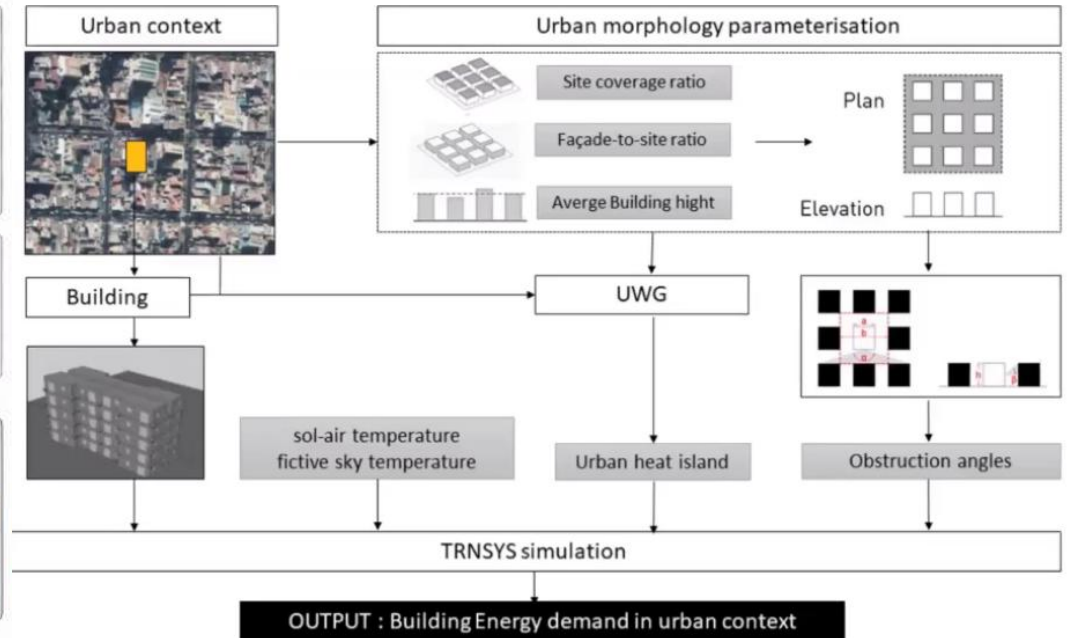
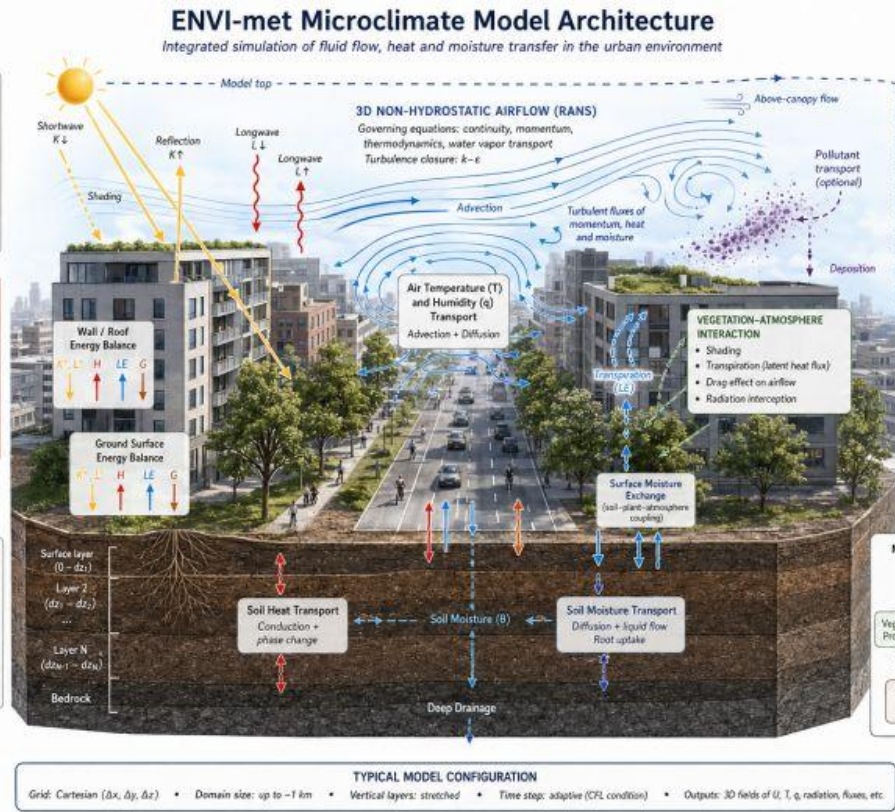


Zero Carbon Buildings Under Urban Heat Stress

How Urban Microclimate Redefines Decarbonization Pathways

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[/www.shadyattia.org](http://www.shadyattia.org)

YouTube [bilibili](https://www.youtube.com/channel/UC...)



www.sbd.uliege.be



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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

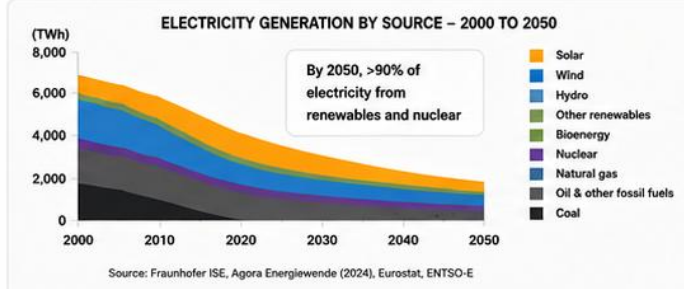
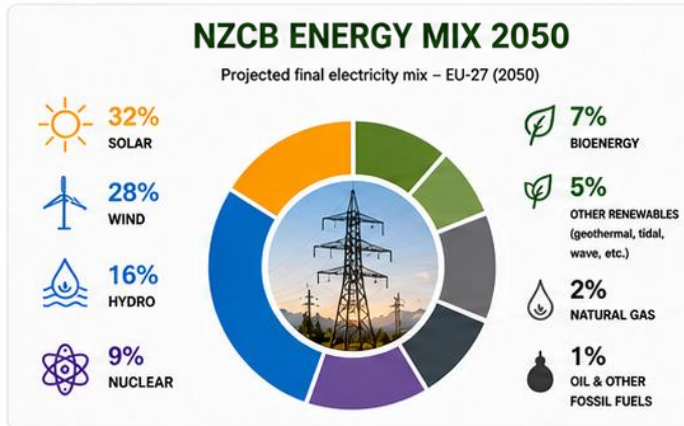


The International Symposium on District Heating and Cooling



What is a Zero Carbon Building (NZCB)?

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



Net-Zero Carbon Buildings (NZCB)

Low carbon by design, powered by clean energy

CLEAN ENERGY
On-site renewables for low operational carbon

BIO-BASED MATERIALS
Timber structure & bio-based materials reduce embodied carbon

LOW CARBON DESIGN
12-storey timber-hybrid structure with high-performance envelope

EXTERNAL SHADING
Reduces cooling demand and improves comfort

EFFICIENT SYSTEMS
MVHR with heat recovery & smart controls for ultra-low energy use

ON-SITE ENERGY
PV on roof & facade
Battery storage
Smart energy management

HIGH PERFORMANCE ENVELOPE

- Excellent insulation
- Airtight construction
- High performance windows (Triple glazing)

PASSIVE DESIGN

- Daylighting
- Natural ventilation
- Thermal mass
- Summer comfort

EFFICIENT SYSTEMS

- MVHR (heat recovery)
- Heat pump (low temp)
- Smart controls
- Low flow fixtures

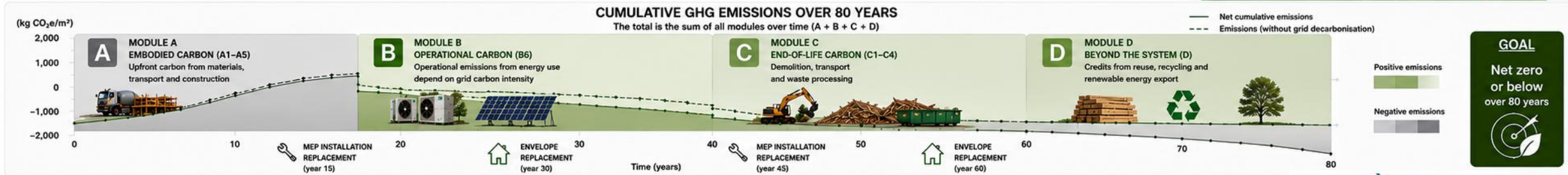
SMART CONTROL

- Monitoring
- Demand response
- User feedback
- Optimised operation

3 STEPS TO REACH LOW CARBON

- 1 REDUCE DEMAND**
 - High insulation (walls, roof, floor)
 - Airtight building envelope (n50 ≤ 0.6 ACH)
 - External shading
 - Passive solar design
 - Efficient lighting & appliances
- 2 USE EFFICIENT SYSTEMS**
 - Heat pump for heating & hot water
 - Mechanical ventilation with heat recovery (MVHR)
 - High efficiency equipment
 - Low energy consumption
- 3 USE CLEAN ENERGY**
 - On-site solar PV
 - Green electricity tariff (wind & solar)
 - Grid decarbonisation
 - Operations = ZERO (B6 module = near zero)

With a clean grid, total lifecycle emissions = zero or below.



01

Reframing Zero Carbon Buildings Definition

Why is the definition itself broken?



