

Low-Carbon Climate Adaptation Strategies for Paris Center

4.433 | Urban Energy Modeling - Final Presentation

Ruoyu Lan, Sacha Moreau, Olivier Faber
May 7th, 2020

Introduction

1 | Architectural Context

2 | A Warming Climate

Introduction

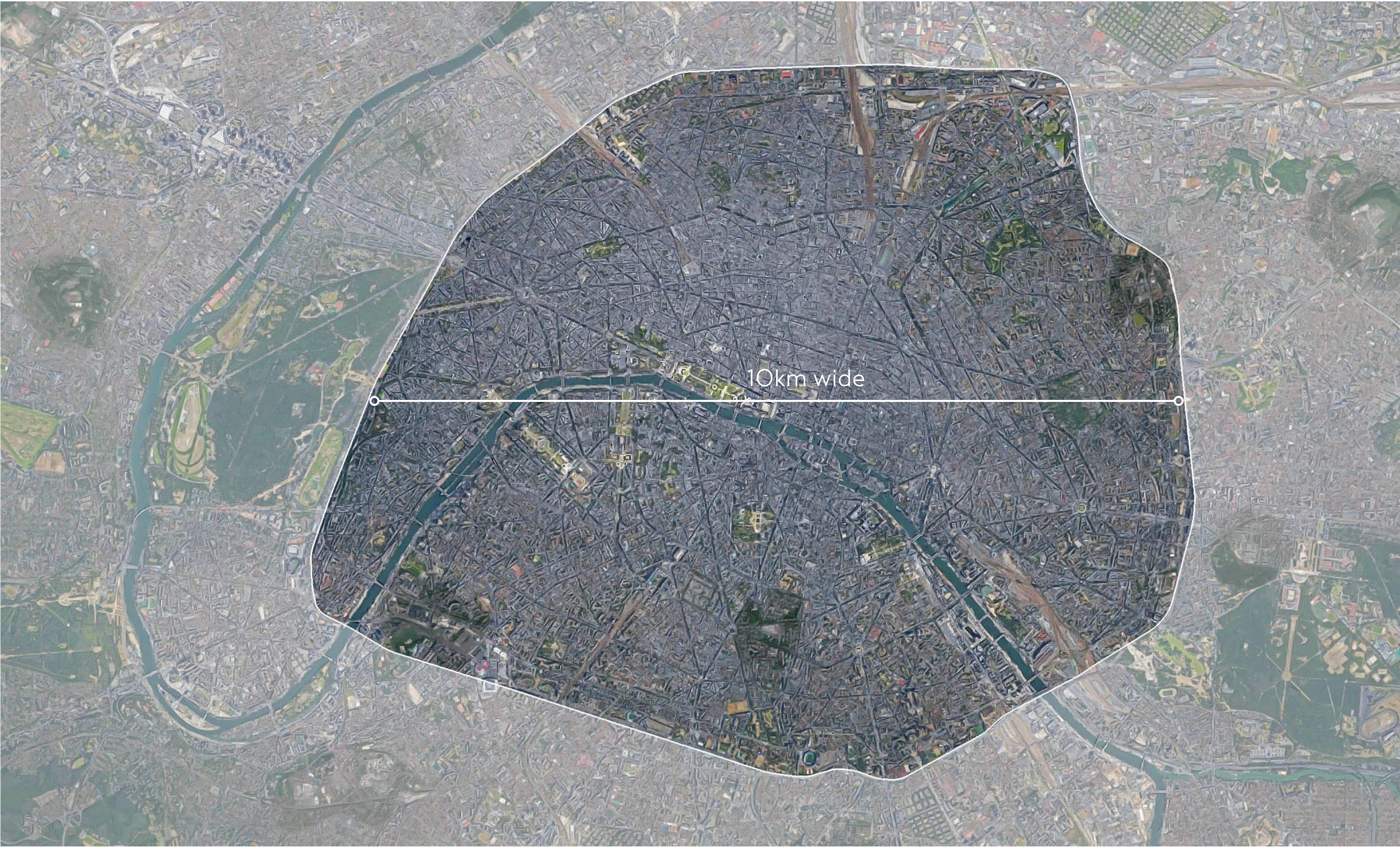
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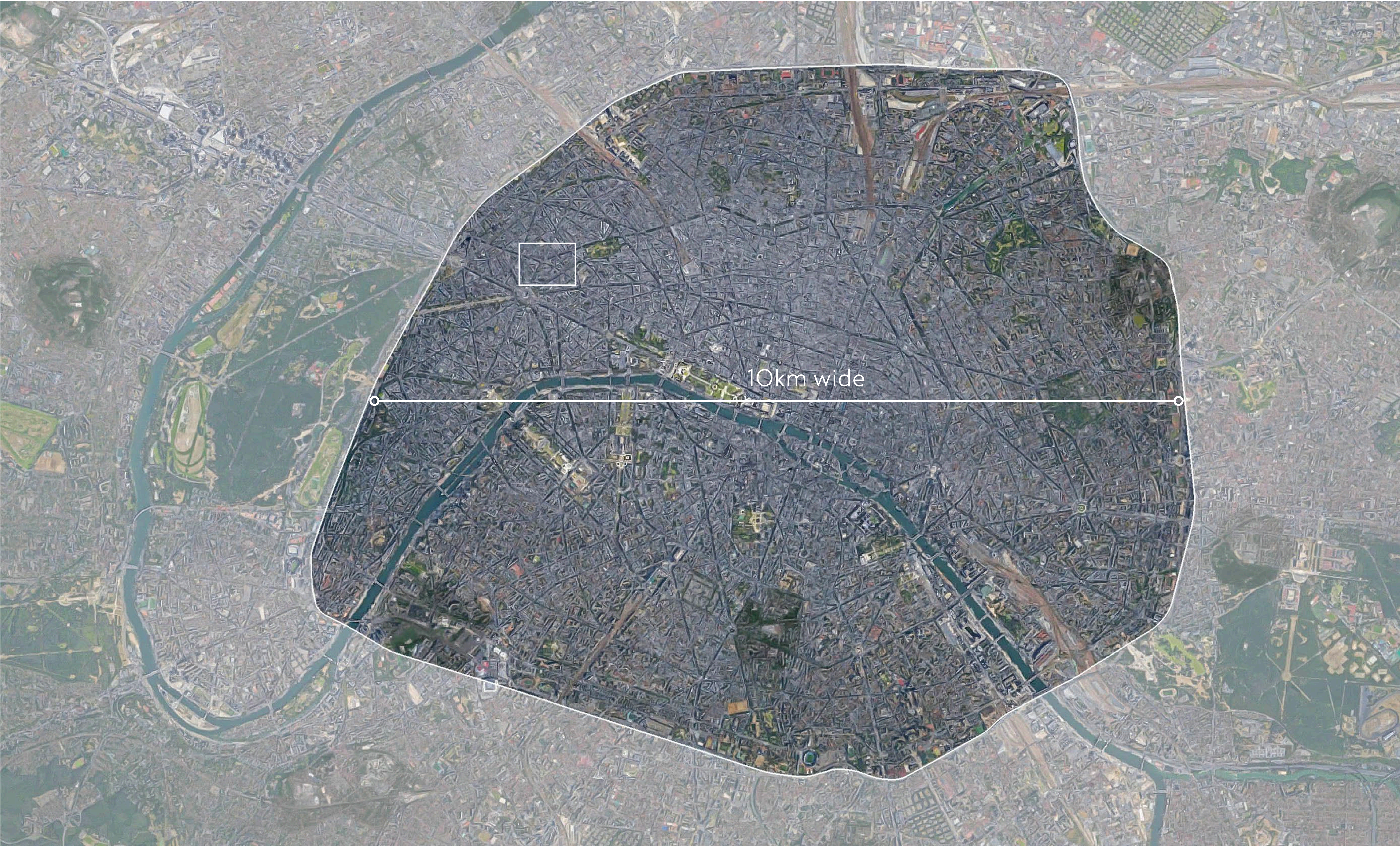
2 | A Warming Climate

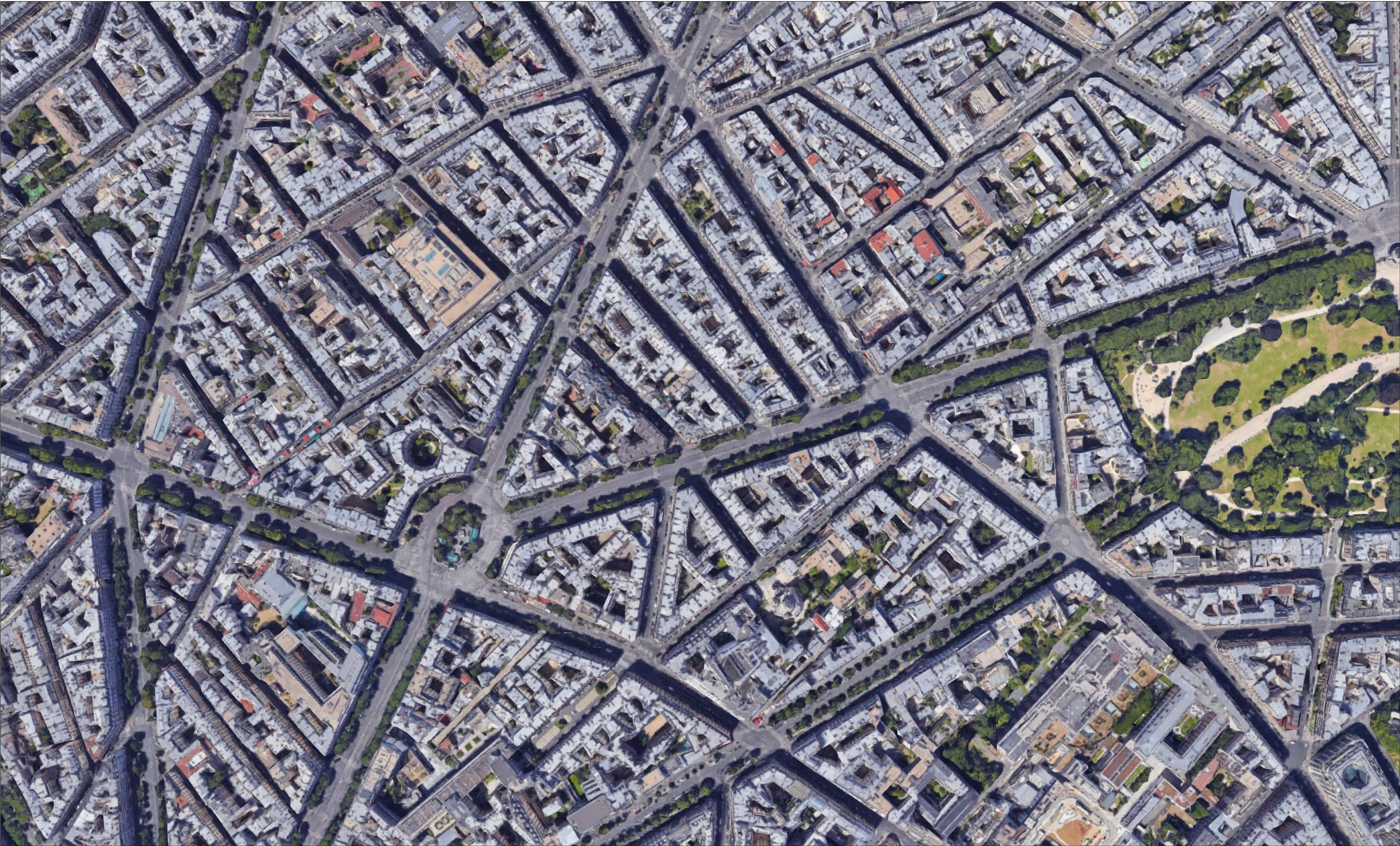


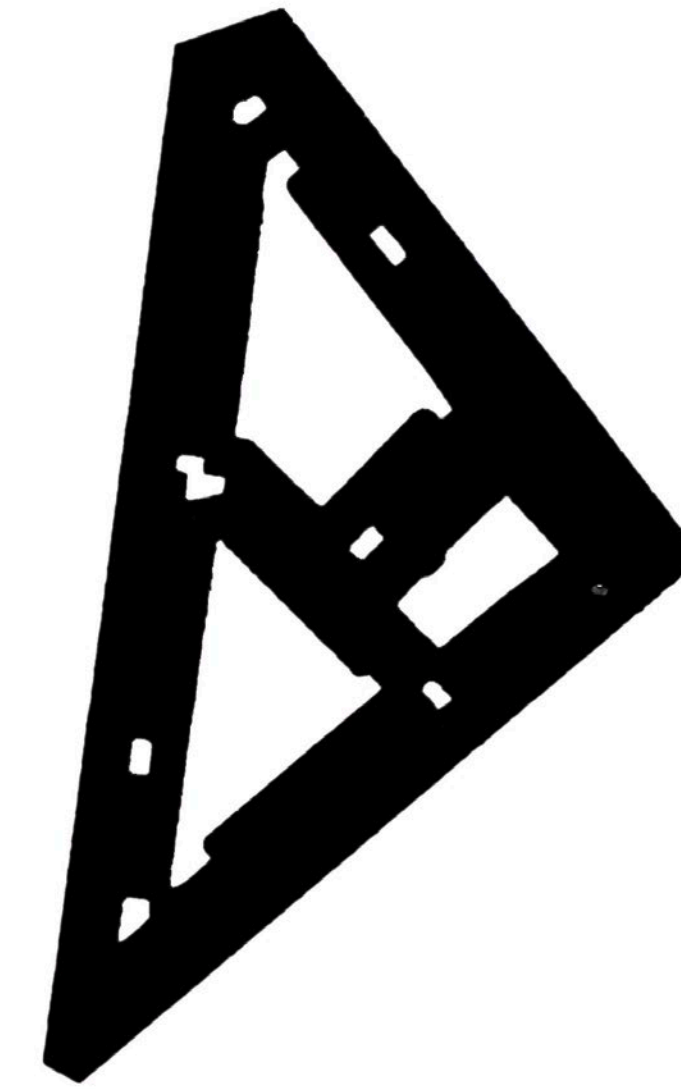
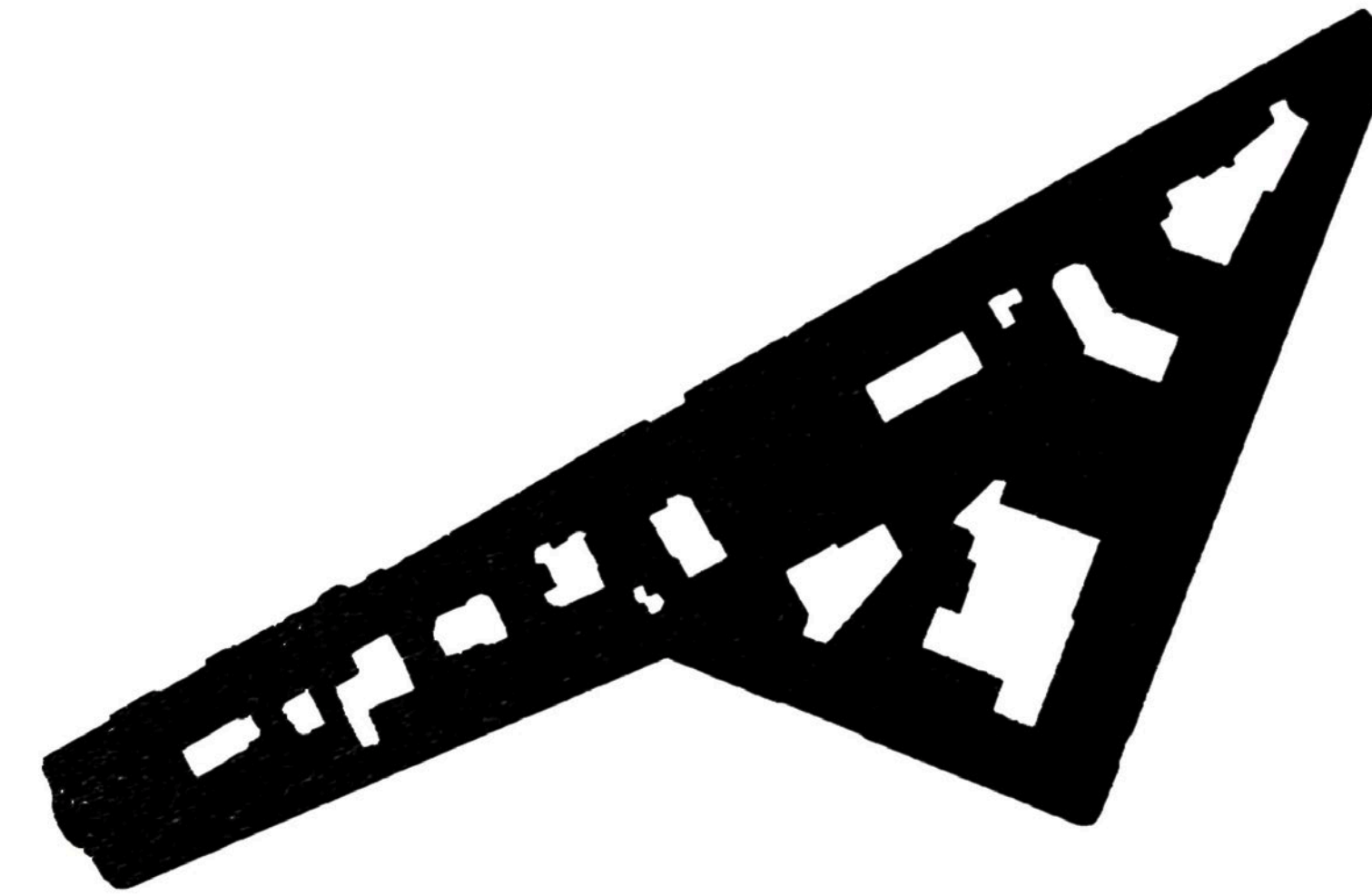
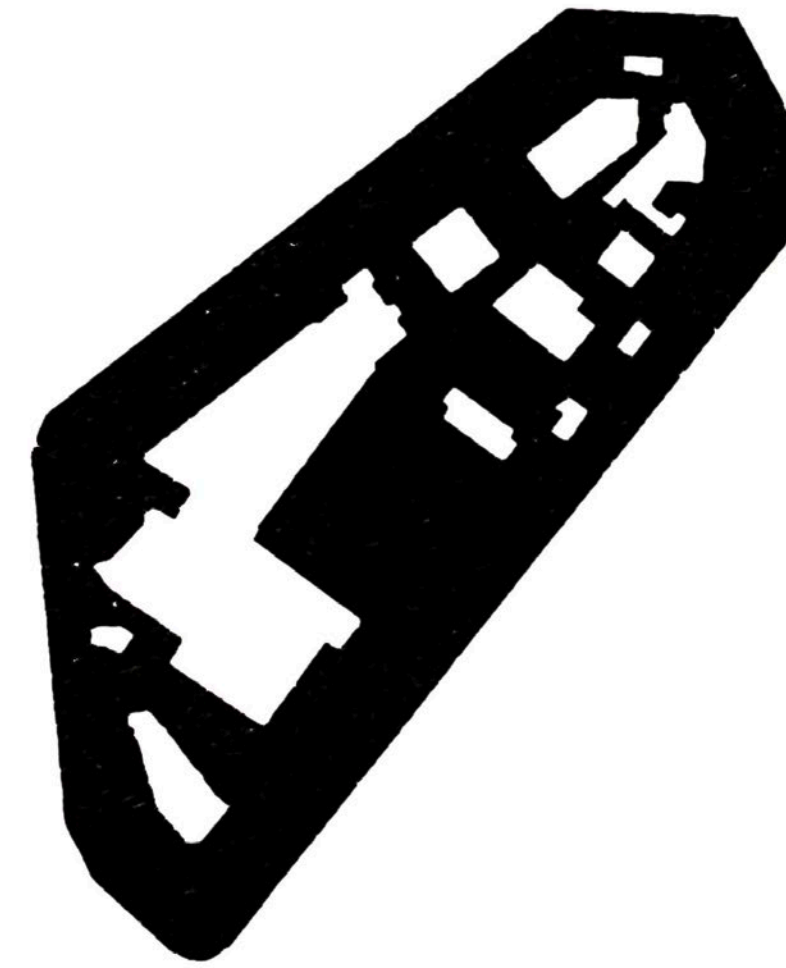
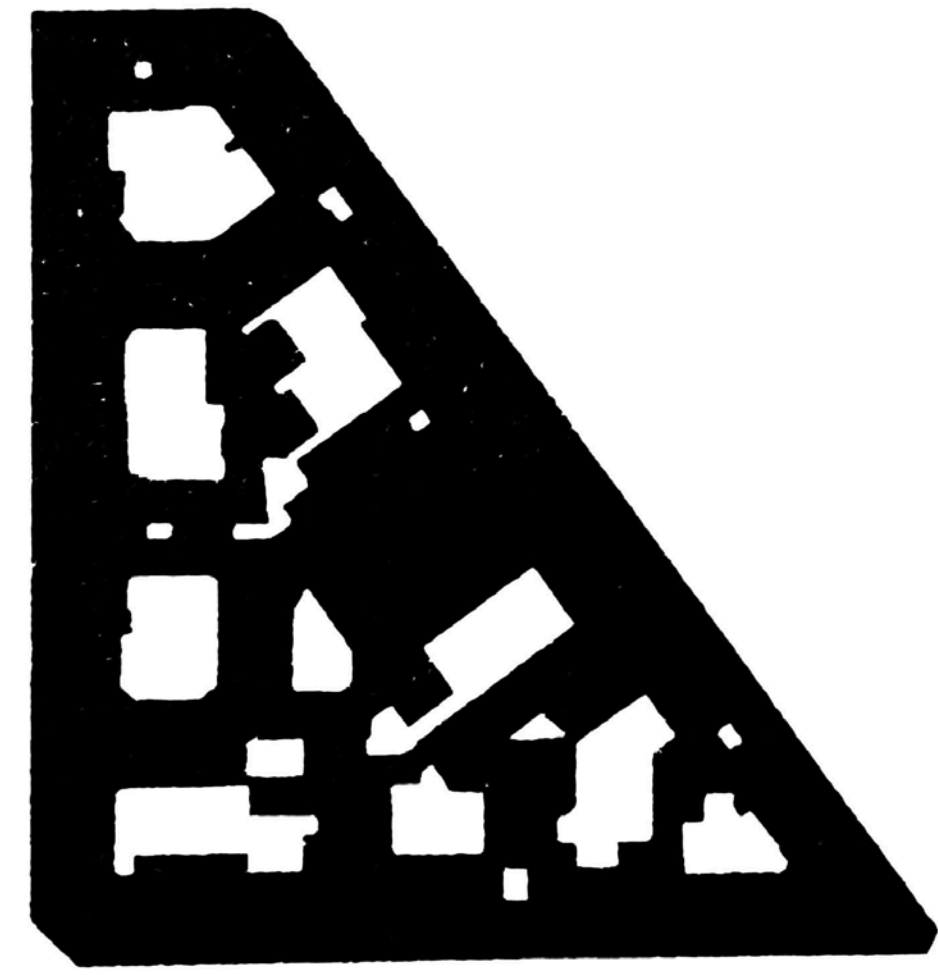
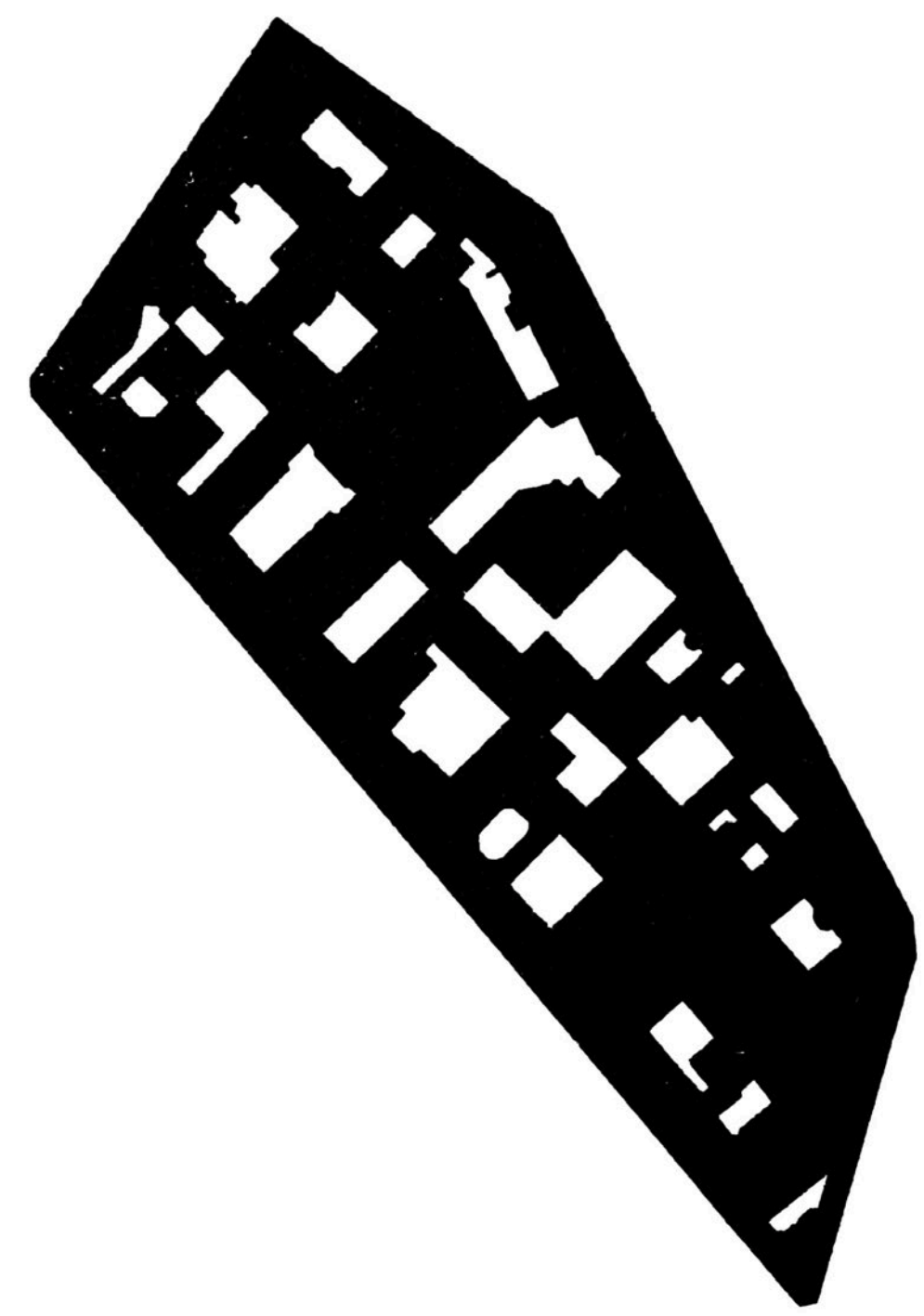
Architectural Context





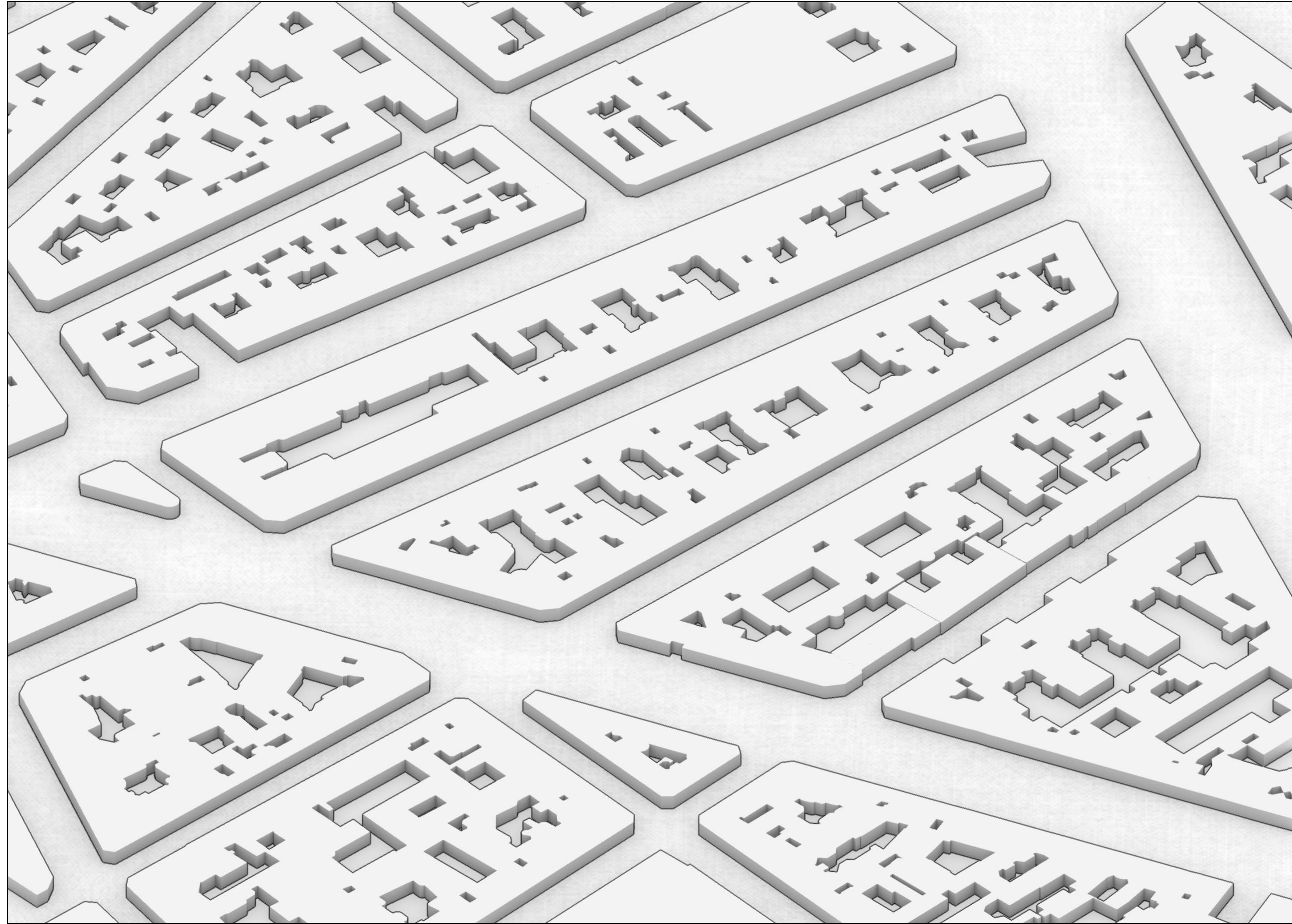




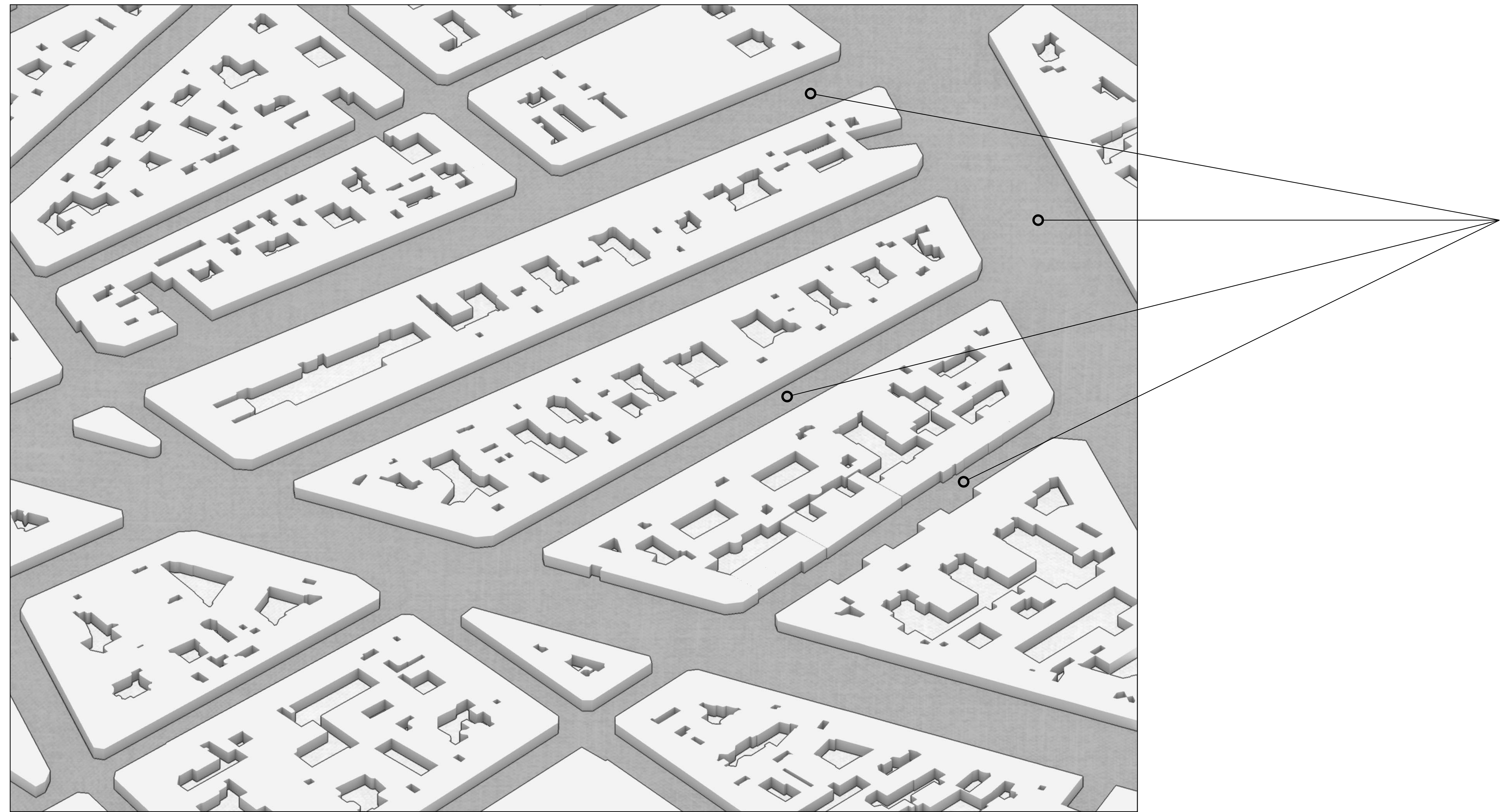


Haussmann City Blocks

1853 – 1870

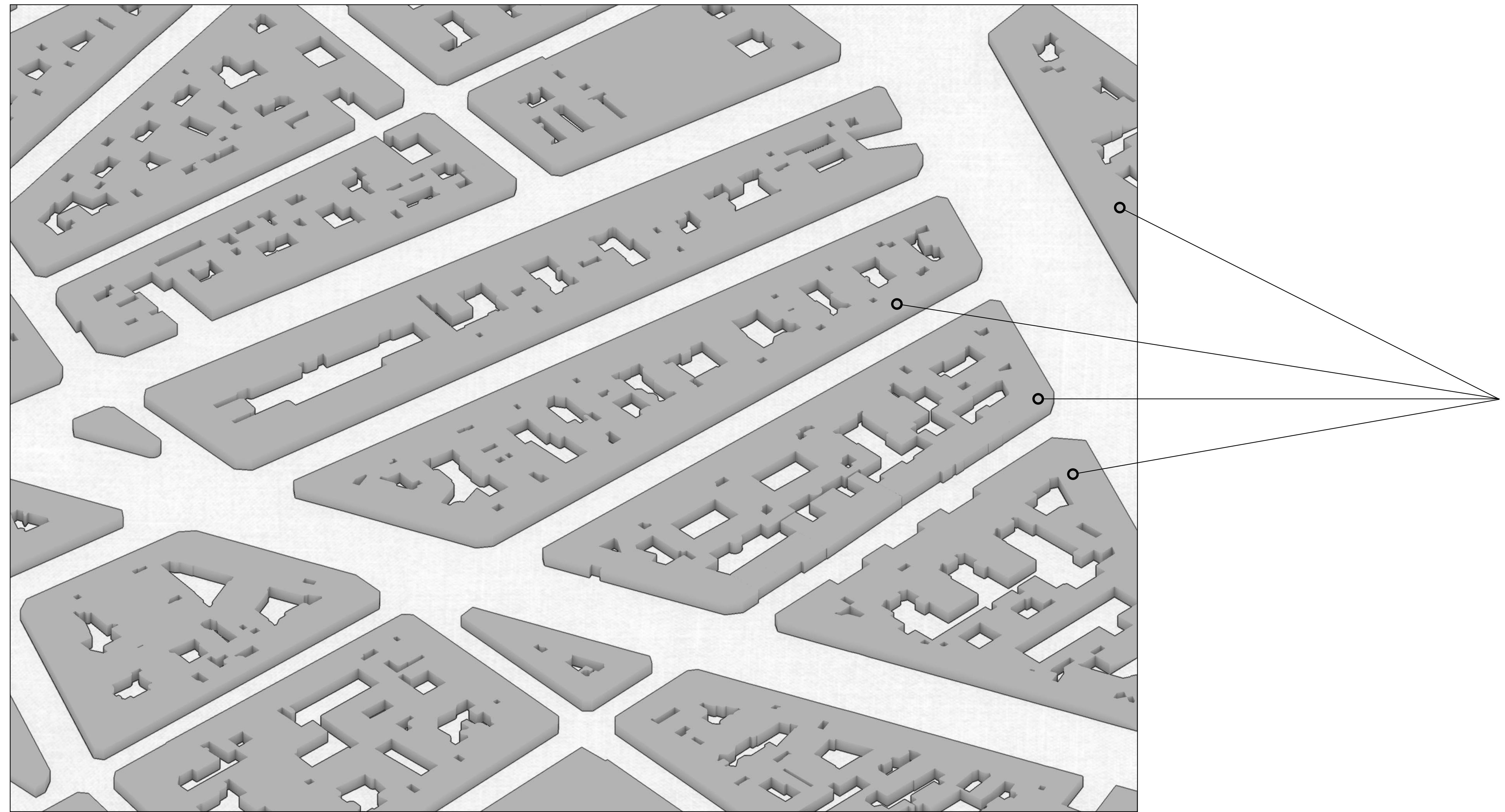


A Naturally Ventilated City



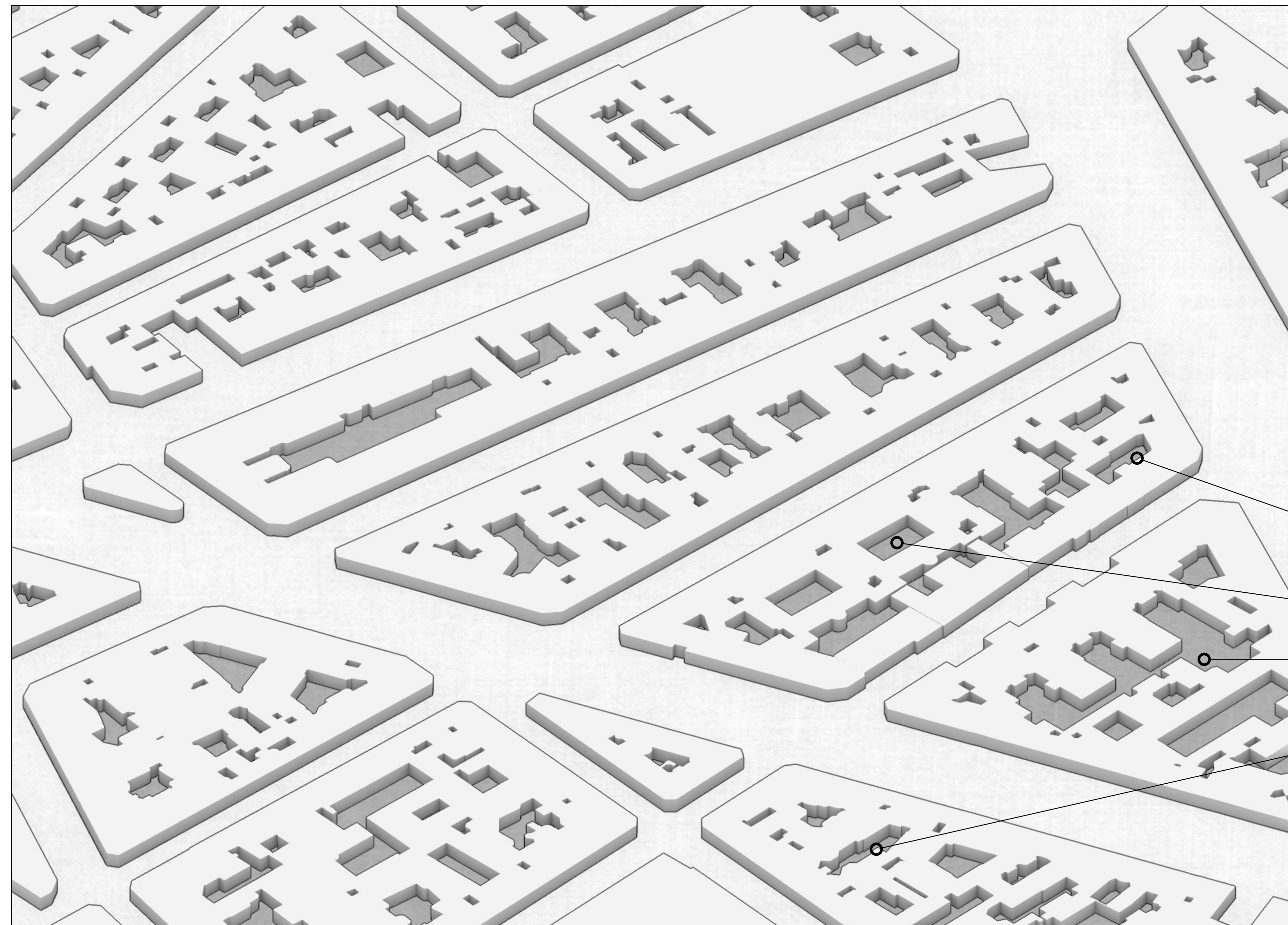
Streets

A Naturally Ventilated City



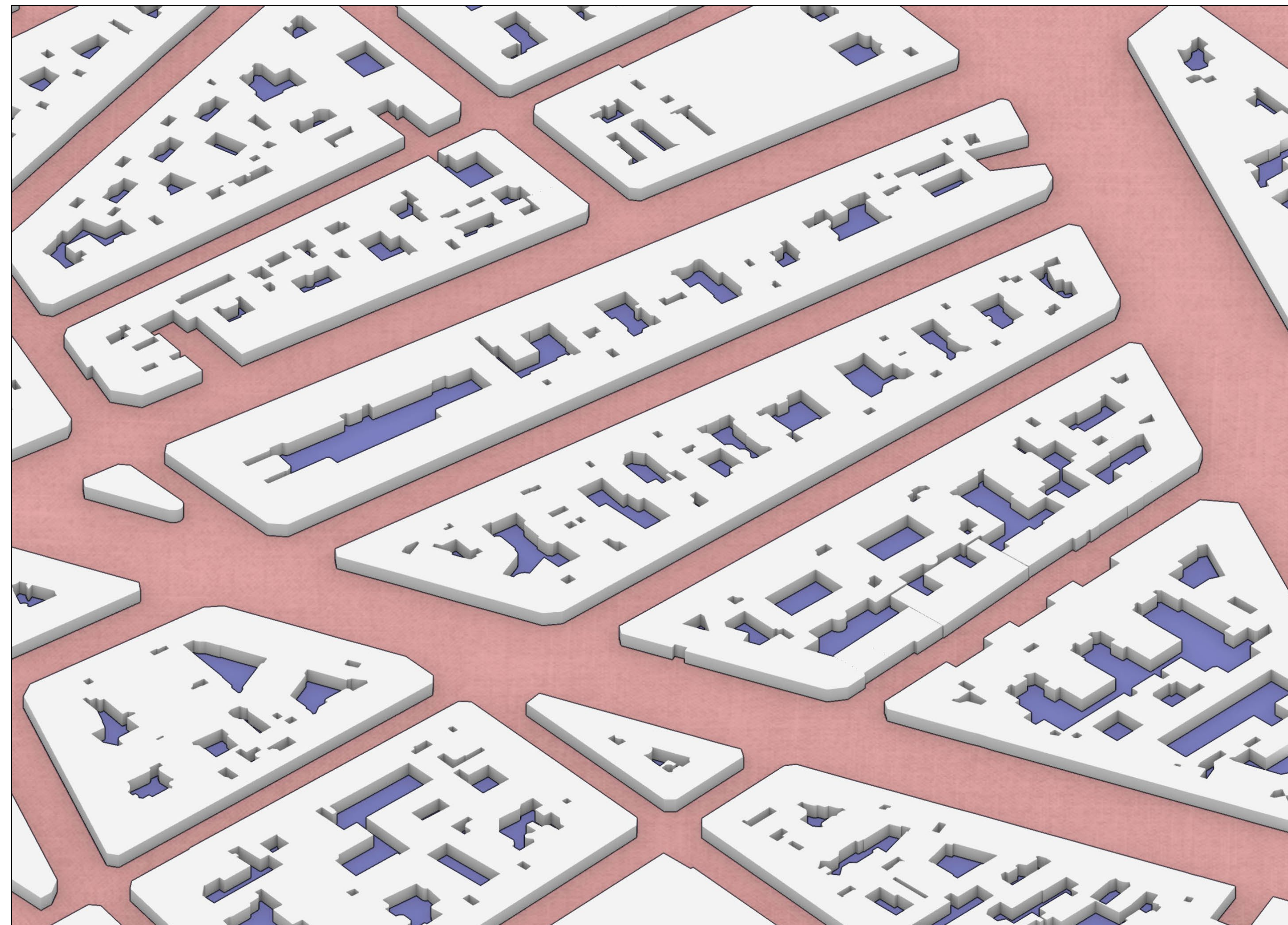
Buildings

A Naturally Ventilated City

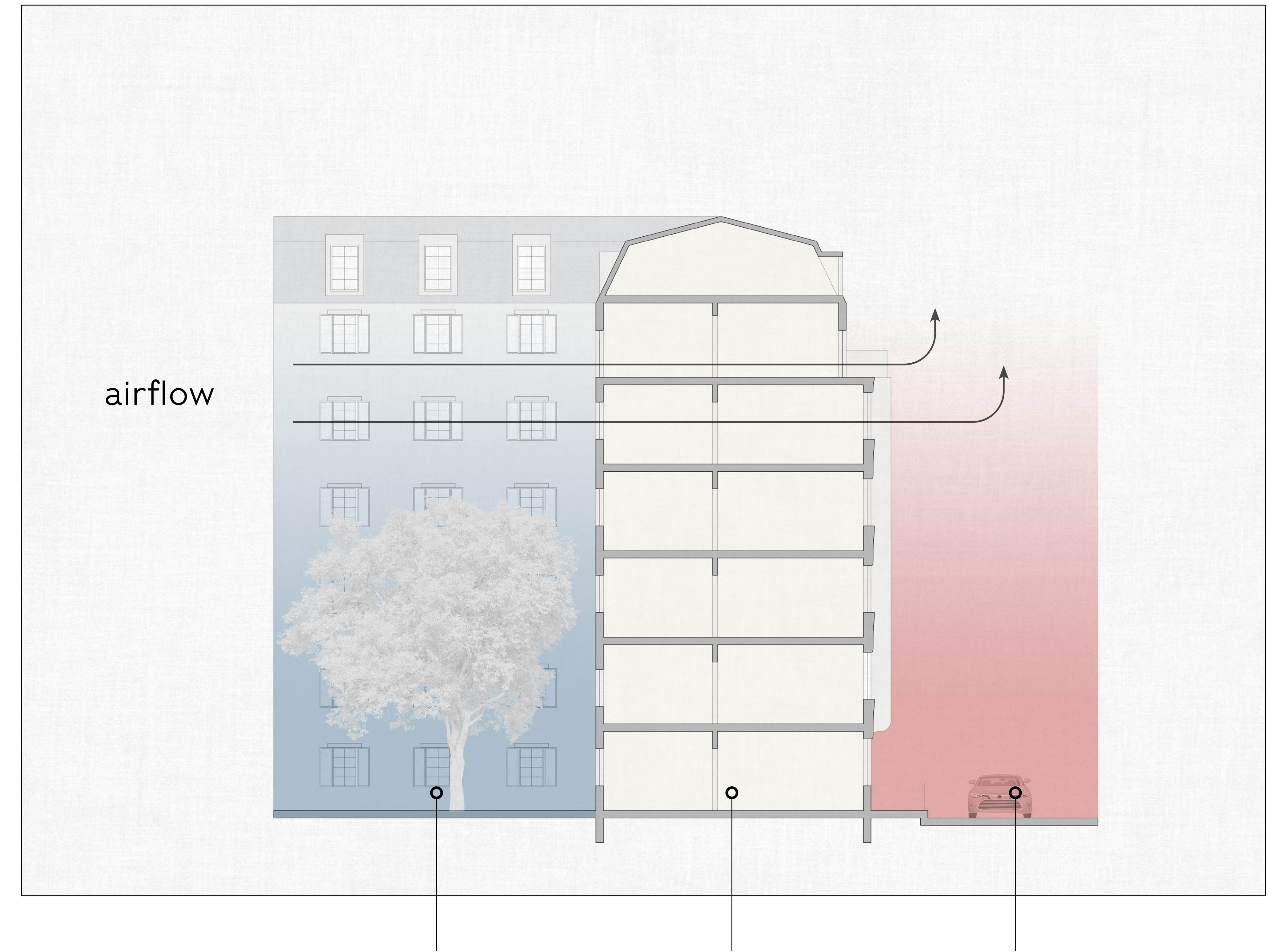
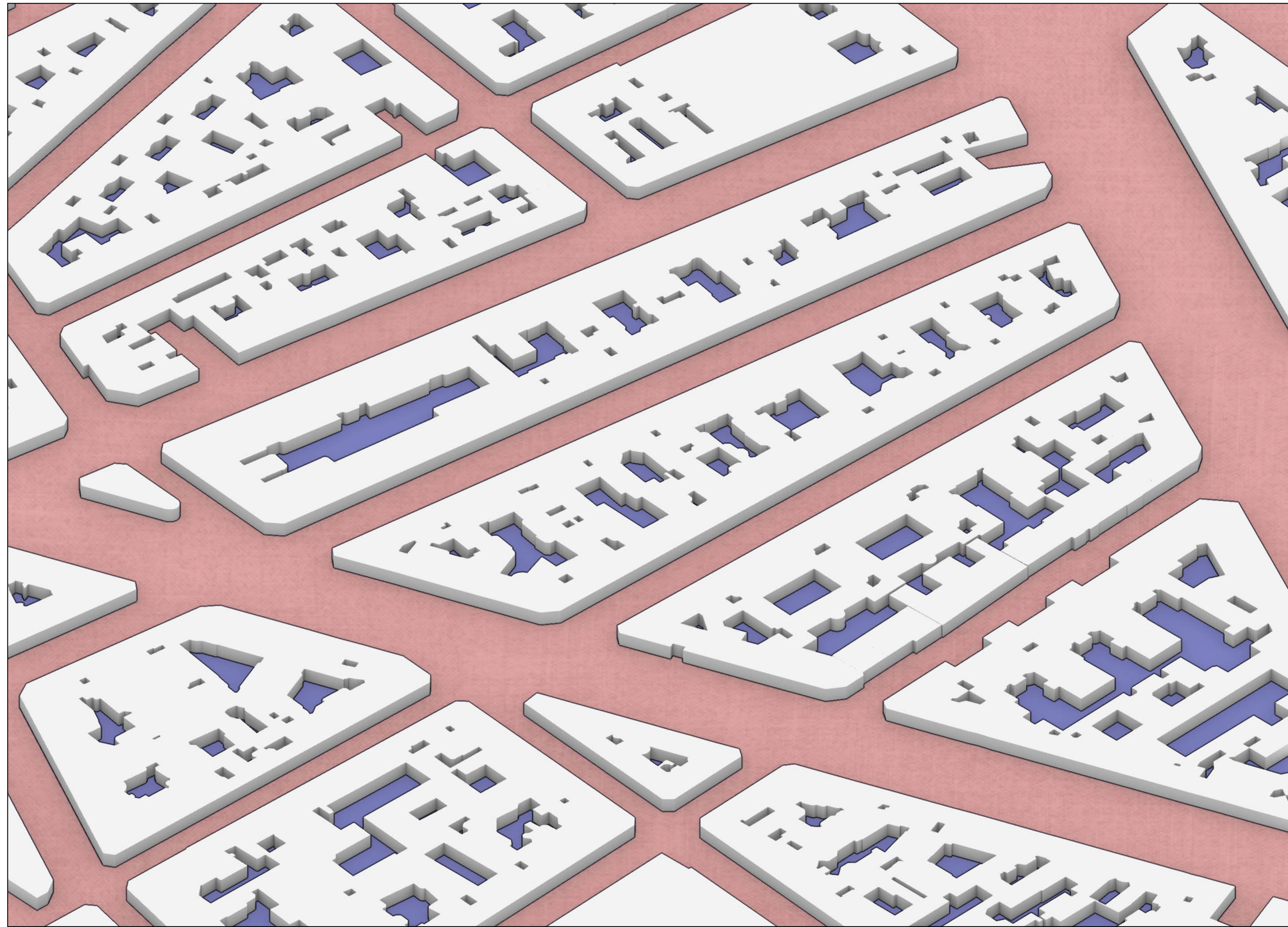


