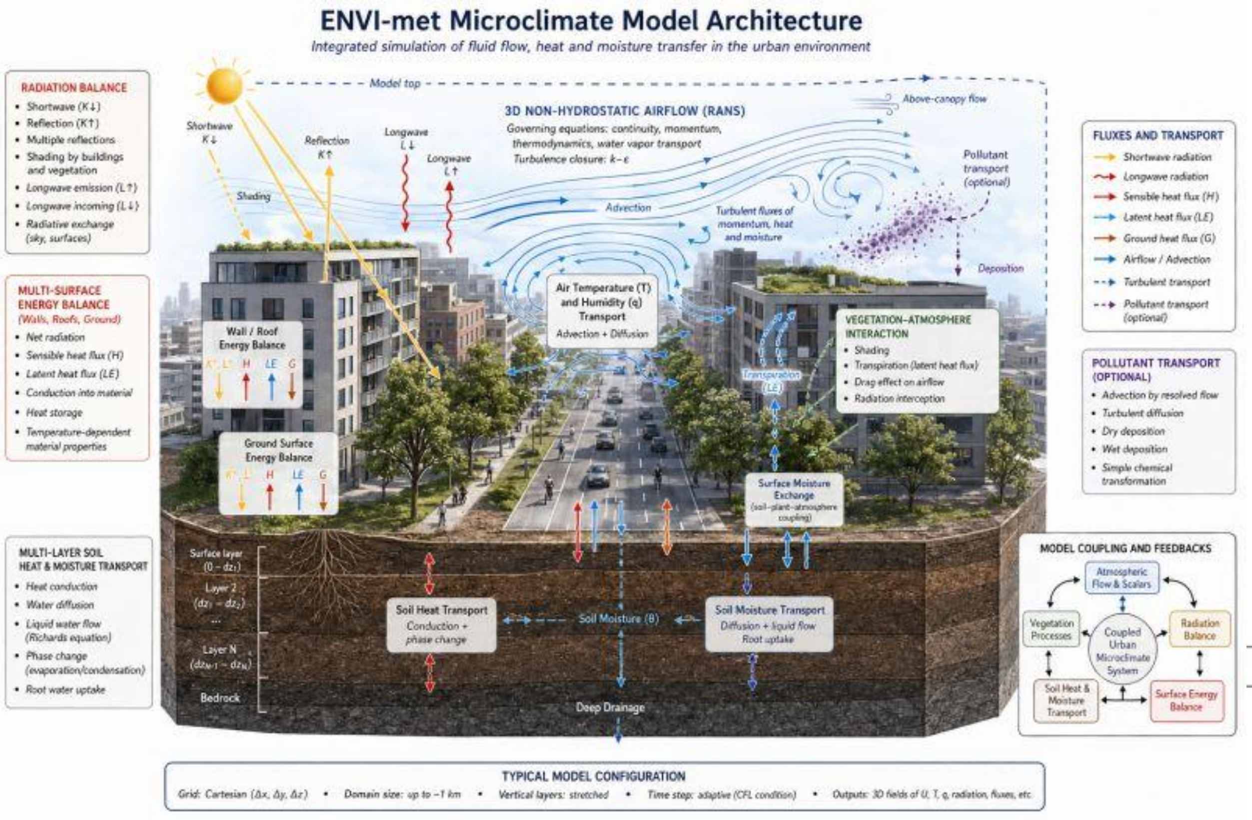
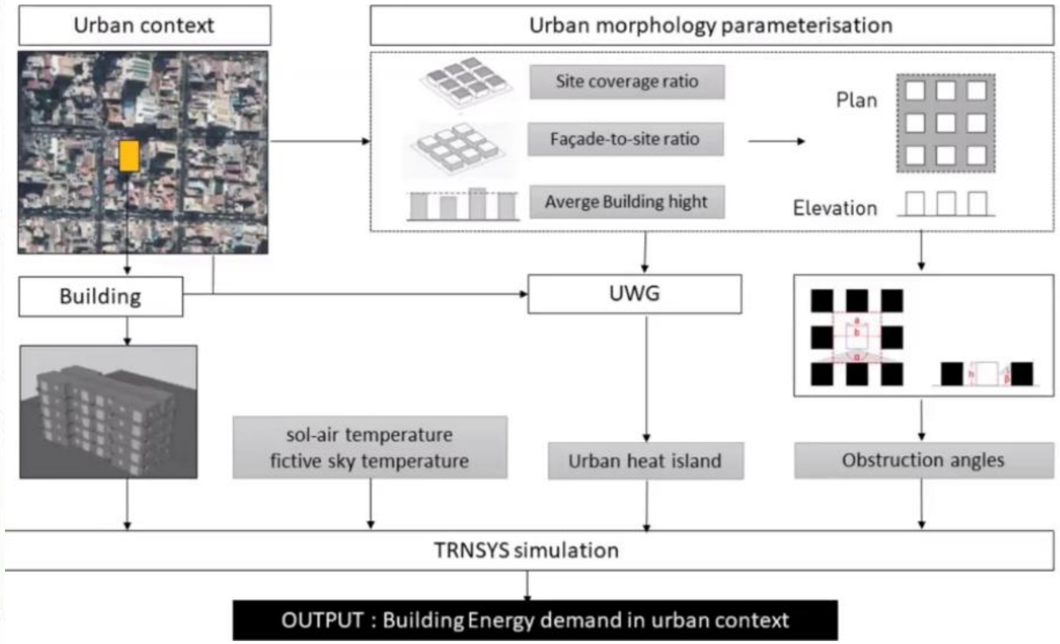
Zero Carbon Buildings Under Urban Heat Stress

How Urban Microclimate Redefines Decarbonization Pathways





Yujin Yang 杨玉锦

Prof. Dr. Shady Attia
Sustainable Building Design Lab, UEE,
School of Engineering, University of Liège, Belgium
shady.attia@uliege.be

/in/shady-attia-14352a7
www.sbd.uliege.be
/www.shadyattia.org

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Acknowledgment

9 May 2026, Tianjin University, Tianjin, China

16 May 2026, Xi'an, China - **International Conference on Urban Climate and Urban Design**

IEA Annex 89, 2024-2028, WLCA ZCB

IEA Annex 97, 2026-2030, Sustainable Cooling

The International Symposium on District Heating and Cooling

What is a Zero Carbon Building (NZCB)?

A building that produces net zero GHG emissions across its entire life

Attia, S. (2025) **Net Zero Energy Buildings (NZEB)** , Elsevier

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01

Reframing Zero Carbon Buildings Definition

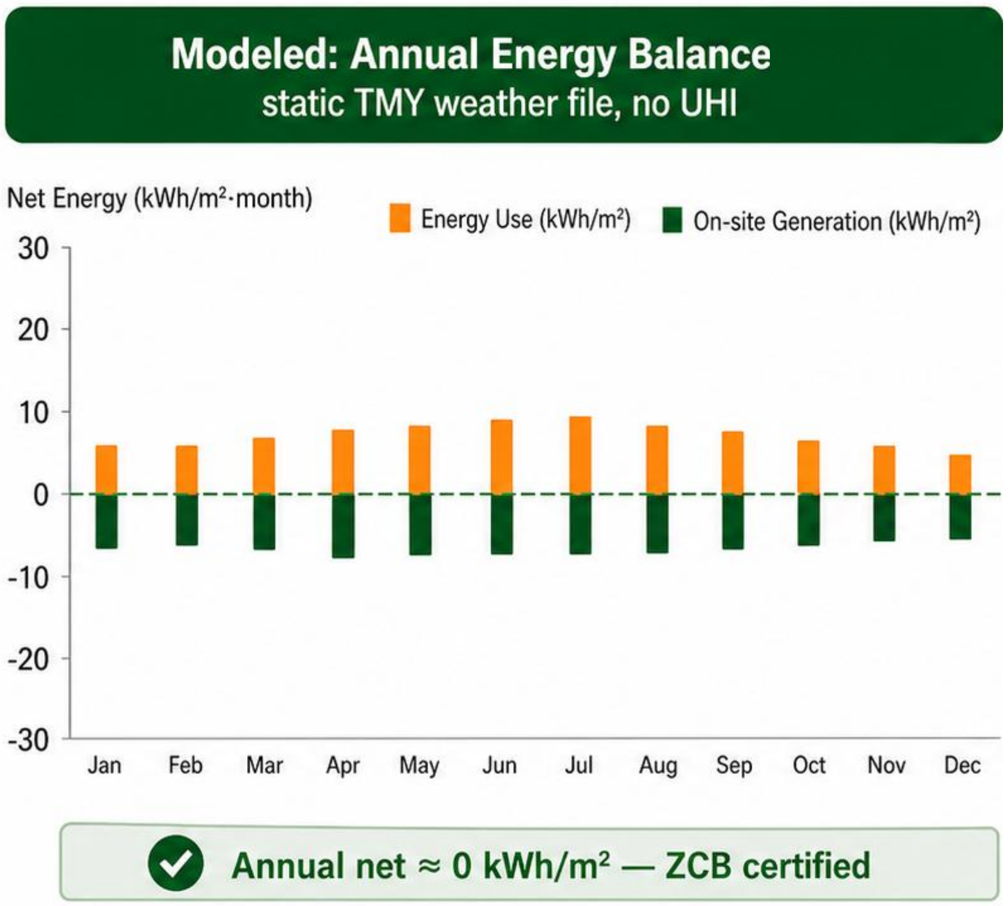
Why is the definition itself broken?

