

EVALUATING THE PRACTICAL ENERGY SAVING POTENTIAL OF A PERSONAL COOLING SYSTEM IN THE TROPICS

THE APPEALING POTENTIAL OF PERSONAL COOLING



Higher background temperature



More effective ventilation



Customized micro-environment



Psychological delight



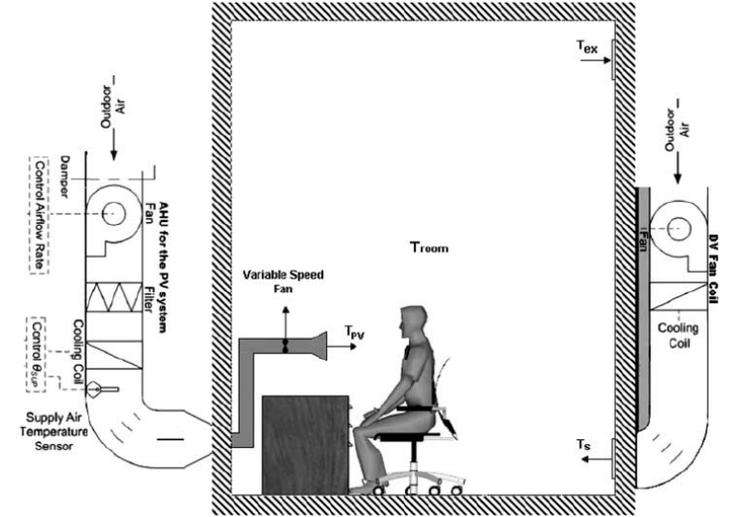
Cooling energy reduction

(up to 51% in hot and humid climate [1])

Better thermal comfort

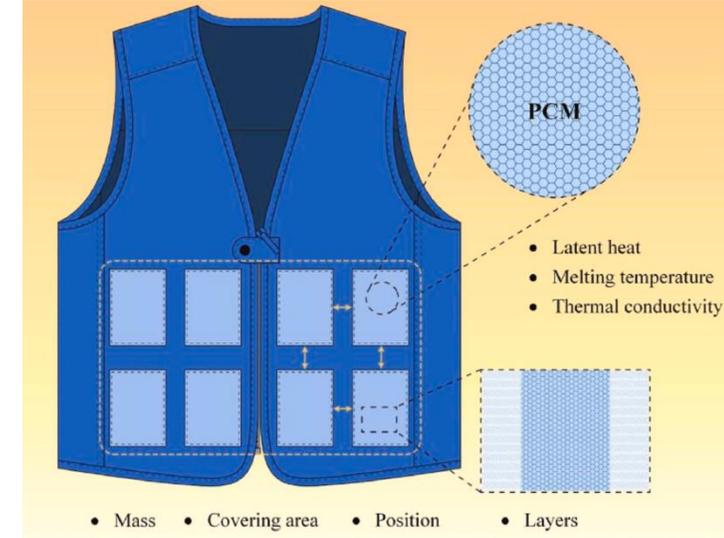
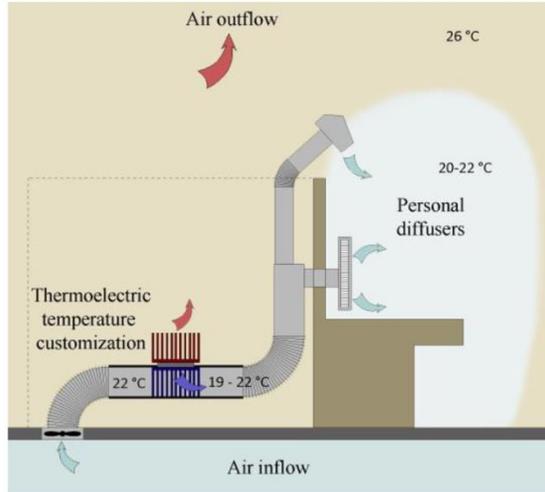
(over 90% occupants found satisfactory [2])

DISTRIBUTED COOLING PROVIDED BY CENTRALIZED SYSTEM



- Hard to install and maintain
- disruptive to the environment
- Significant change in central HVAC system
- Rearrangement disabled by inflexible ductwork

