2026 IAP - Sustainable AI

How AI and the Built Environment Shape Each Other

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26/01/16

At the intersection of architectural engineering and computational science

2016, BS in Energy and Environment Systems Engineering, Zhejiang University

2017, MS in Civil Engineering, Carnegie Mellon University

2022, PhD in the Built Environment, National University of Singapore

2022-24, Research fellow, National University of Singapore

2024-, Postdoctoral Associate in Building Technology, Massachusetts Institute of Technology
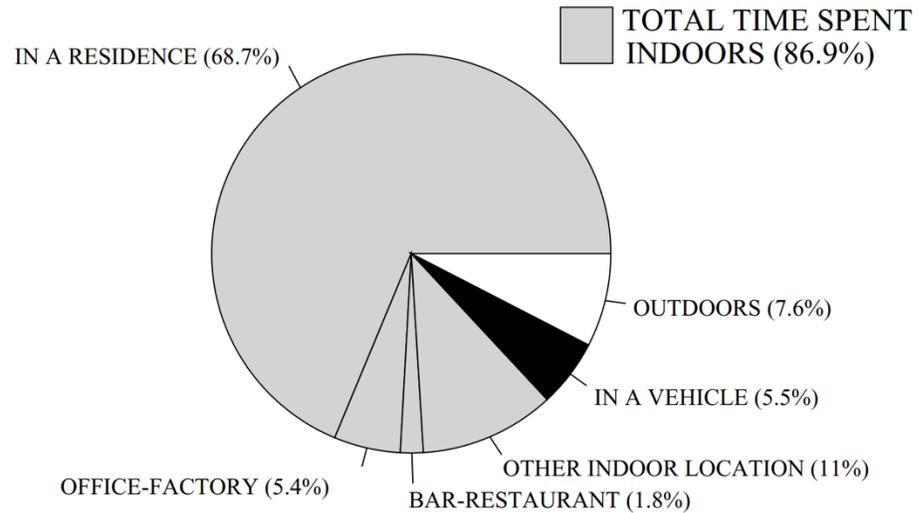
Research interest

Building energy modeling, carbon reduction, energy flexibility, digital twin, smart control, scientific machine learning, optimization
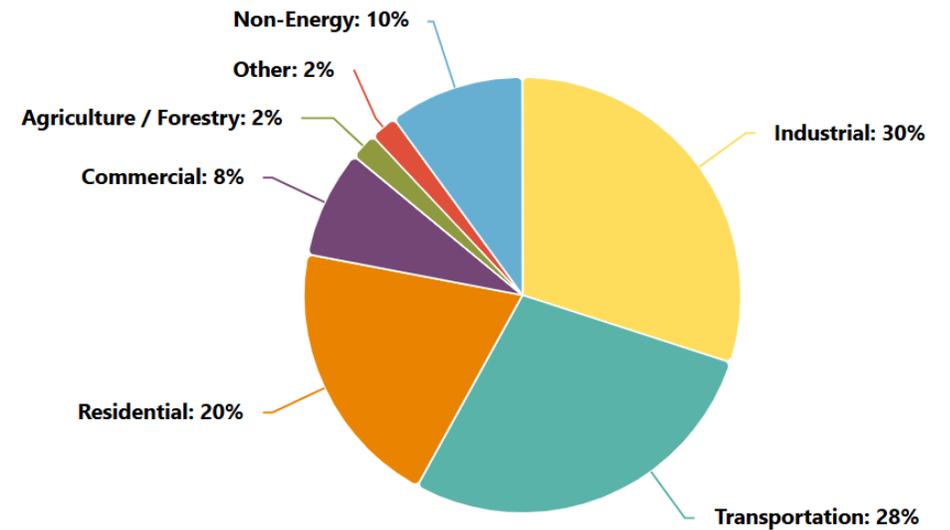
People spend ~90% of daily lives indoor

Buildings account for ~30% of global energy end uses
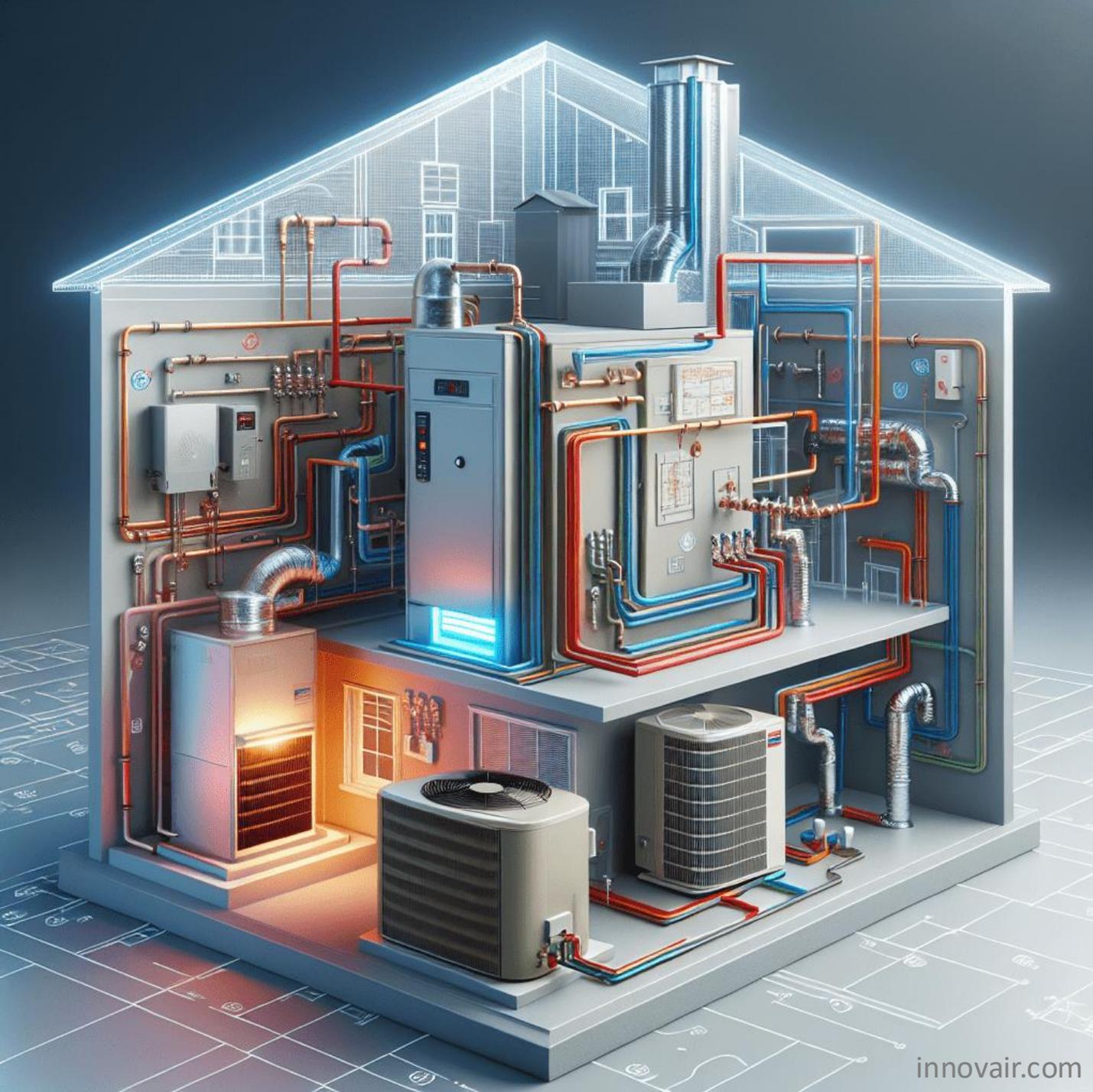