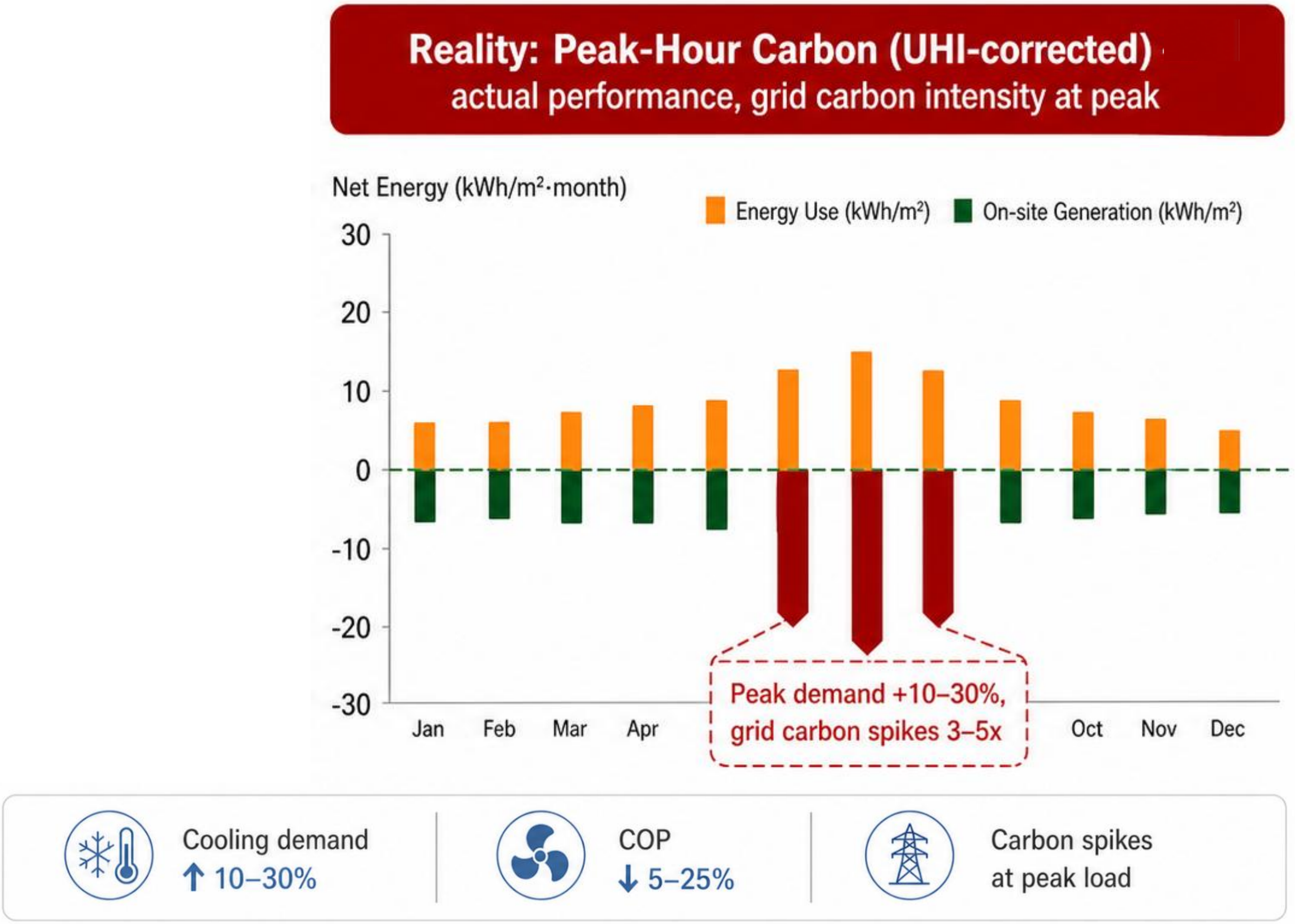
The Illusion of Net-Zero Carbon Buildings

Reframing Zero Carbon

The Performance Gap: Annual Balance ≠ Real Performance

Reframing Zero Carbon





- Modelled annual GHG emissions balance does not correspond to the monitored annual balance

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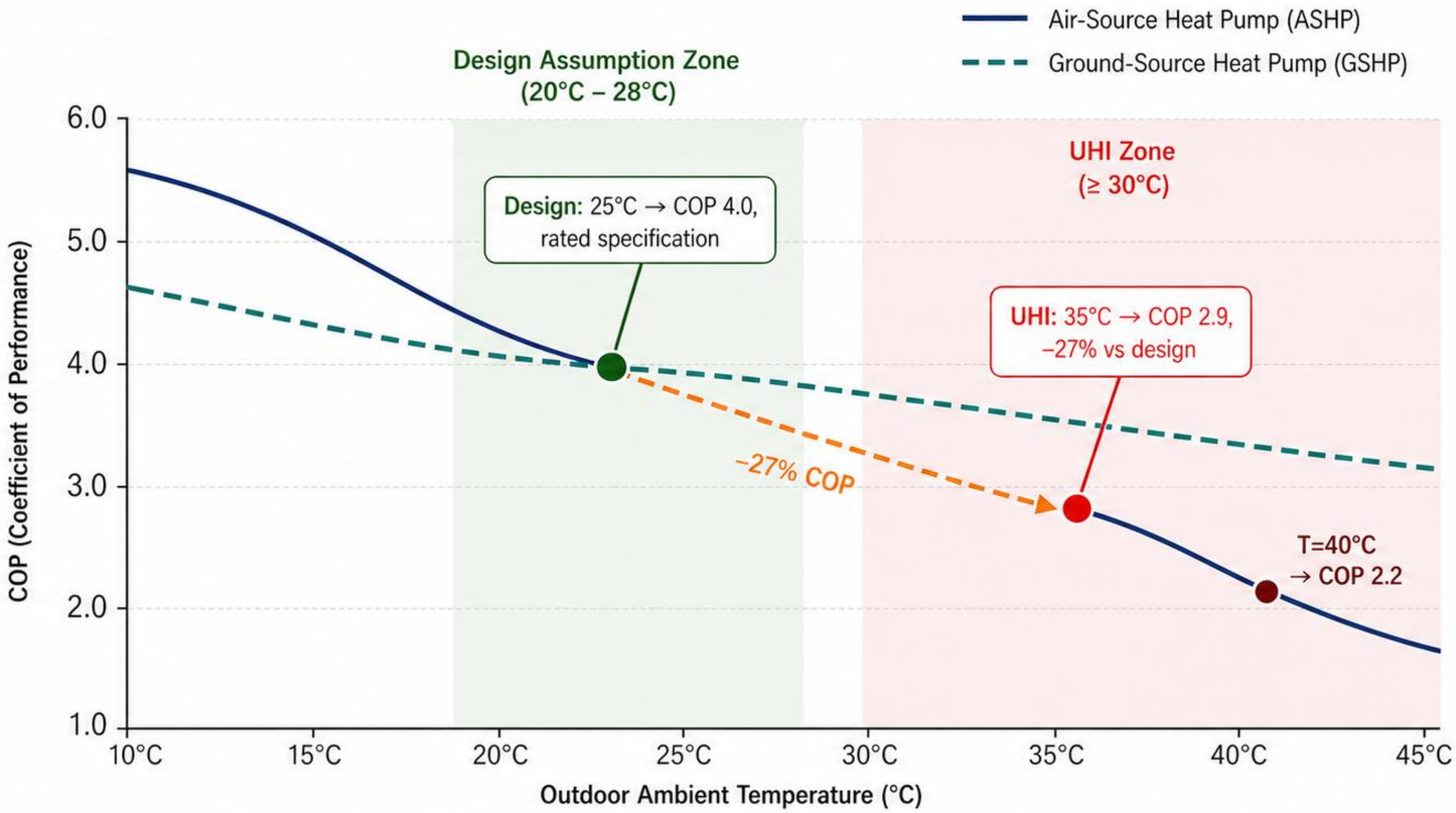
02

NZCB Meets Urban Microclimate

The physics of failure

HVAC Physics: COP vs. Ambient Temperature

NZCB Meets Microclimate



Note: Values are typical for cooling mode performance.
Actual performance varies by system design and operating conditions.

Suburban (25°C)
- COP 4.0
- 100 kWh → 25 kWh elec.
- Close to design

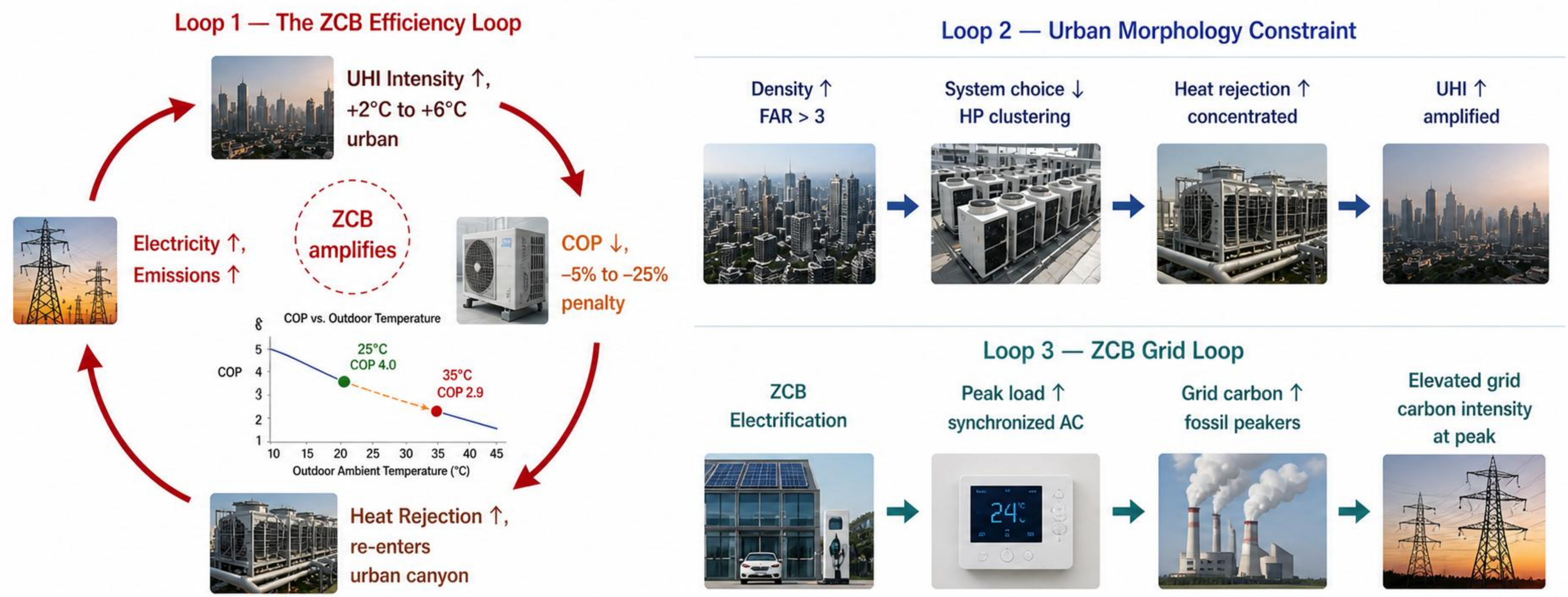
Urban +3°C (28°C)
- COP 3.5
- 100 kWh → 29 kWh elec.
- ↑16% more electricity

Dense city +5°C (30°C)
- COP 2.9
- 100 kWh → 34 kWh elec.
- ↑36% more electricity