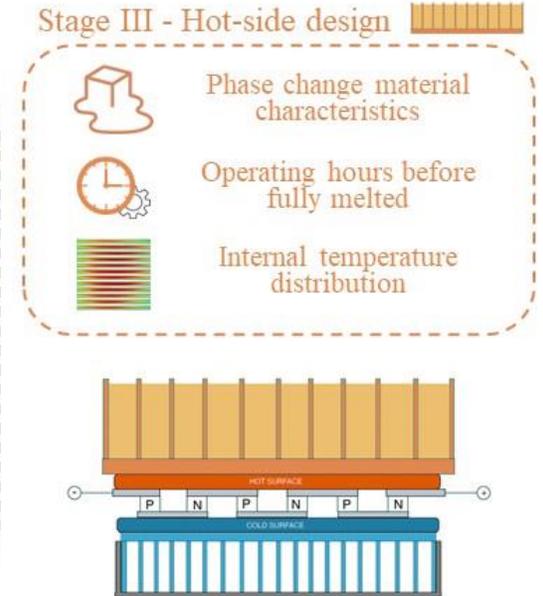
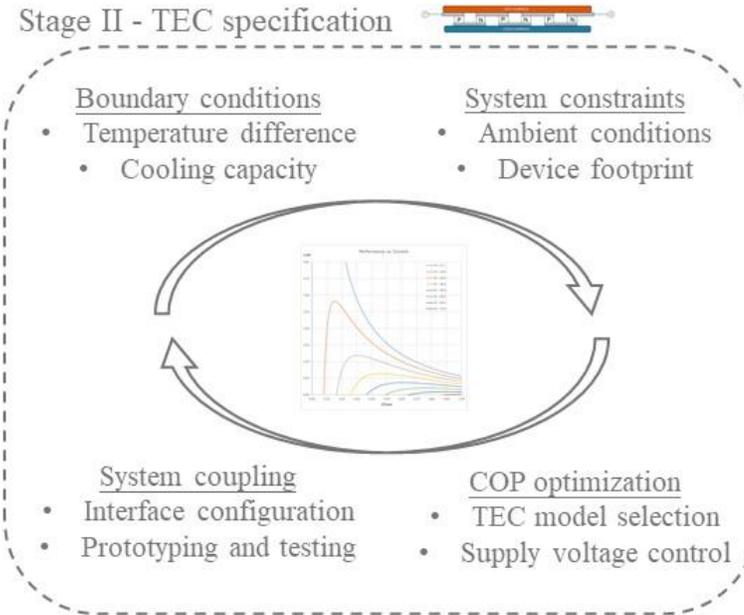
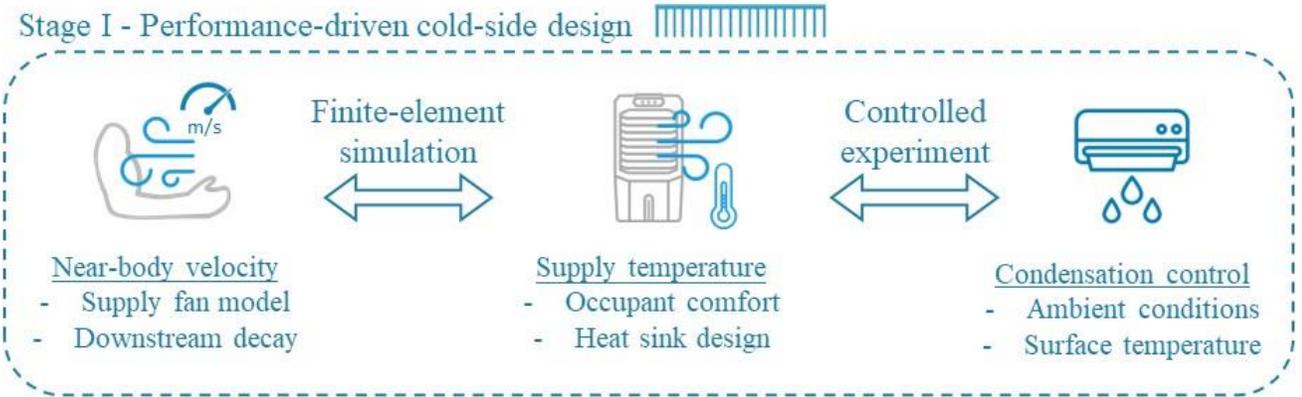
PREVIOUS EFFORTS ON DECENTRALIZED PERSONAL COOLING



