

WHEN COOLING HEATS THE CITY:

HEAT PUMPS, URBAN HEAT ISLANDS, AND 5TH GENERATION DISTRICT COOLING

Brussels European Quarter | Sustainable Cooling in Cities

INDOORS
COOLER

Where does
the heat go?

OUTDOORS
HOTTER

BUILDING SCALE
comfort indoors

CITY SCALE
heat outdoors

ANNEX 97 / TASK 5 Sustainable Cooling in Cities

Cities TCP | EBC Energy in Buildings and Communities Programme

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IEA EBC Annex 97

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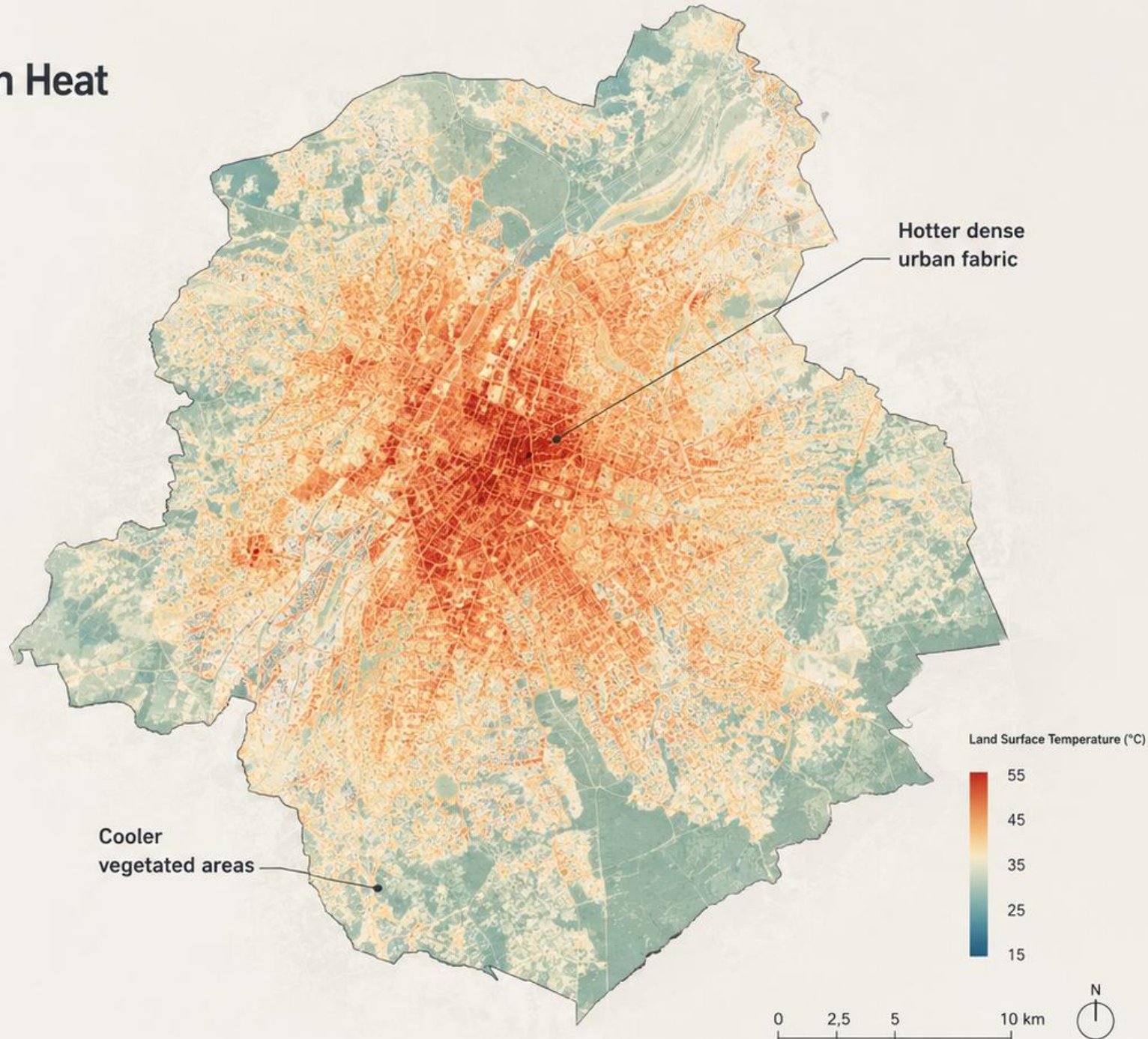
Brussels Is Already Experiencing Urban Heat

Urban heat is spatially concentrated

Heat is not distributed equally across Brussels.

Urban morphology, vegetation, surface properties, and density shape local heat exposure.

Source: Landsat 8 – Land Surface Temperature
Heat wave: 18.08.2018 @ 11:00

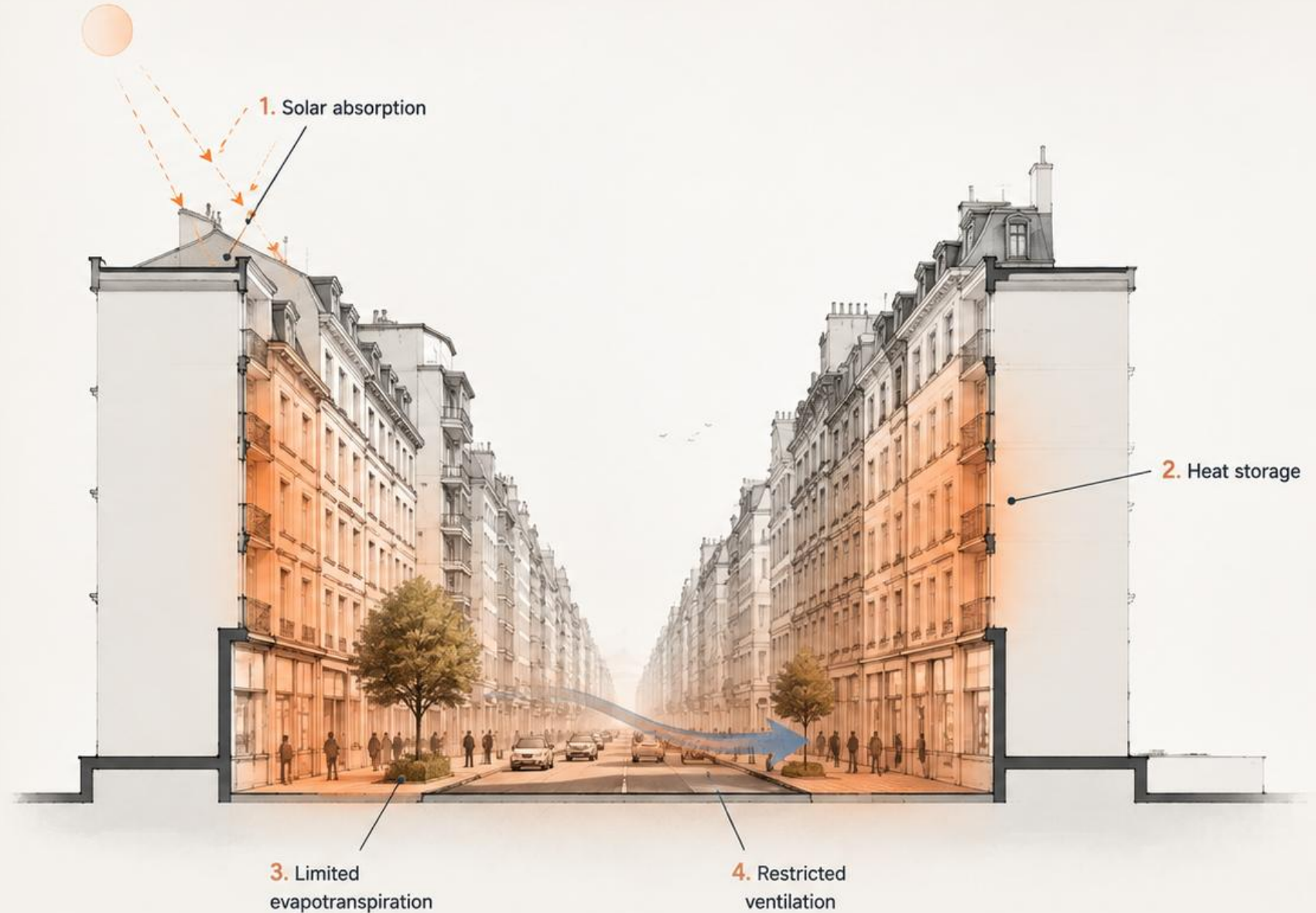


Why Are Some Parts of Brussels Hotter?

Urban form shapes the local heat balance

Urban morphology changes how heat is absorbed, stored, and released.

Density, mineral surfaces, limited vegetation, and restricted airflow can intensify local heat exposure.