Courtyards

A Naturally Ventilated City



A Naturally Ventilated City

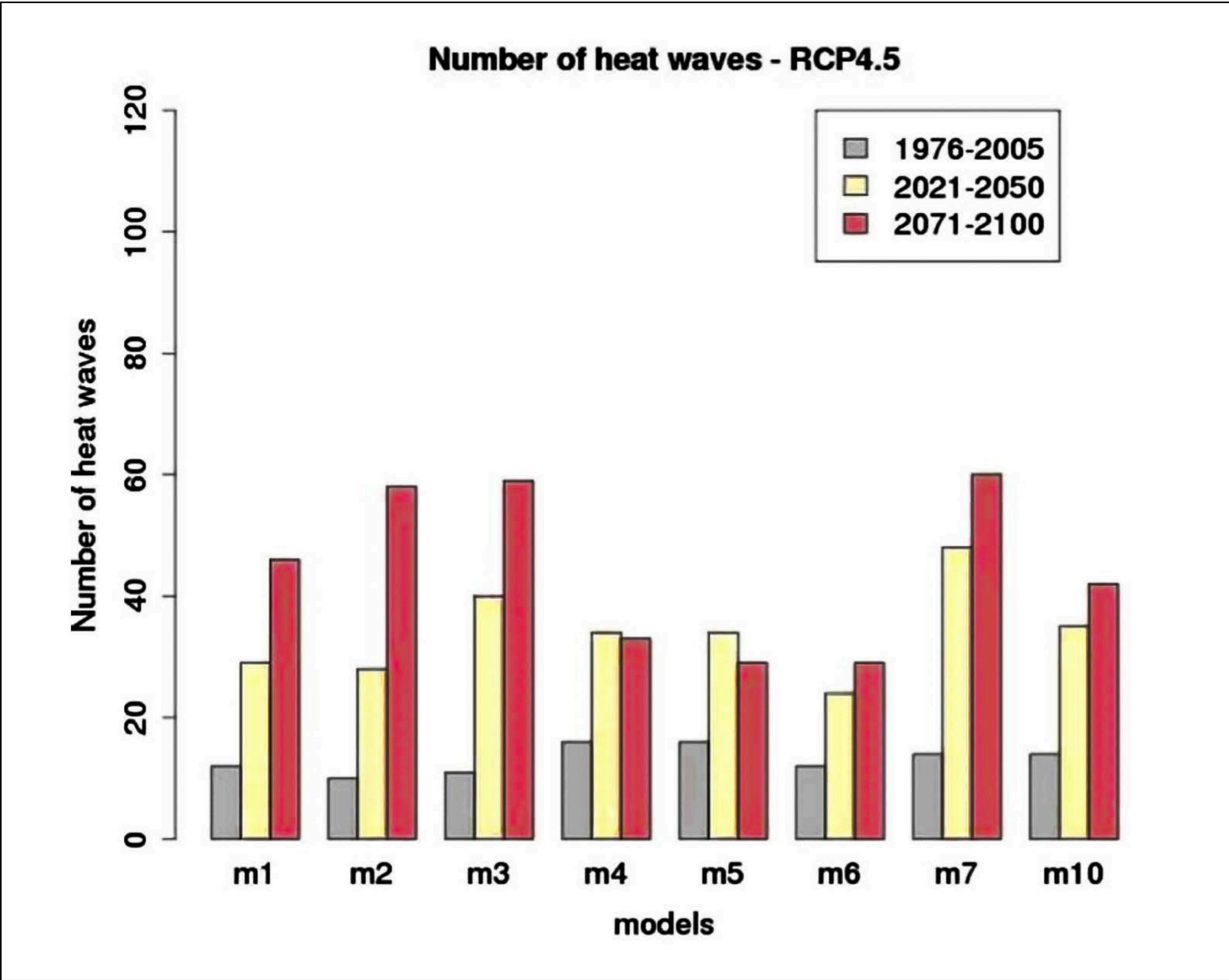


A Naturally Ventilated City

Introduction

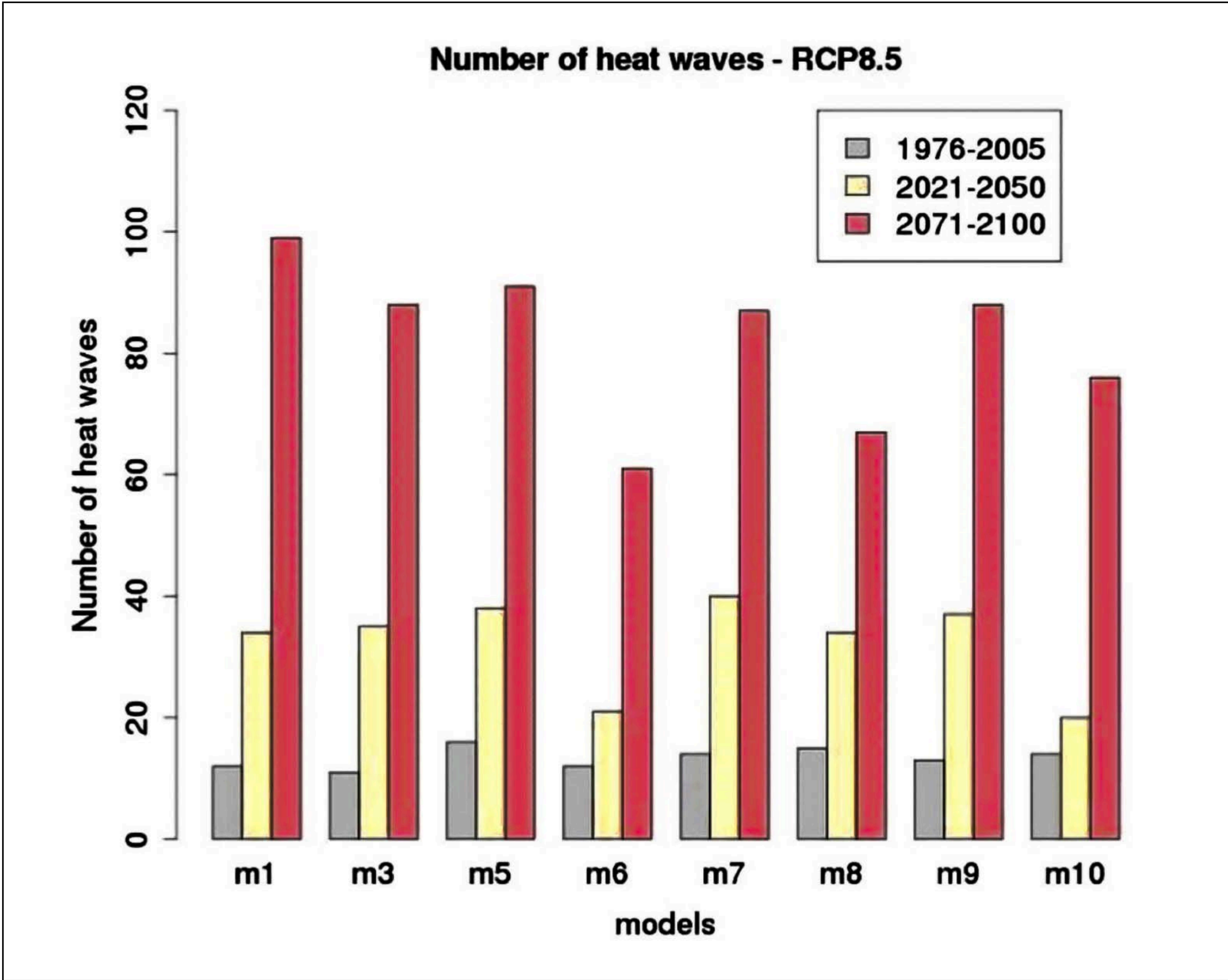
1 | Architectural Context

2 | A Warming Climate



Future Heatwaves in Paris | RCP4.5

Source: EURO-CORDEX ensemble



Future Heatwaves in Paris | RCP8.5

Source: EURO-CORDEX ensemble

Questions

How will the **future climate** in Paris affect the city's natural ventilation?
What **passive resiliency strategies** could maintain thermal comfort,
while **mitigating the energy demand**?

Future Climate Analysis

- 1 | Future Thermal Comfort
- 2 | Temperature Increase Mitigation

Future Climate Analysis

1 | Future Thermal Comfort

2 | Temperature Increase Mitigation

Modeling Framework



Urban Climate Model
TEB-SURFEX

Heat and Water exchanges
+
Building characteristics
+
Land cover



Building Energy Model
ENERGY Plus

Heat and Mass balance
+
Air temperature (inside)
+
Building systems
+
AC energy use



Land-Use & Transport
NEDUM-2D

Urban Expansion
+
Transportation
+
Population

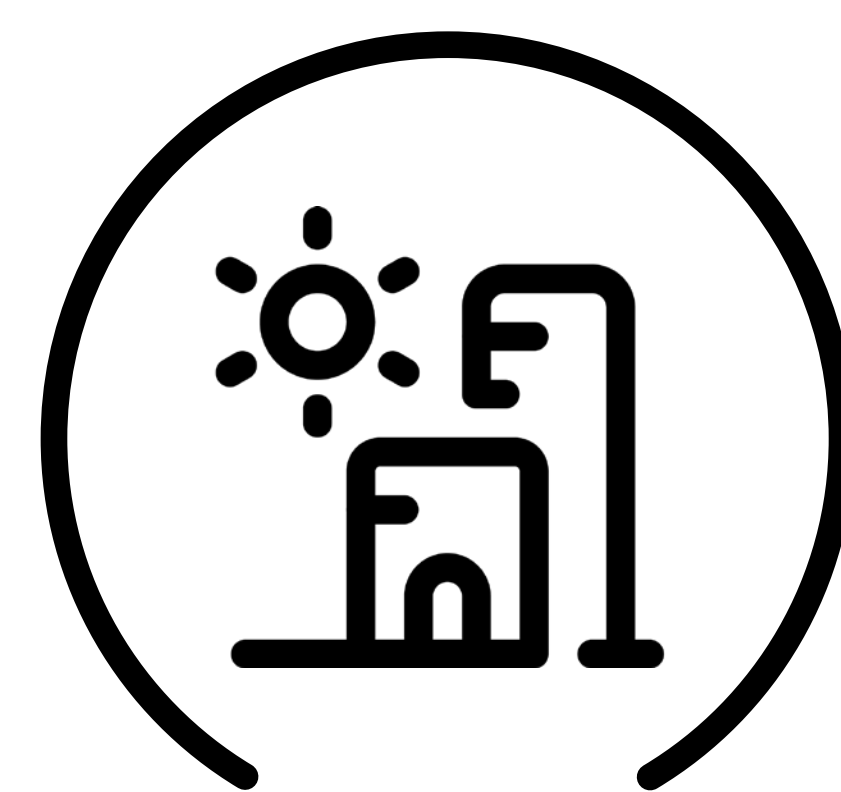
Modeling Framework



Urban Climate Model

TEB-SURFEX

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Building Energy Model

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Land-Use & Transport

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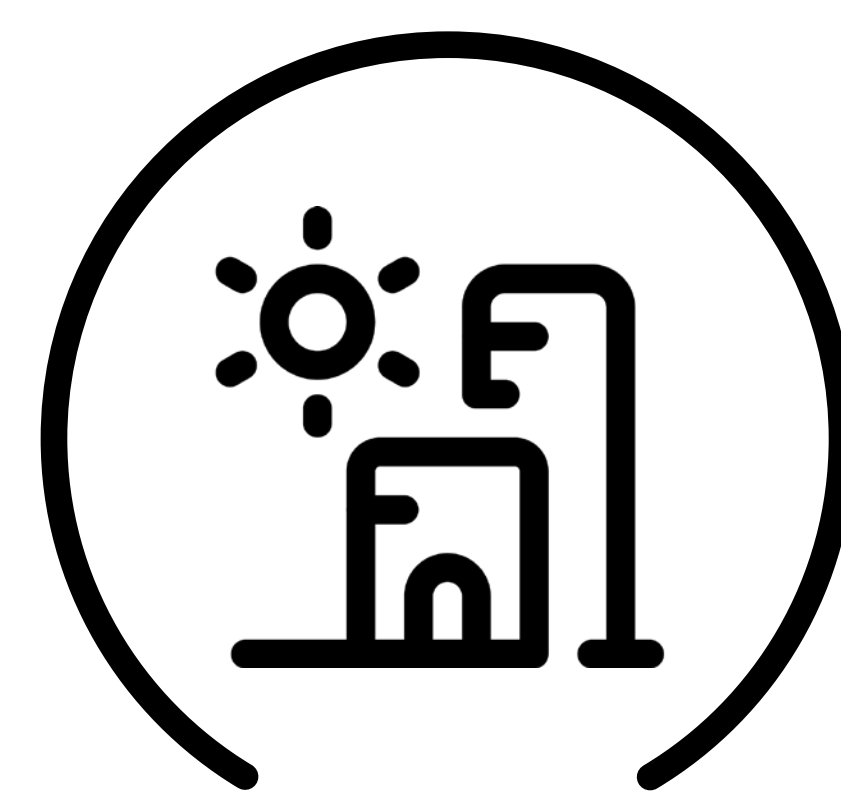
Urban Expansion
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Transportation
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Population

Modeling Framework



Urban Climate Model
TEB-SURFEX

Heat and Water exchanges
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Building characteristics
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Building Energy Model
ENERGY Plus

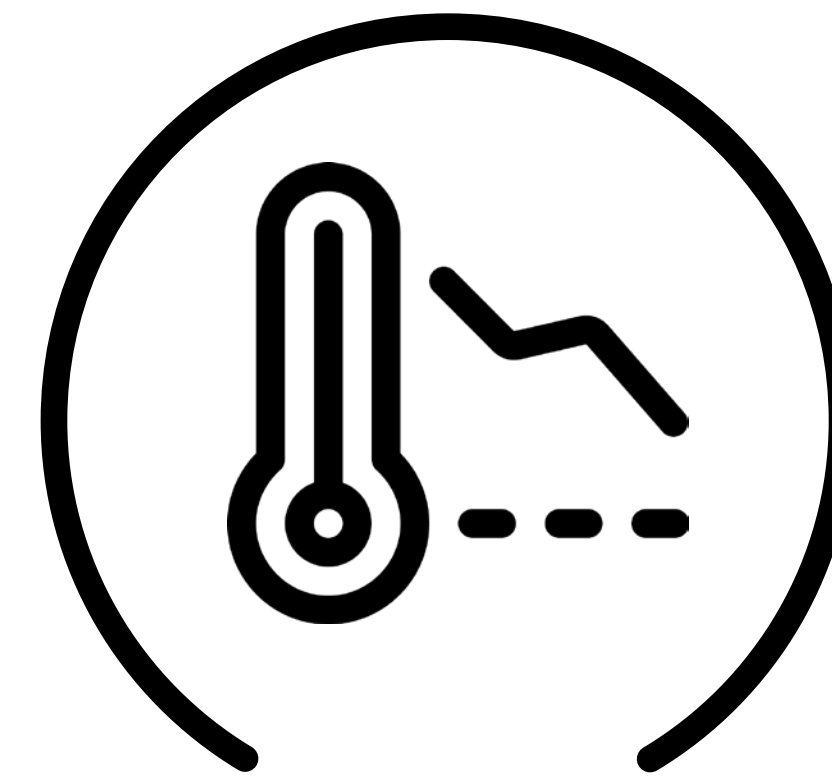
Heat and Mass balance
+
Air temperature (inside)
+
Building systems
+
AC energy use



Land-Use & Transport
NEDUM-2D

Urban Expansion
+
Transportation
+
Population

Base Scenario



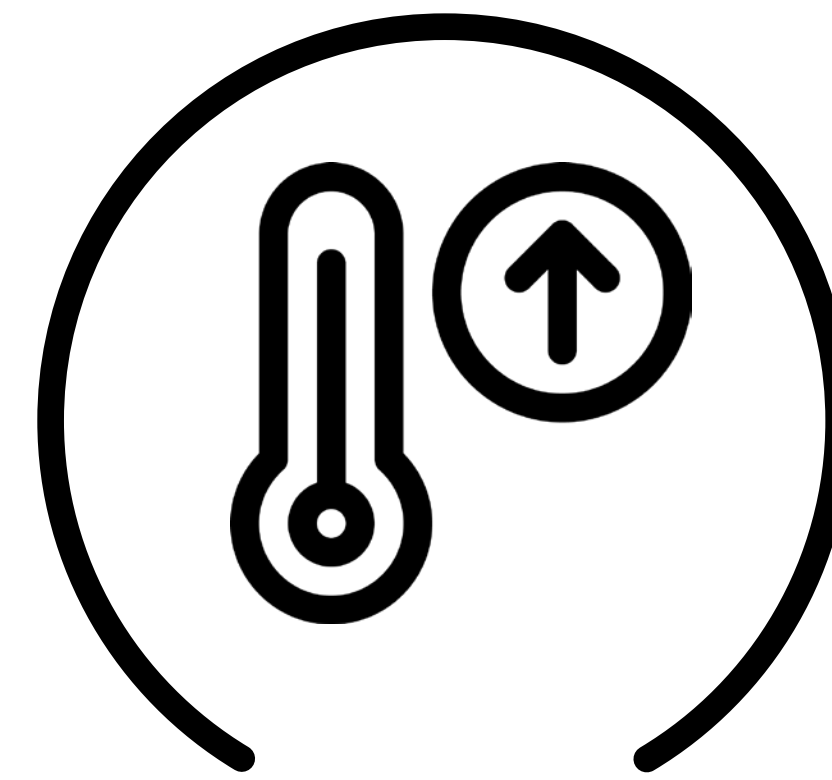
Strong AC Use (23°C)

Base Scenario

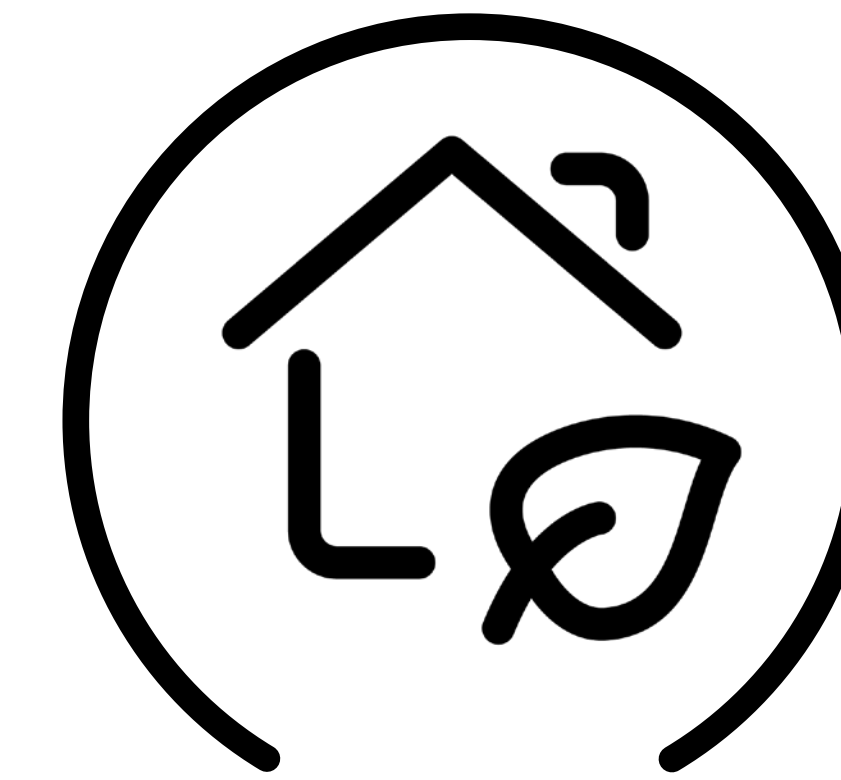
Strategies



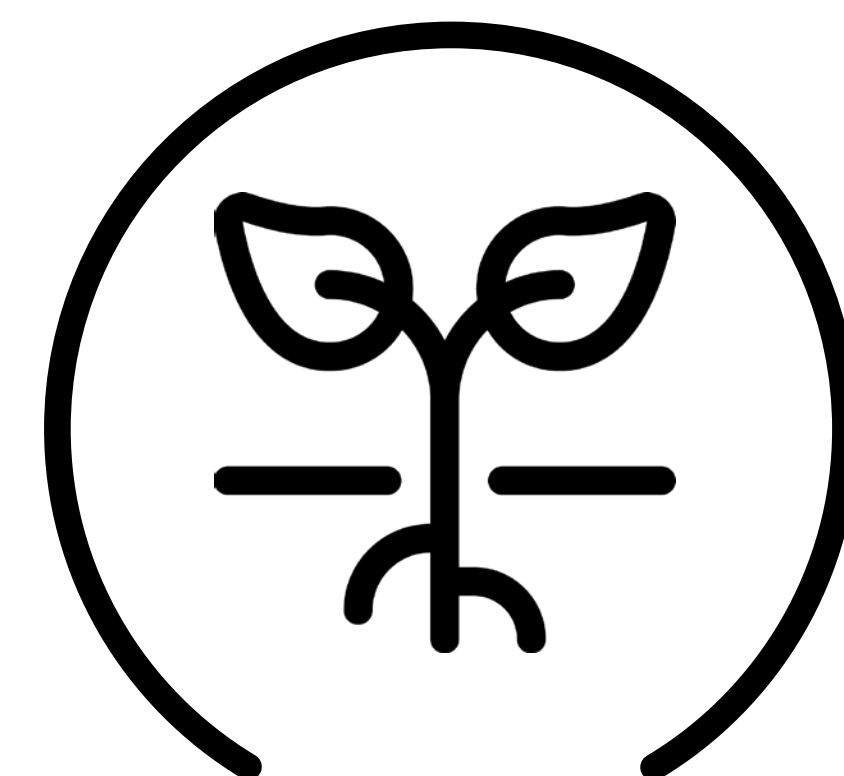
Reflective Roof



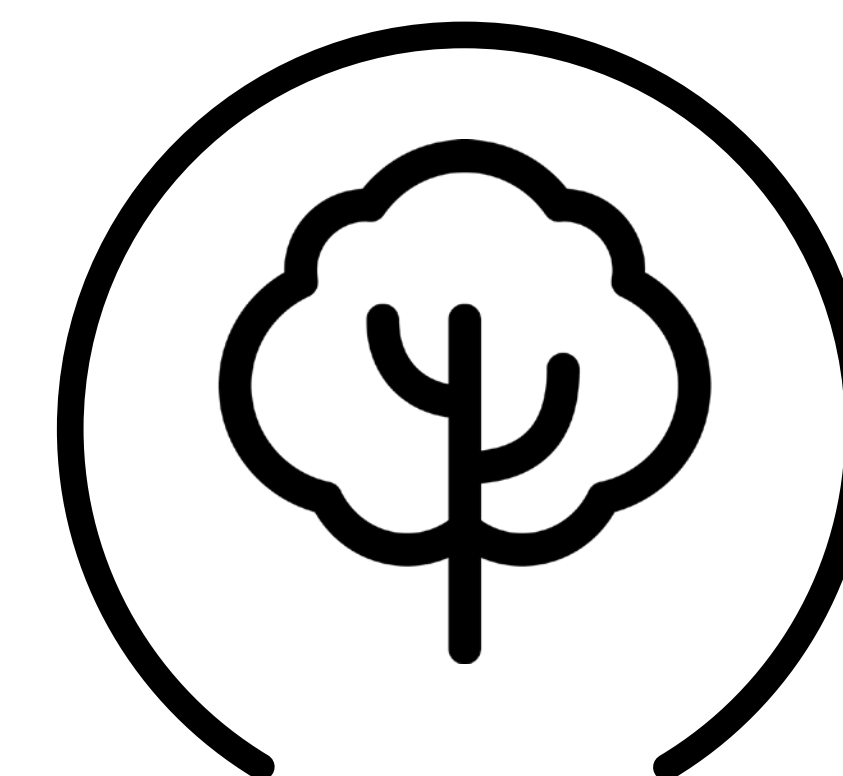
Moderate AC Use (26°C)



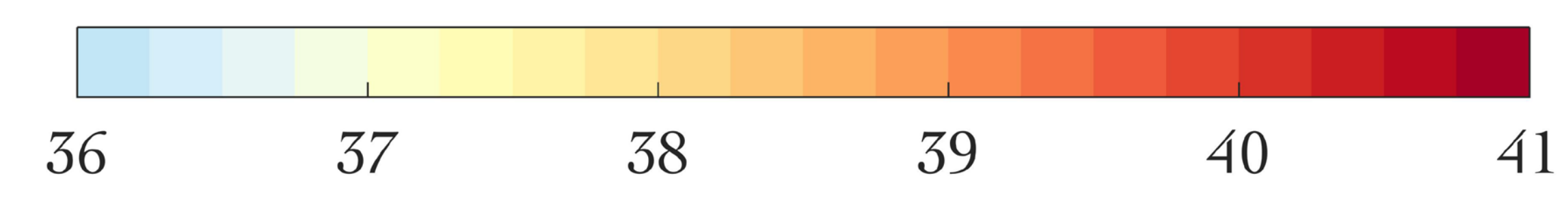
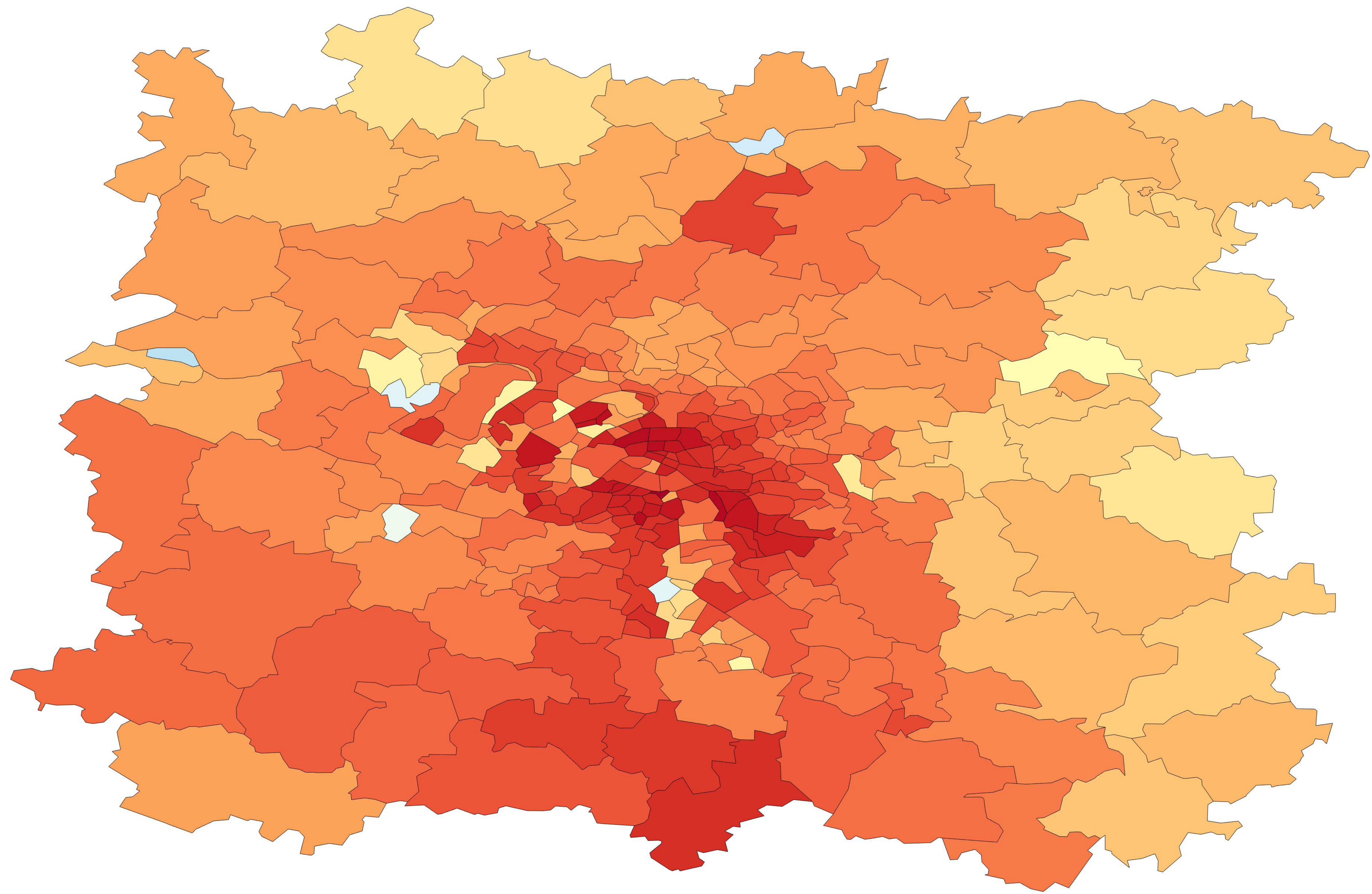
Building Insulation



Green Roof



Street Vegetation



Outside Temperature

38°C

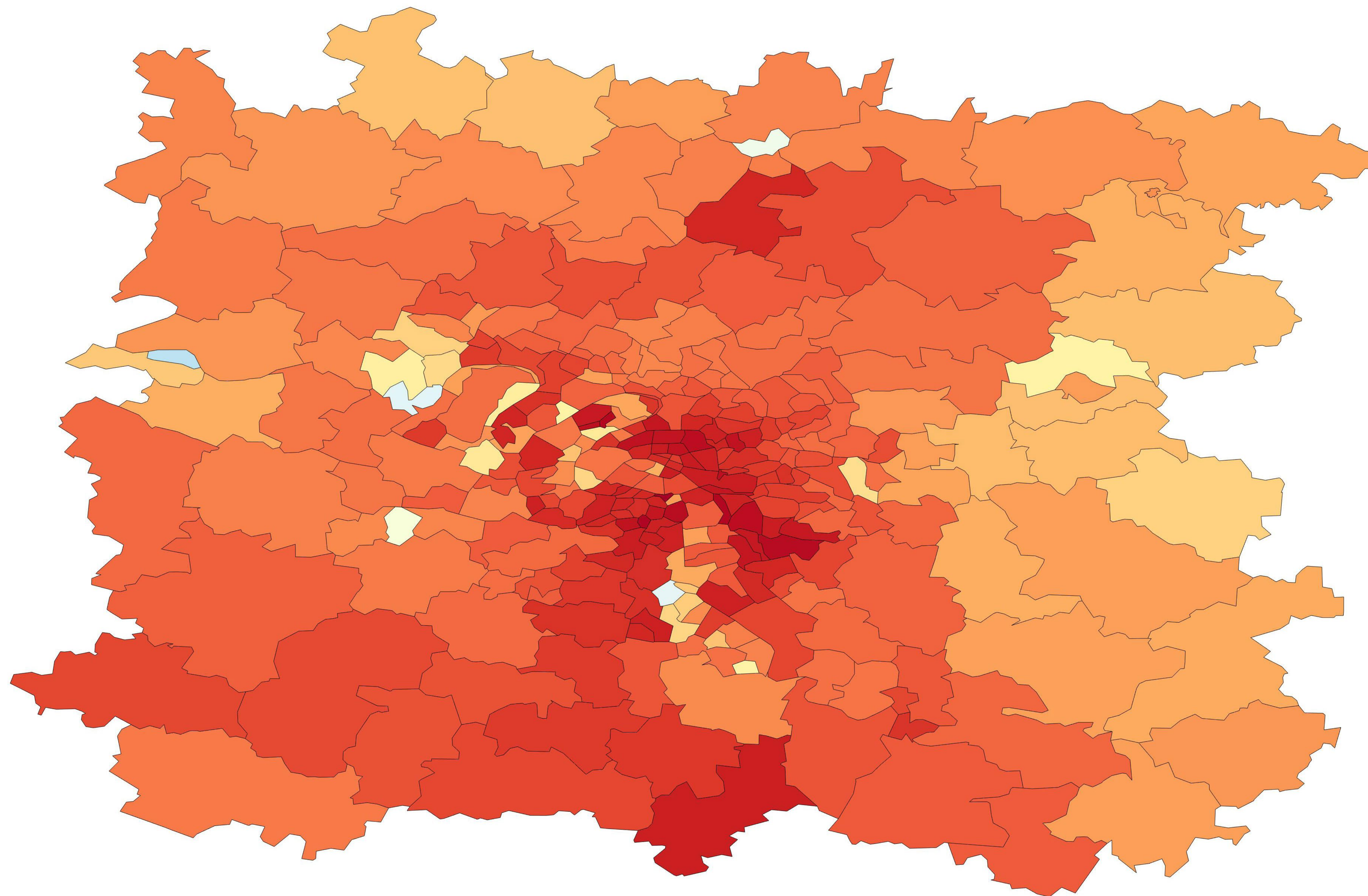
Conditions

2pm during heat wave
Climate file: RCP4.5
Thermal condition: 2003 Heat wave

Variable

No AC use

Scenario OO: day-time
Future Climate Simulations



Outside Temperature

41°C

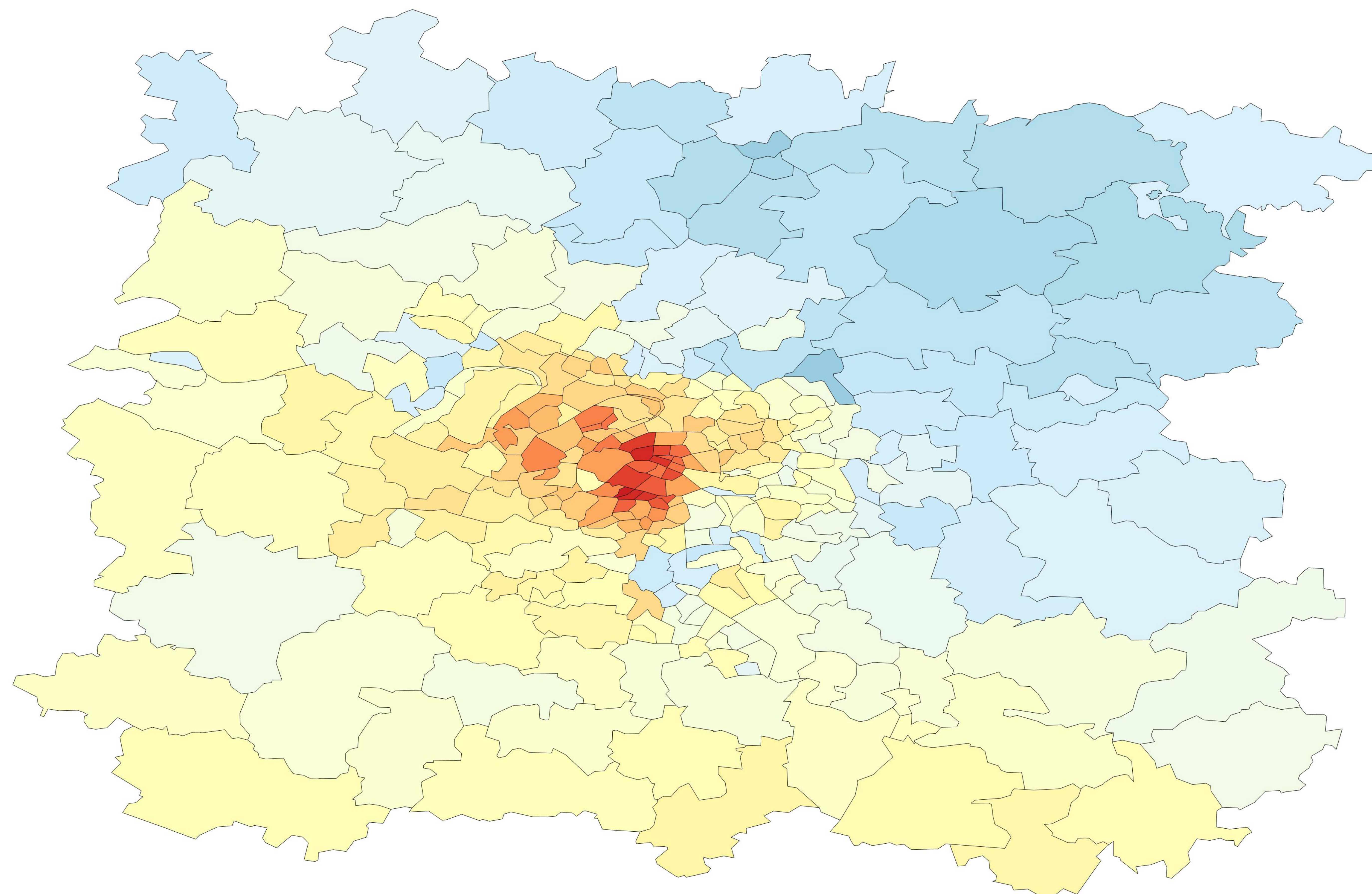
Conditions

2pm during heat wave
Climate file: RCP4.5
Thermal condition: 2003 Heat wave

Variable

Strong AC use: 23°C setpoint

Scenario O1: day-time
Future Climate Simulations



Outside Temperature

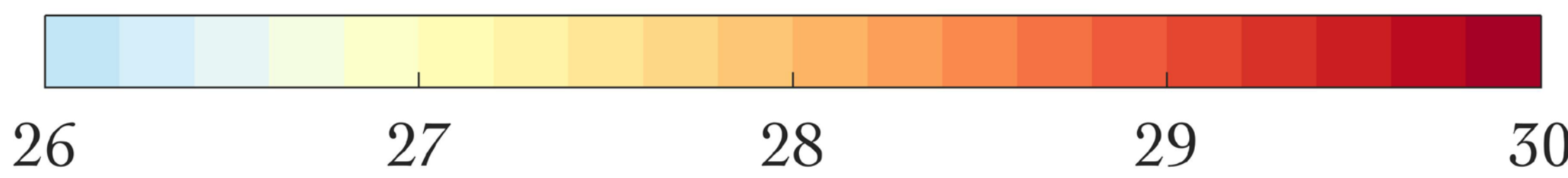
29°C (center)