ZCB electrification increases sensitivity to urban microclimate

Three Coupled Feedback Loops

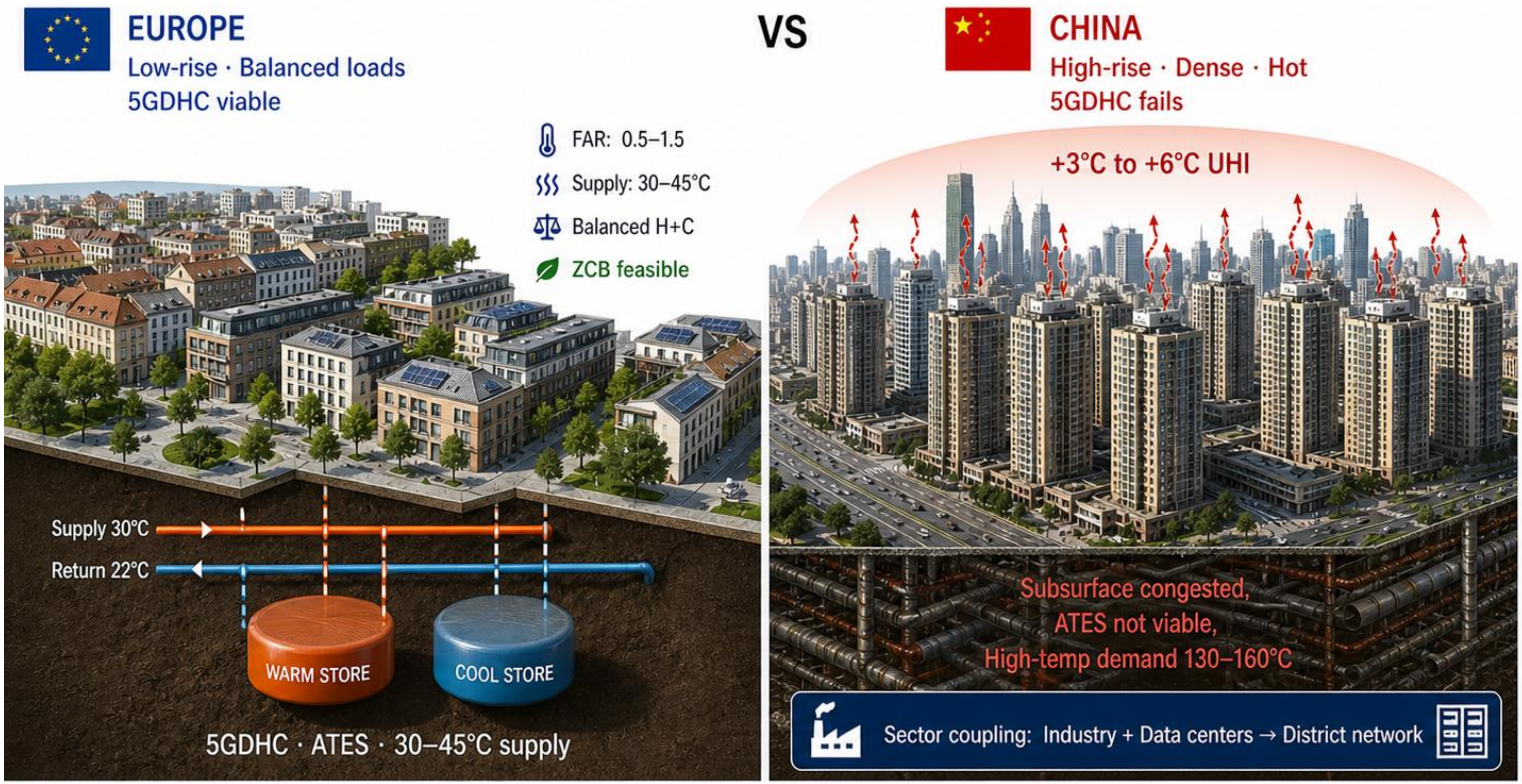
NZCB Meets Microclimate



Net-zero buildings in dense urban clusters can still amplify UHI and peak grid carbon

Loop 2: Urban Morphology Constraint: The FAR Threshold

NZCB Meets Microclimate



FAR < 2

- ZCB systems feasible
- 5GDHC/ATES viable
- Low-rise allows heat distribution

FAR > 3

- System choice severely constrained
- Subsurface too congested
- 5GDHC physically fails

Morphology determines feasibility before any calculation begins

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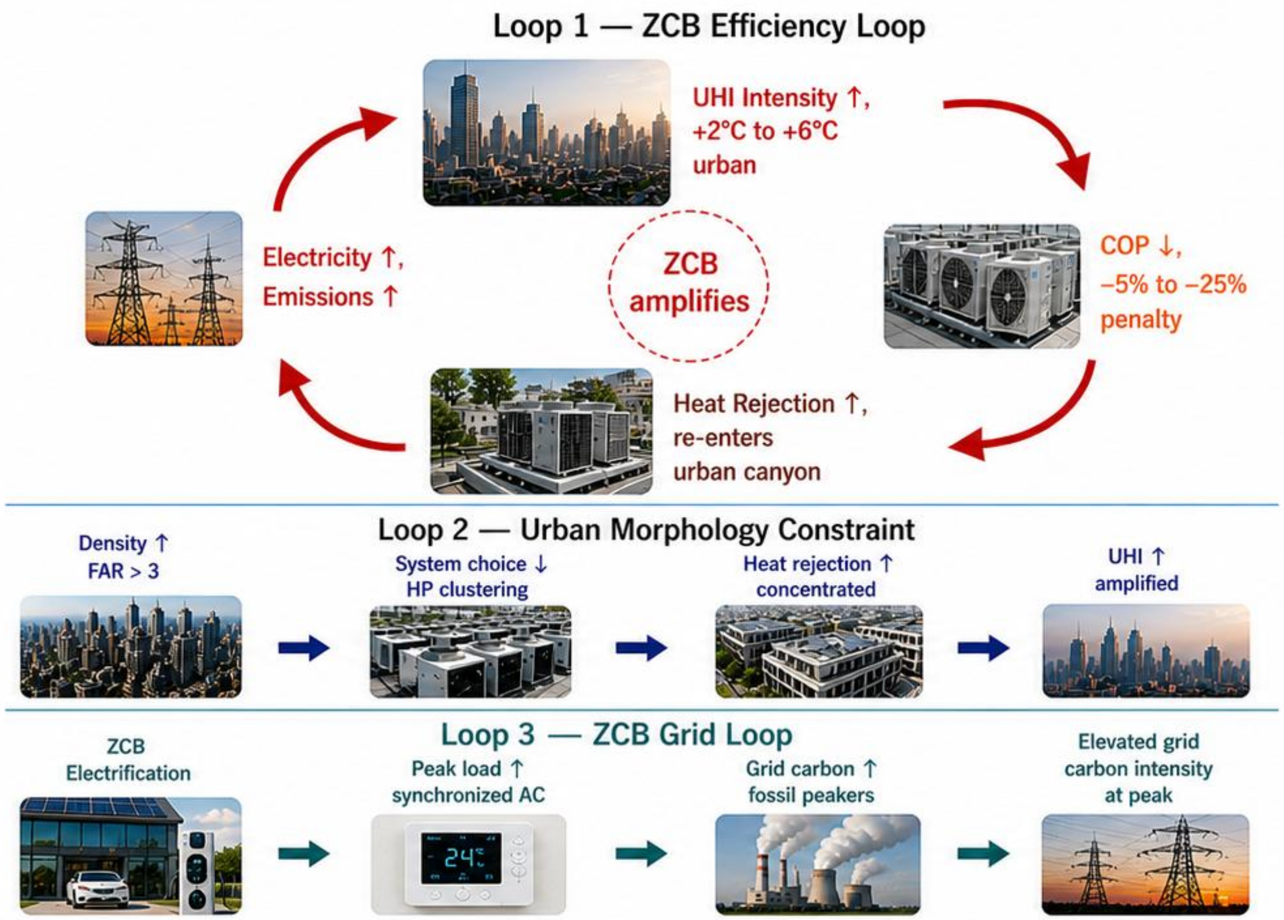
Loop 3: NZCB Grid Loop: Electrification Amplifies Peak Carbon

NZCB Cascading Effect



ZCB Electrification

- All loads shift to electricity
- Simultaneous AC demand at peak
- Districts synchronize peak loads

Peak Load Amplification

- Grid stressed at hottest hours
- Carbon intensity 3–5× higher
- Fossil peakers dispatched

Annual ZCB ≠ Real Zero

- Annual kWh balance hides peak
- Hourly carbon tracking required
- Time-of-use design essential

ZCB shifts emissions from annual average → peak hours. The annual kWh balance hides the real carbon story

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03

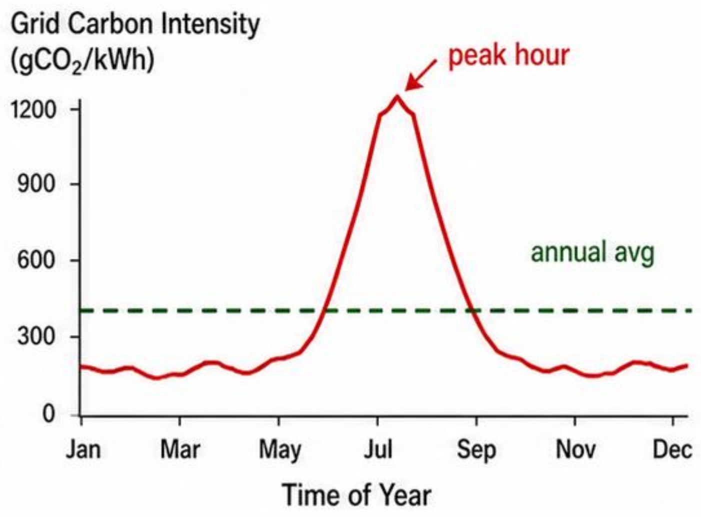
Why Zero Carbon Buildings Fail?