NHAPS - Nation, Percentage Time Spent
Total n = 9,196

TOTAL TIME SPENT INDOORS (86.9%)

IN A RESIDENCE (68.7%)

OUTDOORS (7.6%)

IN A VEHICLE (5.5%)

OTHER INDOOR LOCATION (11%)

BAR-RESTAURANT (1.8%)

OFFICE-FACTORY (5.4%)

Klepeis, N. E. *et al. J. Expo. Sci. Environ. Epidemiol.* **11**, 231–252 (2001).

Non-Energy: 10%

Other: 2%

Agriculture / Forestry: 2%

Commercial: 8%

Residential: 20%

Industrial: 30%

Transportation: 28%

IEA (2023).
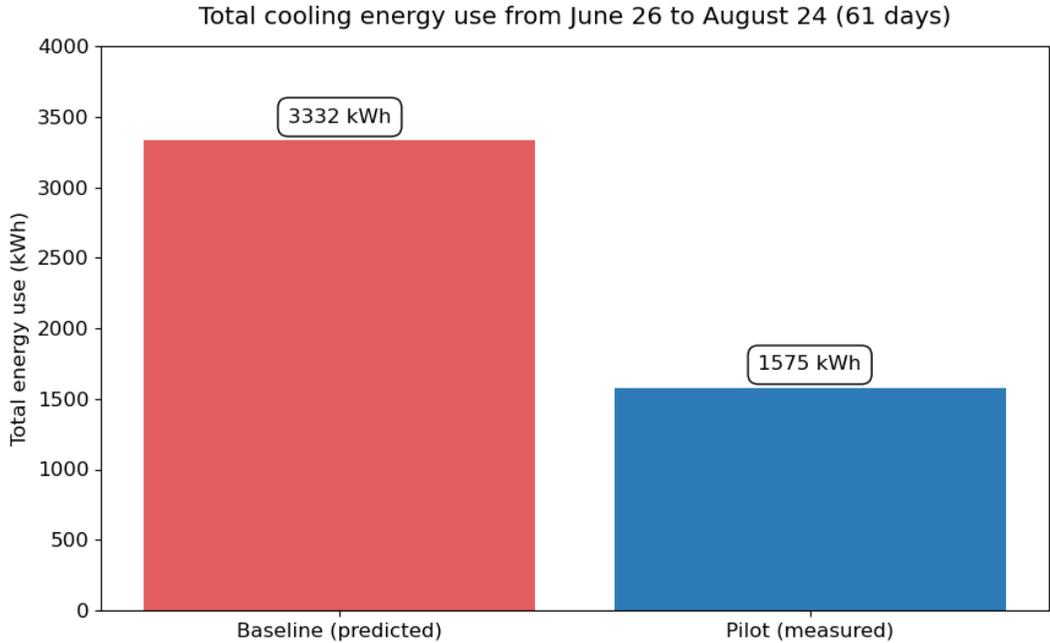
Most life-cycle energy use occurs during operations, consumed by building service systems: HVAC, lighting, and equipment

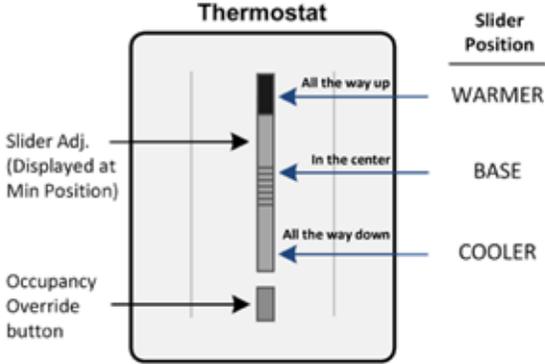Over 40% energy saving potential in intelligent and efficient building operations[1]

innovair.com

Ding, C. *et al. Nat. Commun.* **15**, 5916 (2024).

Avoiding unnecessary heating and cooling

Smart thermostat at
your home

Total cooling energy use from June 26 to August 24 (61 days)

3332 kWh

1575 kWh

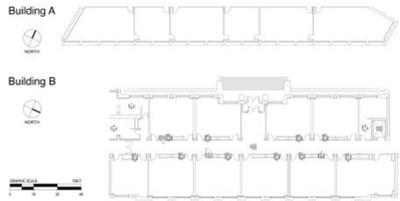Baseline (predicted)   Pilot (measured)

Legacy thermostat at MIT offices
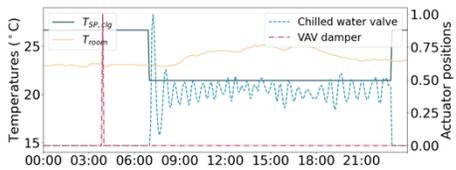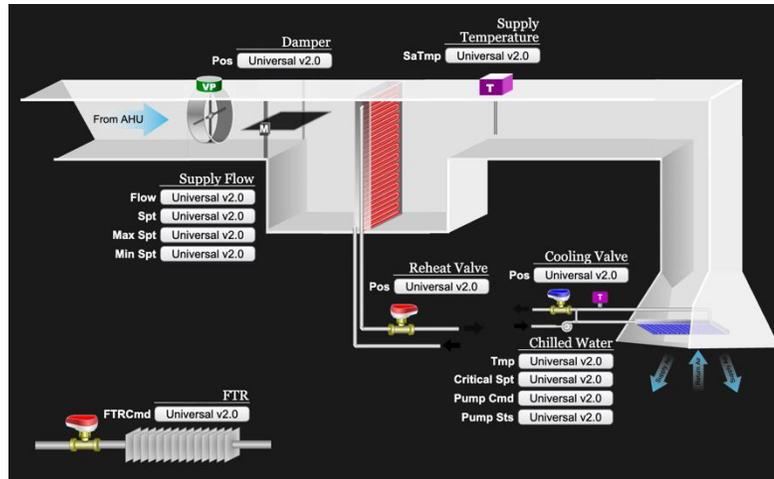learnable occupant behavior -> over 50% savings