Conditions

2am during heat wave
Climate file: RCP4.5
Thermal condition: 2003 Heat wave

Variable

Strong AC use: 23°C setpoint

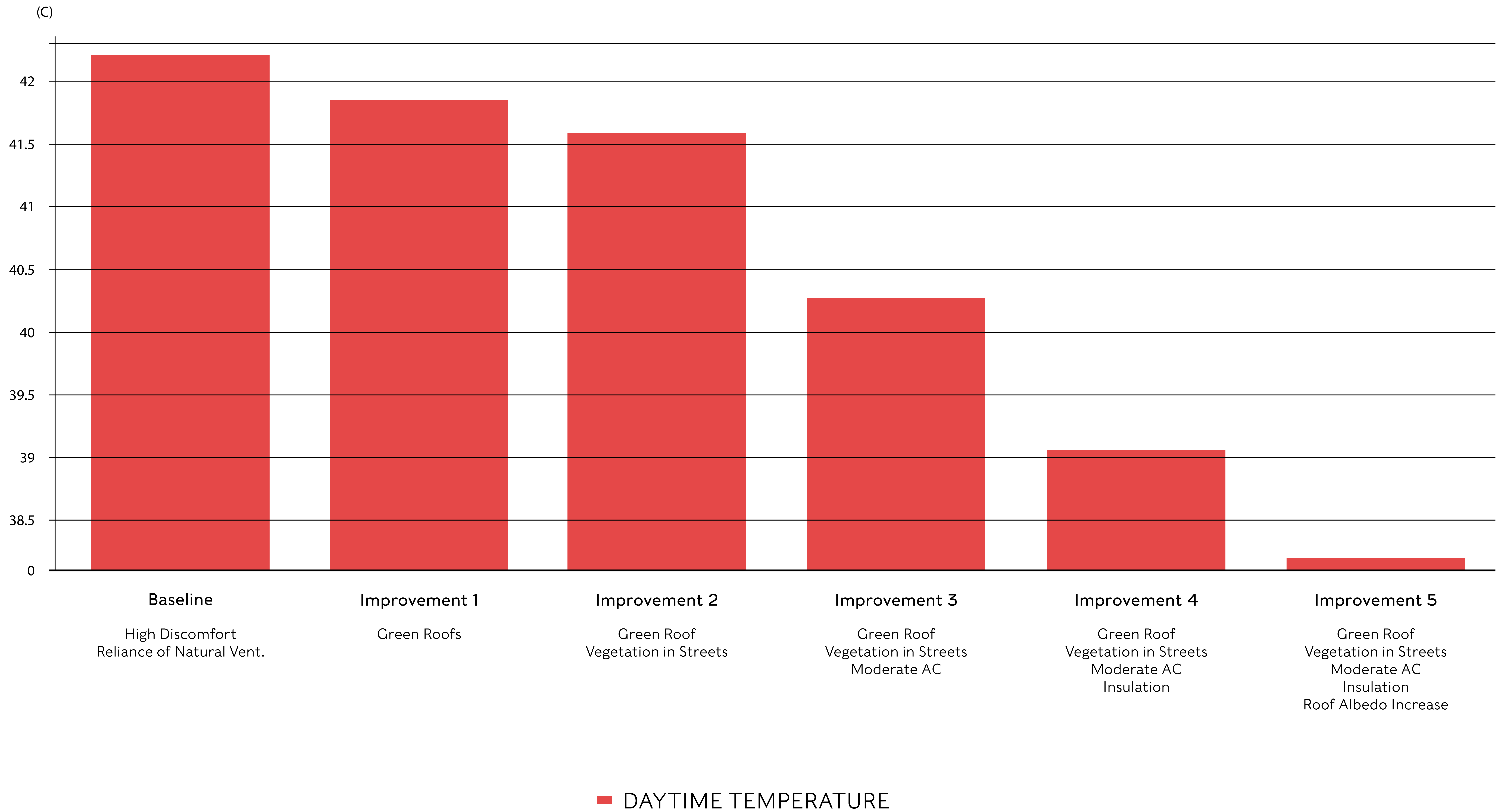


Scenario O1: night-time
Future Climate Simulations

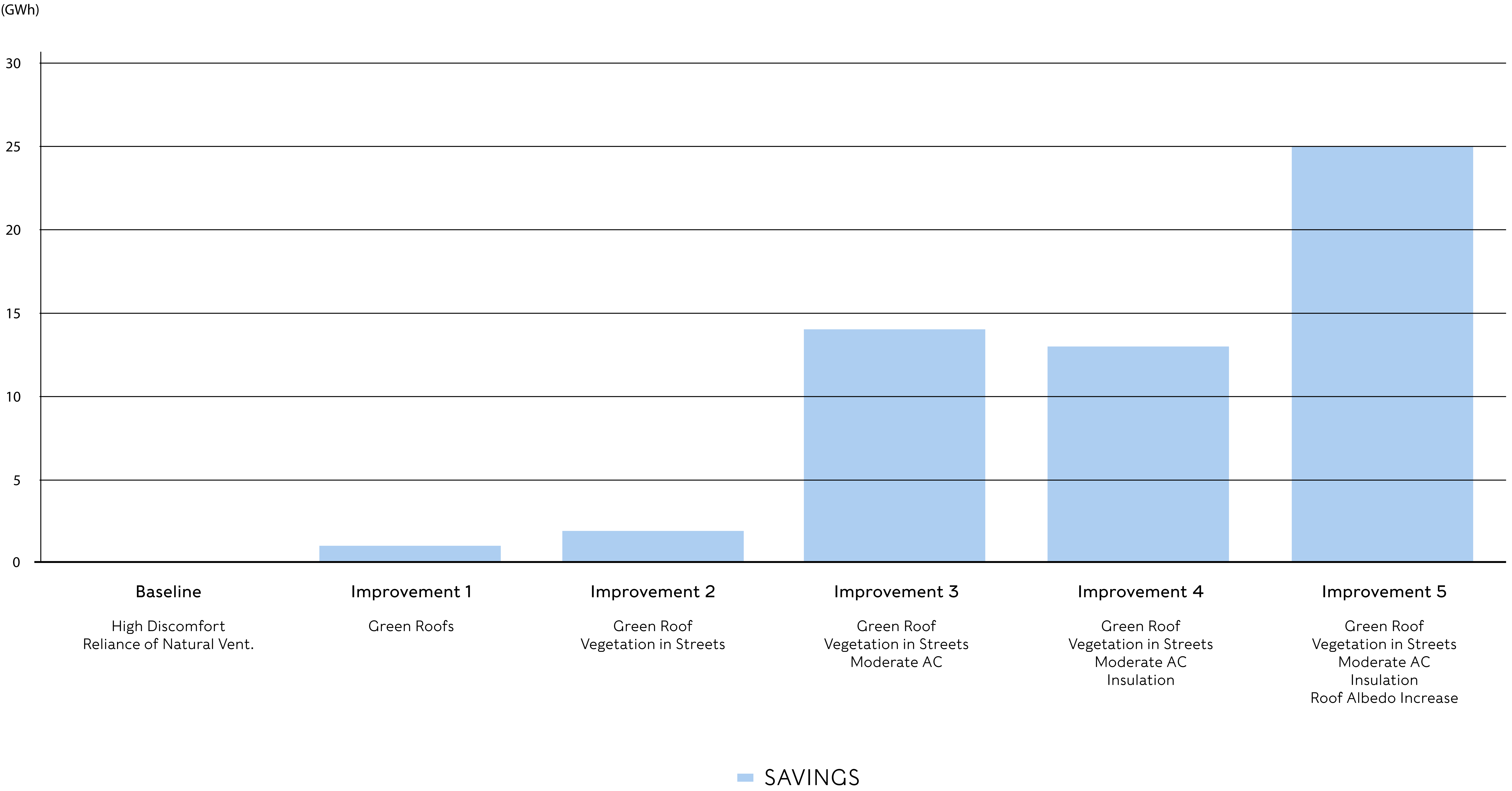
Future Climate Analysis

1 | Future Thermal Comfort

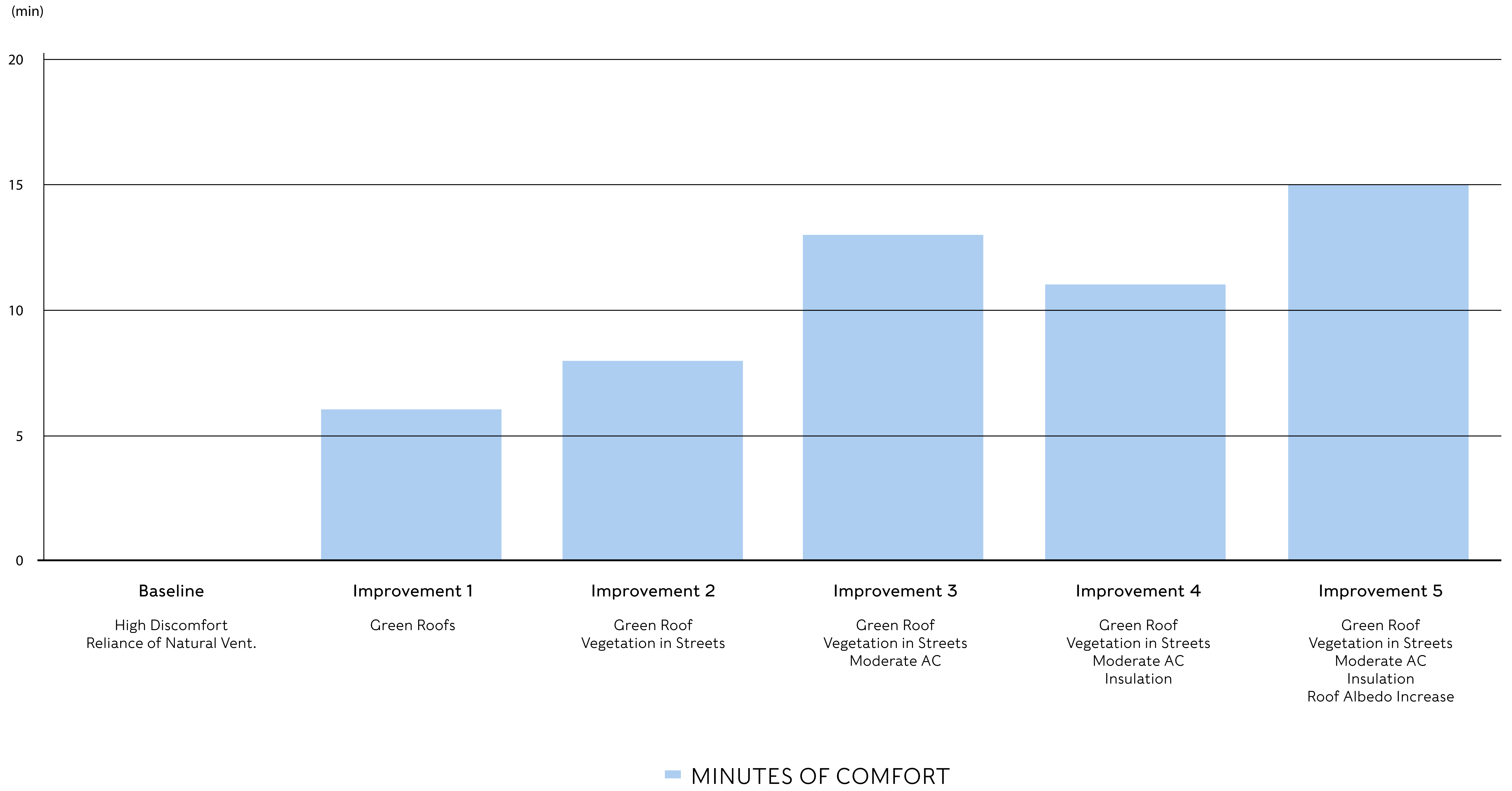
2 | Temperature Increase Mitigation



Average Temperature Decrease (RCP 4.5)
Future Climate Simulations

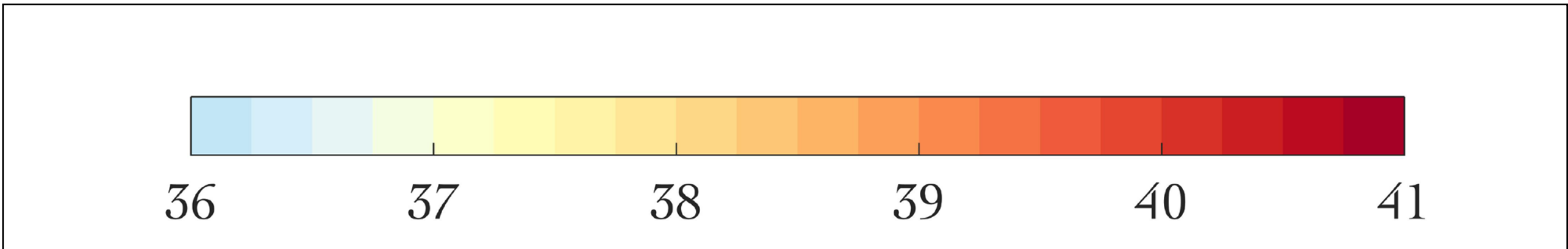
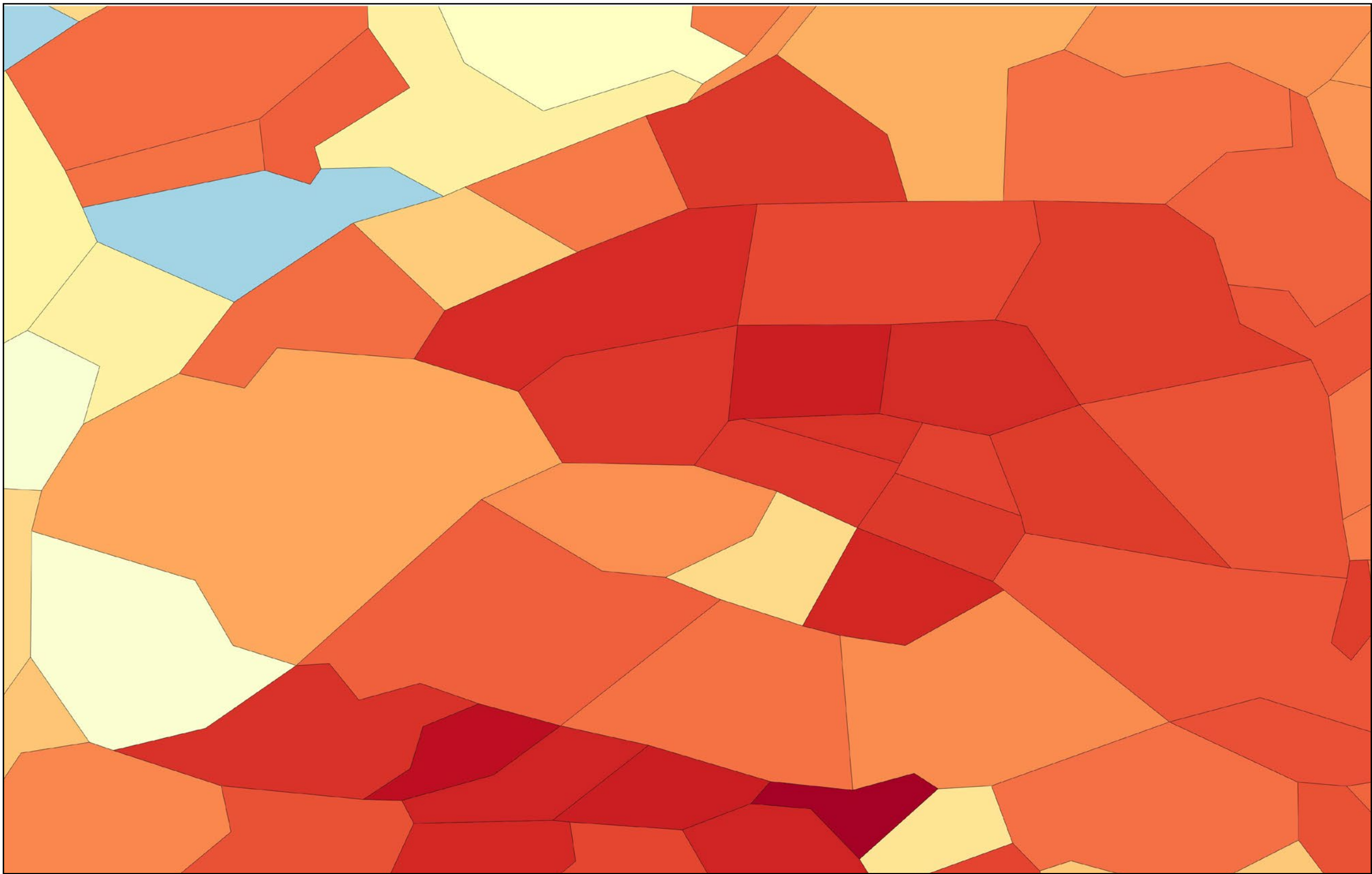


Daily Energy Savings (RCP 4.5)
Future Climate Simulations

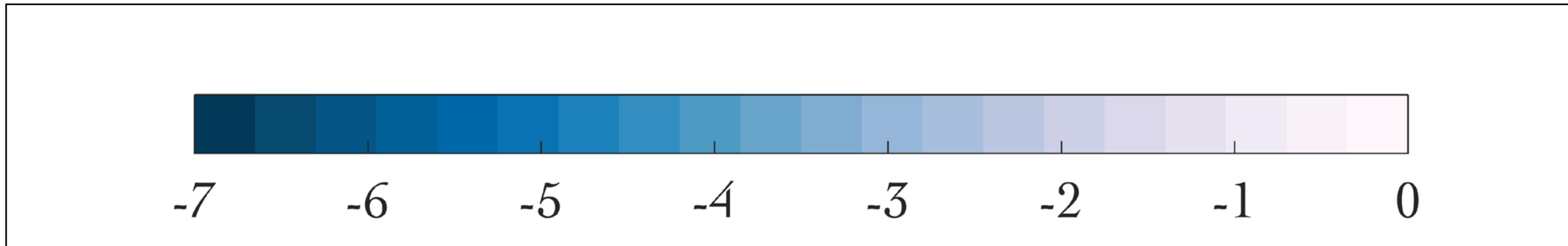
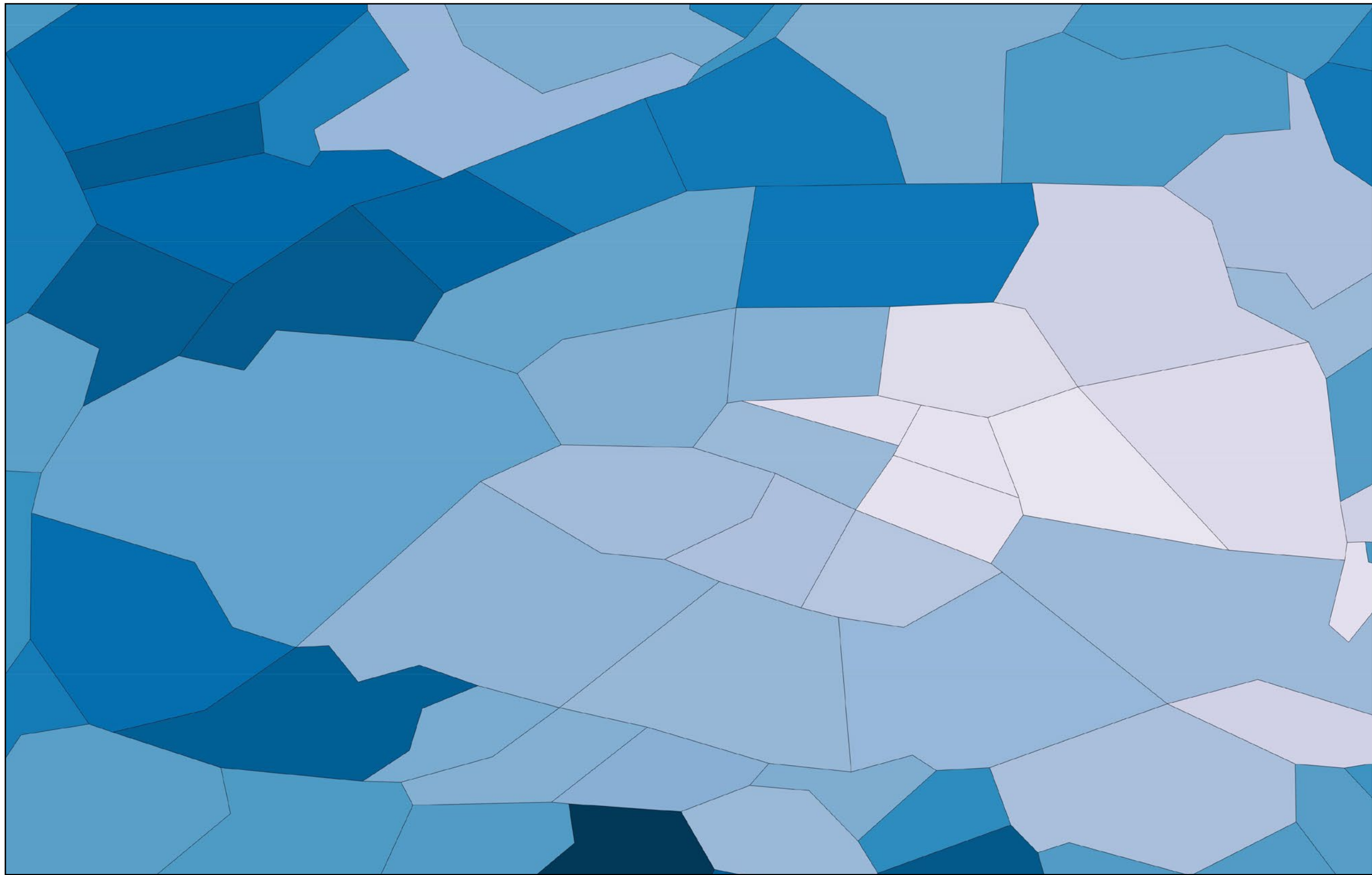


Thermal Comfort Hours (RCP 4.5)
Future Climate Simulations

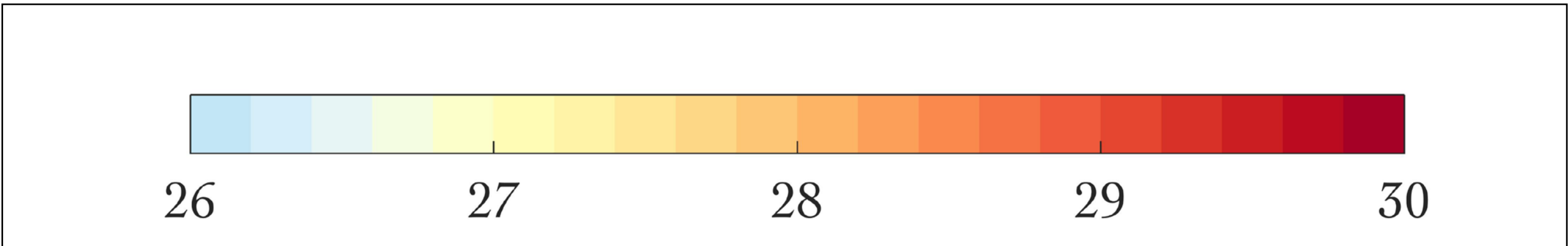
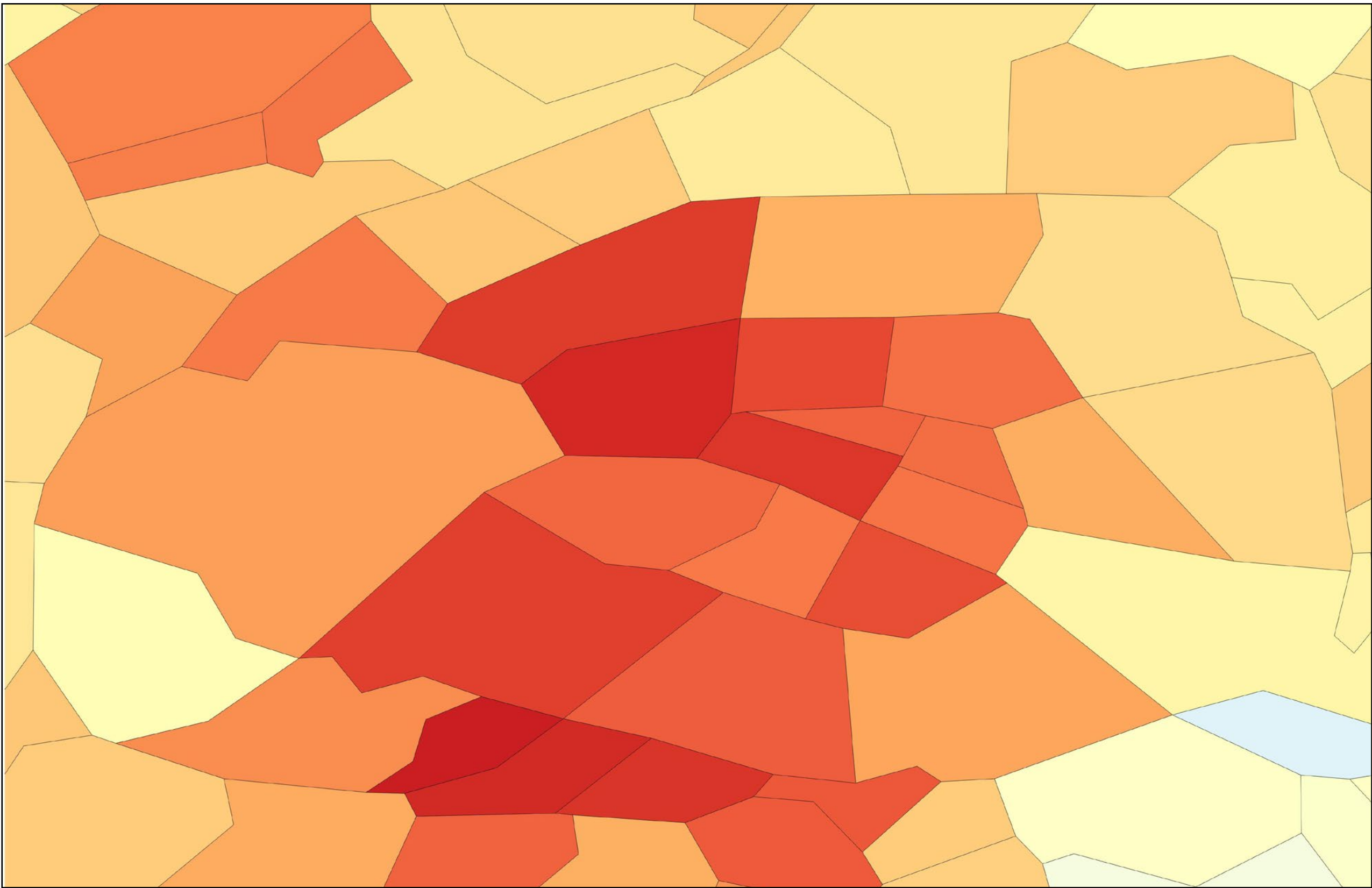
Temperature with strong AC



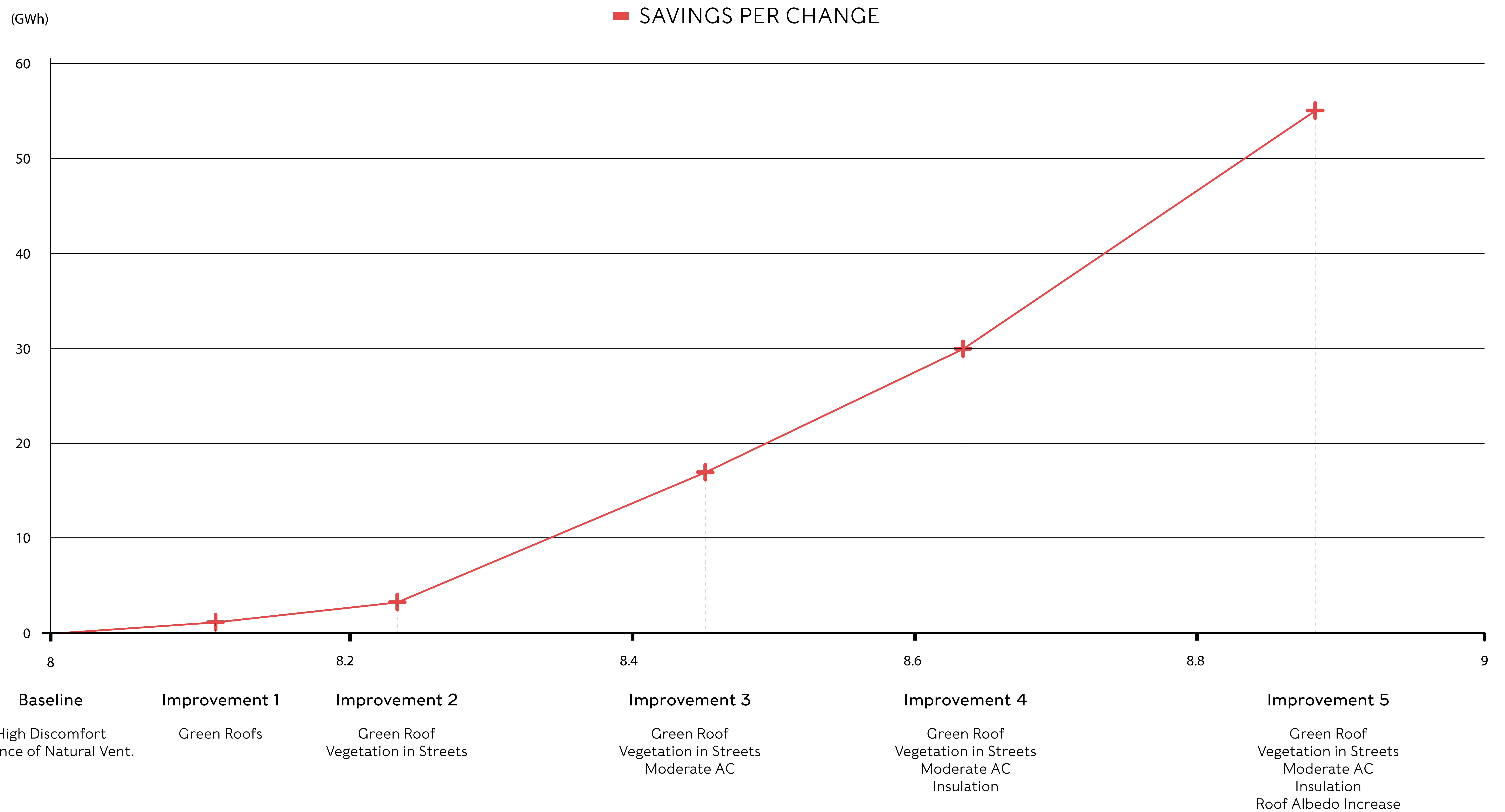
Combination of mitigation plans



Temperature with mitigation



Temperature Increase Mitigation
Future Climate Simulations



Energy Savings and Comfort Hours (RCP 4.5)

Future Climate Simulations

Conclusion

Building insulation
Reflective roofs
Moderate AC Use

Conclusion: Mixed Approach
Future Climate Simulations

Low-Carbon Resiliency Strategy

Paris Protoblock + Renovation Approach

1 | Baseline: Existing

2 | Strategy O1: Renovation

3 | Strategy O2: Sur-Elevation

Low-Carbon Resiliency Strategy

Paris Protoblock + Renovation Approach

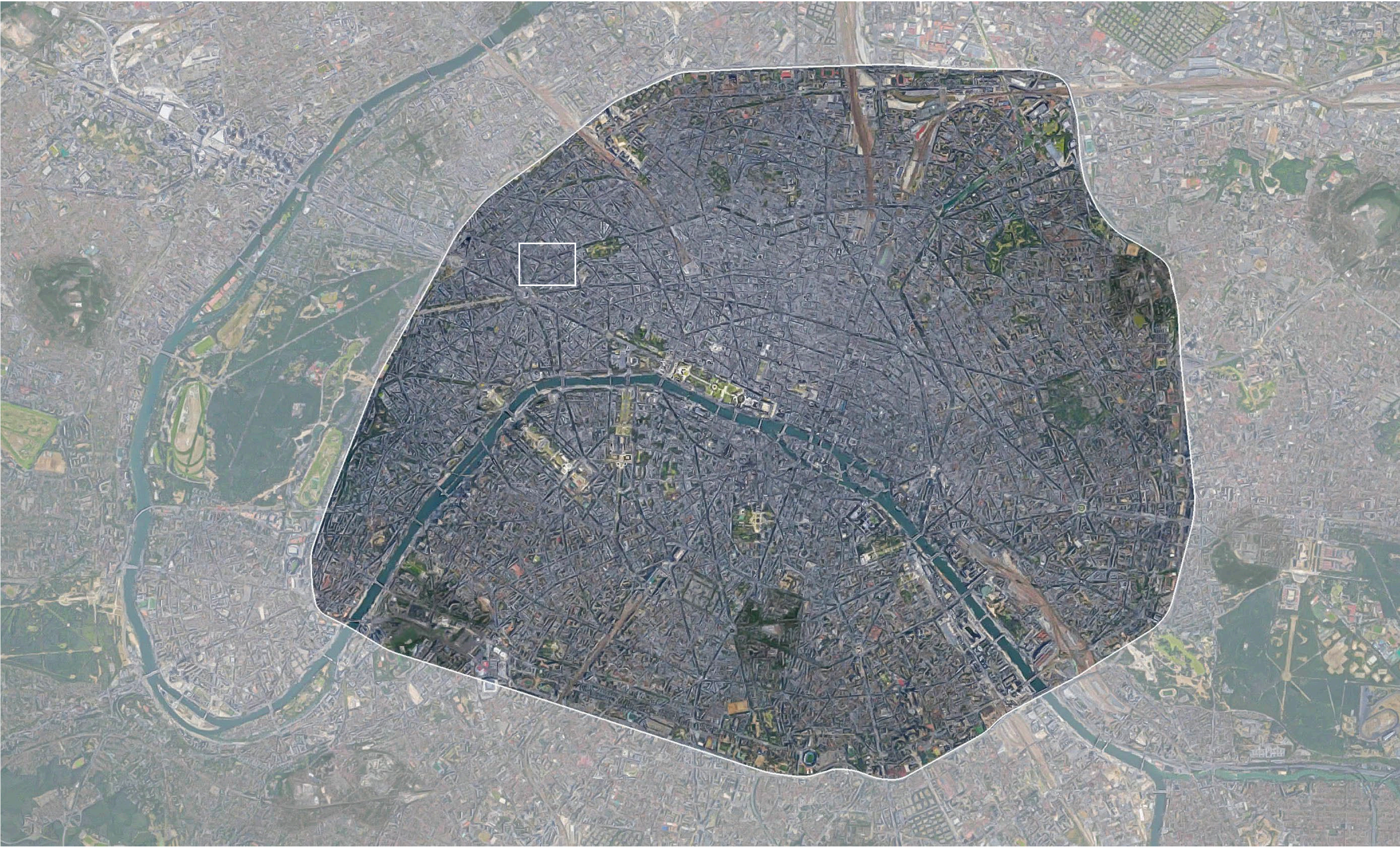
- 1 | Baseline: Existing
- 2 | Strategy O1: Renovation
- 3 | Strategy O2: Sur-Elevation

