012