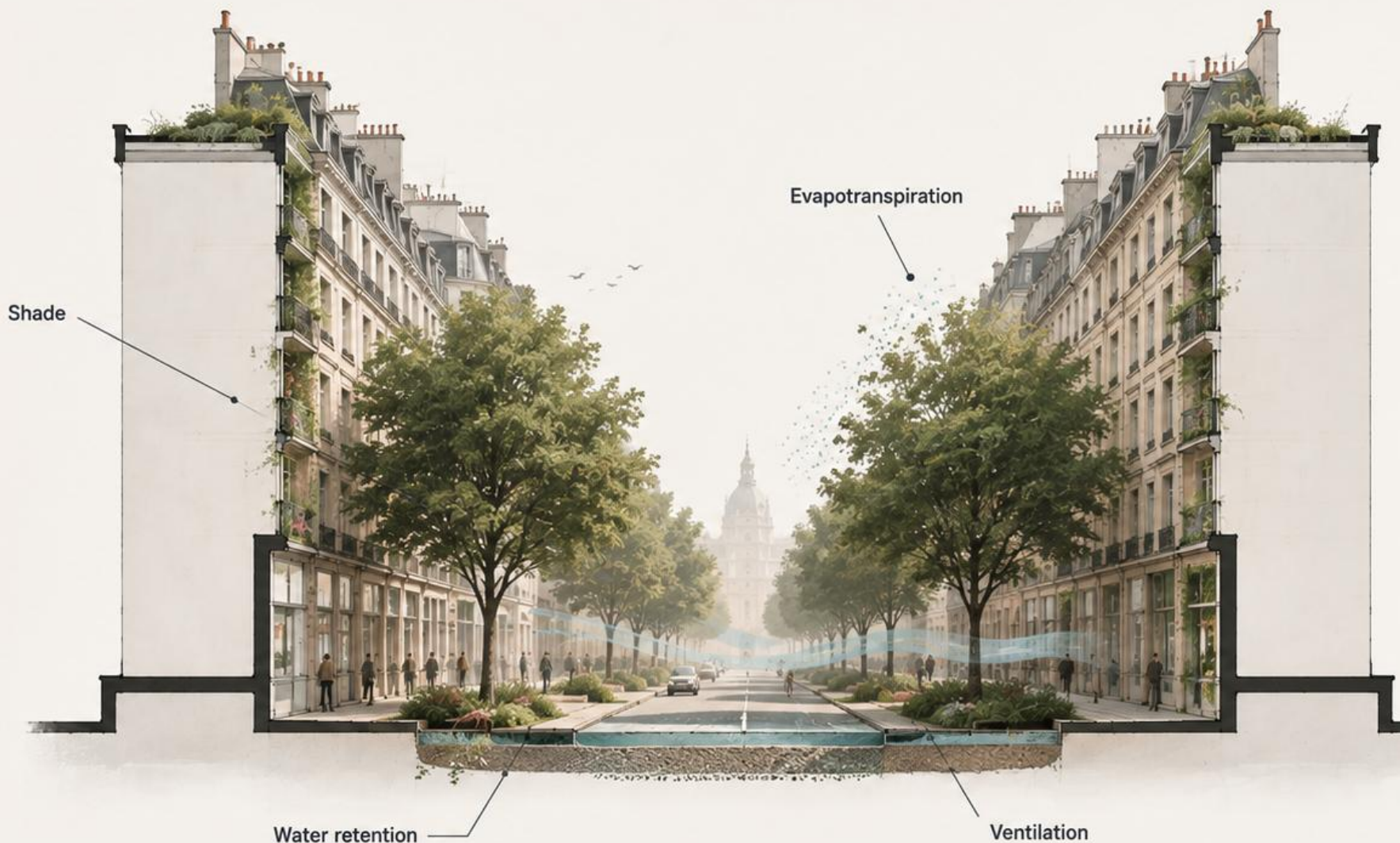
First Response: Reduce the Heat

Sustainable cooling starts before
mechanical cooling

The best cooling
load is the one
we avoid.

Shade, vegetation, soil, water, and
ventilation can reduce outdoor heat
exposure before buildings rely on
active cooling.

AVOID → **COOL**



Electrification Changes the Urban Energy Problem

Combustion disappears from buildings.
Heating and cooling become electrical loads.

COMBUSTION

FUEL → **HEAT**

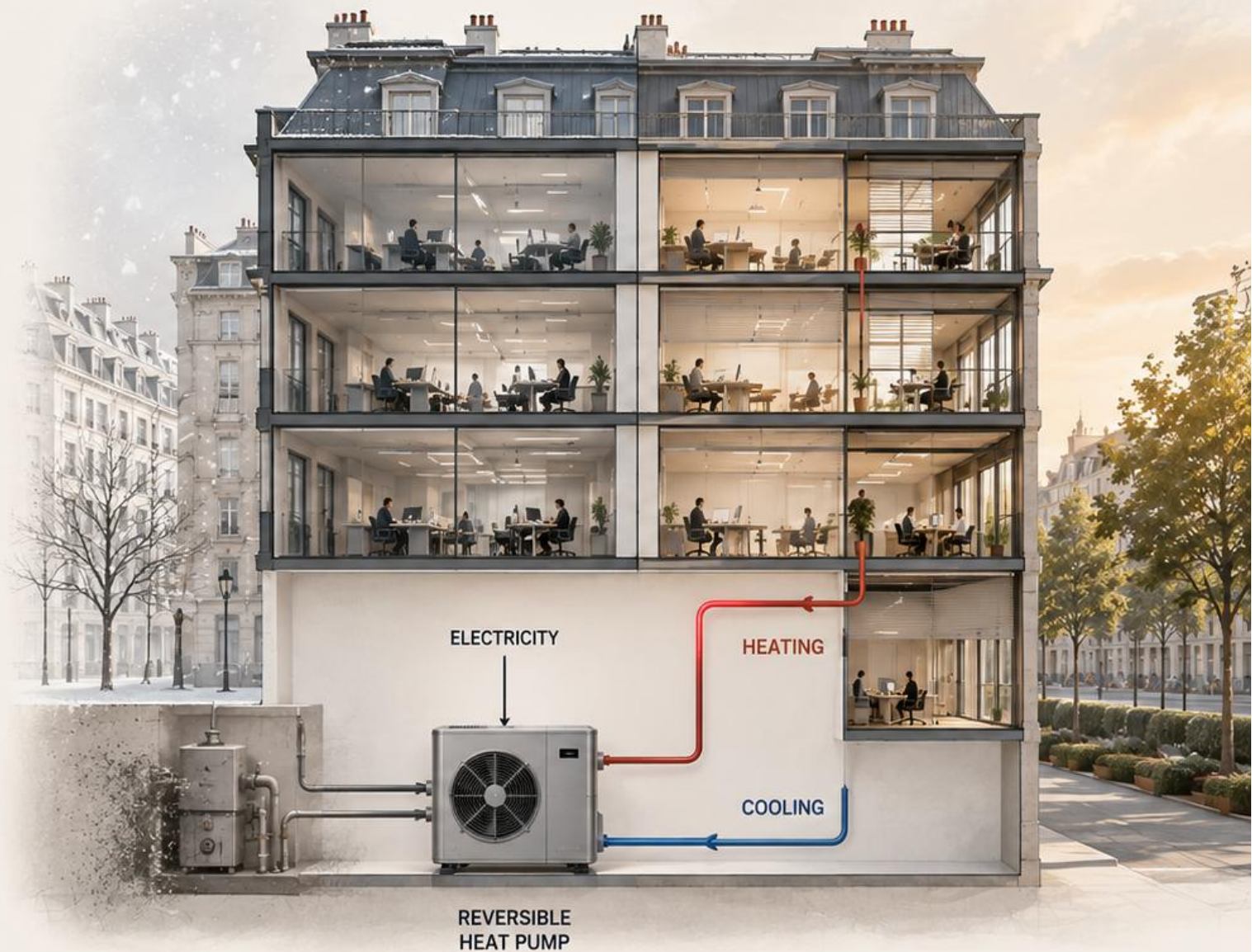


ELECTRIFICATION

ELECTRICITY → **HEATING + COOLING**

One machine.
Two seasonal loads.

The heat pump becomes part of both
the winter and summer energy problem.



Renovation Can Make Cooling the Design Peak

Deep renovation changes the mechanical load balance.

BEFORE RENOVATION

≈ **180 kW**

heating peak



AFTER RENOVATION

≈ **60 kW**

heating peak

BUT COOLING REMAINS

≈ **180 kW**

cooling peak

Cooling becomes the
larger design peak.



WINTER
transmission
losses ↓

SUMMER
solar + internal
gains remain

Cooling Does Not Destroy Heat

A cooling machine removes heat from the building and adds compressor work before rejecting it.

ILLUSTRATIVE COOLING LOAD

100 kW

removed indoors

+

COMPRESSOR WORK

+ 25 kW

electricity input

HEAT THAT MUST LEAVE

125 kW

$100 + 25 = 125 \text{ kW}$



The cooling load disappears from the room.

Not from the city.

100 kW
heat removed

+25 kW
compressor work

125 kW
must go somewhere

Where Does the Rejected Heat Go?

Every cooling system needs a heat sink. The destination of heat becomes a design decision.

THREE POSSIBLE PATHS

1



TO AIR

Rejected to outdoor air, warming the city.

2



TO GROUND

Rejected to the subsurface via boreholes or aquifers.