- The trilemma of cold air delivery, portability, and heat dissipation
 - Cold air typically more desirable than conduction-based cooling
 - Hard to efficiently cool air within limited system size
 - Prevent the exhaust heat to warm up the ambient indoor environment

INTEGRATIVE DESIGN FRAMEWORK

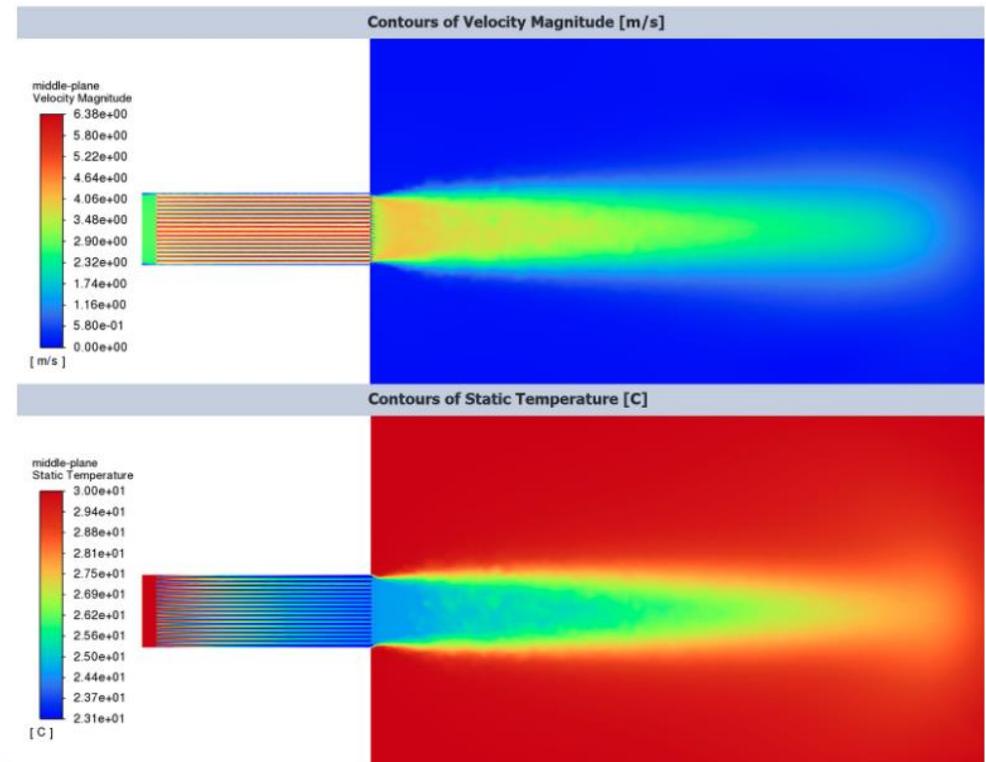
- Three key components
 - Optimal cold-side design
 - Condensation prevention
 - Outlet velocity-temperature trade-off
 - TEC specification
 - Cooling capacity provision
 - COP optimization
 - PCM-based heat dissipation
 - TEC hot-side temperature control
 - Self-contained heat dissipation