The Illusion of Net-Zero Carbon Buildings

Reframing Zero Carbon



Design Assumption



Weather: TMY static file



T_{outdoor}: 28°C



COP: 4.2 rated



Result:
Certified zero carbon



UHI Reality



UHI adds +3°C to +6°C



T_{outdoor} actual: 32–36°C



COP actual: 2.8–3.4



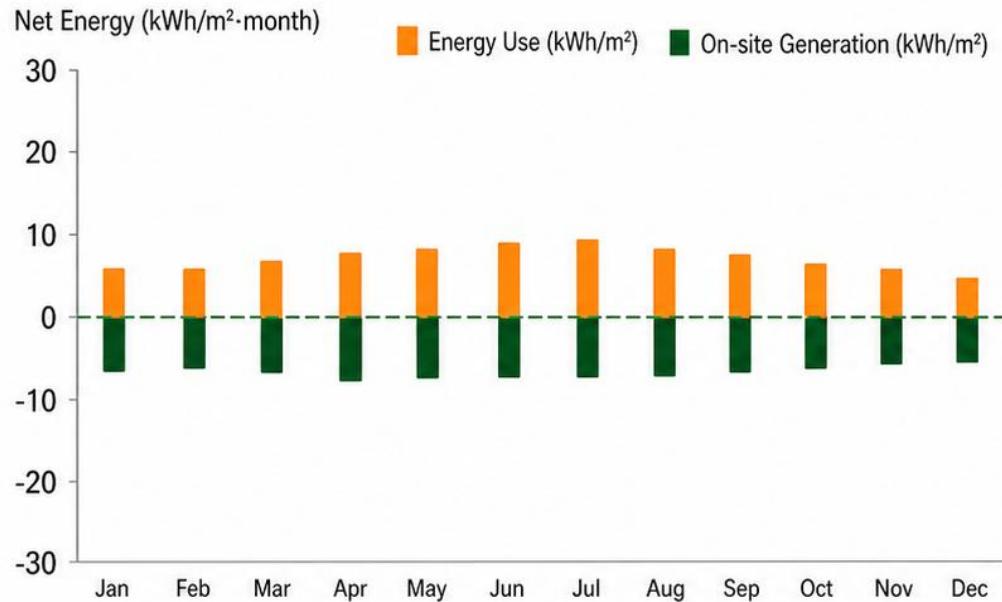
Result:
Not zero carbon

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

The Performance Gap: Annual Balance ≠ Real Performance

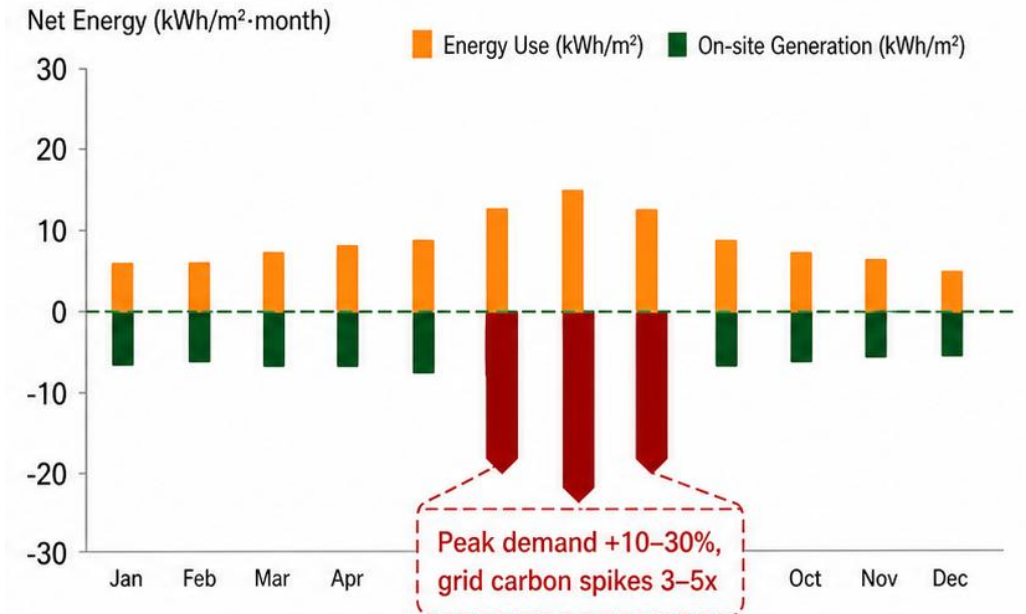
Reframing Zero Carbon

Modeled: Annual Energy Balance
static TMY weather file, no UHI



✓ Annual net ≈ 0 kWh/m² — ZCB certified

Reality: Peak-Hour Carbon (UHI-corrected)
actual performance, grid carbon intensity at peak



Cooling demand
↑ 10-30%



COP
↓ 5-25%



Carbon spikes
at peak load

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

02

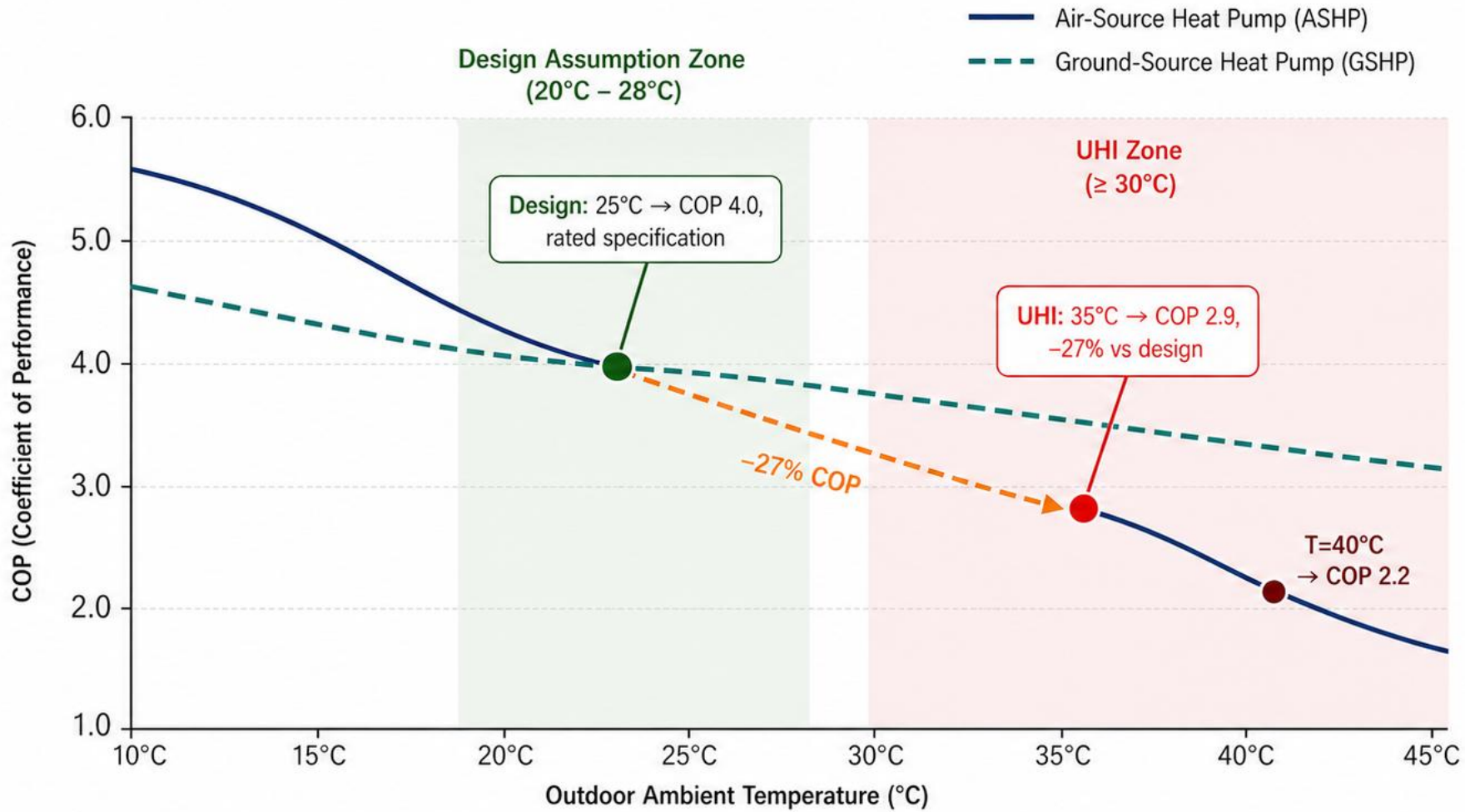
NZCB Meets Urban Microclimate

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)

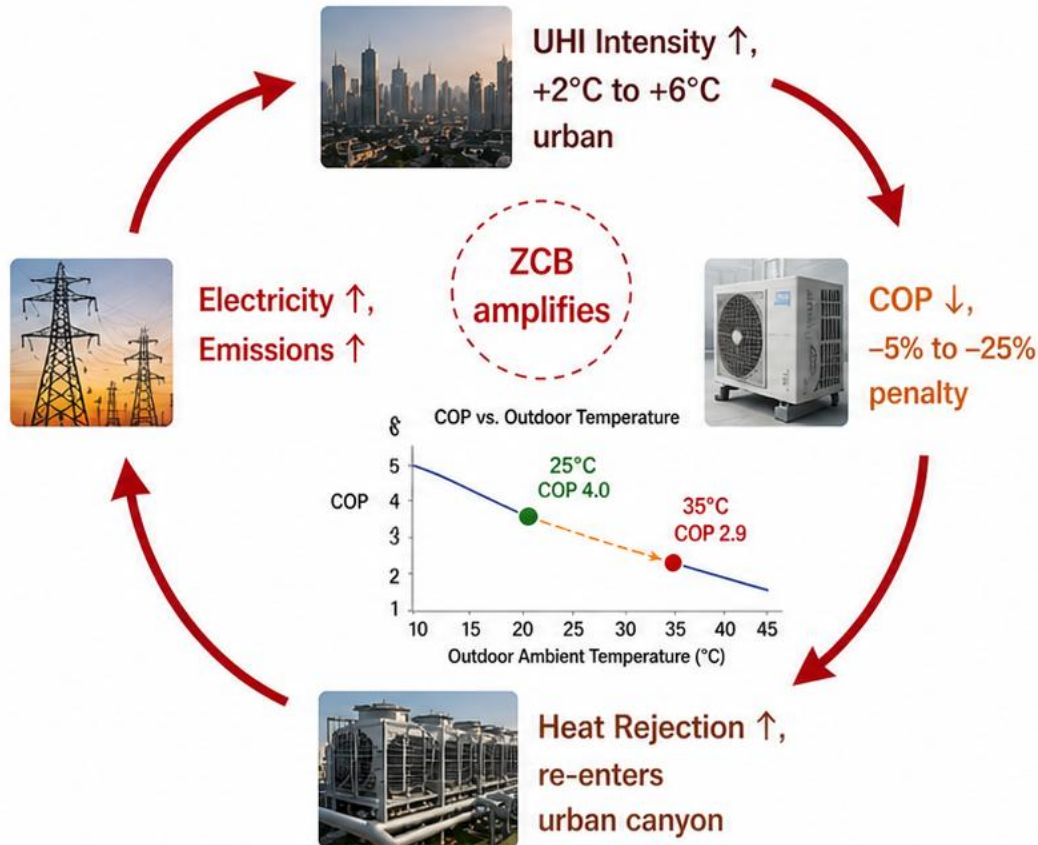
- COP 2.9
- 100 kWh → 34 kWh elec.
- ↑36% more electricity