Misdefined · Mismodeled · Misapplied

Misdefined "Zero": Three Blind Spots

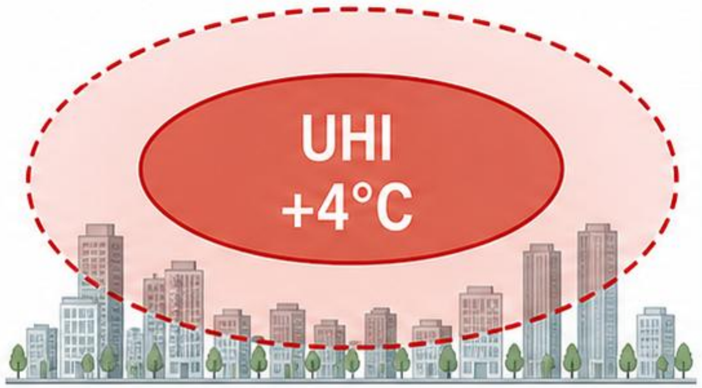
Why NZCB Fails

1 TIME blind spot



- Annual kWh balance hides hourly carbon reality
- Peak hours = fossil peakers dispatched
- Grid carbon intensity 3–5× higher at peak

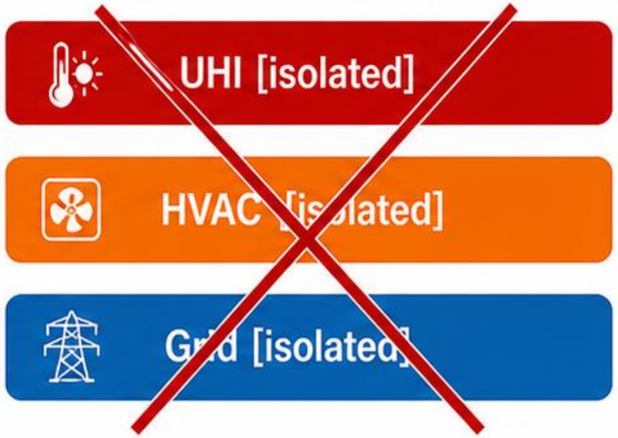
2 SPACE blind spot



✕ not in building model

- Urban heat island not in standard models
- Microclimate adds +2°C to +6°C in reality
- Heat stress and cooling demand underestimated

3 SYSTEM blind spot



- UHI, HVAC and Grid modeled separately
- No tool couples all three systems together
- Interactions and feedbacks are missed

A building certified on annual balance can be a significant carbon emitter at peak

Heat Pump Limits in Dense NZCB Districts

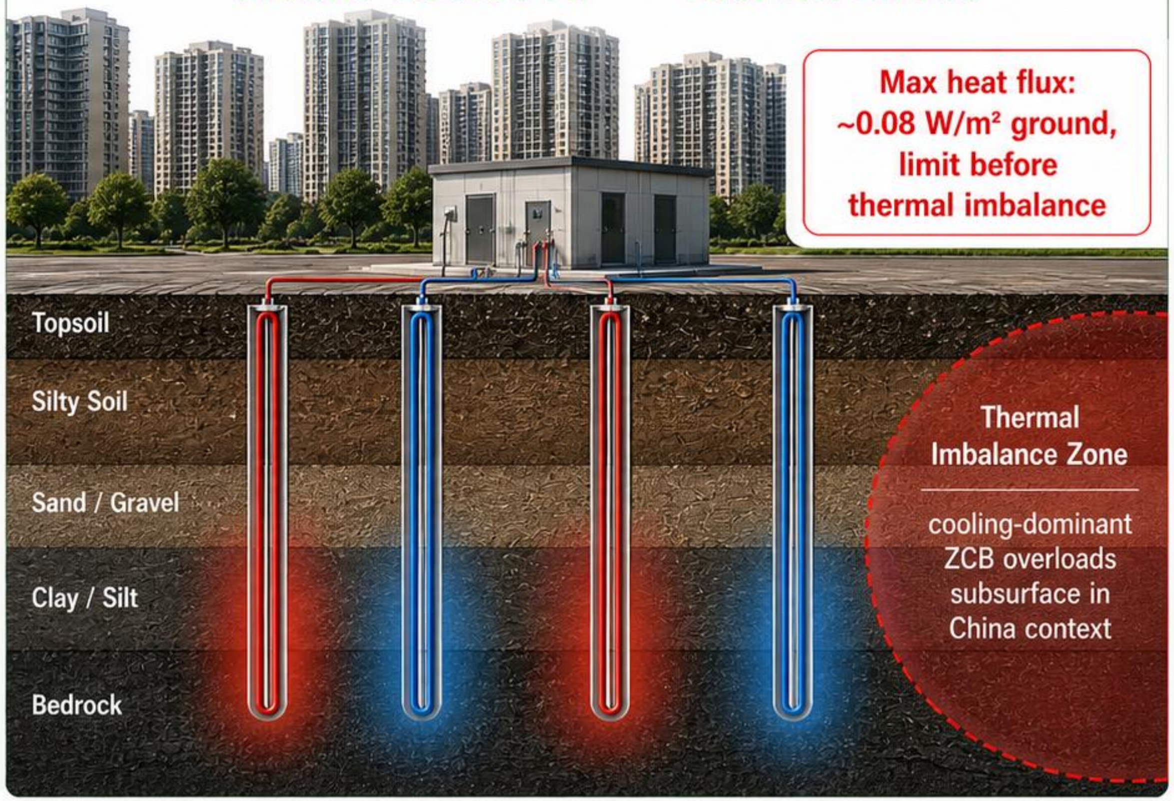
Why NZCB Fails

Air-Source HP — Urban Clustering Effect

Cascade Effects of HP Clustering

- Airflow patterns disrupted in urban canyon
- Pollution dispersion reduced at street level
- Local humidity pockets + frost risk near ground
- **Each unit exports its problem to neighbours**
- No model today accounts for this at district scale