Avoiding unnecessary heating, cooling, and ventilation
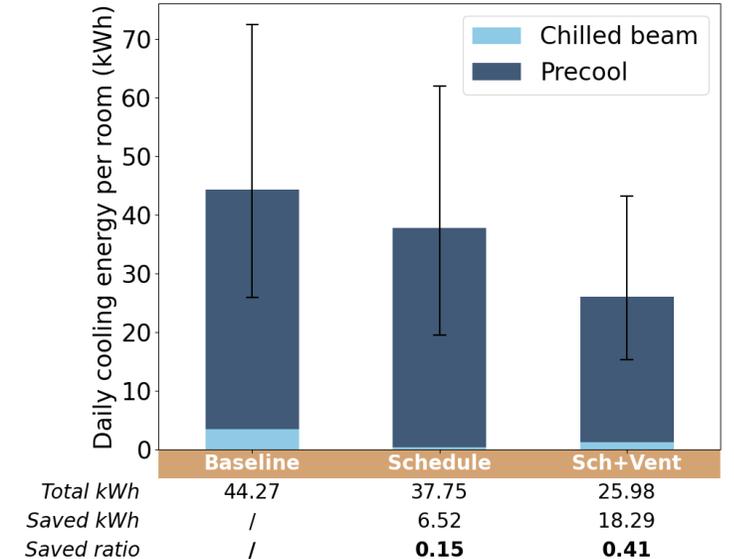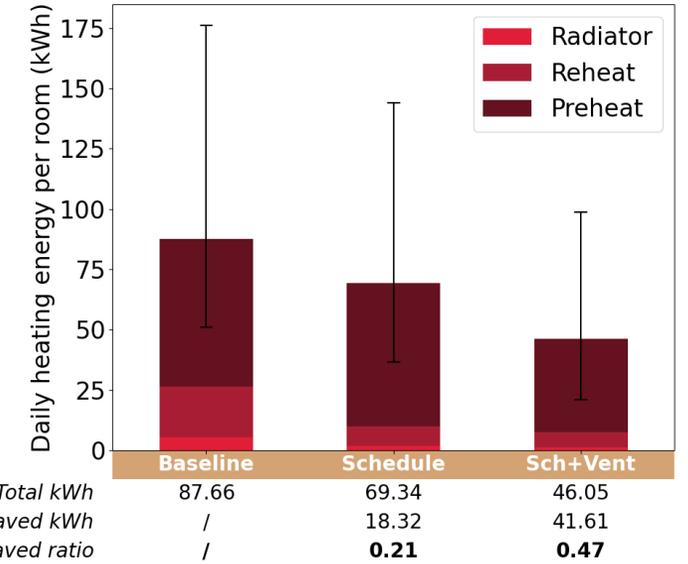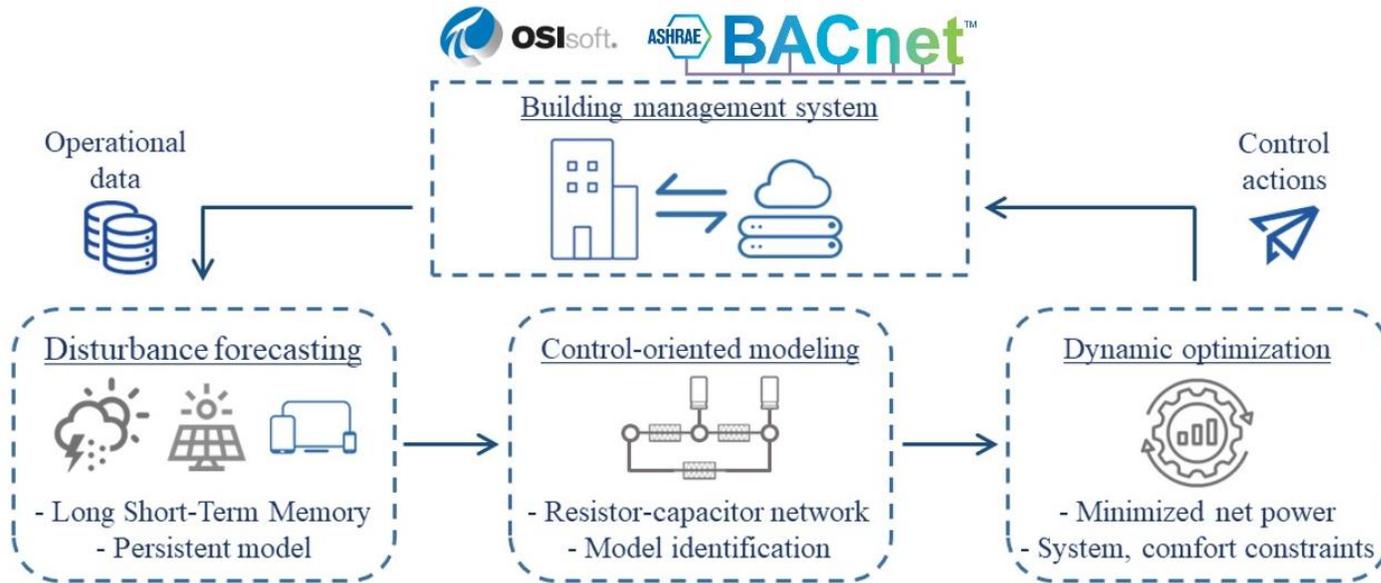

Class schedules

Drawings

Historical data

Building management system

Optimize comfort and energy through MPC

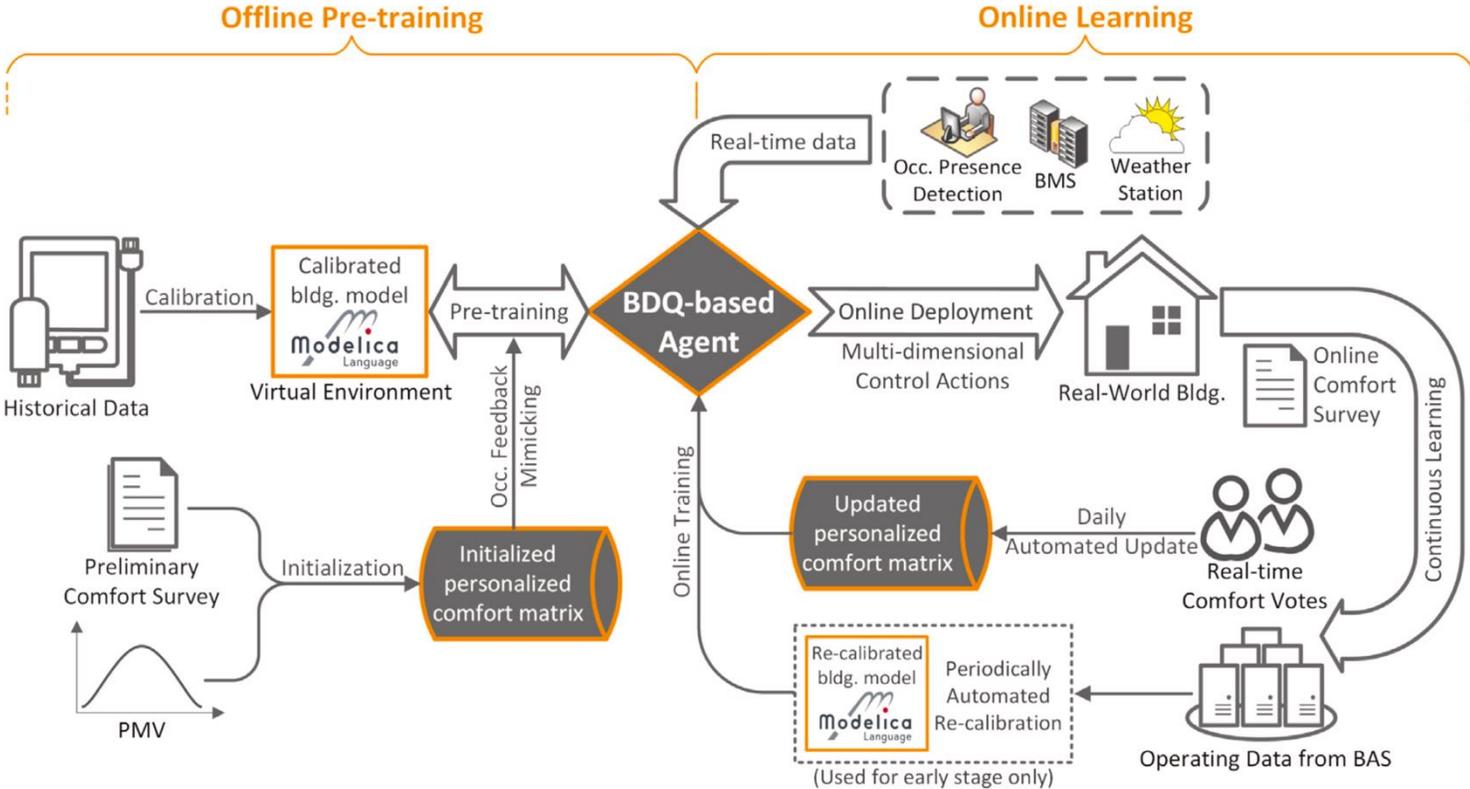Predictive control to resist internal/external disturbances