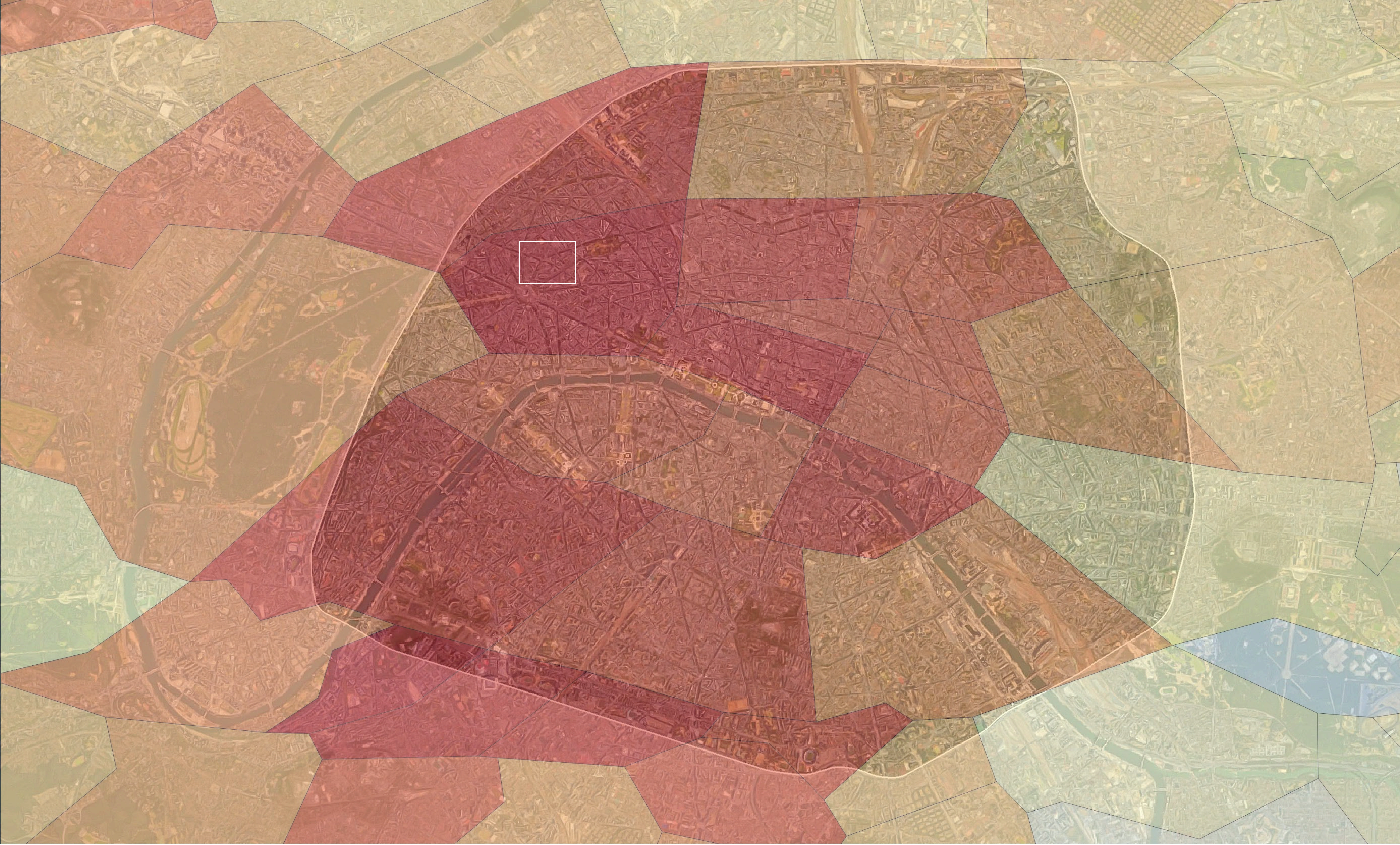


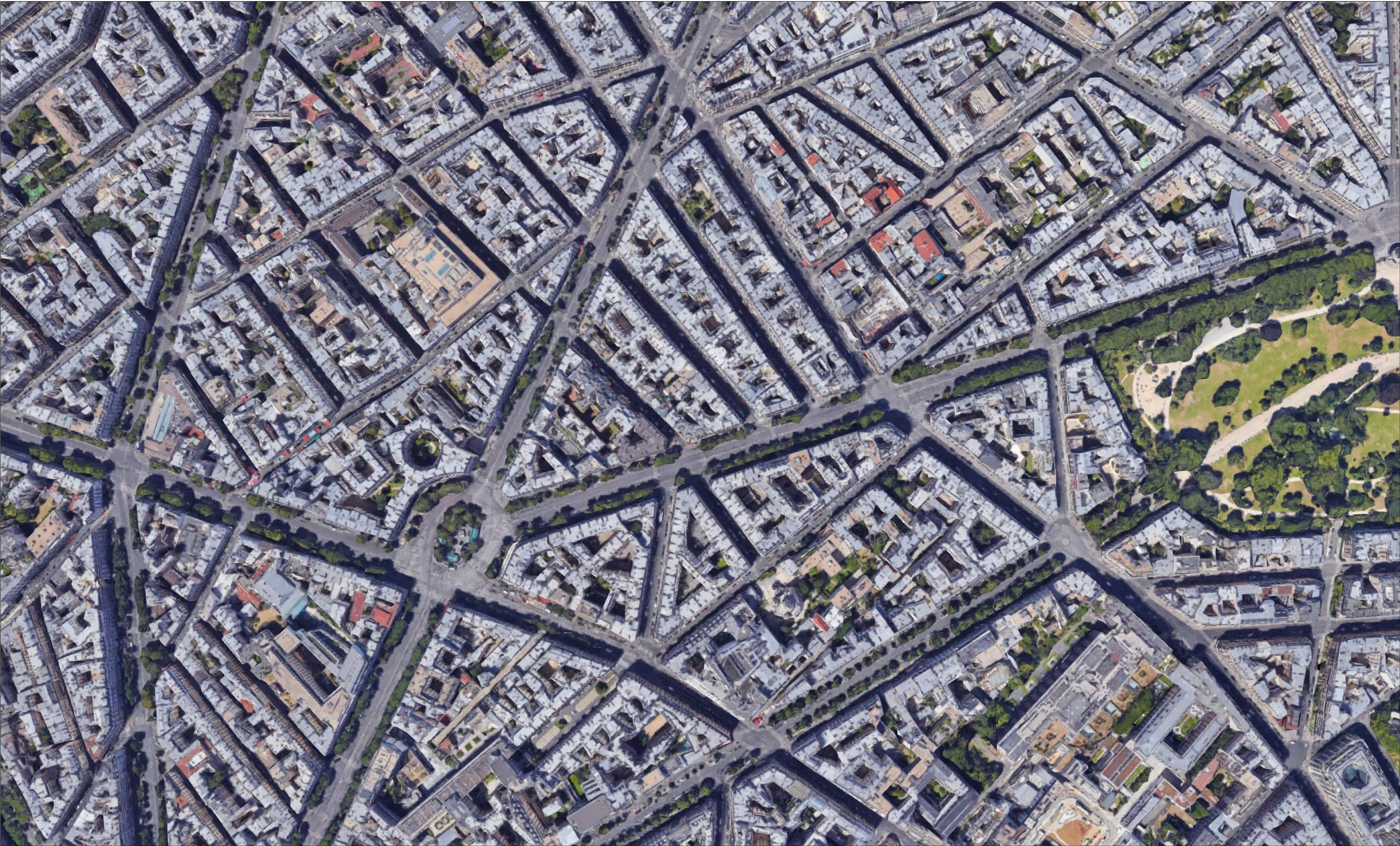
View South

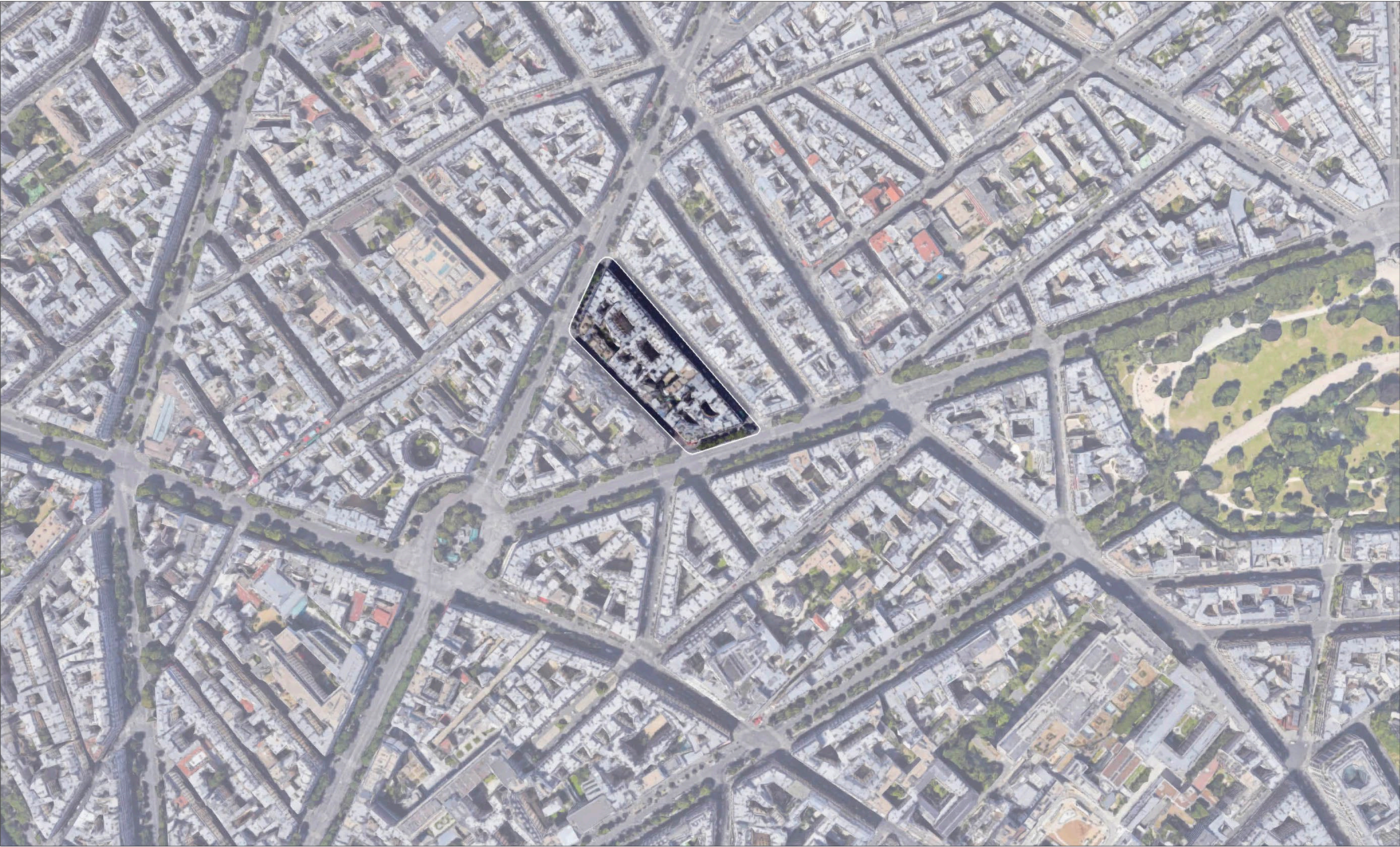


View East

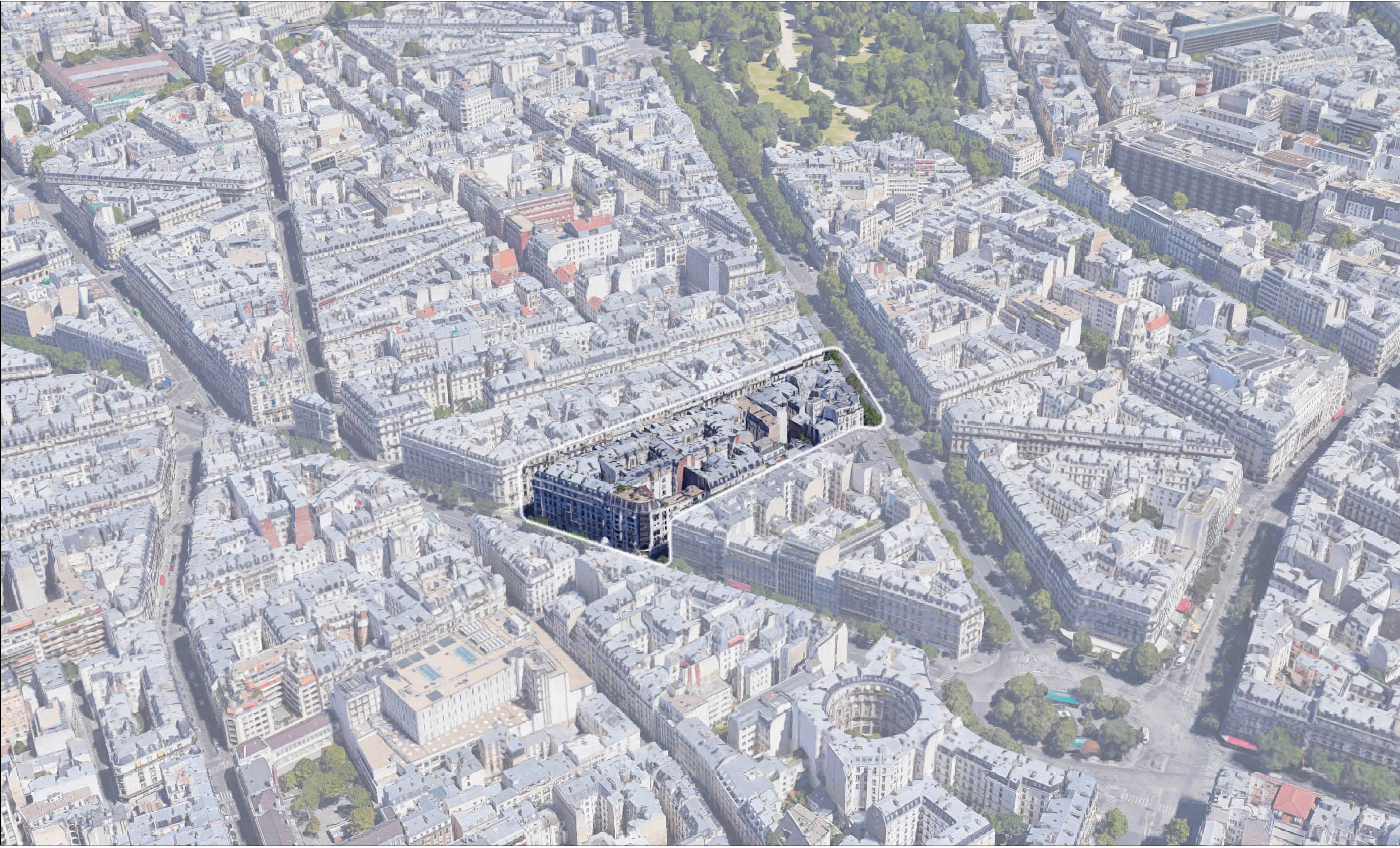


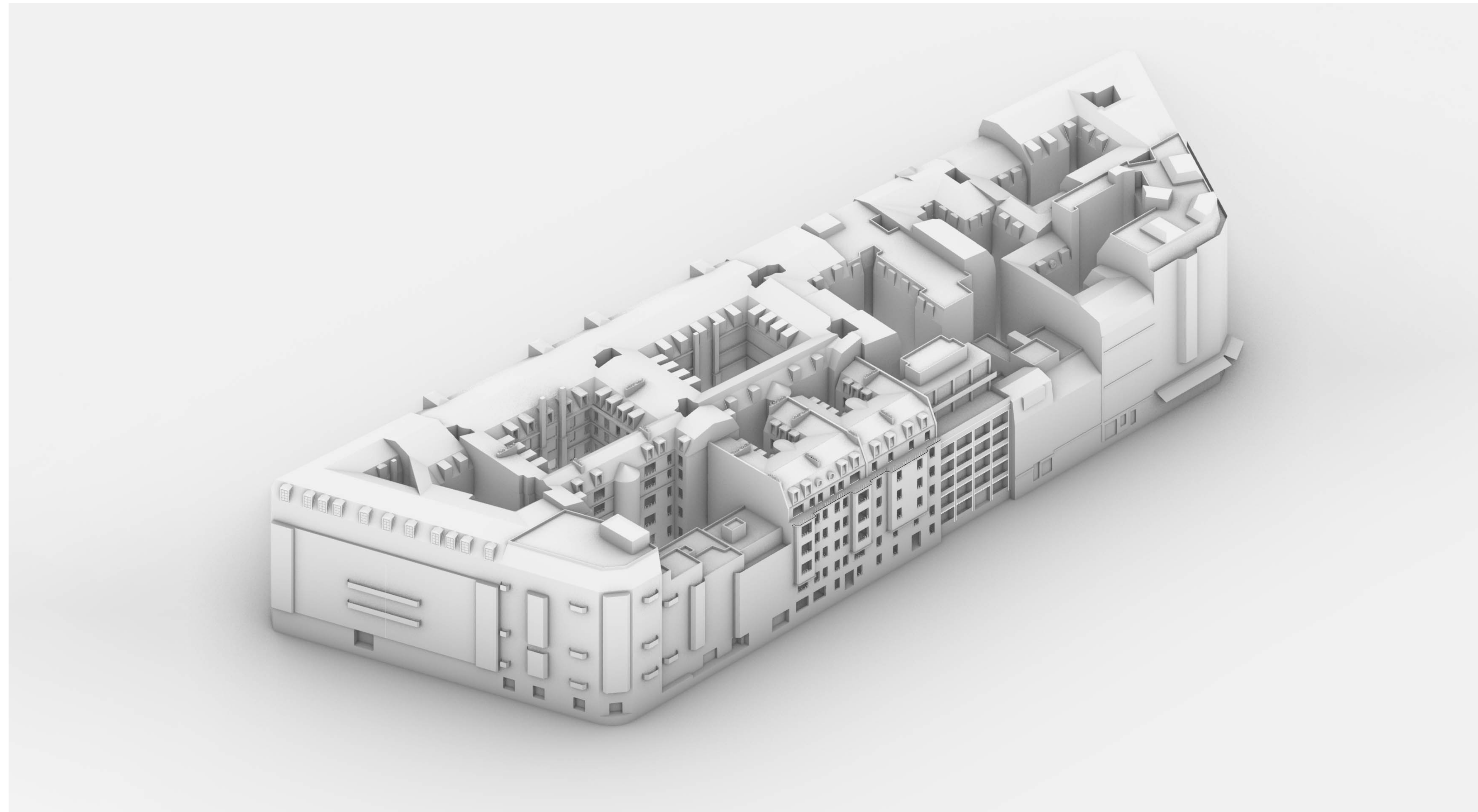




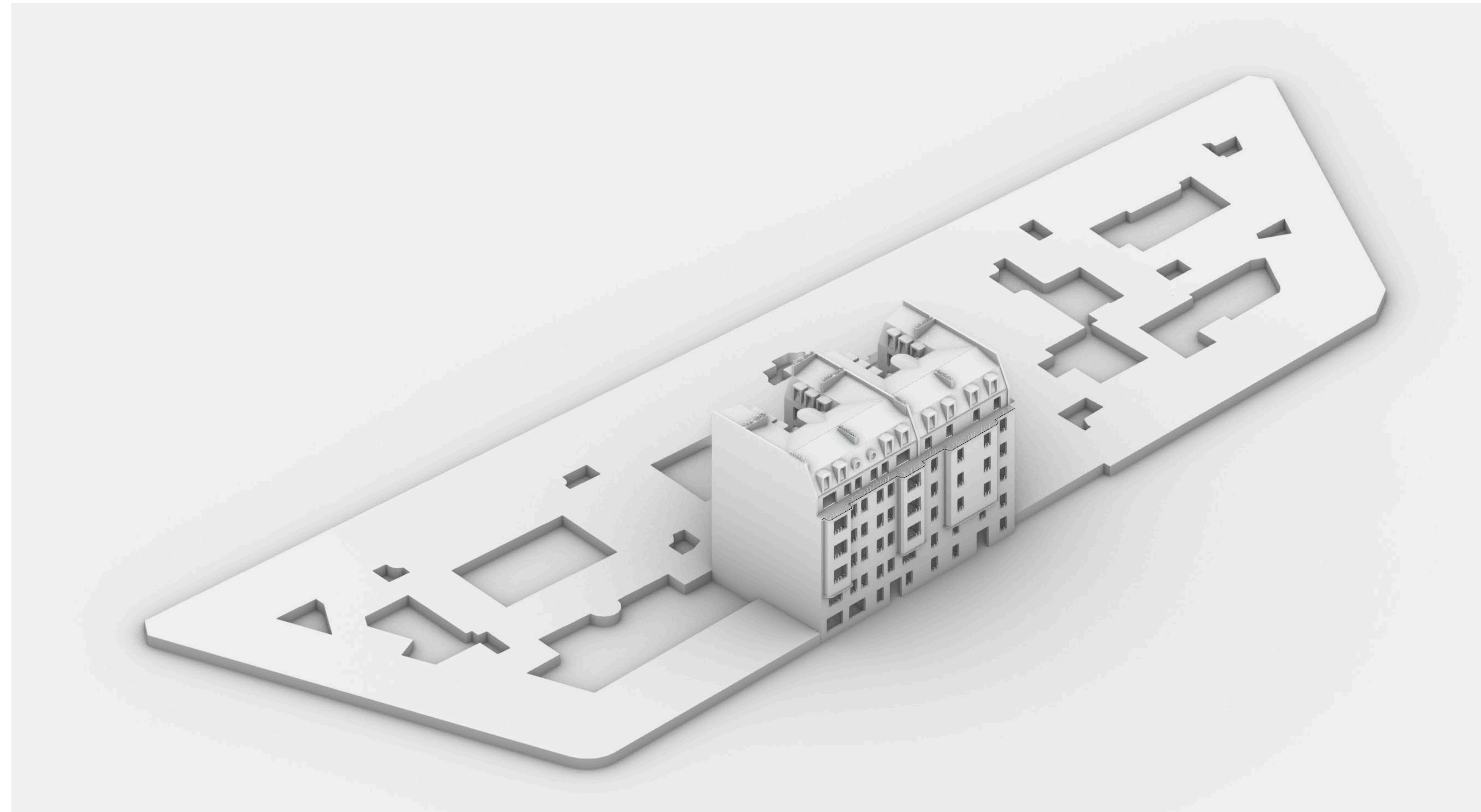








Protoblock



Protoblock



Protoblock Section: **Baseline**

Protoblock

Low-Carbon Resiliency Strategy

Paris Protoblock

+

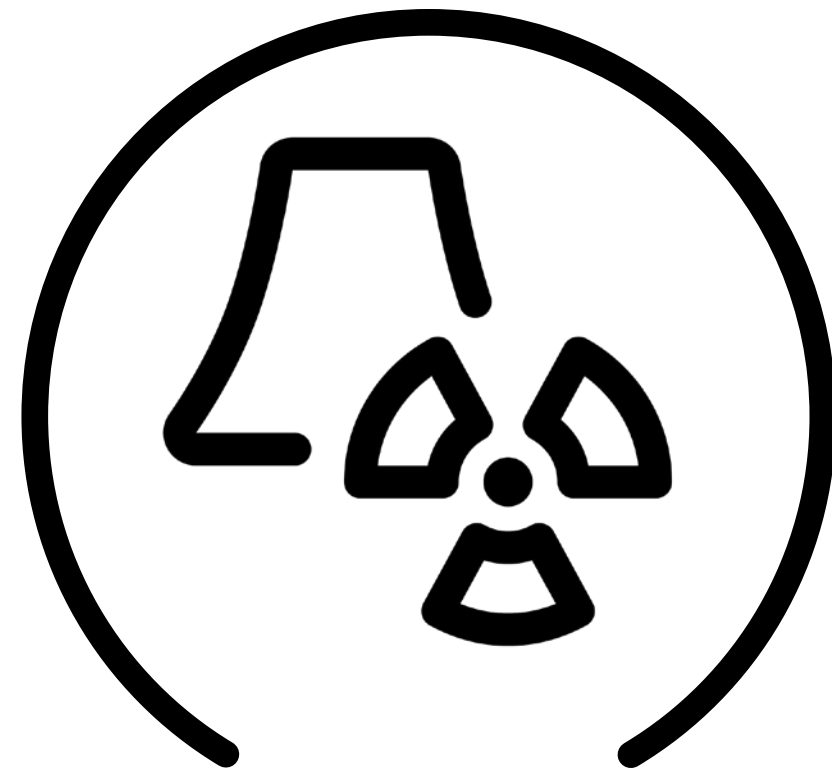
Renovation Approach

1 | Baseline: Existing

2 | Strategy O1: Renovation

3 | Strategy O2: Sur-Elevation

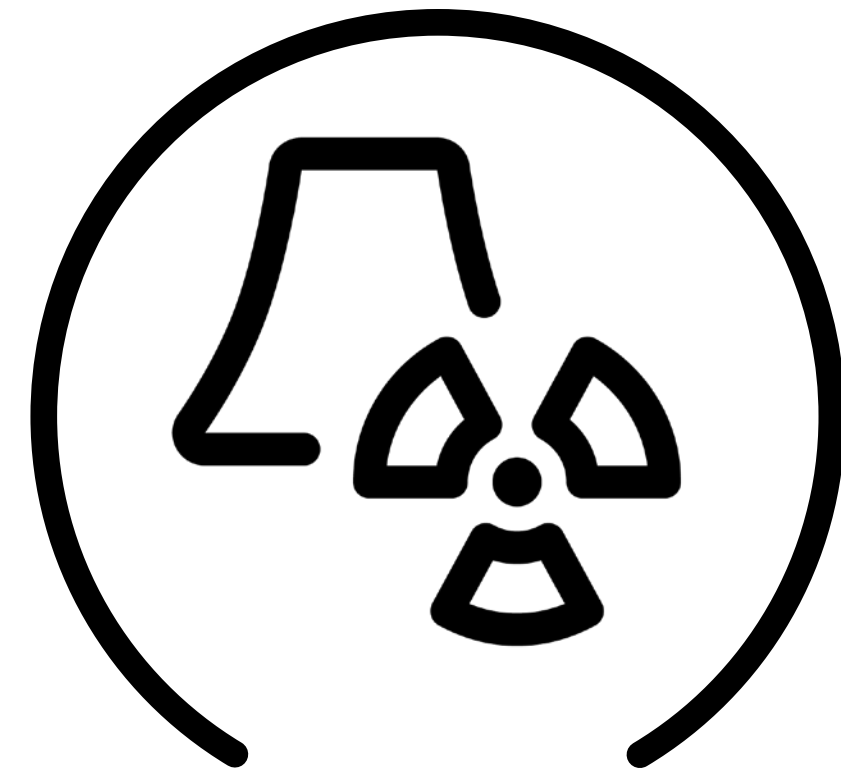
France



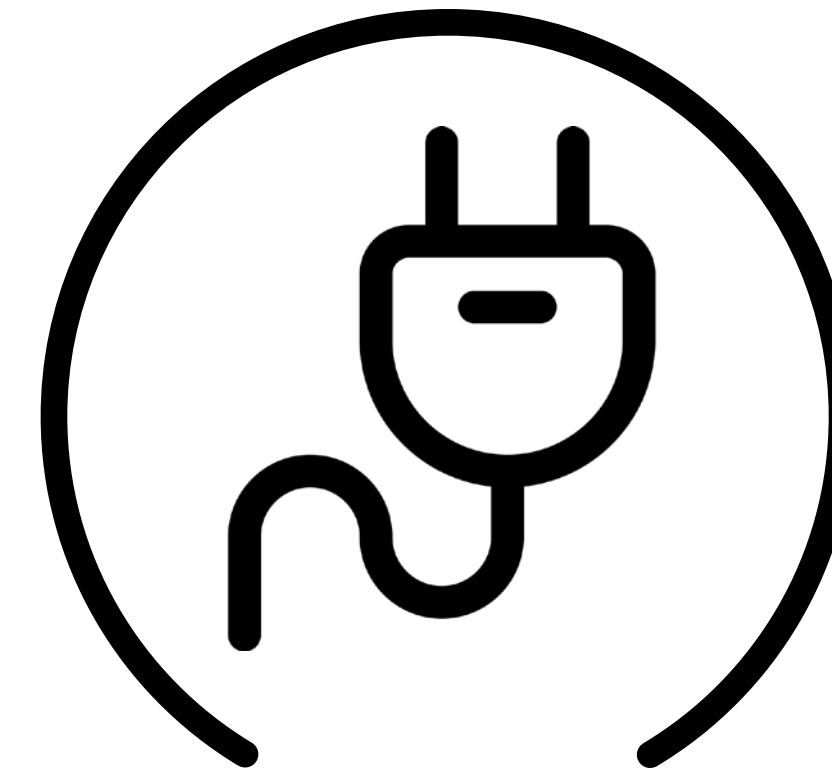
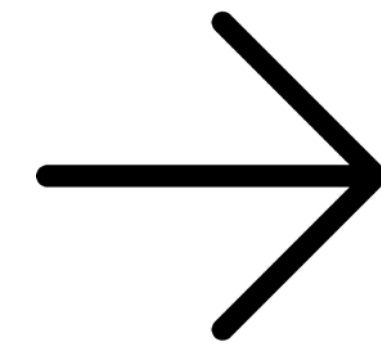
+70% nuclear energy

About Renovation & Energy Price

France



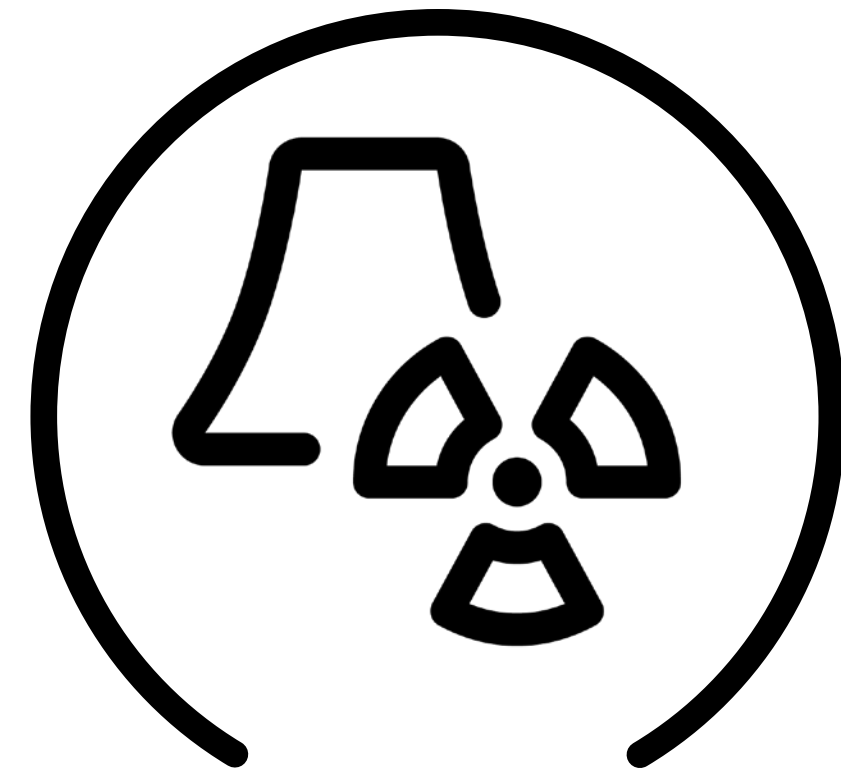
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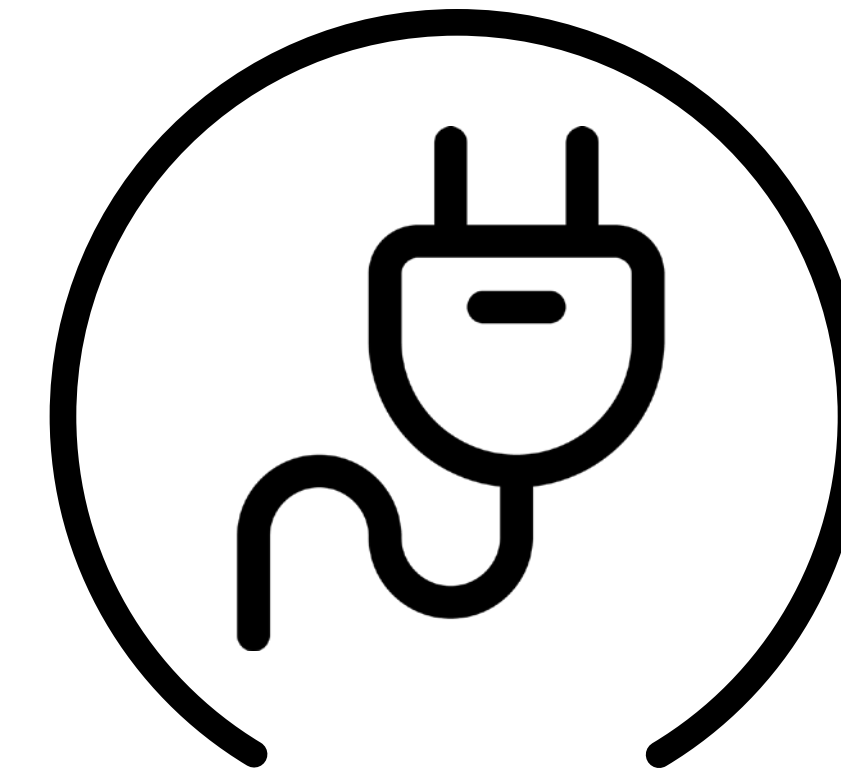
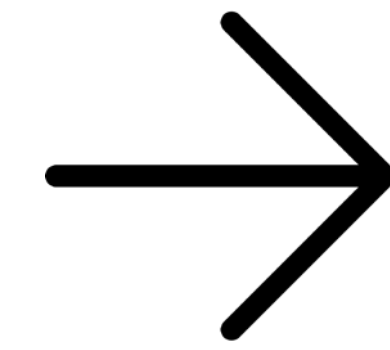
Abundant Electricity

About Renovation & Energy Price

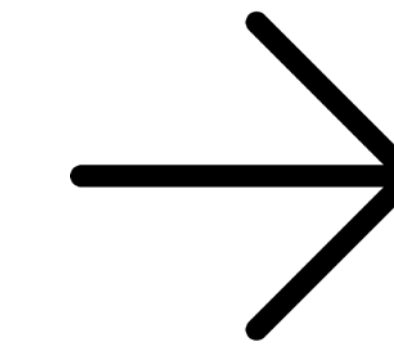
France



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Abundant Electricity

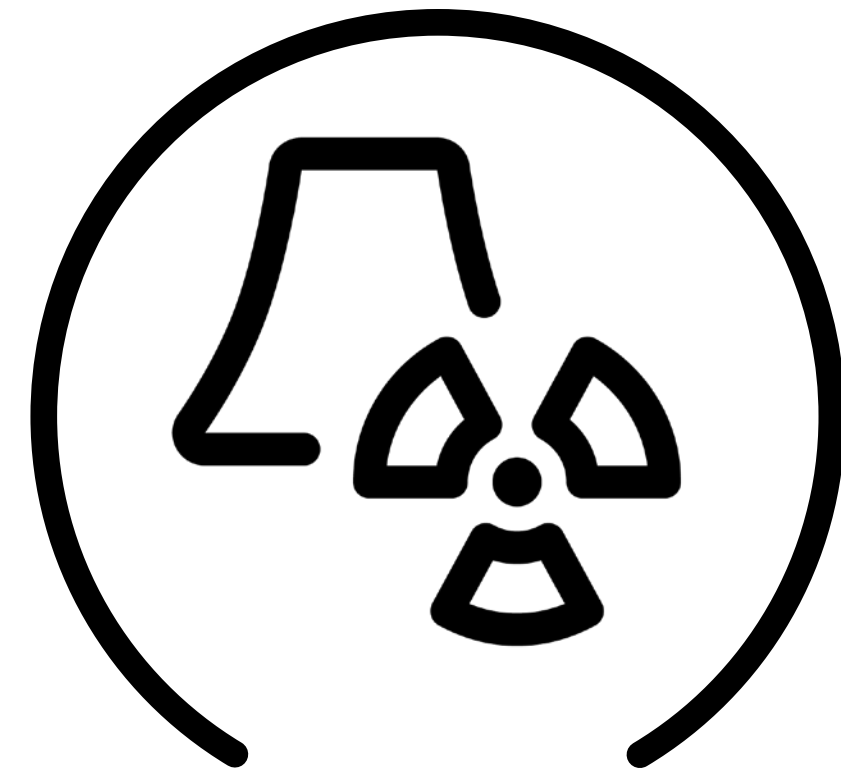


Low Electricity Price

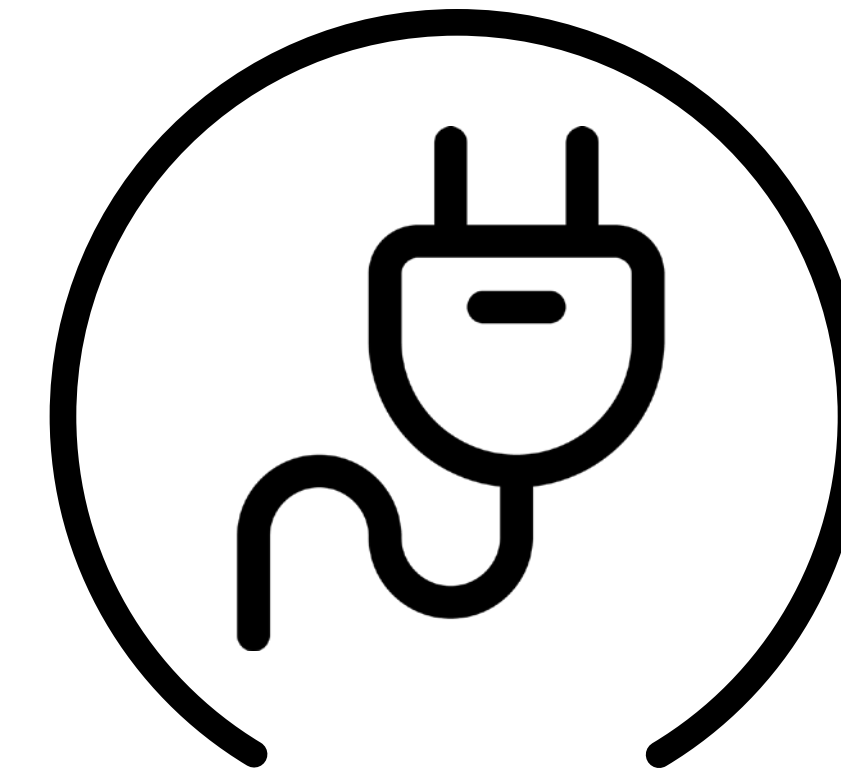
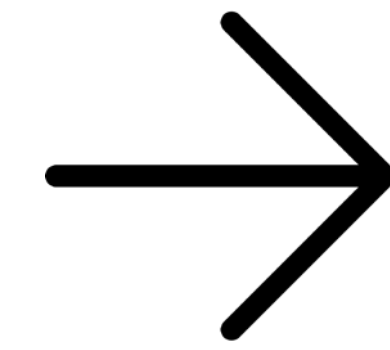
0.15€ / kW

About Renovation & Energy Price

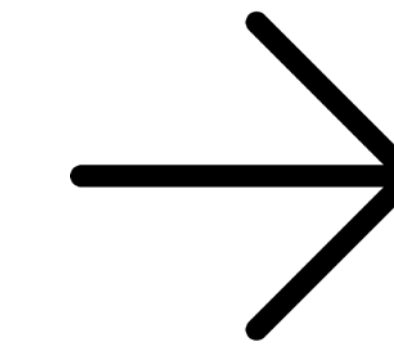
France



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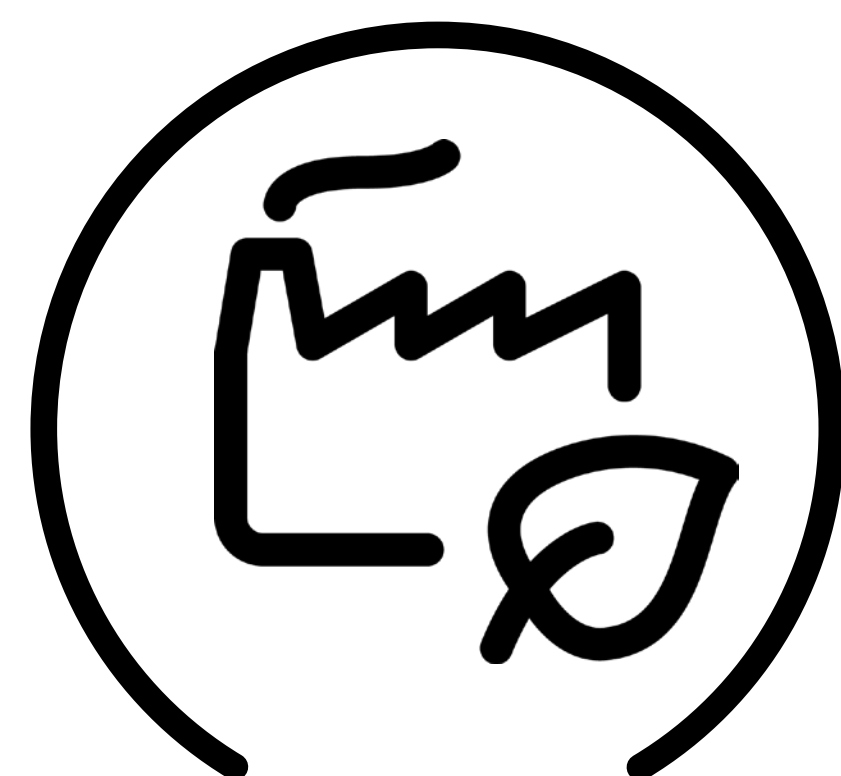
Abundant Electricity



Low Electricity Price

0.15€ / kW

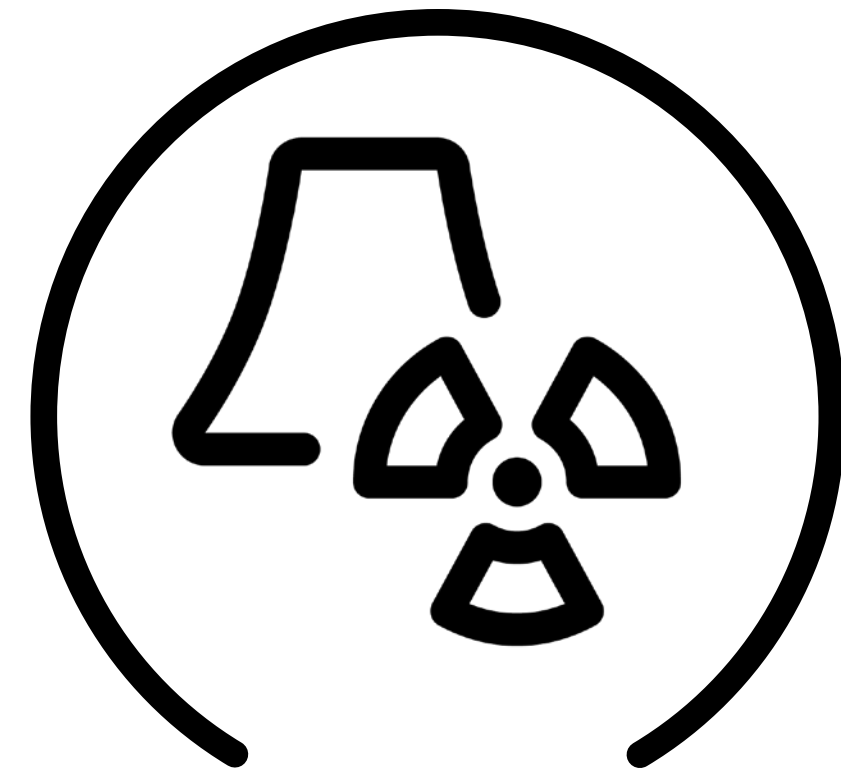
Germany



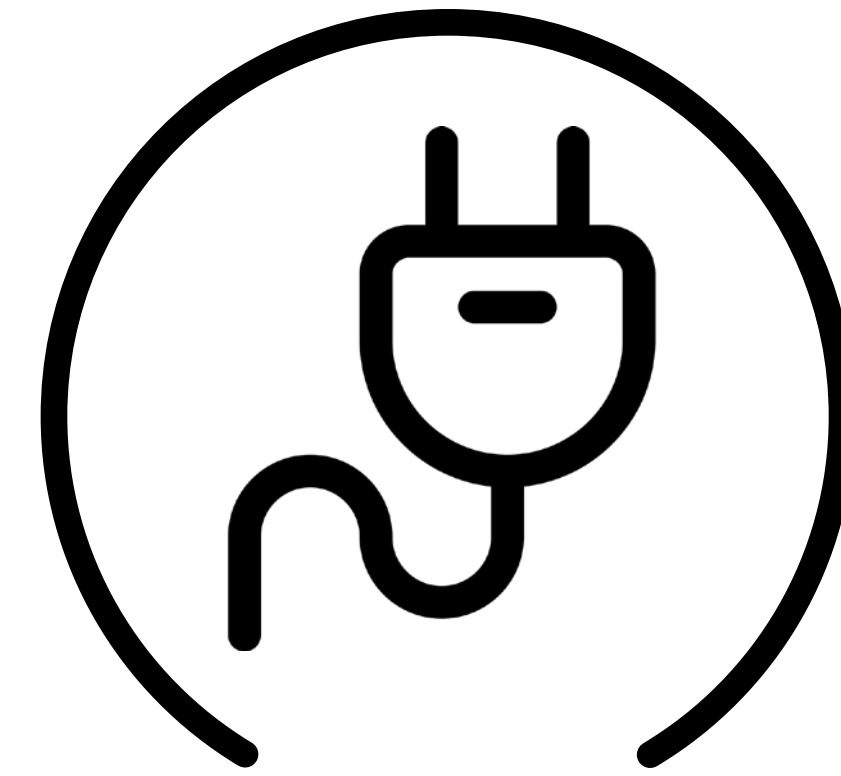
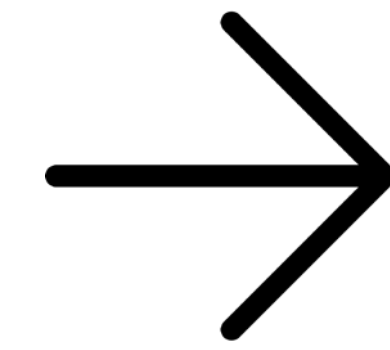
Closed Coal Plants

About Renovation & Energy Price

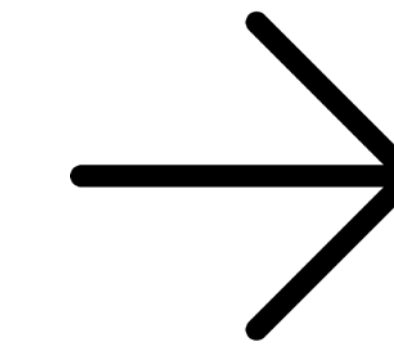
France



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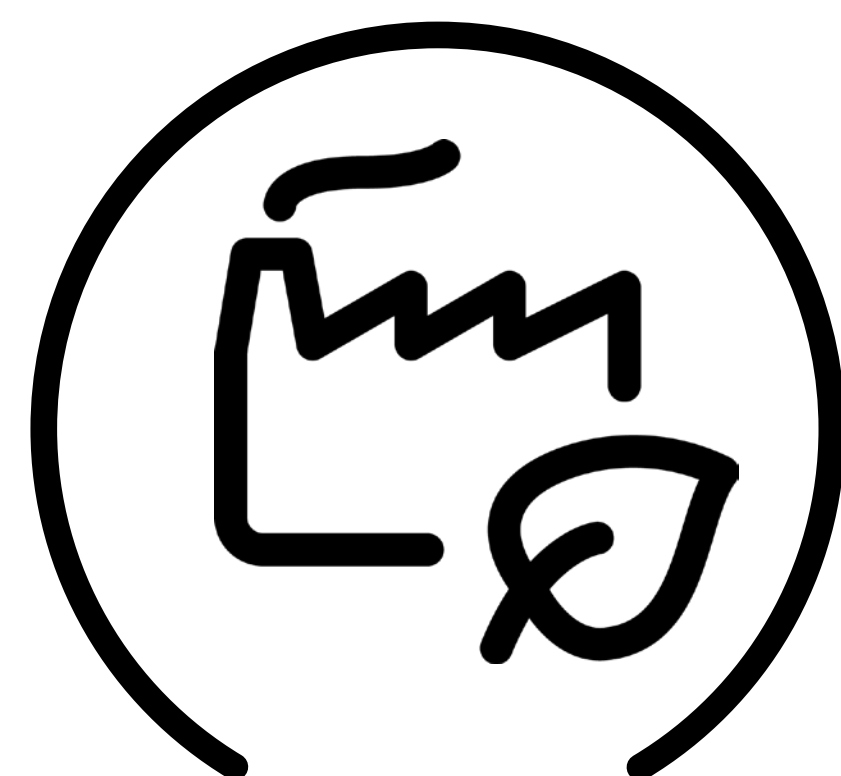
Abundant Electricity



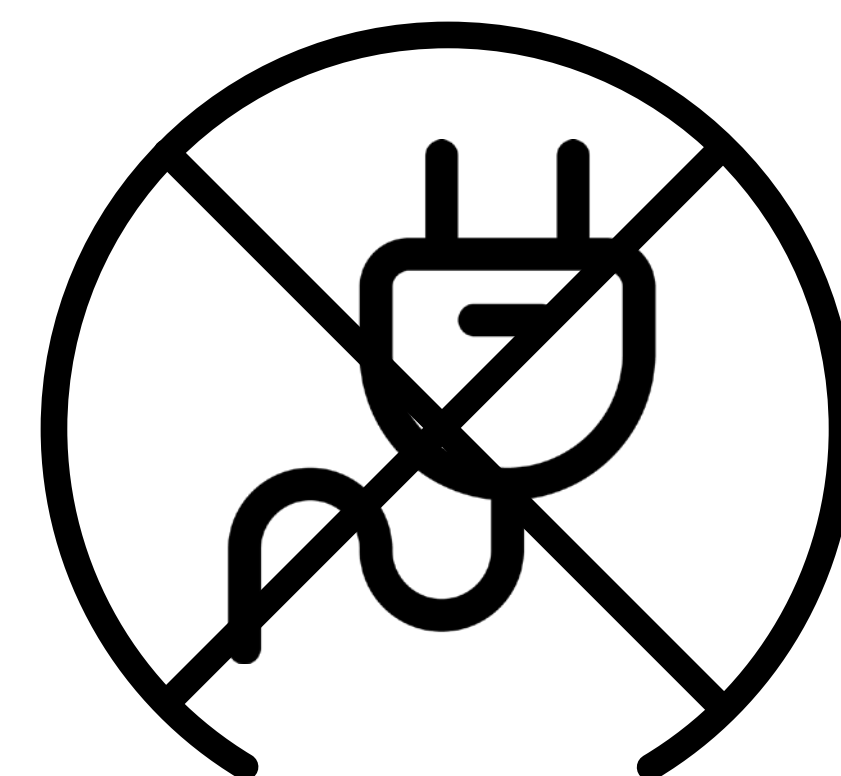
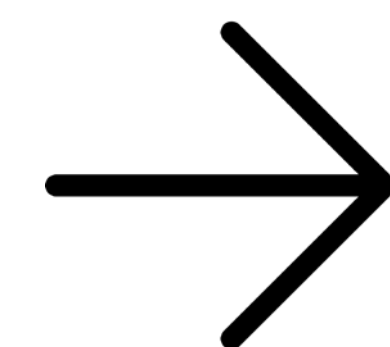
Low Electricity Price

0.15€ / kW

Germany



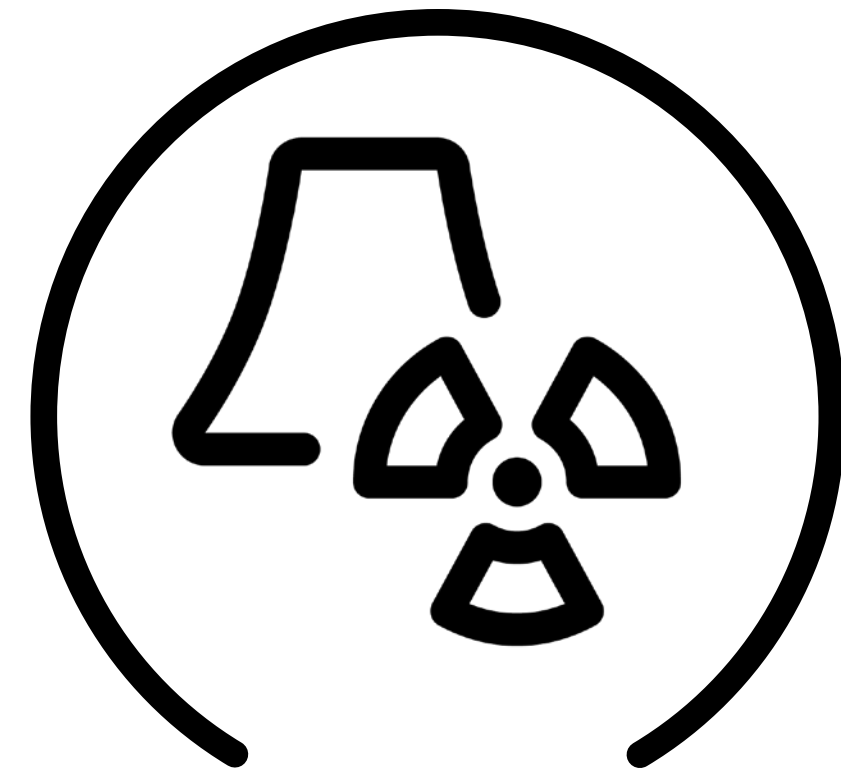
Closed Coal Plants



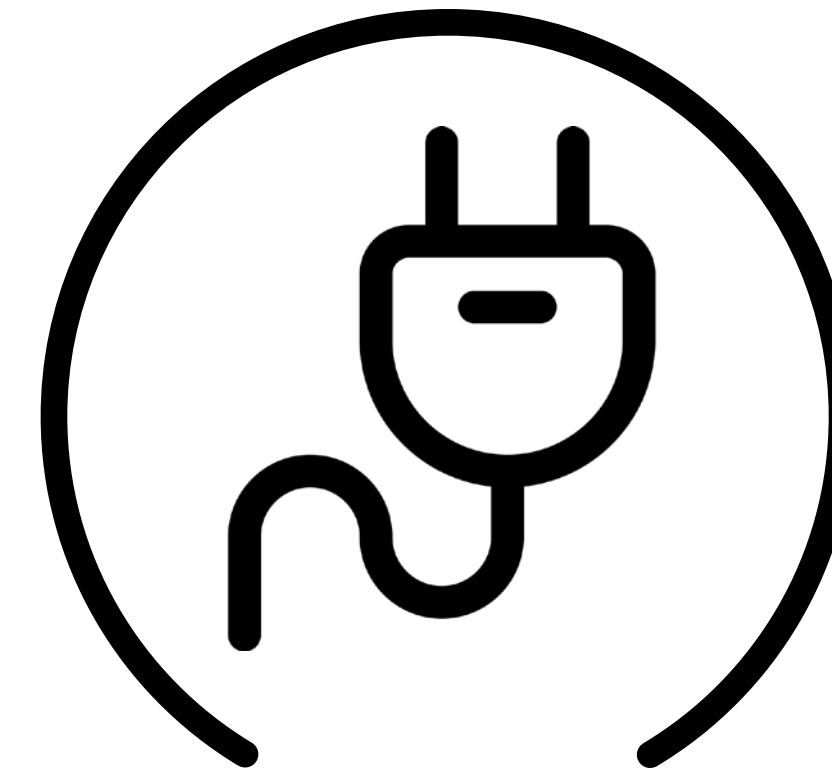
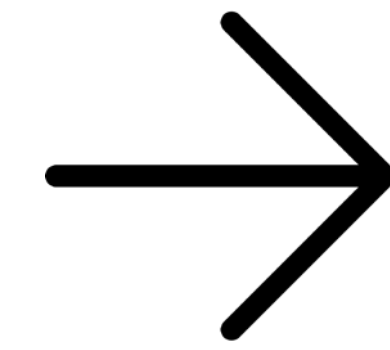
Shortage Electricity

About Renovation & Energy Price

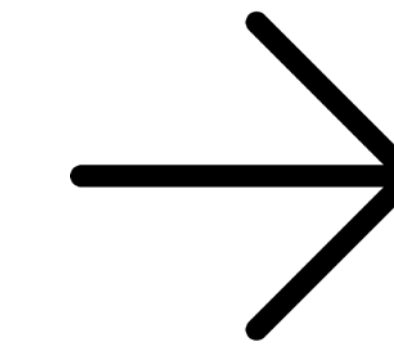
France



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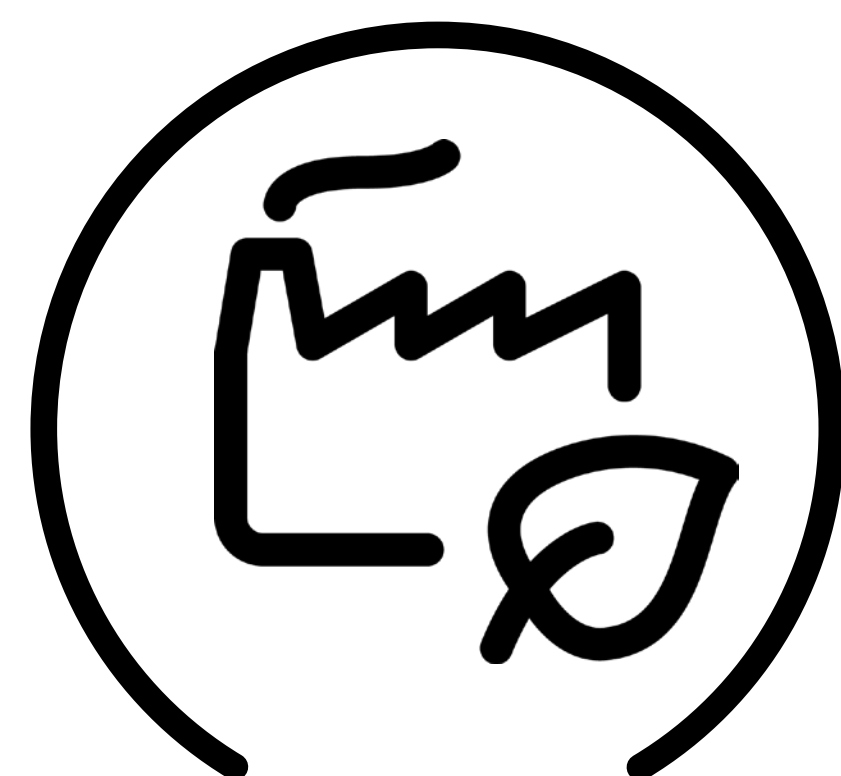
Abundant Electricity



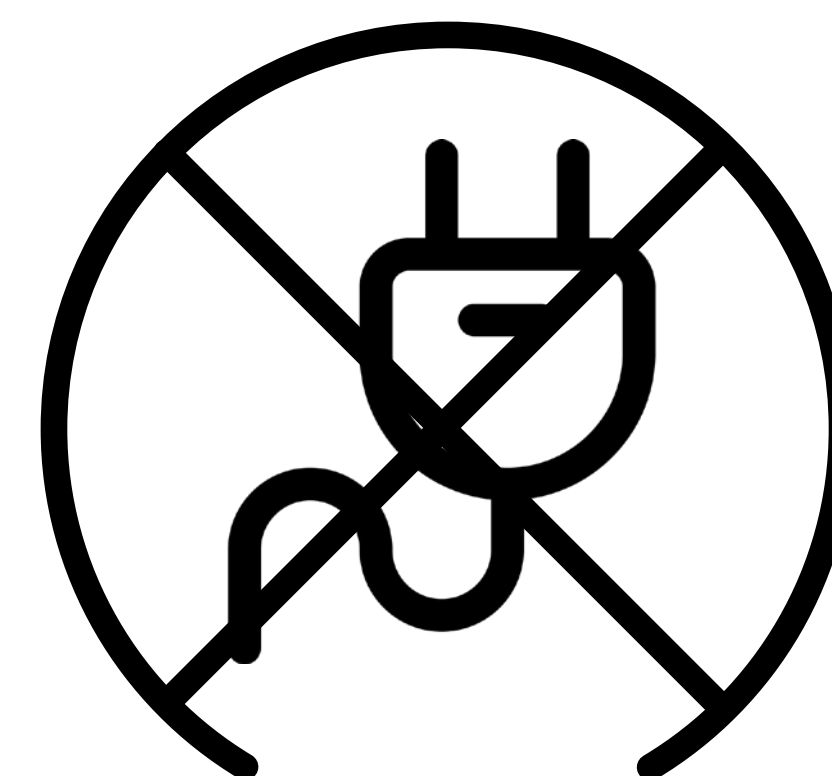
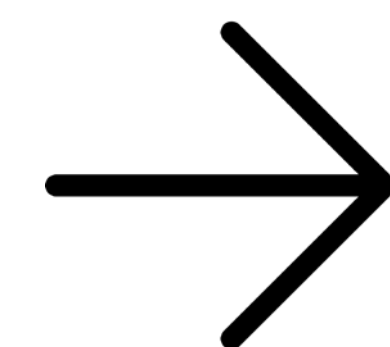
Low Electricity Price

0.15€ / kW

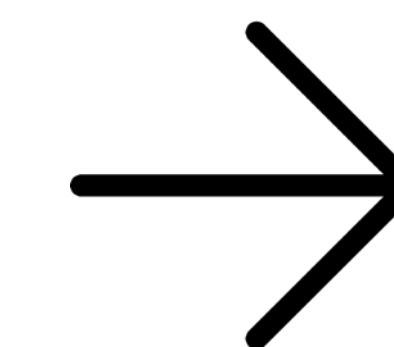
Germany



Closed Coal Plants



Shortage Electricity

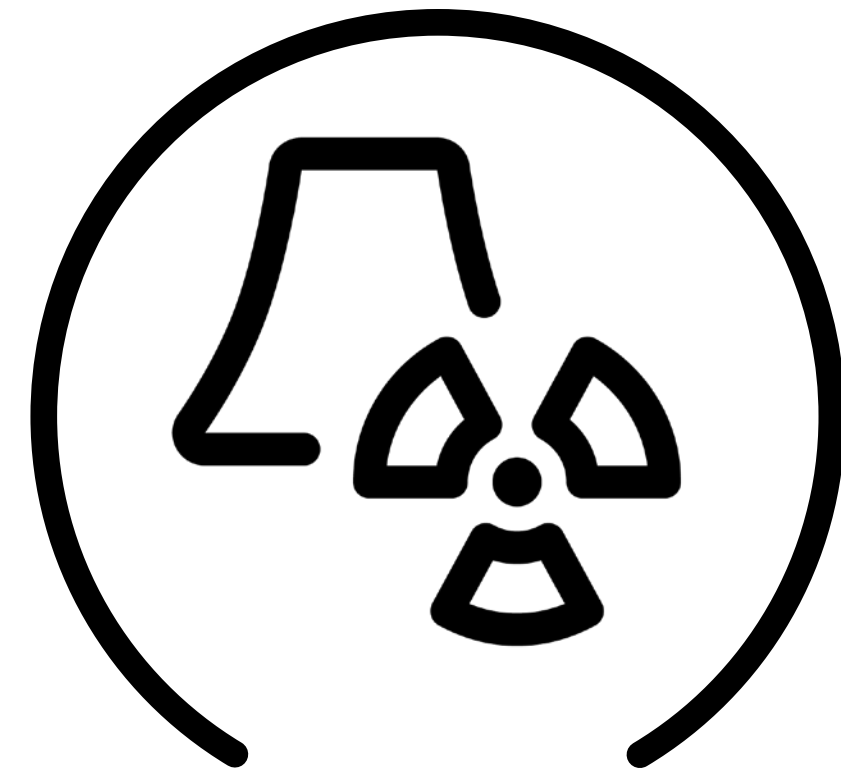


High Electricity Price

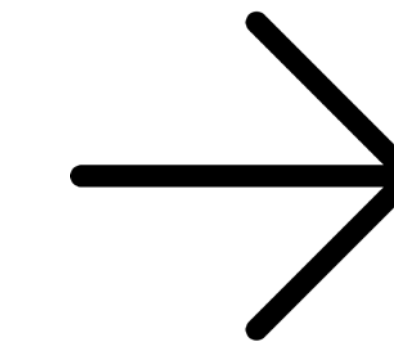
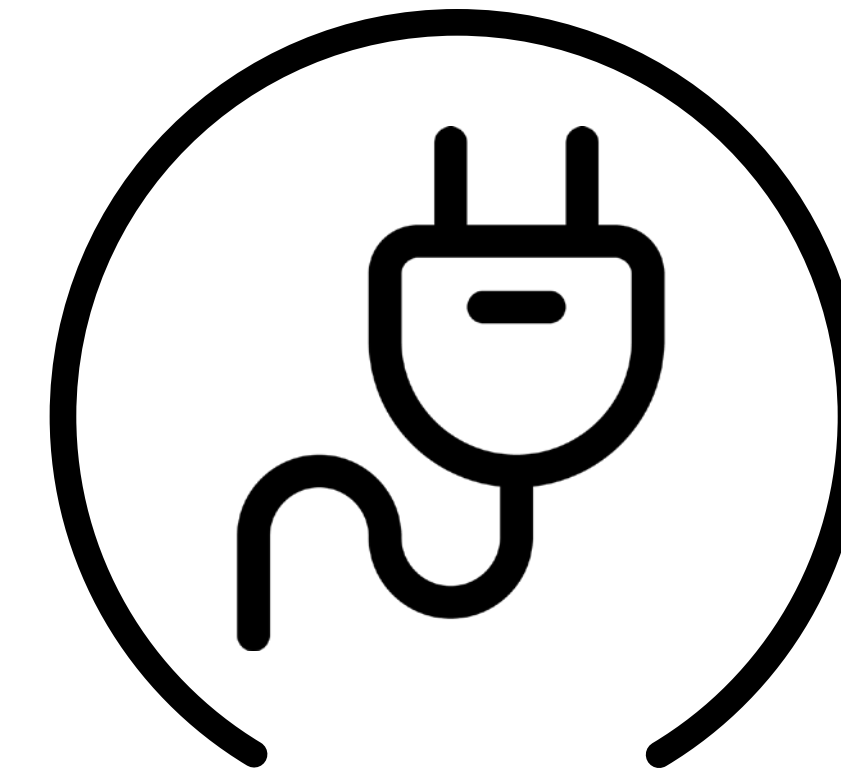
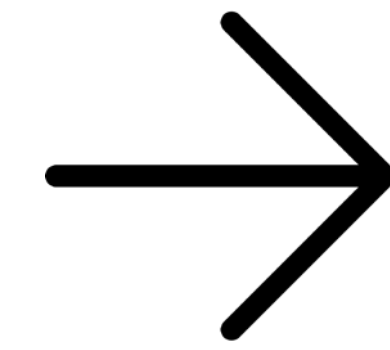
0.38€ / kW