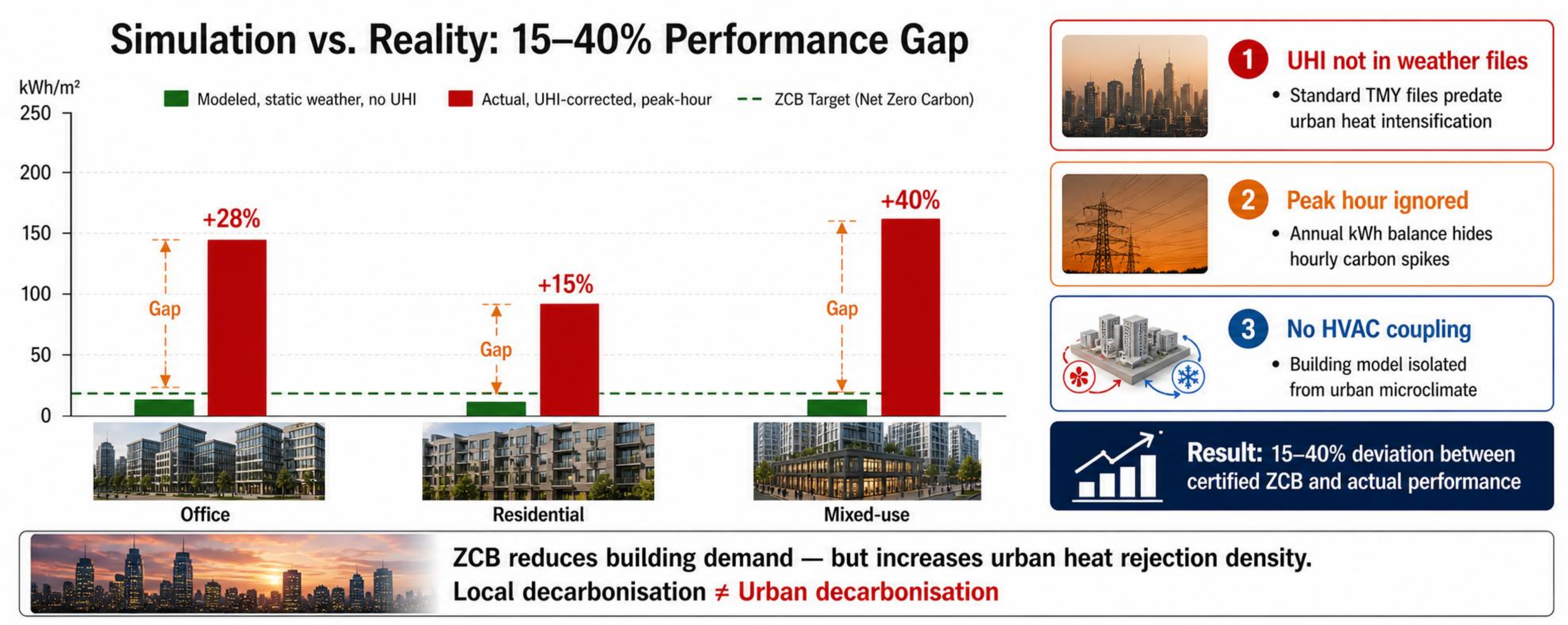
Ground-Source HP — Thermal Limits



Heat pump limits in dense ZCB districts are physical, not theoretical

Simulation vs. Reality: 15–40% Performance Gap

Why NZCB Fails



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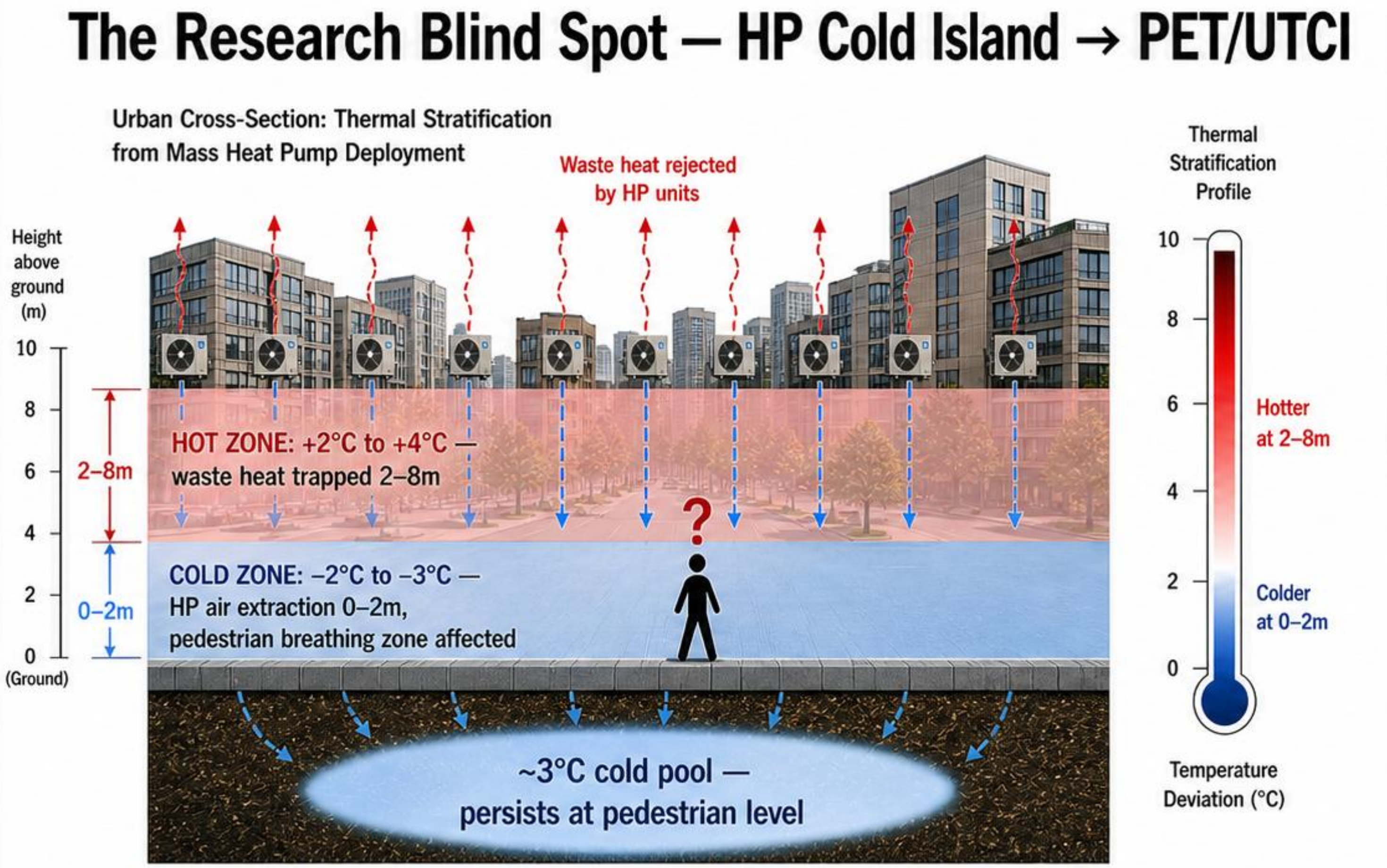
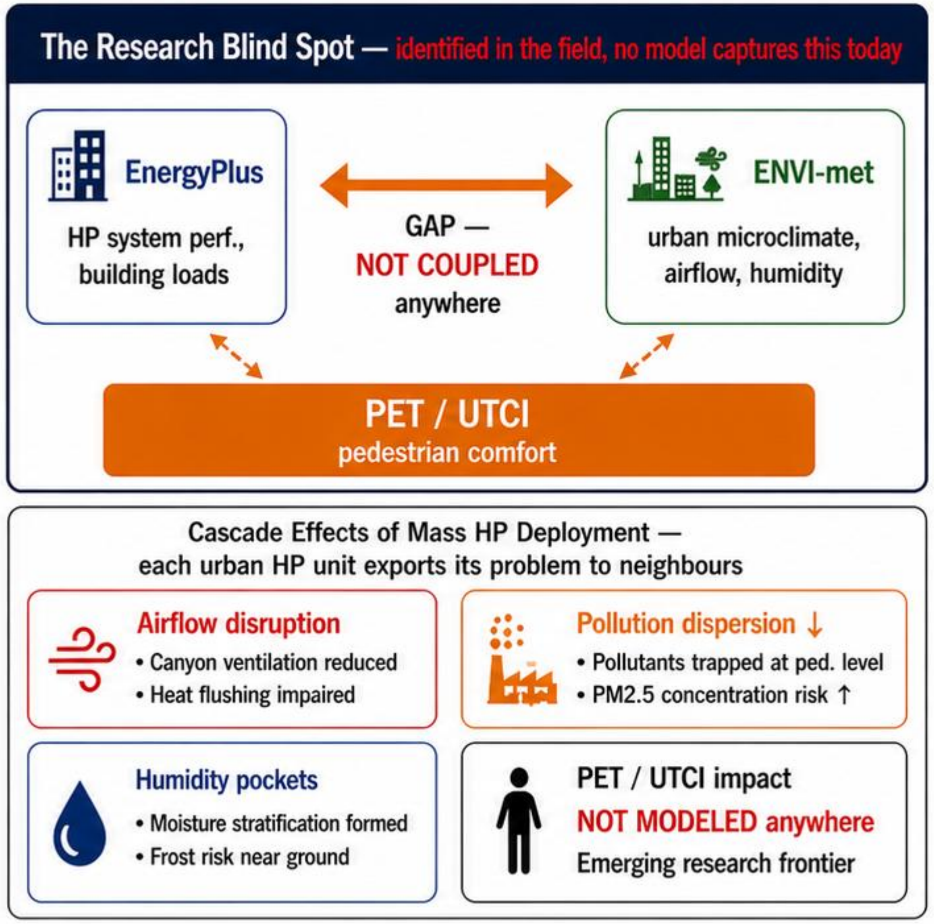
The Research Blind Spot

HP Cold Island → PET / UTCI — What No Model Captures Today (Winter Scenario)





“ The missing link between building physics and urban microclimate

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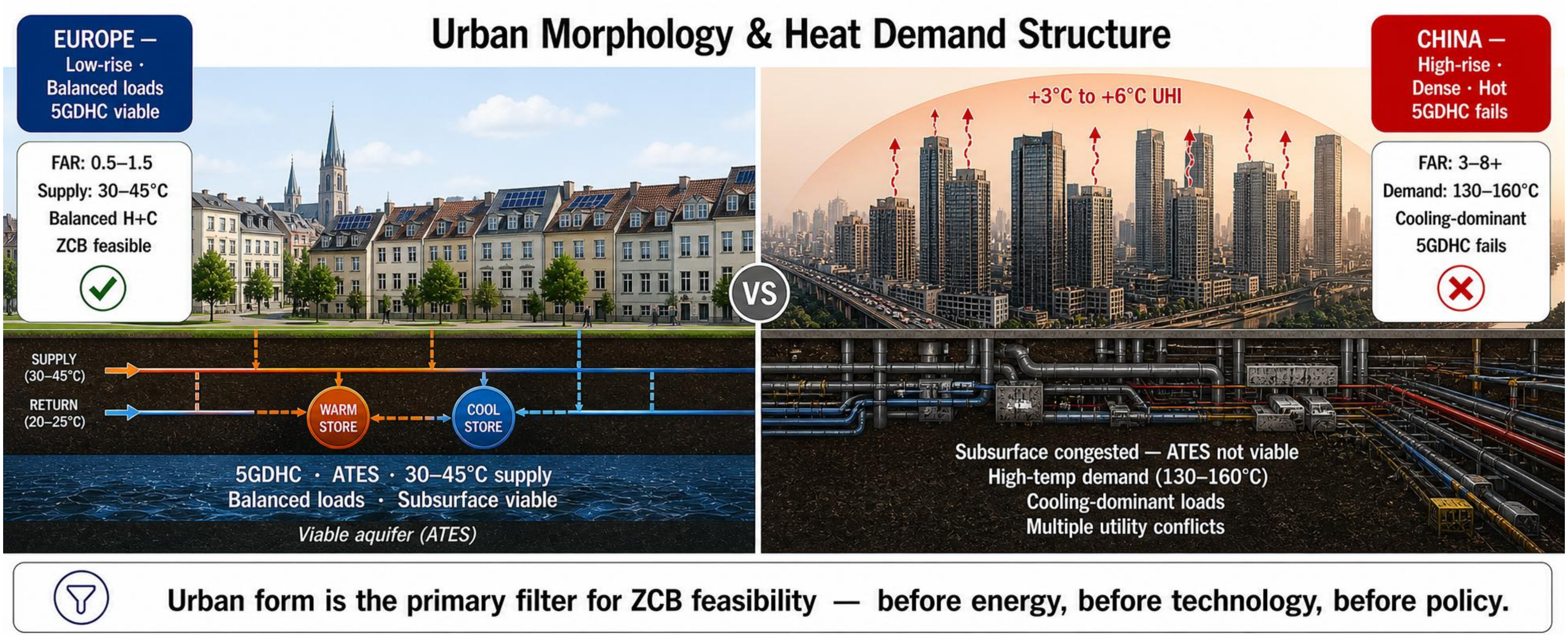
04

Comparative NZCB Pathways

China vs. Europe: why solutions are not transferable

Urban Morphology & Heat Demand Structure

Comparative NZCB Pathways



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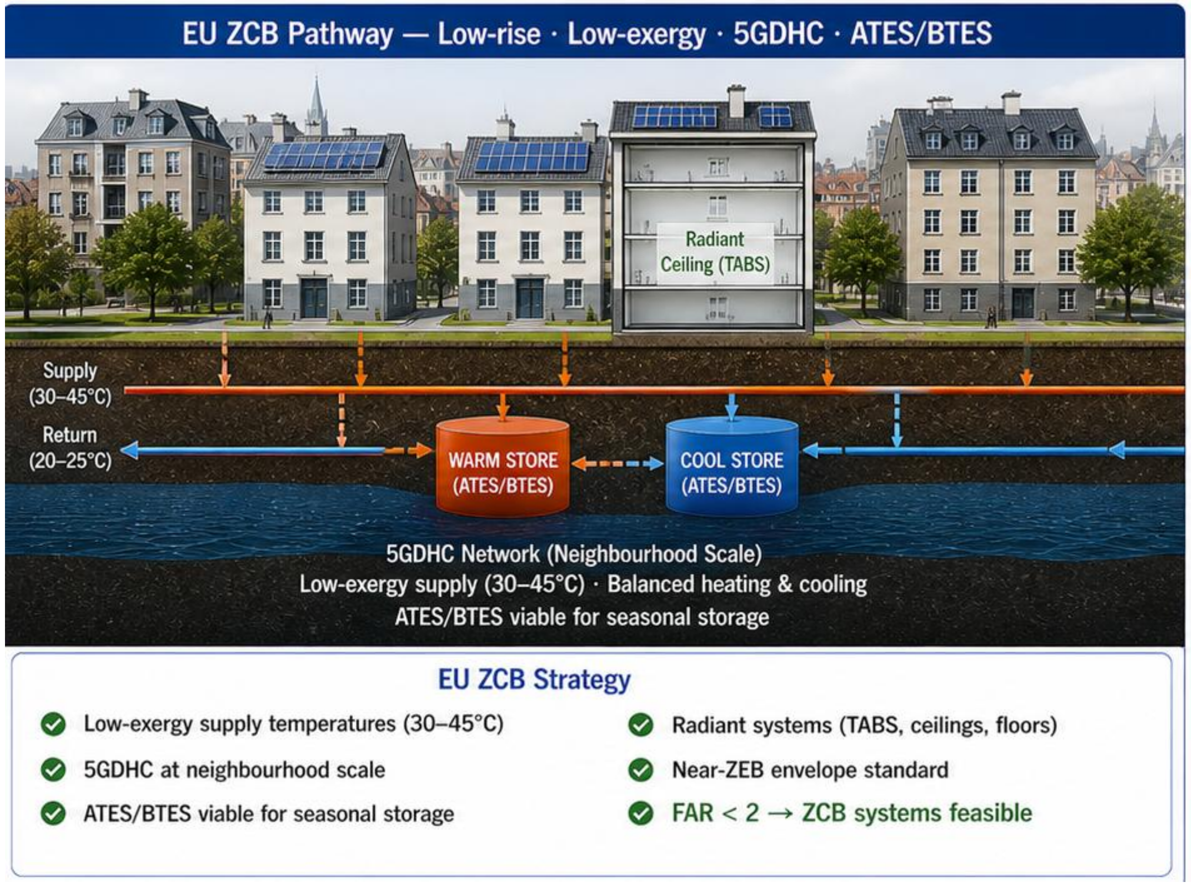
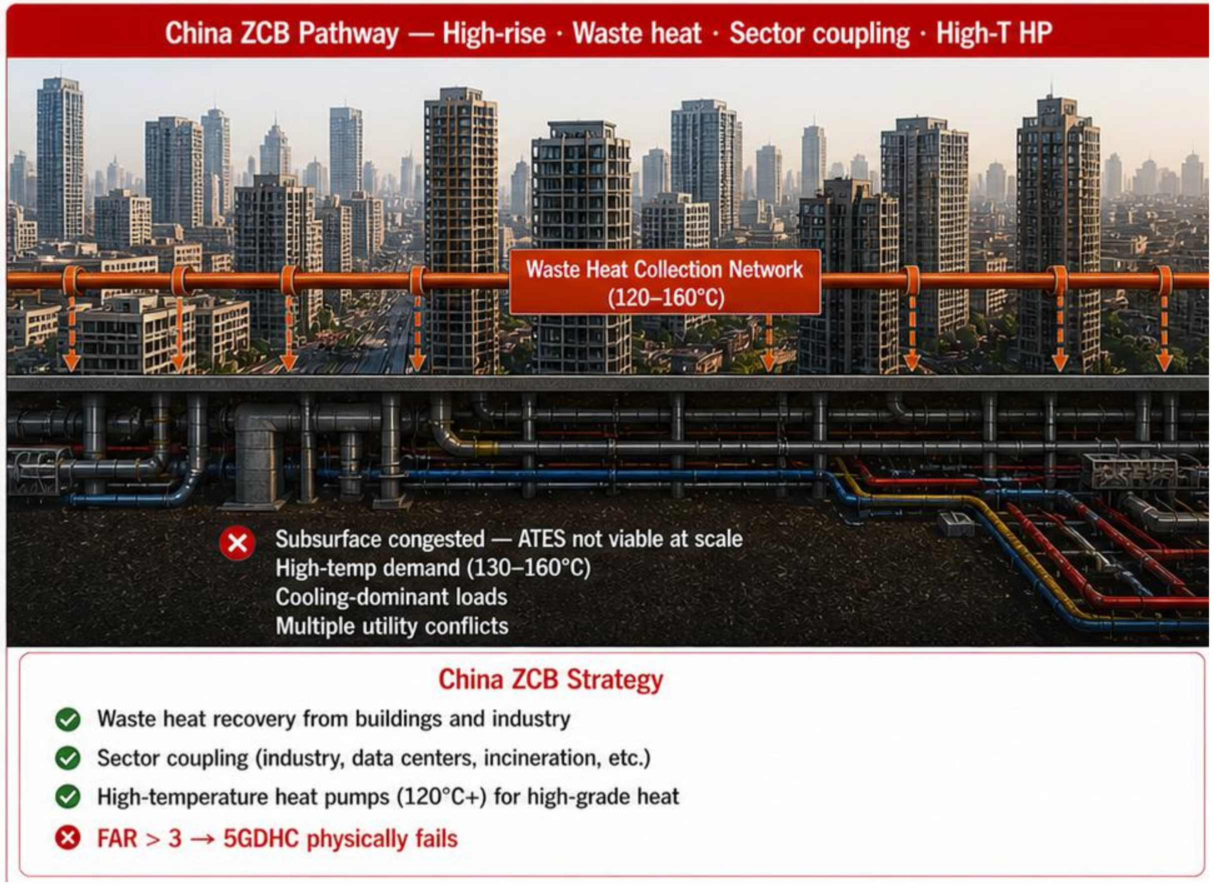
NZCB System Feasibility: EU vs. China