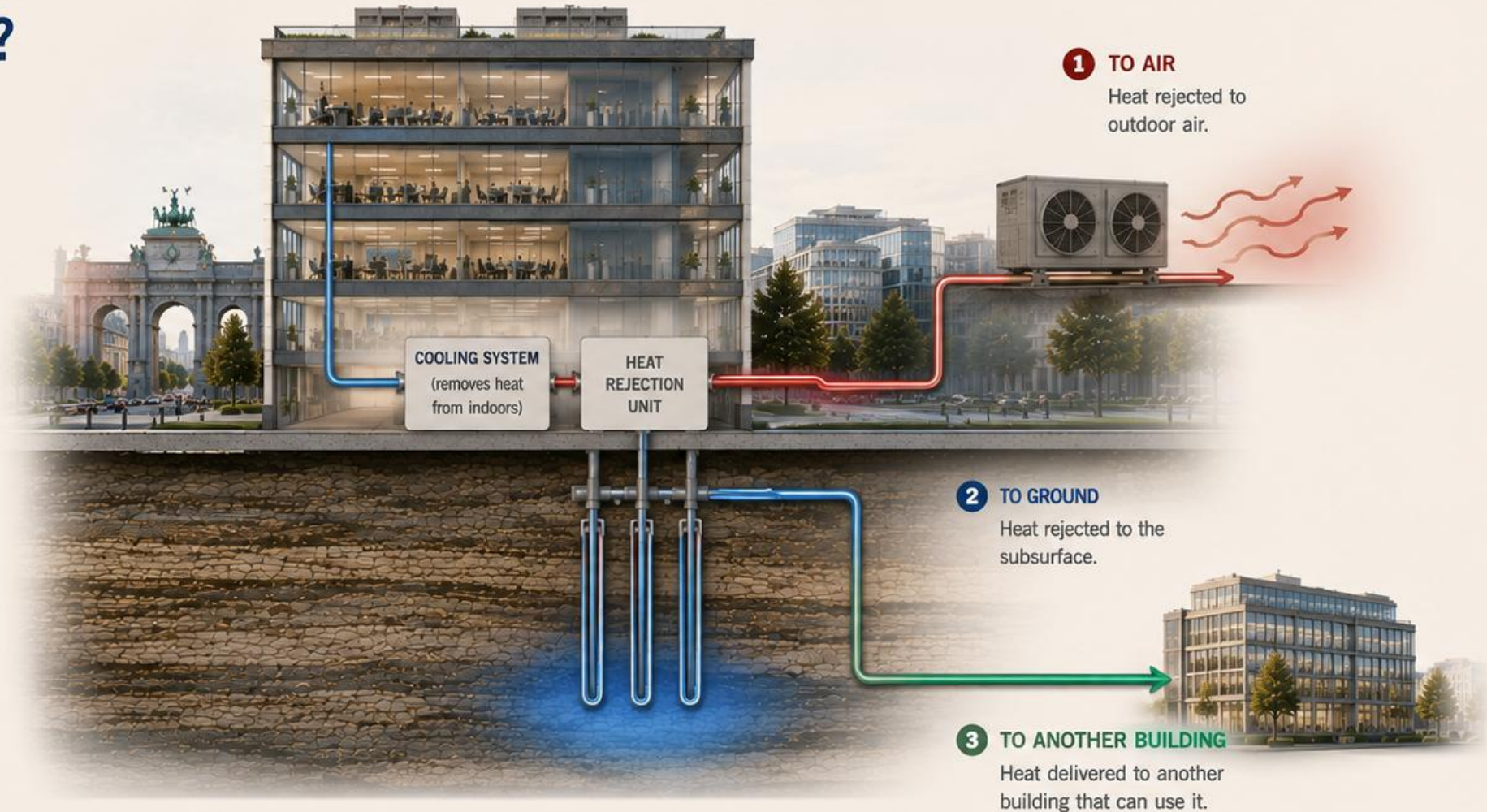
3



TO ANOTHER BUILDING

Rejected to another building that can use the heat.

ONE BUILDING, THREE HEAT SINK OPTIONS



The cooling performance, energy use and urban impact depend on where the heat is rejected.

Air Receives the Heat We Remove Indoors

Air-source cooling rejects building heat into an already hot urban environment.

SUMMER IN BRUSSELS

≈ 30–35°C

OUTDOOR AIR TEMPERATURE



Condenser rejects heat to outdoor air.



**ADDS HEAT TO THE CITY
INSTEAD OF REMOVING IT**



High outdoor temperatures raise condensing temperature, increase compressor lift and electricity demand.



If the Ground Is Cold Enough, Bypass the Compressor

Suitable ground temperatures can permit direct cooling through a heat exchanger.

GROUND
 $\approx 11-12^{\circ}\text{C}$

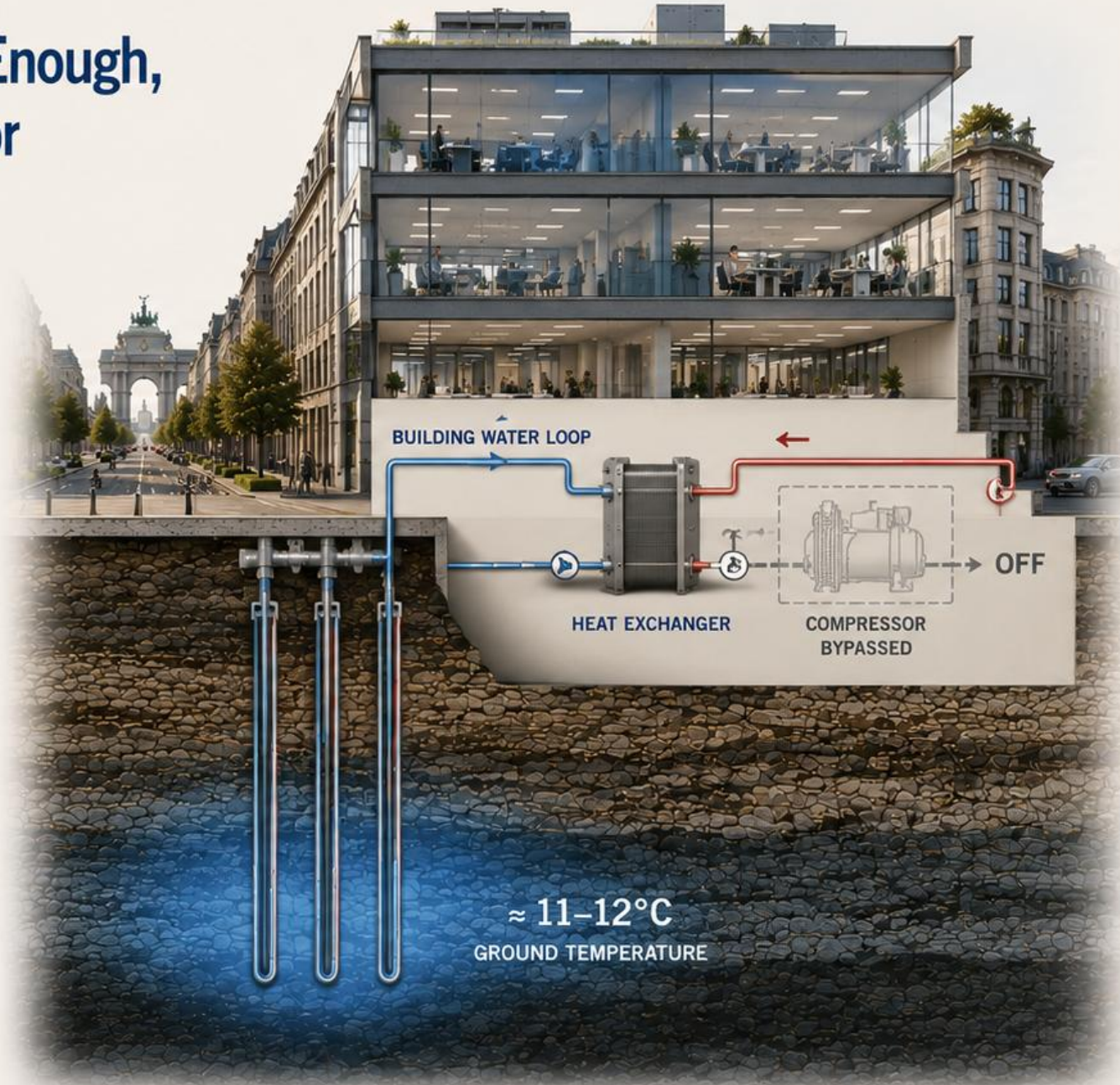
↓

COOL ENOUGH FOR
DIRECT EXCHANGE

↓

COMPRESSOR OFF

Move heat through the heat exchanger,
not through a refrigeration cycle.



No refrigeration cycle.
Just heat exchange.

When the temperature
difference is sufficient.

ⓘ Electricity remains for
circulation pumps,
but compressor
electricity is avoided.

— BUILDING WATER CIRCUIT
(secondary loop)

— GROUND LOOP
(closed circuit)

Geothermal Cooling Has Two Architectures

BTES exchanges heat through solid ground;
ATES moves groundwater carrying heat.



BTES

(Borehole Thermal Energy Storage)

Heat exchange with the solid ground.