ZCB electrification increases sensitivity to urban microclimate

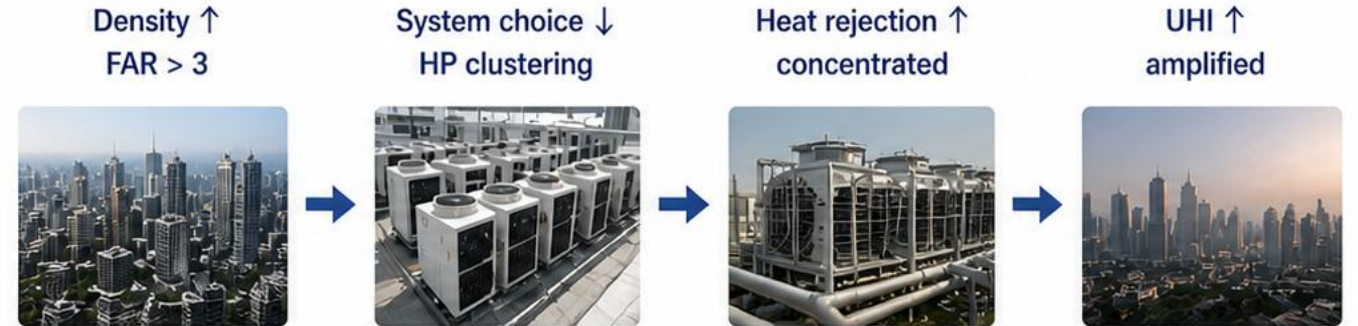
Three Coupled Feedback Loops

NZCB Meets Microclimate

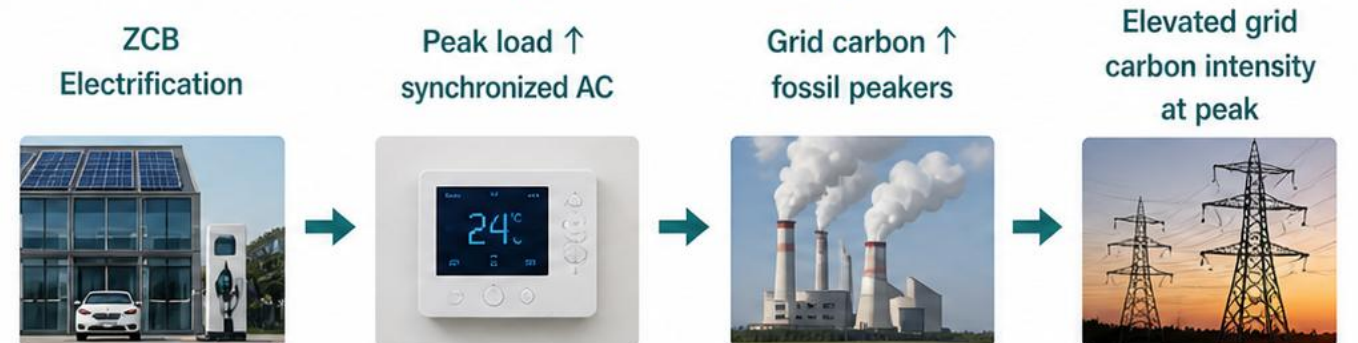
Loop 1 — The ZCB Efficiency Loop



Loop 2 — Urban Morphology Constraint



Loop 3 — ZCB Grid Loop



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

Loop 2: Urban Morphology Constraint: The FAR Threshold

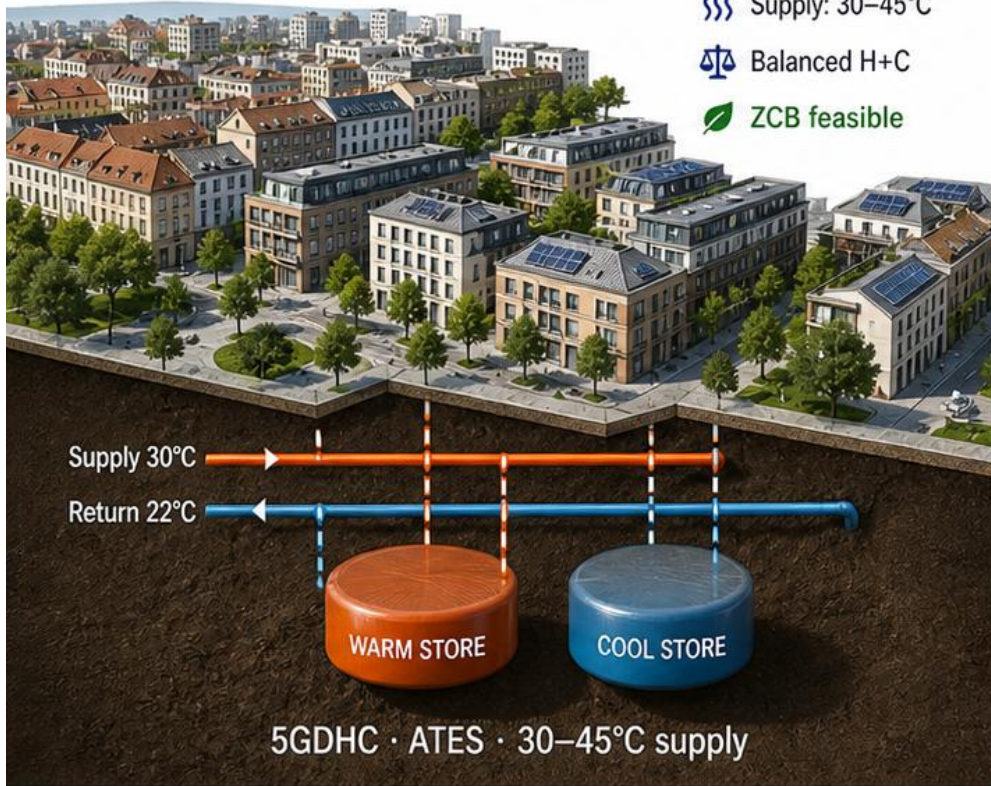
NZCB Meets Microclimate



EUROPE

Low-rise · Balanced loads
5GDHC viable

- FAR: 0.5–1.5
- Supply: 30–45°C
- Balanced H+C
- ZCB feasible



VS



CHINA

High-rise · Dense · Hot
5GDHC fails



FAR < 2

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



FAR > 3

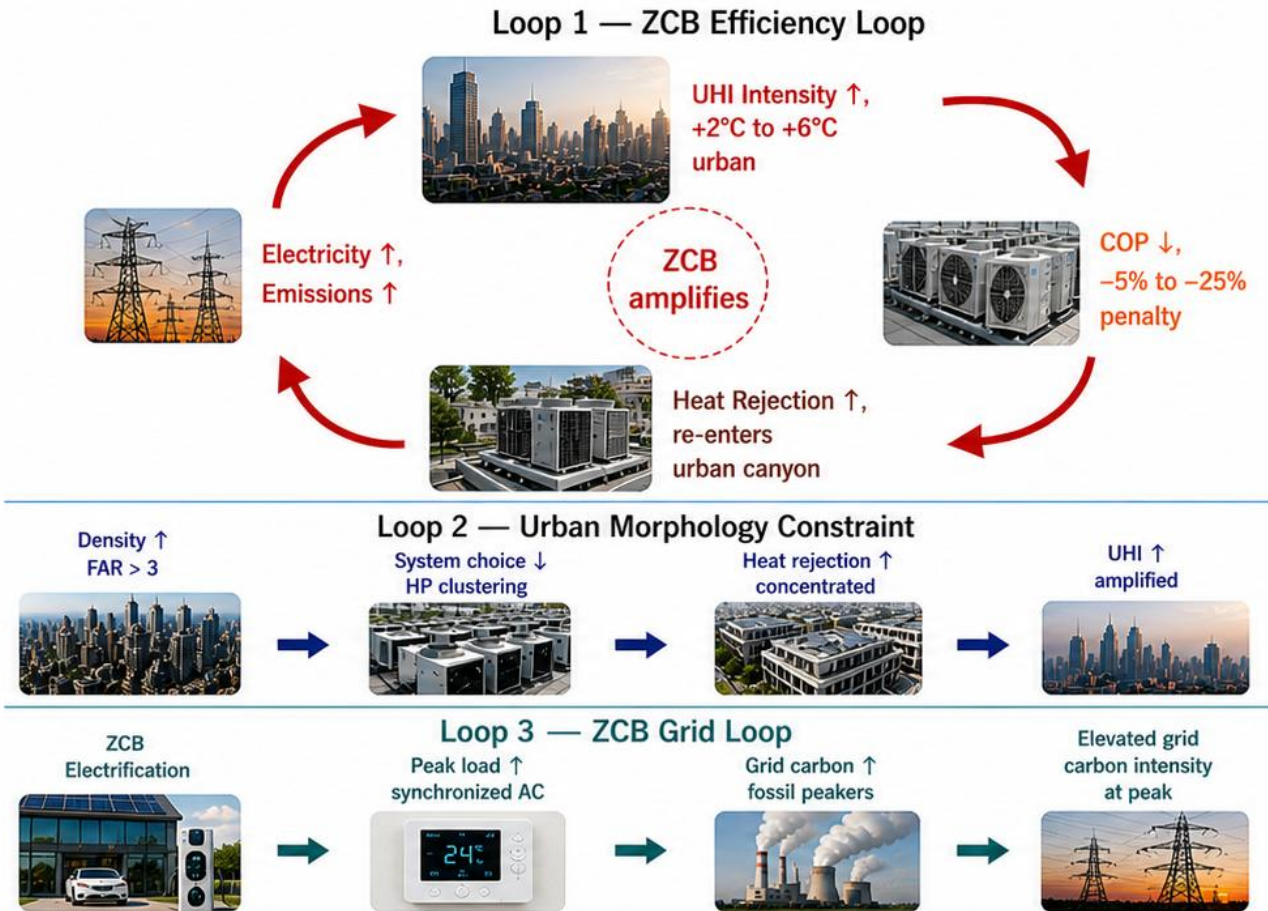
- System choice severely constrained
- Subsurface too congested
- 5GDHC physically fails



Morphology determines feasibility before any calculation begins

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



03

Why Zero Carbon Buildings Fail?