About Renovation & Energy Price

France



+70% nuclear energy



Low Electricity Price

0.15€ / kW

Germany



Closed Coal Plants

Return on Investment
on reducing the energy consumption
at 0.38€ / kW:

Short & Attractive



High Electricity Price

0.38€ / kW

About Renovation & Energy Price

France



+70% nuclear energy

Return on Investment
on reducing the energy consumption
at 0.15€ / kW:

Long & Unattractive



Low Electricity Price
0.15€ / kW

Germany



Closed Coal Plants

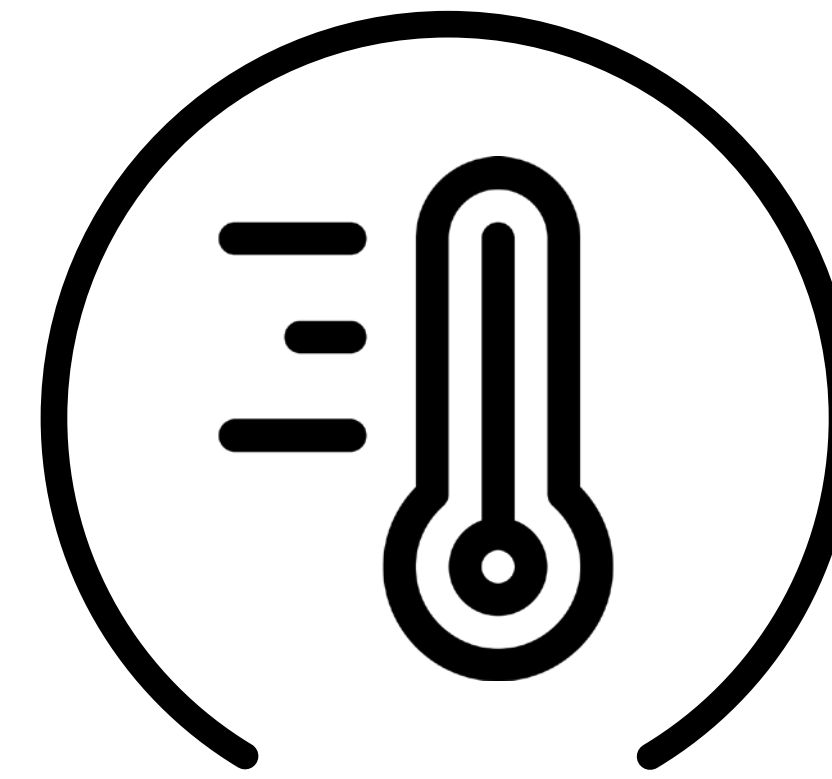
Return on Investment
on reducing the energy consumption
at 0.38€ / kW:

Short & Attractive



High Electricity Price
0.38€ / kW

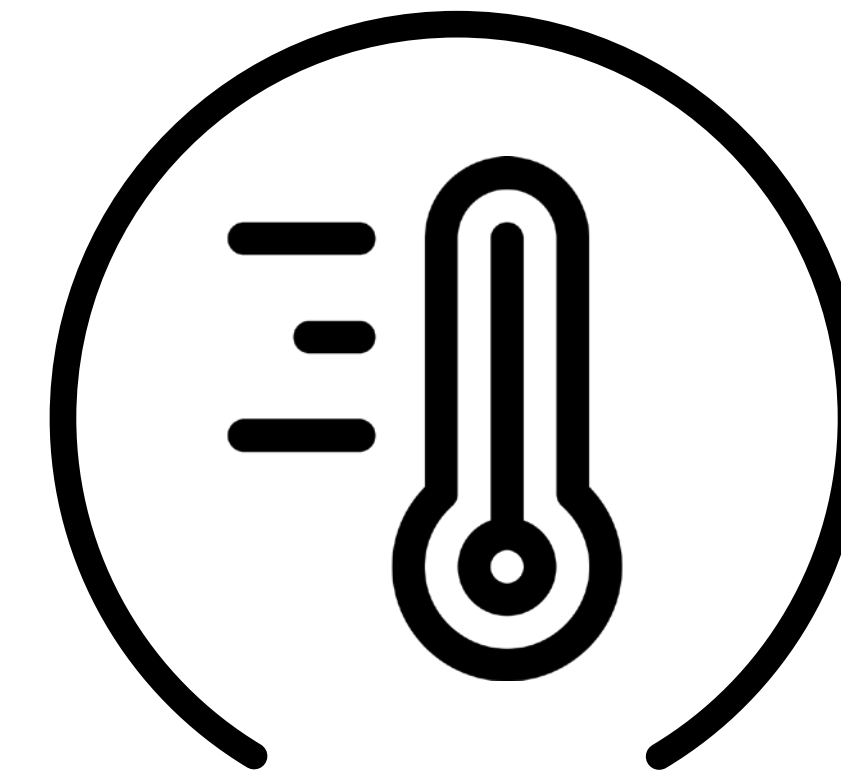
Paris Building Owner



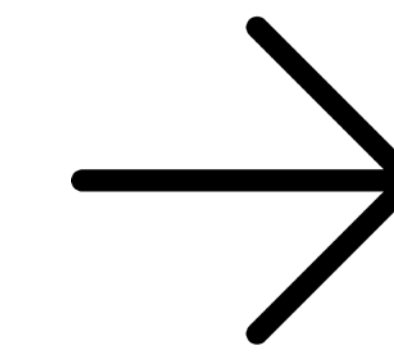
Thermal Comfort

About Renovation & Energy Price

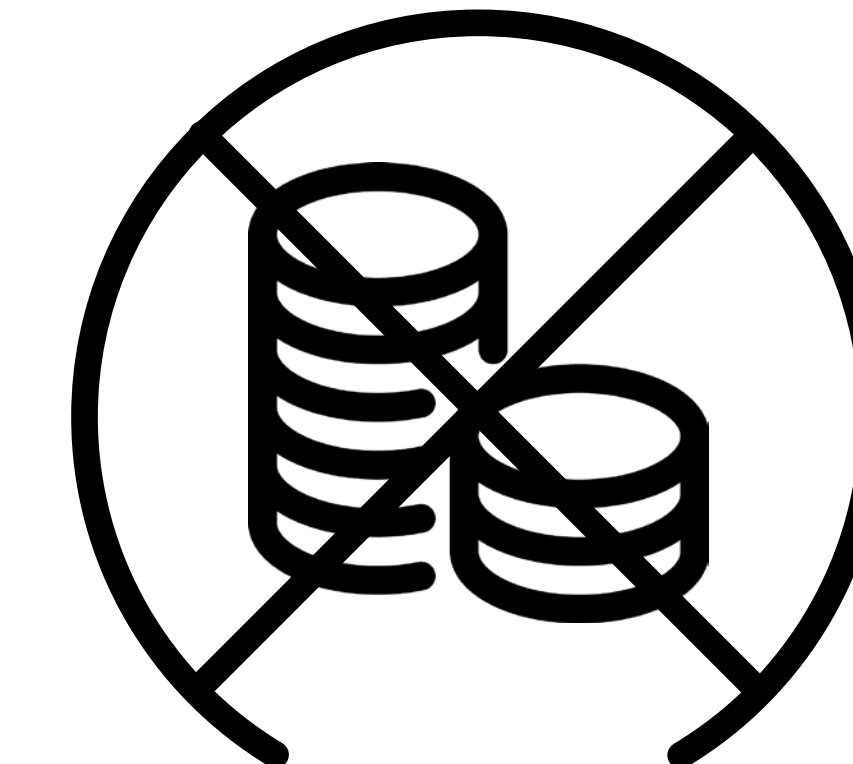
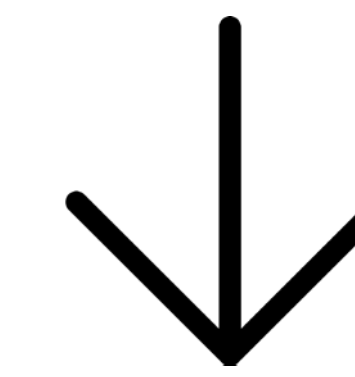
Paris Building Owner



Thermal Comfort



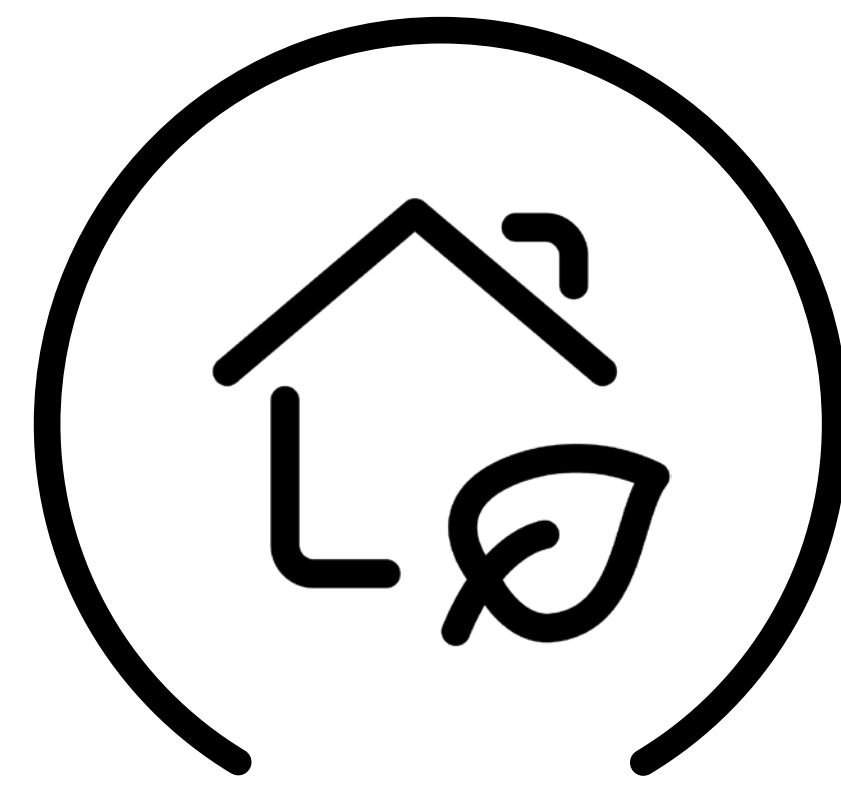
Active System



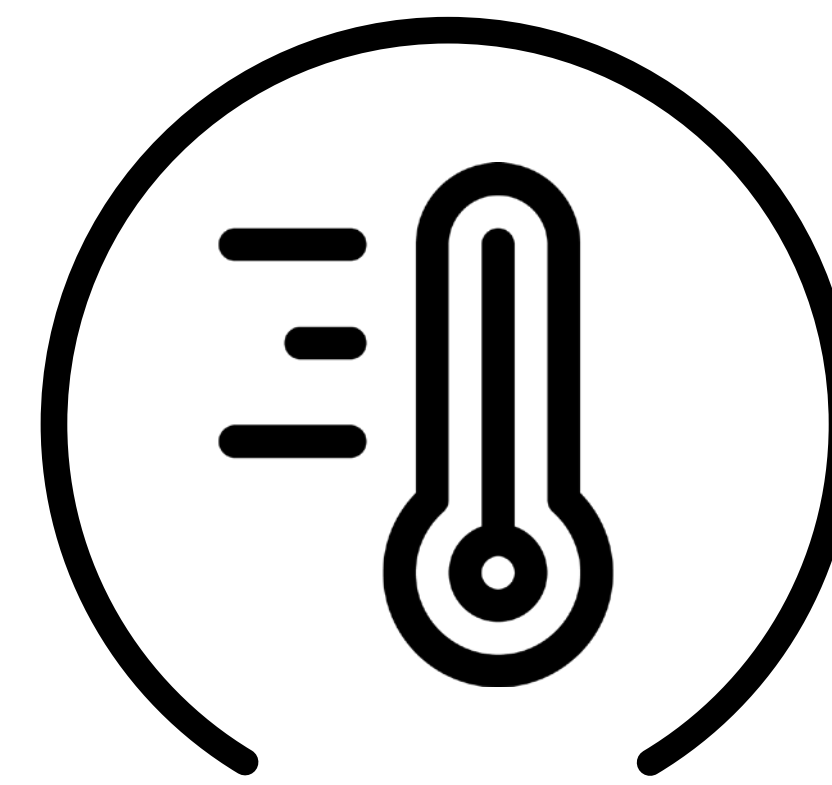
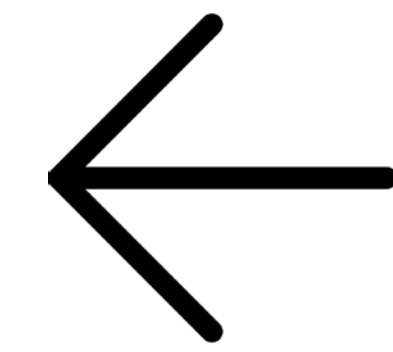
Cheap
+ No Investment Costs

About Renovation & Energy Price

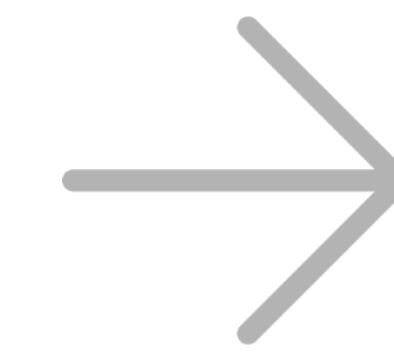
Paris Building Owner



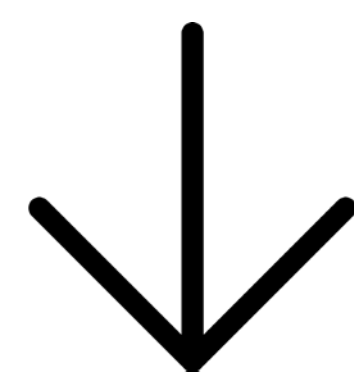
Passive System



Thermal Comfort



Active System



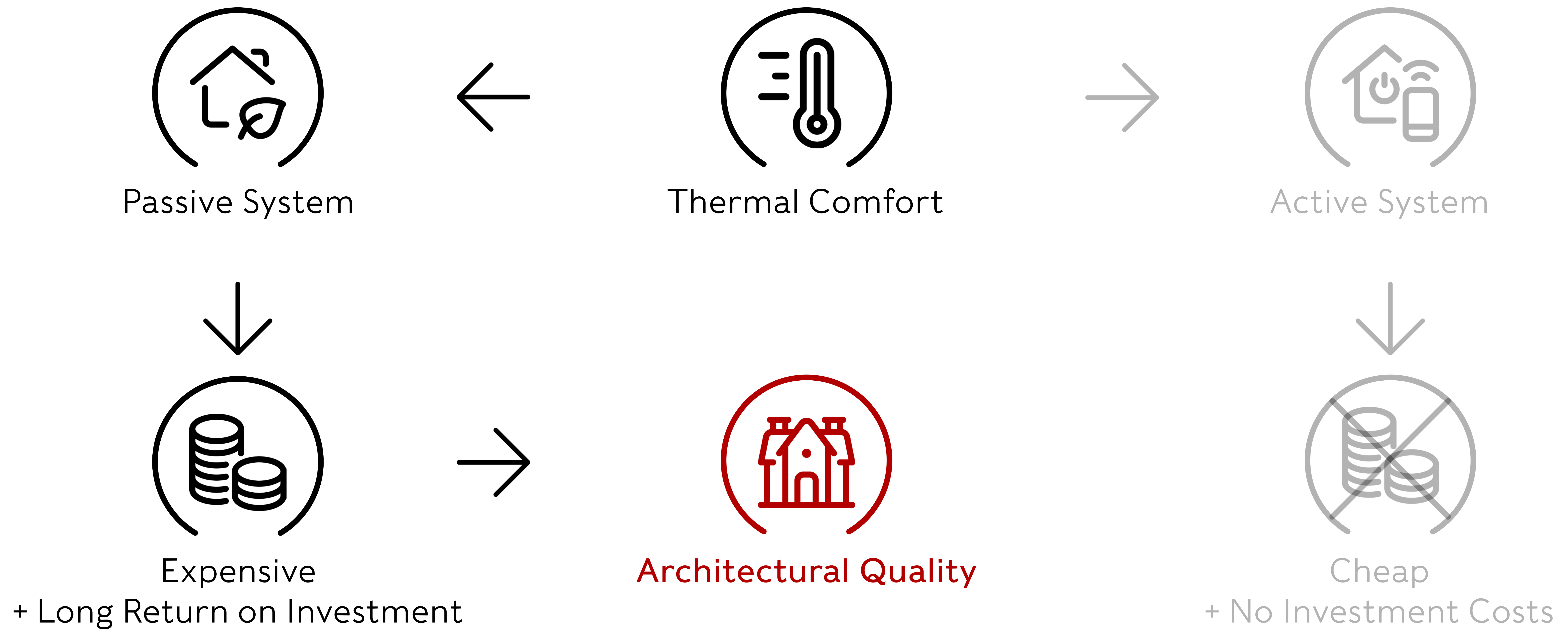
Expensive
+ Long Return on Investment



Cheap
+ No Investment Costs

About Renovation & Energy Price

Paris Building Owner



About Renovation & Energy Price

Paris Building Owner



About Renovation & Energy Price

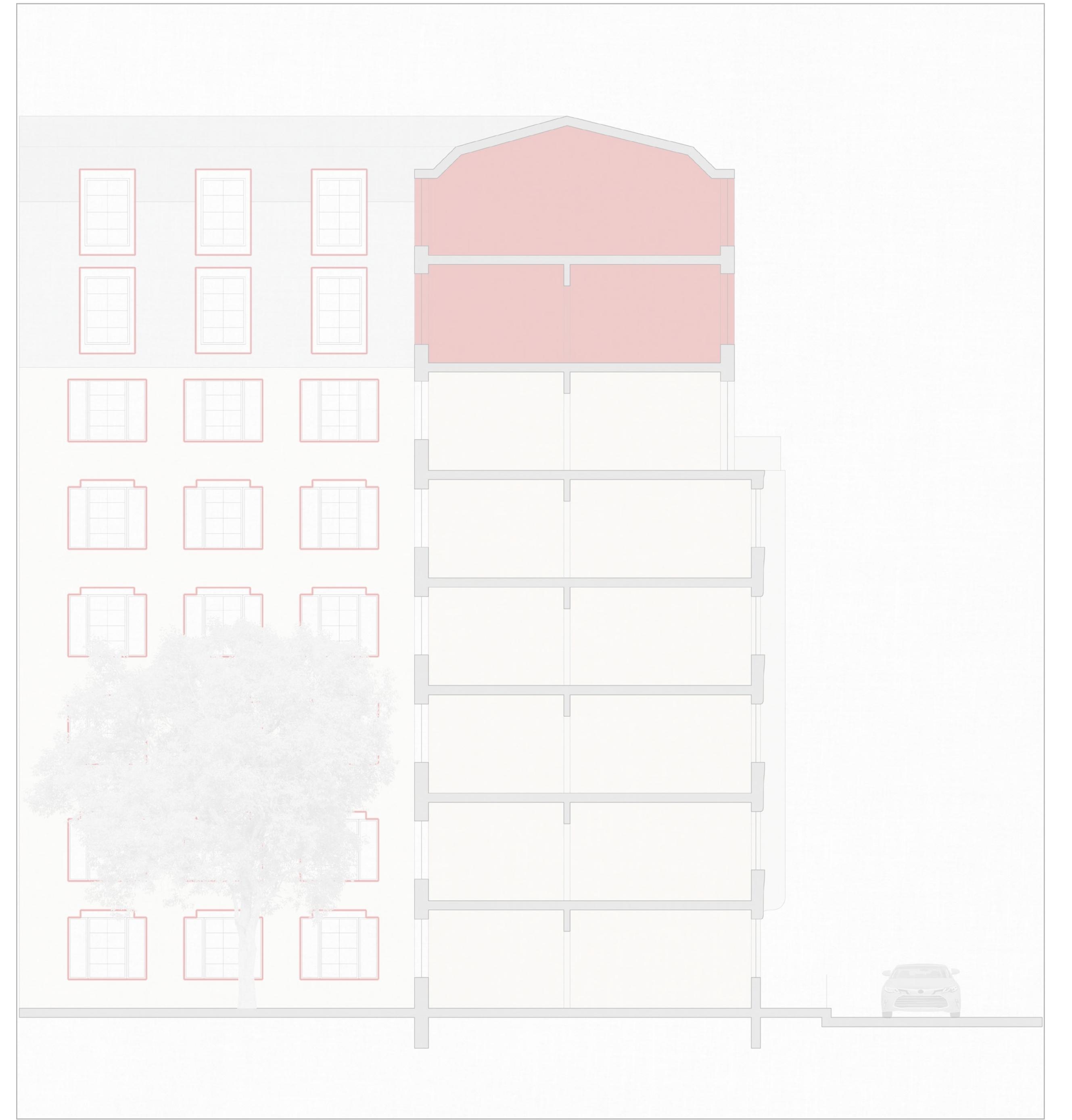


Protoblock Section: **Baseline**



Protoblock Section: **Renovated**

Courtyard Window-to-Wall Ratio: **40%**



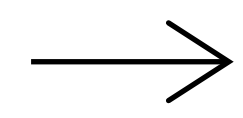
Protoblock Section: **Sur-Elevated**

Courtyard Window-to-Wall Ratio: **40%**
Additional Market-Rate Floors: **2**

Baseline Simulation



Protoblock Section: **Baseline**



Protoblock Section: **Renovated**

Courtyard Window-to-Wall Ratio: **40%**



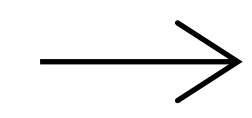
Protoblock Section: **Sur-Elevated**

Courtyard Window-to-Wall Ratio: **40%**
Additional Market-Rate Floors: **2**

Baseline Simulation

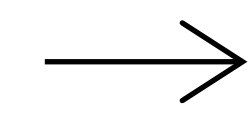


Protoblock Section: **Baseline**



Protoblock Section: **Renovated**

Courtyard Window-to-Wall Ratio: **40%**



Protoblock Section: **Sur-Elevated**

Courtyard Window-to-Wall Ratio: **40%**
Additional Market-Rate Floors: **2**

Baseline Simulation

Baseline
Minimal Insulation
Single Glazing

Walls
Increased Insulation
Low Embodied-E
Design

Groundfloor
Increased Insulation

Roof
Increased Insulation
Increased Albedo

Glass
Double Glazing
Argon Fill

Lights
LED Bulbs
Continuous Dimming

Heating
Electric Heating
Increased Efficiency
100W/m2 limit

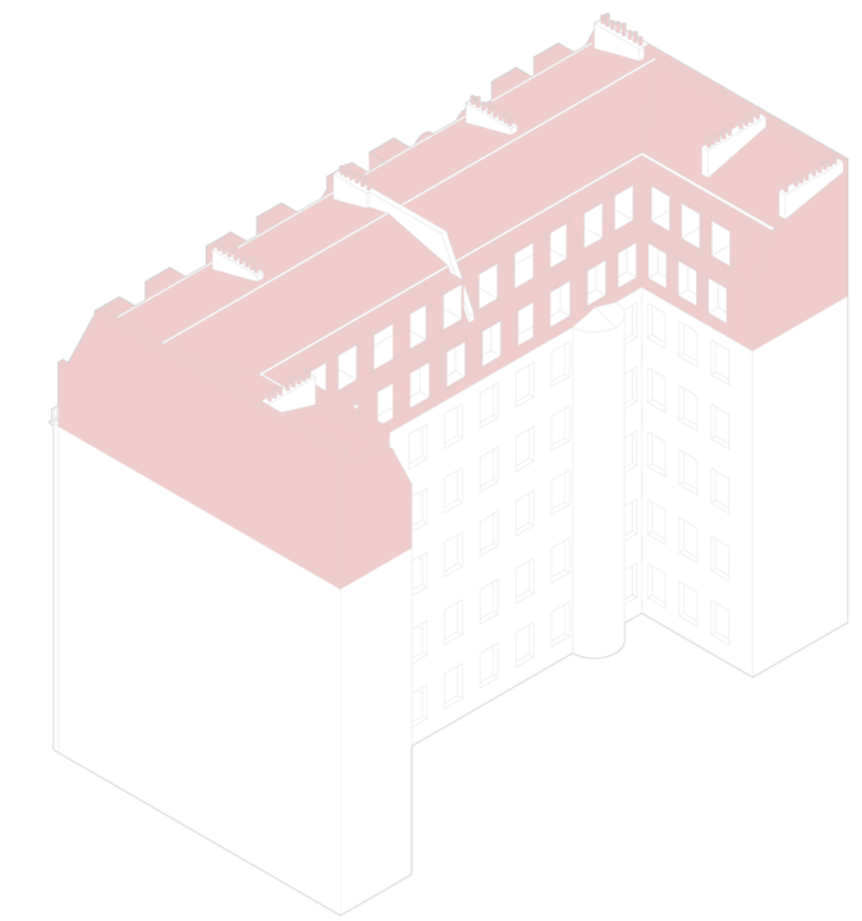
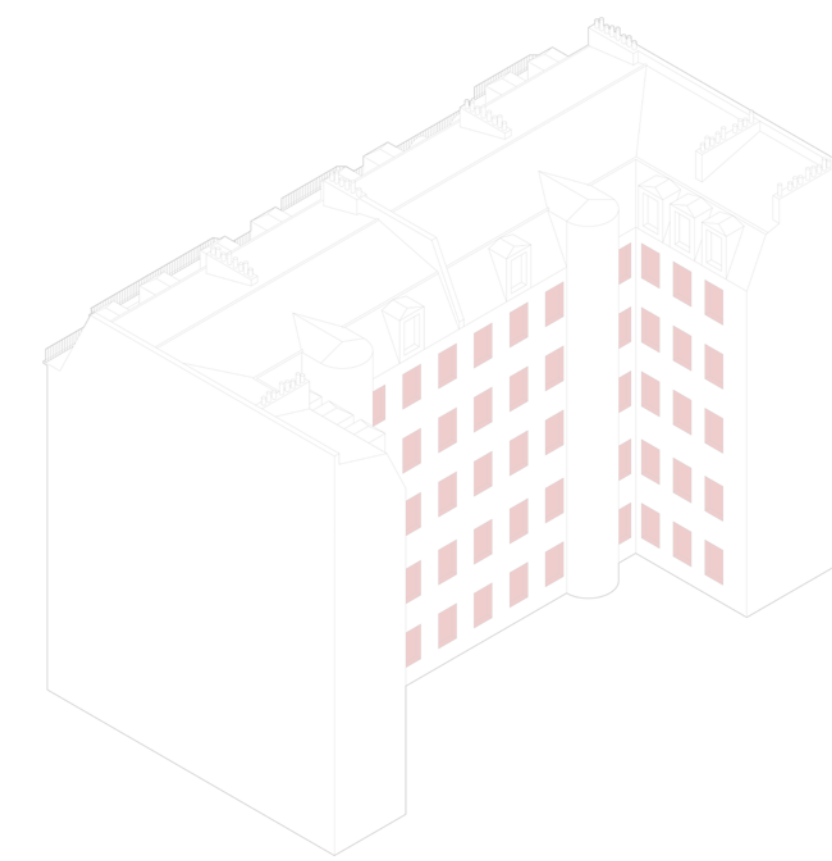
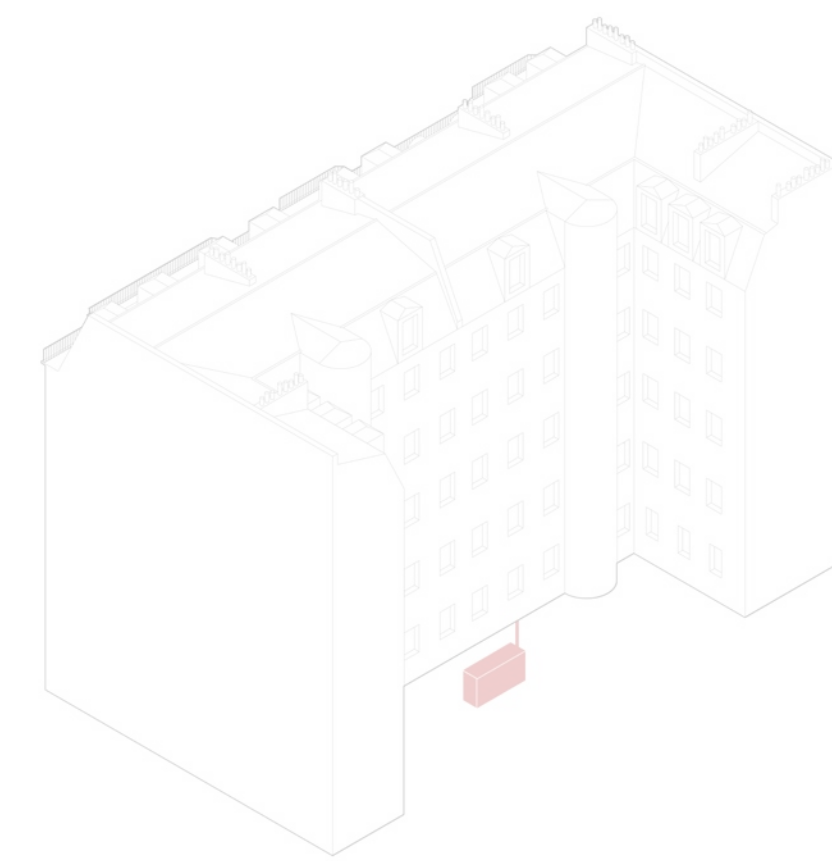
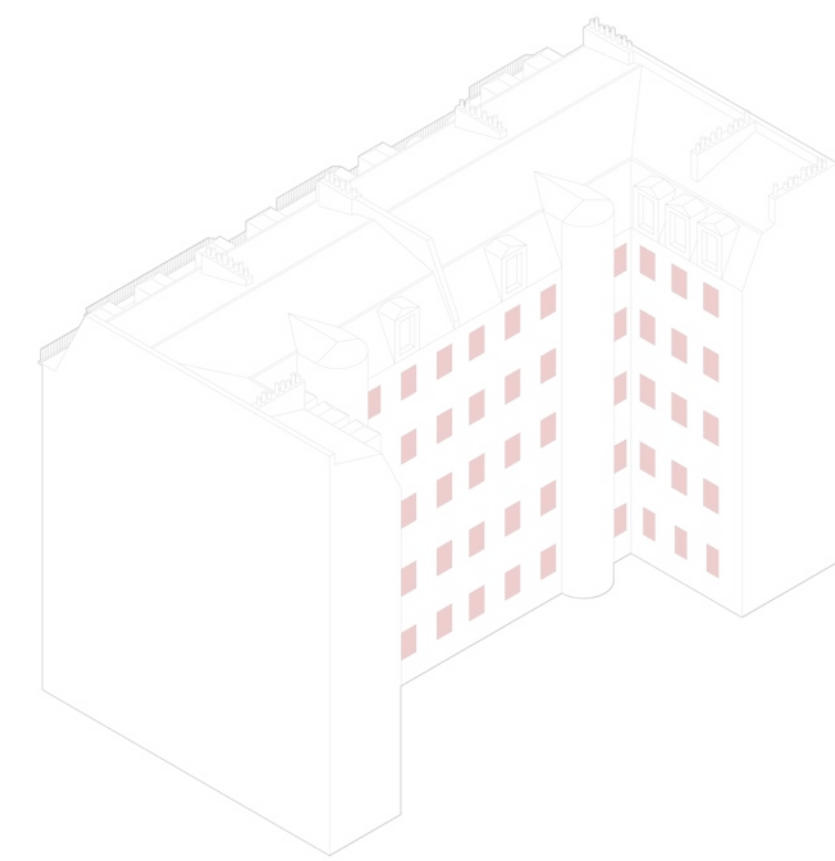
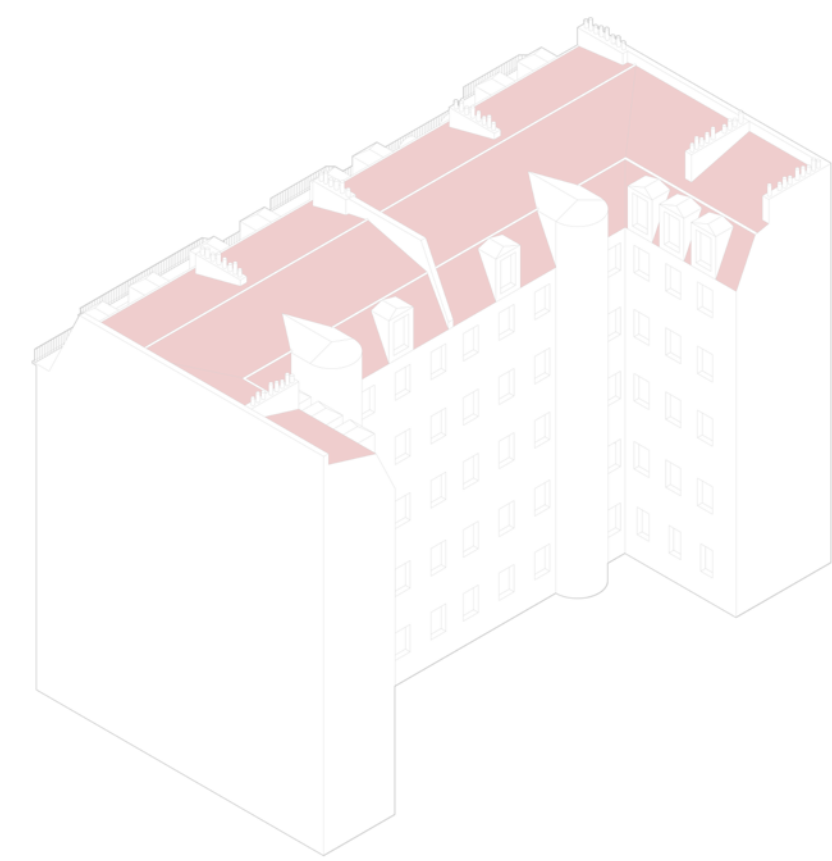
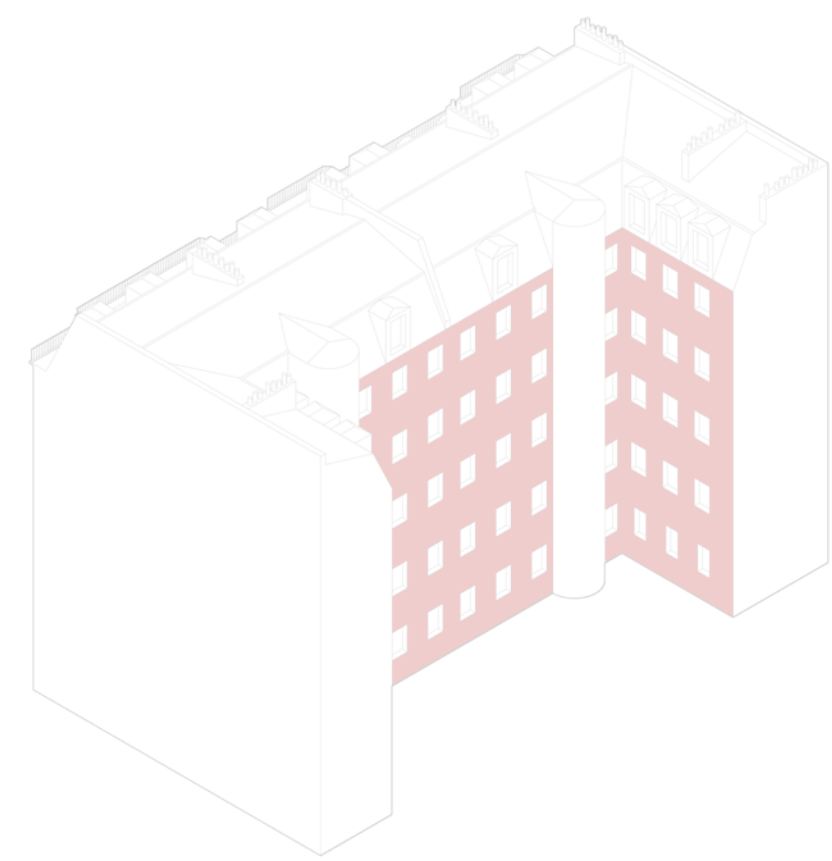
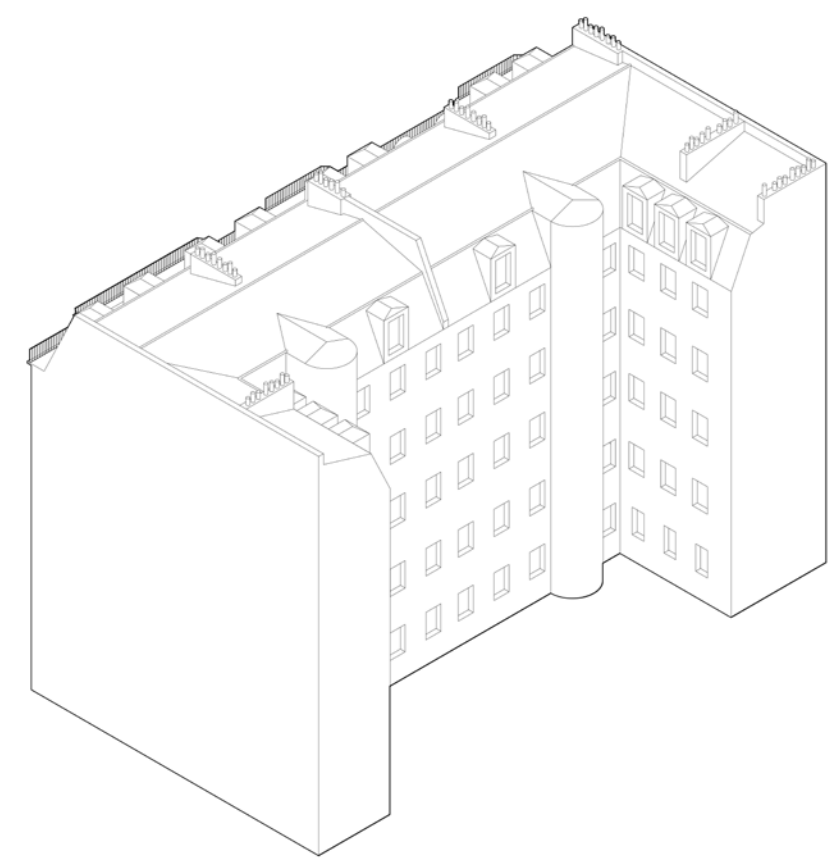
Cooling
A/C On
Increased Efficiency
100W/m2 limit

Boiler
Electric Boiler
Energy Star Efficiency

Windows
WWR increase from:
25% to 40%

Equipment
Limited Usage
Conscious Behaviour

Surelevation
2 Additional Floors
(High Efficiency Build)



Baseline



Renovation



Sur-Elevation

EUI evolution & CO2 emissions

Baseline
Minimal Insulation
Single Glazing

Walls
Increased Insulation
Low Embodied-E
Design

Groundfloor
Increased Insulation

Roof
Increased Insulation
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Glass
Double Glazing
Argon Fill

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LED Bulbs
Continuous Dimming

Heating
Electric Heating
Increased Efficiency
100W/m2 limit

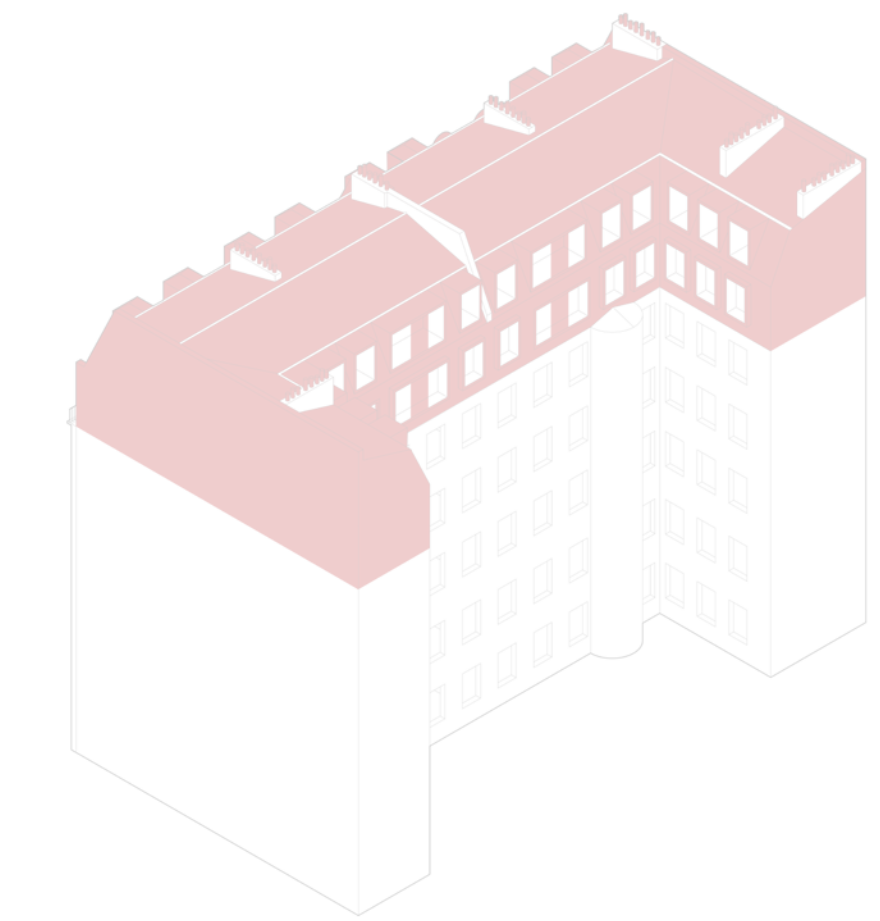
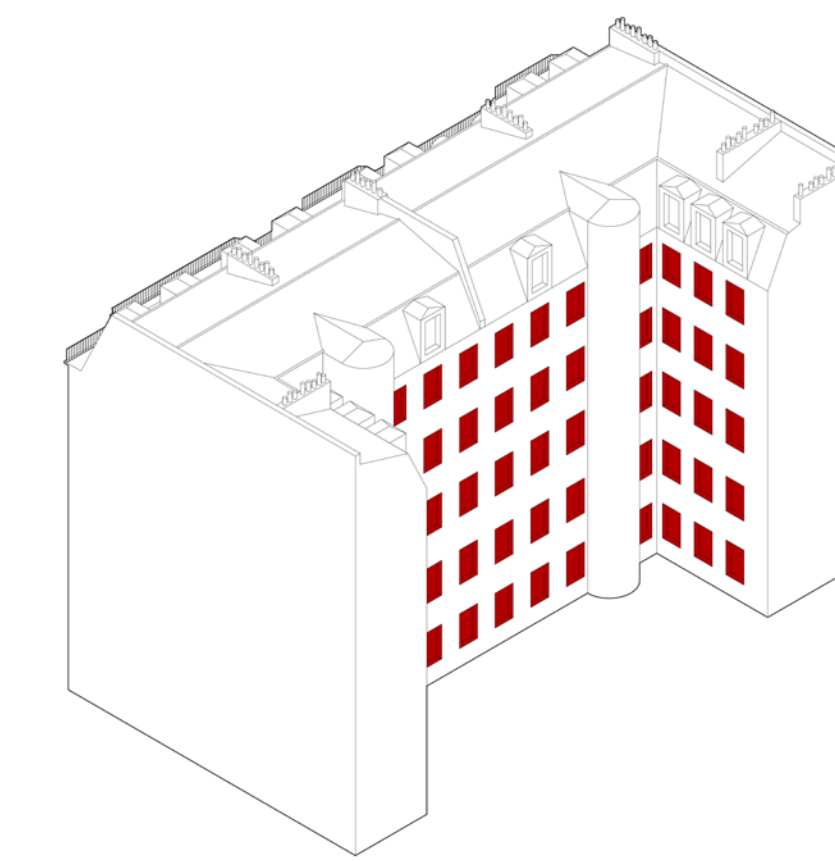
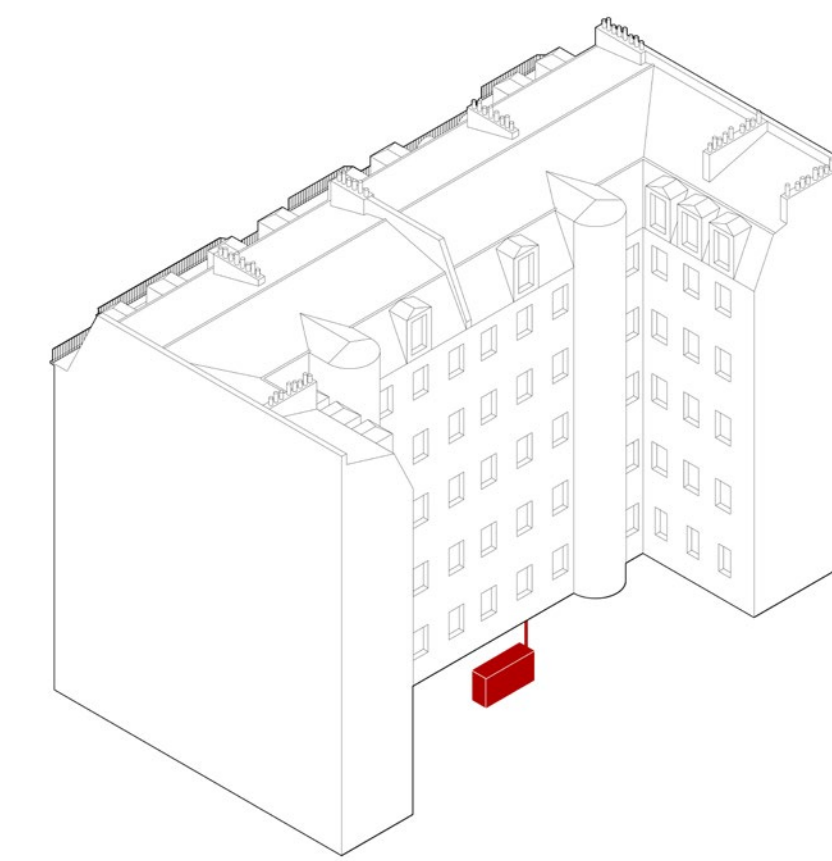
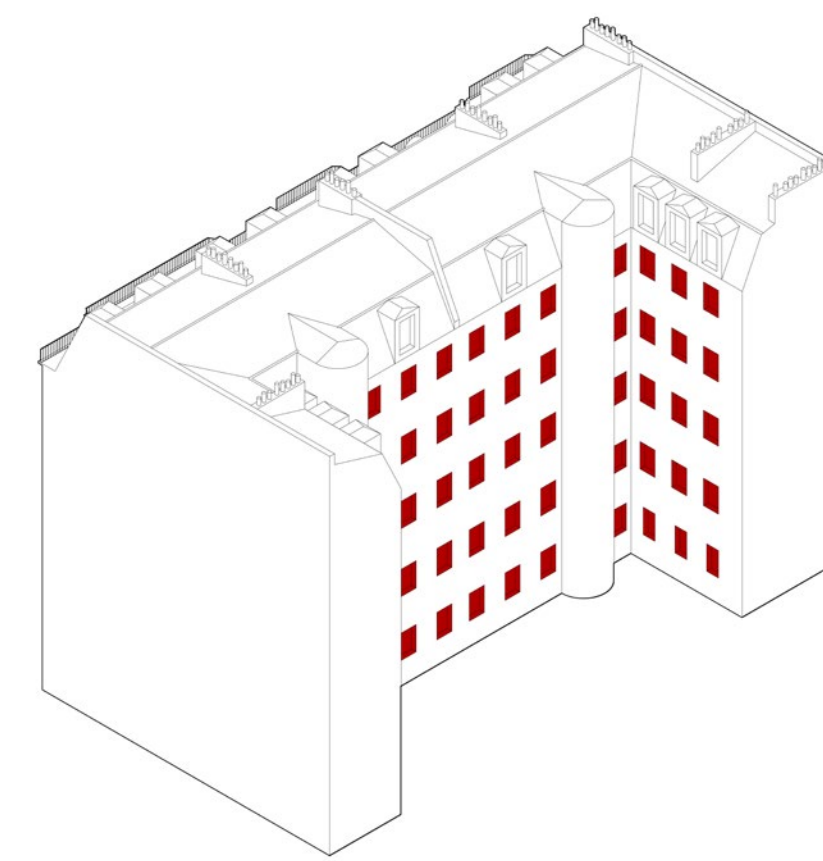
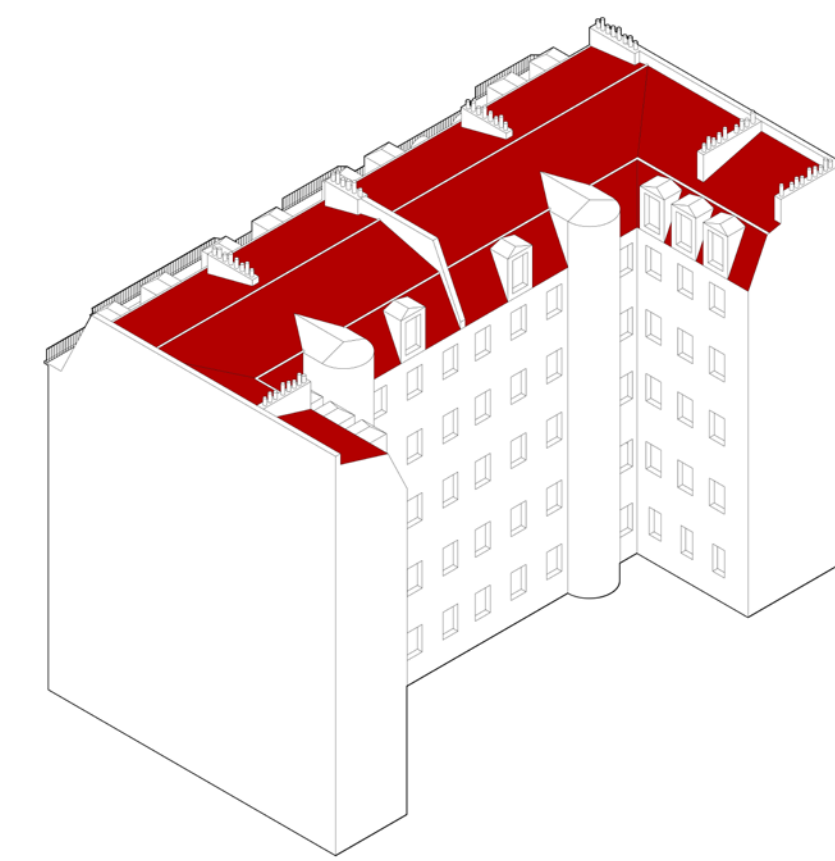
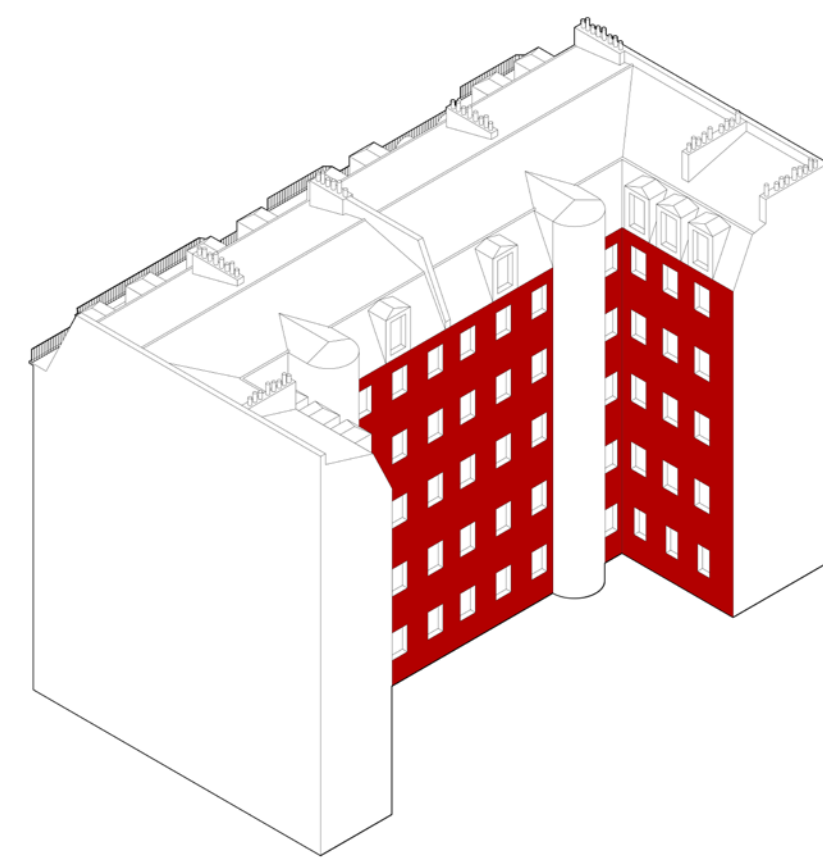
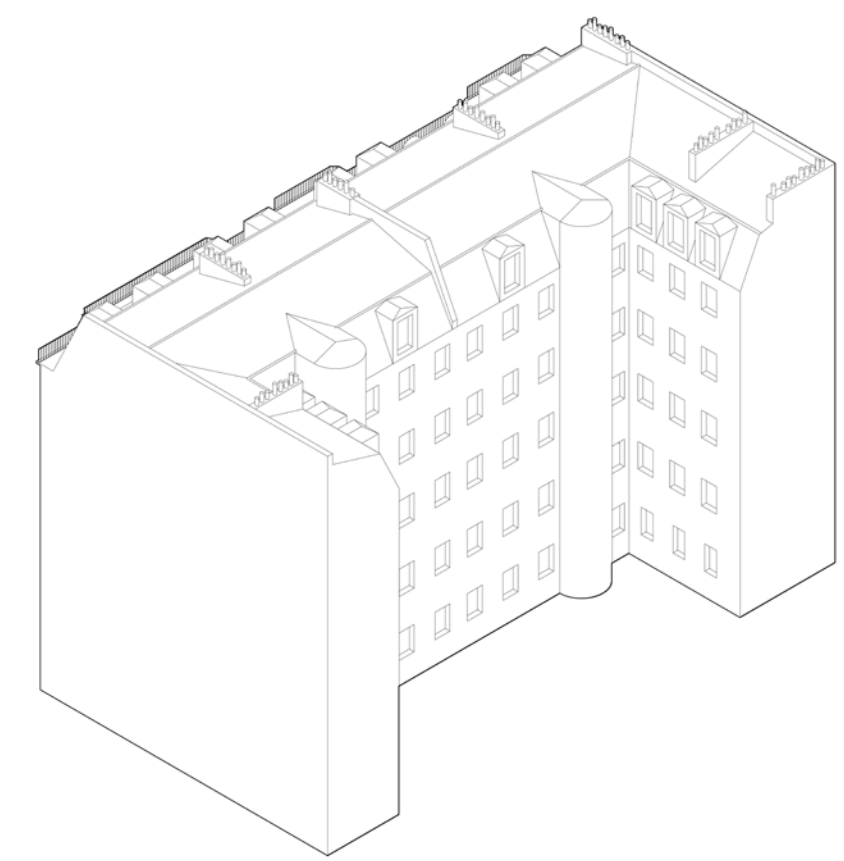
Cooling
A/C On
Increased Efficiency
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Baseline