Comparative ZCB Pathways





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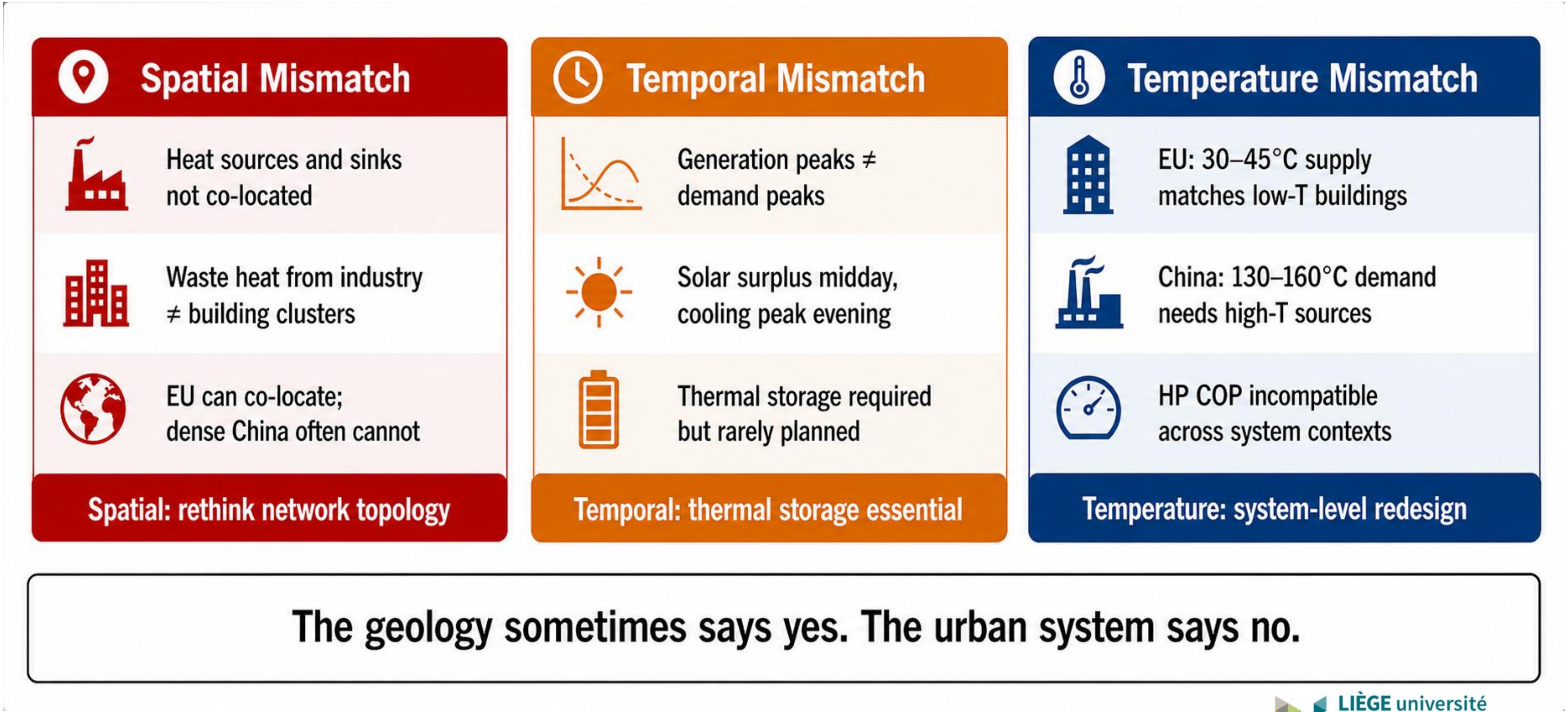
Why NZCB Solutions Are Not Transferable

Comparative NZCB Pathways



05

District & Urban NZCB Systems

Energy–Heat–Water nexus · Research bridge

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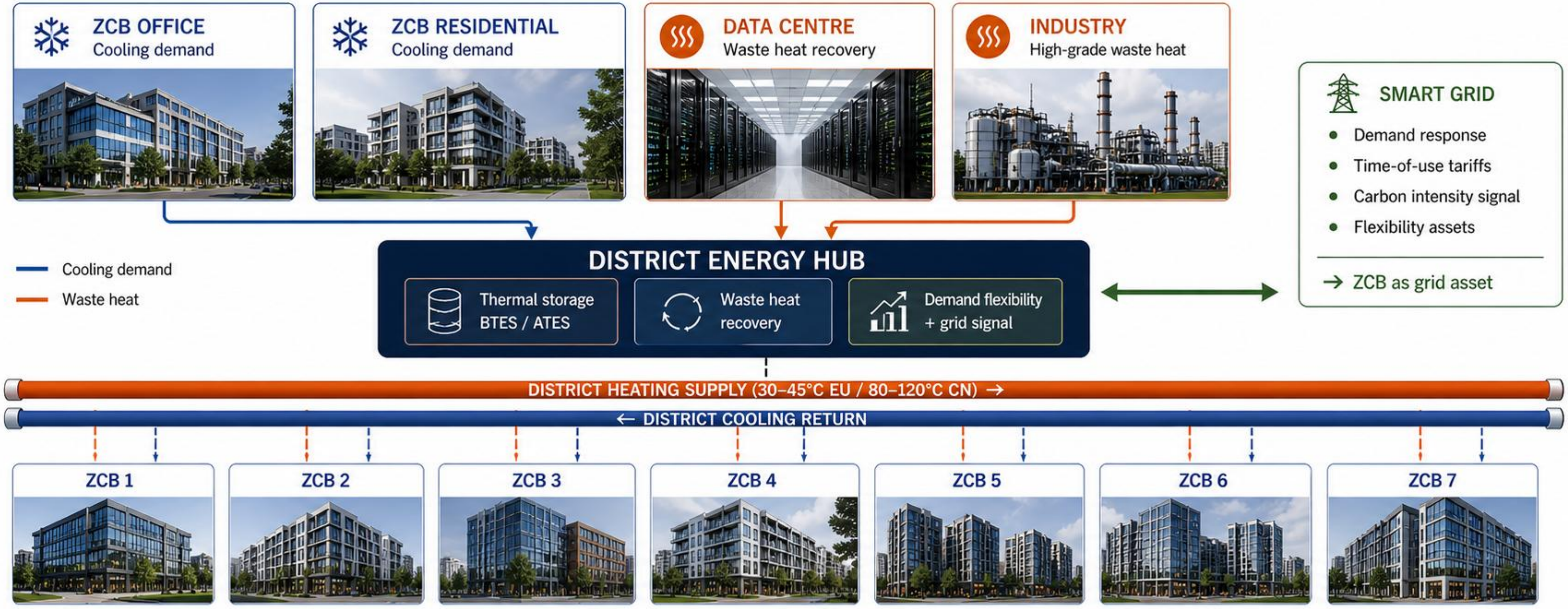
From Building to District: NZCB System Integration