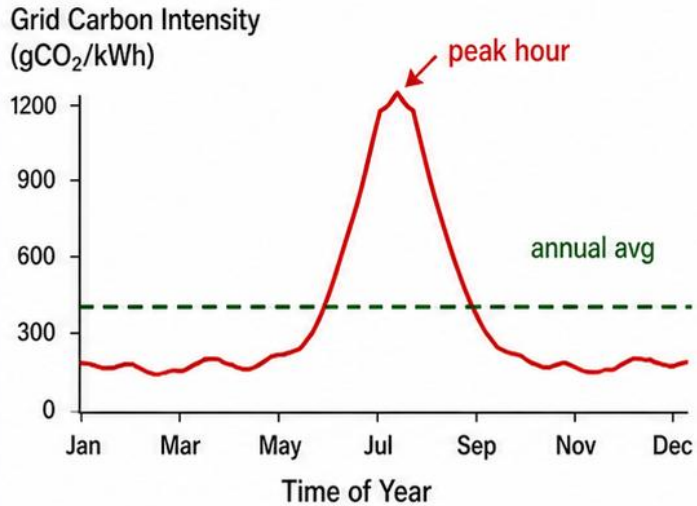
Misdefined · Mismodeled · Misapplied



Misdefined "Zero": Three Blind Spots

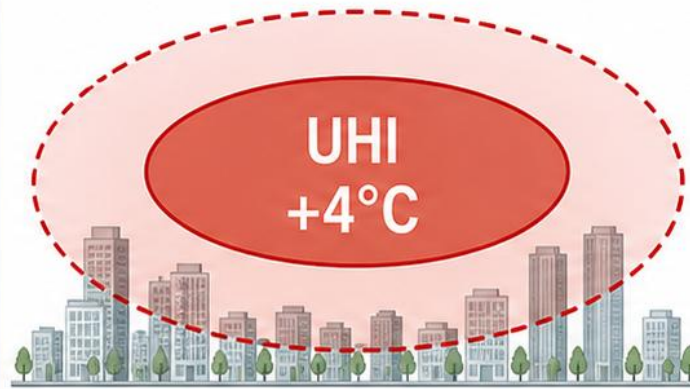
Why NZCB Fails

1 TIME blind spot



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

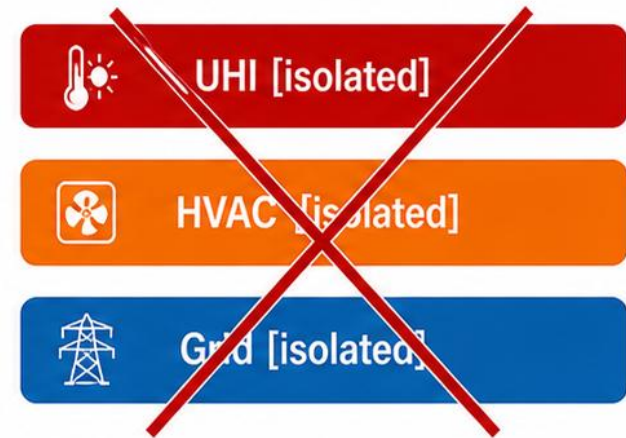
2 SPACE blind spot



X 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

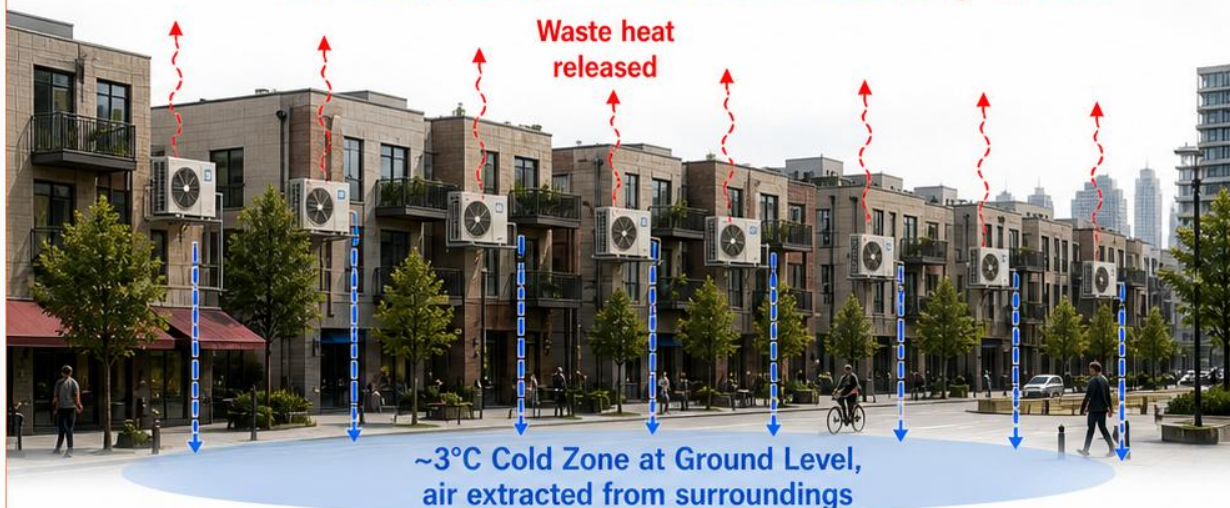


A building certified on annual balance can be a significant carbon emitter at peak