Renovation



Sur-Elevation

EUI evolution & CO2 emissions

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Minimal Insulation
Single Glazing

Walls
Increased Insulation
Low Embodied-E
Design

Groundfloor
Increased Insulation

Roof
Increased Insulation
Increased Albedo

Glass
Double Glazing
Argon Fill

Lights
LED Bulbs
Continuous Dimming

Heating
Electric Heating
Increased Efficiency
100W/m2 limit

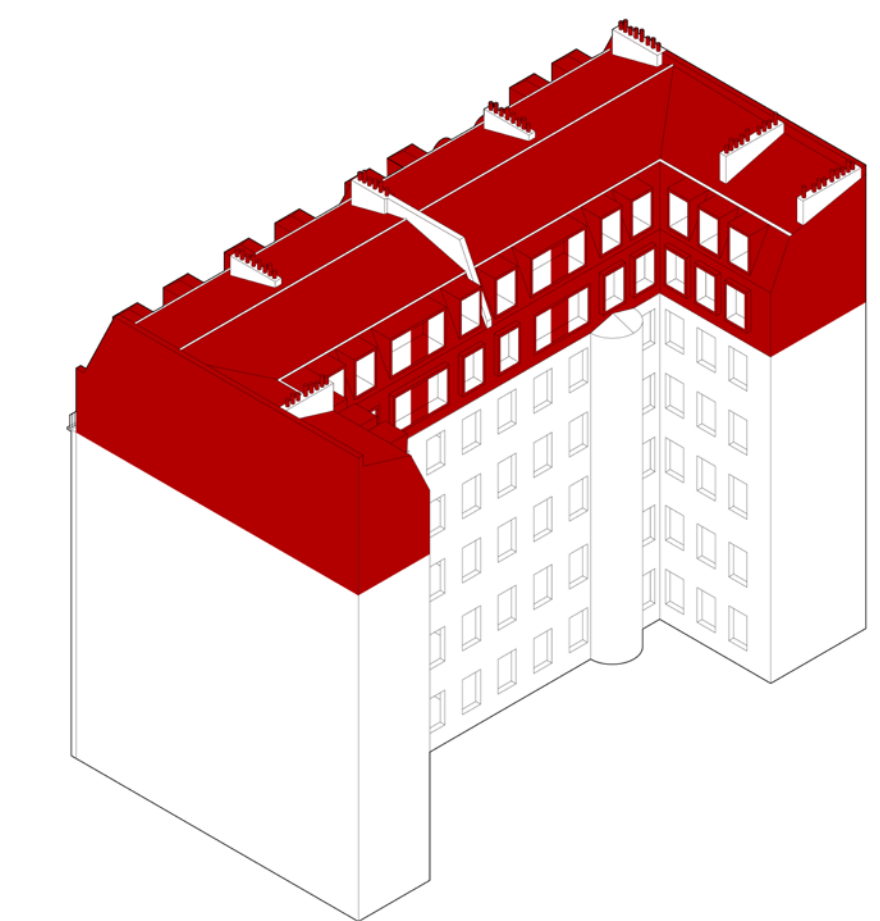
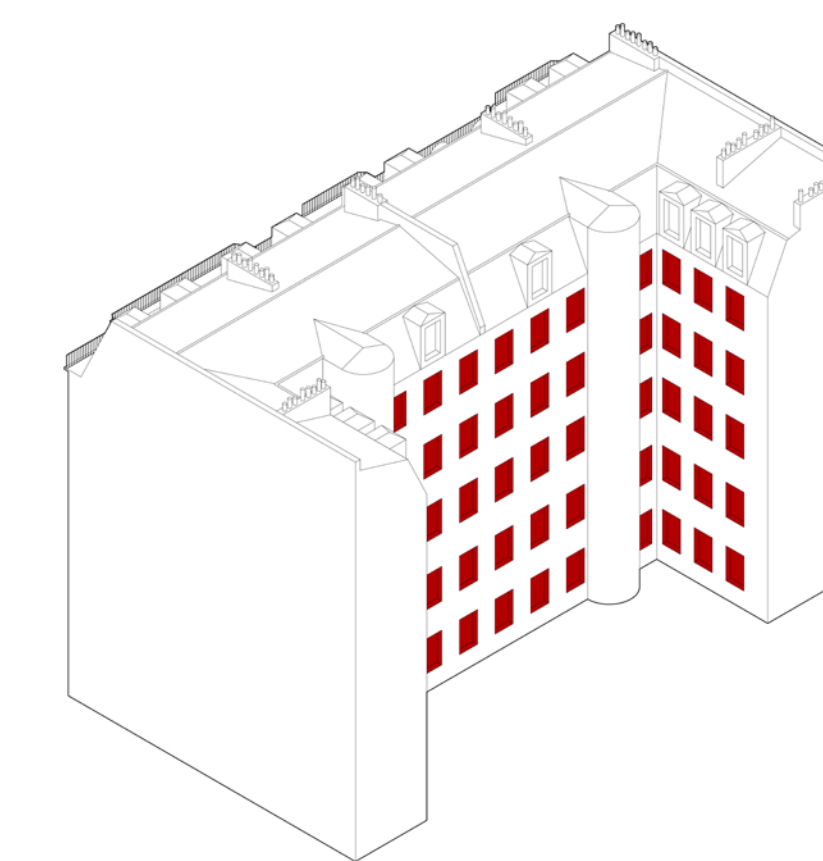
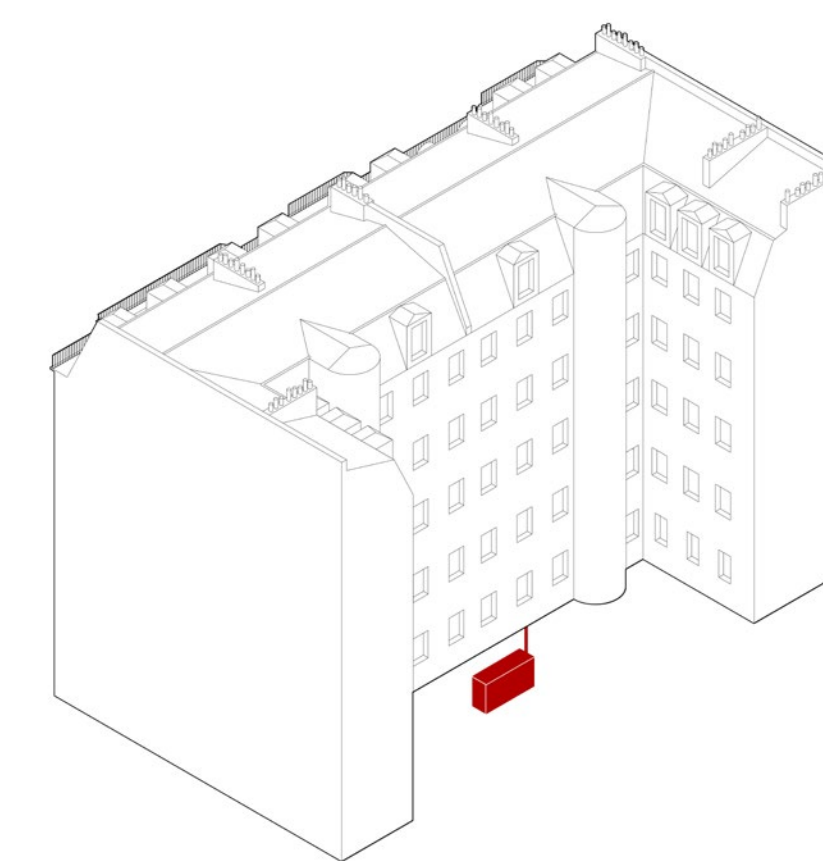
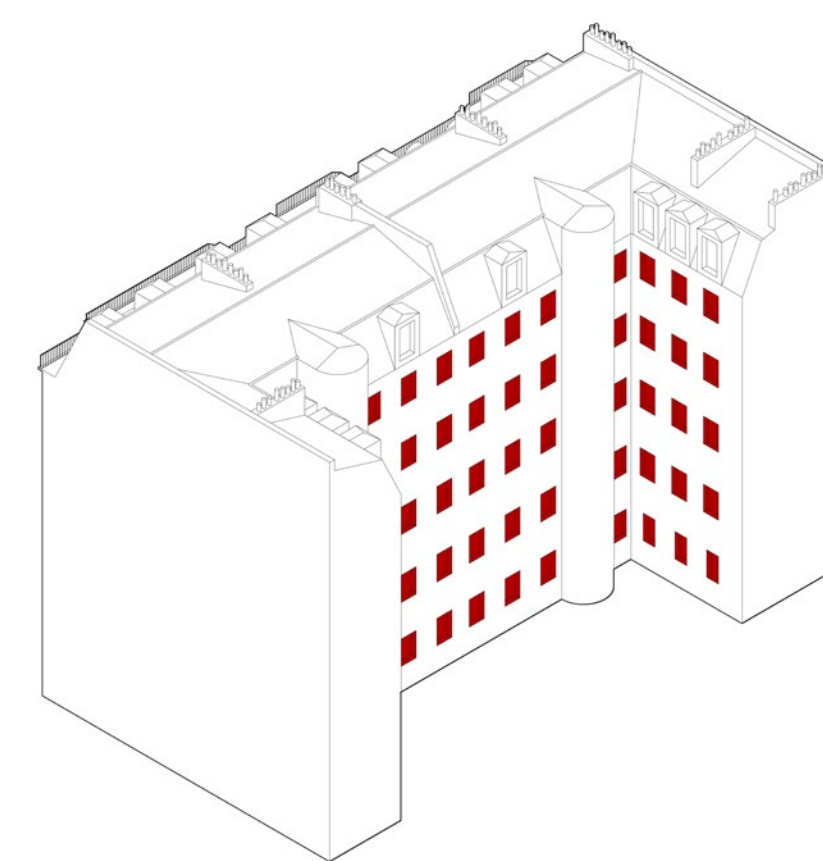
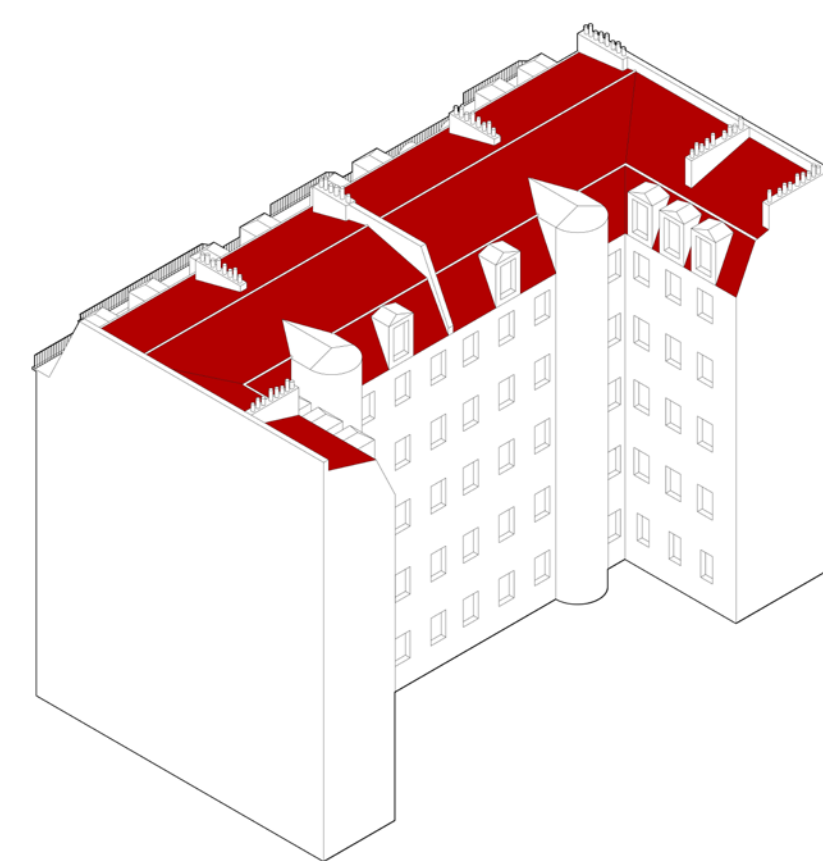
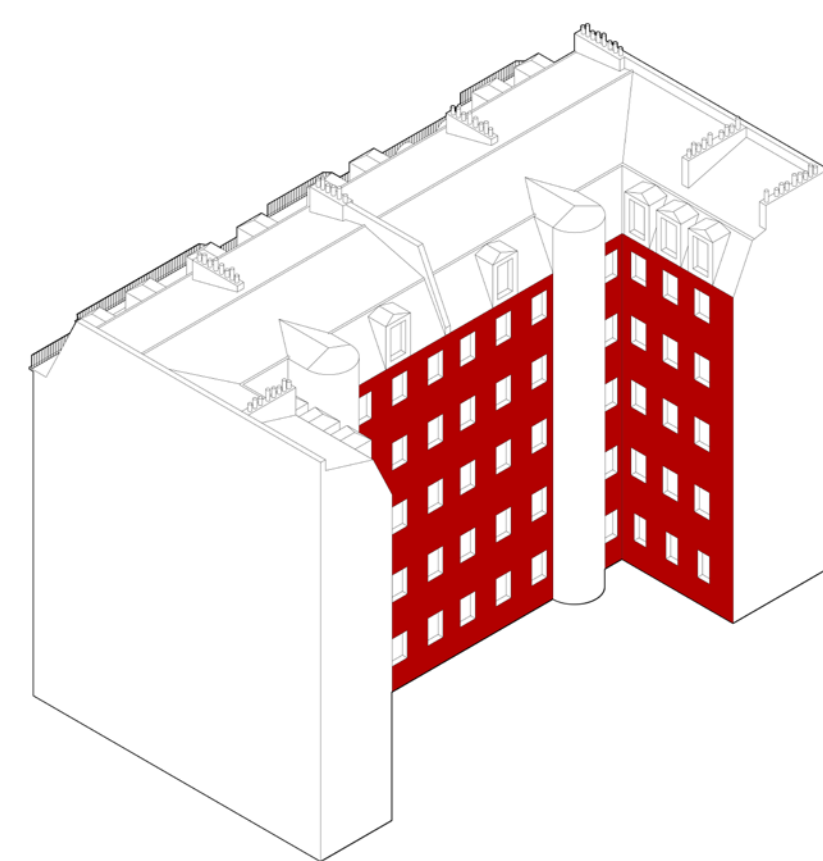
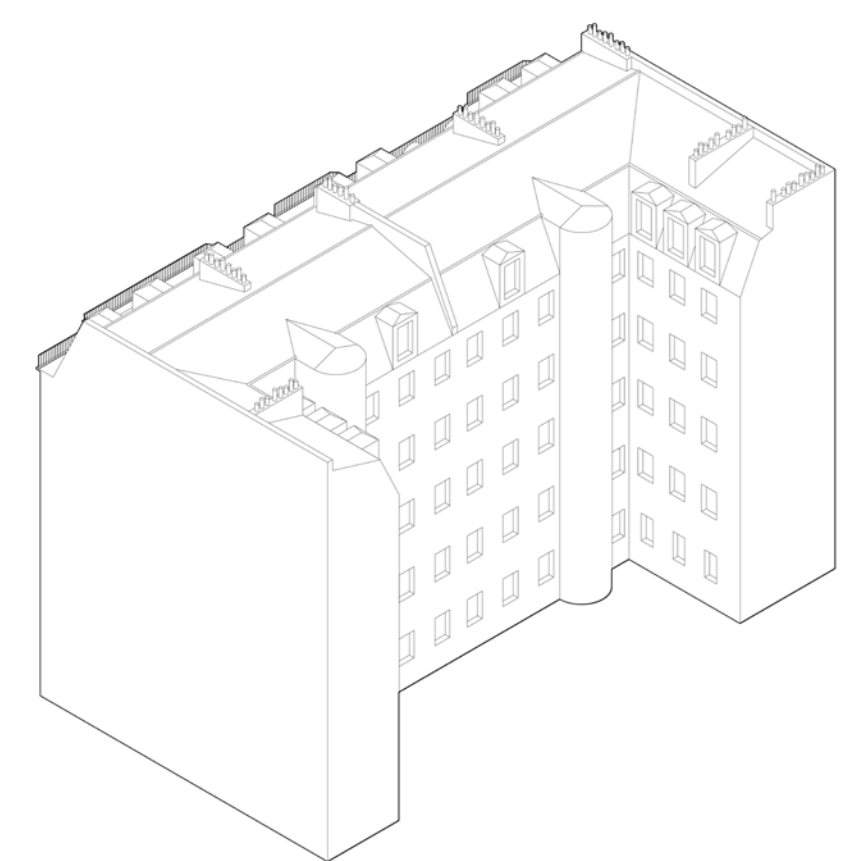
Cooling
A/C On
Increased Efficiency
100W/m2 limit

Boiler
Electric Boiler
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Windows
WWR increase from:
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Equipment
Limited Usage
Conscious Behaviour

Surelevation
2 Additional Floors
(High Efficiency Build)



Baseline



Renovation



Sur-Elevation

EUI evolution & CO2 emissions

Low-Carbon Resiliency Strategy

Paris Protoblock

+

Renovation Approach

1 | Baseline: Existing

2 | Strategy O1: Renovation

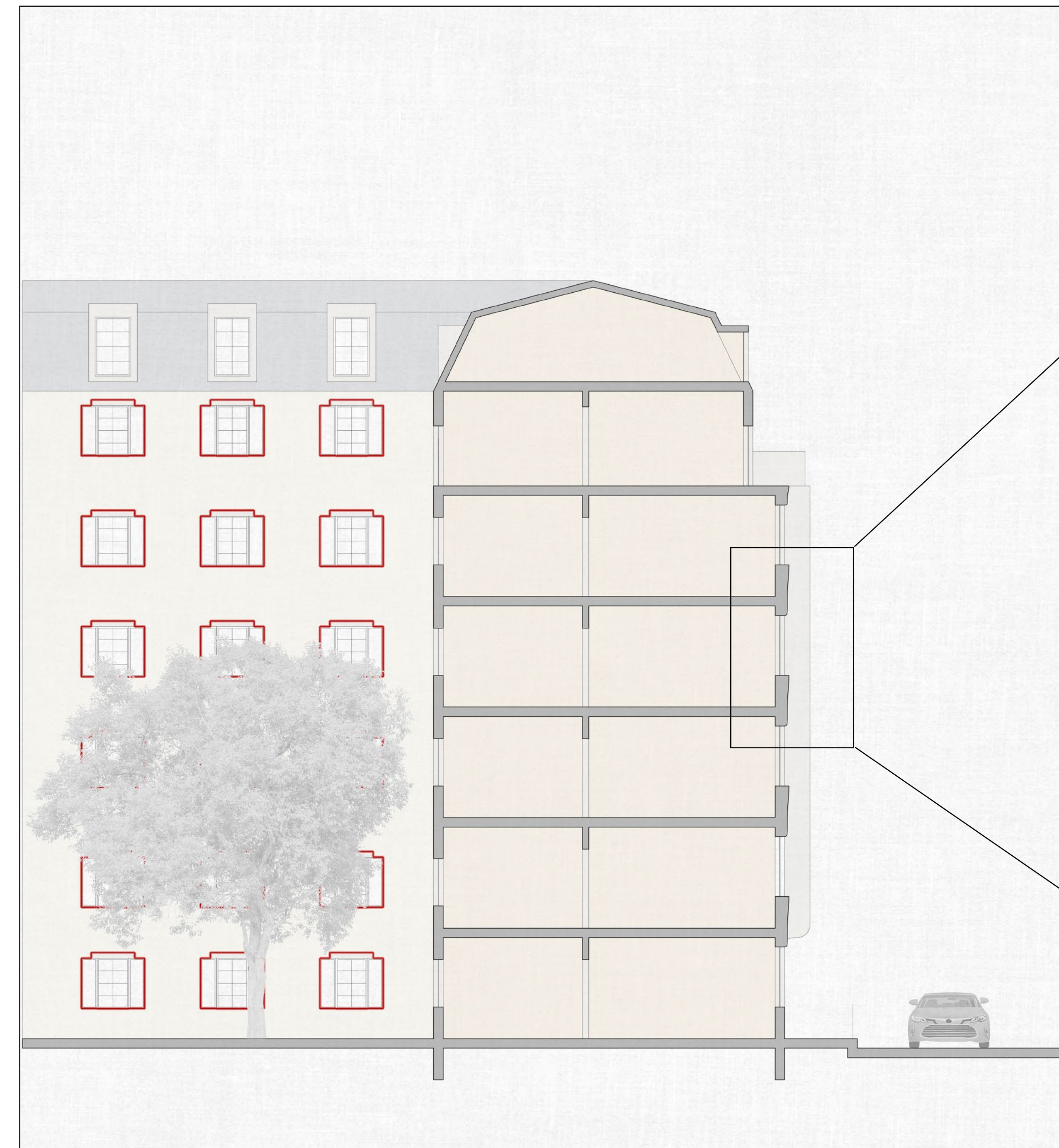
3 | Strategy O2: Sur-Elevation



Protoblock Section: **Baseline**

Courtyard Window-to-Wall Ratio: **25%**

Baseline Simulation



Protoblock Section: **Baseline**

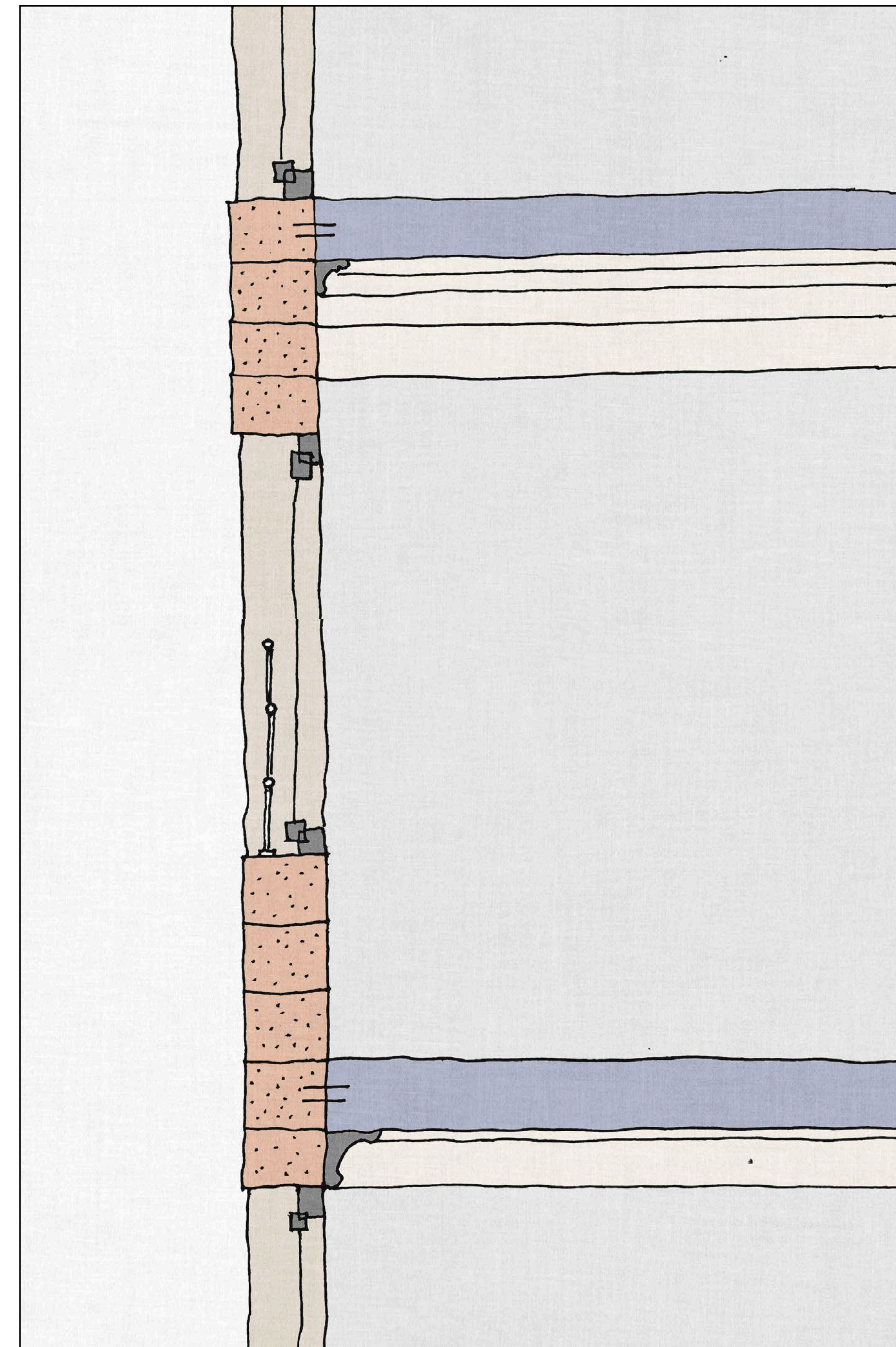
Courtyard Window-to-Wall Ratio: **25%**



Street Wall Composition

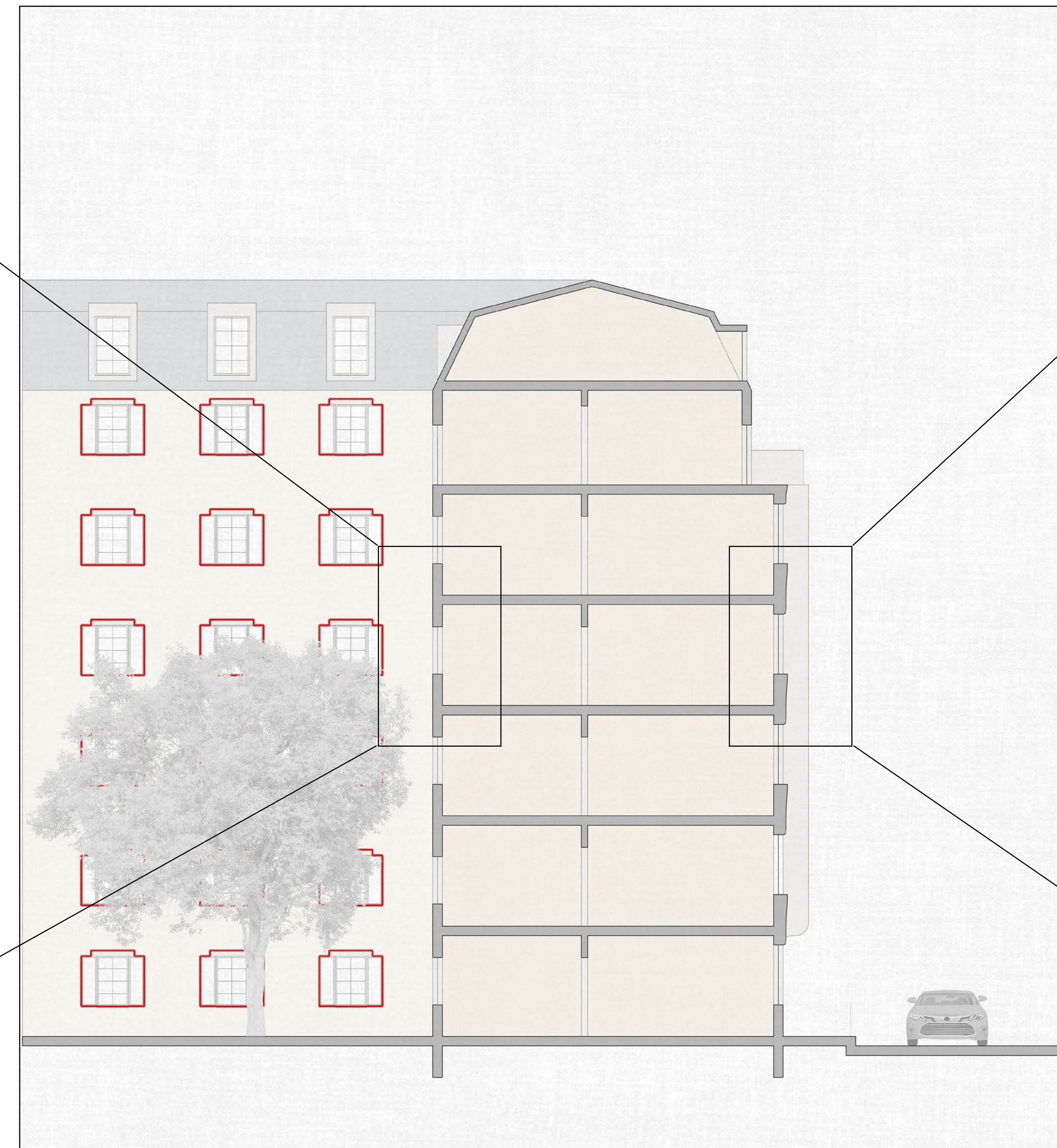
Ornamentation (protected)
60cm Load-Bearing Stone
Double Glazing

Baseline Simulation



Courtyard Wall Composition

30cm Load Bearing Brick
Single Glazing



Protoblock Section: **Baseline**

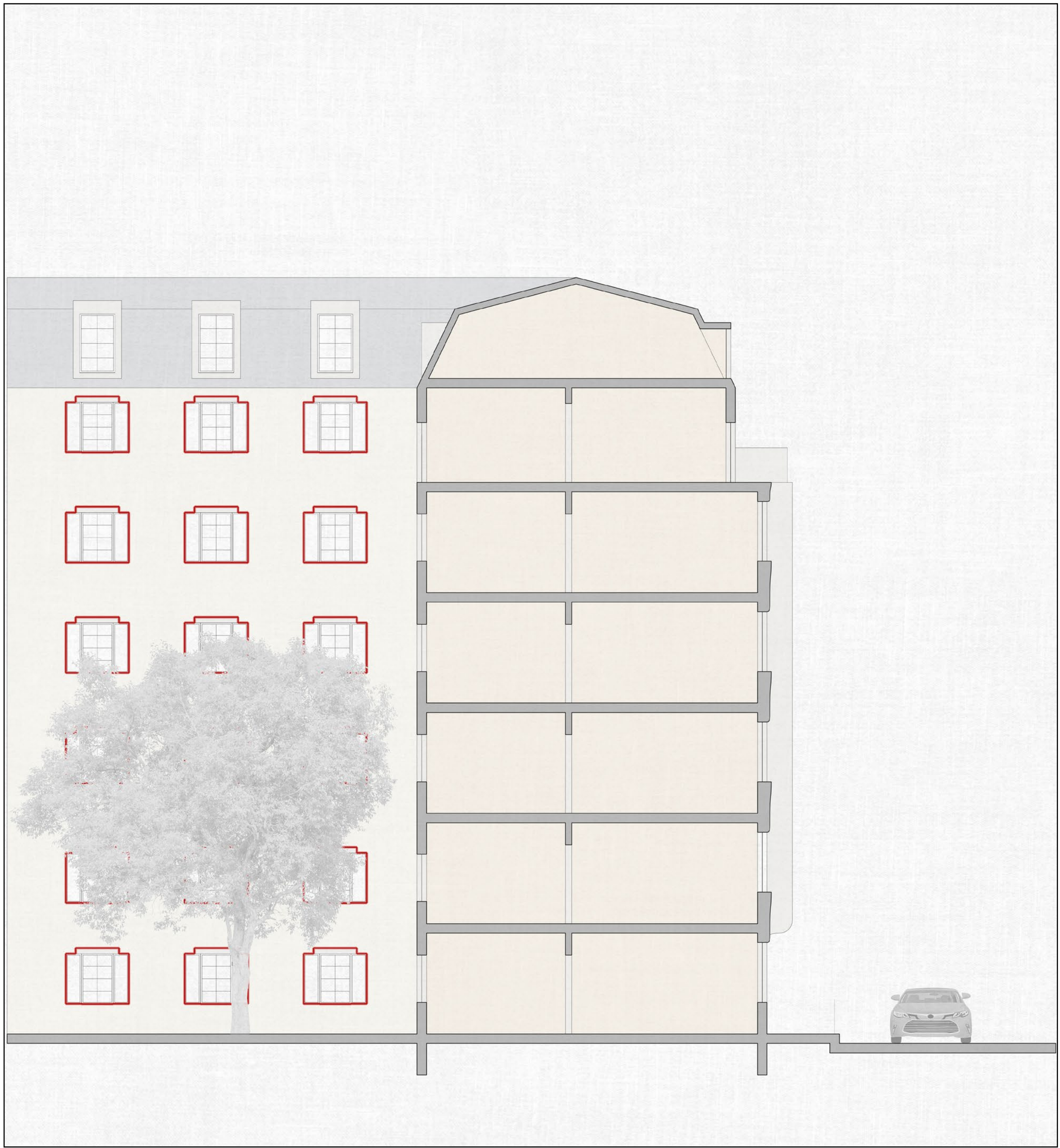
Courtyard Window-to-Wall Ratio: **25%**



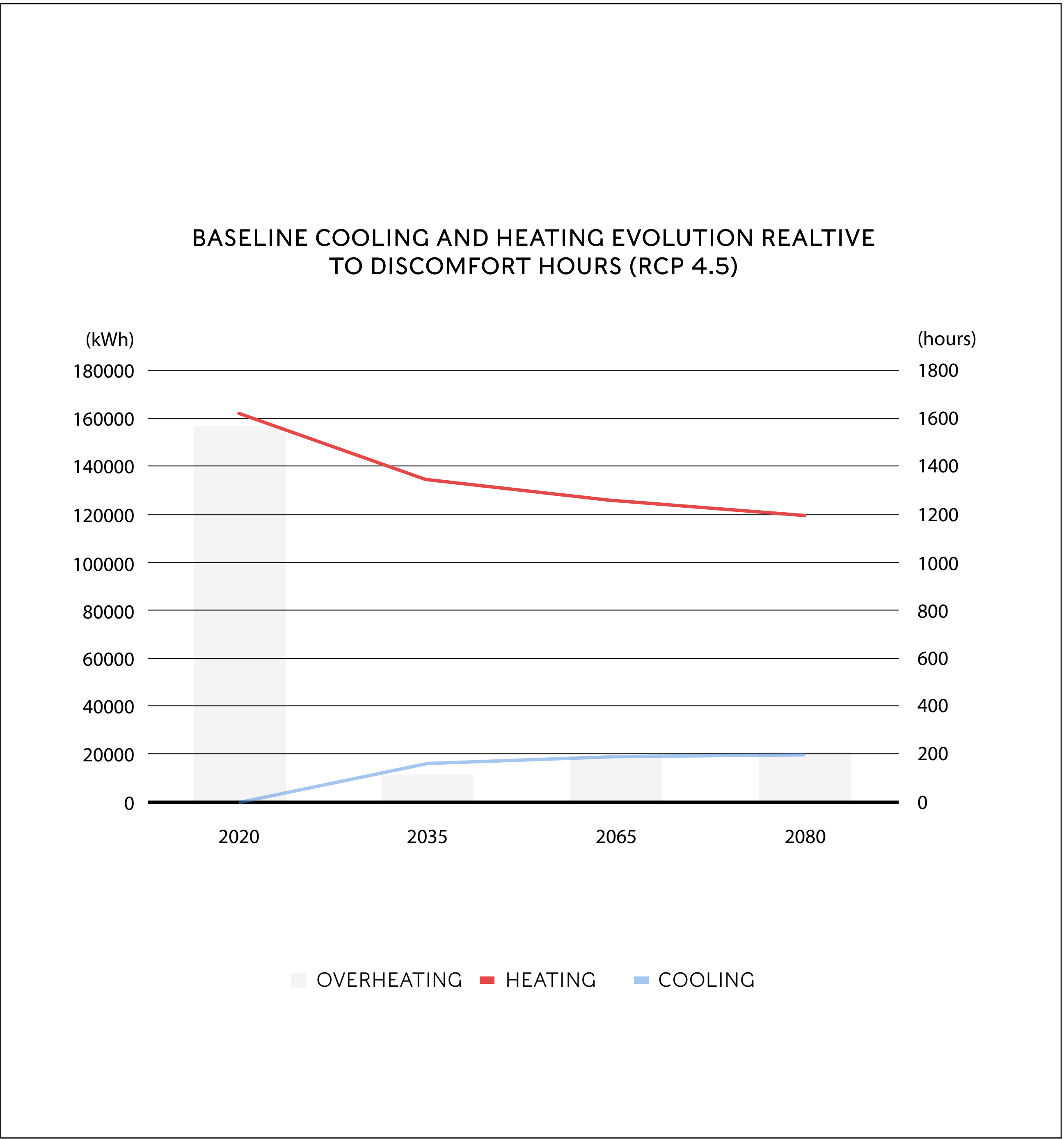
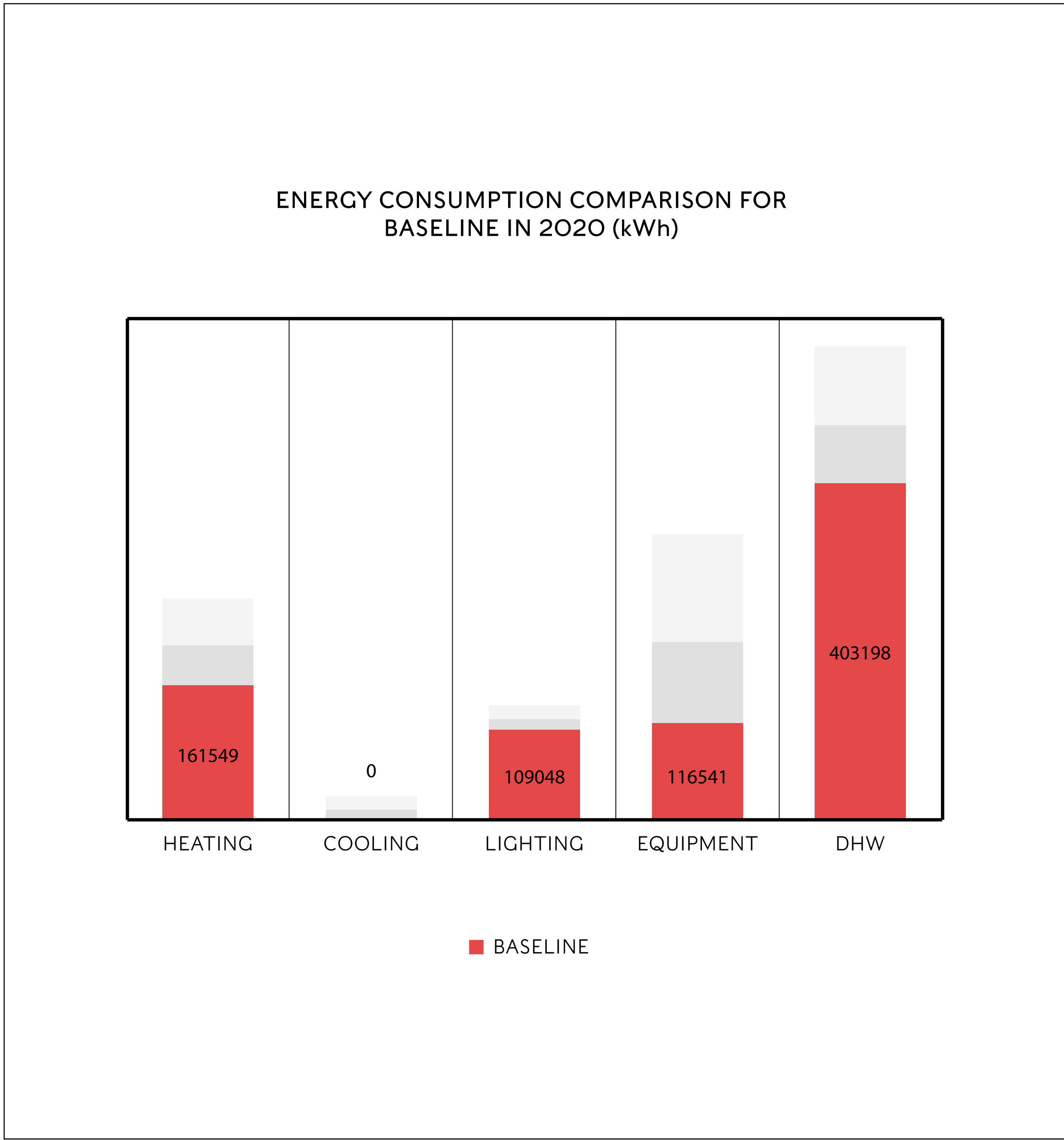
Street Wall Composition