Better thermal comfort with over 10% additional savings

7

Accommodate personal preferences through RL

Coordinated multi-agent RL

10% better individual thermal sensation

14% cooling energy reduction

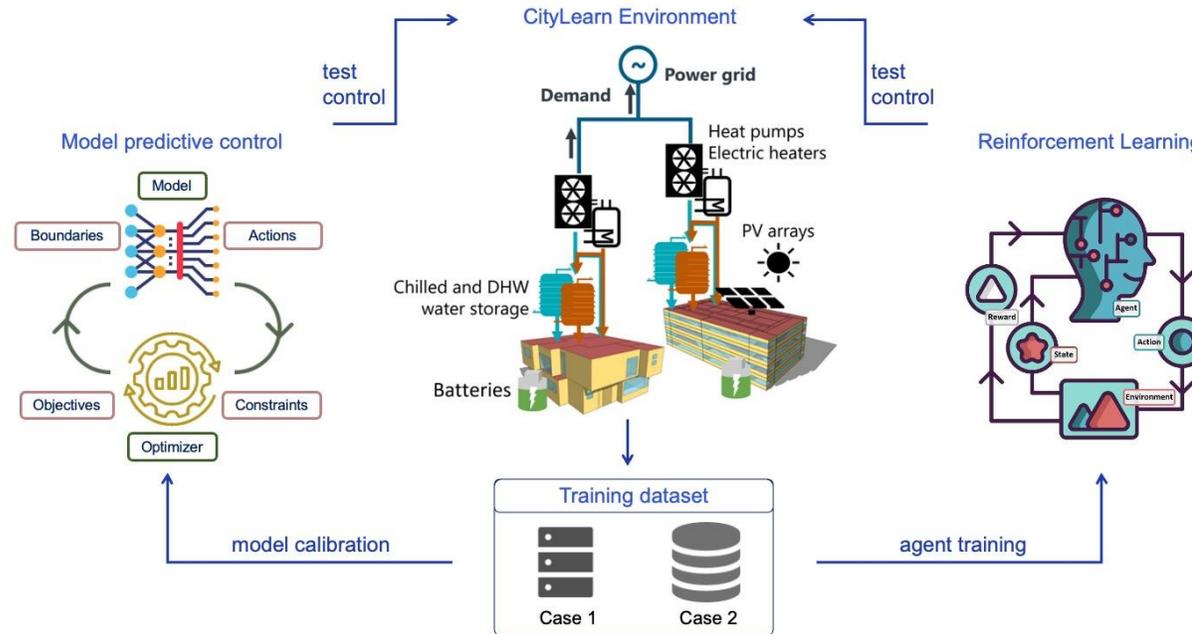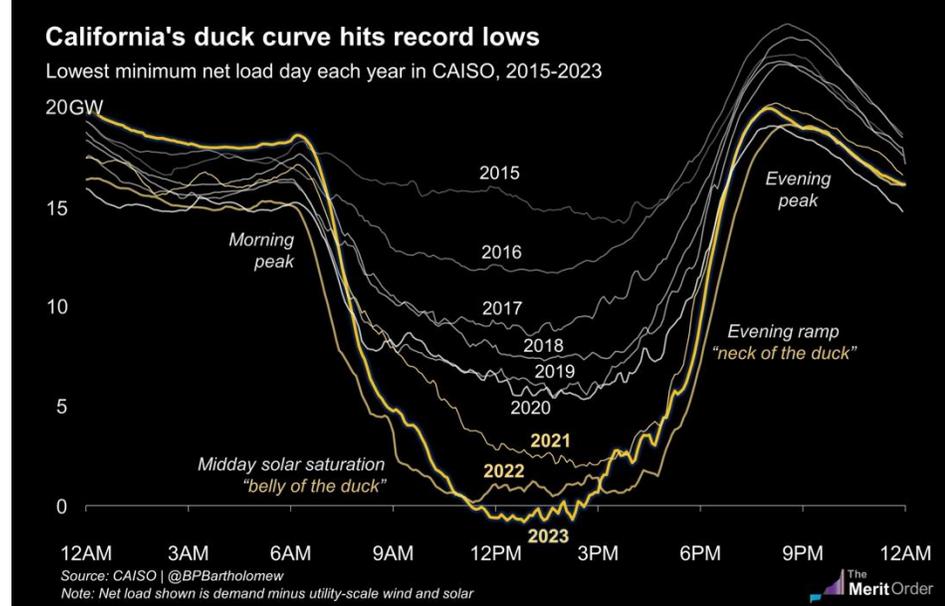Lei, Y. *et al. Appl. Energy* **324**, 114920 (2022).