District & Urban NZCB



ZCB cannot be solved at building scale

District: thermal storage + waste heat + demand balancing

From building components to urban energy infrastructure

WATER NEXUS LINK

Cooling tower → water consumption

Storage ↔ hydrology interaction

→ Nankai University research bridge

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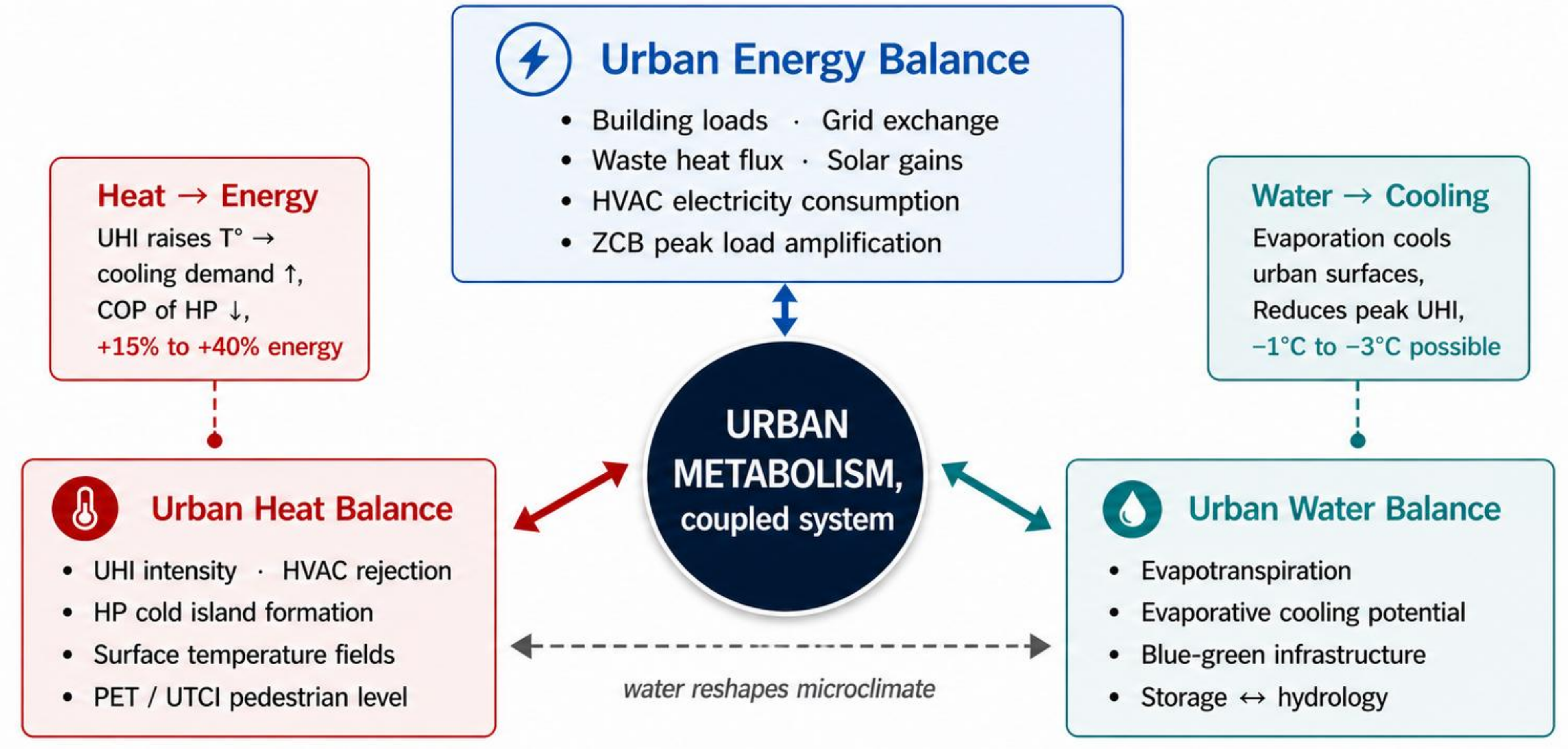
Energy–Heat–Water Nexus

District & Urban NZCB · Research Interface with Nakai Group



Energy, heat, and water are one coupled urban metabolism: ZCB must account for all three simultaneously

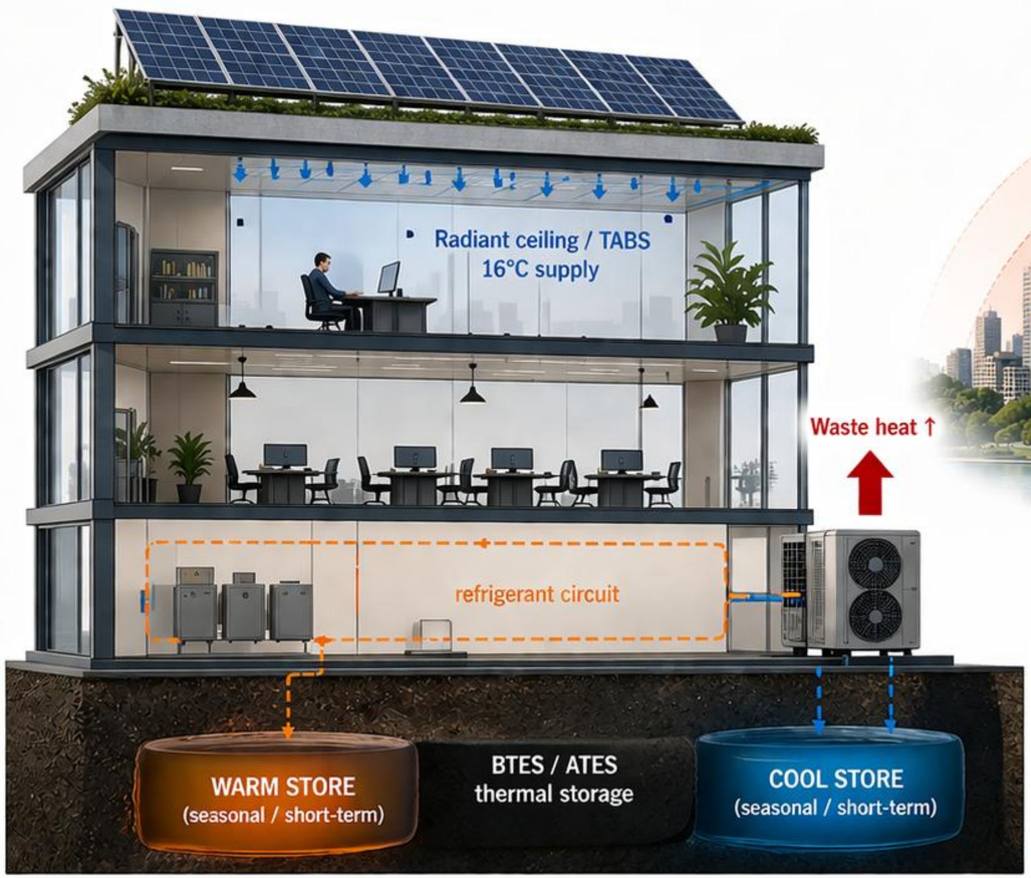
06

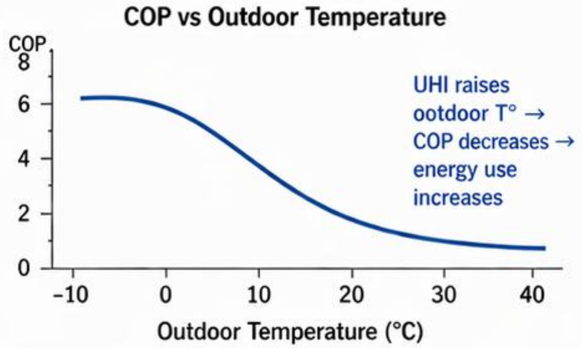
Design Implications for NZCB

Building scale → Urban scale

Design Implications: Building to Urban Scale

Architectural + HVAC Guidance





Building Scale

- Reduce heat rejection — not just demand
- Radiant cooling & TABS (low supply T°)
- Passive-first: form, shading, thermal mass
- UHI-corrected weather files for ZCB design

Urban Scale

- Density-aware system selection
- Limit HVAC clustering → cold islands
- Integrate district thermal storage upstream
- Green/blue infra as microclimate co-tool

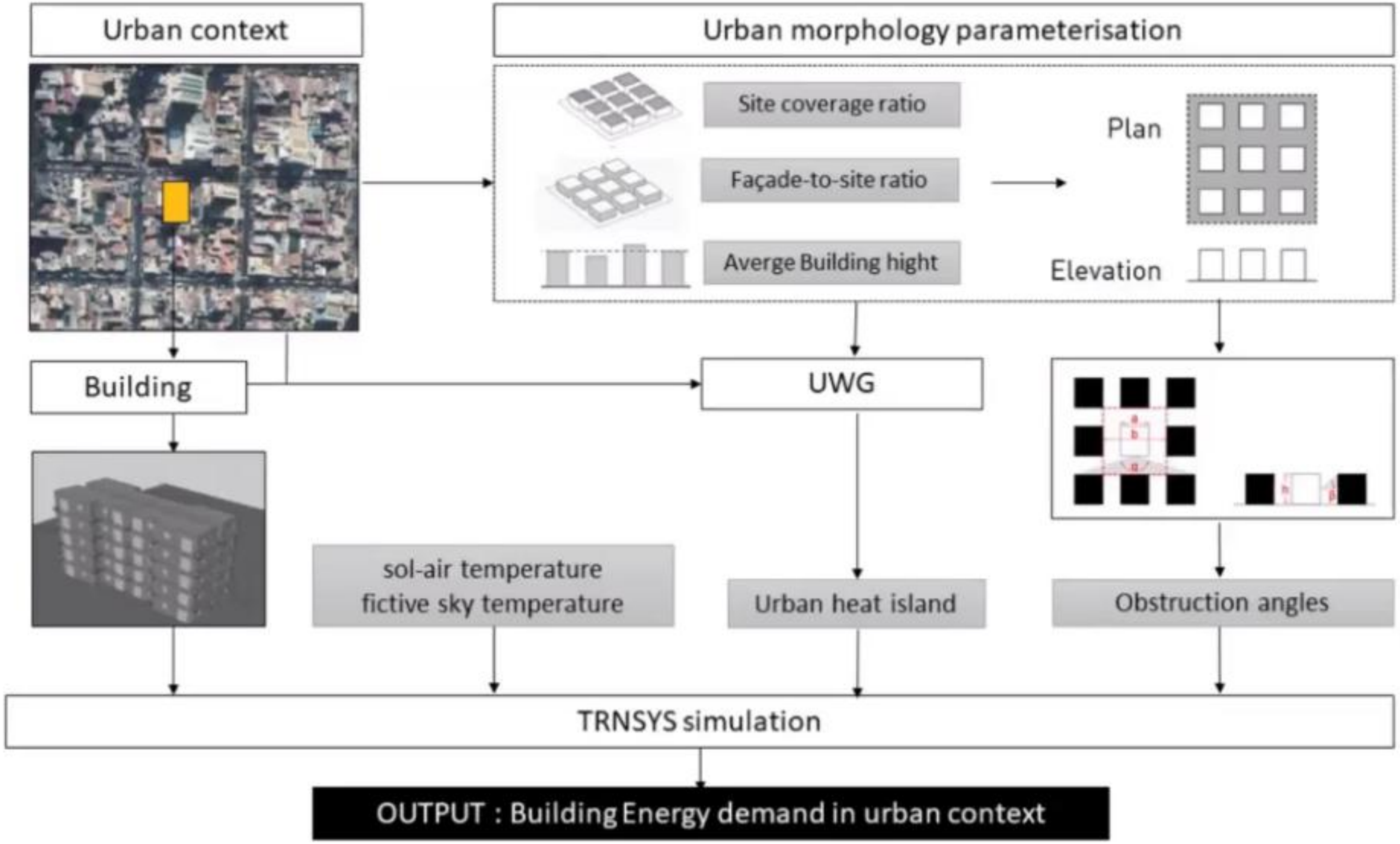
HVAC systems are no longer building components: they are urban climate actors