Ornmentation (protected)
60cm Load-Bearing Stone
Double Glazing

Baseline Simulation



Protoblock Section: **Baseline**



Baseline Simulation

Low-Carbon Resiliency Strategy

Paris Protoblock

+

Renovation Approach

1 | Baseline: Existing

2 | Strategy O1: Renovation

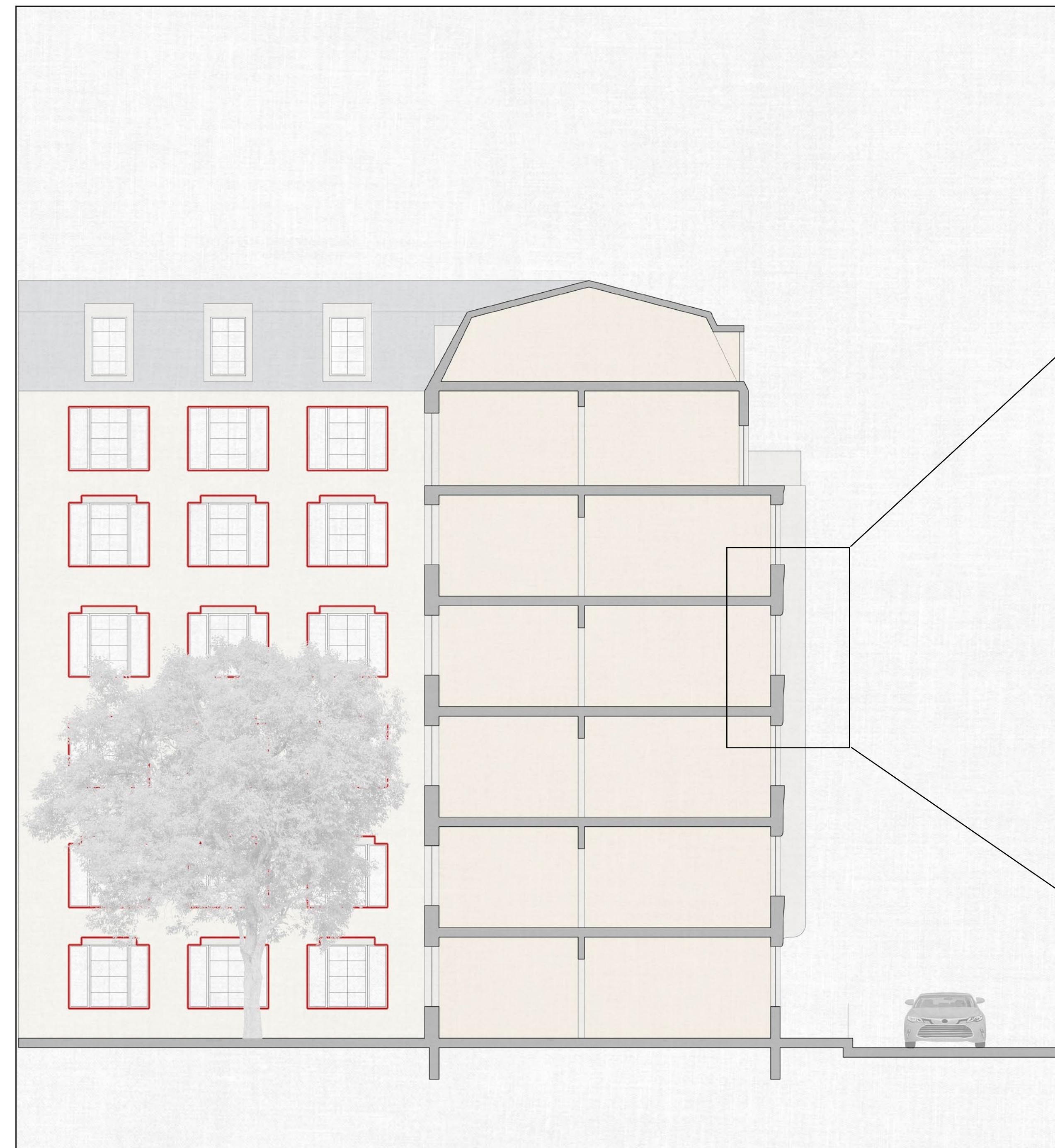
3 | Strategy O2: Sur-Elevation



Protoblock Section: **Renovated**

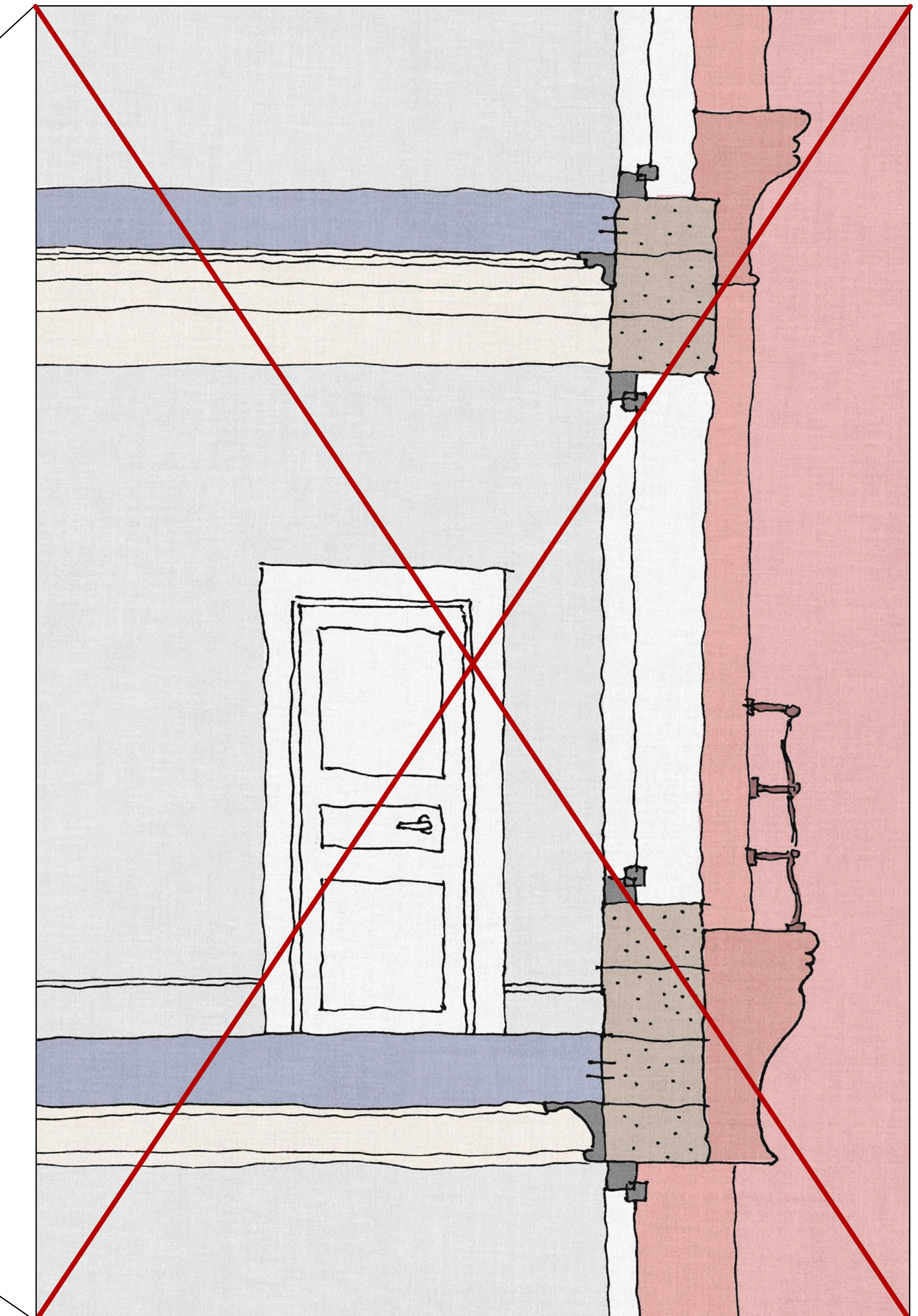
Courtyard Window-to-Wall Ratio: **40%**

Strategy O1: Renovation



Protoblock Section: **Renovated**

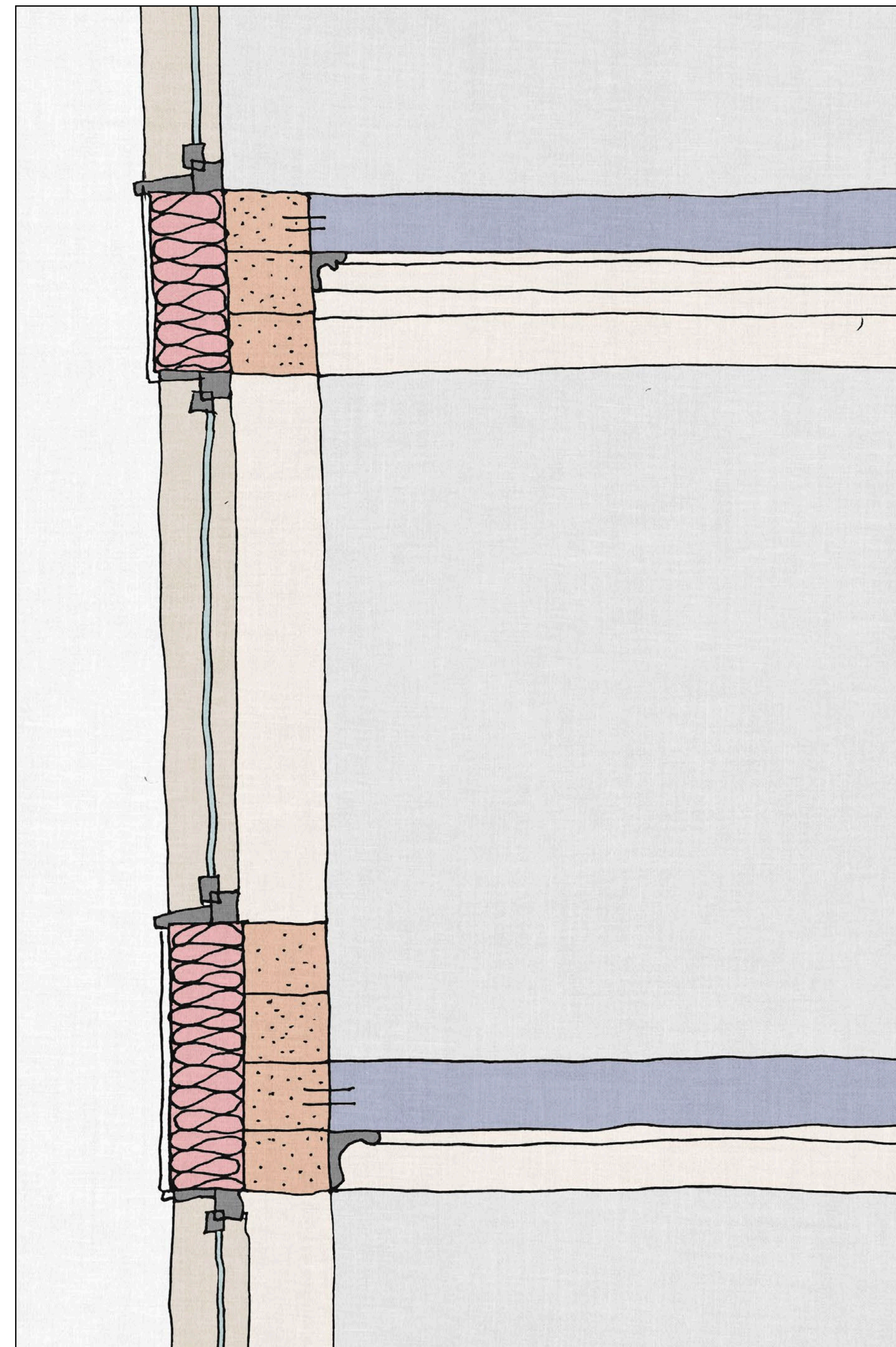
Courtyard Window-to-Wall Ratio: **40%**



Street Wall Composition

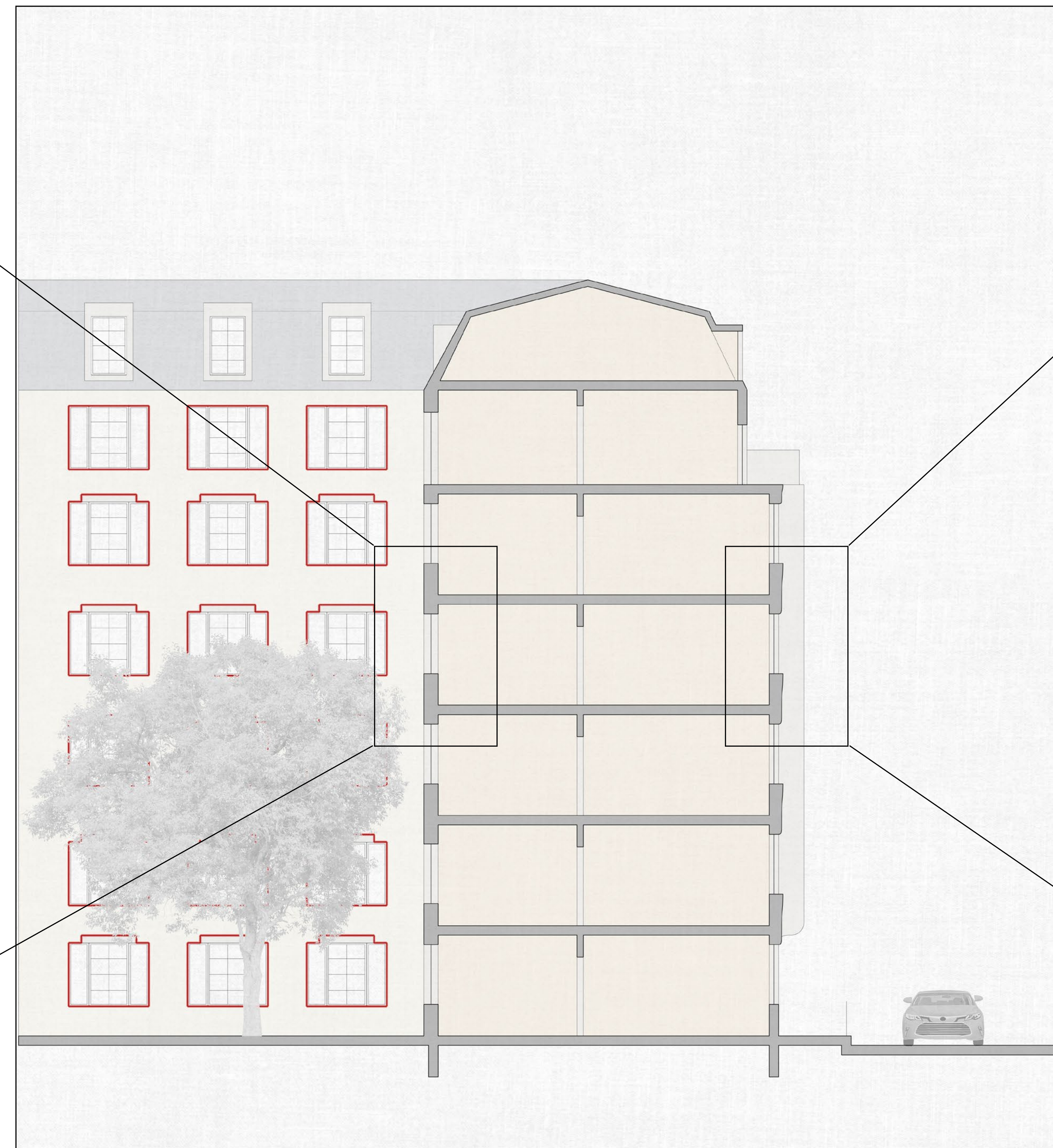
Ornamentation (protected)
60cm Load-Bearing Stone
Double Glazing

Strategy O1: Renovation



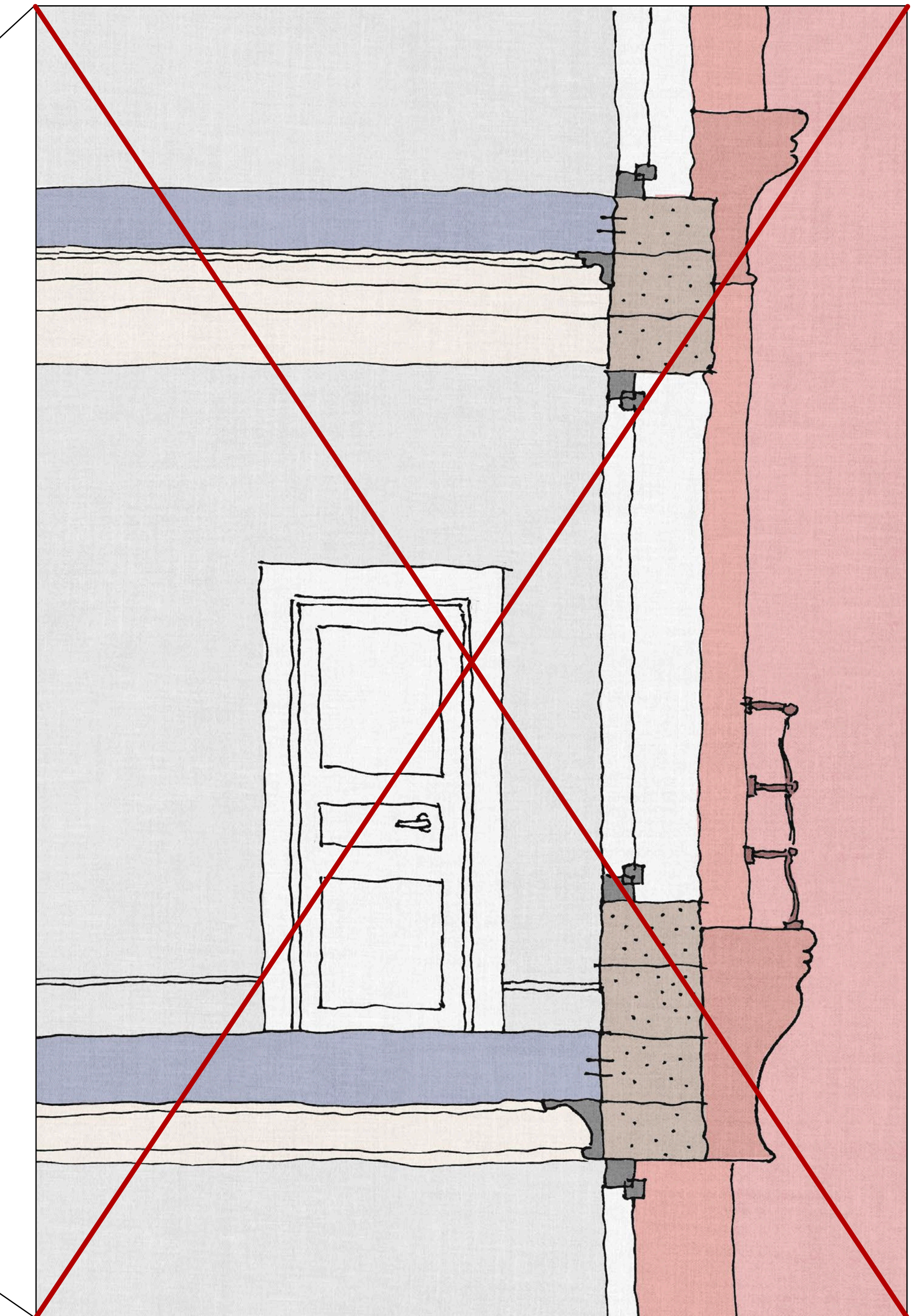
Courtyard Wall Composition

30cm Load Bearing Brick
 20cm Natural Isolant
 Double Glazing



Protoblock Section: **Renovated**

Courtyard Window-to-Wall Ratio: **40%**



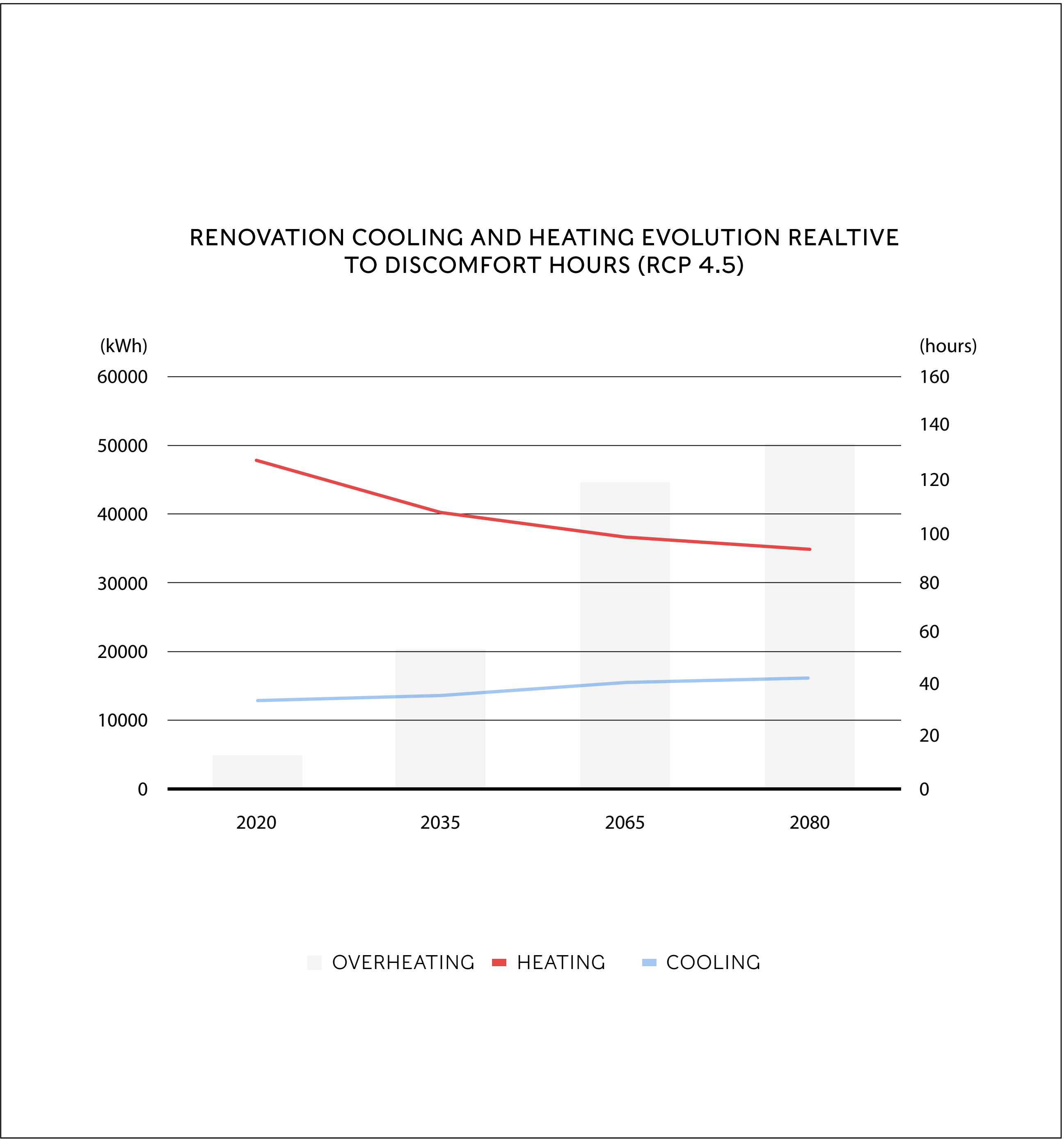
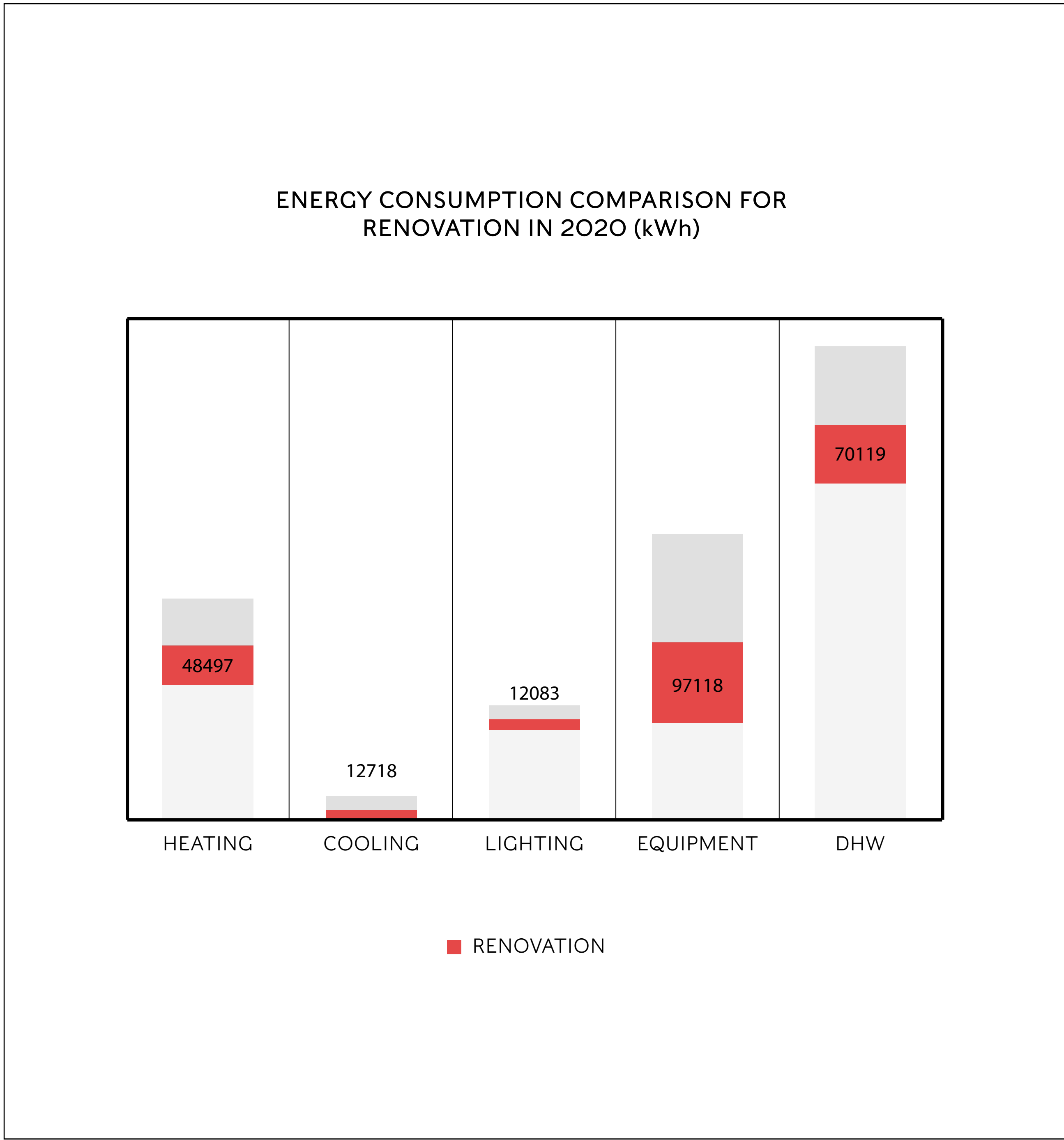
Street Wall Composition

Ornementation (protected)
 60cm Load-Bearing Stone
 Double Glazing

Stratagy O1: Renovation



Protoblock Section: **Renovated**



Walls
Increased Insulation
Low Embodied-E
Design

Groundfloor
Increased Insulation

Roof
Increased Insulation
Increased Albedo

Glass
Double Glazing
Argon Fill

Lights
LED Bulbs
Continuous Dimming

Heating
Electric Heating
Increased Efficiency
100W/m2 limit

Cooling
A/C On
Increased Efficiency
100W/m2 limit

Boiler
Electric Boiler
Energy Star Efficiency

Windows
WWR increase from:
25% to 40%

Equipment
Limited Usage
Conscious Behaviour

Stratagy O1: Renovation

Low-Carbon Resiliency Strategy

Paris Protoblock

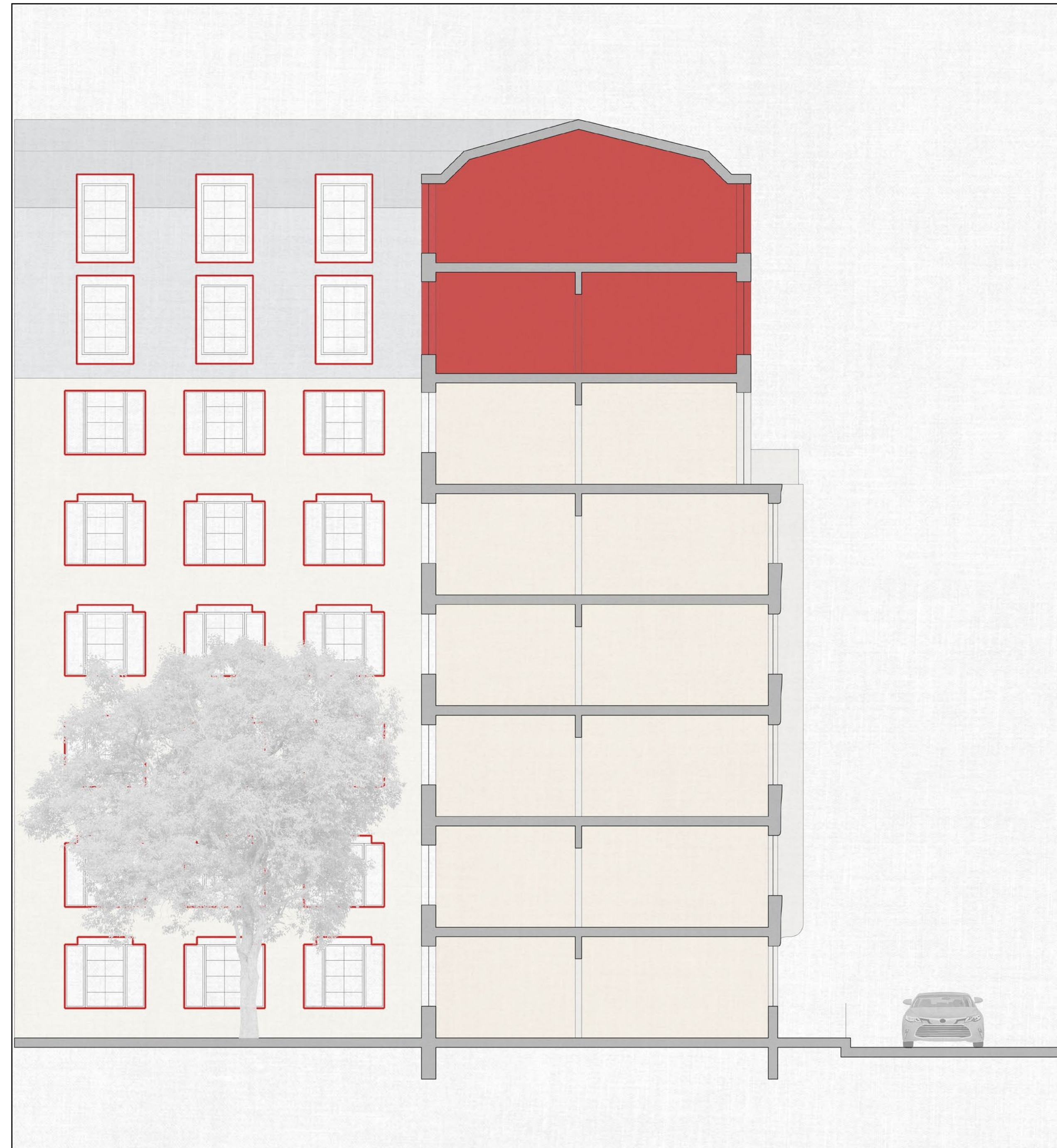
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Renovation Approach

1 | Baseline: Existing

2 | Strategy O1: Renovation

3 | Strategy O2: Sur-Elevation



Protoblock Section: **Sur-Elevated**

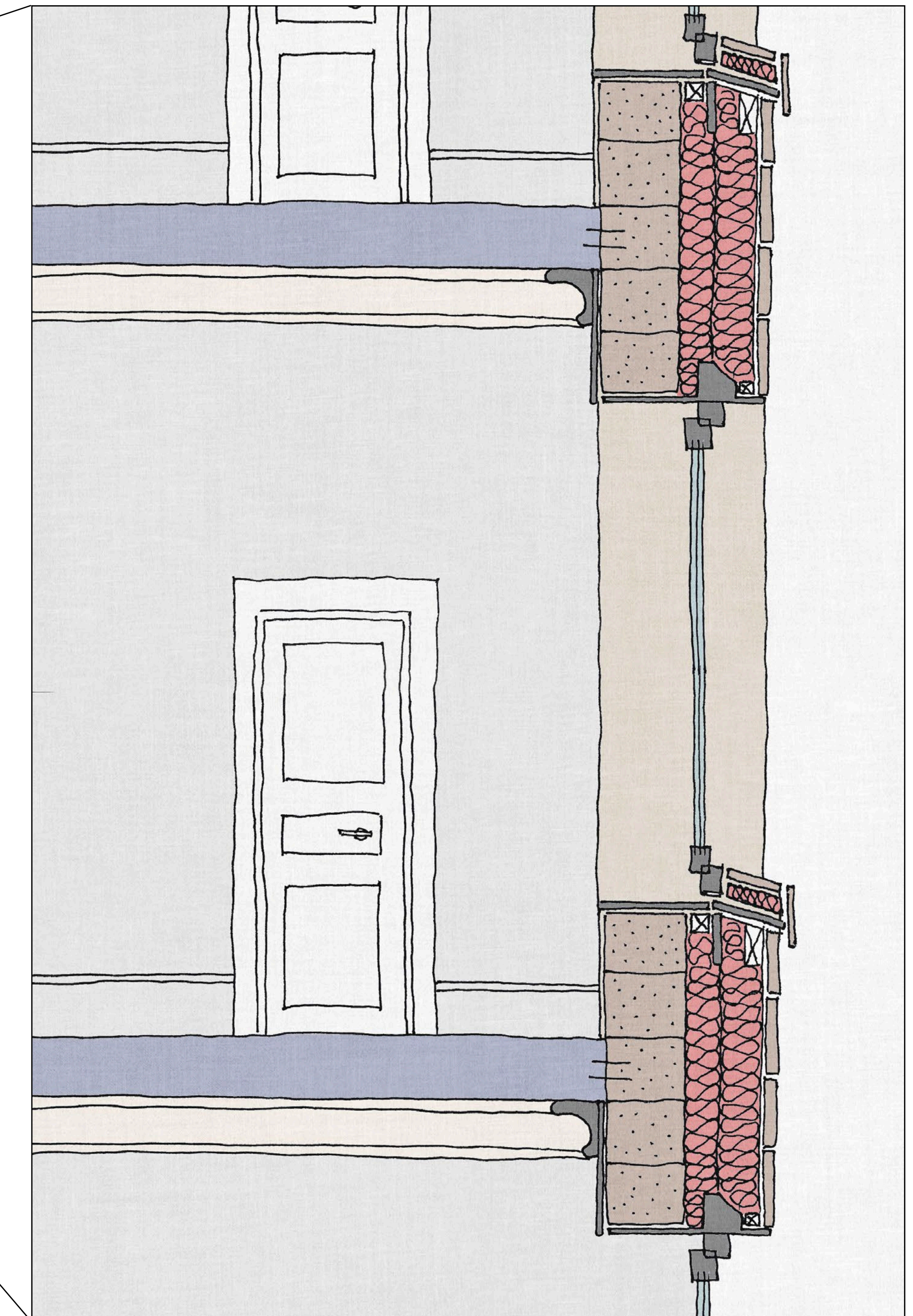
Courtyard Window-to-Wall Ratio: **40%**
Additional Market-Rate Floors: **2**

Strategy O2: Sur-Elevation



Protoblock Section: **Sur-Elevated**

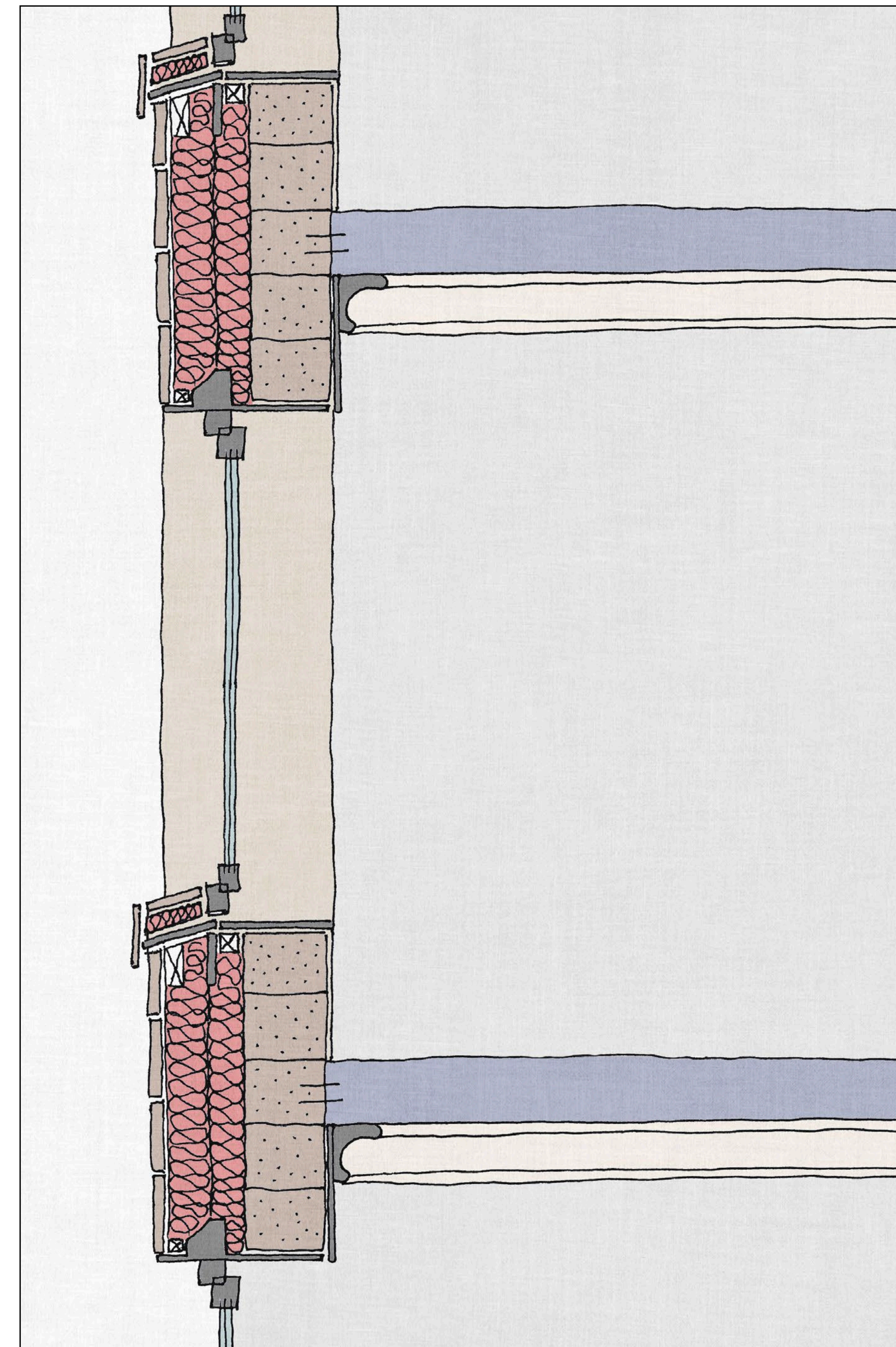
Courtyard Window-to-Wall Ratio: **40%**
Additional Market-Rate Floors: **2**



Street Wall Composition

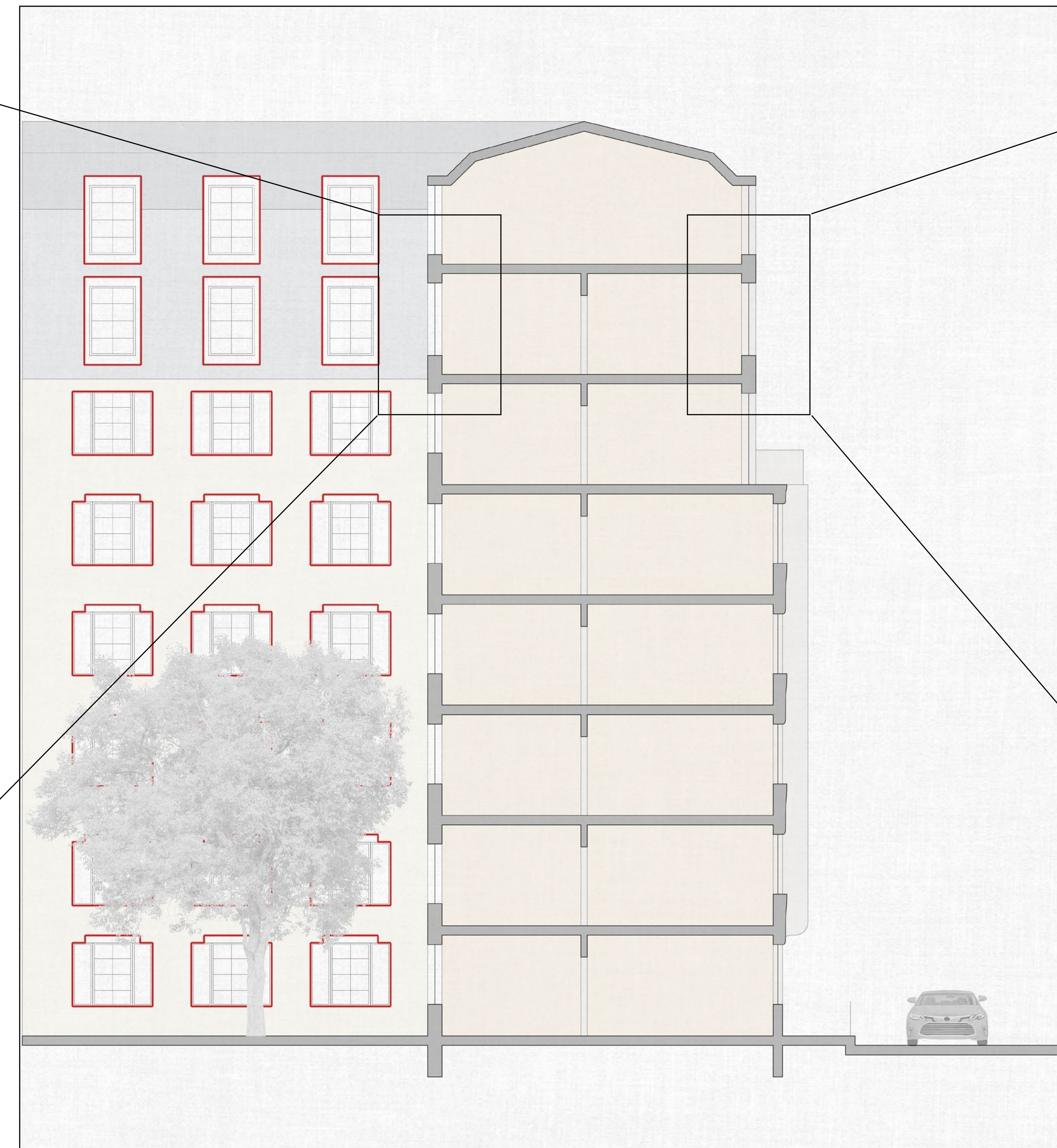
30cm Stone
25cm Natural Insulation
Triple Glazing