Towards a zero-carbon future

Increasing renewable integration

Demand/generation forecasting

Multi-system coordination

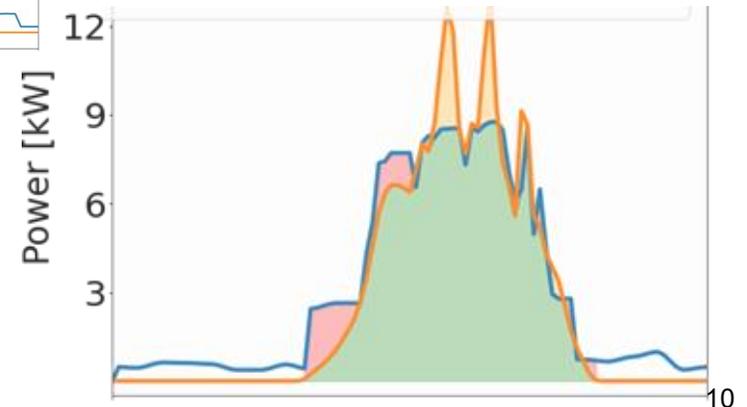10-35% reduction in energy and carbon (CapEx as well)

California's duck curve hits record lows
Lowest minimum net load day each year in CAISO, 2015-2023
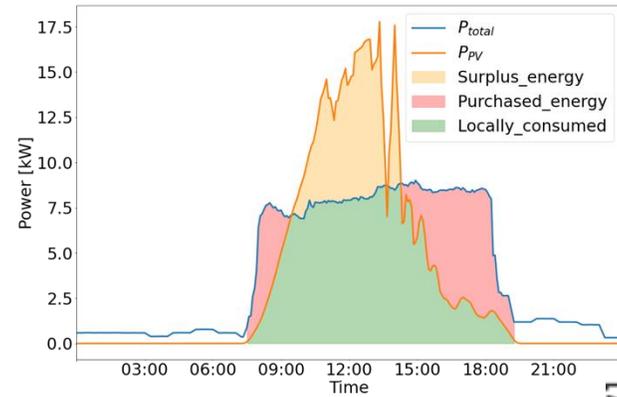
Zhan, S. *et al. IAQVEC.* (2023).

Net zero energy buildings

Buildings with rooftop PV

MPC to provide energy flexibility

20% more self-consumption
10% more self-sufficiency

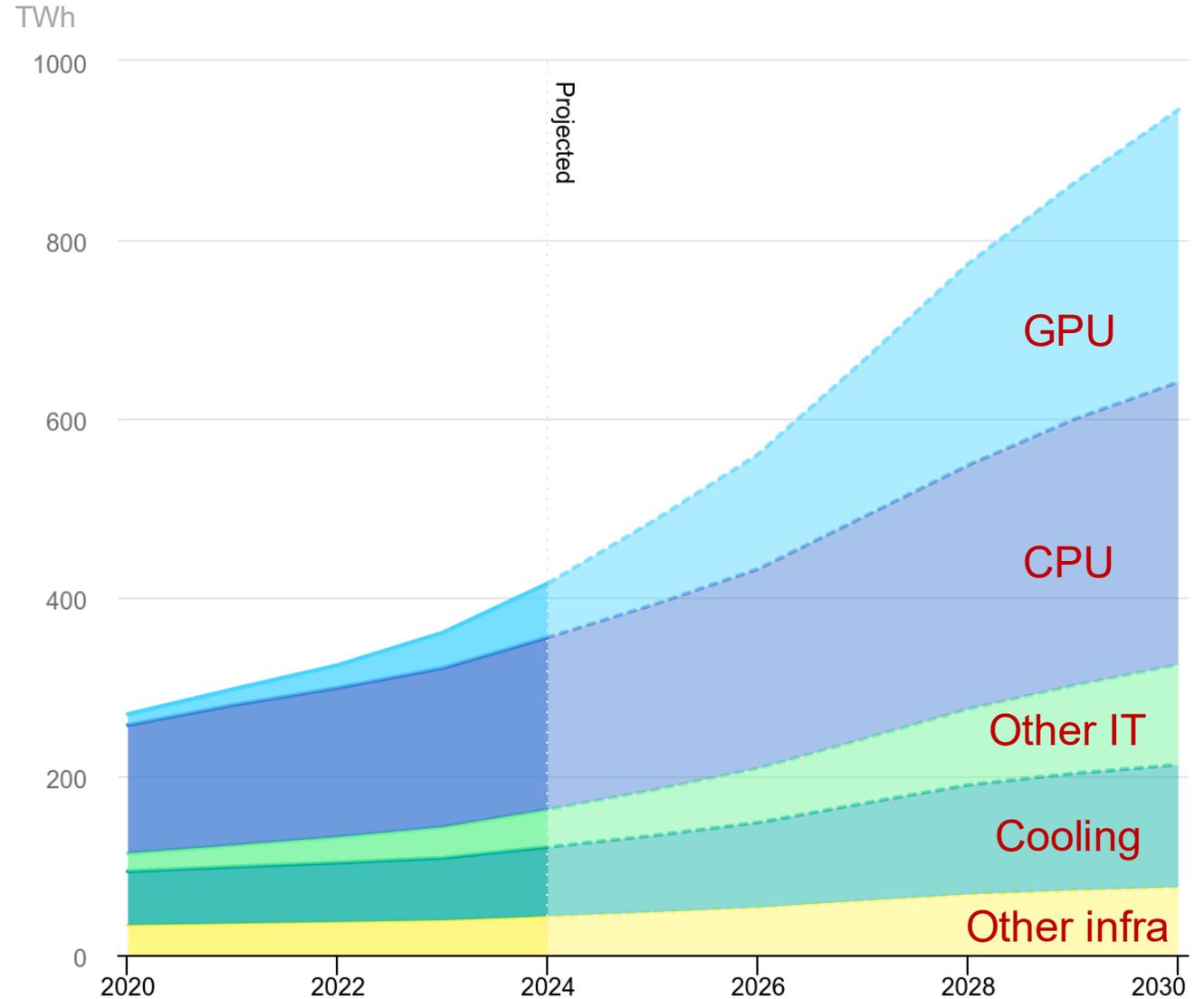Zhan, S. *et al. Energy Build.* **278**, 112606 (2023).

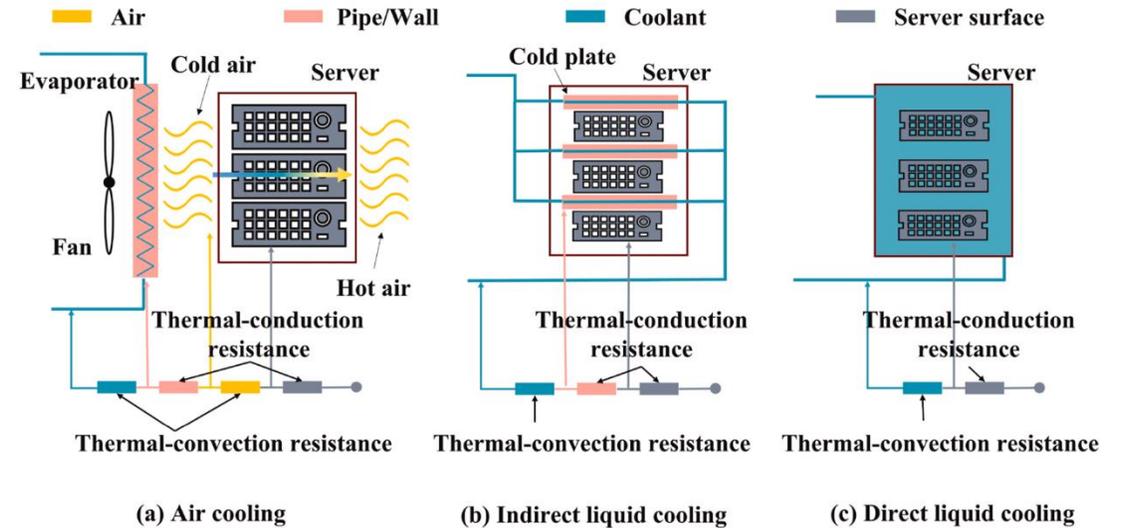# The other side of the story

Increasing DC energy demand

- Increasing power density
  - 60-100W/cm^2 (chip), 5-10kW/m^2 (DC)

