MORE IS GOOD;

HIGH THERMAL MASS BUILDINGS FOR CLIMATE CHANGE ADAPTATION AND MITIGATION STRATEGIES IN FRANCE

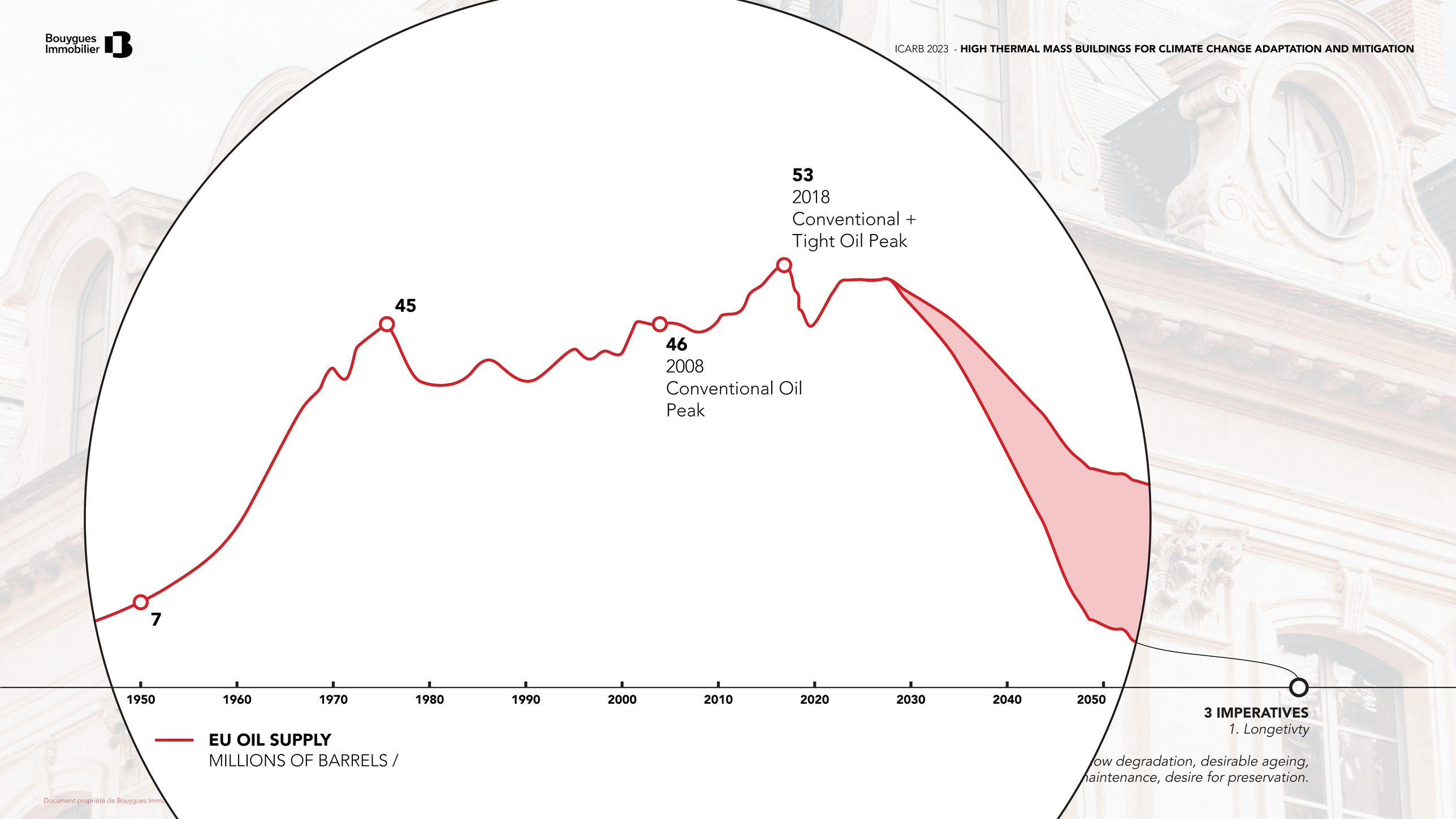
T. de TOLDI, Bouygues Immobilier SAS

3 CHALLENGES

1. LASTING LONGER

3 IMPERATIVES
1. Longevity

Slow degradation, desirable ageing,
possible and frugal maintenance, desire for preservation.



3 IMPERATIVES

1. Longetivty

ow degradation, desirable ageing,
aintenance, desire for preservation.

2. EMITTING LESS

Reducing the embodied impacts of construction materials

3 IMPERATIVES

2. Climate Mitigation

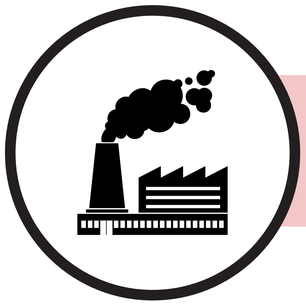
Reducing the material inventory (do more with less)
Selecting materials for their reduced embodied emissions

LCA STAGE B6
1.5 kg CO_2 eq./m²/yr.

OPERATION ENERGY USE

LCA STAGE A3
740 kg CO_2 eq./m²

MANUFACTURING OF CONSTRUCTION MATERIALS



OPERATIONAL

EMBODIED

5 10 15 20 25 30 35 40 45 50

YEARS AFTER CONSTRUCTION

LIFE CYCLE EMISSIONS

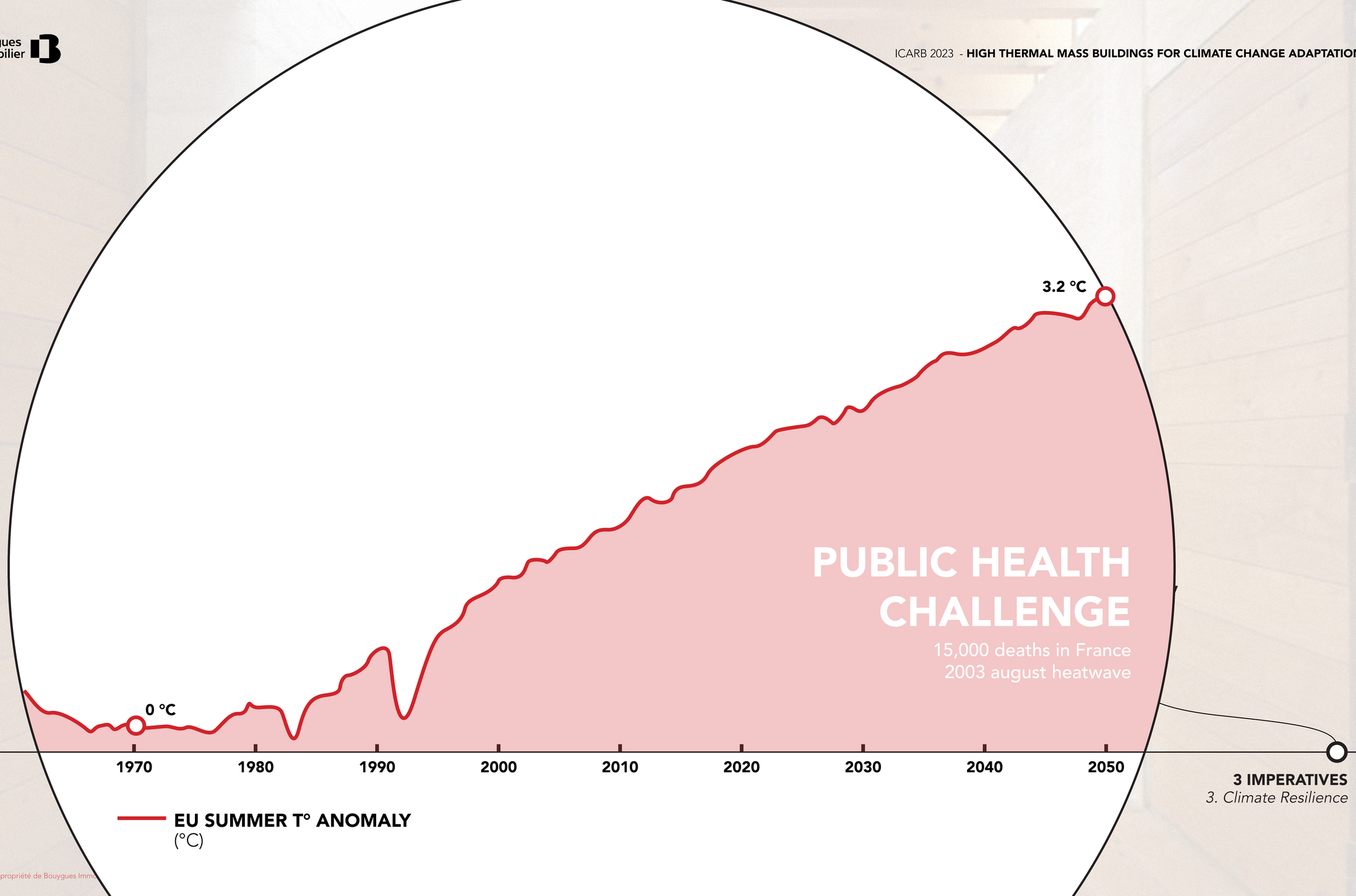
3 IMPERATIVES
2. Climate Mitigation

terial inventory (do more with less)
r their reduced embodied emissions

3.

COOLING PASSIVELY

Guaranteeing the comfort and safety of indoor environments in the context of a increasing frequency and magnitude of heat waves, and a projected rise in fuel scarcity



3 IMPERATIVES
3. Climate Resilience

MECHANICAL COOLING
(AC)

3.2 °C

PUBLIC HEALTH CHALLENGE

15,000 deaths in France
2003 august heatwave

2010 2020 2030 2040 2050

3 IMPERATIVES
3. Climate Resilience

MECHANICAL COOLING
(AC)

COUNTER-PRODUCTIVE
- Amplifies Urban Heat Island Effect
  (outside heat exhaust + GHG effect of refrigerant leakage)
- Escalating contribution to climate change
  (manufacturing and operational emissions,
  fastest growing electricity end-use)

3.2 °C

PUBLIC HEALTH CHALLENGE

15,000 deaths in France
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3 IMPERATIVES
3. Climate Resilience

MECHANICAL COOLING
(AC)

- **COUNTER-PRODUCTIVE**
- **SOCIALLY UNFAIR**

High economic disparities + high mechanical equipment prices and increasingly volatile electricity prices = social imbalances in both the access and utilization of the equipment (e.g., 37% of upper-income households own an AC system, twice as many as among unemployed households);

3.2 °C

PUBLIC HEALTH CHALLENGE

15,000 deaths in France
2003 august heatwave

2010 2020 2030 2040 2050

3 IMPERATIVES
3. Climate Resilience

MECHANICAL COOLING
(AC)

- **COUNTER-PRODUCTIVE**
- **SOCIALLY UNFAIR**
- **UNRELIABLE**

Heatwaves = drought + high-pressure compound events, leading to reduced water flow rates in heated river systems and limited wind availability, thereby posing constraints on nuclear power production (thermal discharges and cooling circuit limitations), wind power production (very low wind load factor), and hydro-electric production (depleted reservoirs).

3.2 °C

PUBLIC HEALTH CHALLENGE

15,000 deaths in France
2003 august heatwave

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3 IMPERATIVES
3. Climate Resilience

COOLING PASSIVELY

What you aim for when
you can't mechanically
cool a space
(which requires fossil fuels)

LASTING LONGER

What you aim for when
you can't rebuild every 50 years
(which requires fossil fuels)

EMITTING LESS

Which is a given
when you can't use fossil fuels to
manufacture materials

COOLING PASSIVELY

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LINKED TO HOW WE BUILT TO WITHSTAND HOT CLIMATES, BEFORE FOSSIL FUELS WERE AROUND

3 IMPERATIVES
1 ANSWER?

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LINKED TO HOW WE BUILT TO WITHSTAND HOT CLIMATES, BEFORE FOSSIL FUELS WERE AROUND

HIGH THERMAL MASS BUILDINGS
BUILT WITH NATURAL (NON-TRANSFORMED) GEOSOURCED MATERIALS

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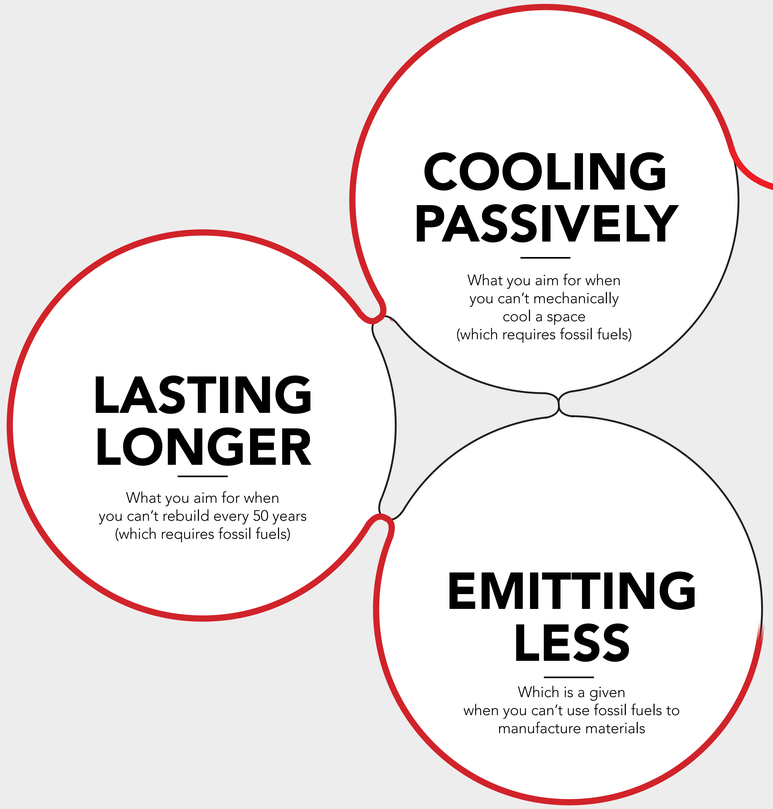

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INDUSTRIAL ECOLOGY ROADMAPS

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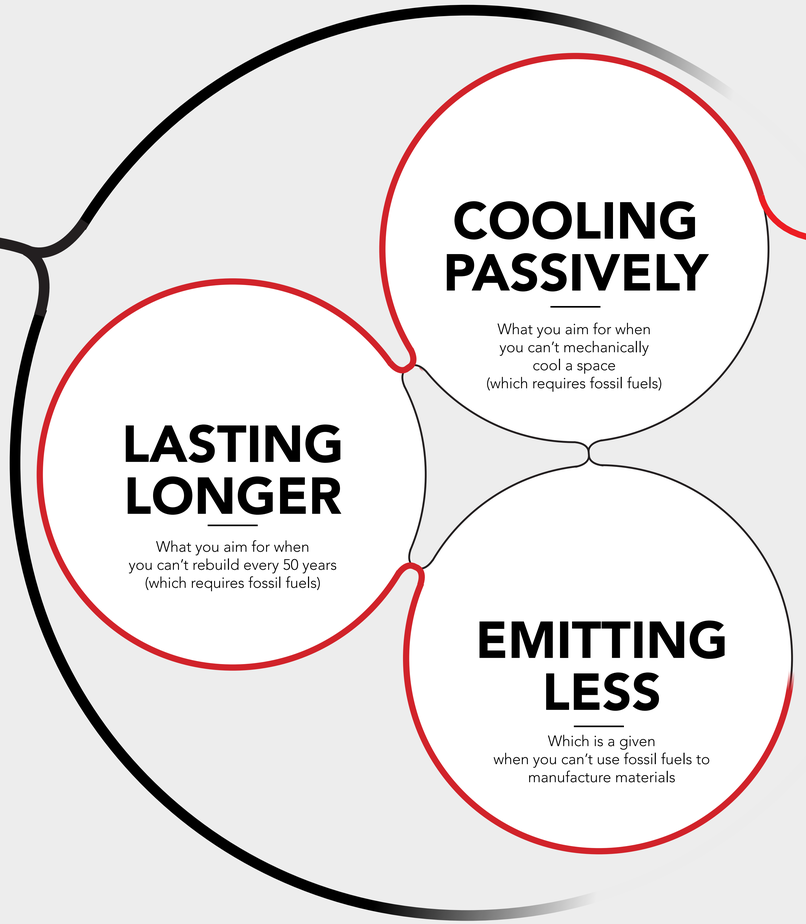
  (structuring industrial supply chains, updating thermal and construction codes, etc. for swift implementation on a large scale)



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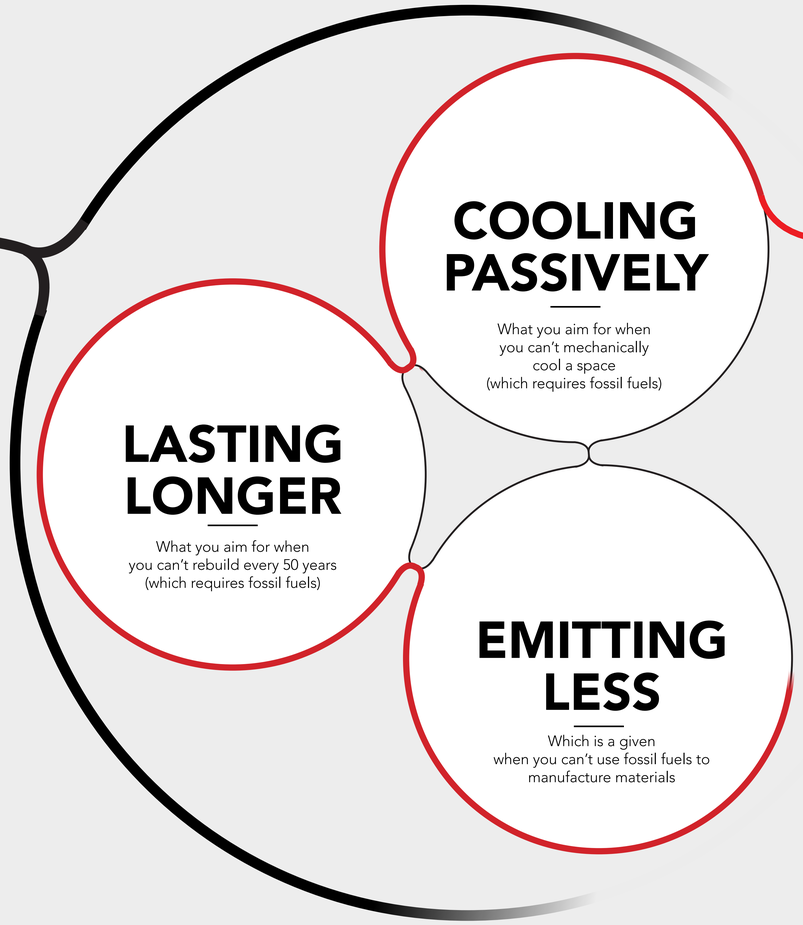

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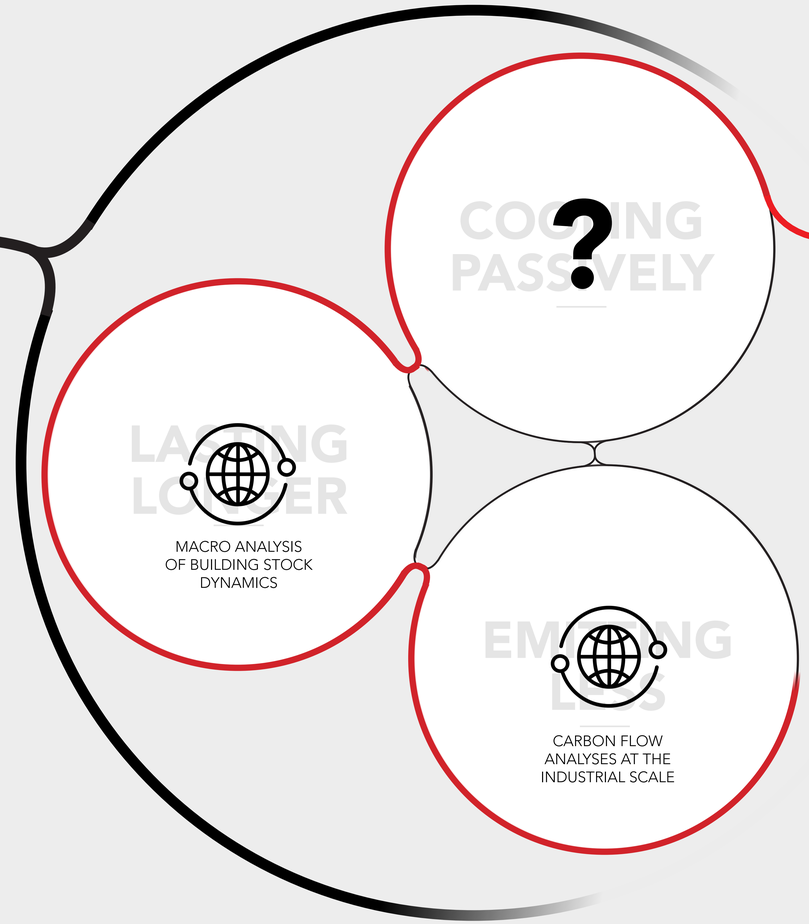

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WHAT

IS A QUANTITATIVE ANALYSIS OF
THE APPLICABILITY OF PASSIVE
COOLING MEASURES
AT THE MACRO-SCALE ?

WHAT

IS A QUANTITATIVE ANALYSIS OF
THE APPLICABILITY OF PASSIVE
COOLING MEASURES
AT THE MACRO-SCALE ?

COOLING
PASSIVELY ?

OPERATE
(THERMAL COMFORT & SAFETY)
WITHOUT FOSSIL FUELS

TO WHAT **EXTENT** CAN **PASSIVE COOLING TECHNIQUES MEET** THE **TEMPERATURE DEMAND** FOR **COMFORT / SAFETY** IN **CURRENT** AND **FUTURE CLIMATES**, AT THE **NATIONAL LEVEL** ?

WHY

IS IT CURRENTLY MISSING ?

RESILIENCE MACRO-SCALE QUANTITATIVE ANALYSIS
THE CONTRIBUTION OF THIS STUDY

WHY

IS IT CURRENTLY MISSING ?

PASSIVE COOLING PERFORMANCE ANALYSIS UNDER SPECIFIC CLIMATE

WHY

IS IT CURRENTLY MISSING ?

PASSIVE COOLING PERFORMANCE ANALYSIS UNDER SPECIFIC CLIMATE

- CURRENT CLIMATES

WHY

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PASSIVE COOLING PERFORMANCE ANALYSIS UNDER SPECIFIC CLIMATE

CURRENT CLIMATES

1.
BUILDING MODEL

WHY

IS IT CURRENTLY MISSING ?

PASSIVE COOLING PERFORMANCE ANALYSIS UNDER SPECIFIC CLIMATE

CURRENT CLIMATES

1.
BUILDING MODEL

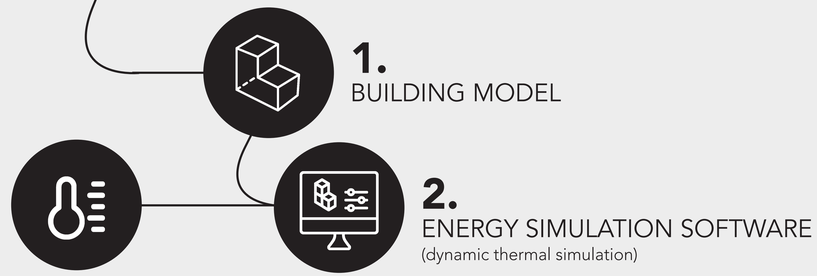
2.
ENERGY SIMULATION SOFTWARE
(dynamic thermal simulation)

WHY

IS IT CURRENTLY MISSING ?