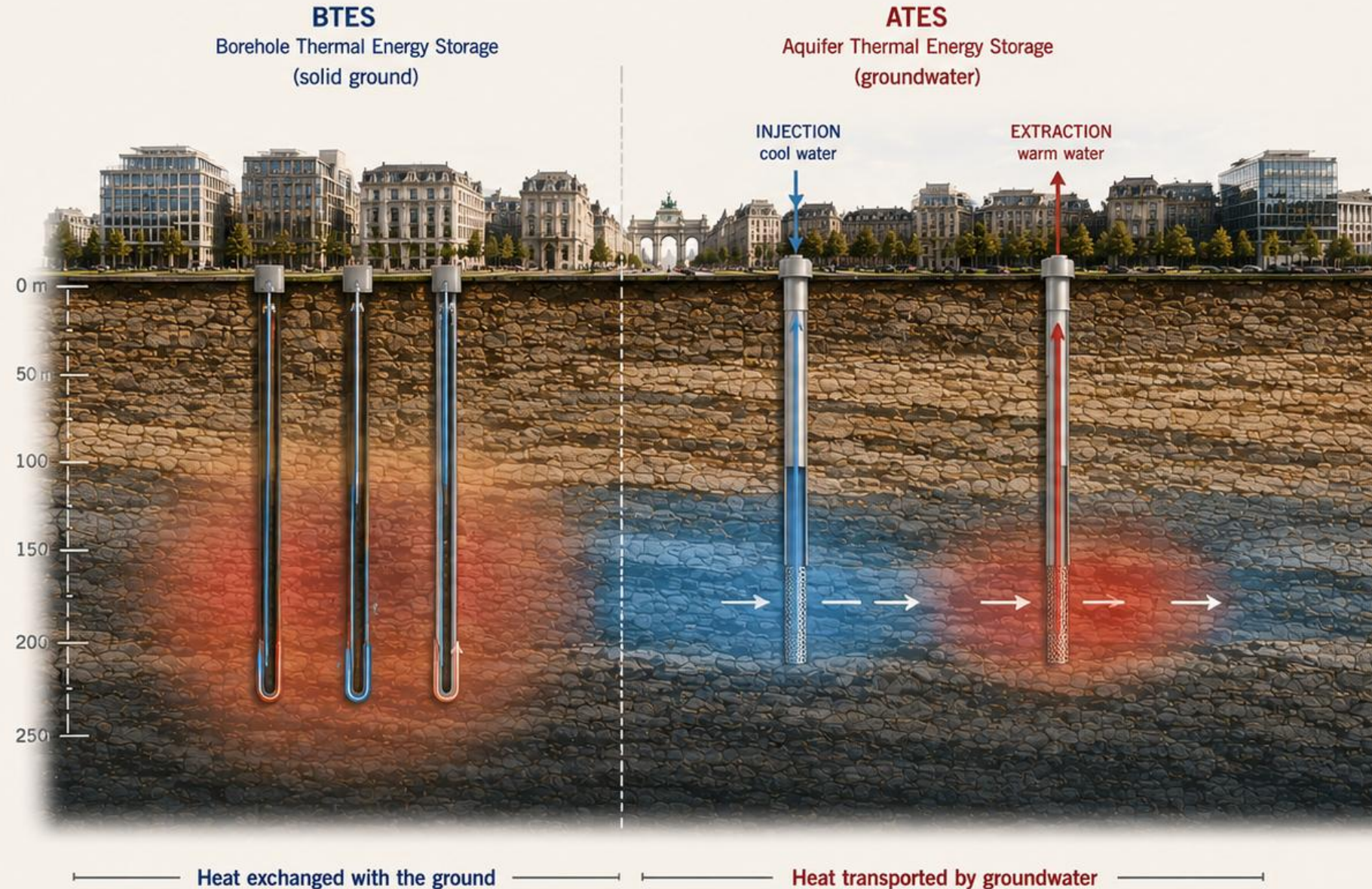


ATES

(Aquifer Thermal Energy Storage)

Heat transfer by pumping groundwater.

Two ways to access the same subsurface.
Different physics. Different implications.



The Heat Sink Changes the Machine

Lower sink temperature reduces condensing temperature, compressor lift and electricity demand.



Same machine:

35°C air vs **≈11–12°C ground/water**

AIR COOLED (SUMMER)

Hot outdoor air ≈ 35°C

Heat rejection
to hot air

≈ 45°C CONDENSING
TEMPERATURE

EVAPORATING
TEMPERATURE ≈ 7°C

COMPRESSOR
LIFT
≈ 38 K



RELATIVE ELECTRICITY DEMAND
≈ 100% (reference)



HIGHER LIFT → HIGHER POWER
Lower efficiency (COP)

WATER / GROUND COOLED

Ground or water ≈ 11–12°C

Heat rejection
to cool ground / water

≈ 20–22°C CONDENSING
TEMPERATURE

EVAPORATING
TEMPERATURE ≈ 7°C

COMPRESSOR
LIFT
≈ 13–15 K



RELATIVE ELECTRICITY DEMAND
≈ 60–65%



LOWER LIFT → LOWER POWER
Higher efficiency (COP)



Cooling from the ground reduces compressor lift and can cut electricity demand by ~35–40%.

Brussels Does Not Have One Ground Temperature

Geothermal feasibility and performance are site-specific.

THE WRONG ASSUMPTION

“Brussels ground = one temperature”

THE REALITY

Temperature varies from site to site.

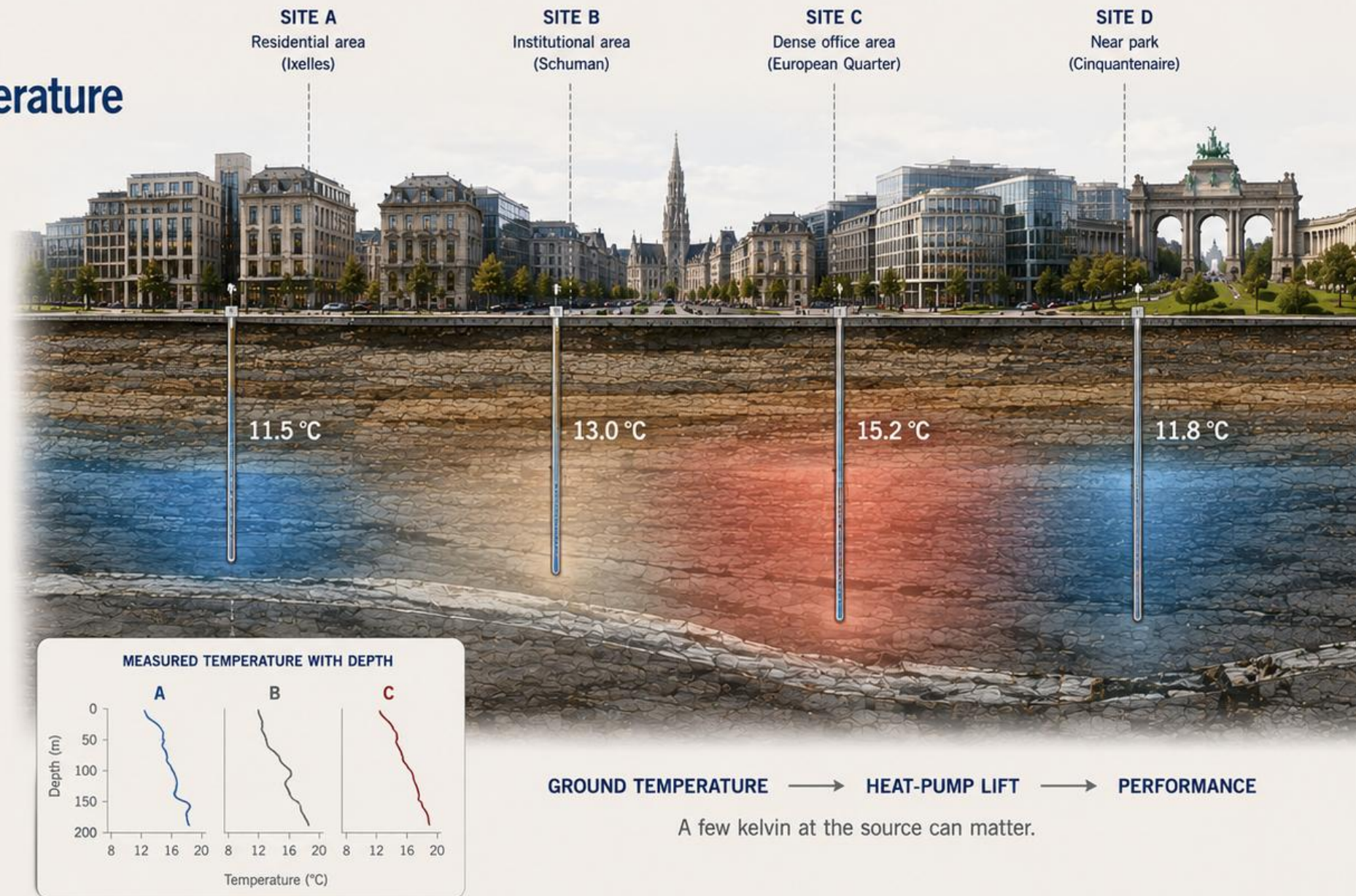
That changes geothermal performance.

There is no single “Brussels ground temperature.”

Local conditions determine the thermal starting point.



Measure the site, not the city average.



The City Has Already Changed the Ground

Urbanization modifies subsurface thermal conditions before geothermal systems are even installed.

WE SEE THE CITY ABOVE GROUND.

But the city also extends thermally below it.

Decades of urbanization leave a subsurface temperature footprint.

The urban heat island does not stop at the pavement.

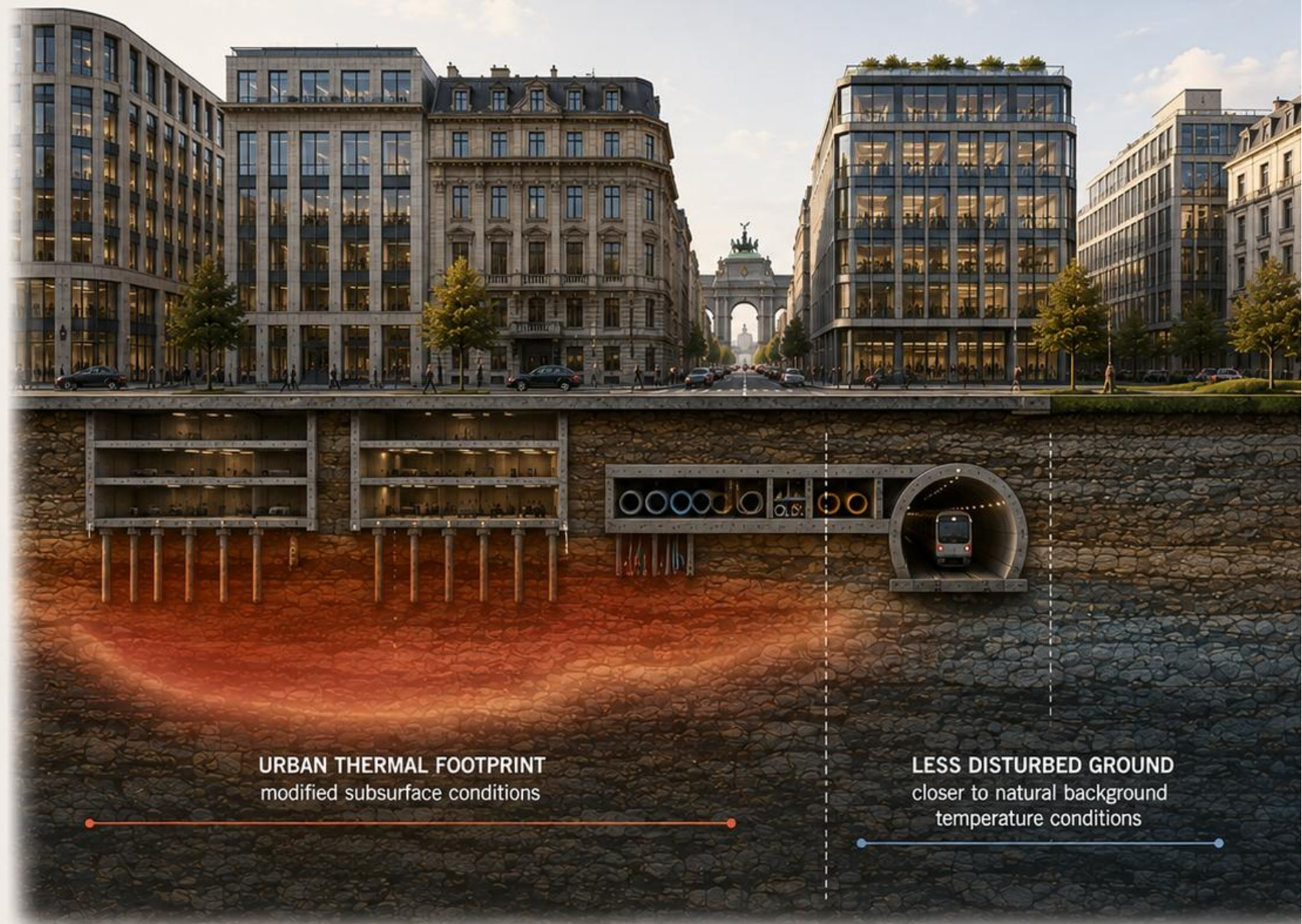
The subsurface also carries a thermal footprint.