- Over 60% fulfilled by fossil fuel

- Negative environmental impact

TWh

Projected

GPU

CPU

Other IT

Cooling

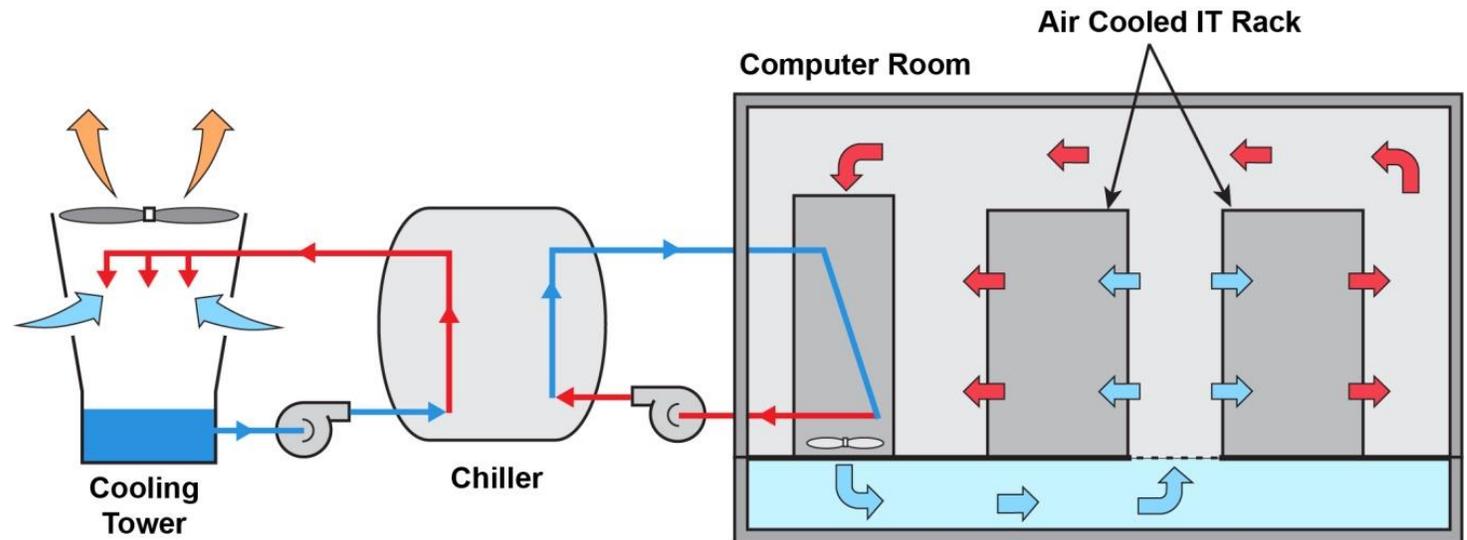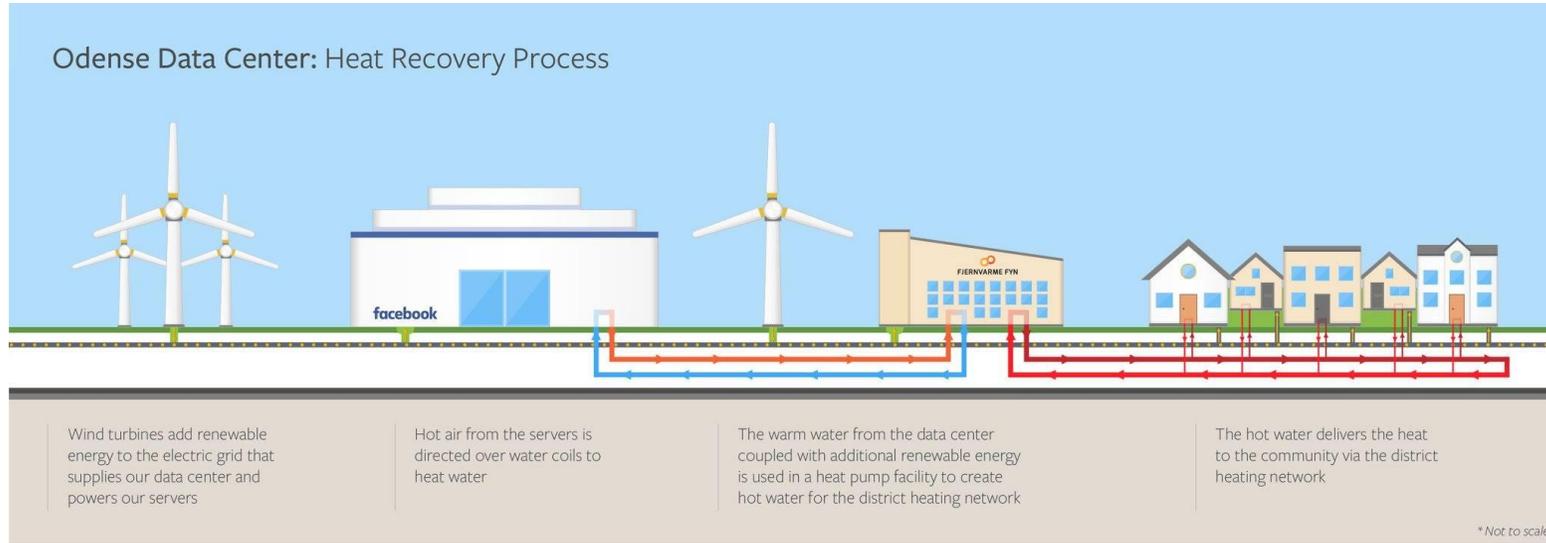Other infra

IEA (2025). 12

Cooling technologies

- Air-based cooling remains the dominant solution, while liquid cooling expected to rise rapidly

- Cooling consumes 30-40% of total energy, and often significant water usage

Kong, R. *et al. Energy* **308**, 132846 (2024).