PASSIVE COOLING PERFORMANCE ANALYSIS UNDER SPECIFIC CLIMATE

CURRENT CLIMATES



1.
BUILDING MODEL

2.
ENERGY SIMULATION SOFTWARE
(dynamic thermal simulation)

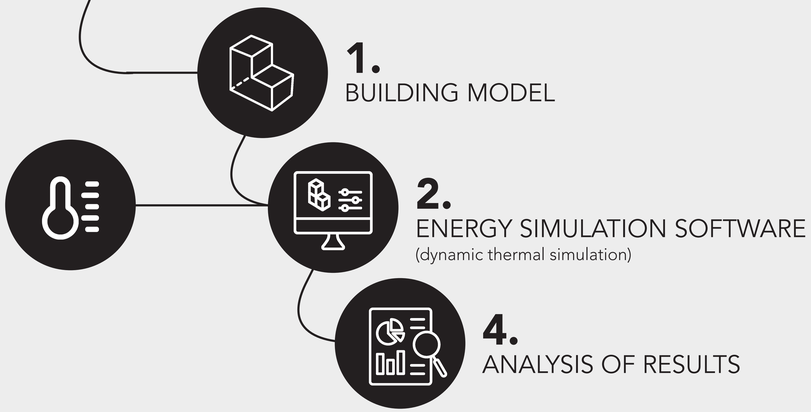
3.
CLIMATE DATA FOR SPECIFIC LOCATION
(Historical data, high temporal resolution, hourly)

WHY

IS IT CURRENTLY MISSING ?

PASSIVE COOLING PERFORMANCE ANALYSIS UNDER SPECIFIC CLIMATE

CURRENT CLIMATES



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4.
ANALYSIS OF RESULTS

WHY

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PASSIVE COOLING PERFORMANCE ANALYSIS UNDER SPECIFIC CLIMATE

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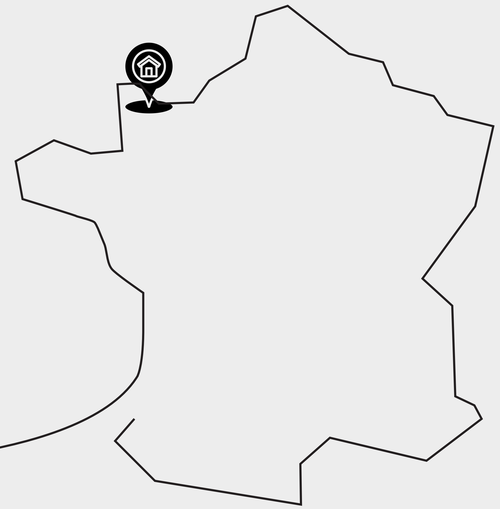

WHY

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PASSIVE COOLING PERFORMANCE ANALYSIS UNDER SPECIFIC CLIMATE

- CURRENT CLIMATES (MACRO-SCALE)

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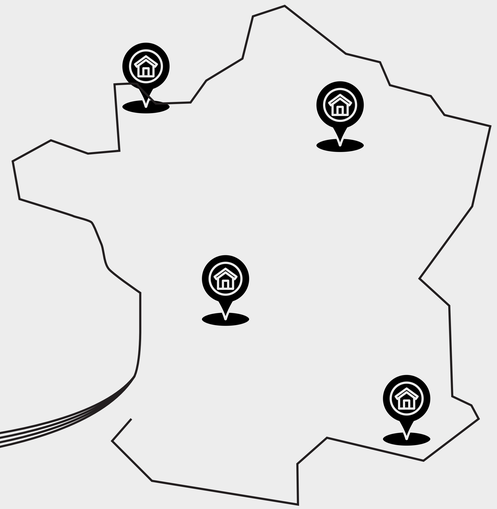

CURRENT FRAMEWORK FOR MACRO-SCALE ANALYSIS
CURRENT CLIMATES: DOMINANT METHODOLOGY

WHY

IS IT CURRENTLY MISSING ?

PASSIVE COOLING PERFORMANCE ANALYSIS UNDER SPECIFIC CLIMATE

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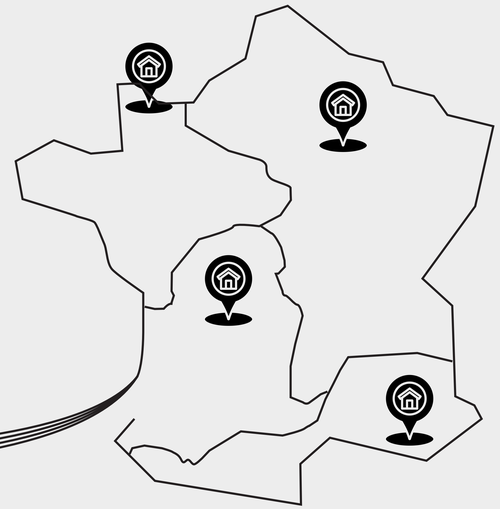

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WHY

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PASSIVE COOLING PERFORMANCE ANALYSIS UNDER SPECIFIC CLIMATE

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- FUTURE CLIMATES (MACRO-SCALE)

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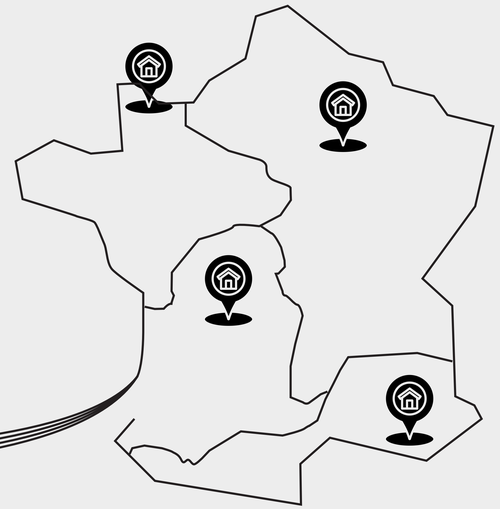

CURRENT FRAMEWORK FOR MACRO-SCALE ANALYSIS
FUTURE CLIMATES: ADAPTATION OF DOMINANT METHODOLOGY

WHY

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PASSIVE COOLING PERFORMANCE ANALYSIS UNDER SPECIFIC CLIMATE

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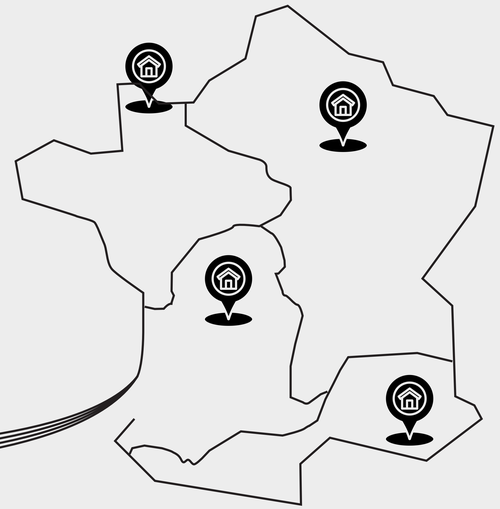

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- CURRENT CLIMATES (MACRO-SCALE)
- FUTURE CLIMATES (MACRO-SCALE)

3bis.
GCM / RCM DATA
EXTRACTION & CONVERSION

1.
BUILDING MODEL

3.
CLIMATE DATA FOR SPECIFIC LOCATION
(Historical data, high temporal resolution, hourly)

2.
ENERGY SIMULATION SOFTWARE
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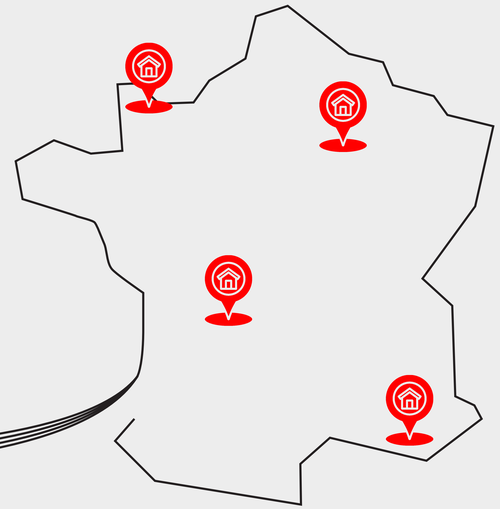
4.
ANALYSIS OF RESULTS
(Building and location specific)



CURRENT FRAMEWORK FOR MACRO-SCALE ANALYSIS
FUTURE CLIMATES: ADAPTATION OF DOMINANT METHODOLOGY

LIMITS?

TO THE EFFICIENCY OF SUCH A METHOD

FUTURE CLIMATES (MACRO-SCALE)

3bis.
GCM / RCM DATA
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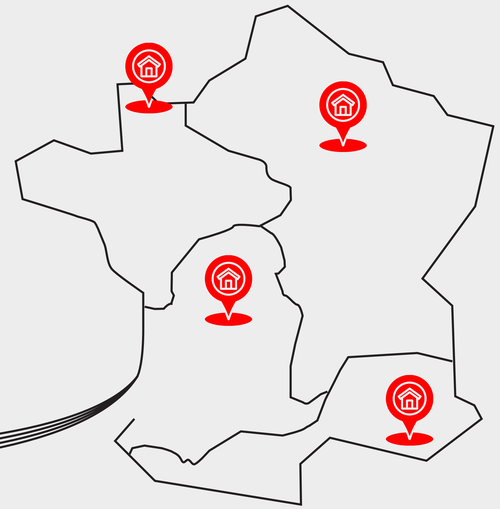

LIMITS?

TO THE EFFICIENCY OF SUCH A METHOD

EXTREMELY TIME AND
COMPUTING INTENSIVE

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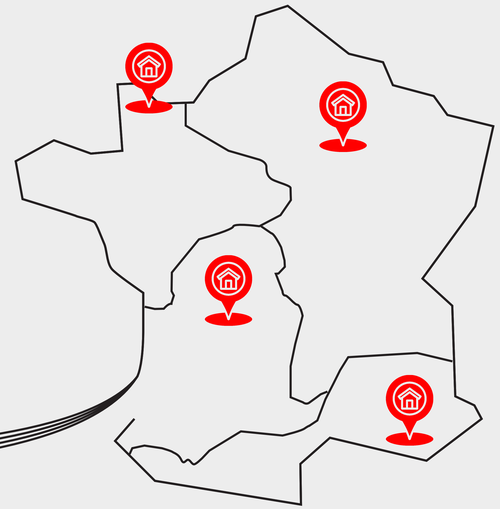

CURRENT FRAMEWORK FOR MACRO-SCALE ANALYSIS
LIMITS OF CURRENT PRACTICES

LIMITS?

TO THE EFFICIENCY OF SUCH A METHOD

- EXTREMELY TIME AND COMPUTING INTENSIVE
- DOESN'T HARNESS FULL POTENTIAL OF GCMs & RCMs

3bis. GCM / RCM DATA EXTRACTION & CONVERSION

1. BUILDING MODEL

3. CLIMATE DATA FOR SPECIFIC LOCATION
(Historical data, high temporal resolution, hourly)

2. ENERGY SIMULATION SOFTWARE
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4. ANALYSIS OF RESULTS
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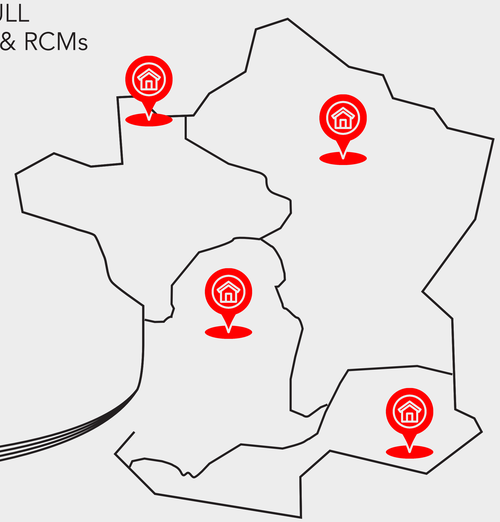

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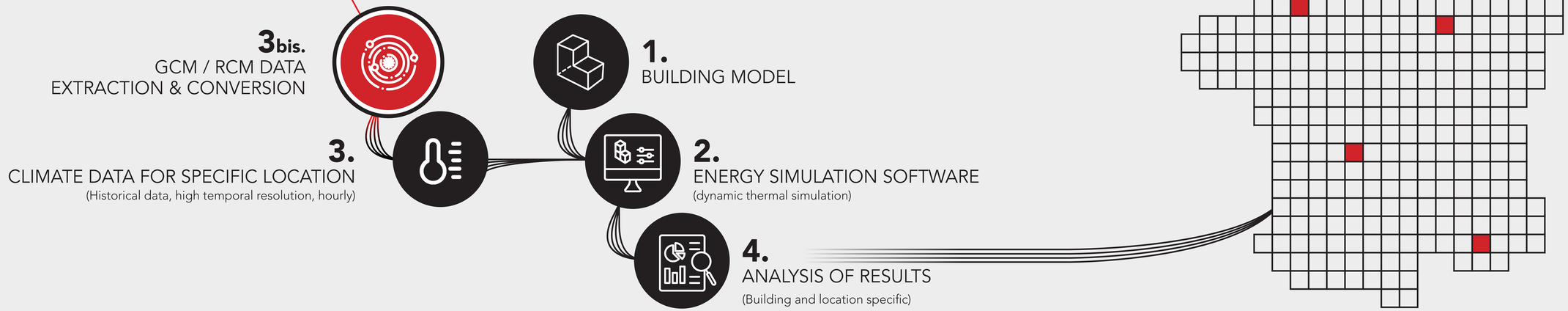

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- EXTREMELY TIME AND COMPUTING INTENSIVE
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3bis.
GCM / RCM DATA
(Median models for strategic foresight vs. Specific models absolute projections)

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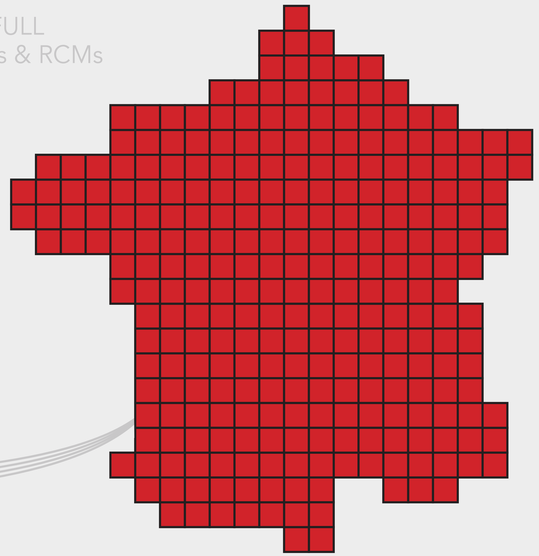
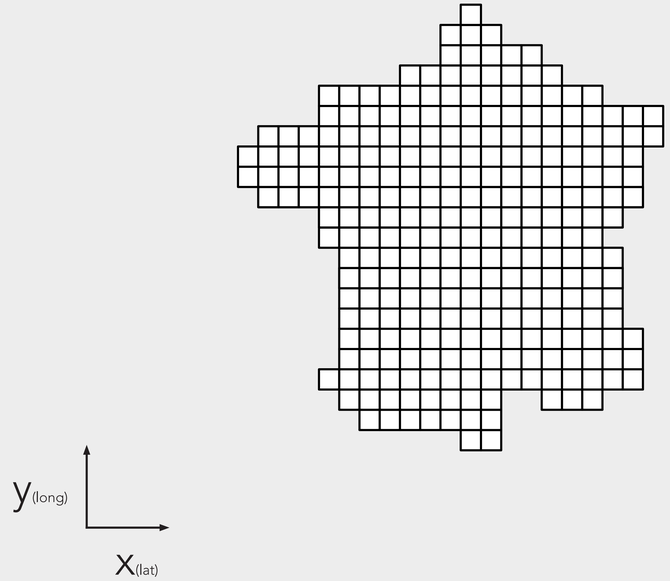
ANALYSIS OF RESULTS
(Building and location specific)



CURRENT FRAMEWORK FOR MACRO-SCALE ANALYSIS
LIMITS OF CURRENT PRACTICES

METHOD



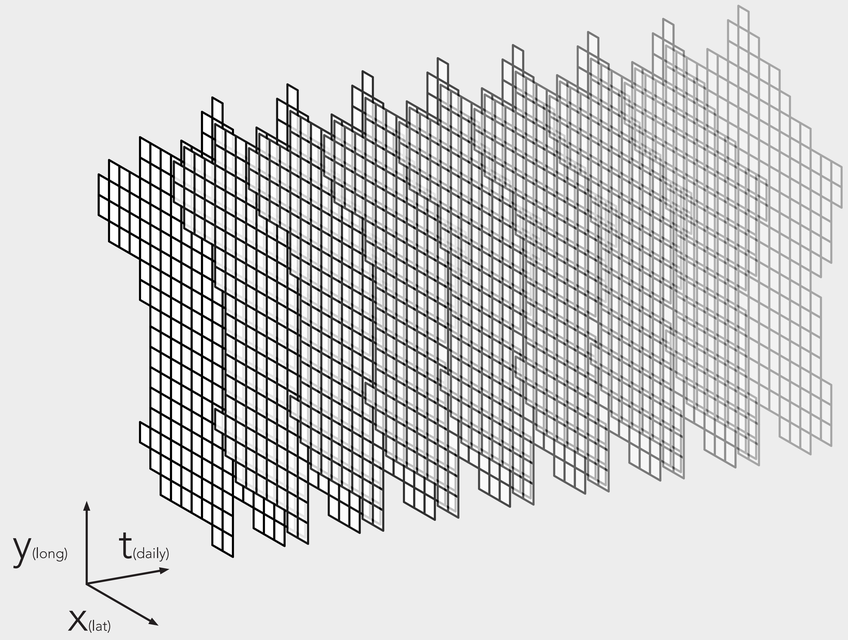
METHOD

RCM DATA

Coordinated Regional Climate Downscaling Experiment (CORDEX)

Gridded Data (3 dimensional matrixes)

NB: Coarse resolution for illustration purposes



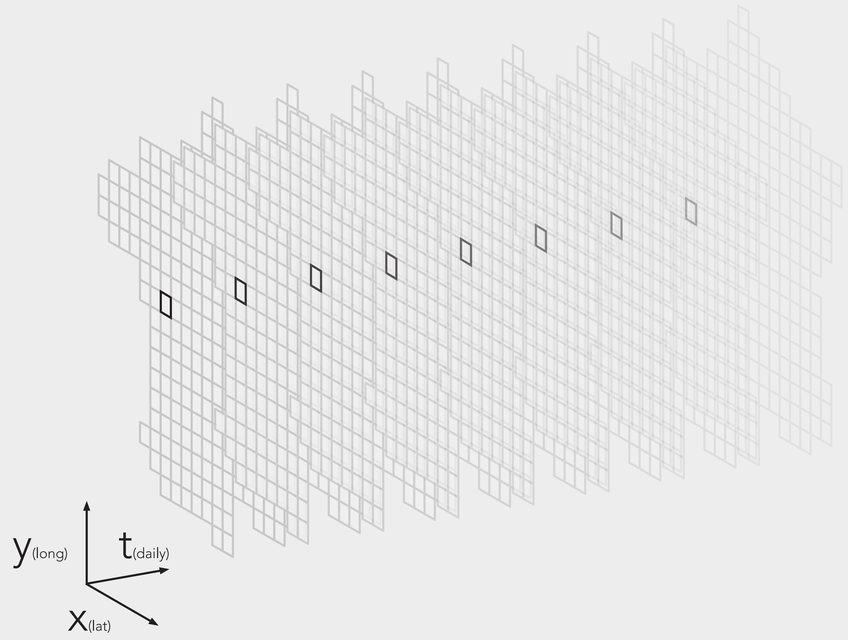
METHOD

RCM DATA

Coordinated Regional Climate Downscaling Experiment (CORDEX)

Gridded Data (3 dimensional matrixes)

NB: Coarse resolution for illustration purposes



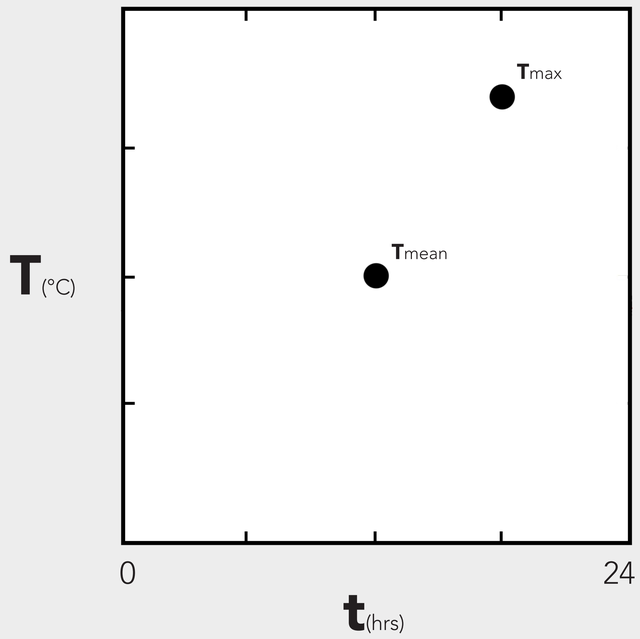
METHOD

RCM DATA

Coordinated Regional Climate Downscaling Experiment (CORDEX)

Gridded Data (3 dimensional matrixes)

NB: Coarse resolution for illustration purposes



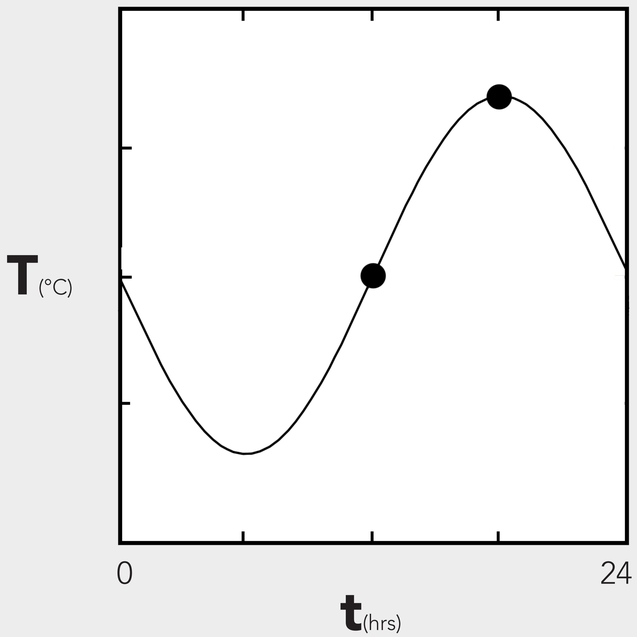
LEGEND

● GCM or RCM extract

METHOD
RCM DATA

Daily variables for specific geographic coordinate

$$T_e(t) = Te_{mean} + \Delta T_e \cos(\omega t)$$



LEGEND

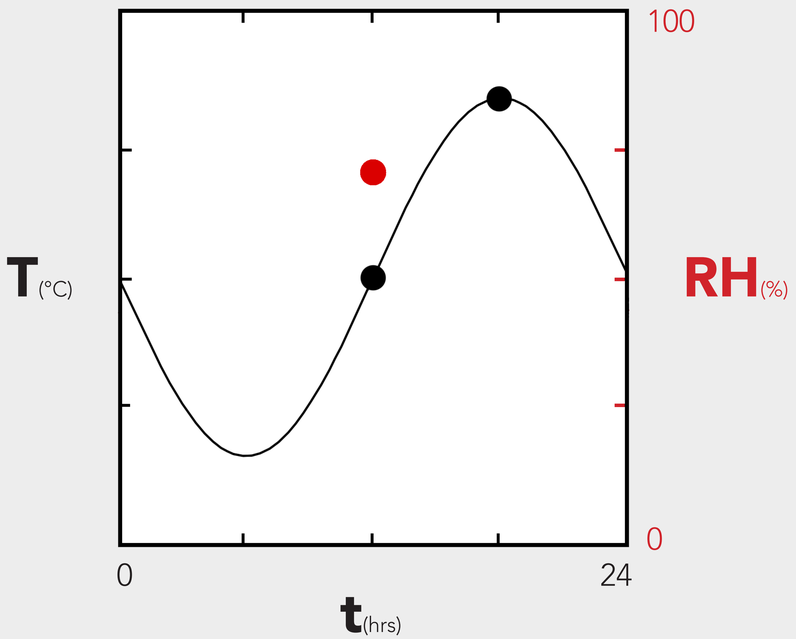
● GCM or RCM extract

—— Exterior Temperature Diurnal Cycle (C°)