PERFORMANCE-DRIVEN COLD SIDE DESIGN

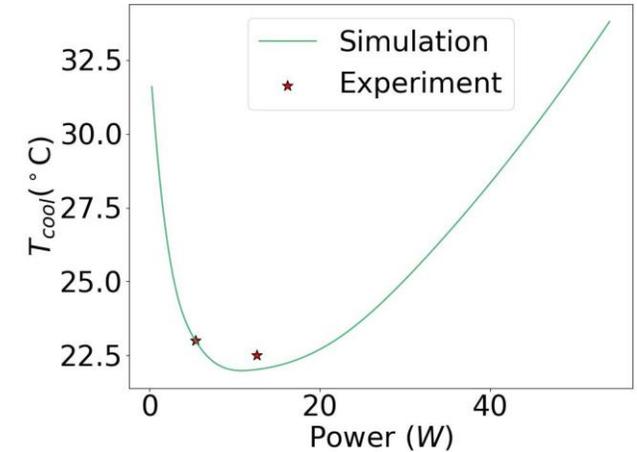
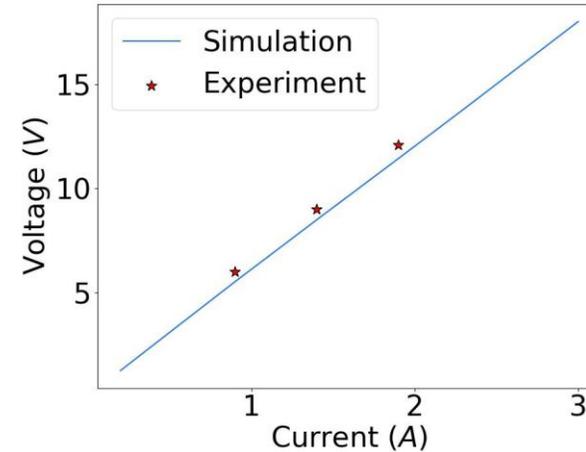
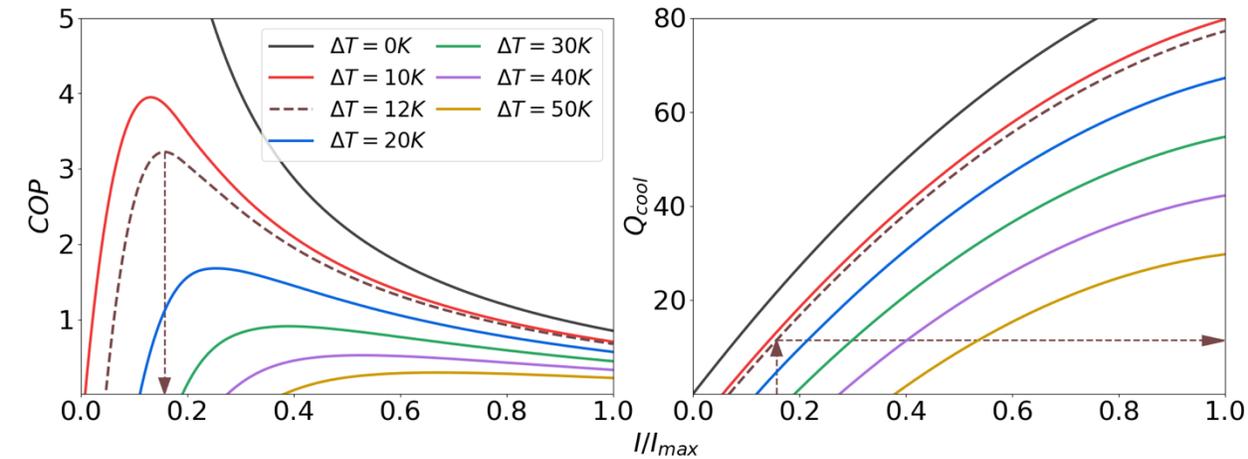
- Lowest surface temperature to be 1°C lower than ambient dewpoint based on empirical analysis
- Heat sink geometry optimization
 - Constrained footprint of 50*150mm
 - NMB 7530 blower supply fan
 - 2mm fin gap to balance cooling efficiency and pressure drop

	$T_{ambient}$	$RH_{ambient}$	$T_{dewpoint}$	$V_{surface}$	$T_{condensation}$
1	31.2°C	74.8%	26.2°C		24.6°C
2	28.4°C	70.6%	22.5°C	5.2 m/s	21.4°C