Heat Pump Limits in Dense NZCB Districts

Why NZCB Fails

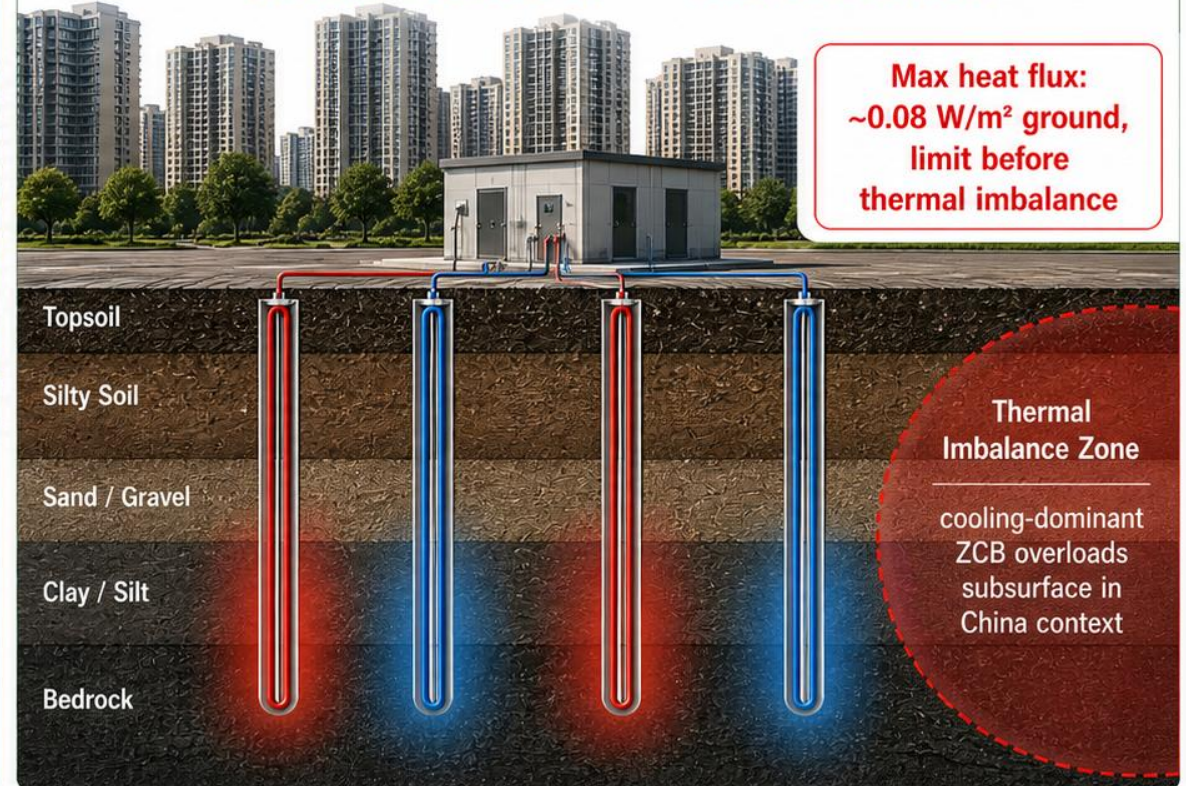
Air-Source HP — Urban Clustering Effect



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

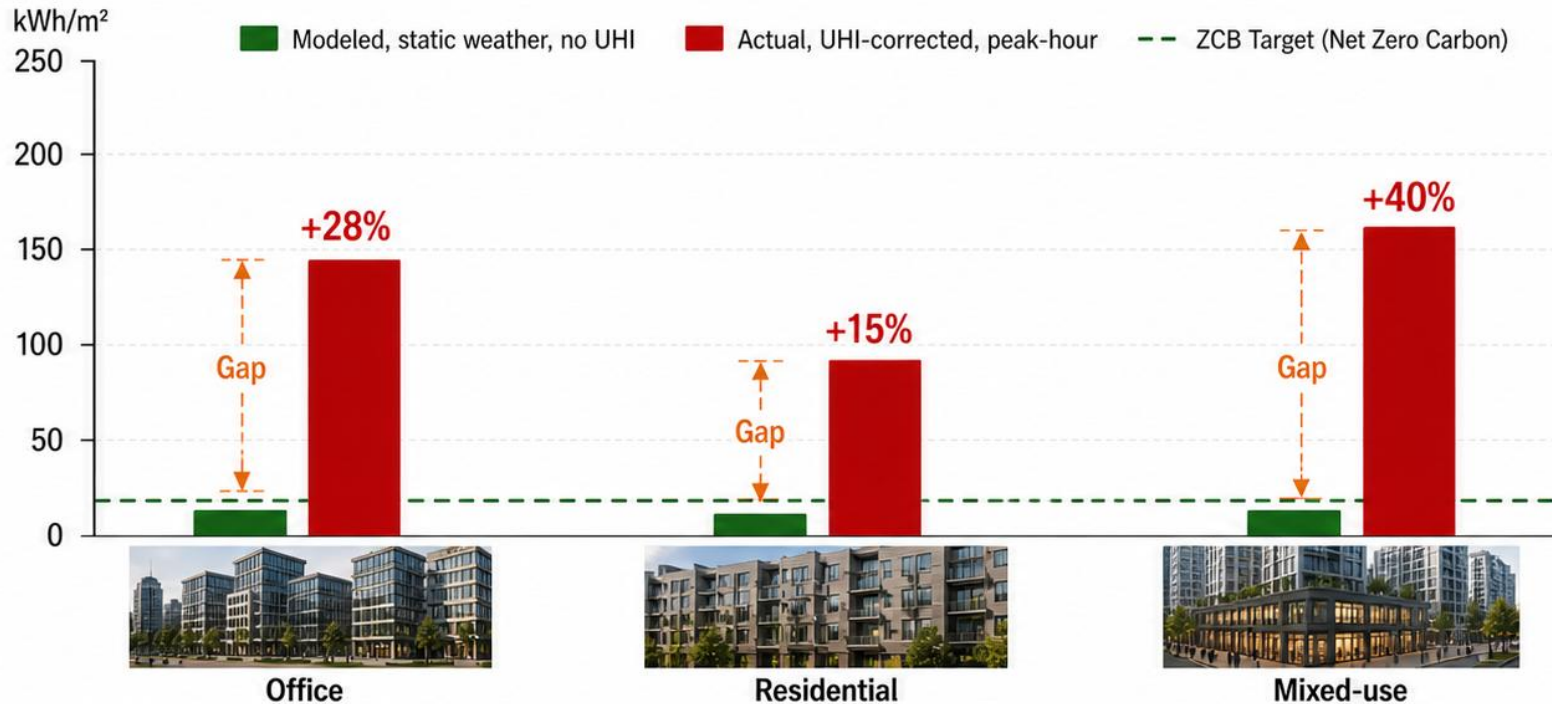


Heat pump limits in dense ZCB districts are physical, not theoretical

Simulation vs. Reality: 15–40% Performance Gap

Why NZCB Fails

Simulation vs. Reality: 15–40% Performance Gap



1 UHI not in weather files

- Standard TMY files predate urban heat intensification



2 Peak hour ignored

- Annual kWh balance hides hourly carbon spikes



3 No HVAC coupling

- Building model isolated from urban microclimate



Result: 15–40% deviation between certified ZCB and actual performance



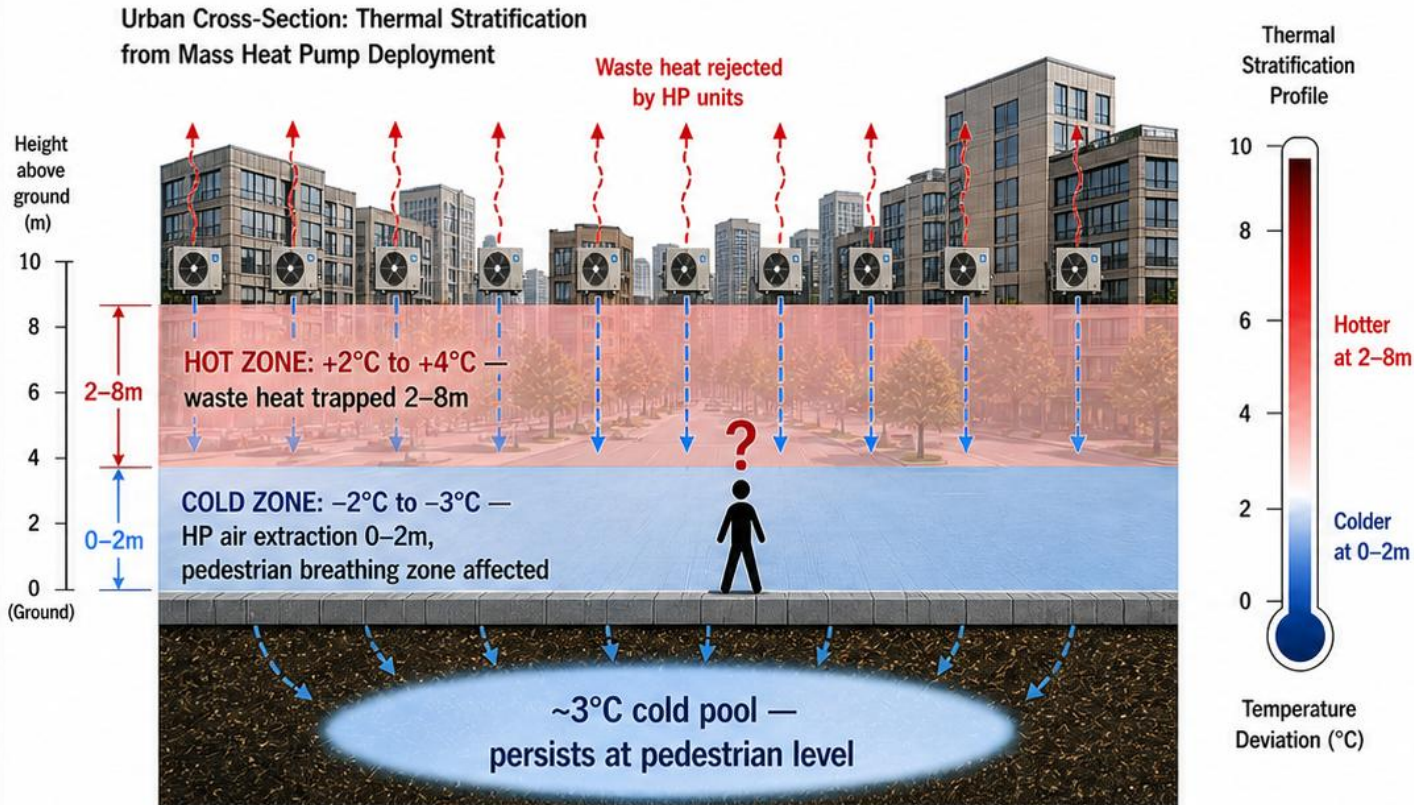
ZCB reduces building demand — but increases urban heat rejection density.

Local decarbonisation \neq Urban decarbonisation

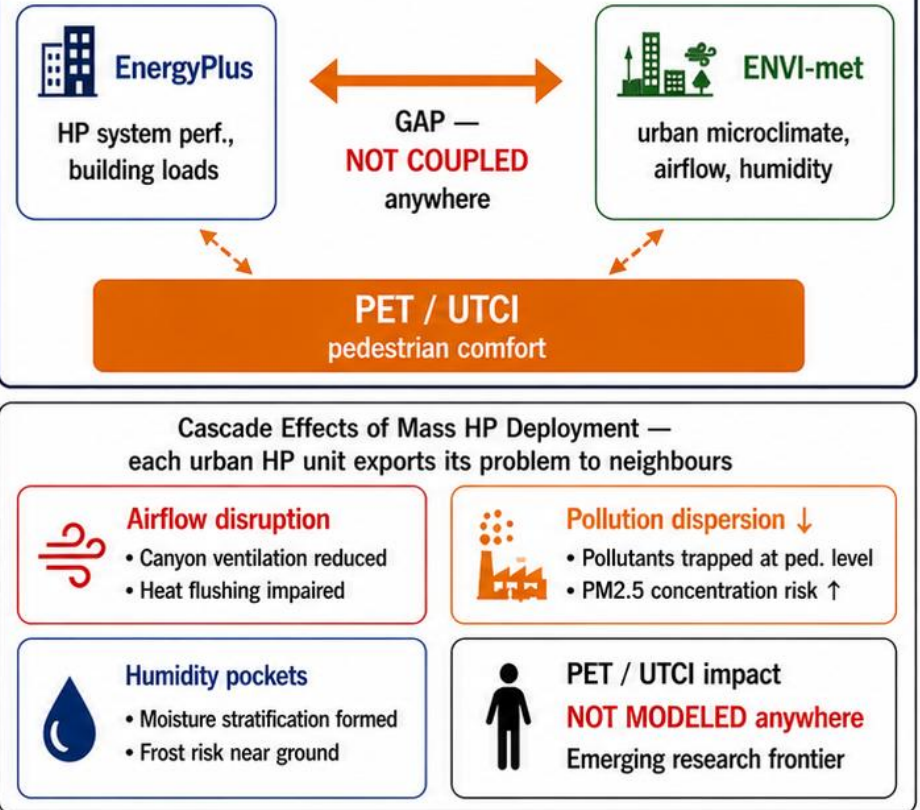
The Research Blind Spot

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

The Research Blind Spot — HP Cold Island → PET/UTCI



The Research Blind Spot — identified in the field, no model captures this today



“ The missing link between building physics and urban microclimate

04

Comparative NZCB Pathways

China vs. Europe: why solutions are not transferable



Urban Morphology & Heat Demand Structure

Comparative NZCB Pathways

Urban Morphology & Heat Demand Structure

EUROPE —
Low-rise ·
Balanced loads
5GDHC viable

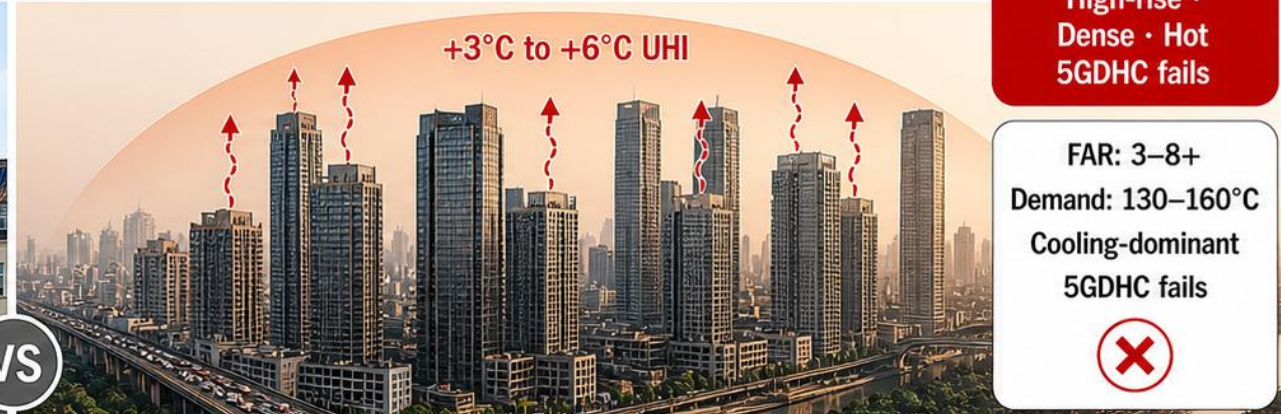
FAR: 0.5–1.5
Supply: 30–45°C
Balanced H+C
ZCB feasible