METHOD
RCM DATA

Daily variables for specific geographic coordinate
Diurnal variations extrapolated assuming harmonic cycles

$$T_e(t) = Te_{mean} + \Delta T_e \cos(\omega t)$$



LEGEND

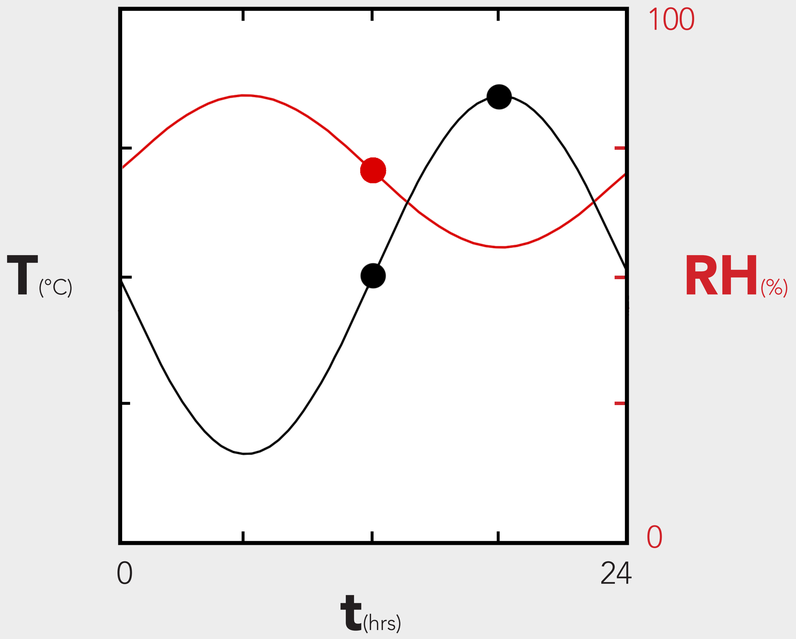
GCM or RCM extract

Exterior Temperature Diurnal Cycle (C°)

METHOD
RCM DATA

Daily variables for specific geographic coordinate
Diurnal variations extrapolated assuming harmonic cycles

$$RH\ (\%) = 100 * \left[\frac{e^{\frac{17.625*Dp}{243.04*Dp}}}{e^{\frac{17.625*T}{243.04+Dp}}}\right]$$



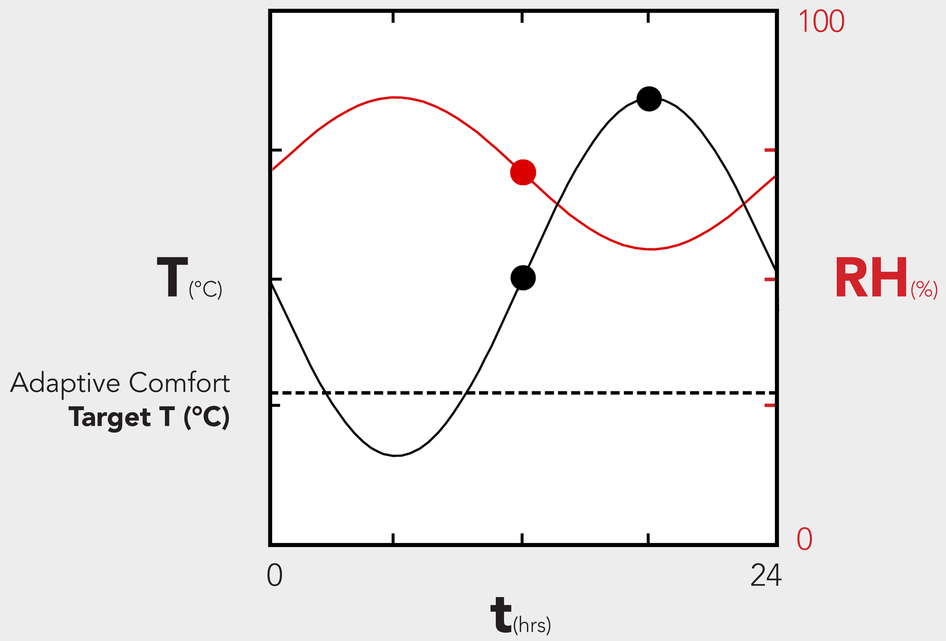
LEGEND

- GCM or RCM extract
- Exterior Temperature Diurnal Cycle (C°)
- Exterior Relative Humidity Diurnal Cycle (%)

METHOD
RCM DATA

Daily variables for specific geographic coordinate
Diurnal variations extrapolated assuming harmonic cycles

$$T_{adapt.} = \max\left\{\left(17.8 + \left(0.31 * Te_{\text{mean,monthly}}\right)\right), 27.875\right\}$$



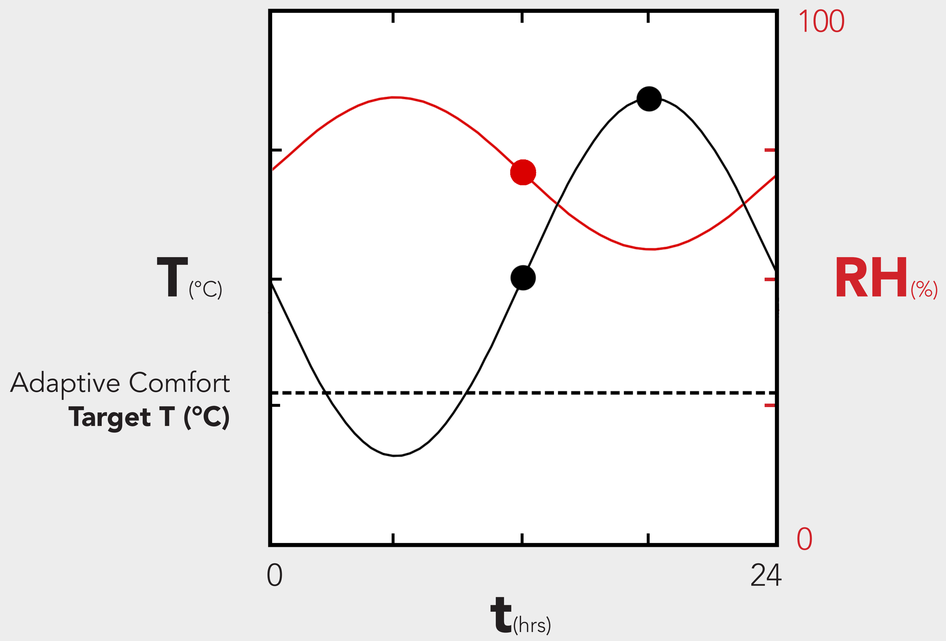
LEGEND

- GCM or RCM extract
- Exterior Temperature Diurnal Cycle (C°)
- Exterior Relative Humidity Diurnal Cycle (%)
- Target Temperatures (C°)

METHOD
TARGET TEMPERATURE

Cooling for comfort:
Adaptive comfort scale
(based on mean running 30 days temperature)

$$T_{adapt.} = \max\left\{\left(17.8 + \left(0.31 * Te_{\text{mean,monthly}}\right)\right), 27.875\right\}$$



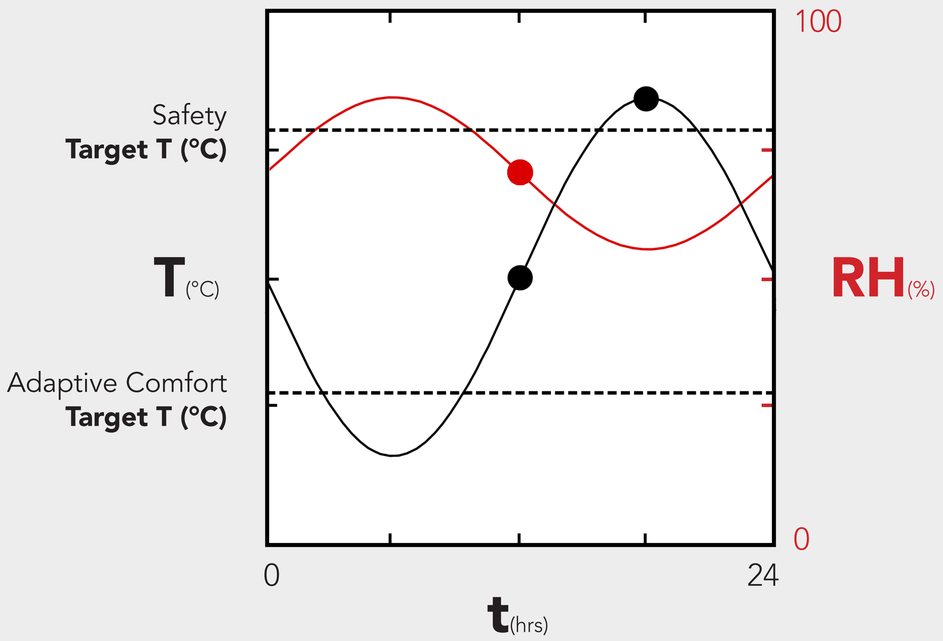
LEGEND

- GCM or RCM extract
- Exterior Temperature Diurnal Cycle (C°)
- Exterior Relative Humidity Diurnal Cycle (%)
- Target Temperatures (C°)

METHOD
TARGET TEMPERATURE

Cooling for comfort:
Adaptive comfort scale
(based on mean running 30 days temperature)

$$T_{safe} = max \left\{ \left(\frac{a - \sqrt{b}}{c} \right), \quad \left(\frac{a + \sqrt{b}}{c} \right) \right\}$$

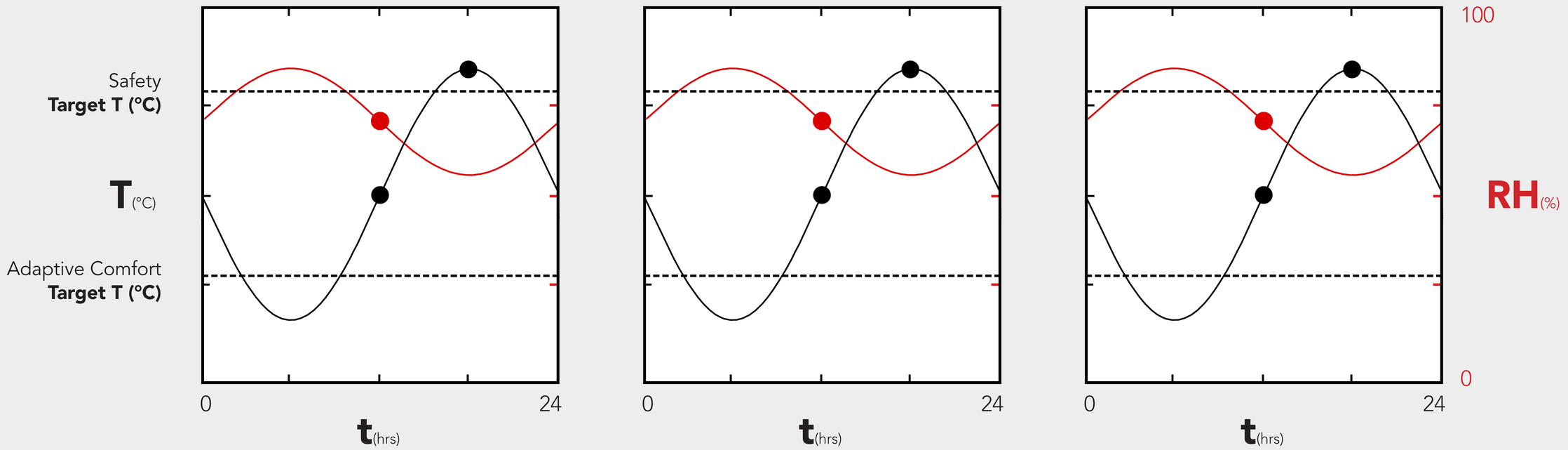


LEGEND

GCM or RCM extract — Exterior Temperature Diurnal Cycle (C°) — Exterior Relative Humidity Diurnal Cycle (%) — Target Temperatures (C°)

METHOD
TARGET TEMPERATURE

Cooling for safety:
Heat Index (extreme caution level: 32.2° apparent temperature)
(based on dry-bulb temperature and RH level)

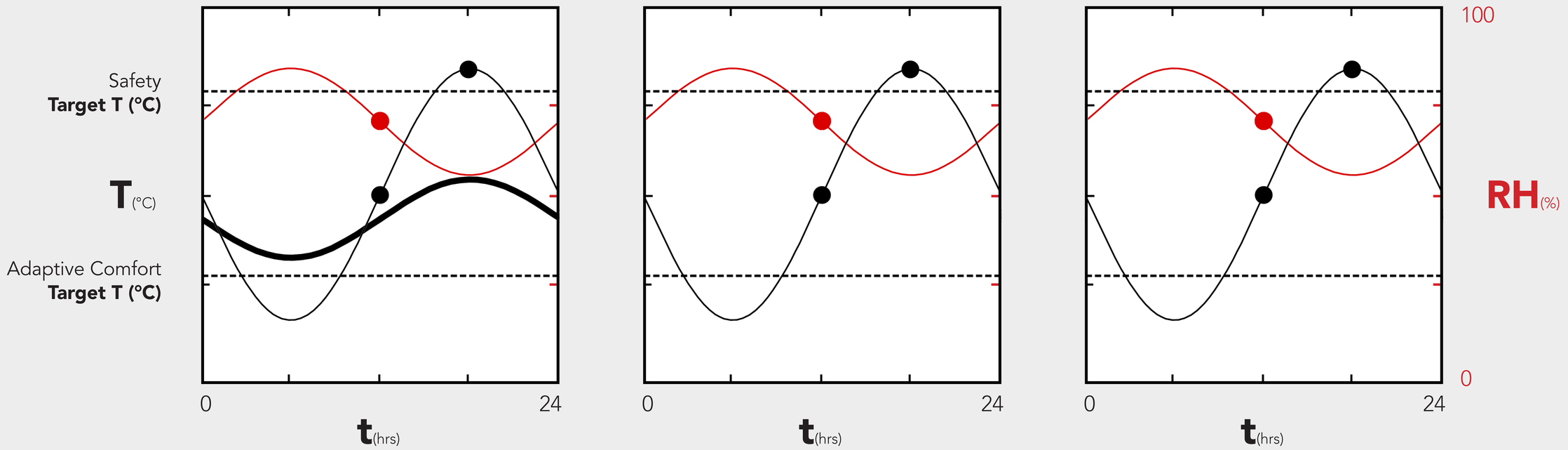


LEGEND

GCM or RCM extract — Exterior Temperature Diurnal Cycle (C°) — Exterior Relative Humidity Diurnal Cycle (%) — Target Temperatures (C°)

METHOD
3 SCENARIOS

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)



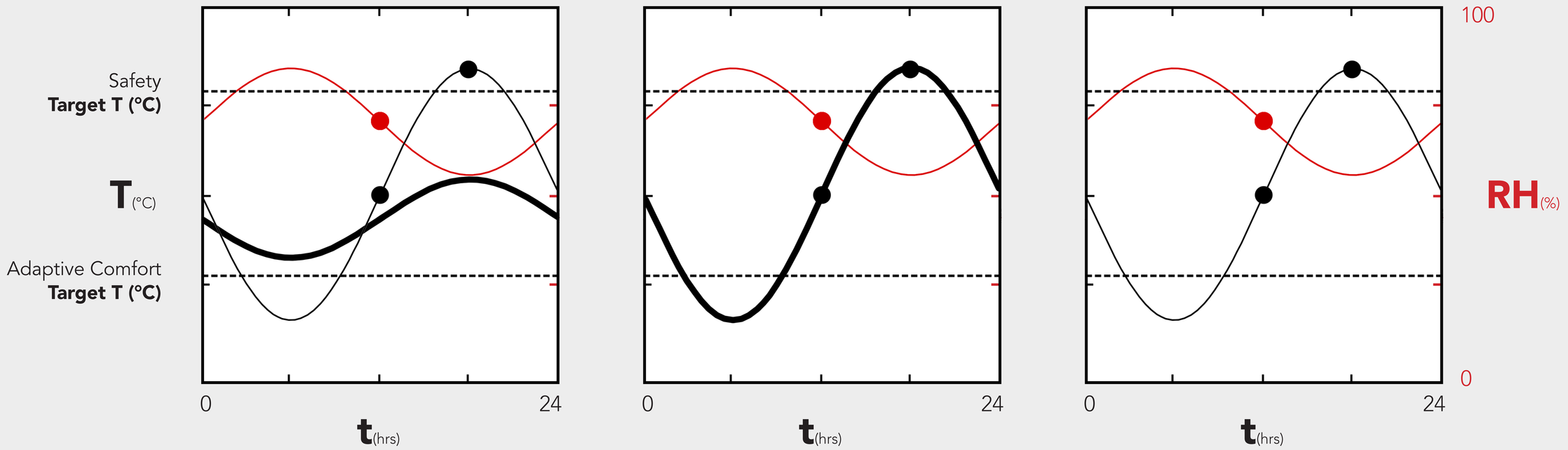
LEGEND

- GCM or RCM extract
- Exterior Temperature Diurnal Cycle (C°)
- Exterior Relative Humidity Diurnal Cycle (%)
- Target Temperatures (C°)
- Interior Temperature Diurnal Cycle (C°)

METHOD
3 SCENARIOS

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated



LEGEND

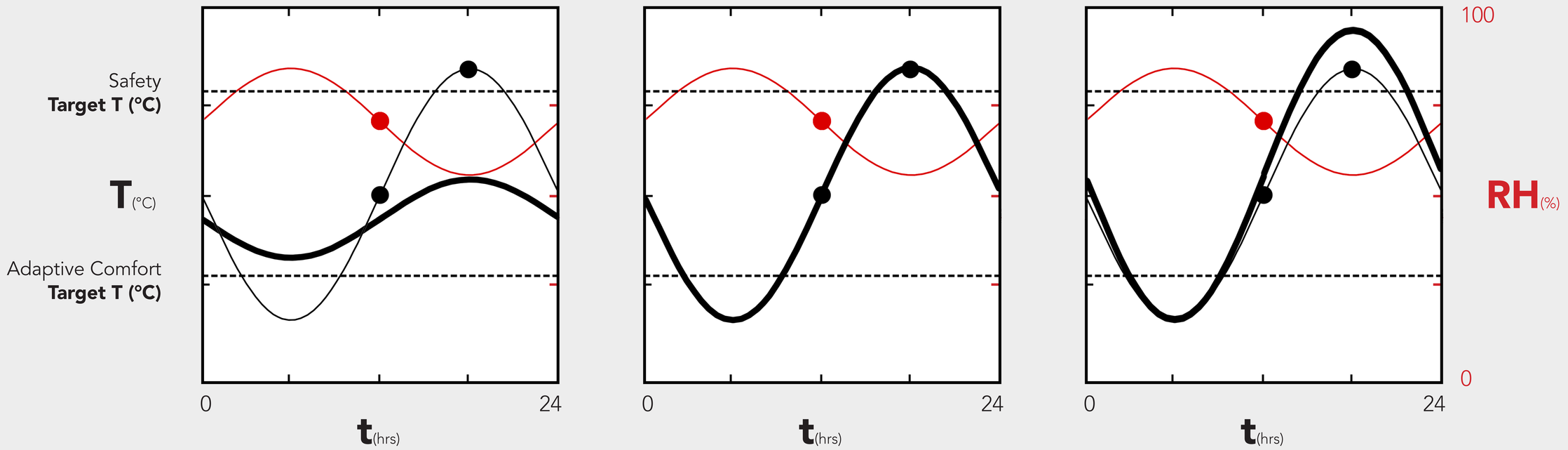
- GCM or RCM extract
- Exterior Temperature Diurnal Cycle (C°)
- Exterior Relative Humidity Diurnal Cycle (%)
- Target Temperatures (C°)
- Interior Temperature Diurnal Cycle (C°)

METHOD
3 SCENARIOS

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)



LEGEND

- GCM or RCM extract
- Exterior Temperature Diurnal Cycle (C°)
- Exterior Relative Humidity Diurnal Cycle (%)
- Target Temperatures (C°)
- Interior Temperature Diurnal Cycle (C°)

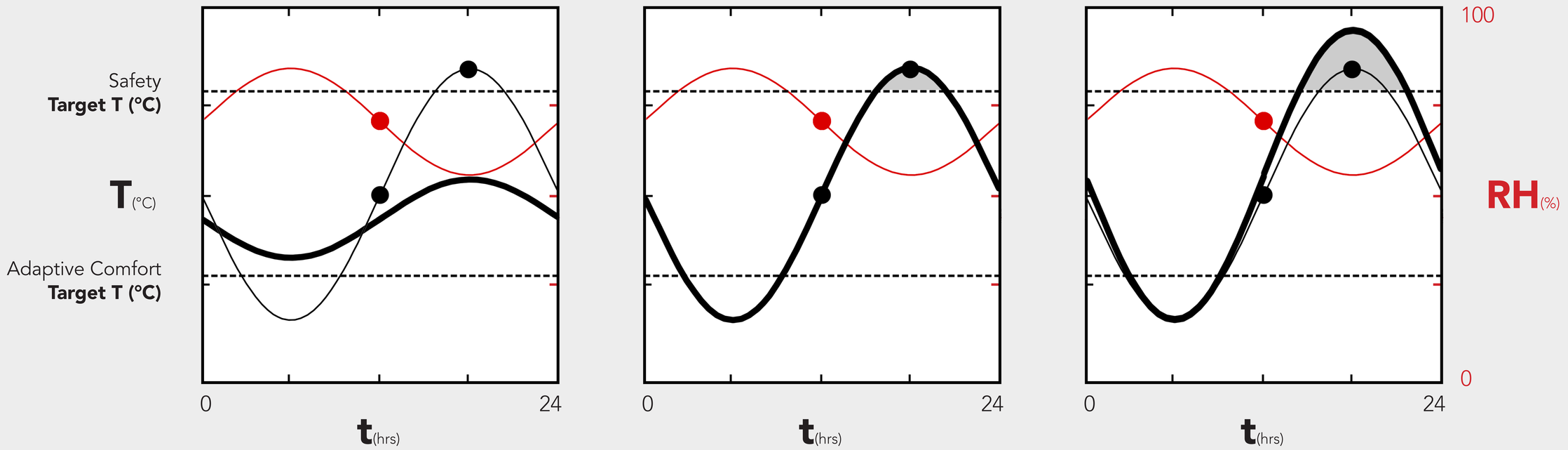
METHOD
3 SCENARIOS

CDD
(COOLING DEGREE DAYS ABOVE SAFETY)

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)



LEGEND

- GCM or RCM extract
- Exterior Temperature Diurnal Cycle (C°)
- Exterior Relative Humidity Diurnal Cycle (%)
- Target Temperatures (C°)
- Interior Temperature Diurnal Cycle (C°)