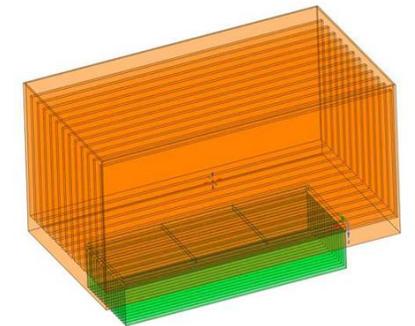
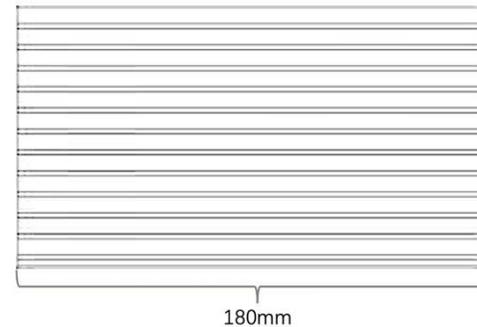
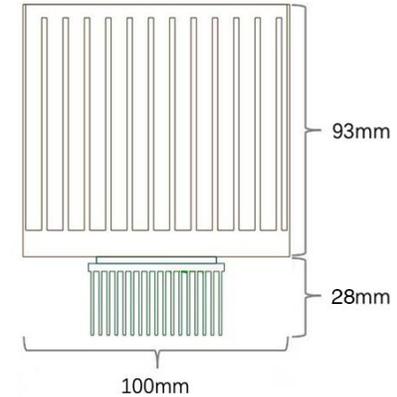
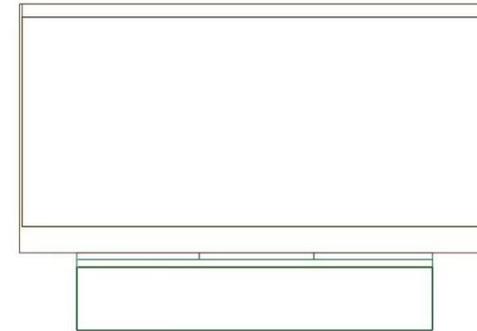
TEC MODEL SPECIFICATION

- Constrained by cold-hot side temperature difference of 12°C
- COP optimization – operate between 0.1-0.2 I_{max}
- Ansys simulation validated by actual experiments



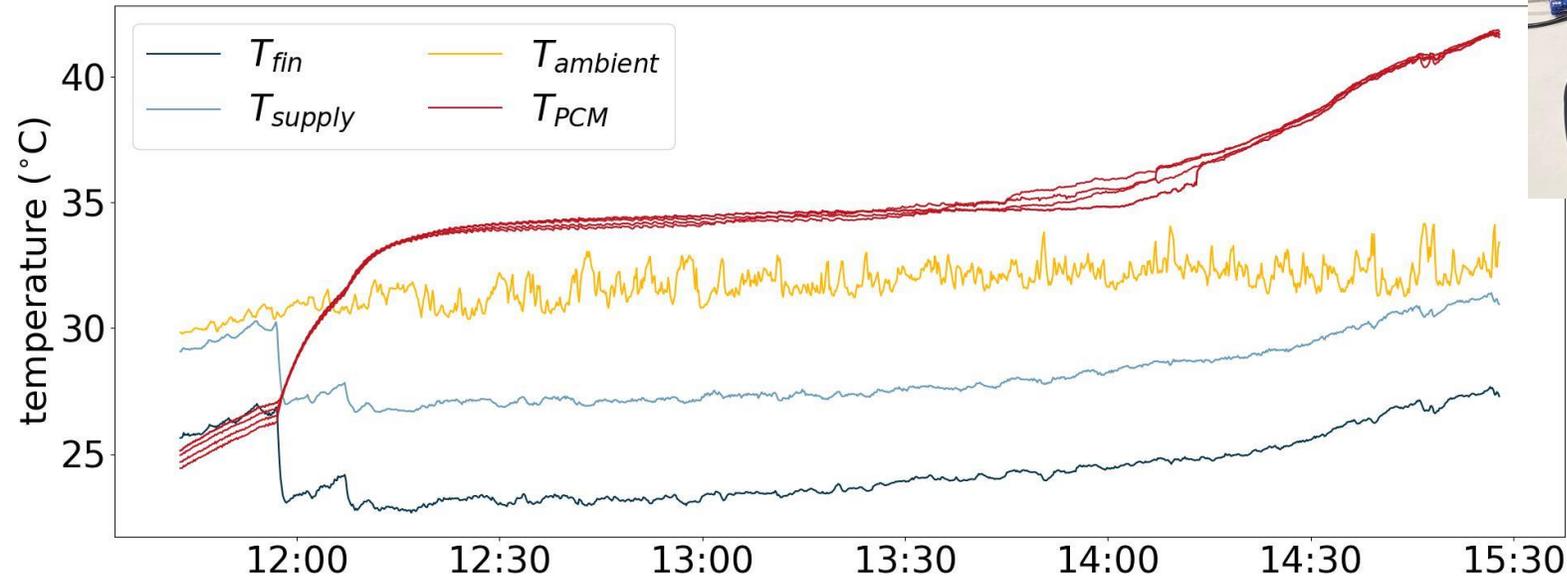
HOT-SIDE DESIGN

- Phase change material
 - Stable hot-side temperature before fully melted
 - Quickly absorb exhaust heat during operation
 - Slowly release to the ambient with minimal impact
- Thicker fins for more uniform internal temperature distribution
- Volume designed for 2 hours of operation at maximum capacity