Waste heat recovery (WHR) towards sustainable AI

Odense Data Center: Heat Recovery Process

Wind turbines add renewable energy to the electric grid that supplies our data center and powers our servers

Hot air from the servers is directed over water coils to heat water

The warm water from the data center coupled with additional renewable energy is used in a heat pump facility to create hot water for the district heating network

The hot water delivers the heat to the community via the district heating network

Not to scale

- Meta in Odense, Denmark
  - Air → water, with heat pump
  - 100GWh/yr to warm 6900 homes
  - 15-25% of total energy

- Tencent in Tianjin, China
  - Water → water, with heat pump
  - Heat nearby office building
  - 28% annual savings
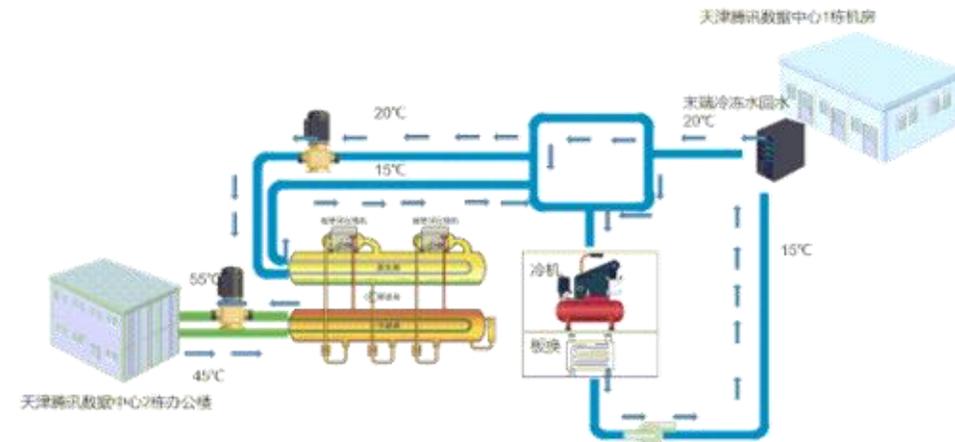
More nuances in WHR

- Many projects have long payback period
  - High CapEx (thermal storage, heat pumps, piping, etc.)
  - Feasibility affected by spatial and temporal distribution

- Liquid cooling provides more opportunity
 - Dedicated operation to elevate exergy (quality of waste heat)
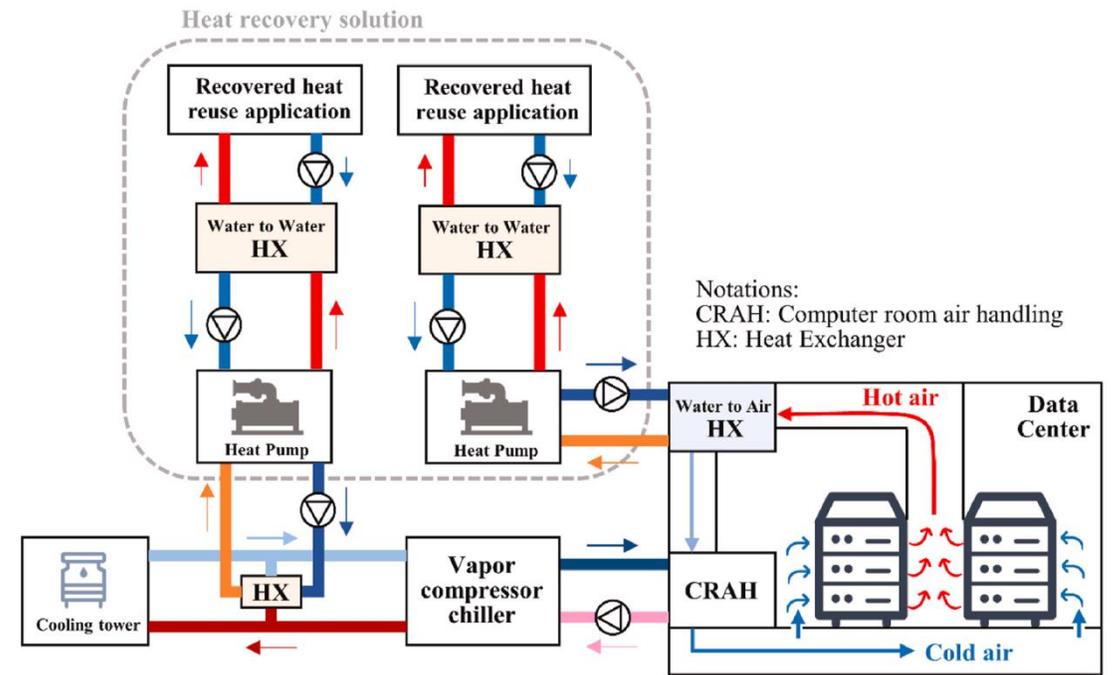
Huang, P., *et al. Appl. Energy* 258, 114109 (2020).

cooling tech	heat source	supply temp (C)	return temp (C)	temp rise (C)
AHU	air	18-27	30-50	10-20
	liquid	7-20	12-20	5-7
rear door HX	liquid		20-30	5-10
	coolant	25-30	35-50	10-20
spray cooling	liquid/vapor	30-55	35-65	5-10
immersion cooling	liquid	30-55	35-65	5-10
single-phase cold plate	liquid	20-50	25-70	5-20
two-phase cold plate	vapor	40-75	40-80	0-5
heat pipe	vapor	40-80		0-5

Heat reuse and thermal networks

- Match the waste heat supply and demand
  - Temperature range
  - Spatial and temporal (diurnal/seasonal)
  - Reduced DC active cooling

- 5th generation district heating and cooling (5GDHC)
  - Adapt to different local climates
  - Connect heterogeneous demands