VS

CHINA —
High-rise ·
Dense · Hot
5GDHC fails

FAR: 3–8+
Demand: 130–160°C
Cooling-dominant
5GDHC fails



SUPPLY
(30–45°C)

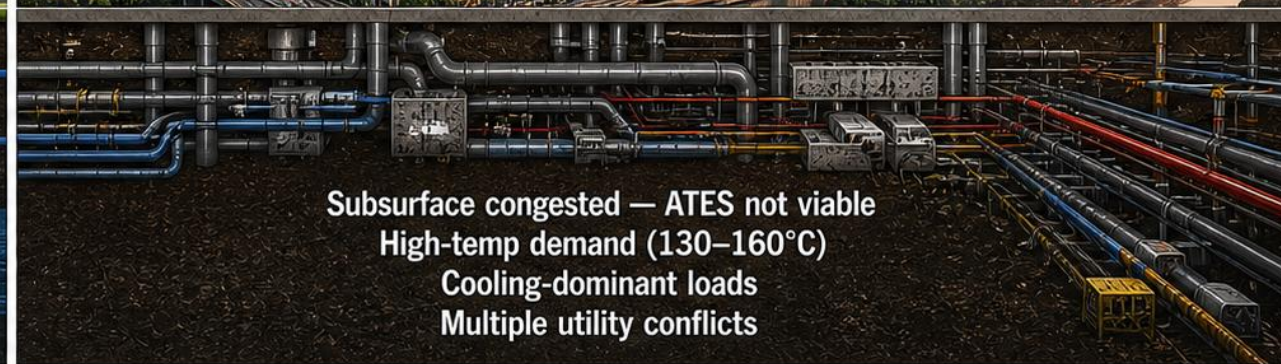
RETURN
(20–25°C)

WARM
STORE

COOL
STORE

5GDHC · ATEs · 30–45°C supply
Balanced loads · Subsurface viable

Viable aquifer (ATEs)



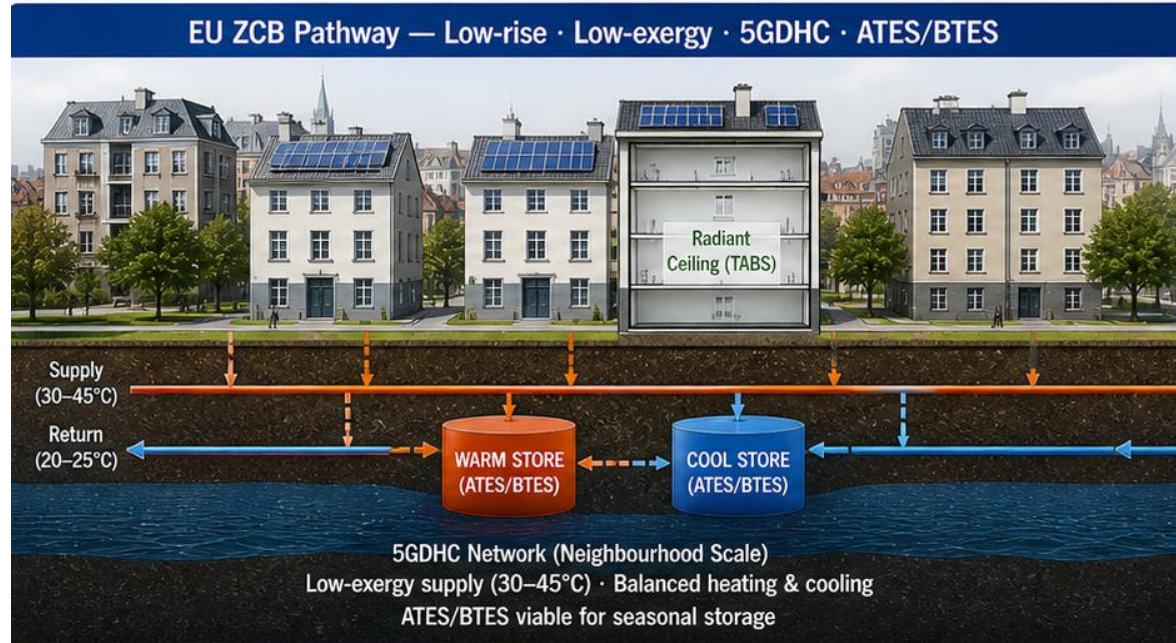
Subsurface congested — ATEs not viable
High-temp demand (130–160°C)
Cooling-dominant loads
Multiple utility conflicts



Urban form is the primary filter for ZCB feasibility — before energy, before technology, before policy.

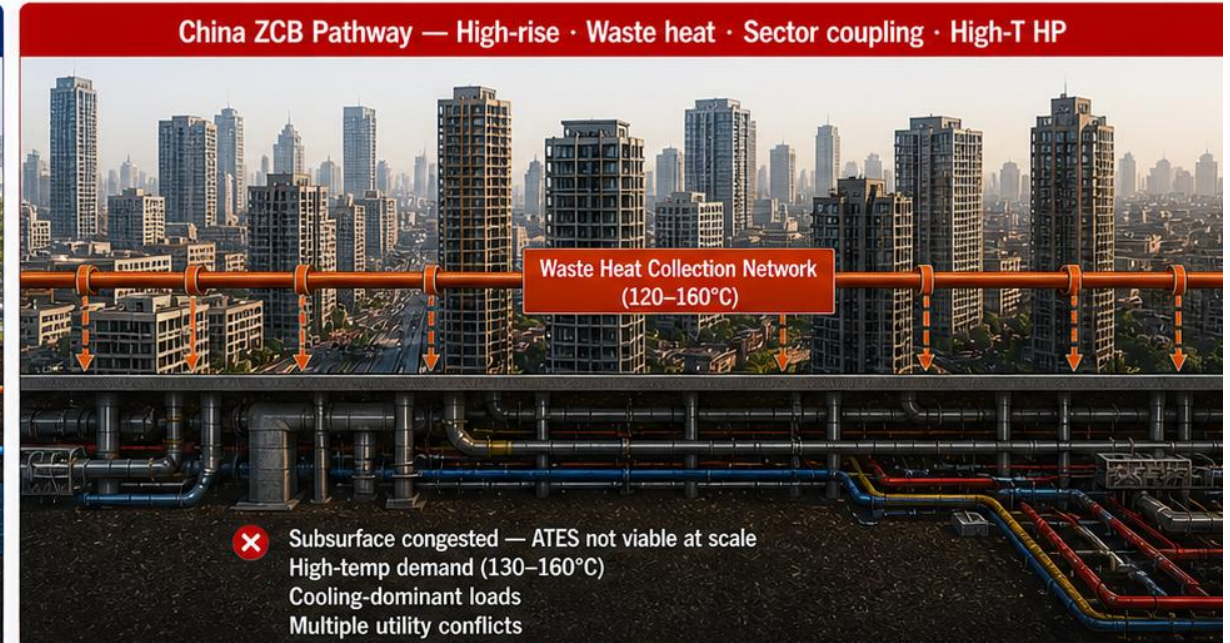
NZCB System Feasibility: EU vs. China

Comparative ZCB Pathways



EU ZCB Strategy

- ✓ Low-exergy supply temperatures (30–45°C)
- ✓ 5GDHC at neighbourhood scale
- ✓ ATEs/BTES viable for seasonal storage
- ✓ Radiant systems (TABS, ceilings, floors)
- ✓ Near-ZEB envelope standard
- ✓ $FAR < 2 \rightarrow$ ZCB systems feasible

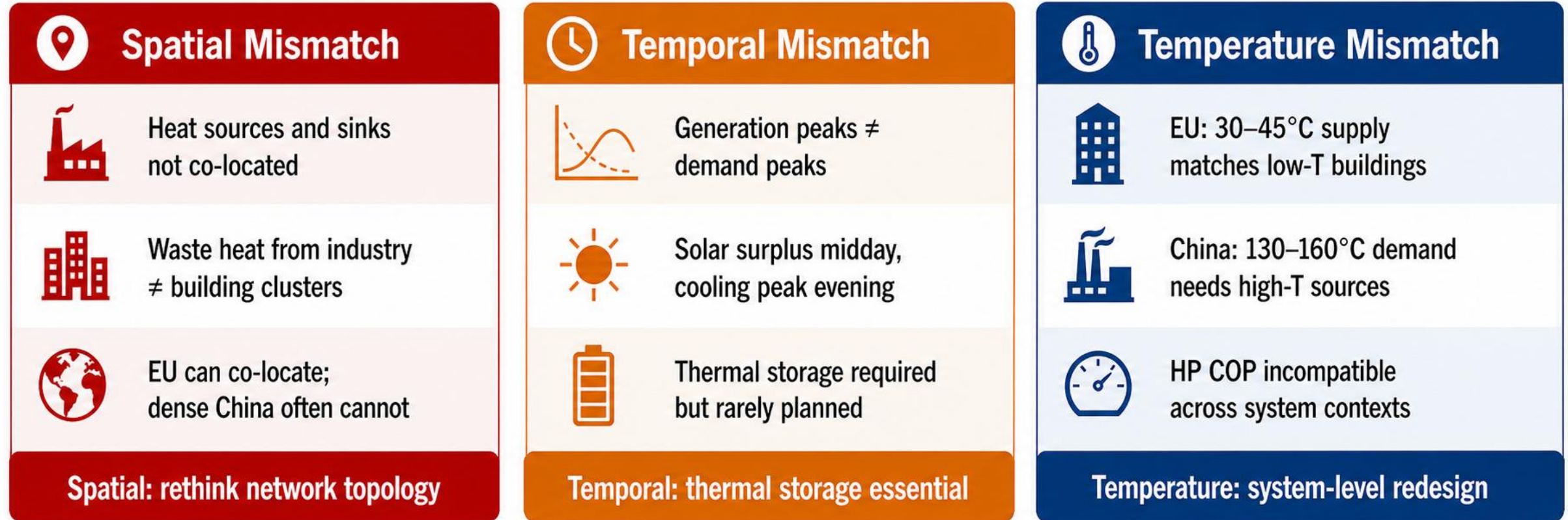


China ZCB Strategy

- ✓ Waste heat recovery from buildings and industry
- ✓ Sector coupling (industry, data centers, incineration, etc.)
- ✓ High-temperature heat pumps (120°C+) for high-grade heat
- ✗ $FAR > 3 \rightarrow$ 5GDHC physically fails

Why NZCB Solutions Are Not Transferable

Comparative NZCB Pathways



The geology sometimes says yes. The urban system says no.