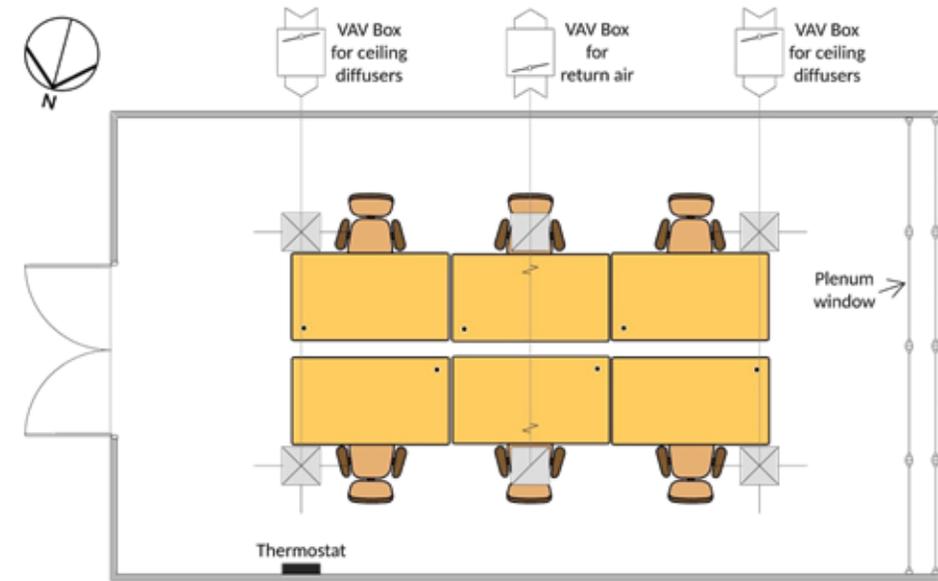
PROTOTYPE AND PERFORMANCE VALIDATION

- Temperature decrease of 4°C
- Two hours of stable operation
- Uniform hot-side surface temperature



ENERGY SAVING POTENTIAL ESTIMATION

- Calibrated model of a 50m² office with 6 occupants
 - Two devices per person
 - Operable windows for potential mixed-mode ventilation
- Three device operating modes based on ambient temperature and corresponding power range
- Combined with four ambient environment control modes: baseline, hybrid 1, hybrid 2, and mixed-mode