INITIAL GROUND TEMPERATURE IS A SITE CONDITION

Urban geothermal design inherits the thermal history of the site.



Urban form changes both cooling demand above ground and thermal conditions below it.



Dense Cities Have Limited Ground to Share

Geothermal potential is constrained by parcels, infrastructure, geometry, and neighboring systems.

ABOVE GROUND

Every square meter has an owner.

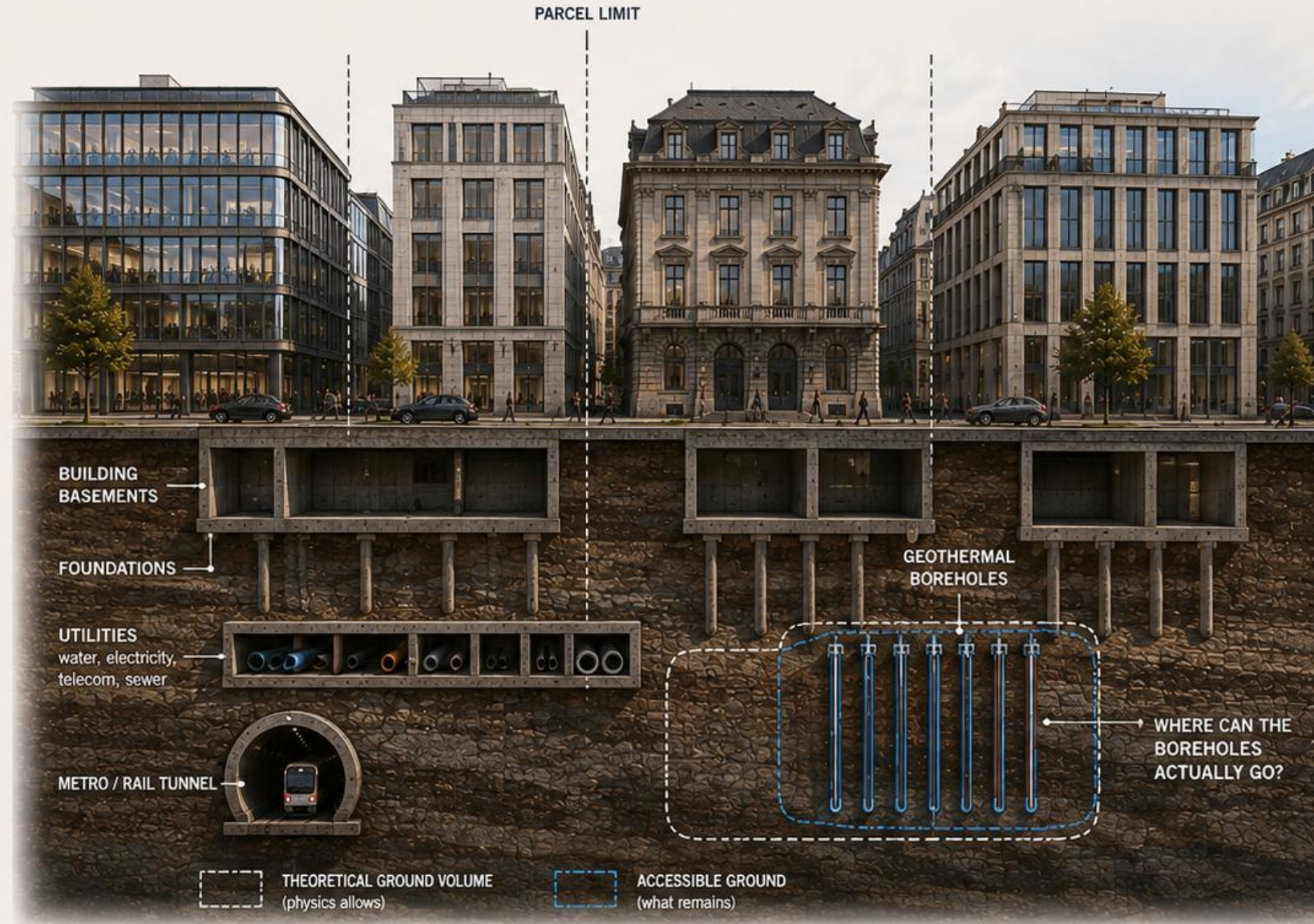
BELOW GROUND

Every meter already has competition.

Geothermal design must fit into what remains.

Geology is continuous.
Access is fragmented.

THE CONSTRAINT IS NOT ONLY HOW MUCH GROUND EXISTS.
It is how much ground can actually be accessed.



EUROPEAN QUARTER

Dense parcels + deep basements + underground infrastructure + limited open ground.

The Ground Does Not Respect Property Lines

In dense districts, neighboring geothermal systems can become thermally coupled.

ABOVE GROUND

Mine. Yours.

BELOW GROUND

The heat spreads.

Thermal influence extends beyond the parcel boundary.

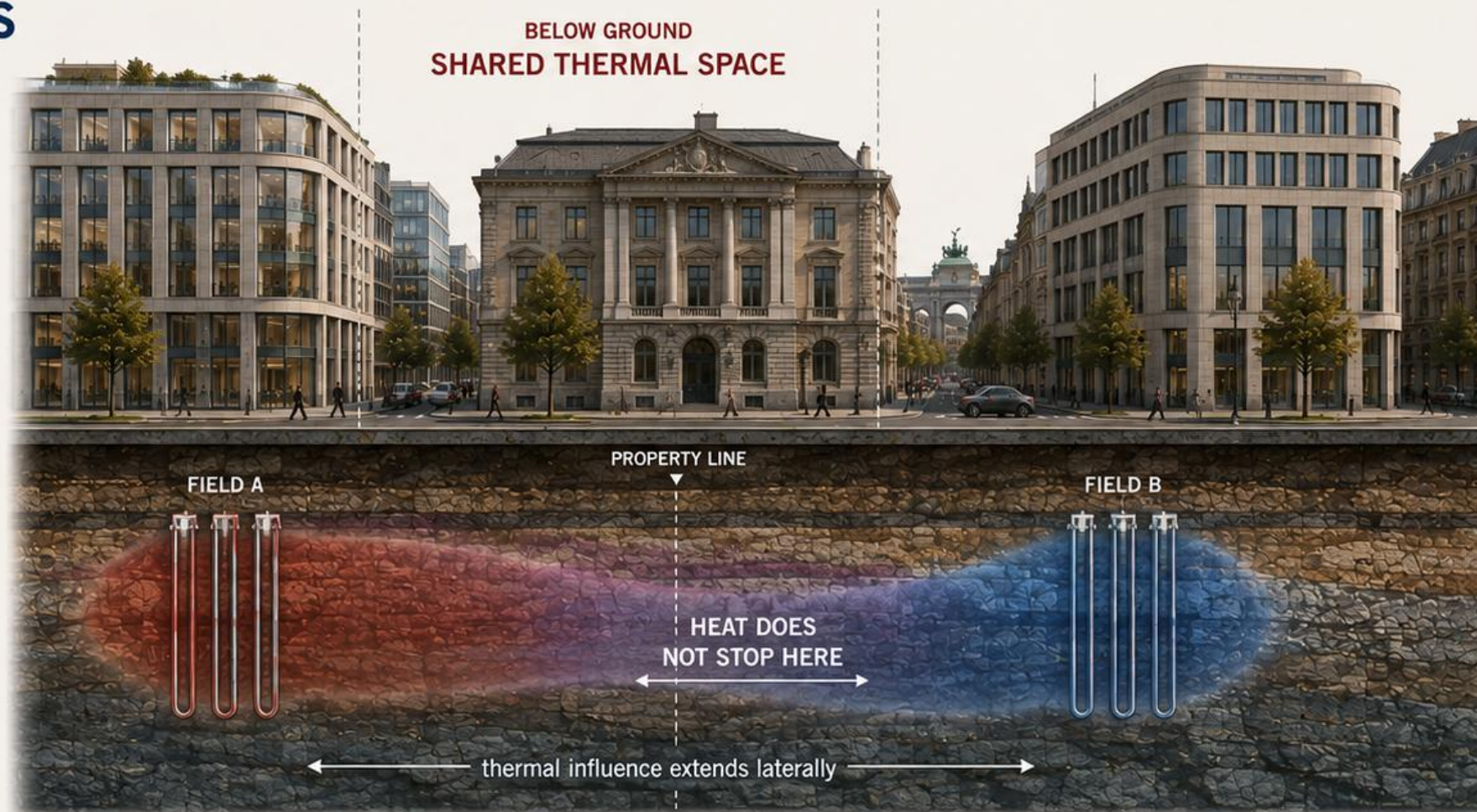
Your boreholes can change my source temperature.