05

District & Urban NZCB Systems

Energy–Heat–Water nexus · Research bridge



From Building to District: NZCB System Integration

District & Urban NZCB

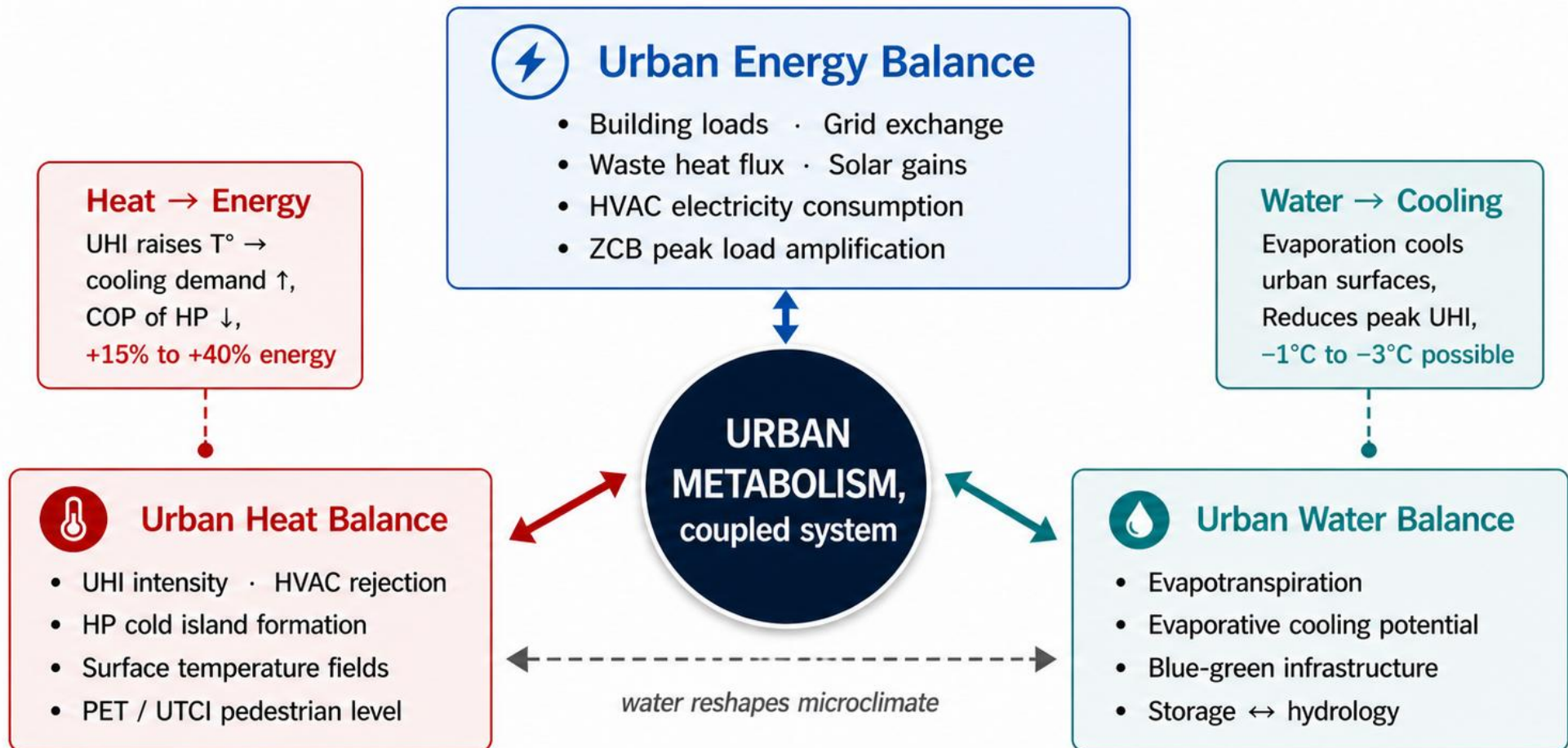


ZCB cannot be solved at building scale
District: thermal storage + waste heat + demand balancing
From building components to urban energy infrastructure

WATER NEXUS LINK
Cooling tower → water consumption
Storage ↔ hydrology interaction
→ Nankai University research bridge

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

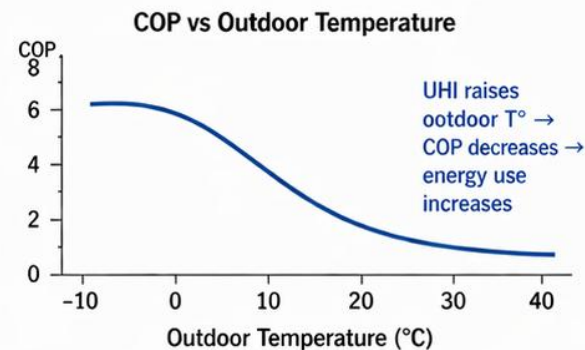
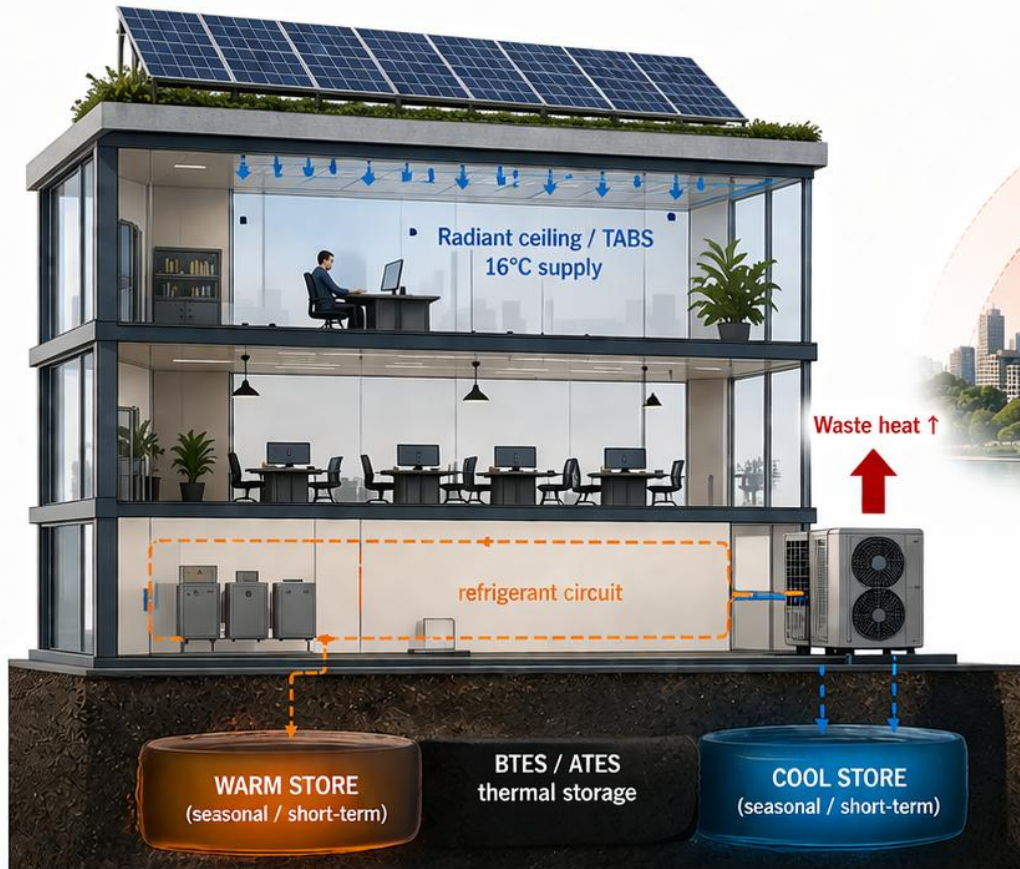
Design Implications for NZCB

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

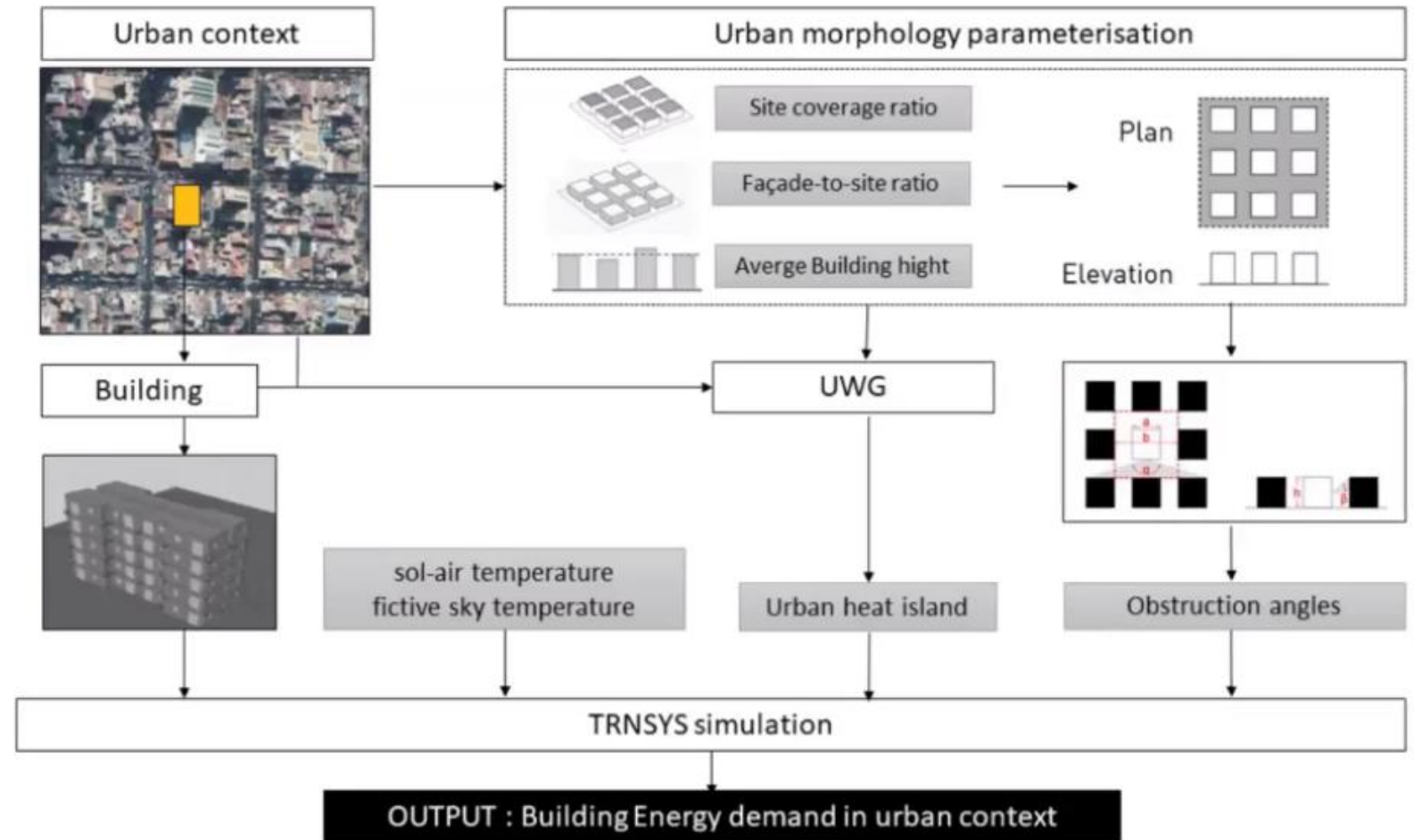
HVAC systems are no longer building components: they are urban climate actors