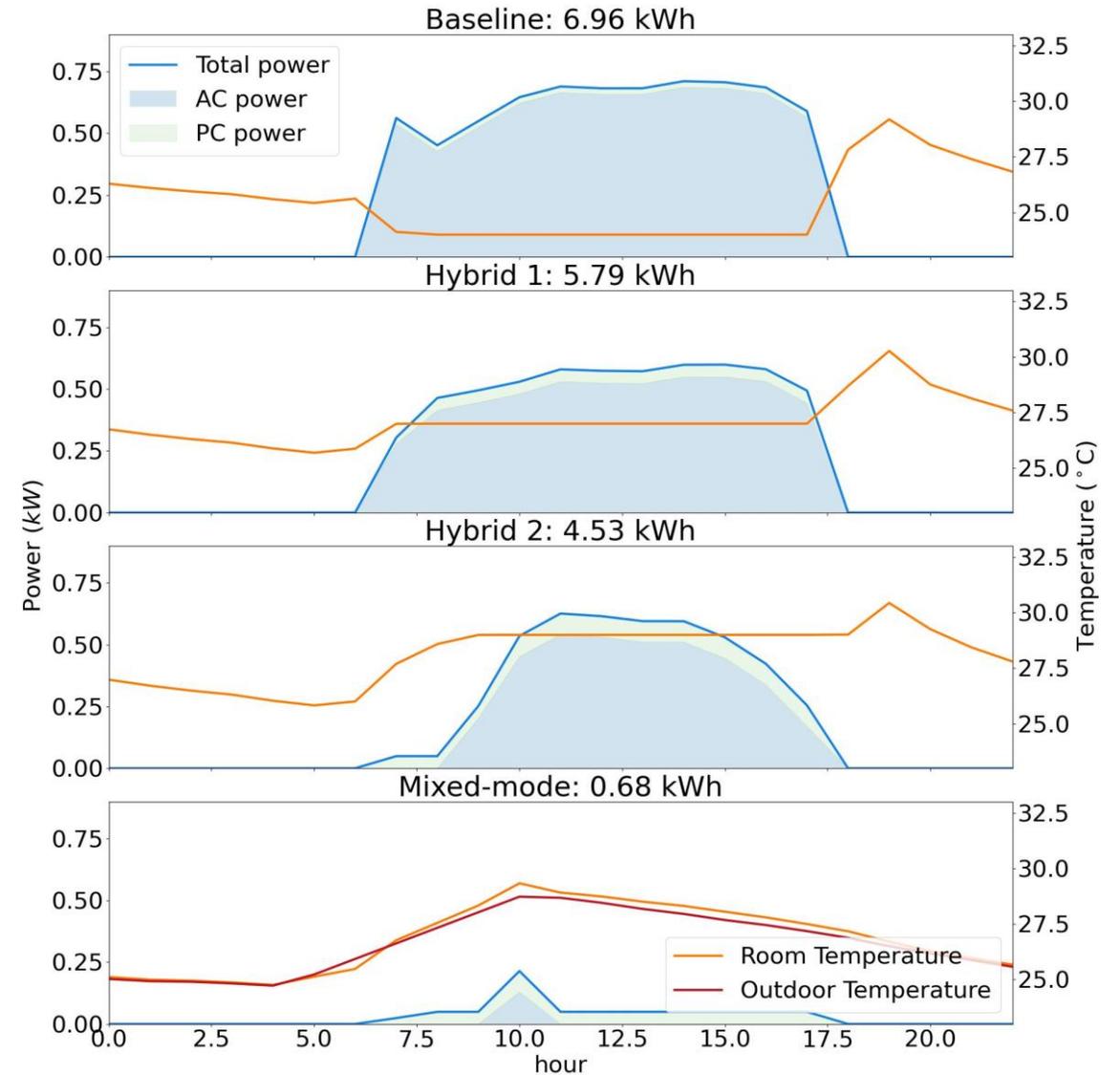


Ambient temperature (°C)	Operating mode	Power (W)
$T_{amb} < 27$	Personal ventilation	1.2-2.8
$27 \leq T_{amb} \leq 29$	Customized	1.2-7
$29 < T_{amb}$	Personal cooling	3.5-10.4

Mode	Cooling setpoint (°C)	Natural ventilation	Personal cooling mode
Baseline	24	No	Off
Hybrid 1	27	No	Personal ventilation
Hybrid 2	29	No	Customized
Mixed-mode	29	Yes	Customized