Interference can help or hurt, depending on load balance and spacing.

ABOVE GROUND
SEPARATE BUILDINGS

but

BELOW GROUND
SHARED THERMAL SPACE



Interaction is inevitable.
Its value depends on coordination.



Direct exchange requires
simultaneous useful loads.

REAL BRUSSELS OPPORTUNITY

GeoCamb investigated whether surplus heat from PHS could serve sections of neighboring RBINS.¹

¹ Brussels / GeoCamb case material | PHS-RBINS investigations.

What If This Building Could Heat Its Neighbor?

Cooling creates surplus heat.
Urban proximity can turn it into useful supply.

Cooling here.
Heating there.

Why reject the heat?

ILLUSTRATIVE SIMULTANEOUS LOAD

100 kW → **100 kW**
surplus heat useful heat

*Conceptual balanced-load example,
not measured PHS-RBINS operation*

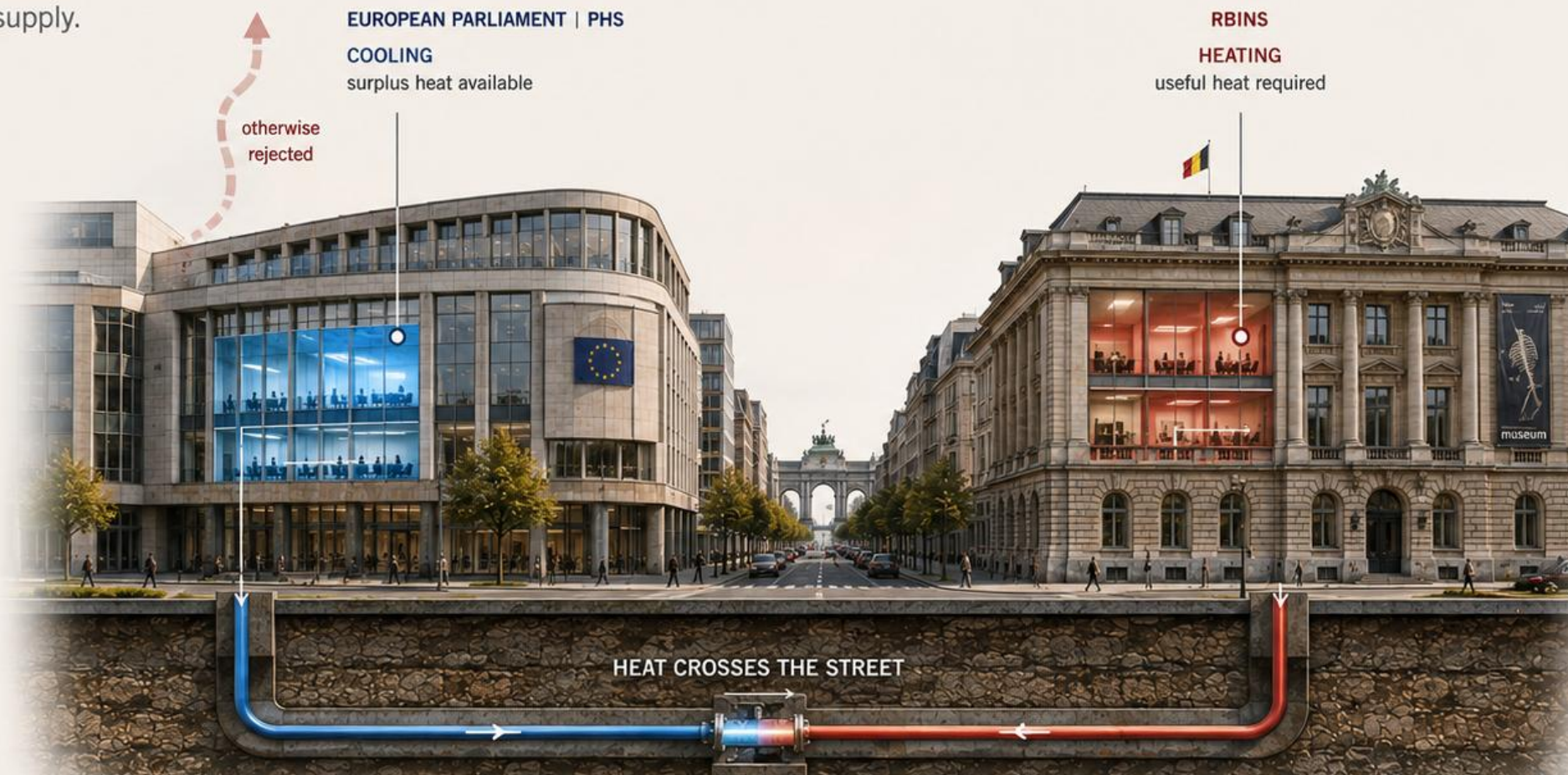
⌚ Direct exchange requires
simultaneous useful loads.

REAL BRUSSELS OPPORTUNITY

GeoCamb investigated whether surplus heat from PHS could serve sections of neighboring RBINS.¹

The heat did not change.
Its destination did.

A cooling load can become another building's heating source.



¹ Brussels / GeoCamb case material | PHS-RBINS investigations.

5GDHC Trades Compressor Work for Pumping Work

Moving heat requires pumping, but the hydraulic penalty can be much smaller than the compressor work avoided.

HEAT-PUMP ELECTRICITY

10.4 → 6.2 kWh/m²·a

versus

CIRCULATION PUMPS

0.16 → 0.30 kWh/m²·a

−4.2 kWh/m²·a

+0.14 kWh/m²·a

therefore $\approx 30 : 1$
compressor saving : pumping penalty

COMPRESSOR SAVING

4.2

PUMPING PENALTY

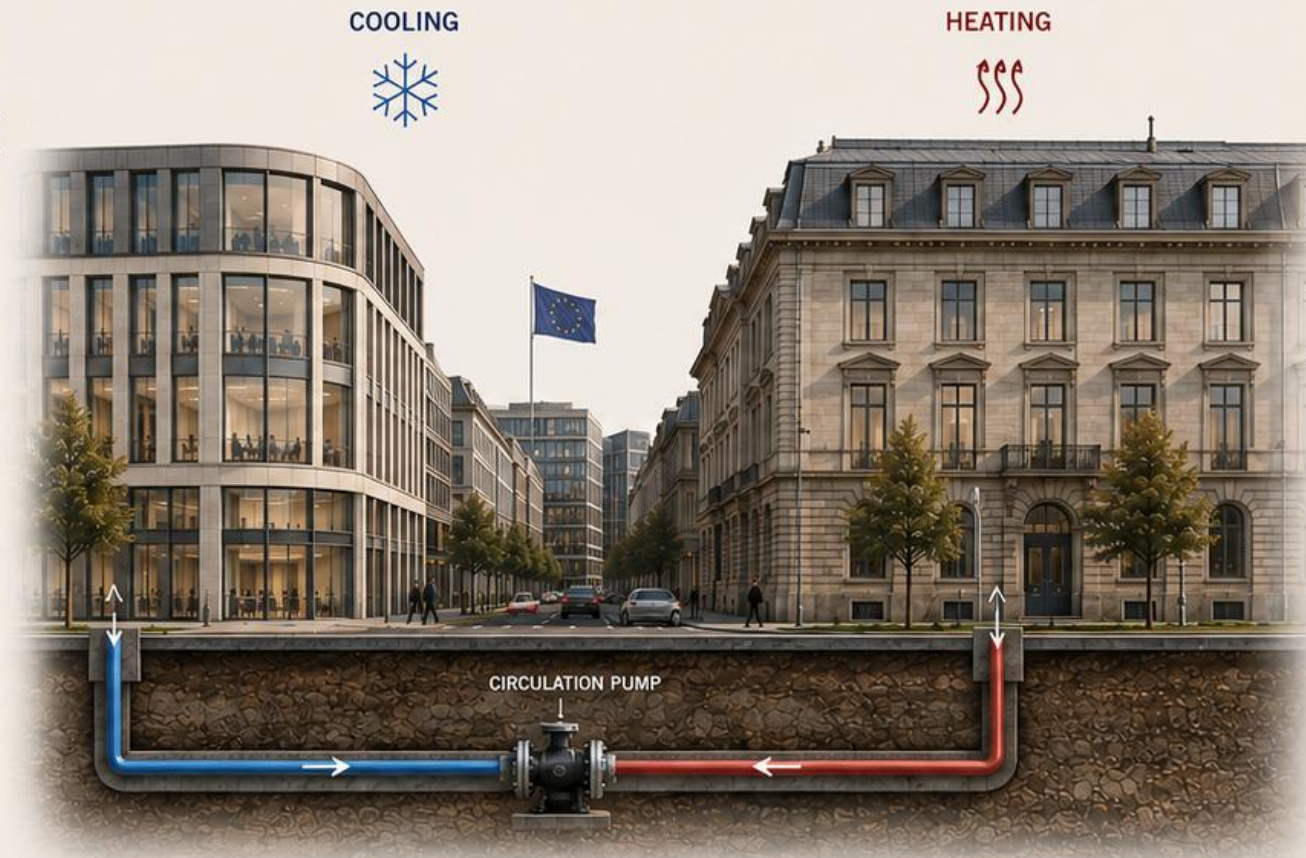
0.14

$\approx 30 \times$

Case comparison: heat-pump electricity 10.4 → 6.2 kWh/m²·a;
circulation electricity 0.16 → 0.30 kWh/m²·a.

Illustrative case result

¹ Brussels / GeoCamb case material | Commerce 46, Isala and PHS-RBINS investigations.



Moving heat is not free.
But neither is rejecting it.

The relevant comparison is
pumping work versus avoided compressor work.