METHOD
3 SCENARIOS

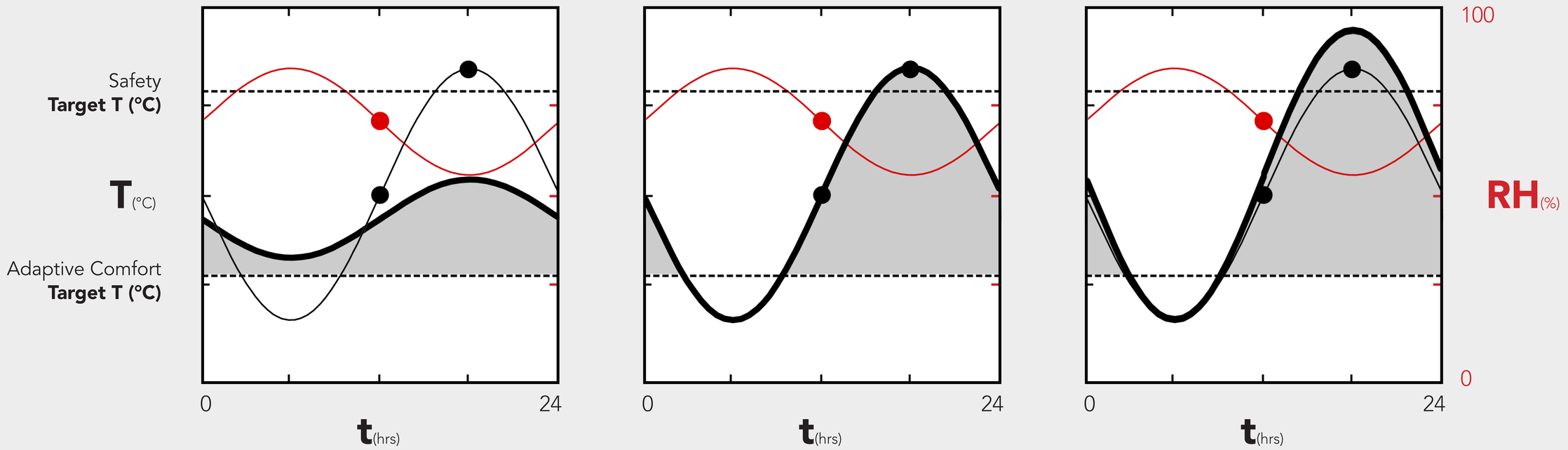
CDD

(COOLING DEGREE DAYS ABOVE COMFORT)

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)

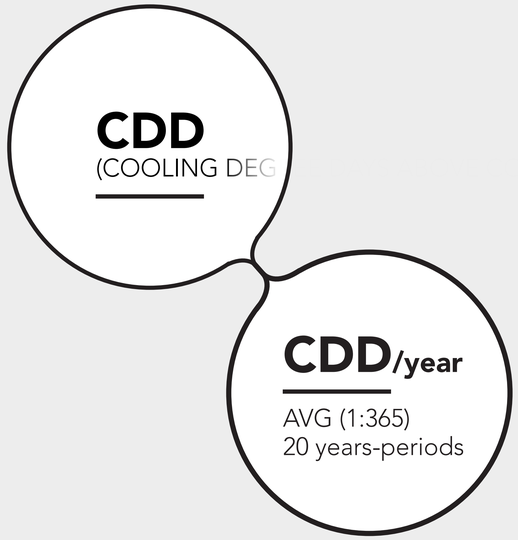


LEGEND

- GCM or RCM extract
- Exterior Temperature Diurnal Cycle (C°)
- Exterior Relative Humidity Diurnal Cycle (%)
- Target Temperatures (C°)
- Interior Temperature Diurnal Cycle (C°)

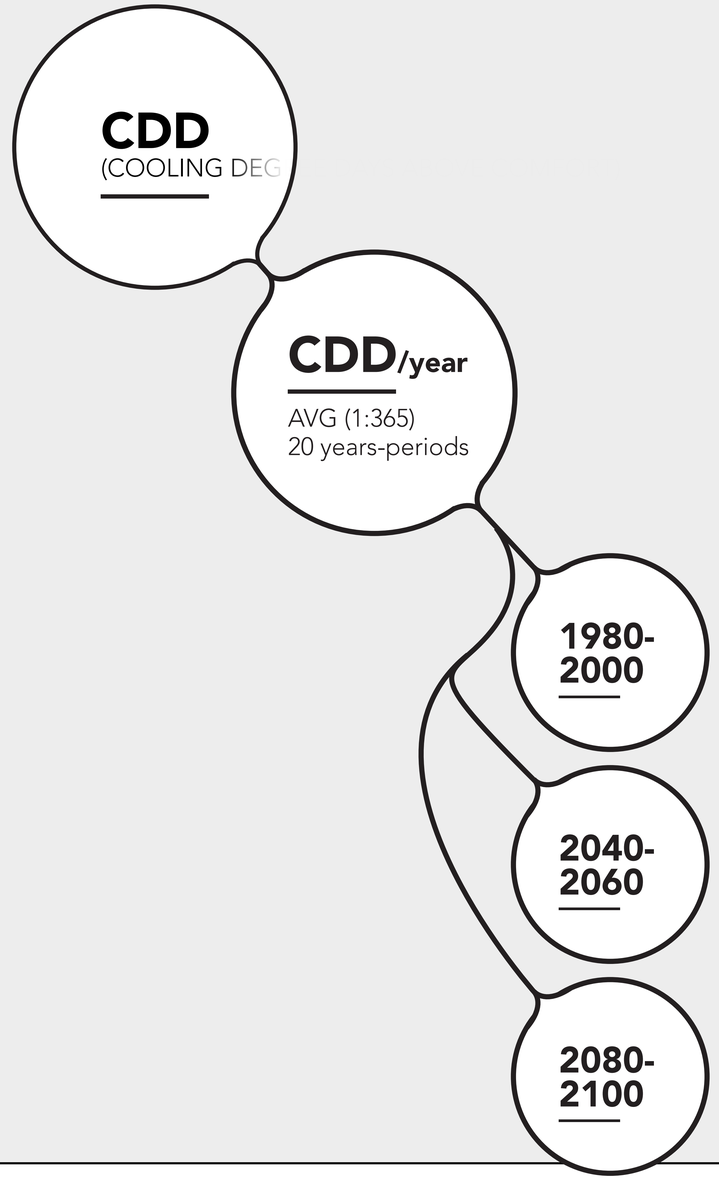
METHOD
3 SCENARIOS

CDD
(COOLING DEG

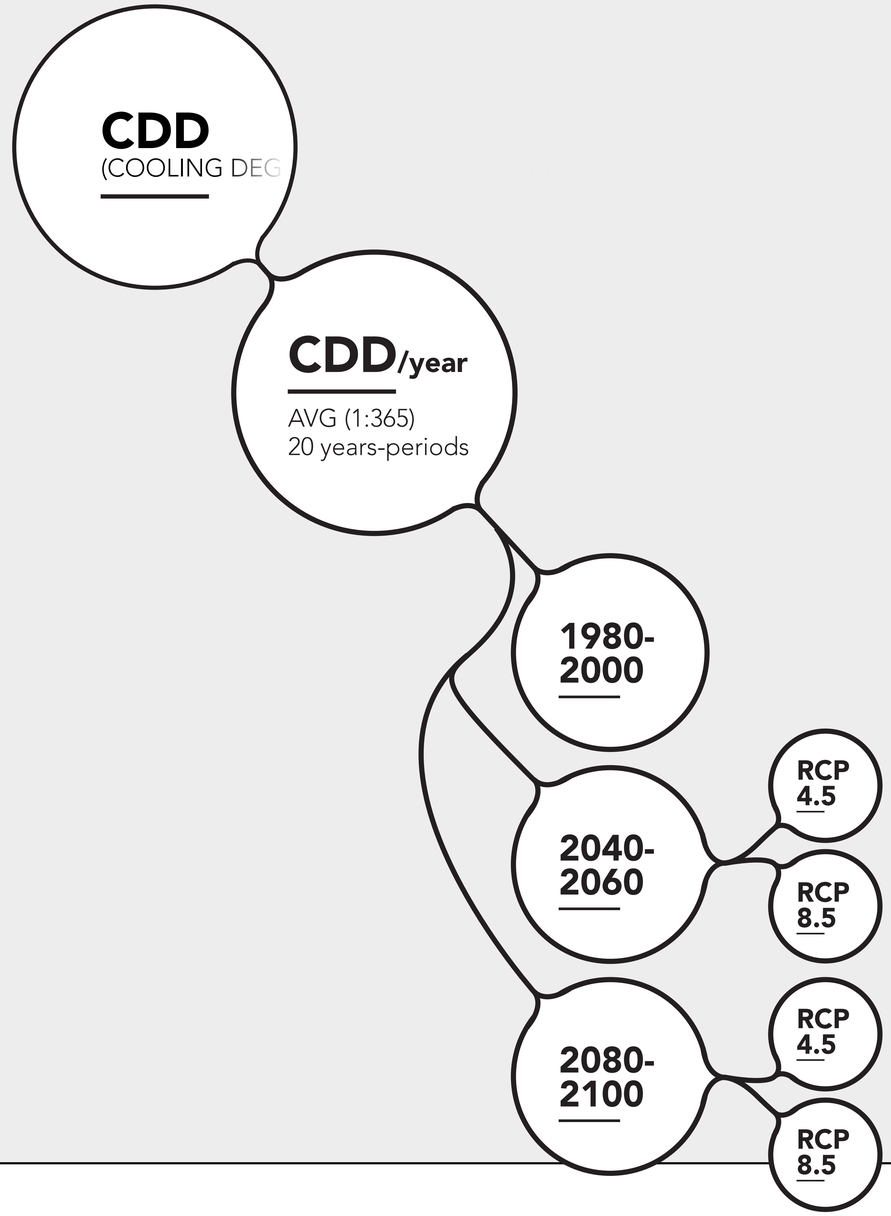


METHOD

CDD to CDD.yr^{-1}



METHOD
CDD to CDD.yr^{-1}
AVERAGE OVER 20 yr. PERIODS

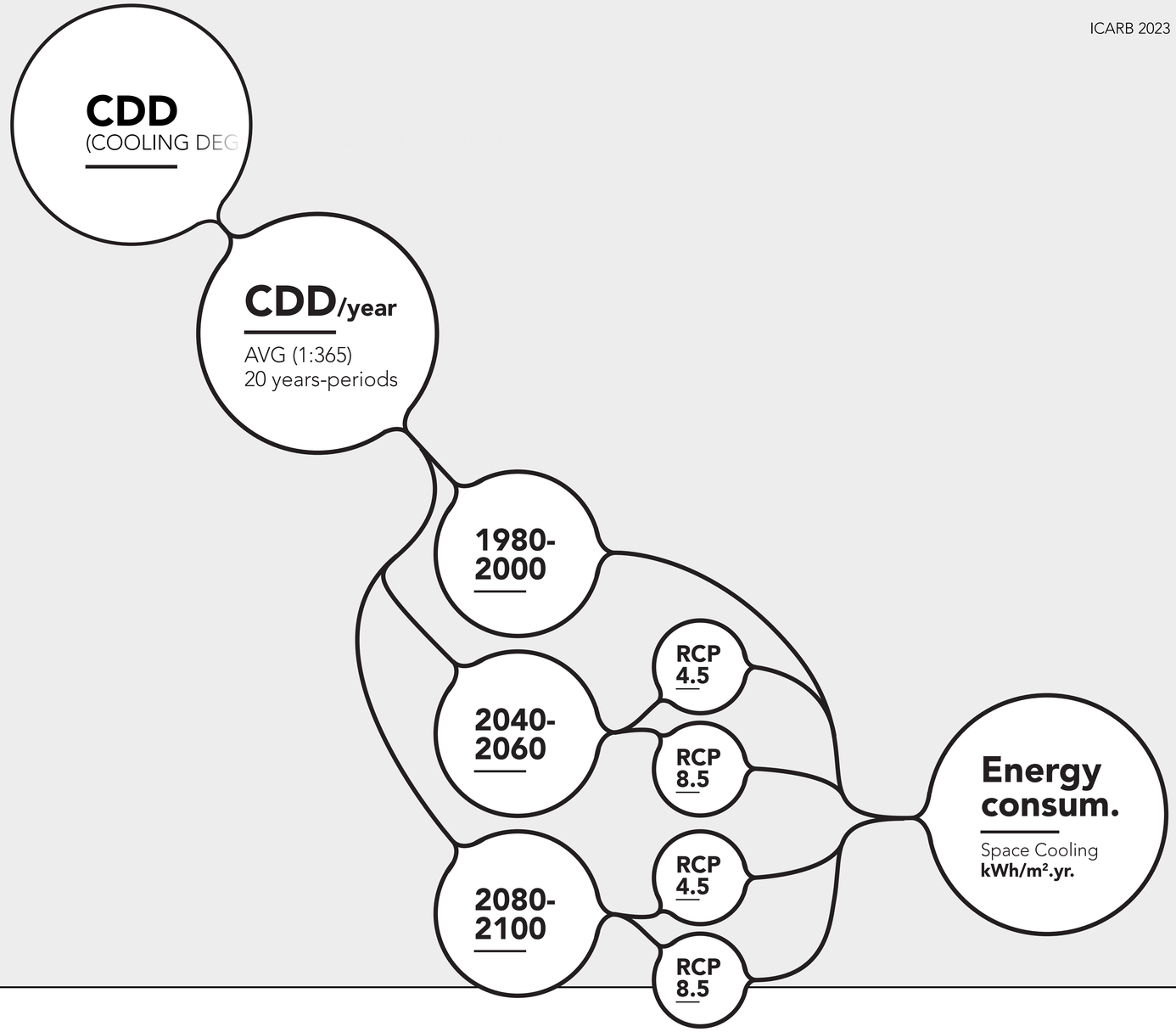


METHOD

CDD to CDD.yr^{-1}

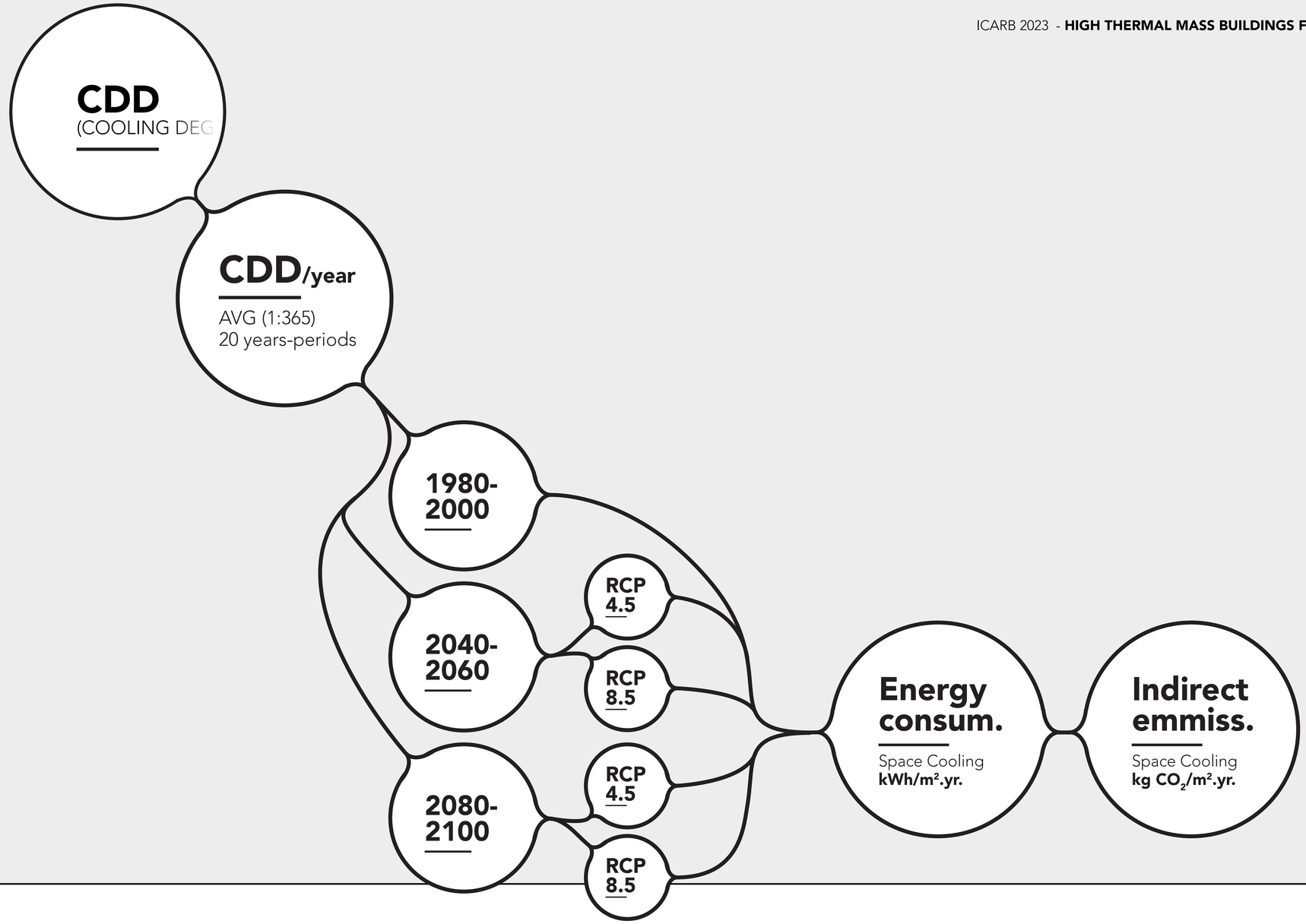
AVERAGE OVER 20 yr. PERIODS FOR 2 CLIMATE SCENARIOS

RCP4.5 = 1.8°C global warming by 2100
RCP4.5 = 3.7°C global warming by 2100



METHOD
CDD.yr^{-1}to kWh

CDD.yr^{-1} thresholds triggering households to adopt and operate cooling equipment



METHOD
kWh to CO_2

Local emission factors for electricity mix

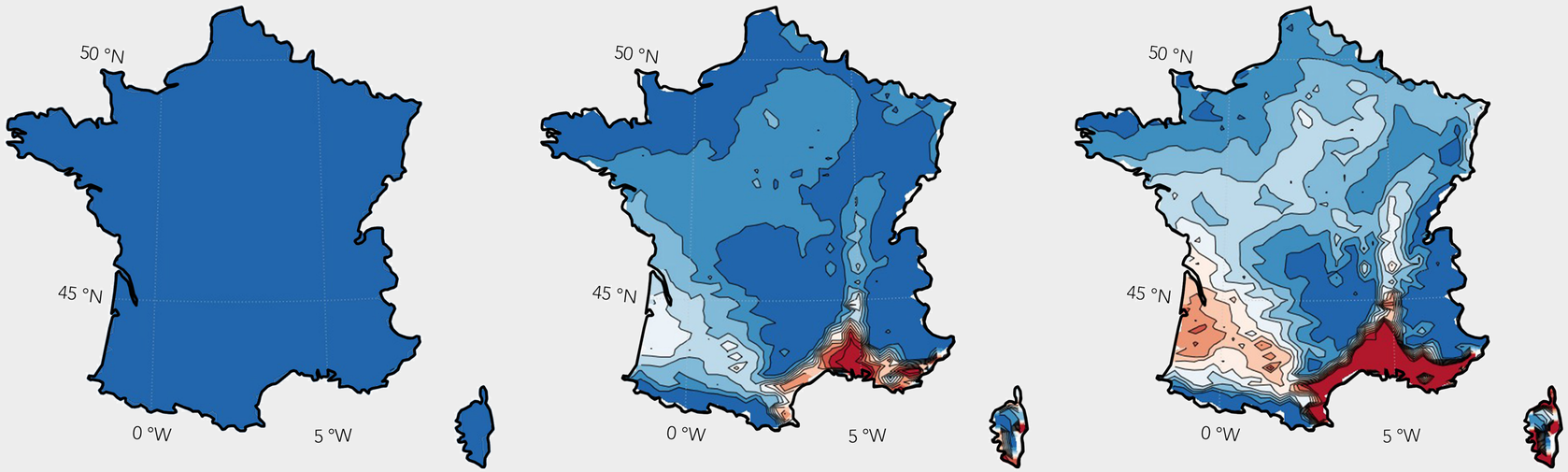
RESULTS

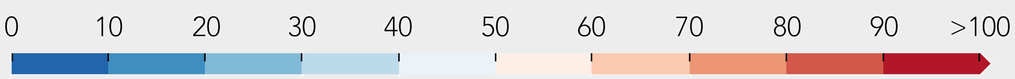
1980-2000

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)





CDD.yr^{-1}
(Temperature Demand for Comfort)

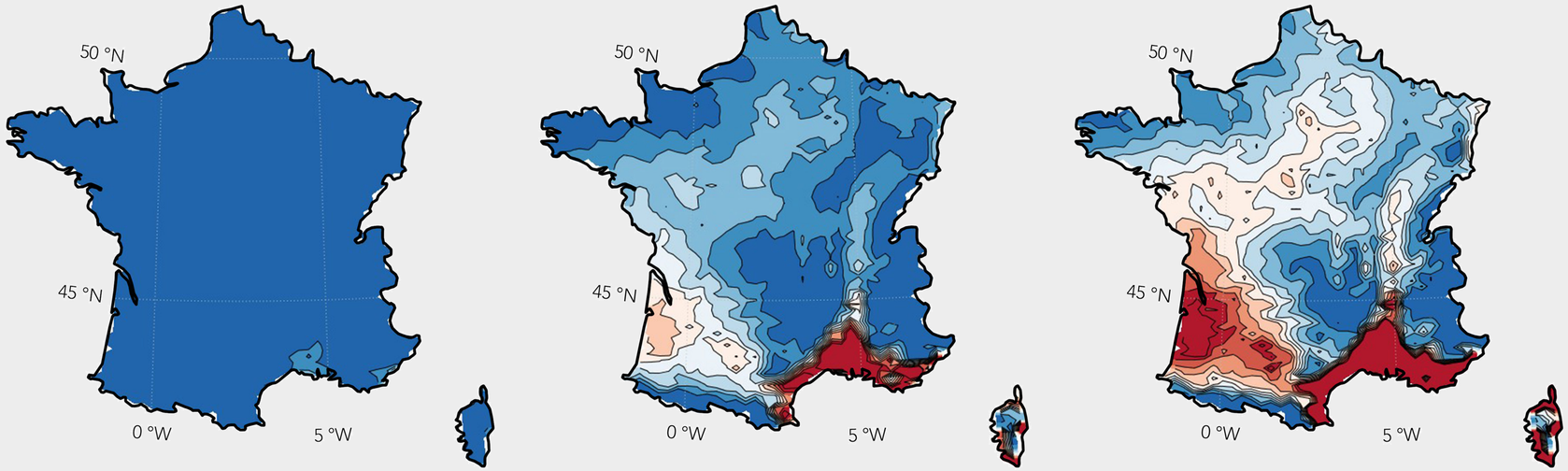
RESULTS
HIST / TEMPERATURE DEMAND FOR COMFORT

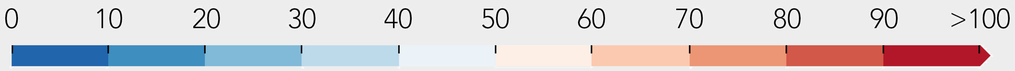
2040-2080

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)





CDD.yr^{-1}
(Temperature Demand for Comfort)