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

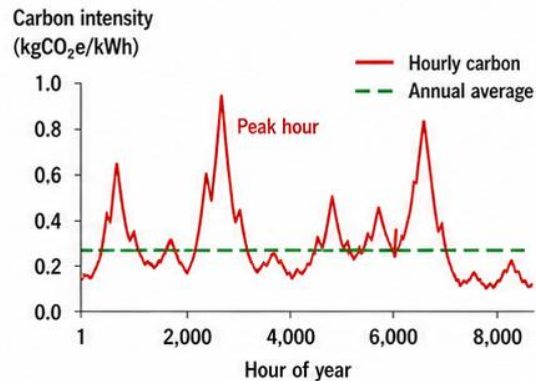


Larger computational complexity, capacity and time

Synthesis: Redefining Zero Carbon: Four Conditions

Conclusion

1 Time-Dependent, hourly carbon accounting



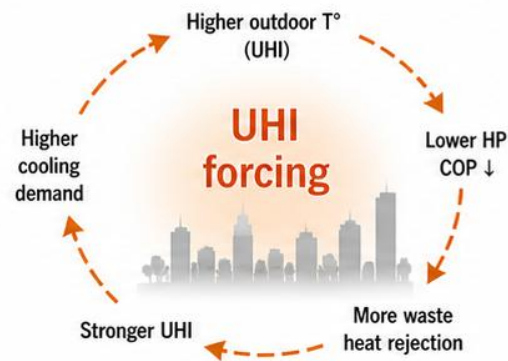
Annual ≠ true zero

- Peak hours drive real emissions
- Annual averages hide high-carbon peaks
- ZCB must hold at every hour

Hourly carbon tracking required

Zero at every hour, not just annual

2 Microclimate-Aware, UHI as forcing variable



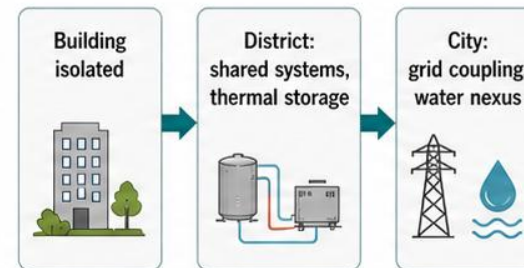
UHI must be designed for

- UHI raises T° and energy demand
- Degrades HP efficiency (COP↓)
- Waste heat intensifies UHI
- Requires UHI-corrected targets

Microclimate = design input

UHI-corrected performance target

3 System-Based, district integration



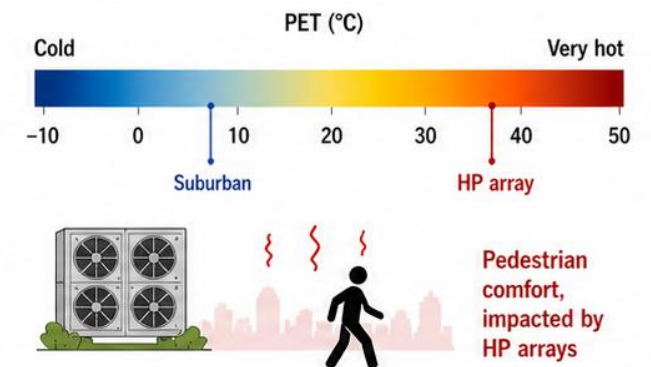
ZCB alone is not enough

- Buildings interact through energy, heat, and water
- District systems cut peaks and improve efficiency
- City-scale coordination is essential for true decarbonization

Scale up or fail to decarbonize

District-integrated ZCB target

4 Thermally Livable, PET/UTCI at pedestrian level



HP cold island → PET/UTCI coupling

- HP clustering creates cold islands
- Alters PET/UTCI at pedestrian scale
- Comfort is a core climate outcome
- **The emerging research gap**

EnergyPlus ↔ ENVI-met coupling

Zero carbon + thermally livable



Redefining zero carbon: It must be time-dependent, microclimate-aware, system-based, and thermally livable — all at once.

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.**

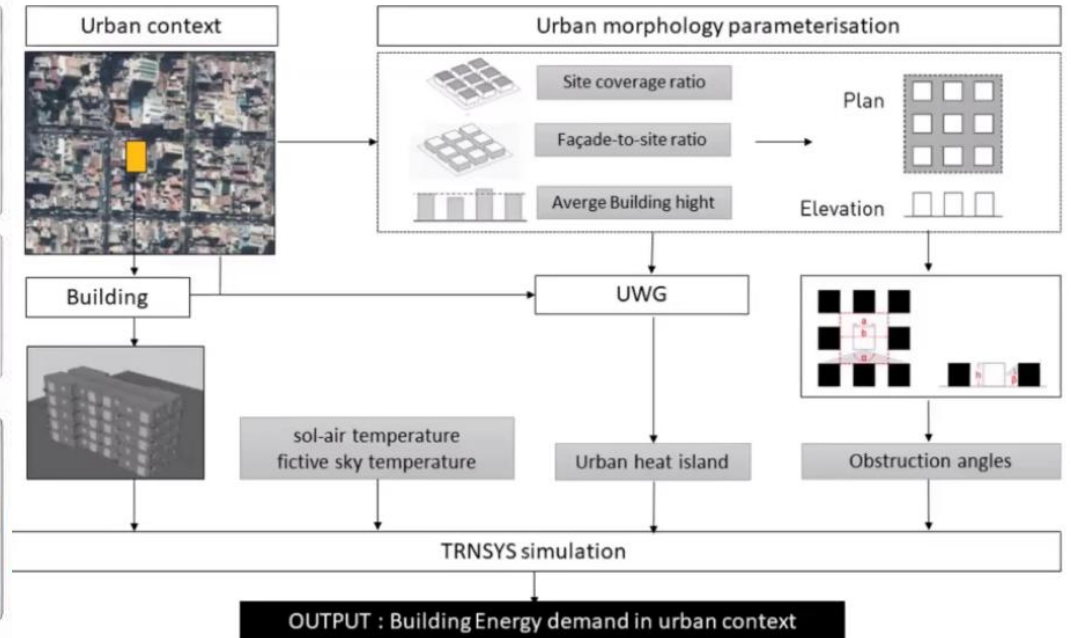
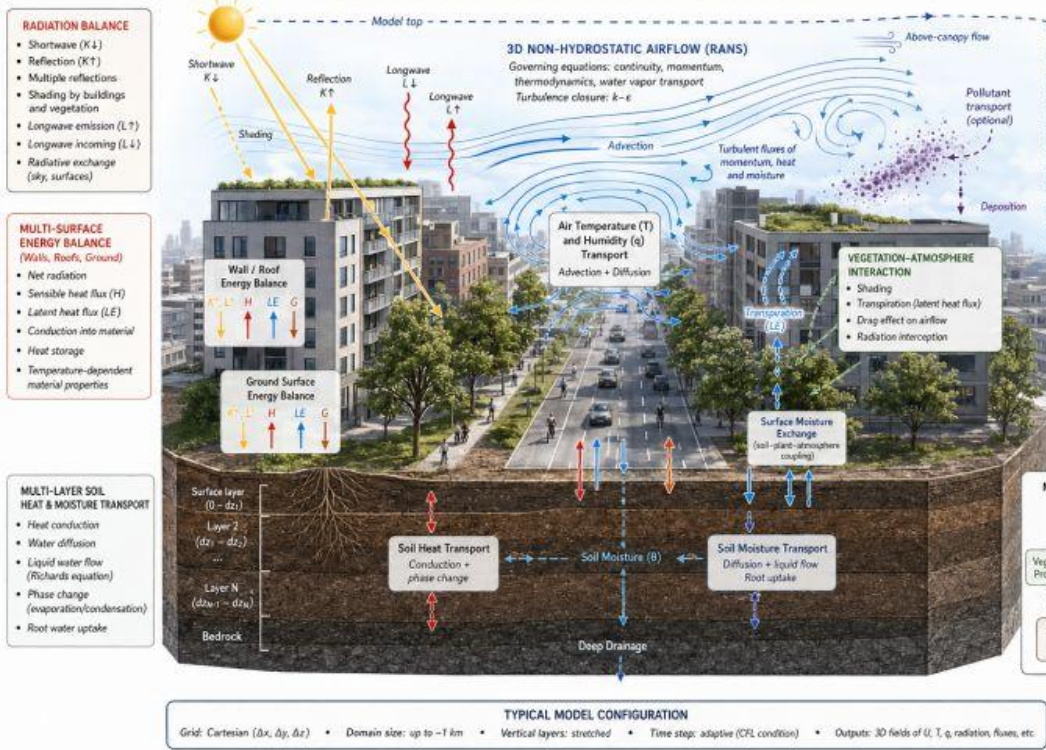
Zero Carbon Buildings Under Urban Heat Stress

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ENVI-met Microclimate Model Architecture

Integrated simulation of fluid flow, heat and moisture transfer in the urban environment



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