NETWORK DESIGN STILL MATTERS.
Pumping depends on flow, pressure loss,
distance, and pipe sizing.

The European Quarter Already Has the Pieces

The opportunity is not one better building,
but better coordination between buildings

The pieces already exist.
They do not yet act as
one thermal system.



INDIVIDUAL

building optimizes itself



COORDINATED

heat finds the best
nearby destination



DENSITY IS A CONSTRAINT

little space for individual
heat rejection and geothermal fields



DENSITY IS ALSO AN OPPORTUNITY

many thermal loads
within short distance



Density limits space.
Density creates neighbors.

Sometimes the Most Important Component Is the Setpoint

FREE-COOLING CUTOFF

14°C → **16°C**
+2 K

ANNUAL FREE COOLING

10 → **57 MWh**

5.7×
more free cooling

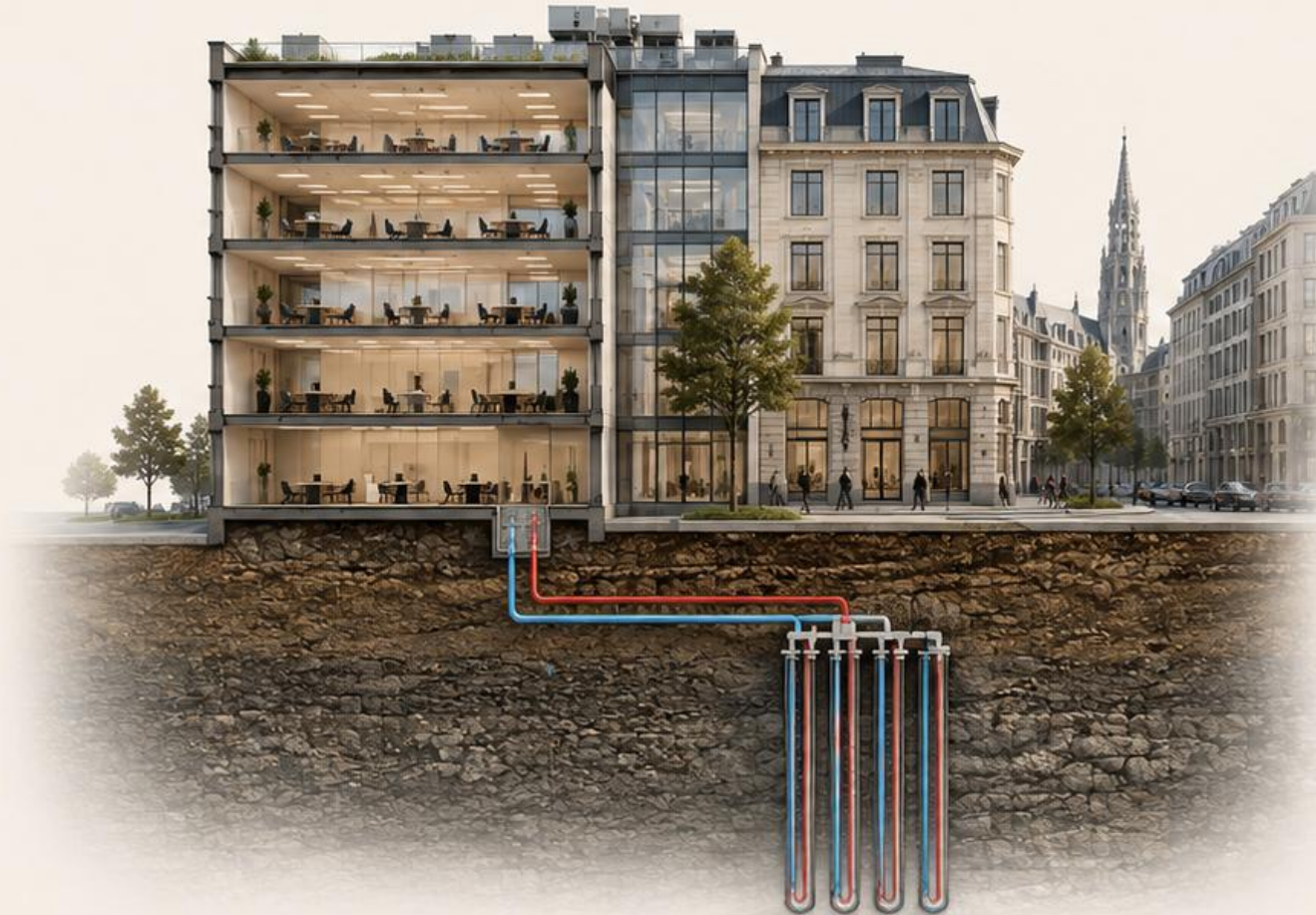
Observed case result | 2021 → 2022

The geology did not change.
The control logic did.

Available capacity is useless
if control does not allow you to use it.

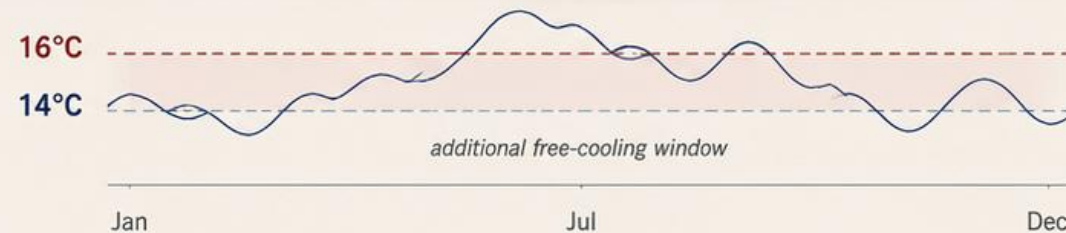
Control begins before summer.

Winter extraction can influence the next cooling season.¹



same building
same boreholes
same geology

different control



¹ GeoCamb | monitored Brussels free-geocooling operation, 2021–2022, Figures 26–27.

The Ground Remembers

Seasonal balance today shapes free cooling capacity tomorrow — and for years to come.

KEY LEARNINGS



Seasonal balance matters

Summer heat injection and winter extraction determine the ground's thermal state.



More extraction can help free cooling

Higher winter extraction → colder spring ground → longer and deeper summer free cooling.



Imbalance creates long-term drift

Persistent surplus or deficit accumulates and shifts ground temperatures over years.



The ground stores time, not just energy

It is a temporal buffer connecting seasons and even years.



Control is the key differentiator

Setpoints, operation and coordination unlock the real potential of the resource.

SEASONAL CYCLE



COUNTERINTUITIVE INSIGHT

More winter extraction can lead to colder spring ground temperatures and therefore longer and more effective summer free cooling.

ANNUAL BALANCE AND LONG-TERM IMPACT

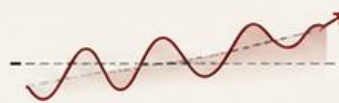
BALANCED OPERATION

Injection ≈ extraction
→ stable ground temperature



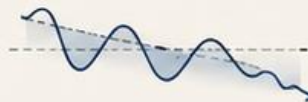
NET INJECTION EXCESS

More injected than extracted
→ ground warms over years



NET EXTRACTION EXCESS

More extracted than injected
→ ground cools over years



IMPACT HORIZON

🕒	Daily	Hours
🌿	Seasonal	Months
📅	Interannual	Years
∞	Long-term	Decades



The Next Control Boundary Is Larger Than the Building

The same equipment can perform differently when heat destinations are coordinated

What if the controlled variable is not only room temperature...

...but the destination of every thermal kilowatt?



Local control asks:
How should this machine operate?



District coordination asks:
Where should this heat go?



SPACE
neighboring loads

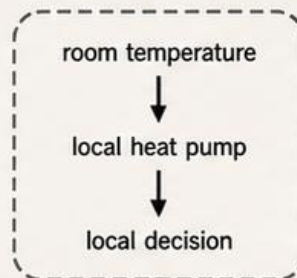


TIME
seasonal storage



STATE
ground temperature

BUILDING CONTROL



DISTRICT CONTROL

sees more opportunities



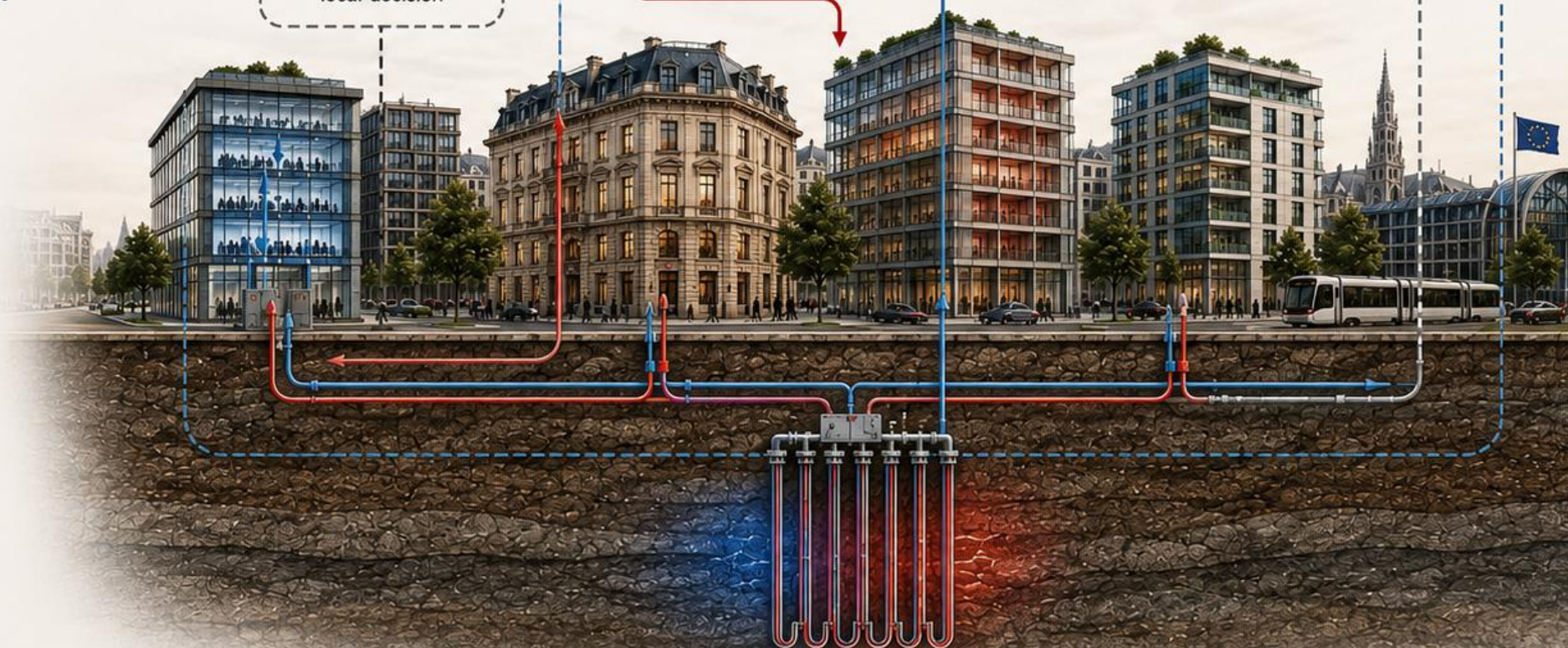
OPPORTUNITY 1
Surplus heat from one building can meet a neighbor's need