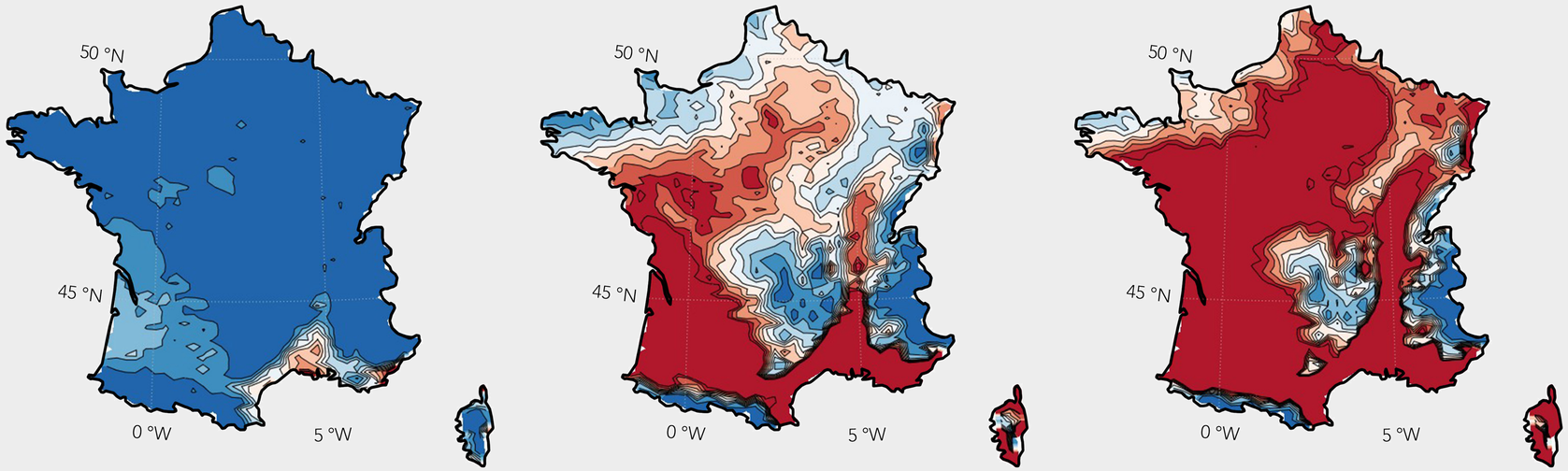
RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR COMFORT
(3.7°C Global Warming Scenario)

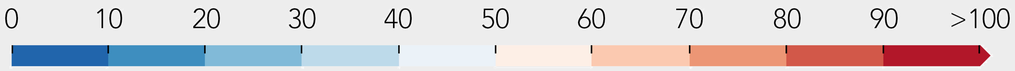
2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)





CDD.yr^{-1}
(Temperature Demand for Comfort)

RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR COMFORT
(3.7°C Global Warming Scenario)

2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
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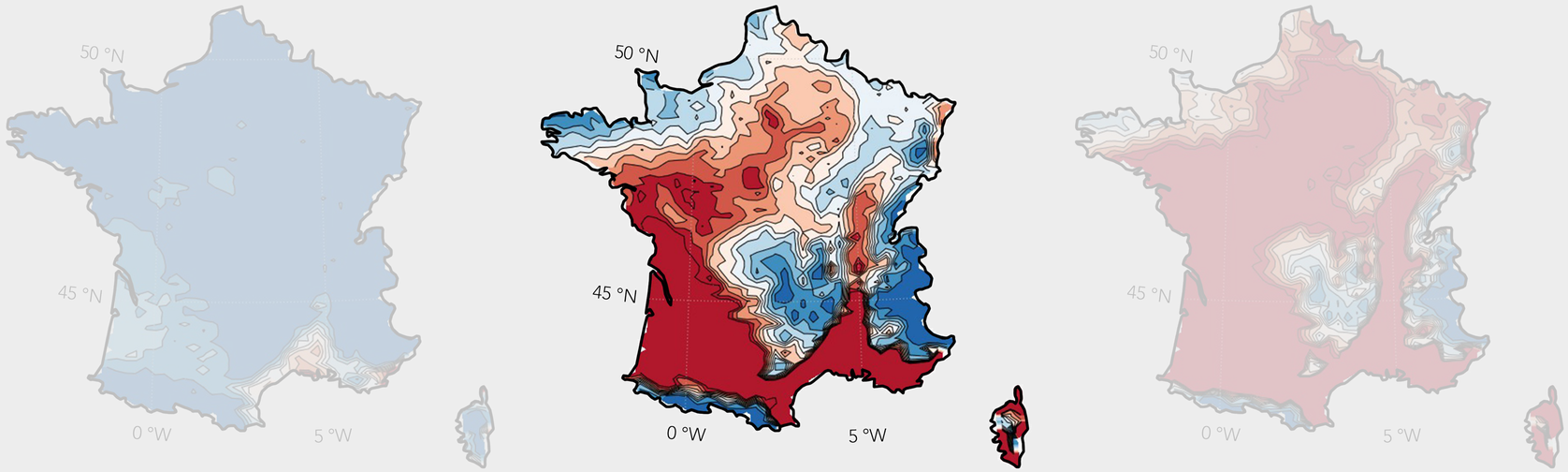
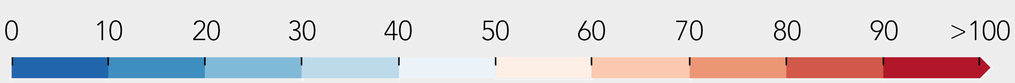
Poor ventilation
(overheating risk)





CDD.yr^{-1}
(Temperature Demand for Comfort)

RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR COMFORT
(3.7°C Global Warming Scenario)

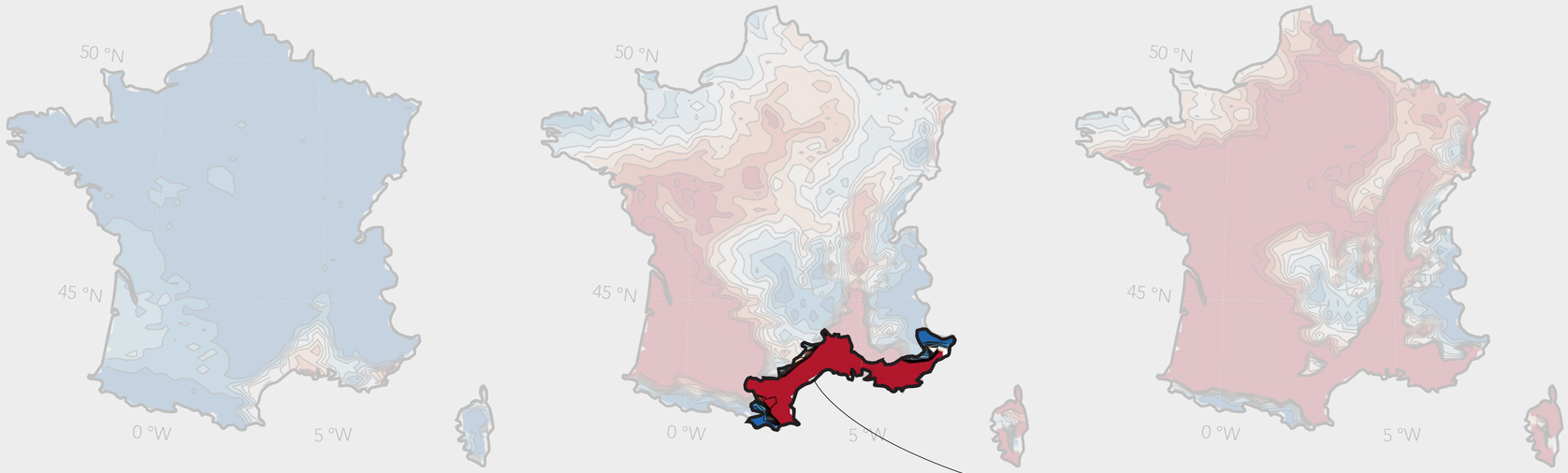
End of the century: +451% temperature demand for comfort (RCP8.5)
+221% temperature demand for comfort (RCP4.5)

2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)



0 10 20 30 40 50 60 70 80 90 >100

CDD.yr^{-1}
(Temperature Demand for Comfort)

RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR COMFORT
(3.7°C Global Warming Scenario)

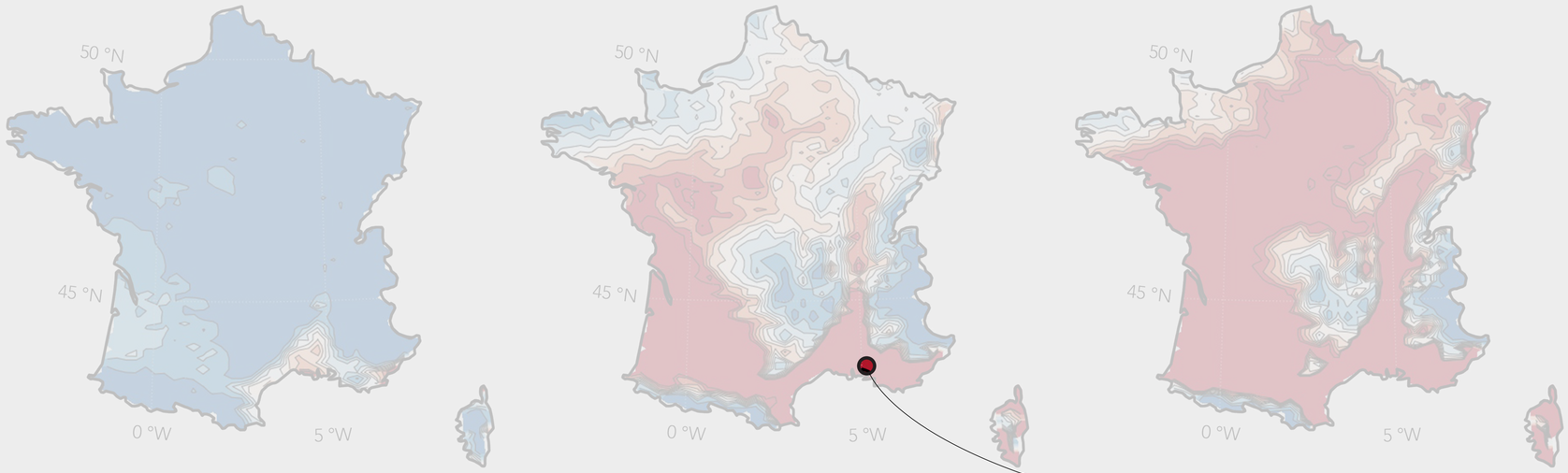
zone H3, cooling required for 73 ± 37 days/year (RCP8.5)
51 ± 33 days/year (RCP4.5)

2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)



0 10 20 30 40 50 60 70 80 90 >100

CDD.yr^{-1}
(Temperature Demand for Comfort)

RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR COMFORT
(3.7°C Global Warming Scenario)

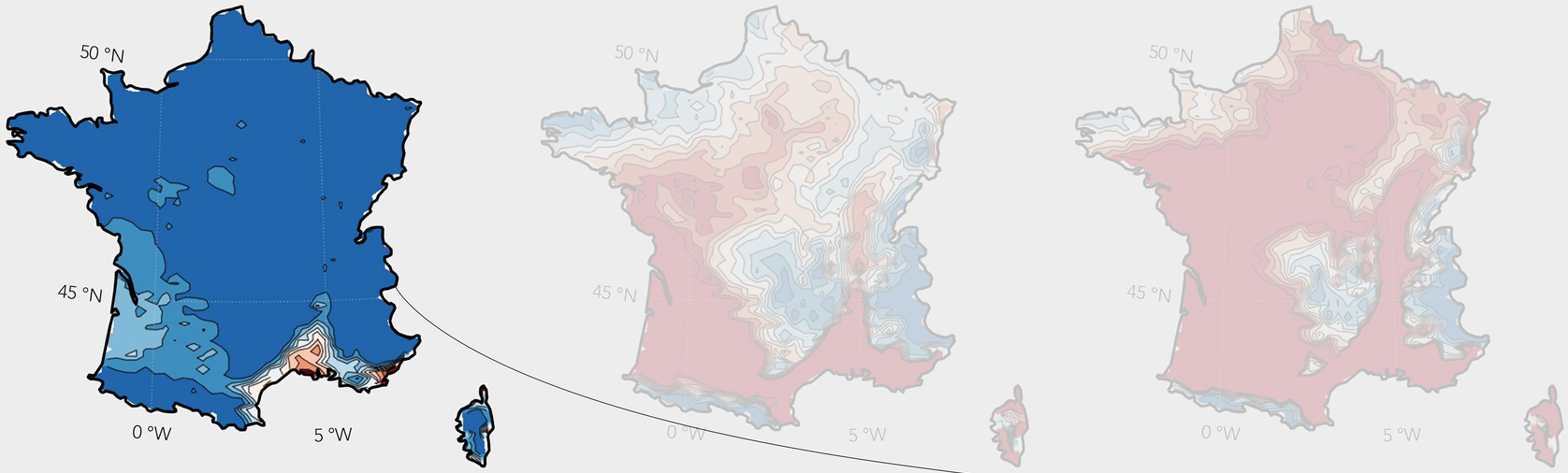
Some locations require cooling for more than 130 days/year

2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)



0 10 20 30 40 50 60 70 80 90 >100

CDD.yr^{-1}
(Temperature Demand for Comfort)

RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR COMFORT
(3.7°C Global Warming Scenario)

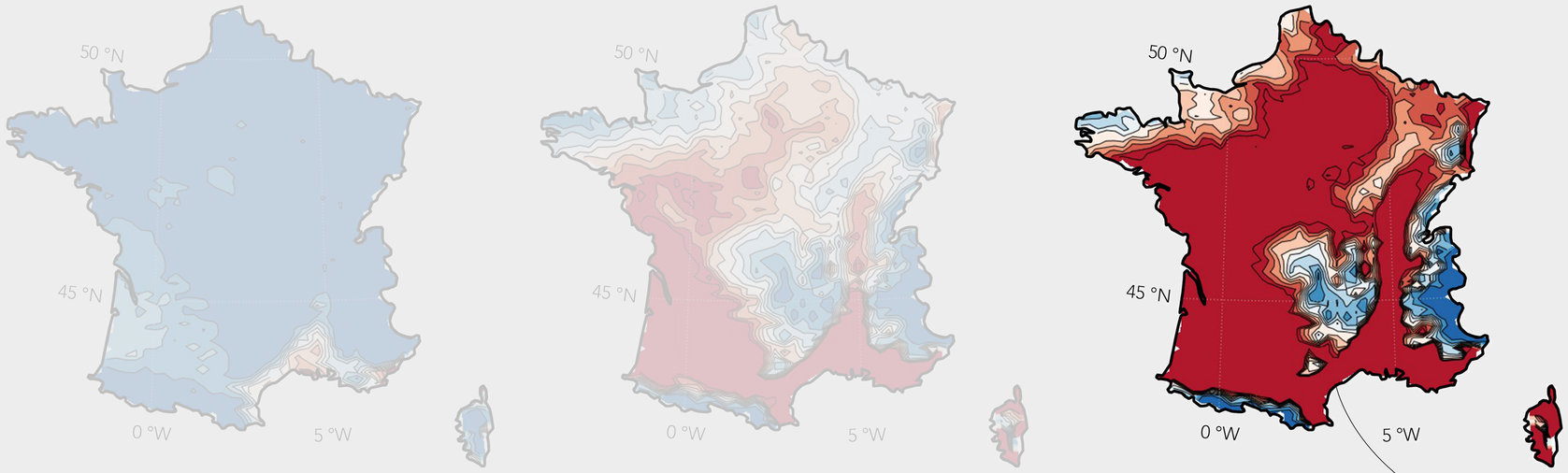
Combination of high thermal mass and nocturnal convective cooling leads to a remarkable decrease (-99%) in CDD.yr^{-1} across all RCP scenarios and time periods considered

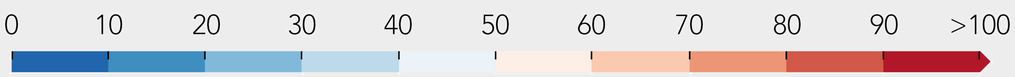
2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)





CDD.yr^{-1}
(Temperature Demand for Comfort)

RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR COMFORT
(3.7°C Global Warming Scenario)

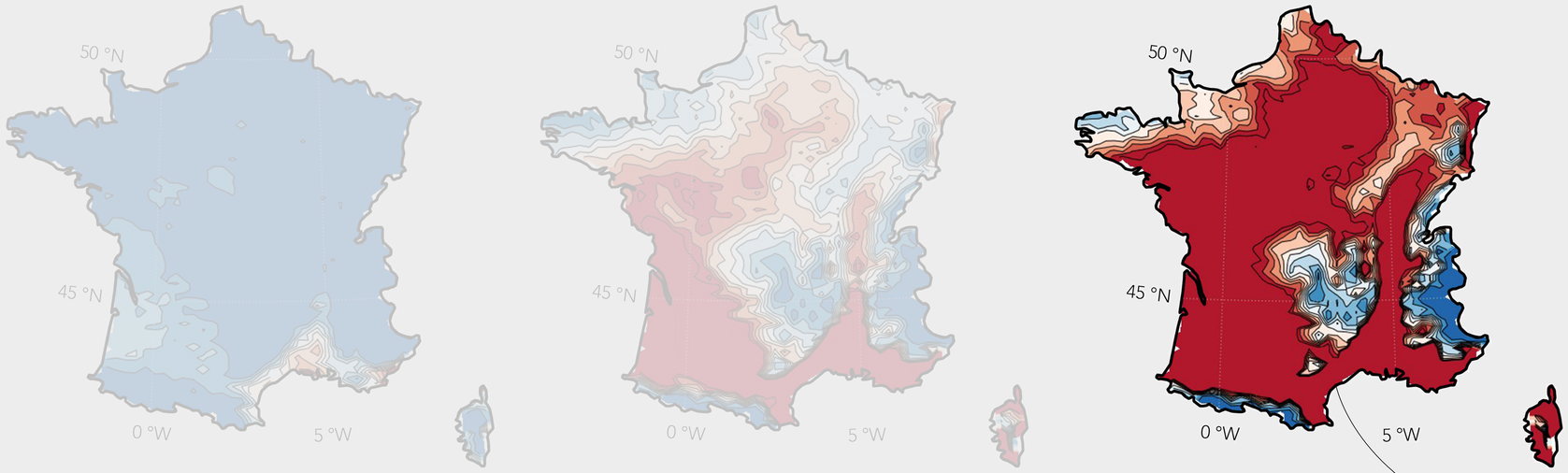
Conversely, in the absence of mechanical cooling, poorly ventilated light inertia buildings display increasingly uncomfortable interior temperatures.

2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)



0 10 20 30 40 50 60 70 80 90 >100

CDD.yr^{-1}
(Temperature Demand for Comfort)

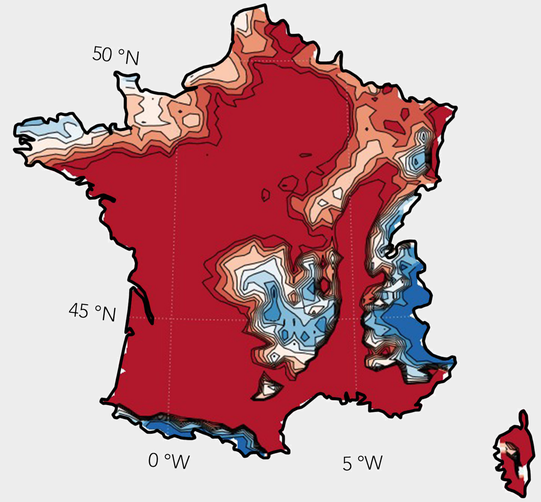
RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR COMFORT
(3.7°C Global Warming Scenario)

Upper threshold set by the french regulation (52 CDD.yr^{-1}) surpassed over 83.5% of the territory (RCP 8.5)
52.8% of the territory (RCP 4.5)

IS DISCOMFORT A SAFETY CONCERN ?

(in terms of associated relative humidity levels)

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)



70 80 90 >100

nfort)

RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR COMFORT
(3.7°C Global Warming Scenario)

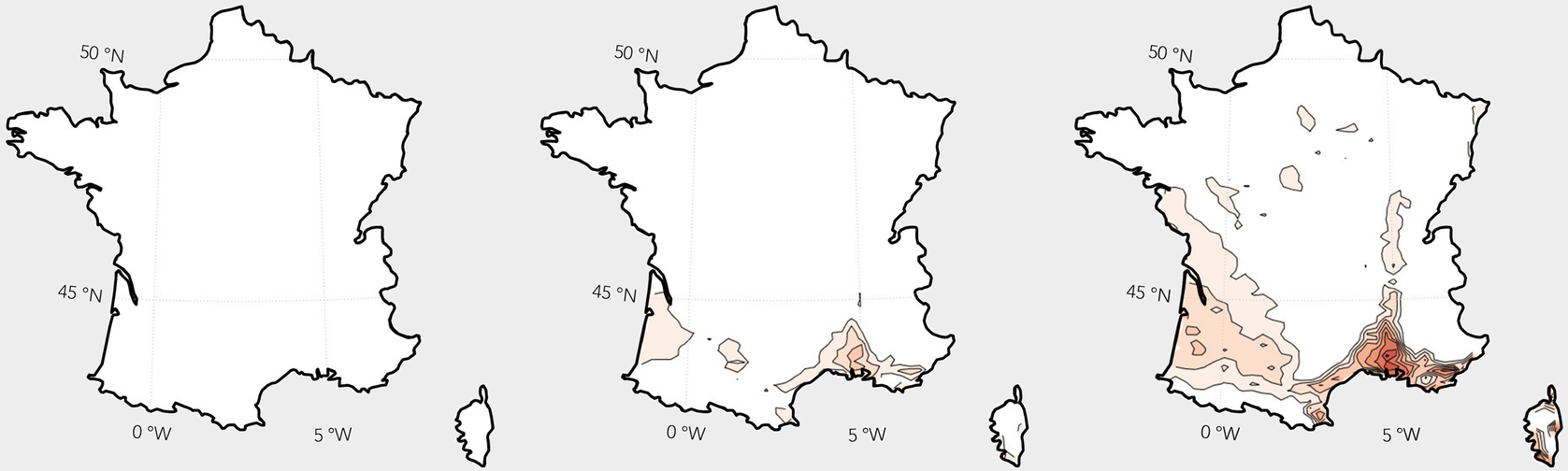
Upper threshold set by the french regulation (52 CDD.yr⁻¹) surpassed over 83.5% of the territory (RCP 8.5)
52.8% of the territory (RCP 4.5)

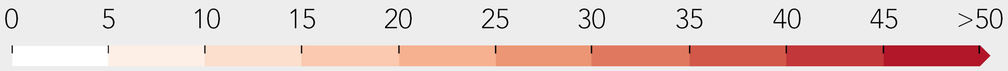
1980-2000

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)





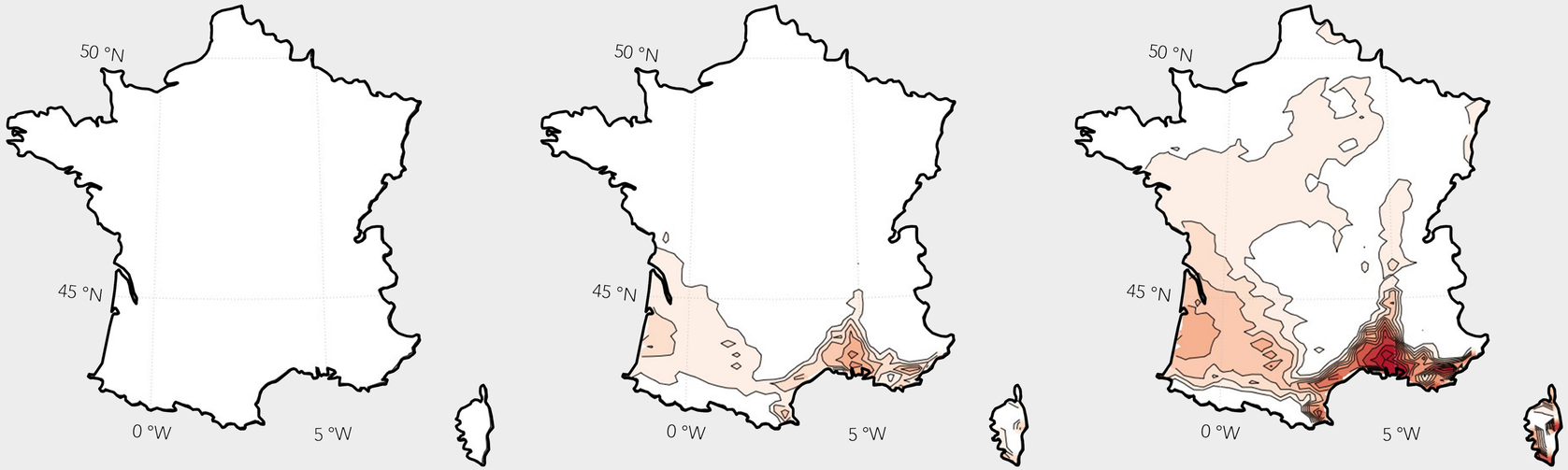
CDD.yr^{-1}
(Temperature Demand for Safety)