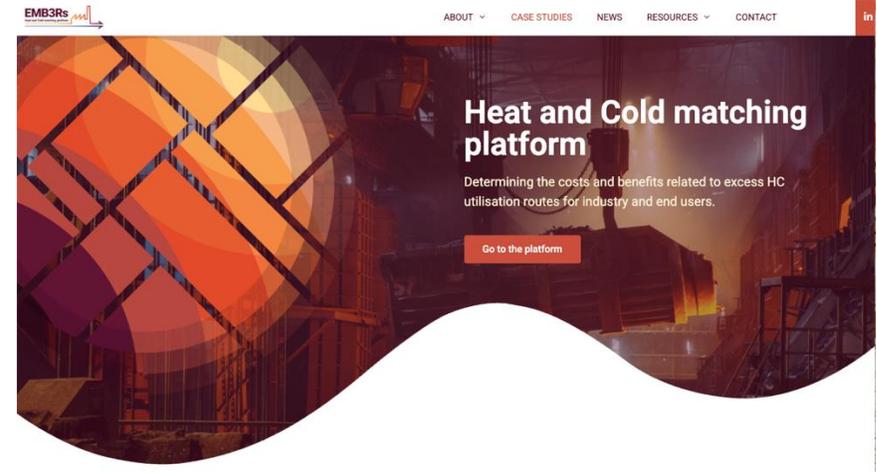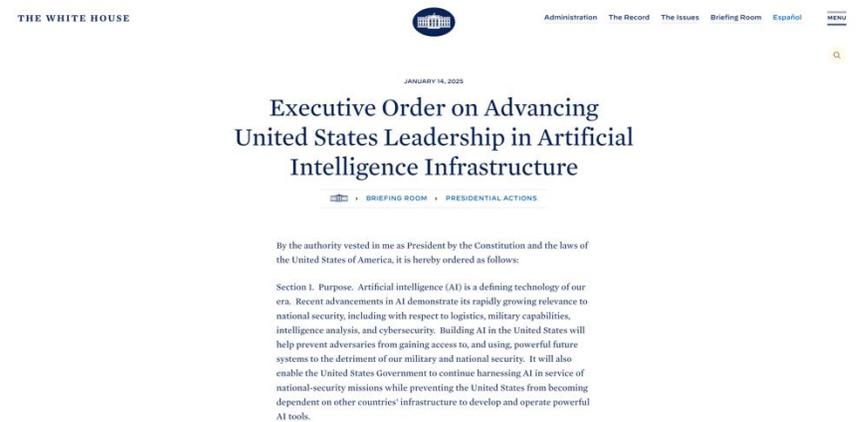| usage	technology	driving temp (C)
heating	same building	45-60
	district heating	
	5GDHC	15-25
cooling	absorption	65-90
	adsorption	50-100
power	ORC	65-100
production	desalination	40-70
	greenhouse	20-40
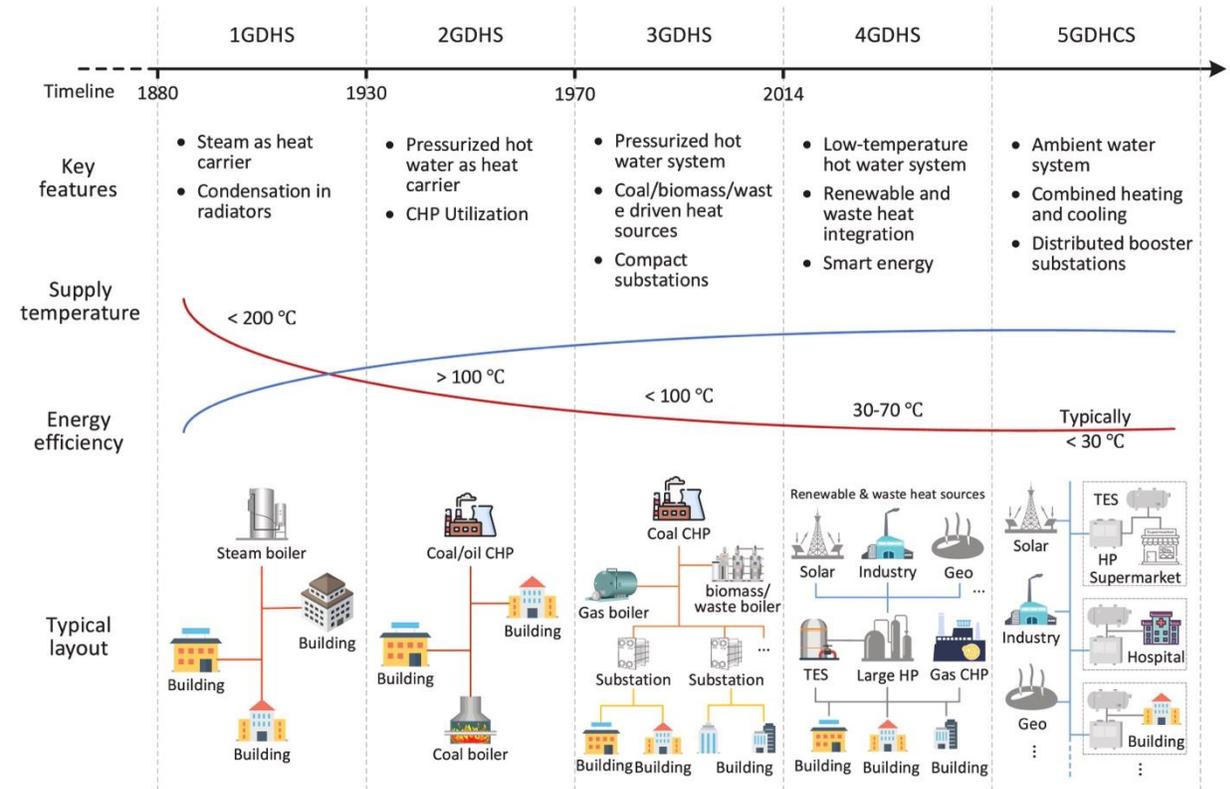
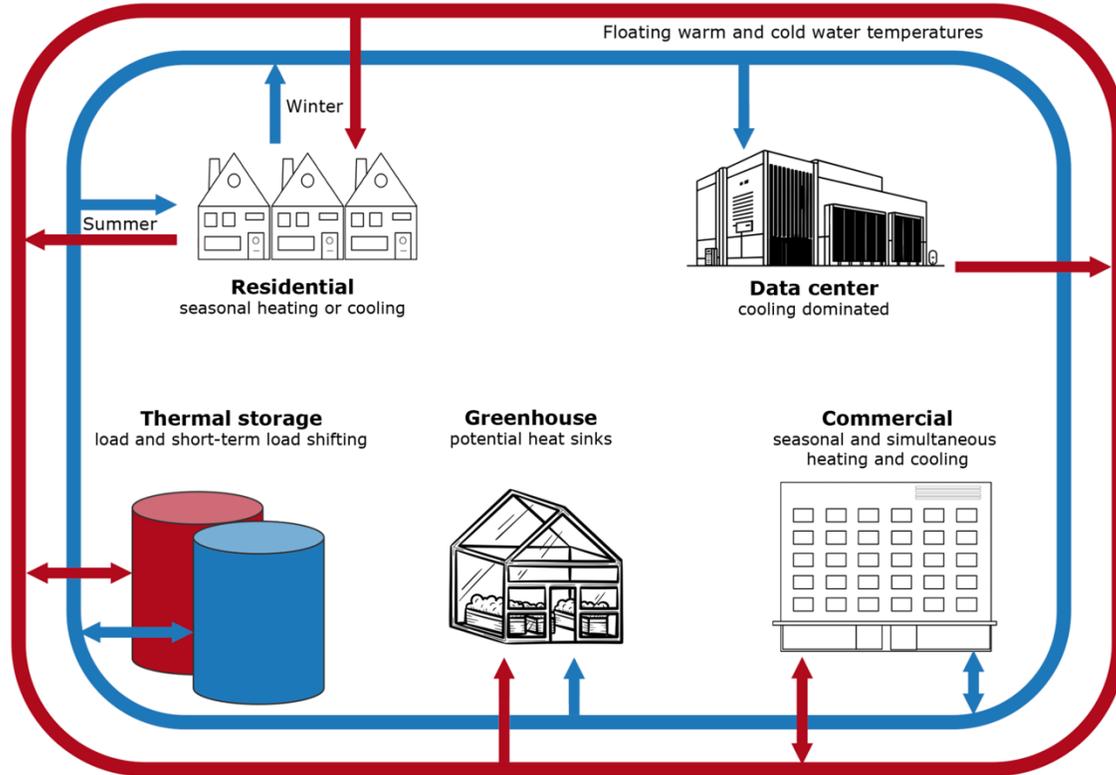Yao, S., et al. (2024). Renewable and Sustainable Energy Reviews, 202, 114729.

Recent relevant policies and platforms

DC WHR x 5GDHC

- Data centers
  - Lower cooling consumption
  - Offset climate harms

- Heat users
  - Decentralized heat pump to boost electrification
  - Higher heating and cooling efficiency

- Power grid
  - Relaxed expansion pressure
  - Easier renewable integration

Thank you!

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