OPPORTUNITY 2
When no immediate use exists, store for later

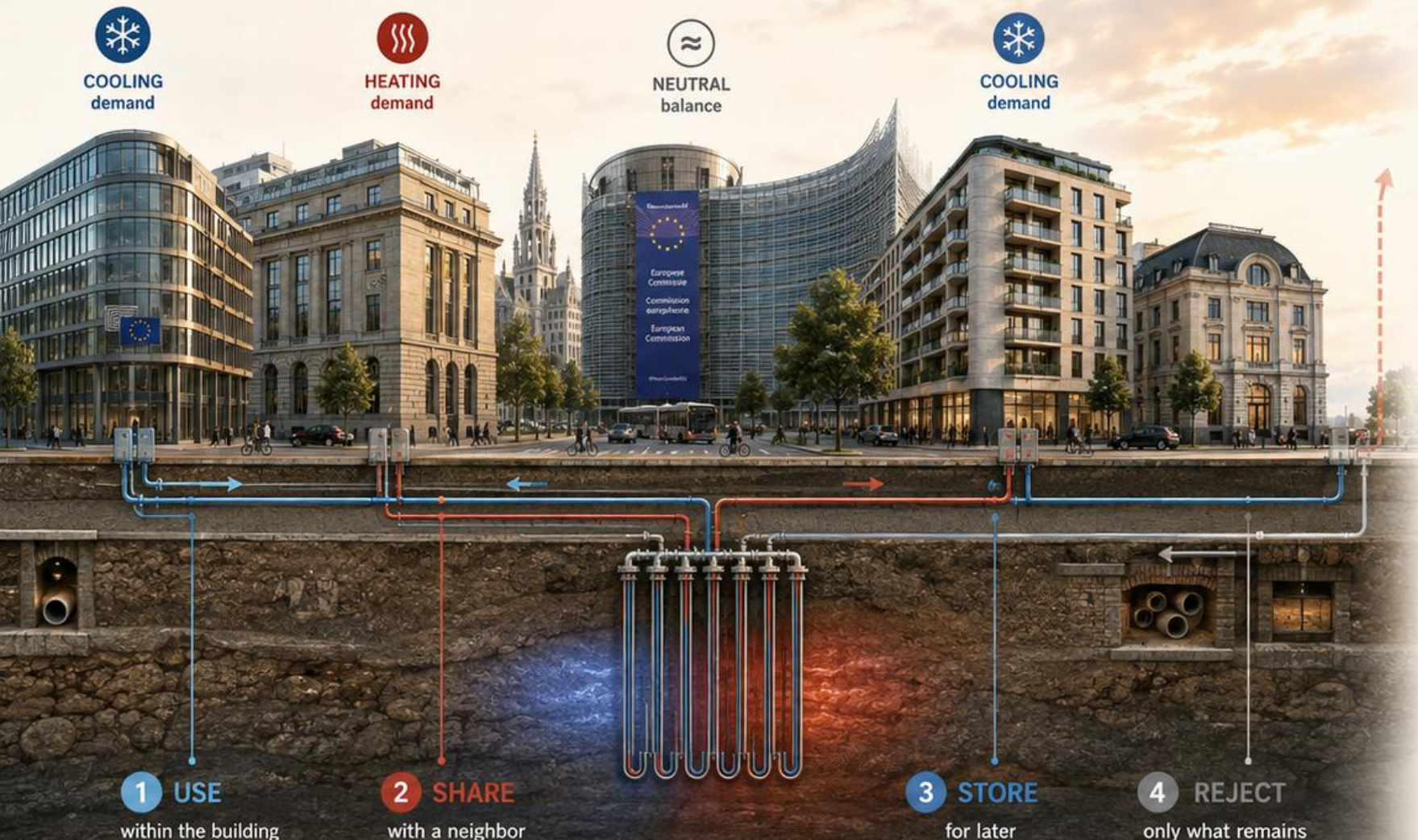


OPPORTUNITY 3
Only a small residual is rejected to the environment



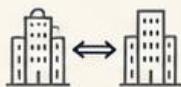
Cooling Is Urban Heat Management

The design question is no longer only how to cool a building, but *where* its heat should go.



USE
↓
SHARE
↓
STORE
↓
REJECT

Choose the highest-value destination available.

SPACE

share heat

TIME

store heat

LAST RESORT

reject heat

Density creates constraints, but also **thermal neighbors**.

CONTROL QUESTION

Where should the next thermal kilowatt go?



Better heat destinations → lower temperature lift → less compressor work

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Brussels Evidence Base

Evidence

The Brussels case combines documented urban-climate, geothermal, building and thermal-system evidence with a strategic interpretation of how these assets could support coordinated thermal infrastructure.

1. URBAN CLIMATE + HEAT STRESS

Evidence for Brussels urban heat, morphology, climate exposure and cooling demand

- Attia, S. (2026). *Zero Carbon Buildings Under Urban Heat Stress: How Urban Microclimate Redefines Decarbonization Pathways. Sixth International Conference on Urban Climate and Urban Design*, Xi'an. [hdl:2268/344693](#)
- Wyard, C. et al. (2018). Belgian radiation and cloudiness climatology. *Atmosphere*, 9, 262.
- perspective.brussels (2023). *Quartier Européen: Cahier de vision*. Vision partagée. Région de Bruxelles-Capitale.
- Bruxelles Environnement. *Brussels urban heat*, climate adaptation and regional environmental datasets.

3. DISTRICT THERMAL INTEGRATION

Evidence for 5GDHC, thermal sharing and coordinated heat-source / heat-sink strategies

- Koutra, S., Harcouët-Menou, V., Dupont, N., Kaufmann, O., Becue, V., & Attia, S. (2026). Feasibility of Fifth-Generation district heating and cooling using mine water in Belgium: A Multi-Site Techno-Economic assessment. *Sustainable Energy Technologies and Assessments*, 86, 104853. [DOI: 10.1016/j.seta.2026.104853](#)
- Buffa, S., Cozzini, M., D'Antoni, M., Baratieri, M., & Fedrizzi, R. (2019). A review on fifth-generation district heating and cooling systems. *Renewable and Sustainable Energy Reviews*, 104, 504–522. [DOI: 10.1016/j.rser.2018.12.042](#)
- Lund, H., Werner, S., Wiltshire, R., Svendsen, S., Thorsen, J.-E., Hvelplund, F., & Mathiesen, B.V. (2014). 4th Generation District Heating. *Energy*, 68, 1–11. [DOI: 10.1016/j.energy.2014.02.089](#)
- IEA EBC Annex 97. *Sustainable Cooling in Cities*.

2. BRUSSELS SUBSURFACE + GEOTHERMAL

Measured and operating evidence for geothermal heating, cooling and thermal storage

- De Paoli, C., Duren, T., Petitclerc, E., Agniel, M., & Dassargues, A. (2023). Modelling interactions between three Aquifer Thermal Energy Storage systems in Brussels (Belgium). *Applied Sciences*, 13, 2934. [DOI: 10.3390/app13052934](#)
- **GeoCamb**. Monitored Brussels geothermal case, 2017–2022.
- **Brussels Environment / Be.SHARE** (2026). *Forages tests et premiers résultats*. Parc Maximilien geothermal test: 150 m borehole | 11.1°C mean ground temperature | 2.4 W/m·K conductivity | Paleozoic bedrock 3.3 W/m·K.
- IFTech (2023). *Shallow Geothermal Energy: The Fourth Energy Transition*.
- Attia, S. (2023). *Underground Thermal Energy Storage for Carbon Neutral Communities. International Conference on Underground Space Environments*. [hdl:2268/309250](#)

4. HEAT-SINK + HEAT-PUMP PHYSICS

Evidence supporting the relationship between heat-sink temperature, temperature lift and cooling performance

- Yu, F. W., & Chan, K. T. (2006). The effects of outdoor temperature and rejection temperature on the performance of air-cooled chillers. *Building and Environment*, 41, 1723–1730. [DOI: 10.1016/j.buildenv.2005.07.014](#)
- NIST TN 2068r1 (2021). Laboratory Tests of a Prototype Carbon Dioxide Ground-Source Air Conditioner. [DOI: 10.6028/NIST.TN.2068r1](#)
- Attia, S. (2025). *Comparison of Zero Carbon Heating and Cooling Pathways in China and Europe. International Seminar on Low Carbon Buildings*, Southwest Jiaotong University. [hdl:2268/338881](#)