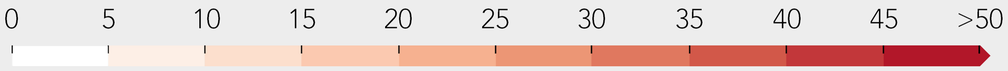
2040-2060

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)





CDD.yr^{-1}
(Temperature Demand for Safety)

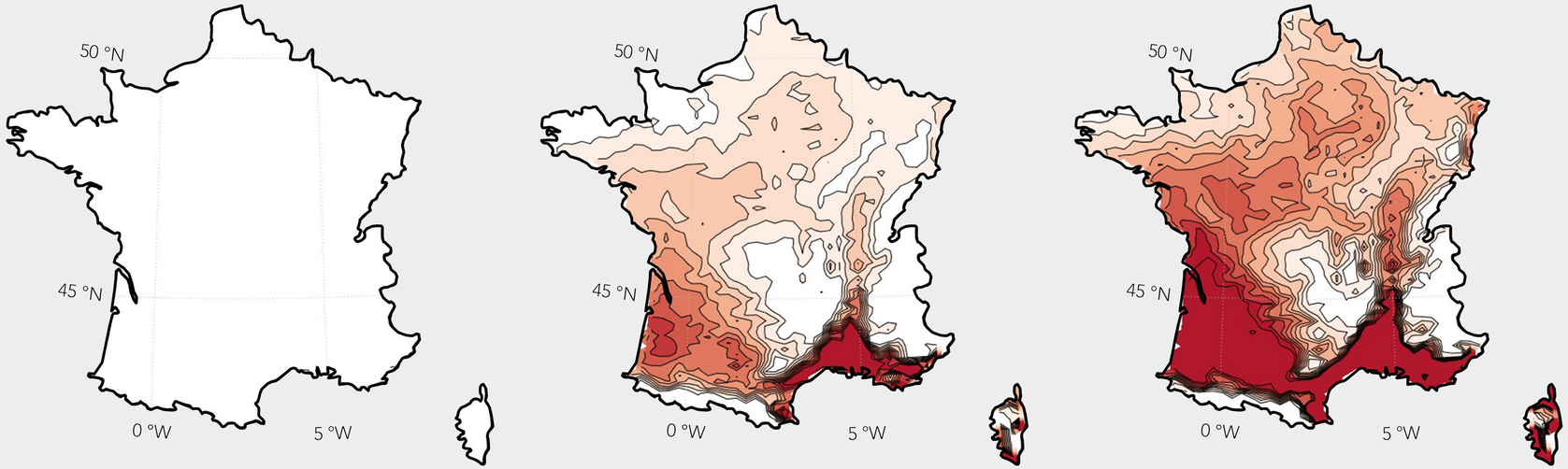
RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR SAFETY
(3.7°C Global Warming Scenario)

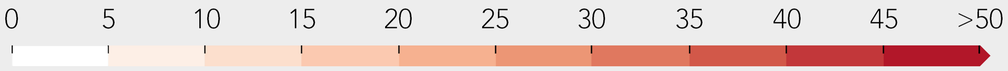
2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)





CDD.yr^{-1}
(Temperature Demand for Safety)

RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR SAFETY
(3.7°C Global Warming Scenario)

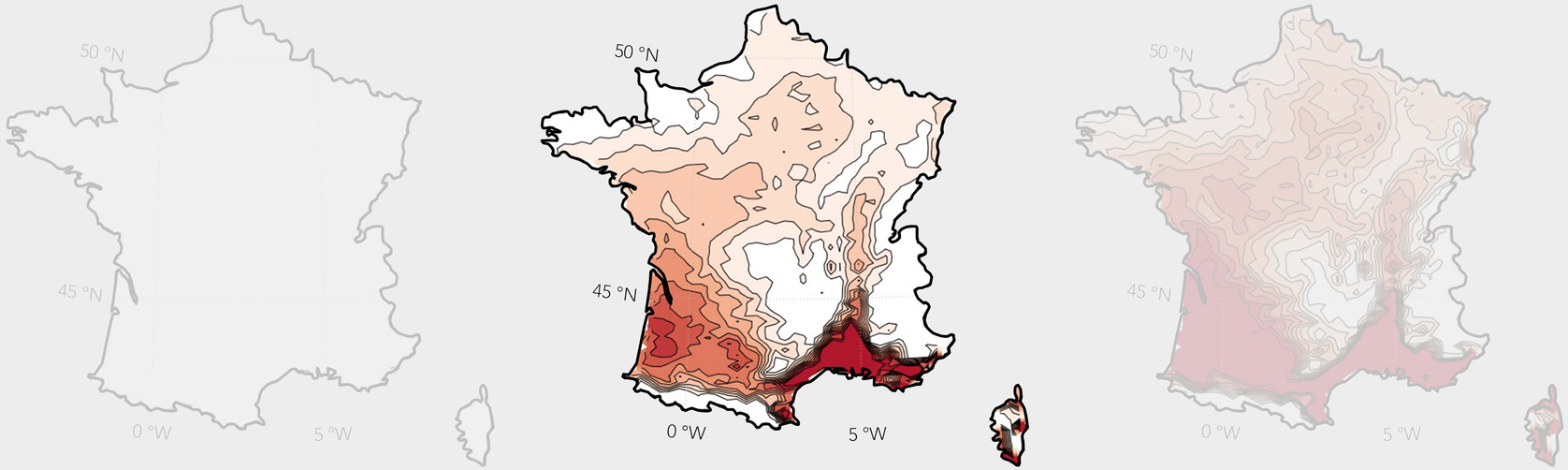
France is not immune to unsafe compound extreme events involving temperature and humidity

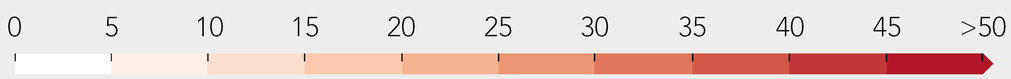
2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)





CDD.yr^{-1}
(Temperature Demand for Safety)

RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR SAFETY
(3.7°C Global Warming Scenario)

End of the century: +969% temperature demand for safety (RCP8.5)

2080-2100

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Well Ventilated

SCENARIO 3
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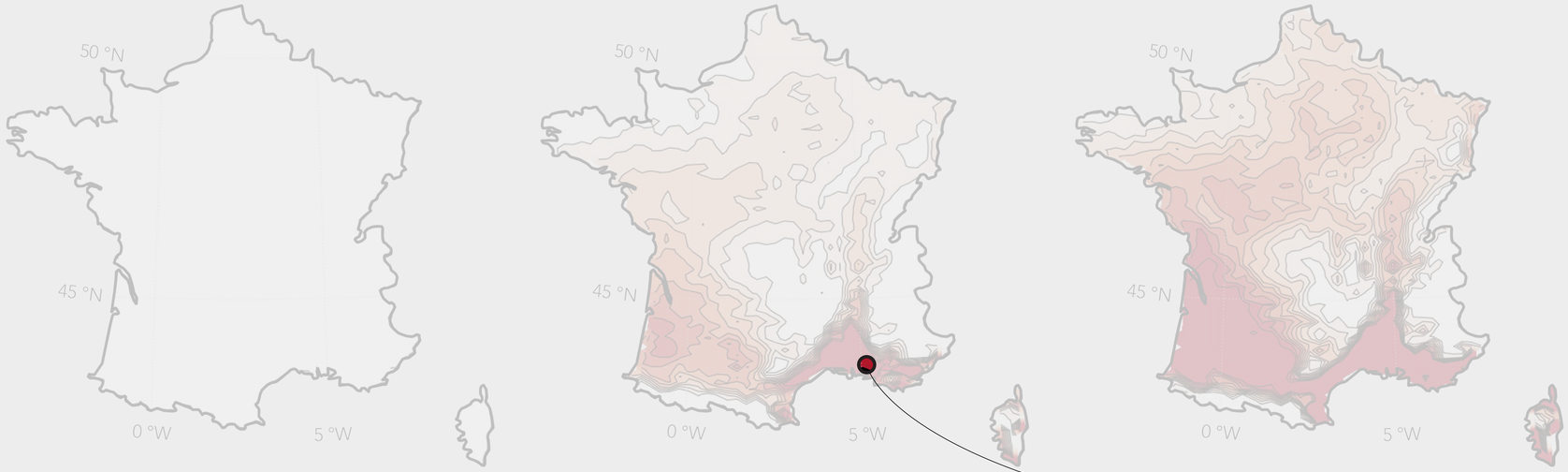
Poor ventilation
(overheating risk)



0 5 10 15 20 25 30 35 40 45 >50

CDD.yr^{-1}
(Temperature Demand for Safety)

RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR SAFETY
(3.7°C Global Warming Scenario)

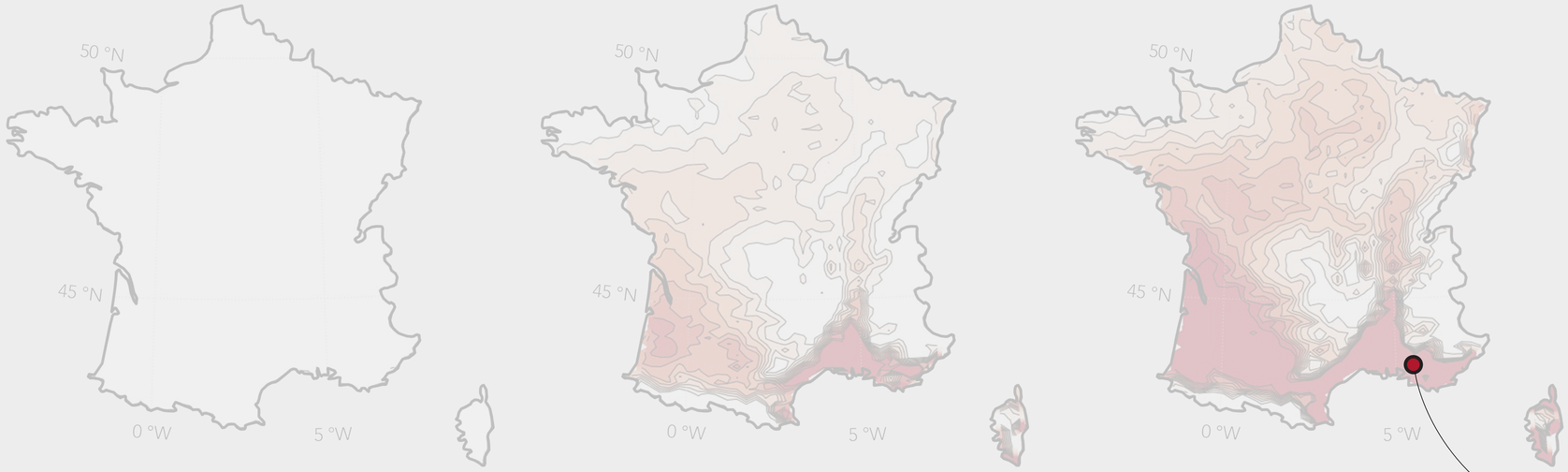
Some locations witnessing up to 87 CDD.yr^{1}

2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)



0 5 10 15 20 25 30 35 40 45 >50

CDD.yr^{-1}
(Temperature Demand for Safety)

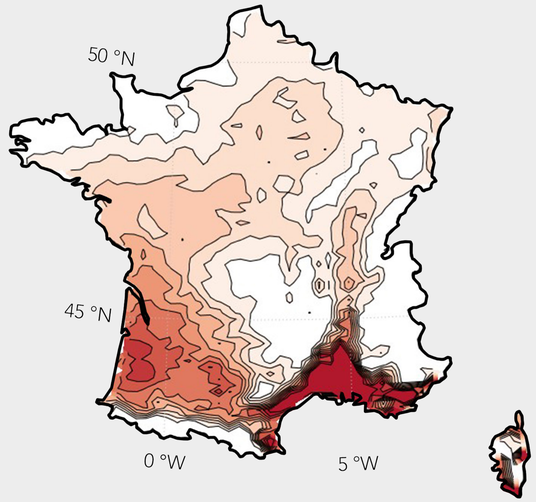
RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR SAFETY
(3.7°C Global Warming Scenario)

Some locations witnessing up to 144 CDD.yr^{1}

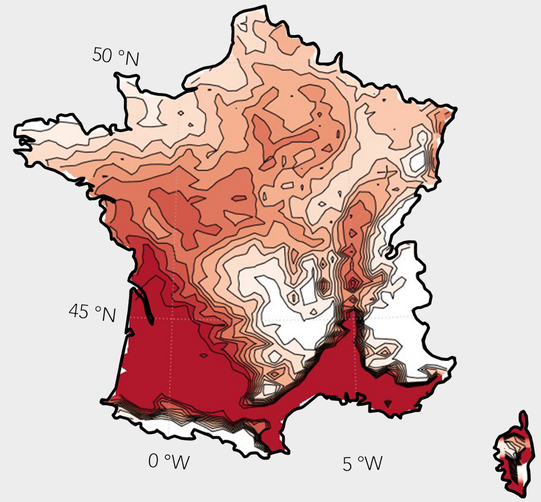
2080-2100

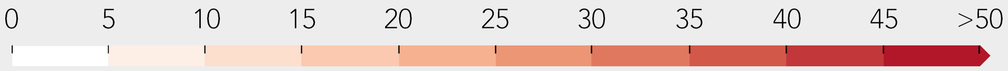
SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated



SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)





CDD.yr^{-1}
(Temperature Demand for Safety)

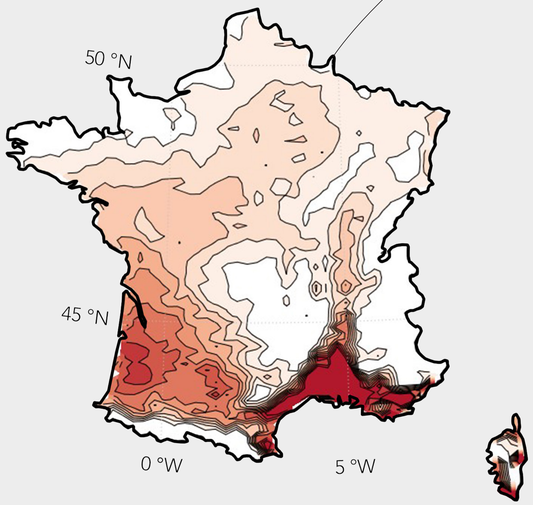
RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR SAFETY
(3.7°C Global Warming Scenario)

Occurrences not be confined to regions where adaptation has long been necessary (H3), and where adaptation measures are more common

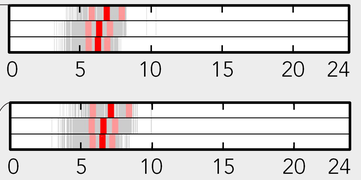
2080-2100

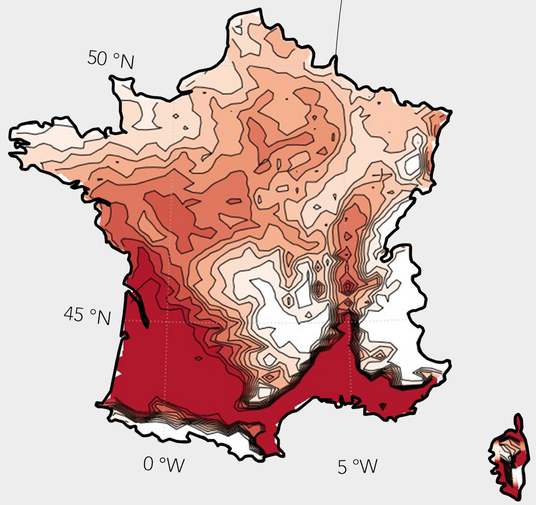
SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

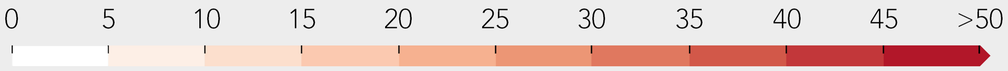
SCENARIO 2
Low Internal Thermal Mass
Well Ventilated



SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)







CDD.yr^{-1}
(Temperature Demand for Safety)

RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR SAFETY
(3.7°C Global Warming Scenario)

"Extreme caution" level Heat Index scale warns of potential heat strokes, heat cramps, and heat exhaustion during prolonged exposure
Average hours/day that exceeding threshold > 5 , across all future climate scenarios and periods considered

2080-2100

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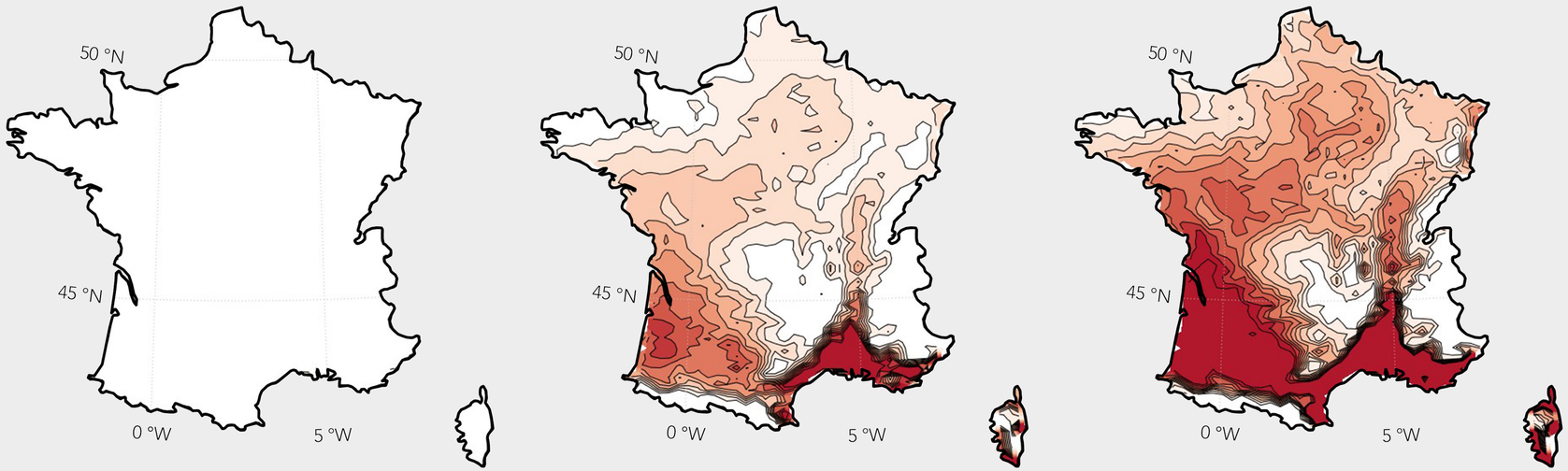
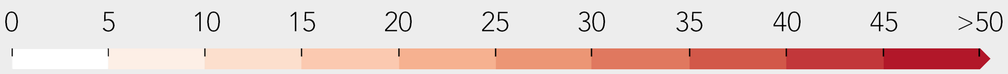
Poor ventilation
(overheating risk)





CDD.yr^{-1}
(Temperature Demand for Safety)

RESULTS
RCP8.5 / TEMPERATURE DEMAND FOR SAFETY
(3.7°C Global Warming Scenario)

Passive cooling (thermal mass + nocturnal convective cooling) fulfills100% of the temperature demand for safety across present and future climates in all considered RCP scenarios

1980-2000

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SCENARIO 3
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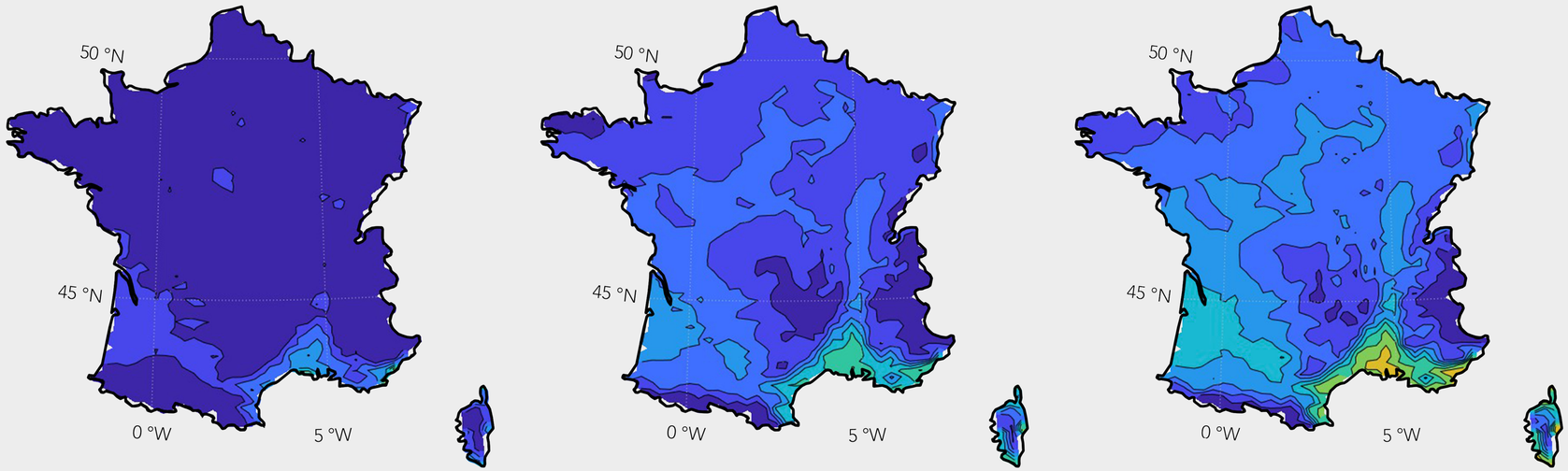
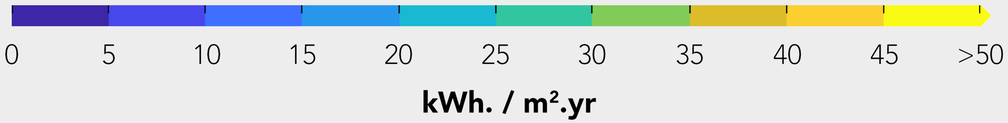
Poor ventilation
(overheating risk)