Simulation Coupling Implications: Building to Urban Scale

TRNSYS + UWG

-We need large scale tools and workflows for Urban Carbon Modeling and Urban Climate Modeling

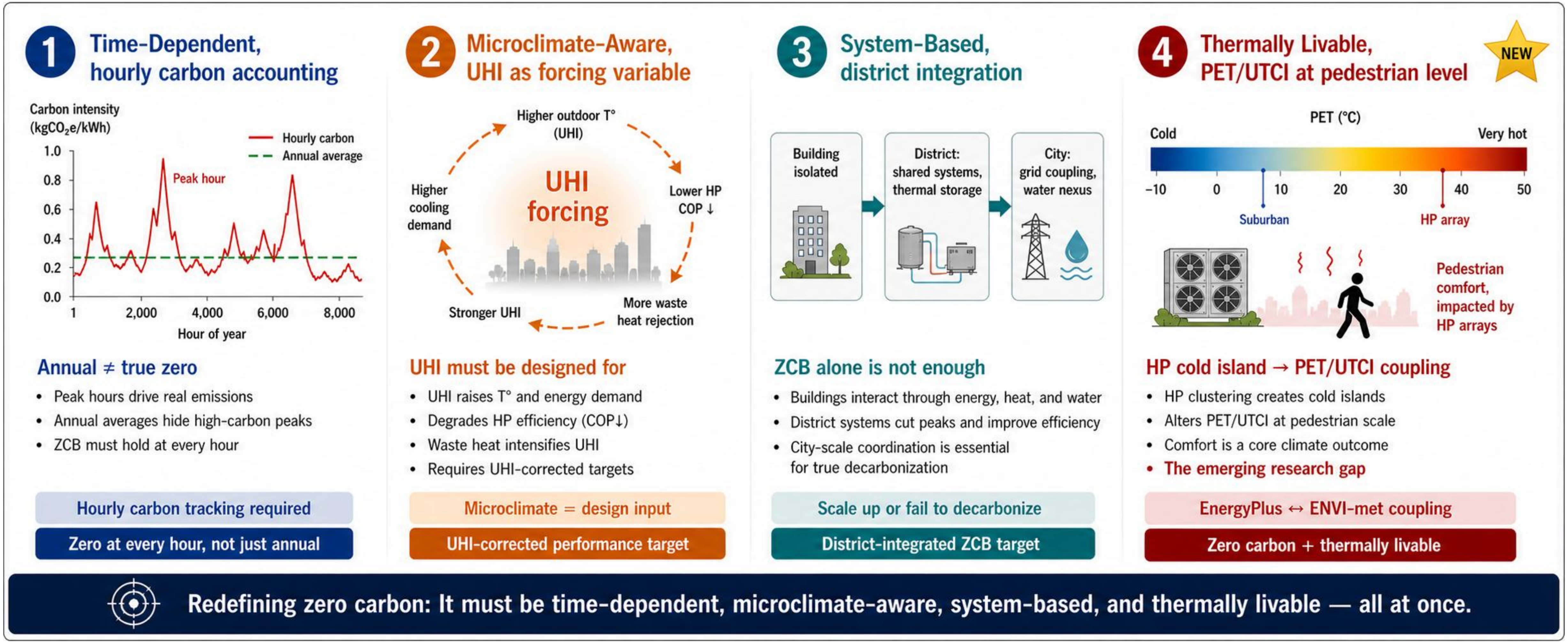
-Coupling is the only way to capture extreme and intense heatwave's impact instead of relying on historical weather data



Larger computational complexity, capacity and time

Synthesis: Redefining Zero Carbon: Four Conditions

Conclusion



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Closing Statement

A net-zero carbon building is not net-zero carbon in a heat-stressed city

NZCB electrification increases sensitivity to urban microclimate

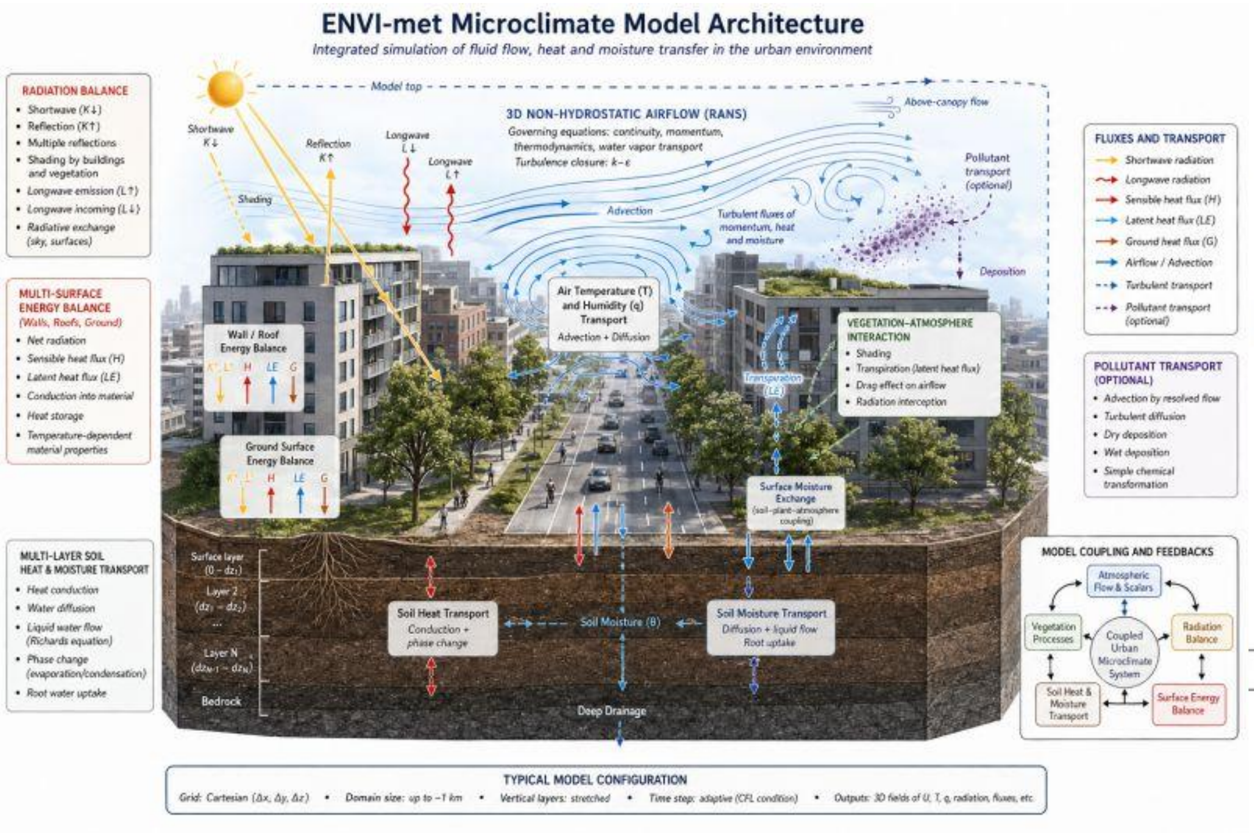
Annual balance hides the real carbon story: time, space, and system matter

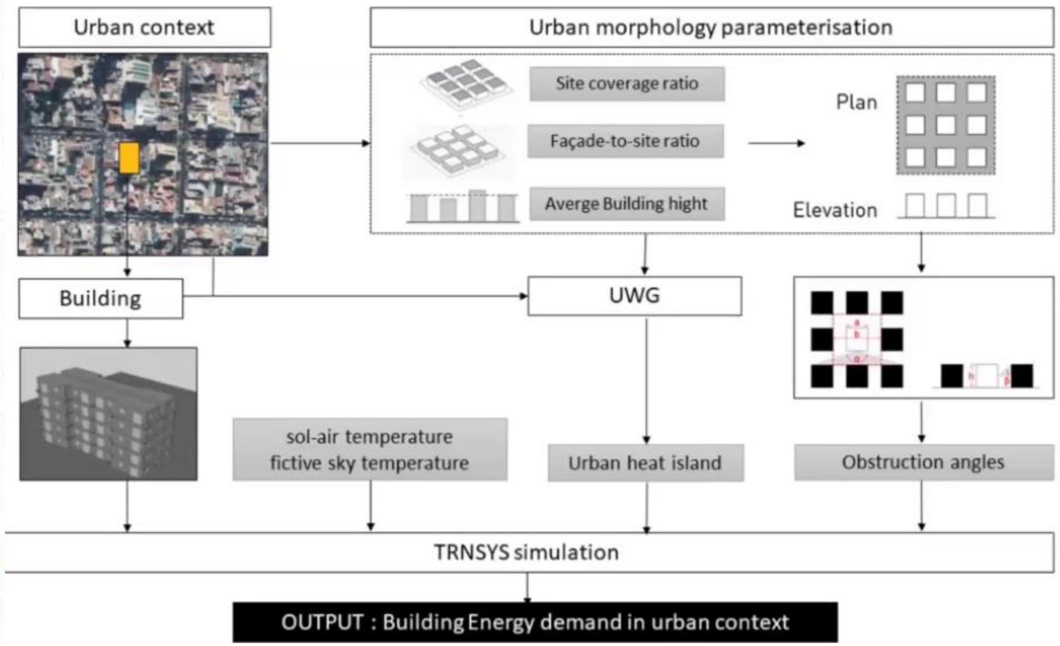
Zero carbon must also be thermally livable: PET/UTCI at pedestrian level

We are not decarbonizing buildings.
We are redesigning urban thermodynamics.

Zero Carbon Buildings Under Urban Heat Stress

How Urban Microclimate Redefines Decarbonization Pathways





Yujin Yang 杨玉锦

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Sustainable Building Design Lab, UEE,

School of Engineering, University of Liège, Belgium

shady.attia@uliege.be

/in/shady-attia-14352a7

/www.shadyattia.org

www.sbd.uliege.be

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