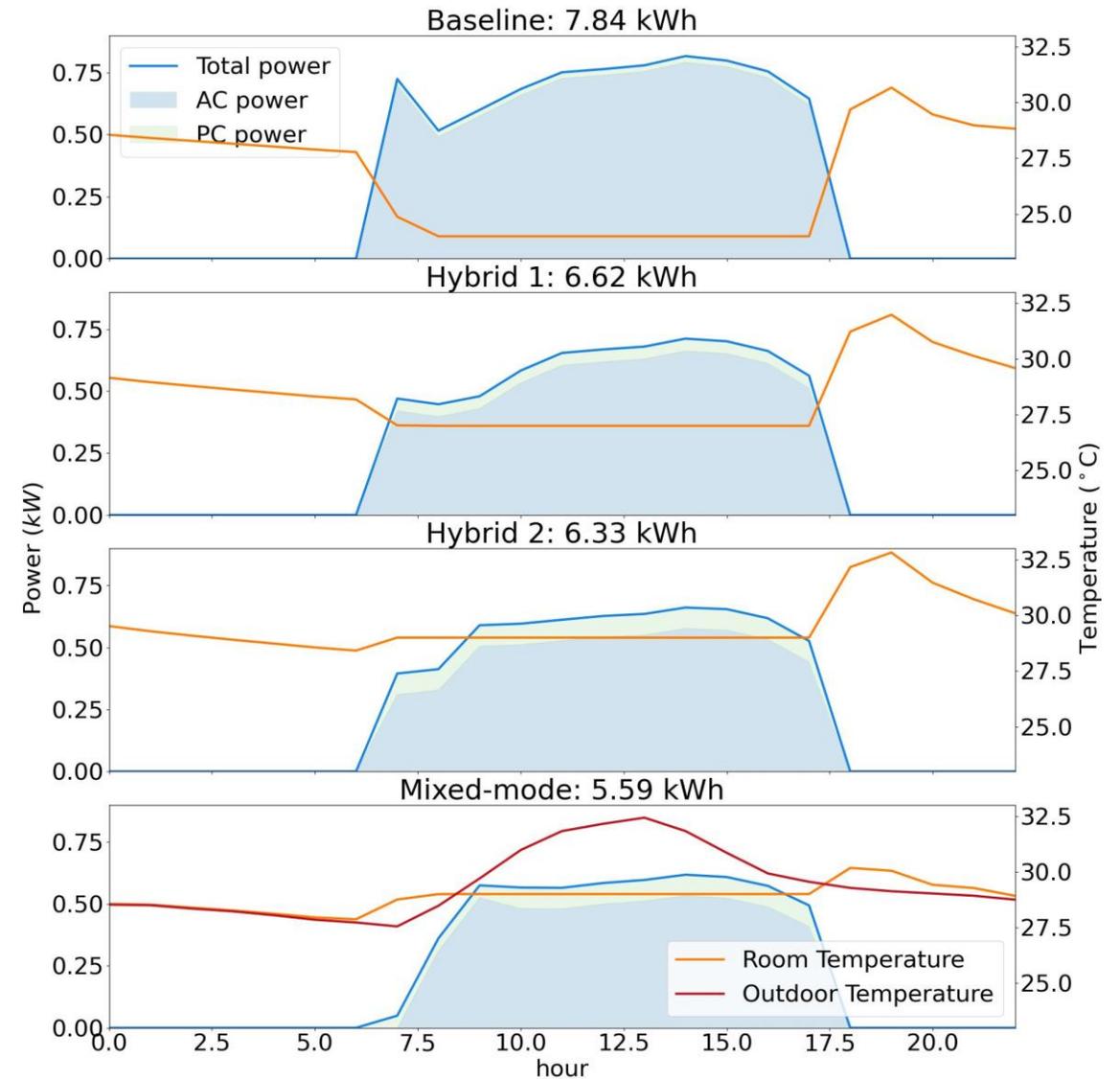
TYPICAL BEHAVIOR ON A COOL DAY

- PC devices consumption generally much lower than central AC
- Increase of cooling setpoint gradually reduced AC consumption
- Mixed-mode significantly reduced energy consumption by leverage natural ventilation for free cooling



TYPICAL BEHAVIOR ON A HOT DAY

- Outdoor temperature mostly above 29°C
- Less energy reduction from hybrid or mixed-mode cooling
- Slightly reduced AC energy compensated by the increased PC energy
- Less free cooling from natural ventilation



ENERGY SAVING POTENTIAL

Mode	AC energy ^a (<i>kWh</i>)	Peak load (<i>kW</i>)	Cooling hours	PC energy (<i>kWh</i>)	Saving percentage (%)
Baseline	1761.2	4.5	2871	NA	NA
Hybrid 1	1427.8	3.8	2860	73.6	14.8
Hybrid 2	1140.7	3.4	2666	141.6	27.2
Mixed-mode	820.6	3.3	1915	134.4	45.8

^a The numbers have been converted to electricity energy assuming an overall COP of 5.

FUTURE DEVELOPMENT

- Real-time system condition monitoring and energy efficiency optimization
- Dedicated components design and fabrication (TEC, fan, heat sink)
- Subject experiments for more robust cooling effect evaluation
- More volume efficient heat dissipation for longer operating hours

THANK YOU!

References

[1] Schiavon, S., Melikov, A. K., & Sekhar, C. (2010). Energy analysis of the personalized ventilation system in hot and humid climates. *Energy and buildings*, 42(5), 699-707.

[2] Chen, Y., Raphael, B., & Sekhar, S. C. (2012). Individual control of a personalized ventilation system integrated with an ambient mixing ventilation system. *HVAC&R Research*, 18(6), 1136-1152.