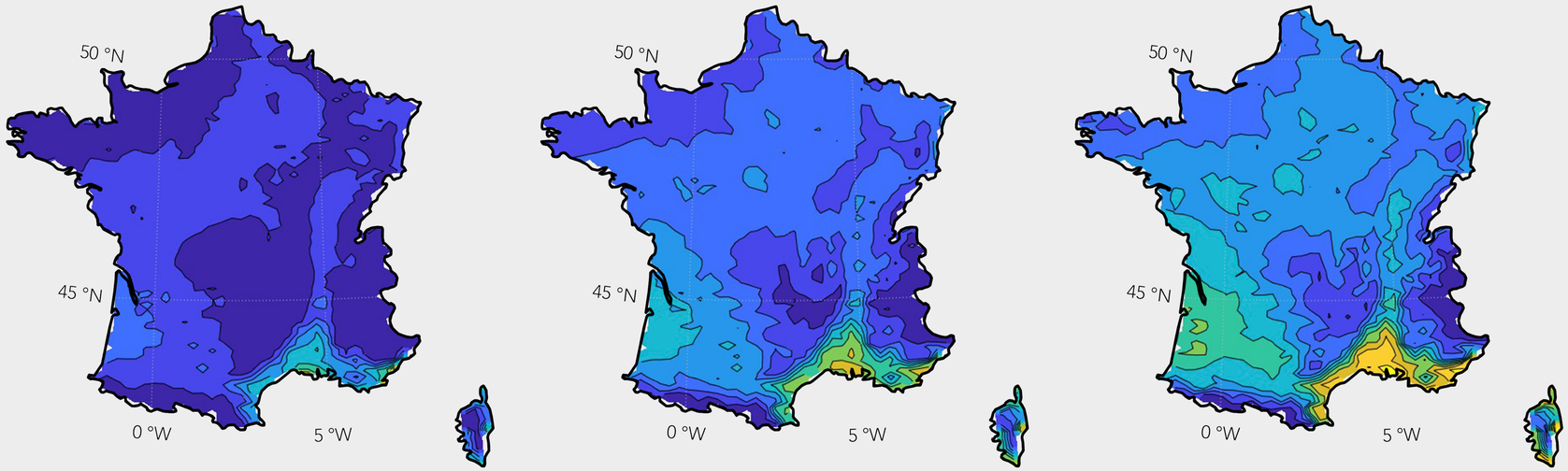


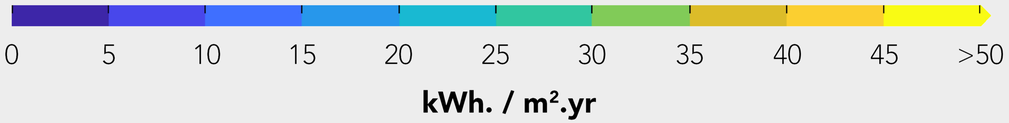
2040-2060

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)





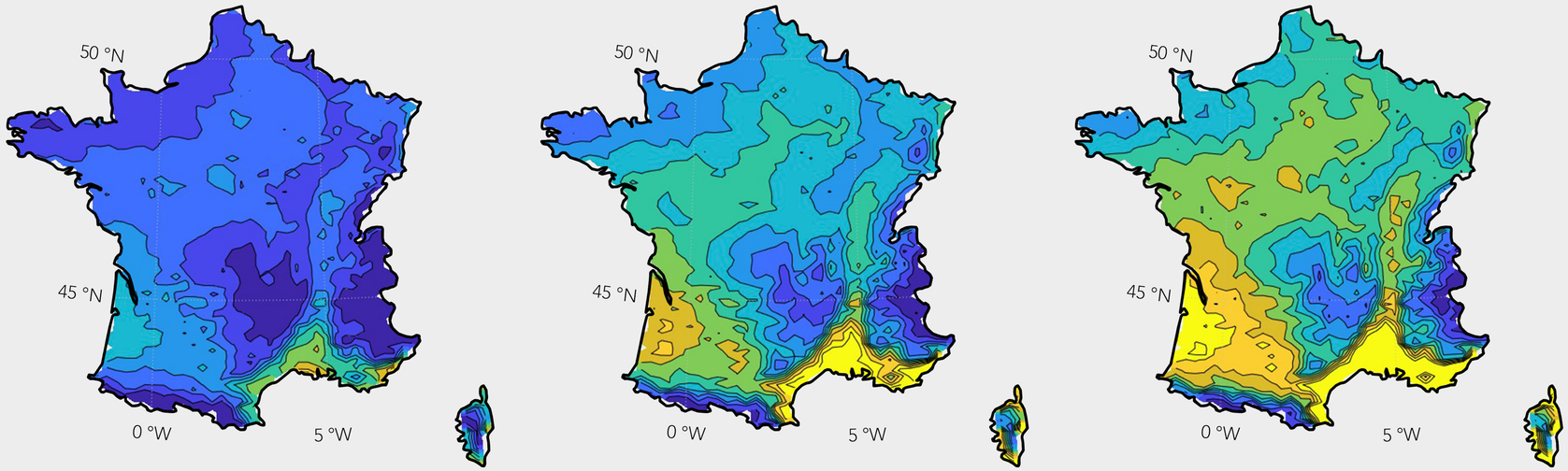
RESULTS
RCP8.5 / ENERGY USE FOR SPACE COOLING
(3.7°C Global Warming Scenario)

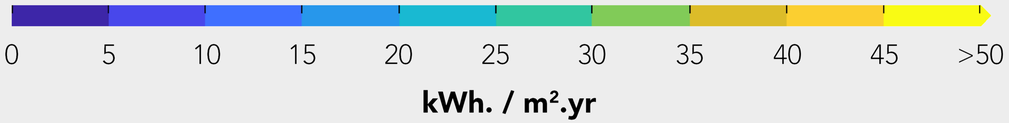
2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)





RESULTS
RCP8.5 / ENERGY USE FOR SPACE COOLING
(3.7°C Global Warming Scenario)

2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

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SCENARIO 3
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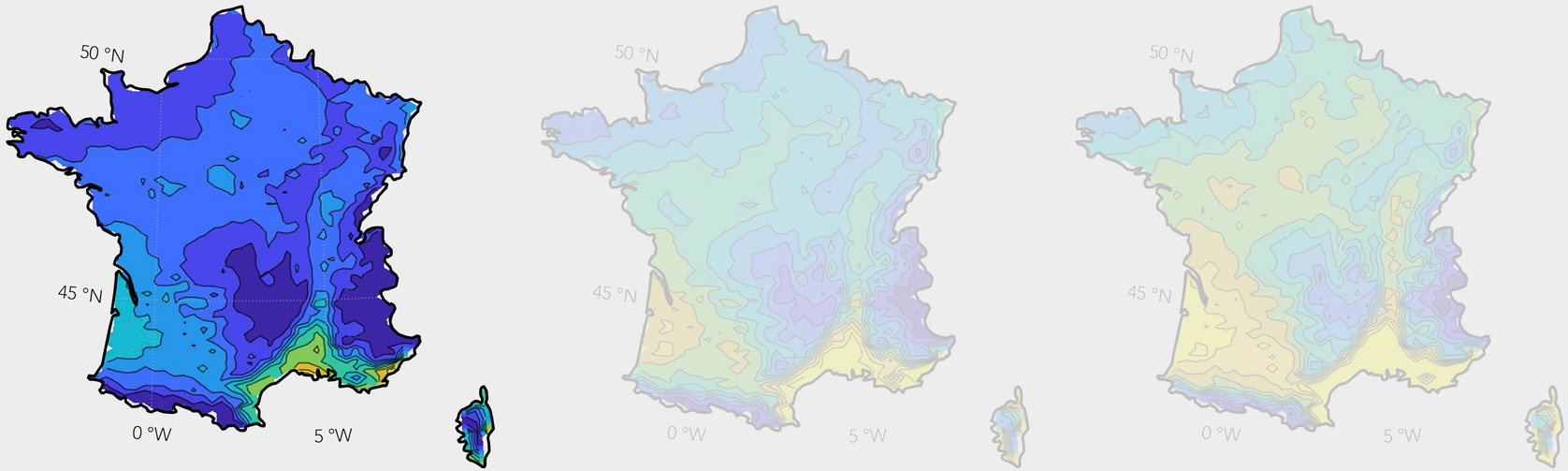
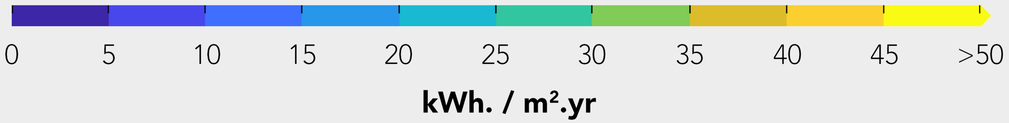
Poor ventilation
(overheating risk)





RESULTS
RCP8.5 / ENERGY USE FOR SPACE COOLING
(3.7°C Global Warming Scenario)

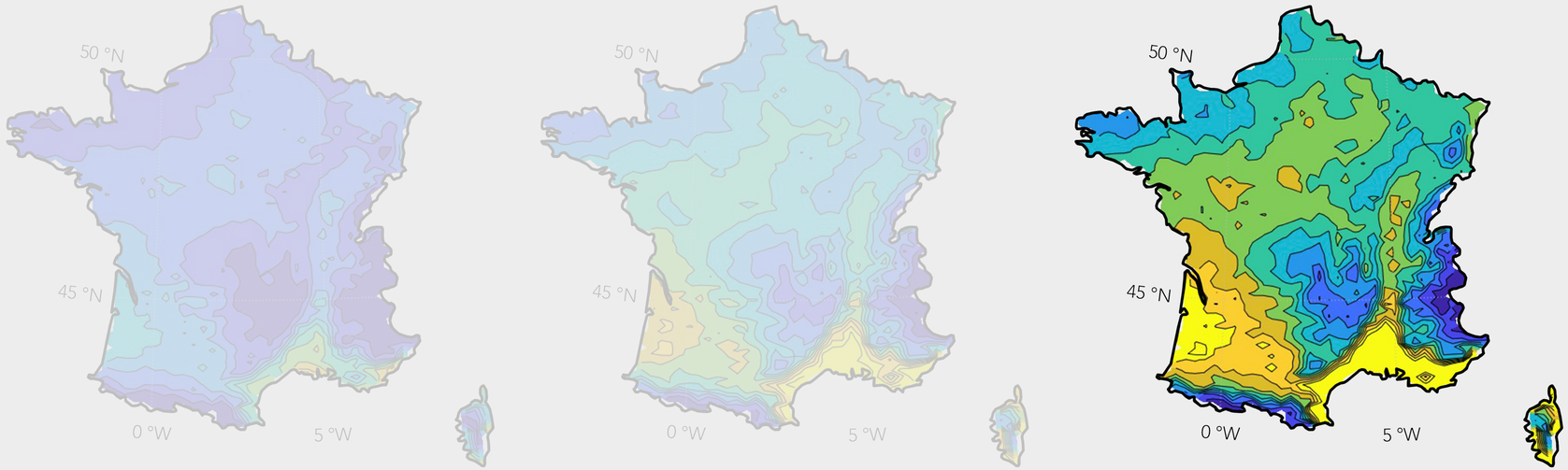
Significant ability of high thermal mass buildings to delay the requirement for AC equipment installation, offering enhanced climate resilience

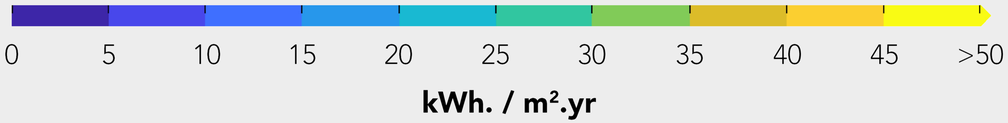
2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)





RESULTS
RCP8.5 / ENERGY USE FOR SPACE COOLING
(3.7°C Global Warming Scenario)

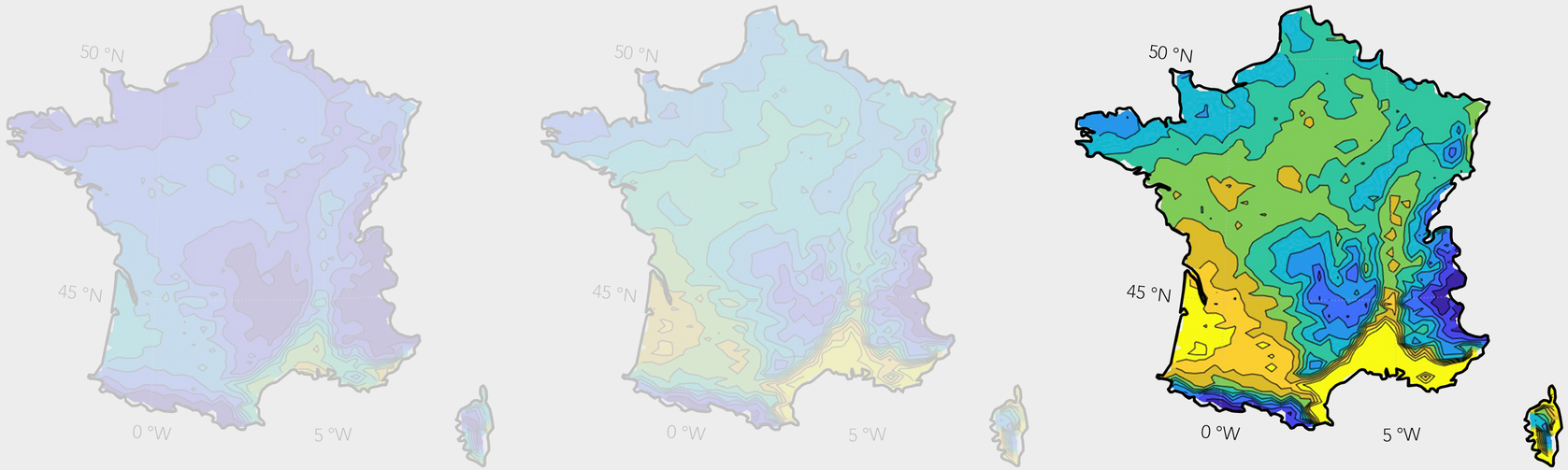
70% of the national territory facing climates that necessitate > 20 kWh/m².yr for buildings exposed to overheating risks (RCP8.5)
20% of the national territory facing climates that necessitate > 20 kWh/m².yr for buildings exposed to overheating risks (RCP4.5)

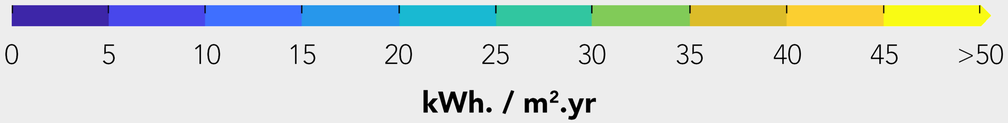
2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)





RESULTS
RCP8.5 / ENERGY USE FOR SPACE COOLING
(3.7°C Global Warming Scenario)

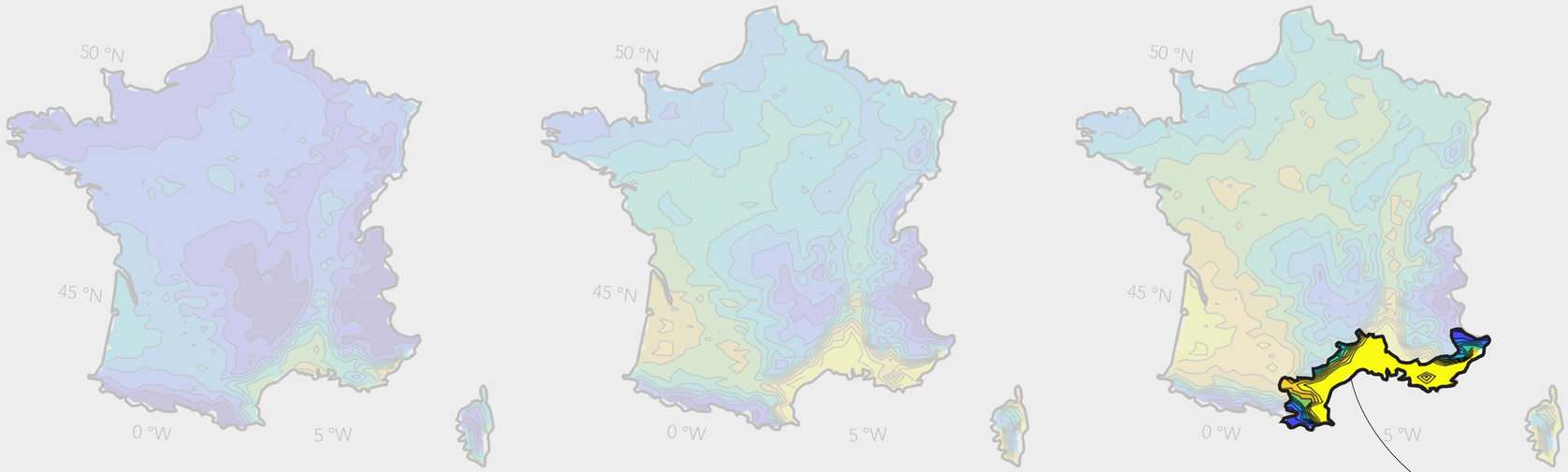
8% of the national territory facing climates that necessitate > 50 kWh/m².yr for buildings exposed to overheating risks (RCP8.5)
2% of the national territory facing climates that necessitate > 20 kWh/m².yr for buildings exposed to overheating risks (RCP4.5)

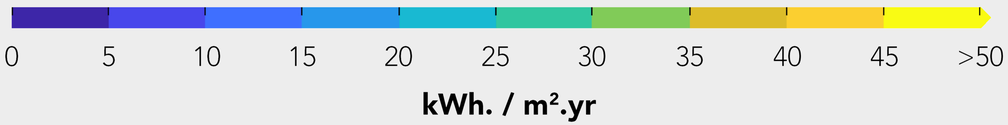
2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)





RESULTS
RCP8.5 / ENERGY USE FOR SPACE COOLING
(3.7°C Global Warming Scenario)

38% of H3 zone facing climates that necessitate > 50 kWh/m².yr for buildings exposed to overheating risks (RCP8.5)
10% of H3 zone facing climates that necessitate > 20 kWh/m².yr for buildings exposed to overheating risks (RCP4.5)

2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
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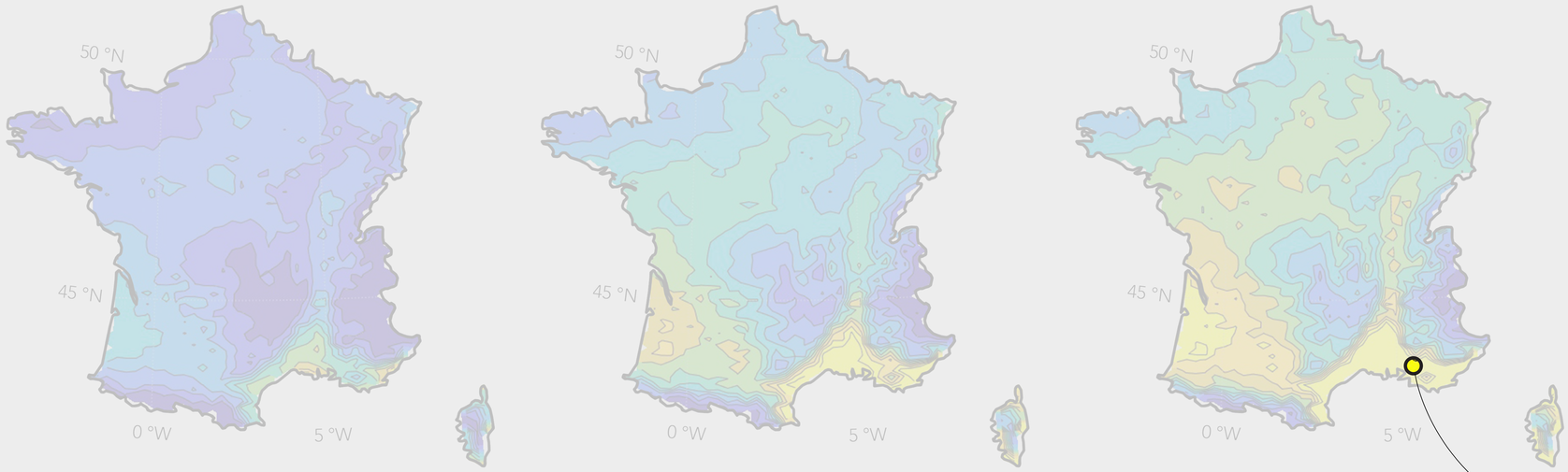
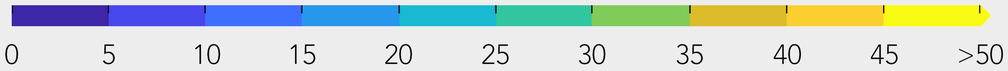
Poor ventilation
(overheating risk)





kWh. / m².yr

RESULTS
RCP8.5 / ENERGY USE FOR SPACE COOLING
(3.7°C Global Warming Scenario)

Peak values of 75 kWh/m².yr for buildings exposed to overheating risks (RCP8.5)
Peak values of 57 kWh/m².yr for buildings exposed to overheating risks (RCP4.5)

2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
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Poor ventilation
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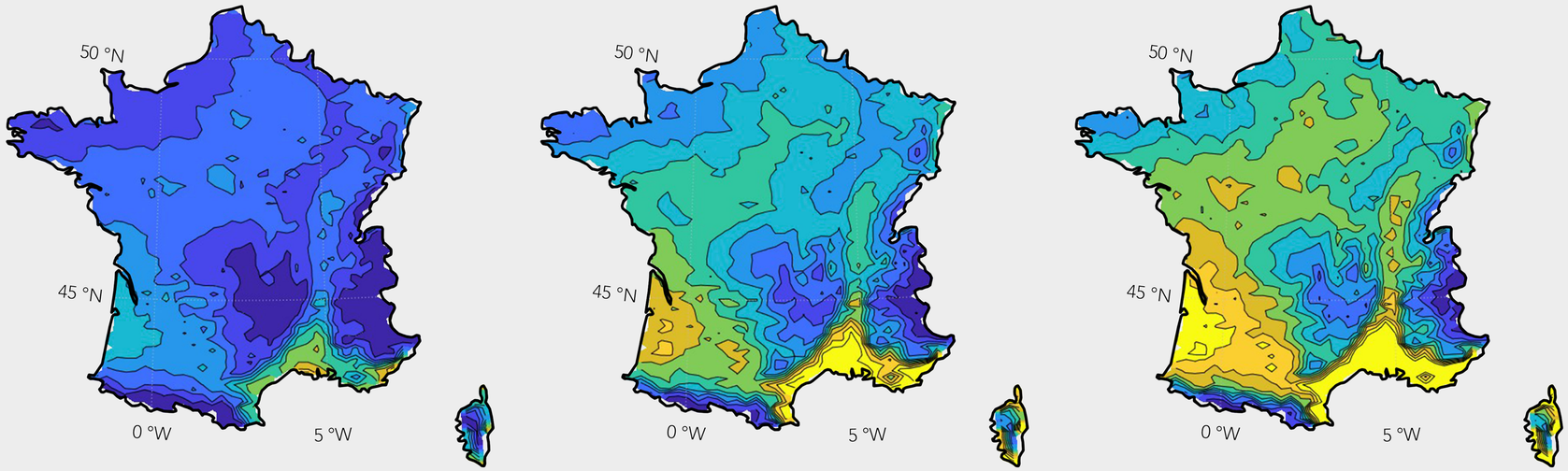
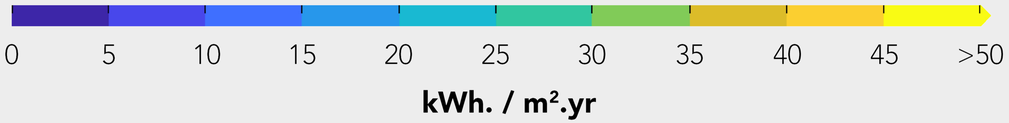




RESULTS
RCP8.5 / ENERGY USE FOR SPACE COOLING
(3.7°C Global Warming Scenario)

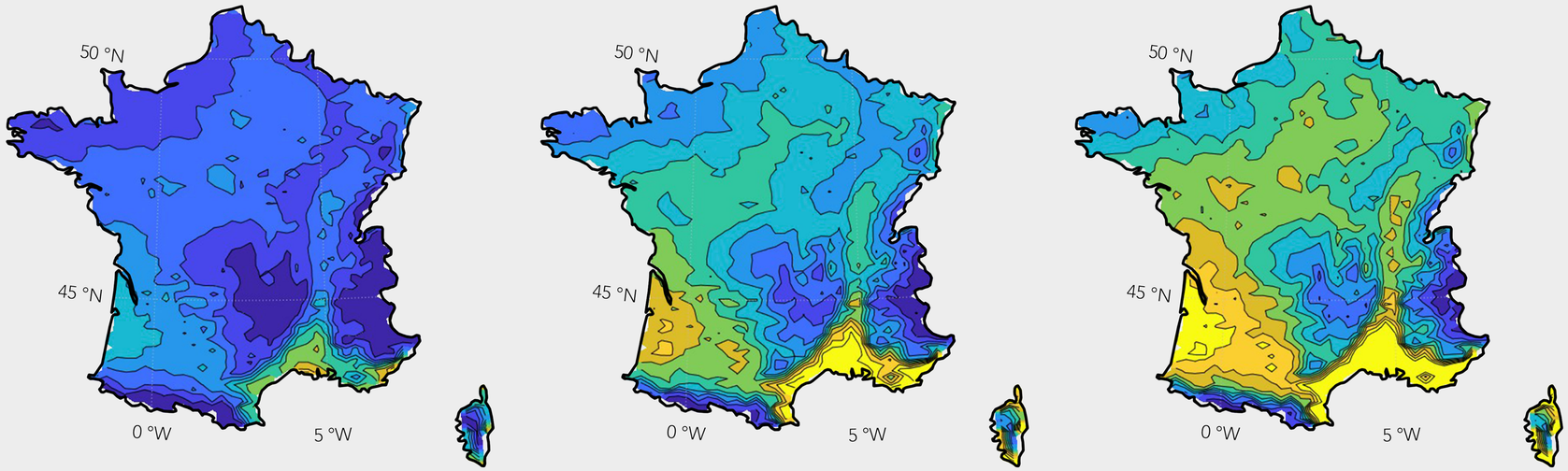
Given the maximum primary energy consumption thresholds of 70 kWh/m².yr established by the RE2020 regulation, thermal mass strategies could occupy a strategic role to reduce stress on the grid

2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)



kg CO2eq. / m².yr

0 0.29 0.58 0.87 1.16 1.45 1.74 2.03 2.32 2.61 >2.90

RESULTS
RCP8.5 / OPERATIONAL EMISSIONS FOR SPACE COOLING
(3.7°C Global Warming Scenario)

Direct correlation with energy consumption
Examined in light of the operational emission cap set by the RE2020 regulation (6.5 kgCO_2/m².yr)

2080-2100

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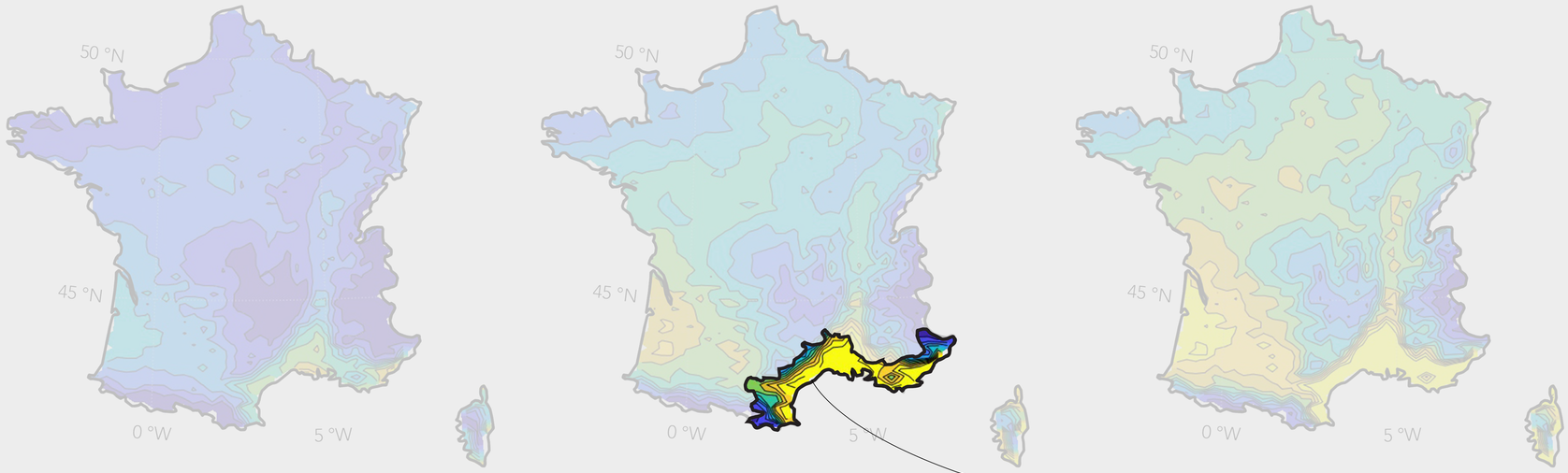


kg CO2eq. / m².yr

0 0.29 0.58 0.87 1.16 1.45 1.74 2.03 2.32 2.61 >2.90

RESULTS
RCP8.5 / OPERATIONAL EMISSIONS FOR SPACE COOLING
(3.7°C Global Warming Scenario)

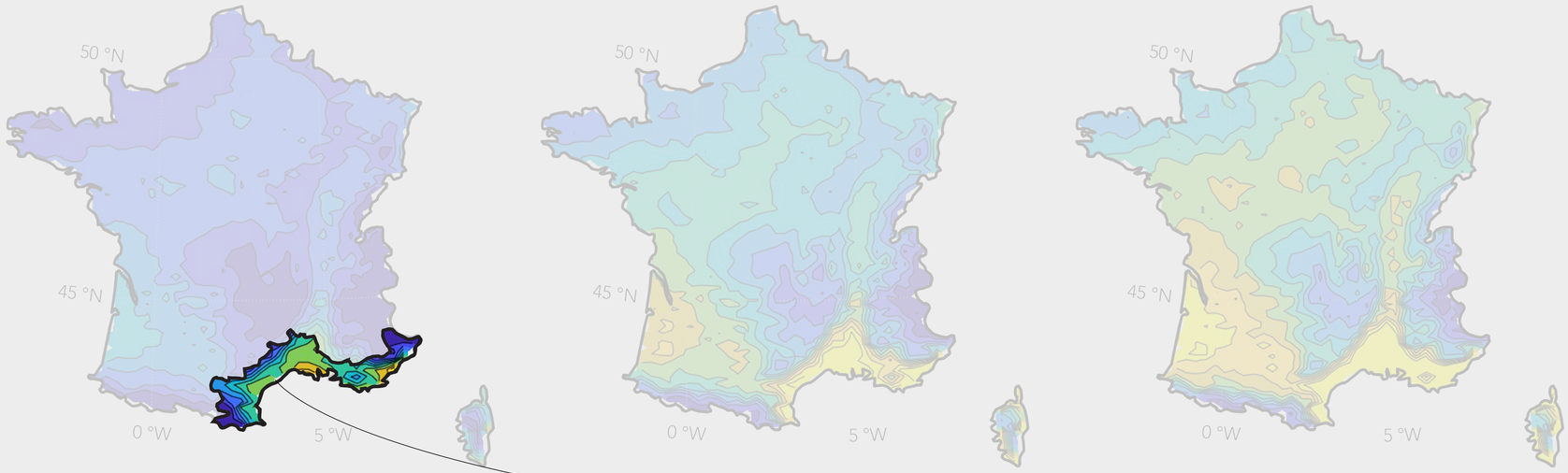
47% of H3 zone under climates where space cooling >1/4 (1.6 kgCO_2/m².yr) of operational emissions (RCP 8.5)
41% of H3 zone under climates where space cooling >1/4 (1.6 kgCO_2/m².yr) of operational emissions (RCP 4.5)

2080-2100

SCENARIO 1
High Internal Thermal Mass
Nocturnal Convective Cooling
(Givoni Model)

SCENARIO 2
Low Internal Thermal Mass
Well Ventilated

SCENARIO 3
Low Internal Thermal Mass
Poor ventilation
(overheating risk)

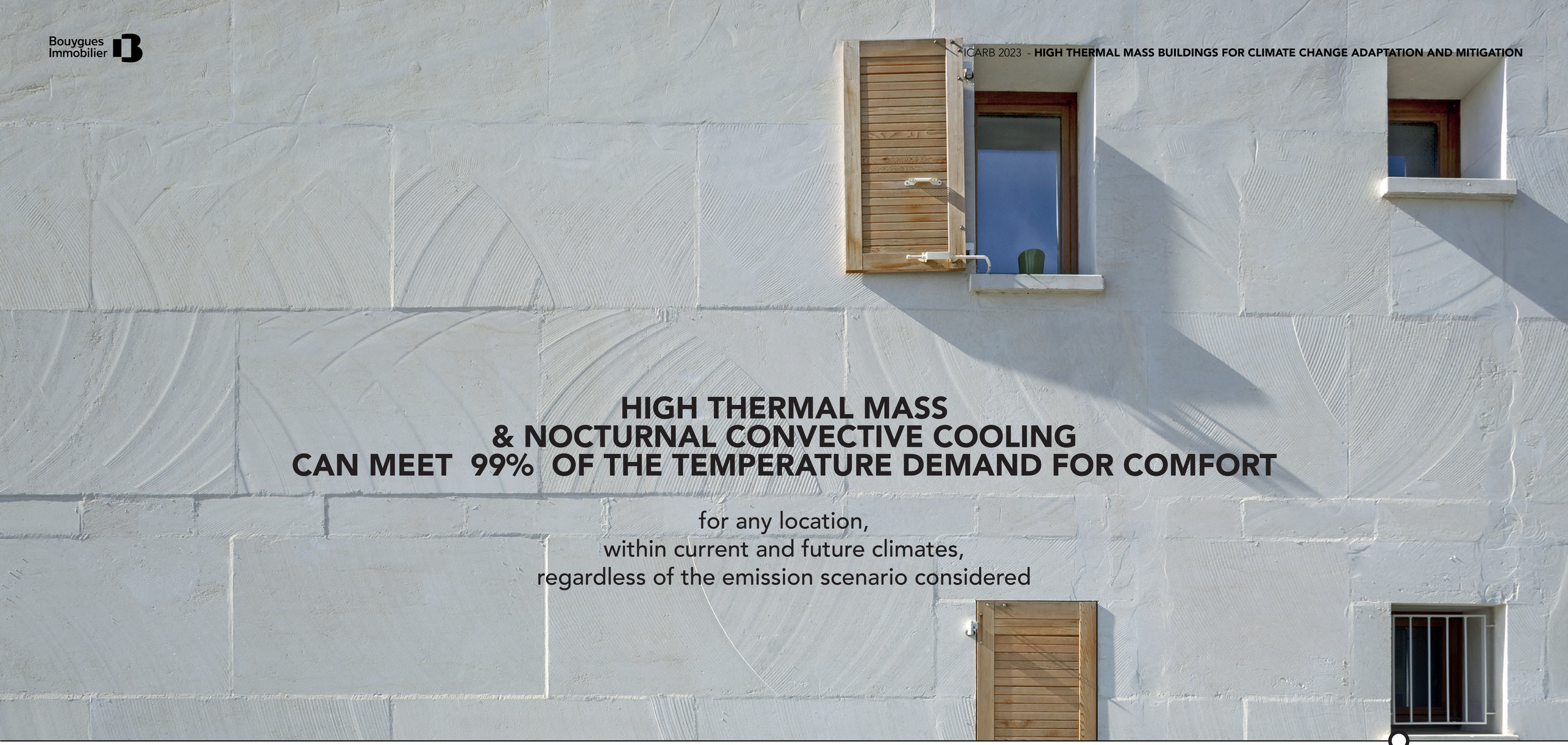


RESULTS
RCP8.5 / OPERATIONAL EMISSIONS FOR SPACE COOLING
(3.7°C Global Warming Scenario)

Hight thermal mass could maintain operational emissions from space cooling at 0.67 ± 0.66 kgCO_2/m².yr in H3 zone (RCP8.5 scenario, end of the century)

CONCLUSIONS

(relating to the French context)



HIGH THERMAL MASS & NOCTURNAL CONVECTIVE COOLING CAN MEET 99% OF THE TEMPERATURE DEMAND FOR COMFORT

for any location,
within current and future climates,
regardless of the emission scenario considered

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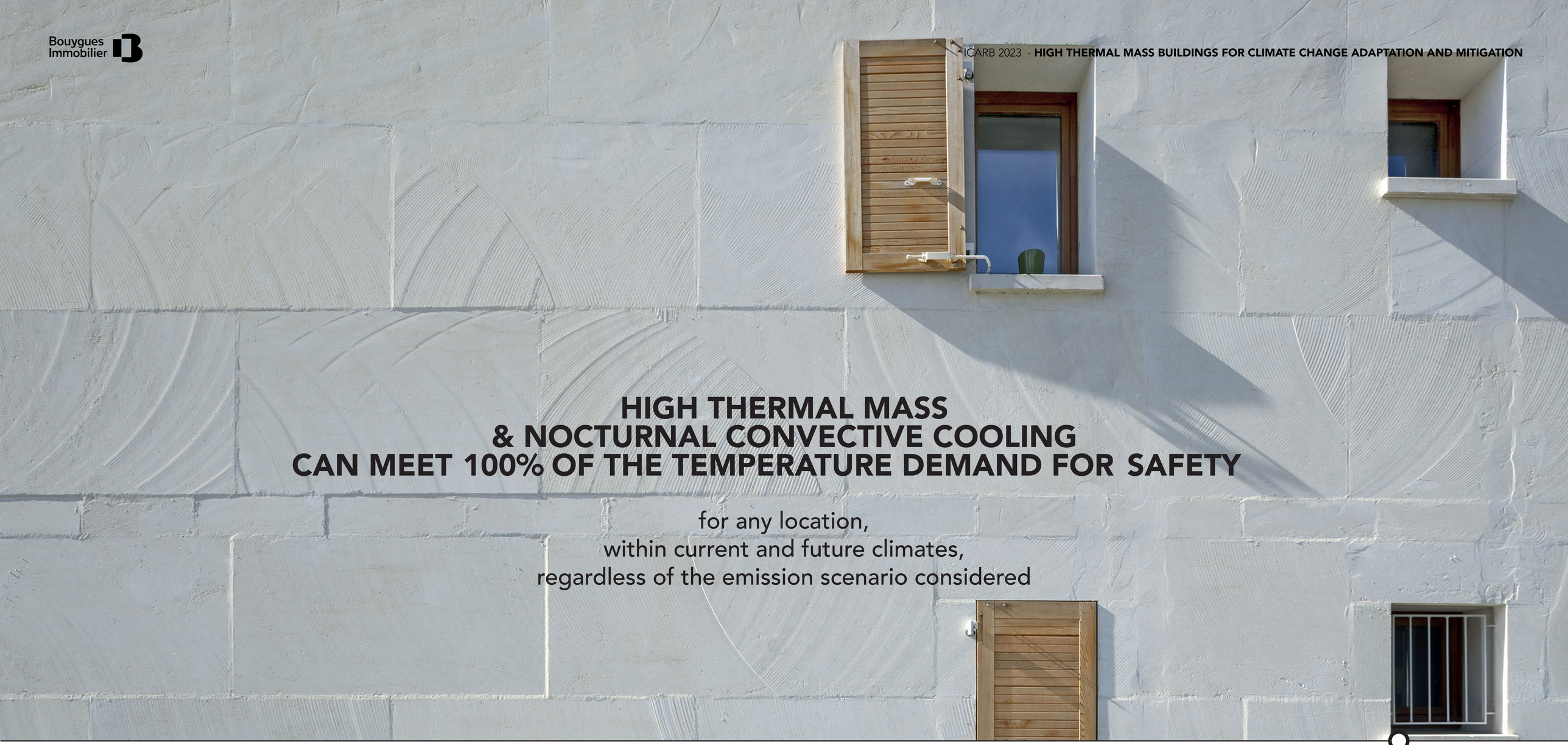

HIGH THERMAL MASS & NOCTURNAL CONVECTIVE COOLING CAN MEET 100% OF THE TEMPERATURE DEMAND FOR SAFETY

for any location,
within current and future climates,
regardless of the emission scenario considered

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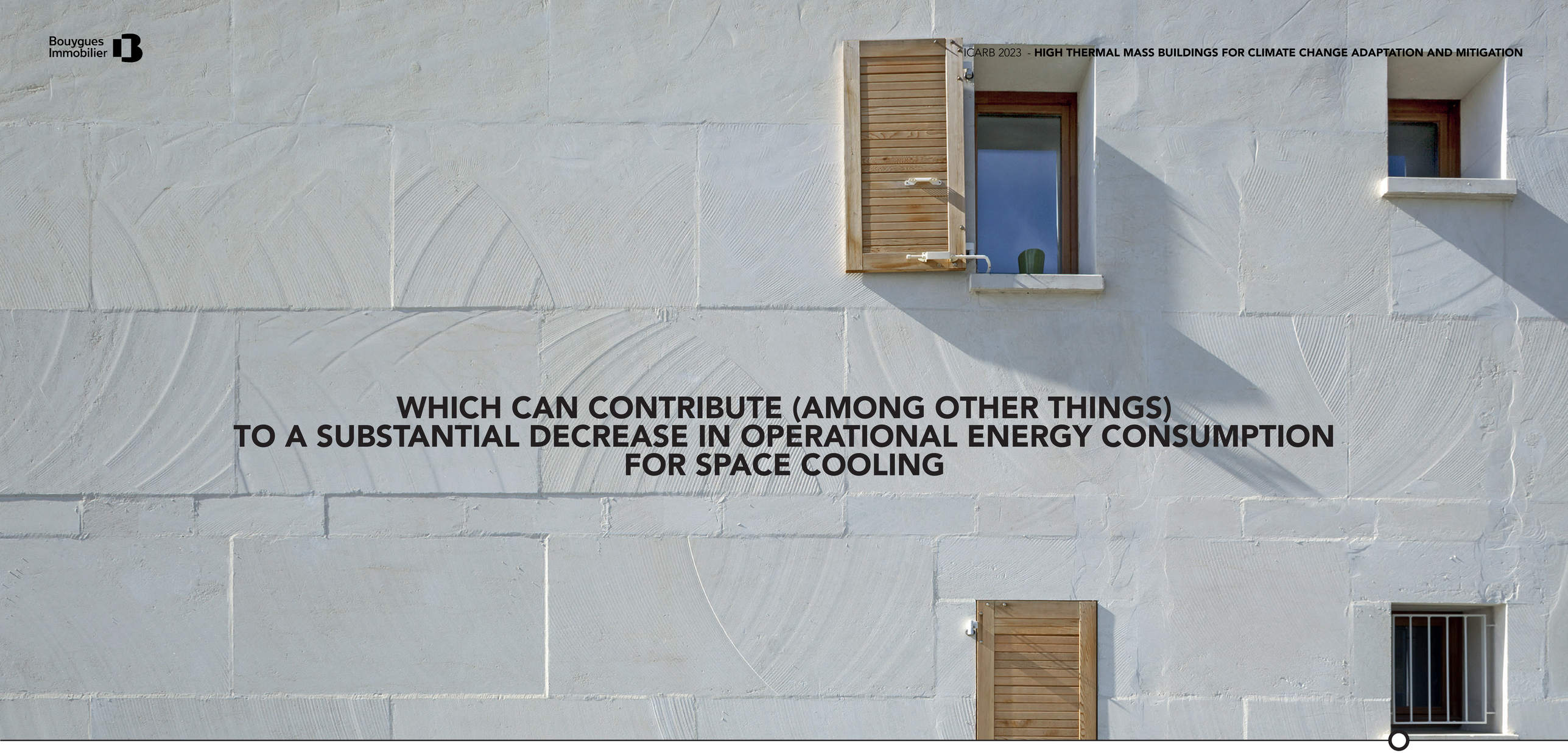

WHICH CAN CONTRIBUTE (AMONG OTHER THINGS) TO A SUBSTANTIAL DECREASE IN OPERATIONAL ENERGY CONSUMPTION FOR SPACE COOLING

CONCLUSIONS

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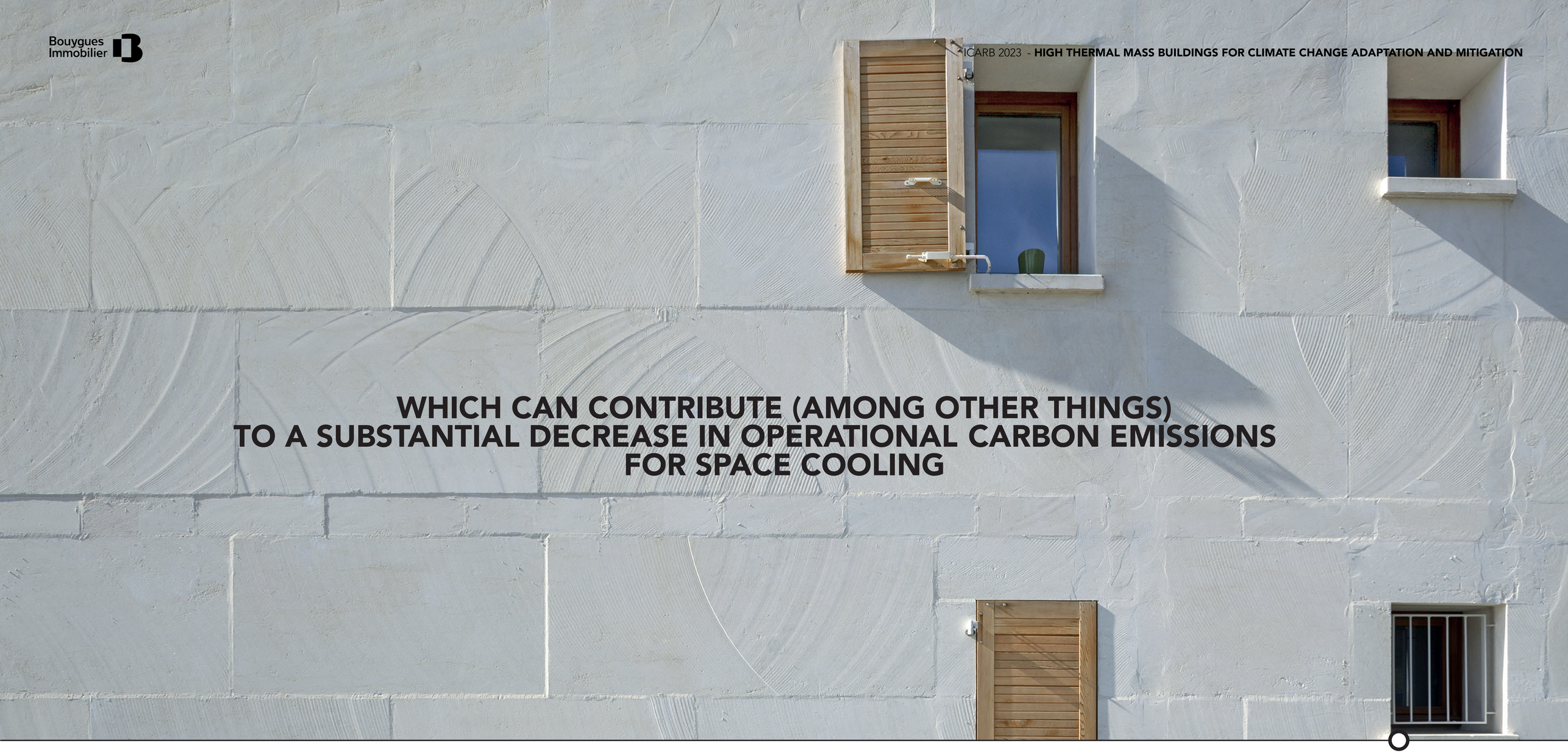

WHICH CAN CONTRIBUTE (AMONG OTHER THINGS) TO A SUBSTANTIAL DECREASE IN OPERATIONAL CARBON EMISSIONS FOR SPACE COOLING

CONCLUSIONS

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THANK YOU

ICARB