Strategy O2: Sur-Elevation



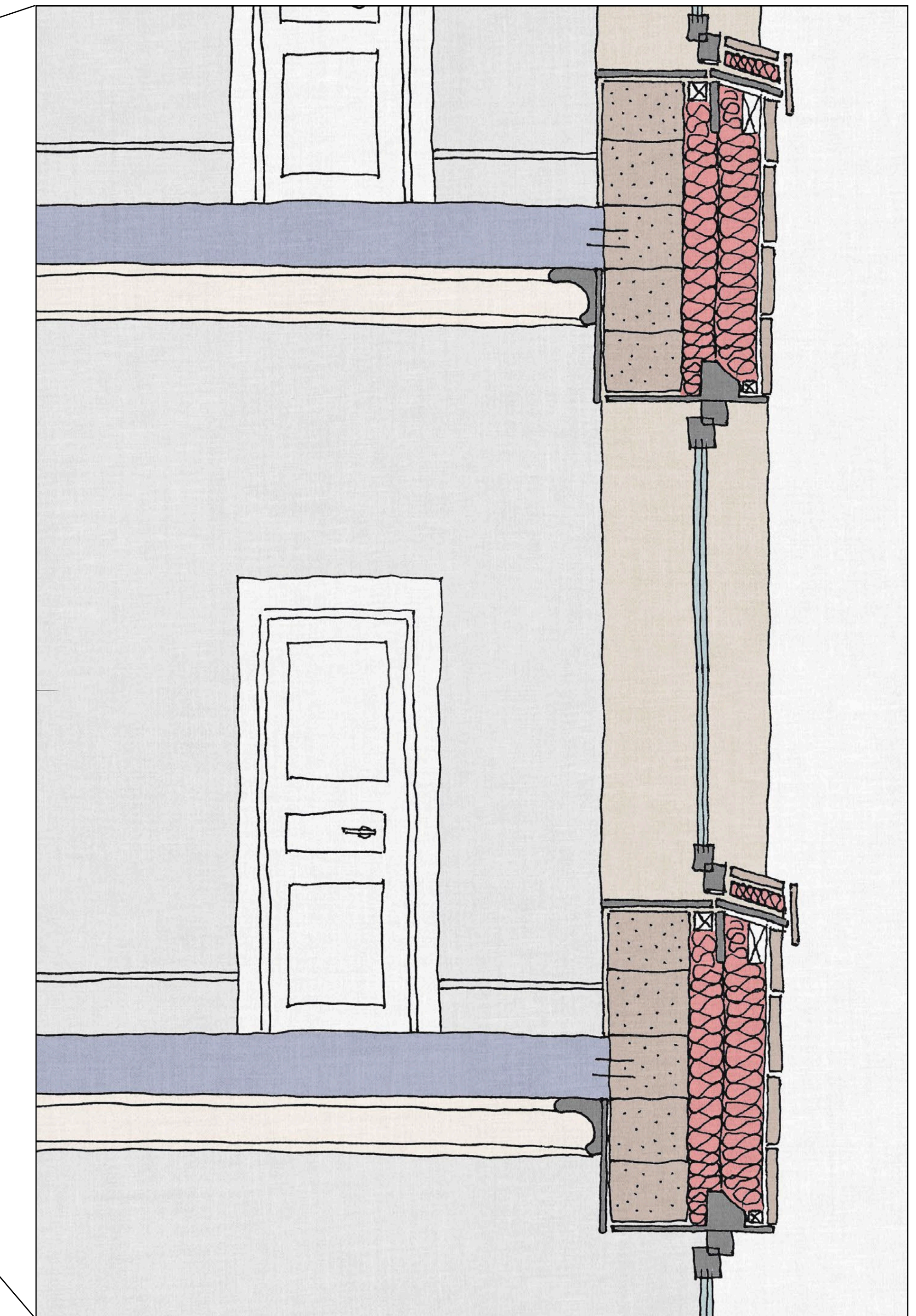
Courtyard Wall Composition

30cm Stone
25cm Natural Insulation
Triple Glazing



Protablock Section: **Sur-Elevated**

Courtyard Window-to-Wall Ratio: **40%**
Additional Market-Rate Floors: **2**



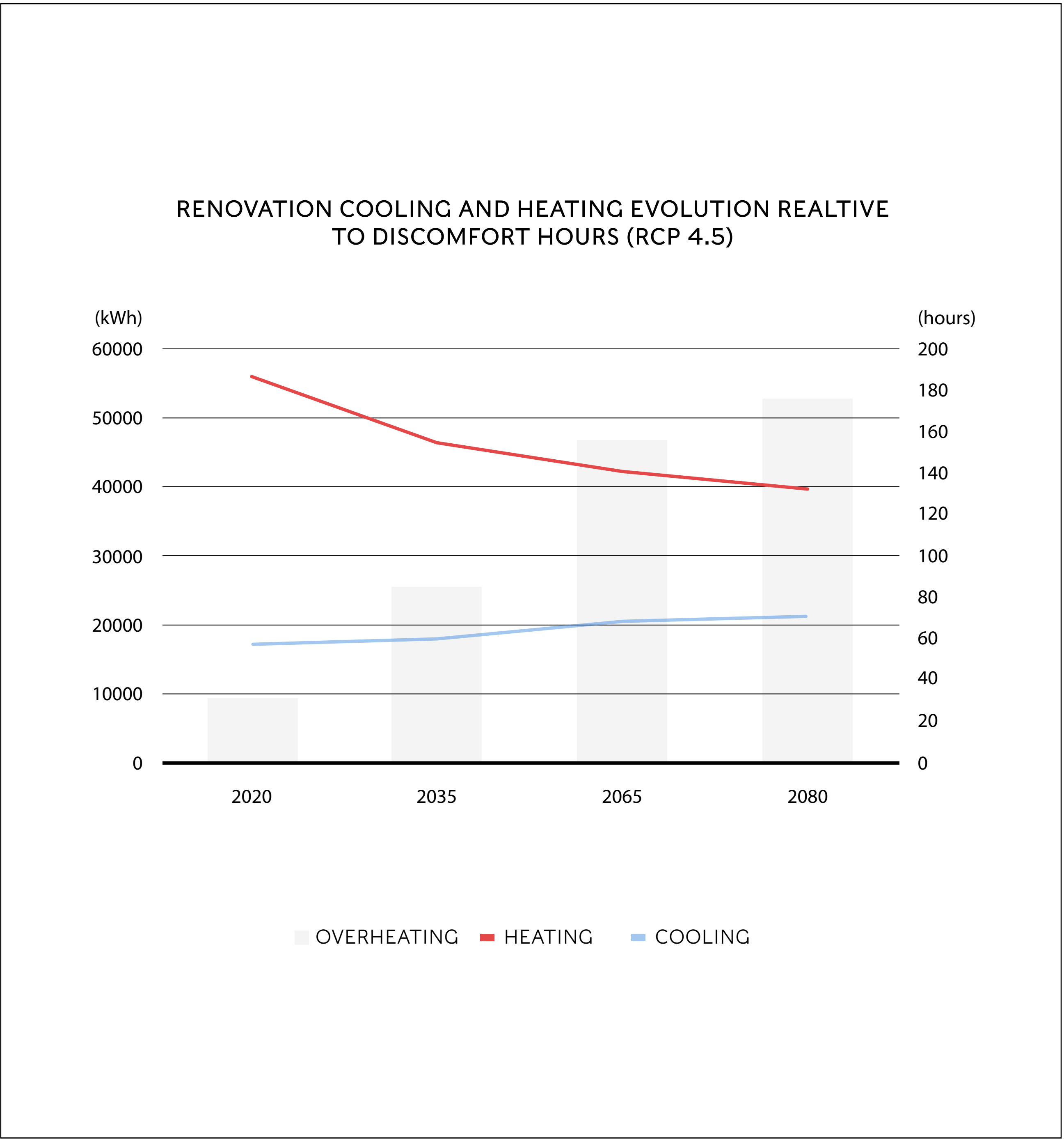
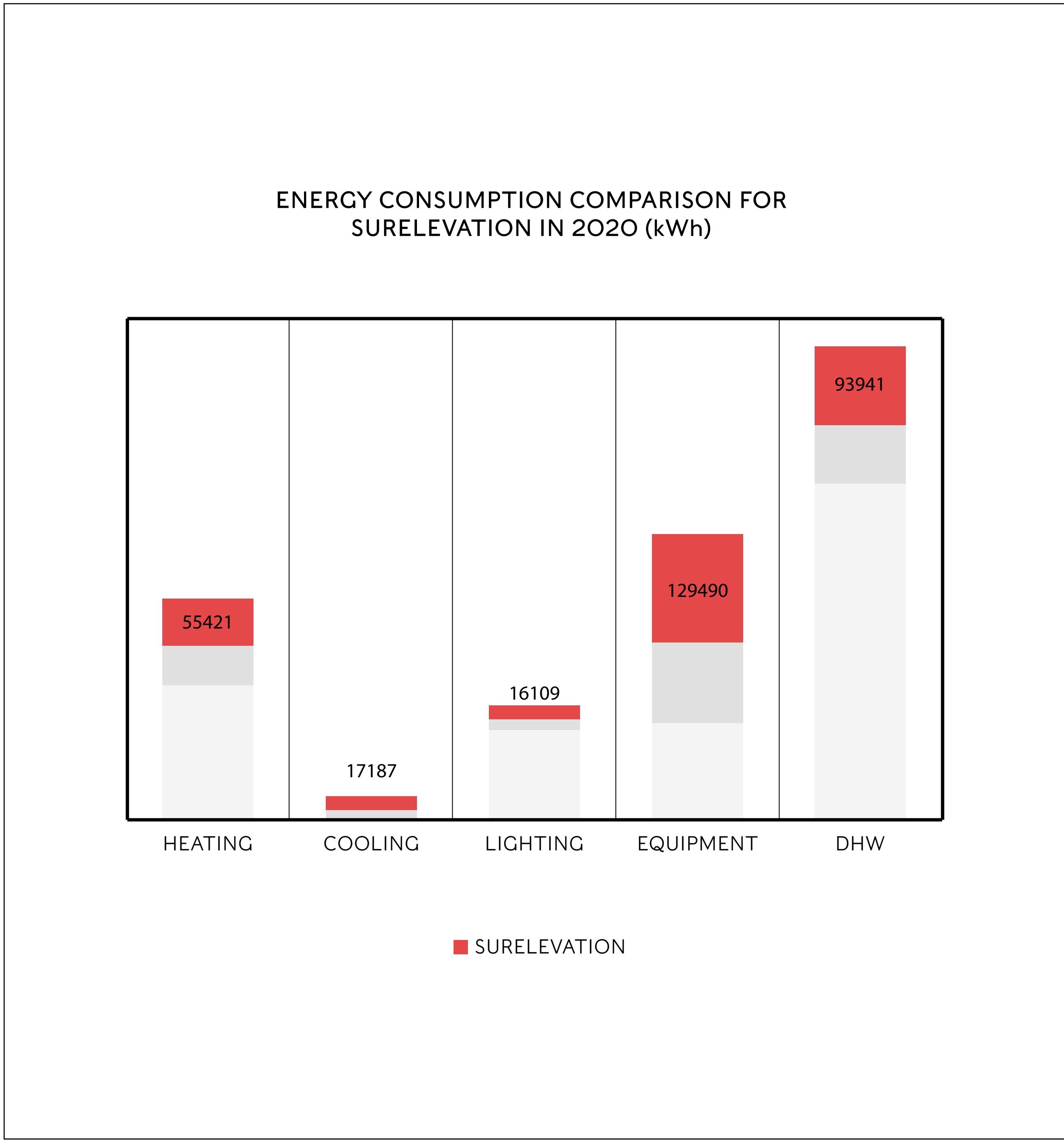
Street Wall Composition

30cm Stone
25cm Natural Insulation
Triple Glazing

Strategy O2: Sur-Elevation

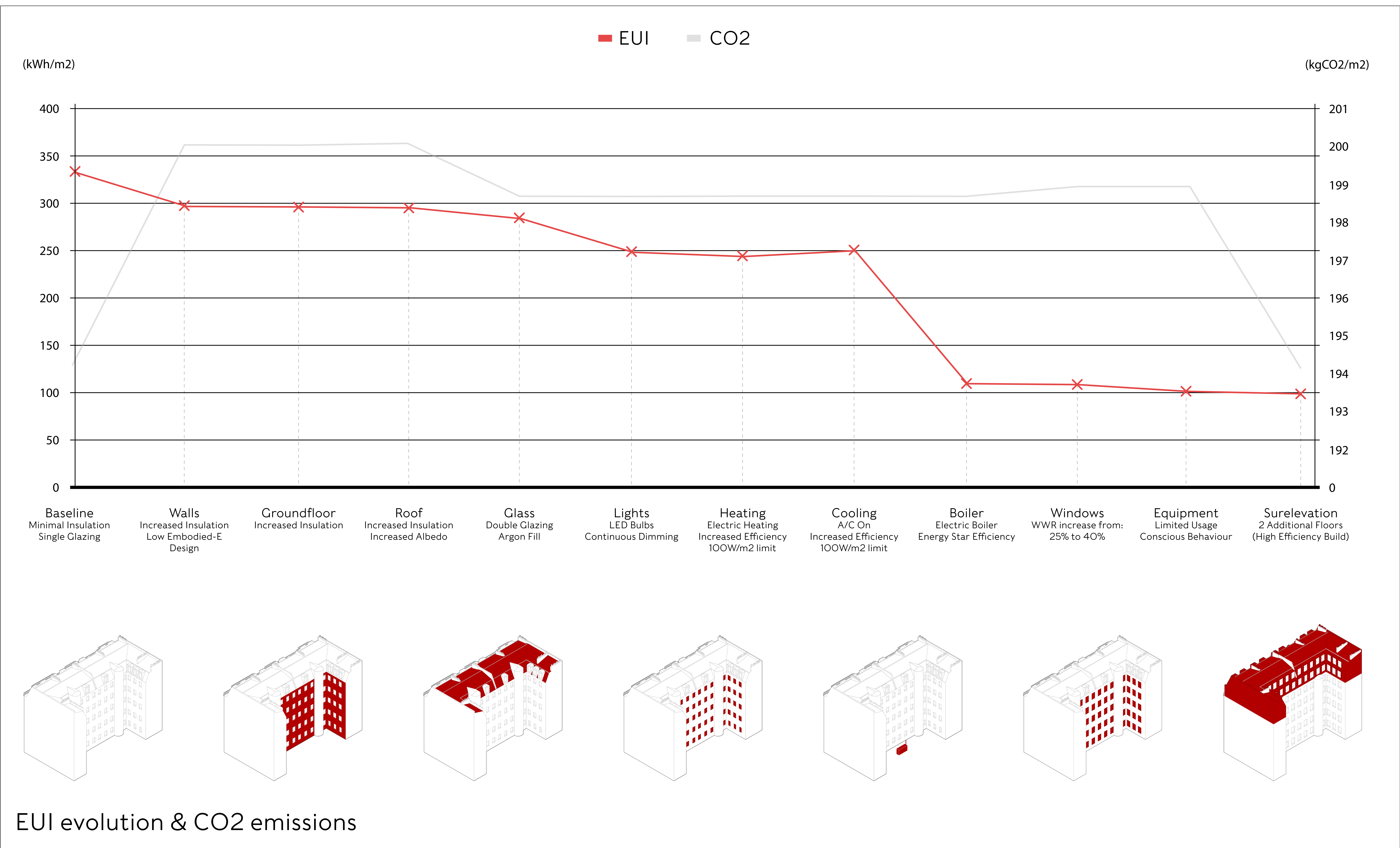


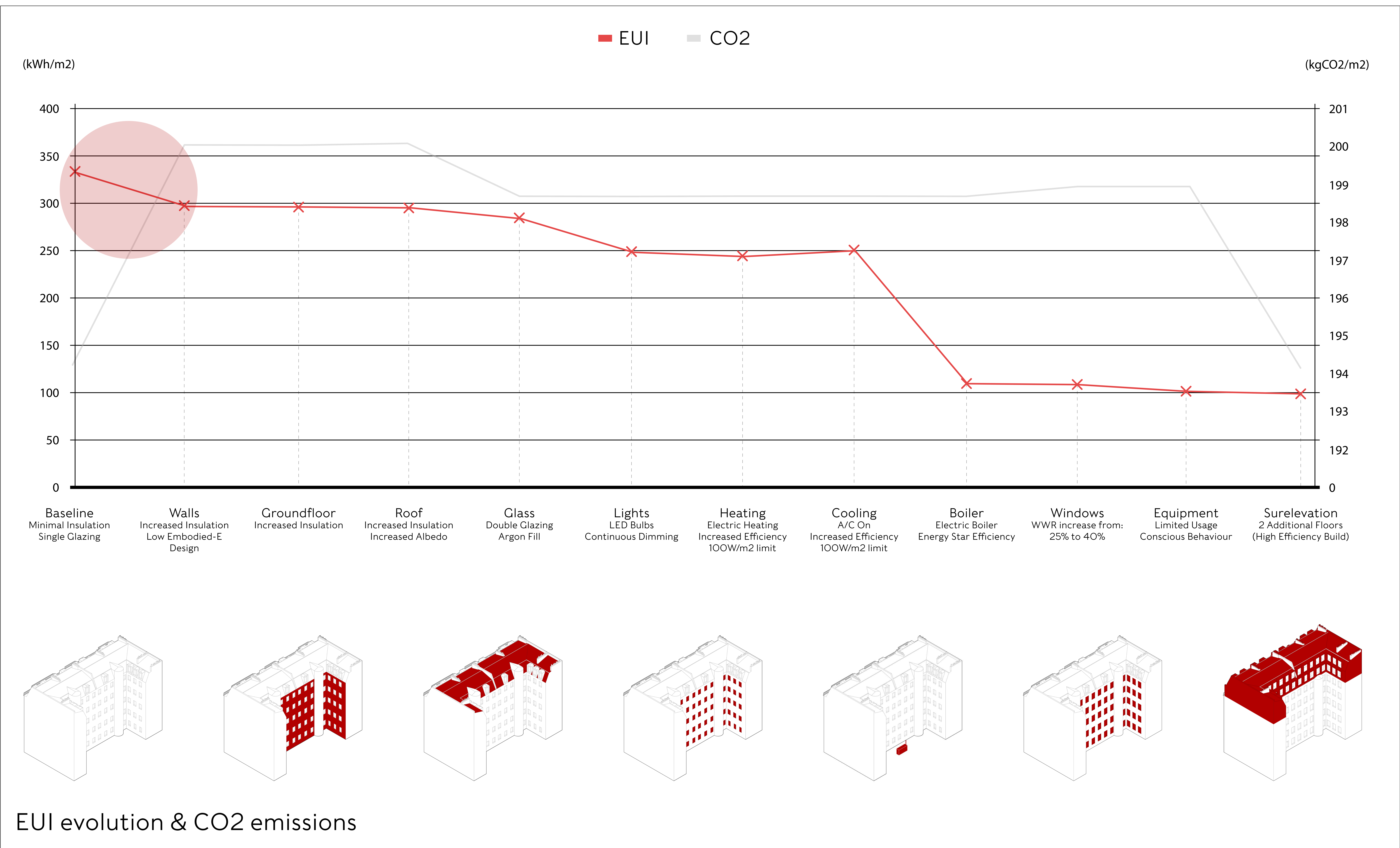
Protoblock Section: **Sur-Elevated**

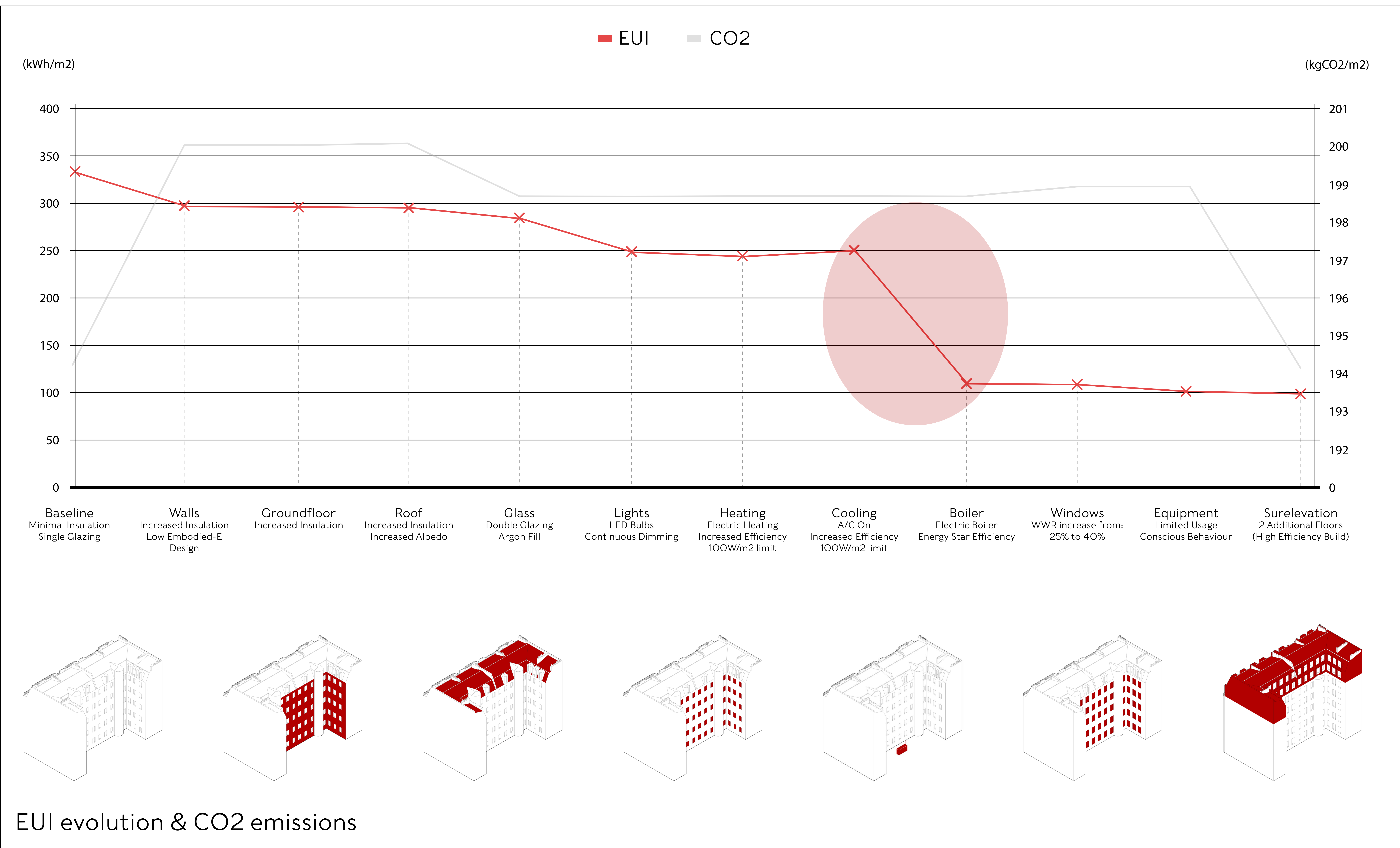


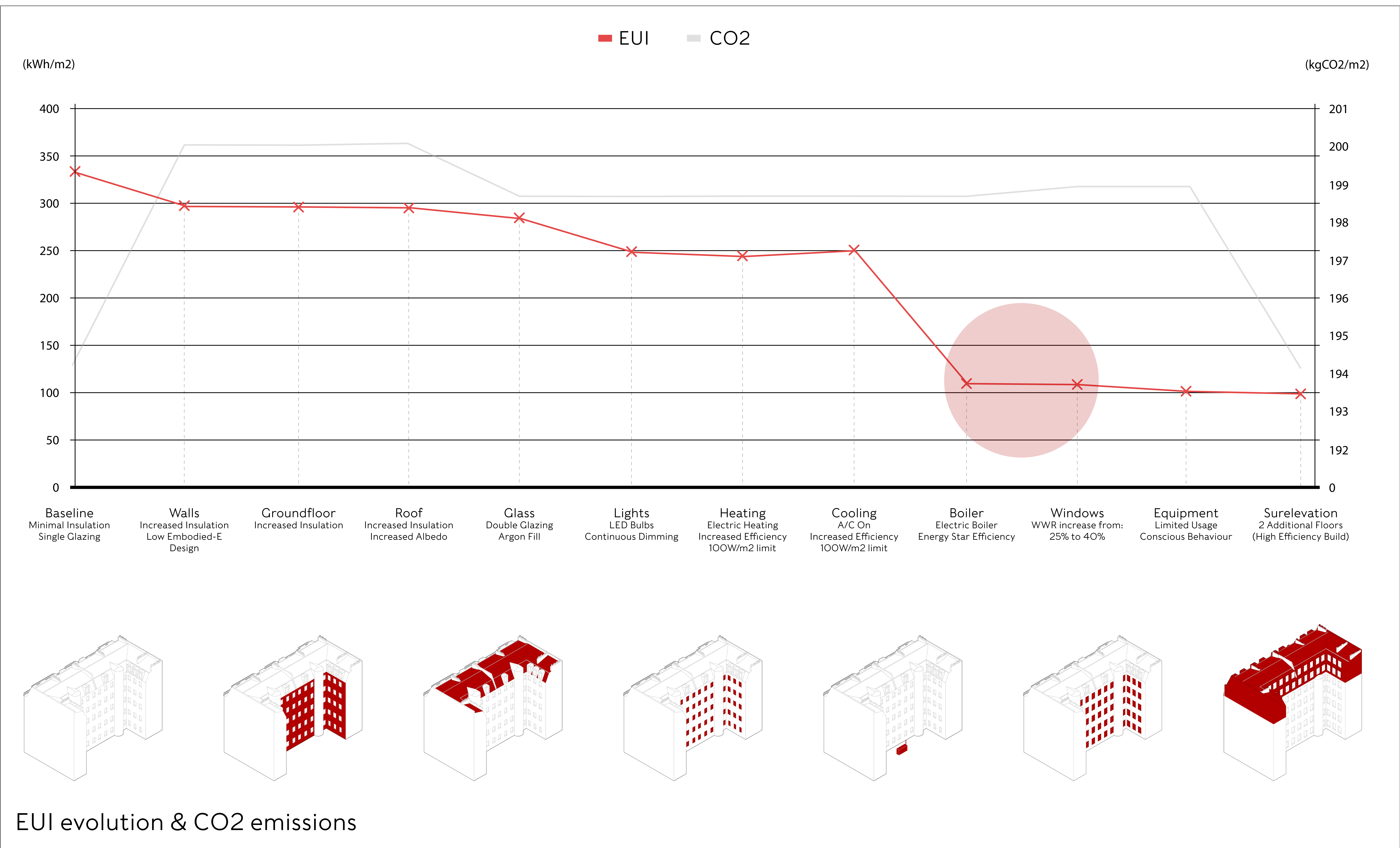
Strategy O2: Sur-Elevation

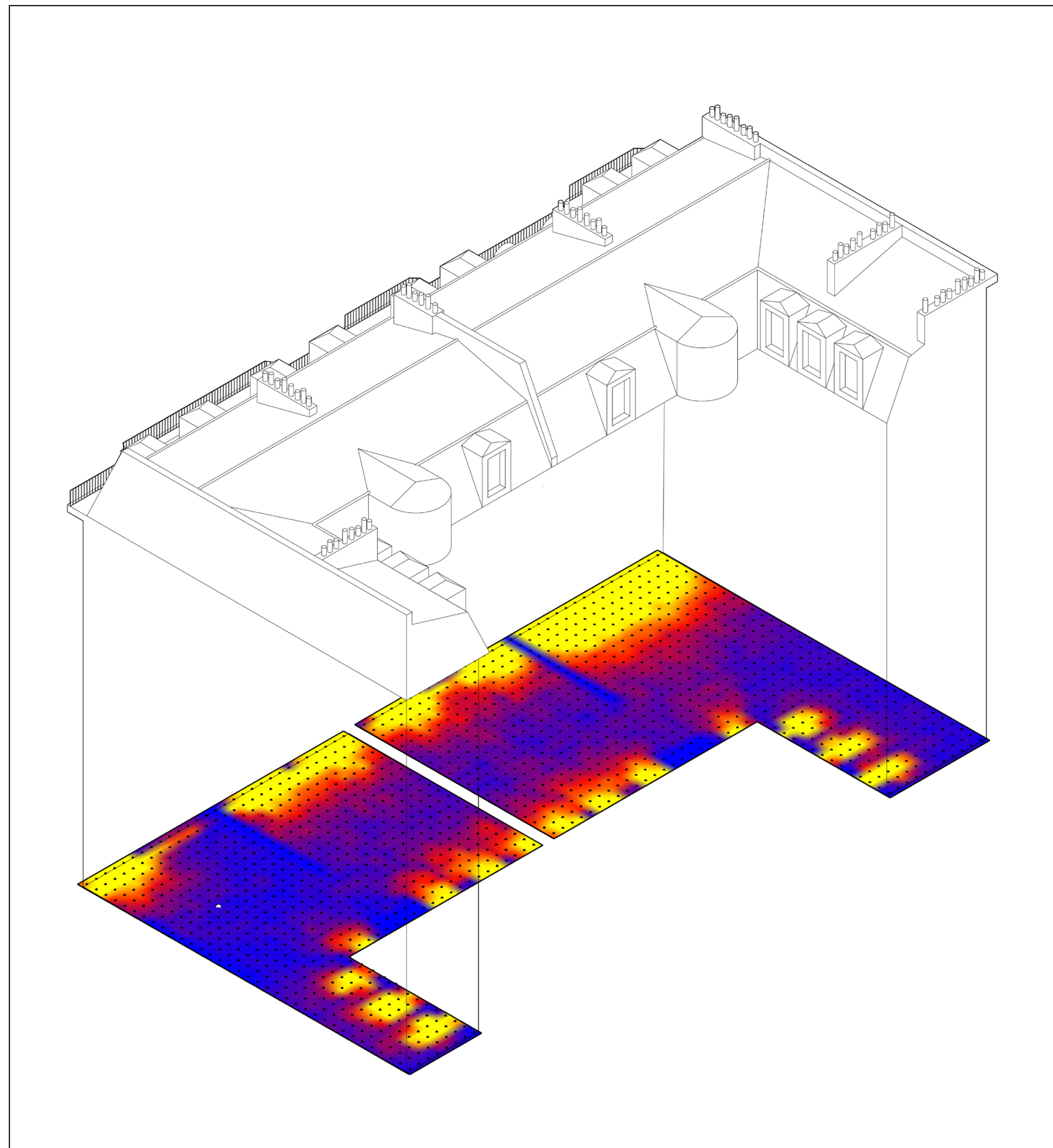
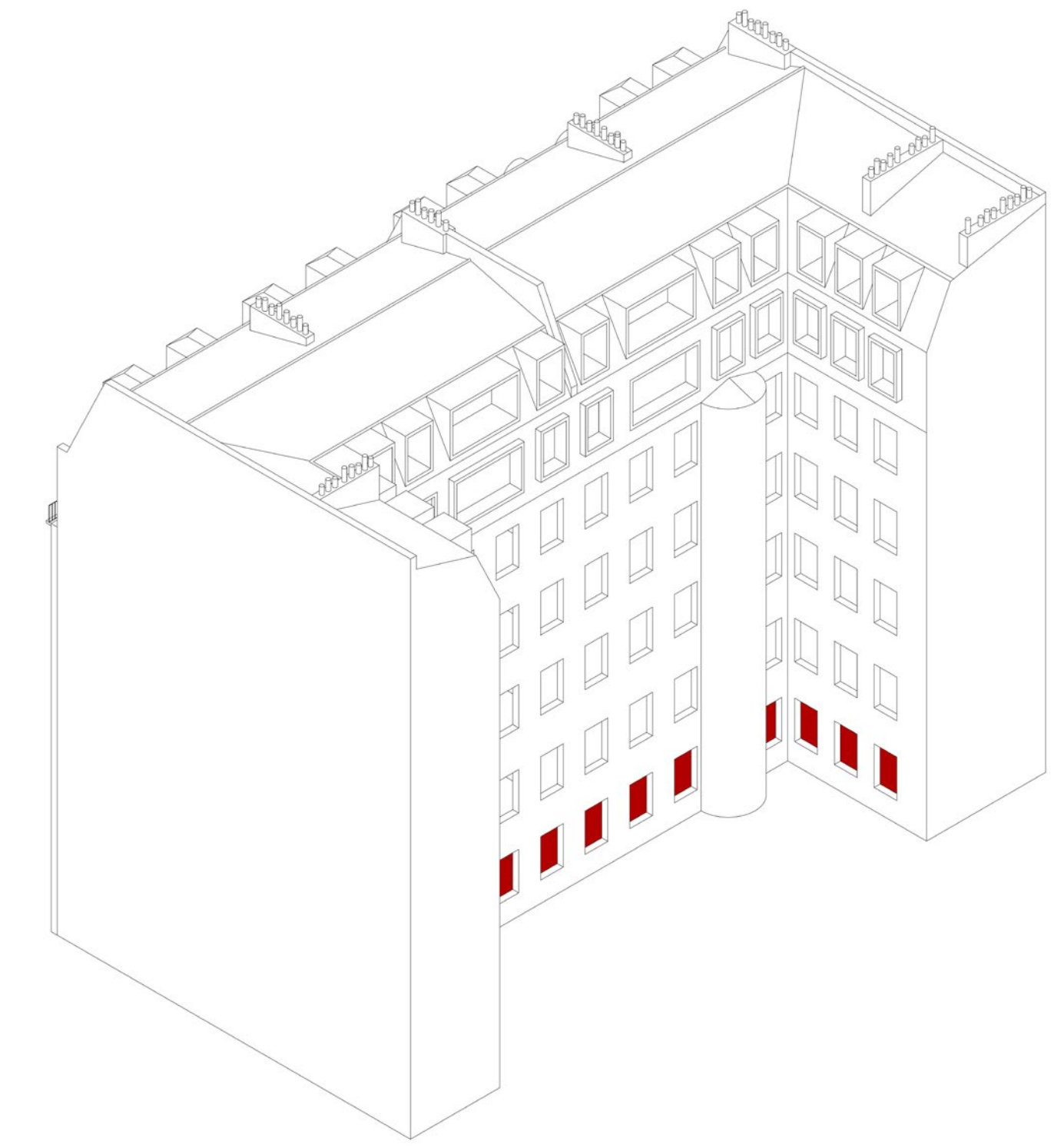
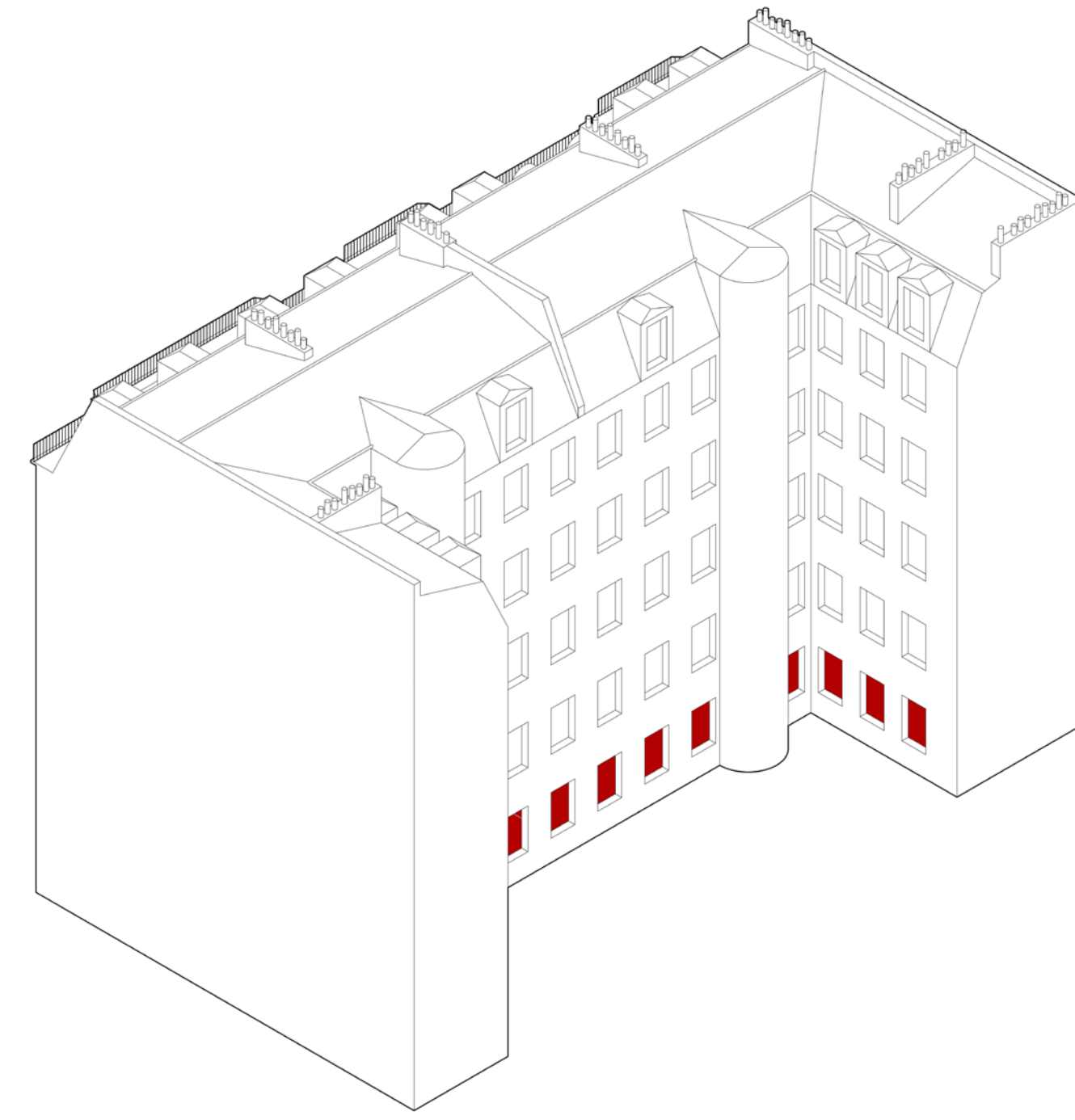
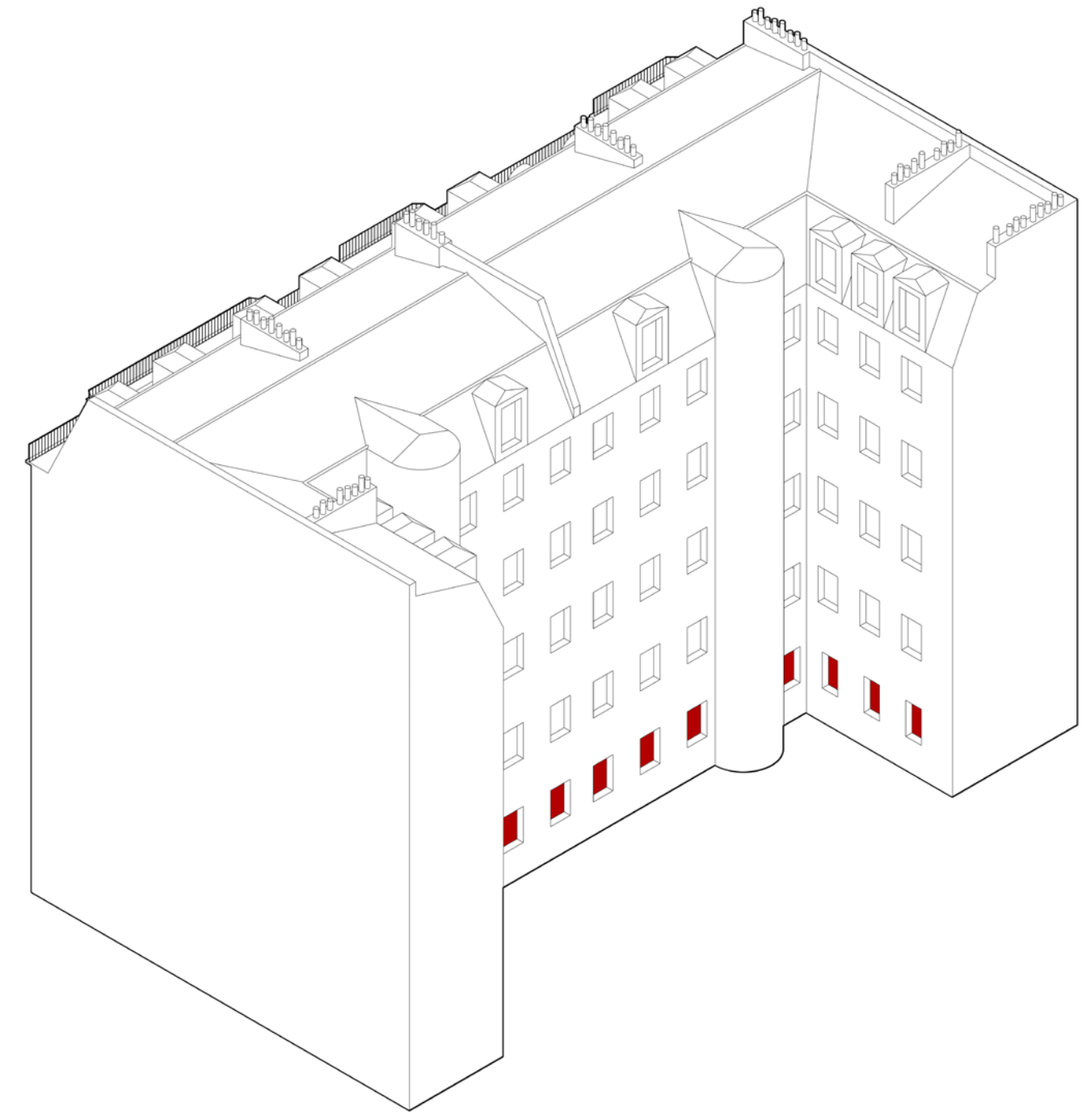
Conclusions





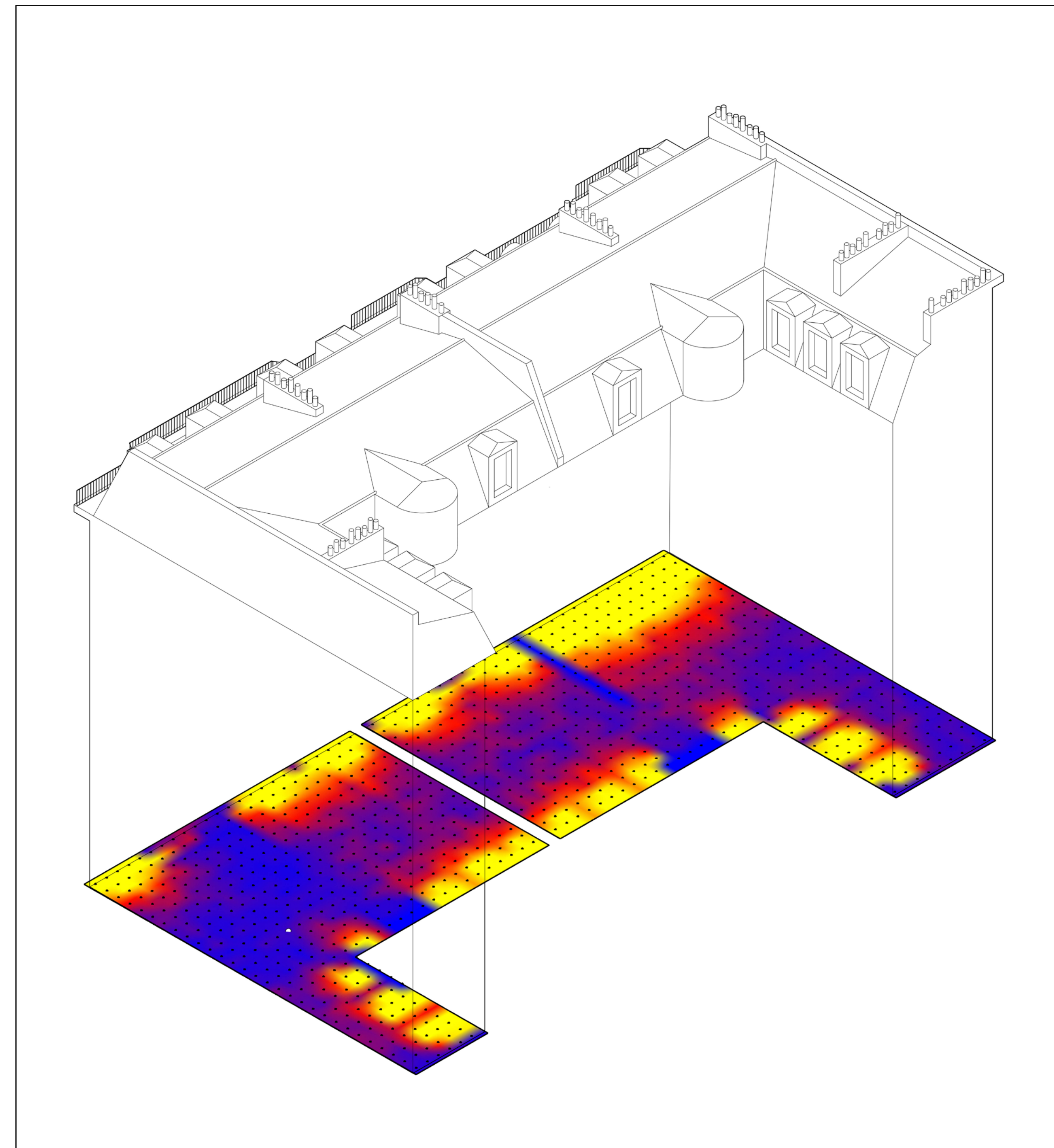






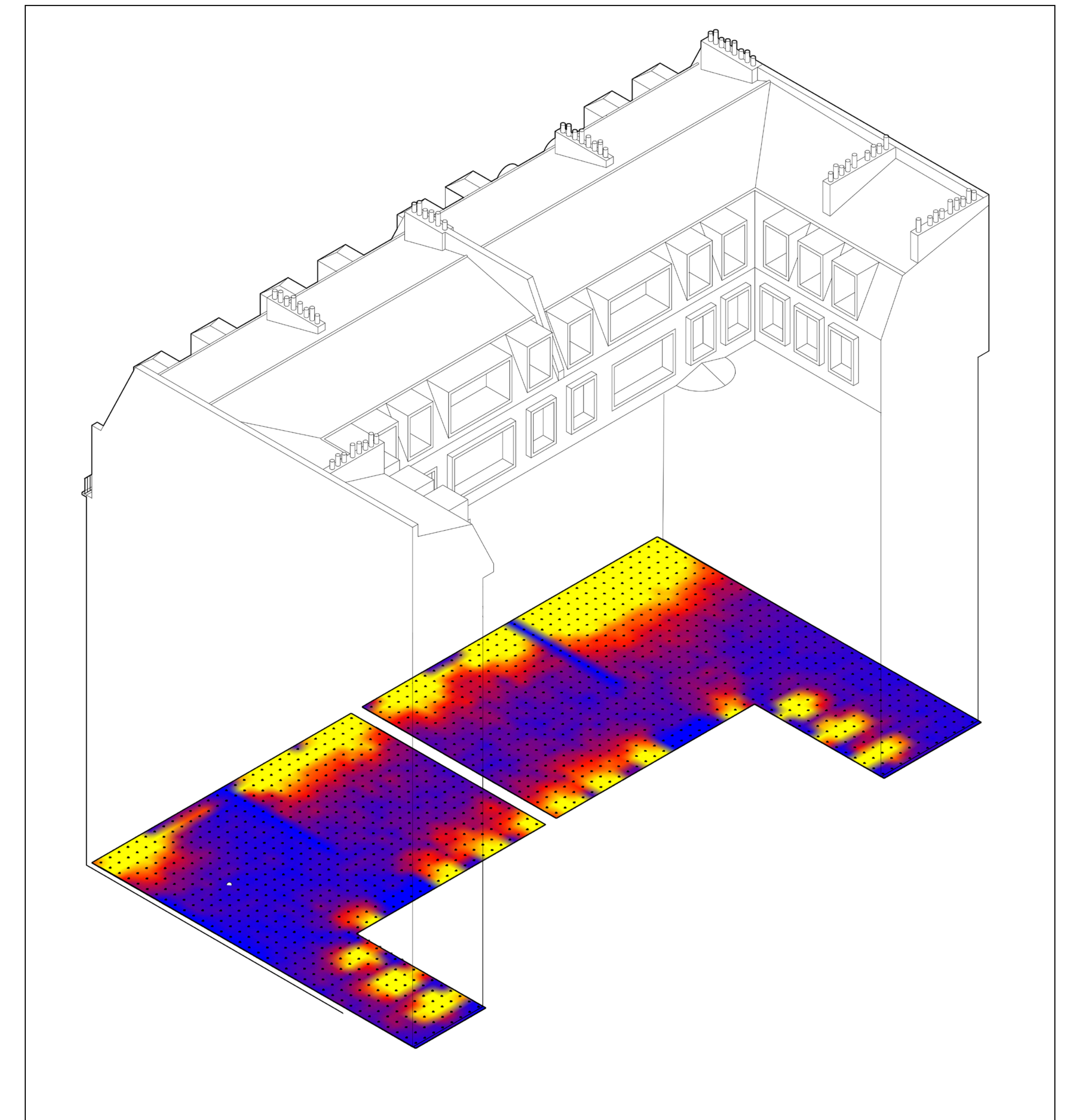
Baseline

sDA: **4.2%**
aV LUX lvl: **107 lx**



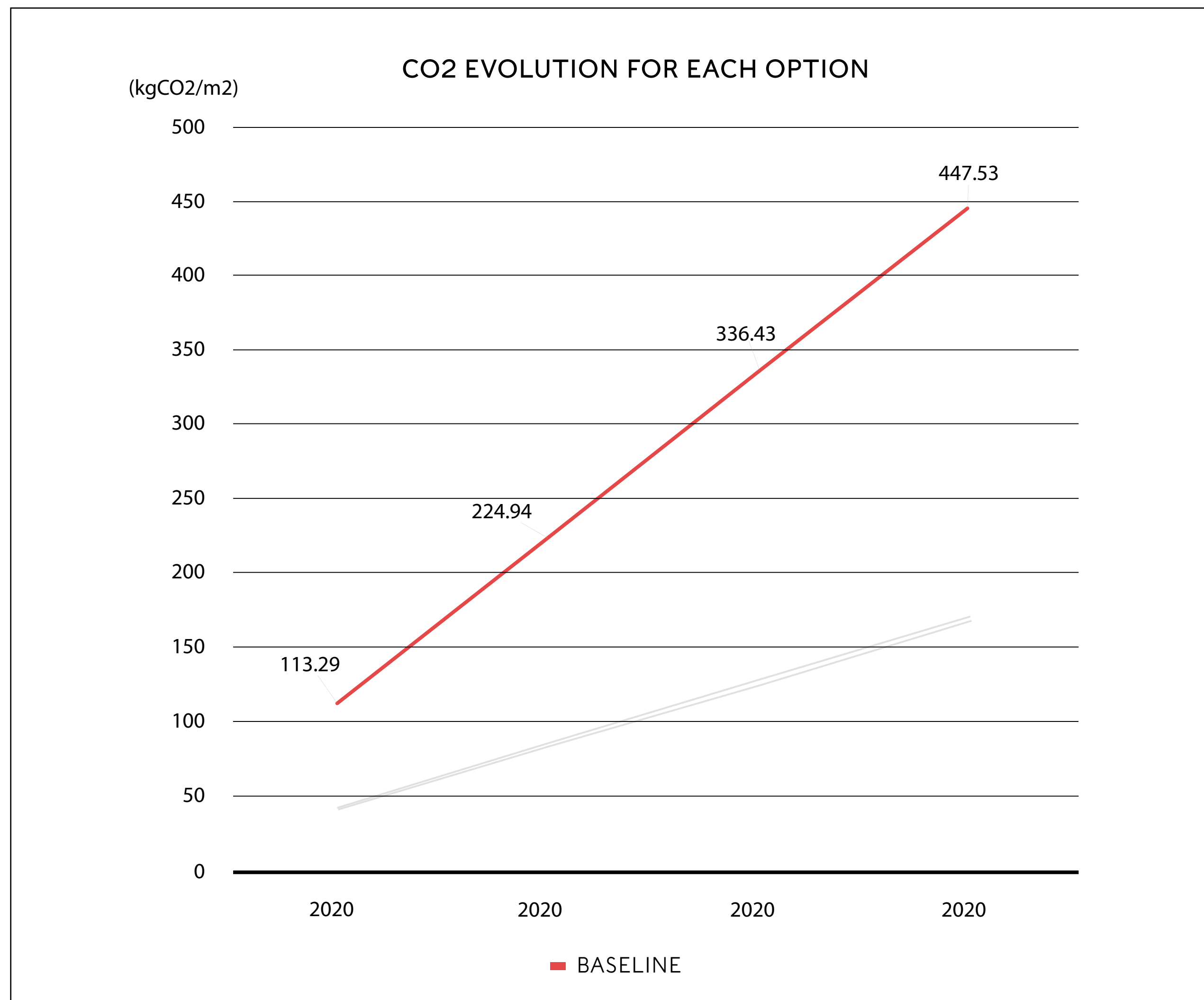
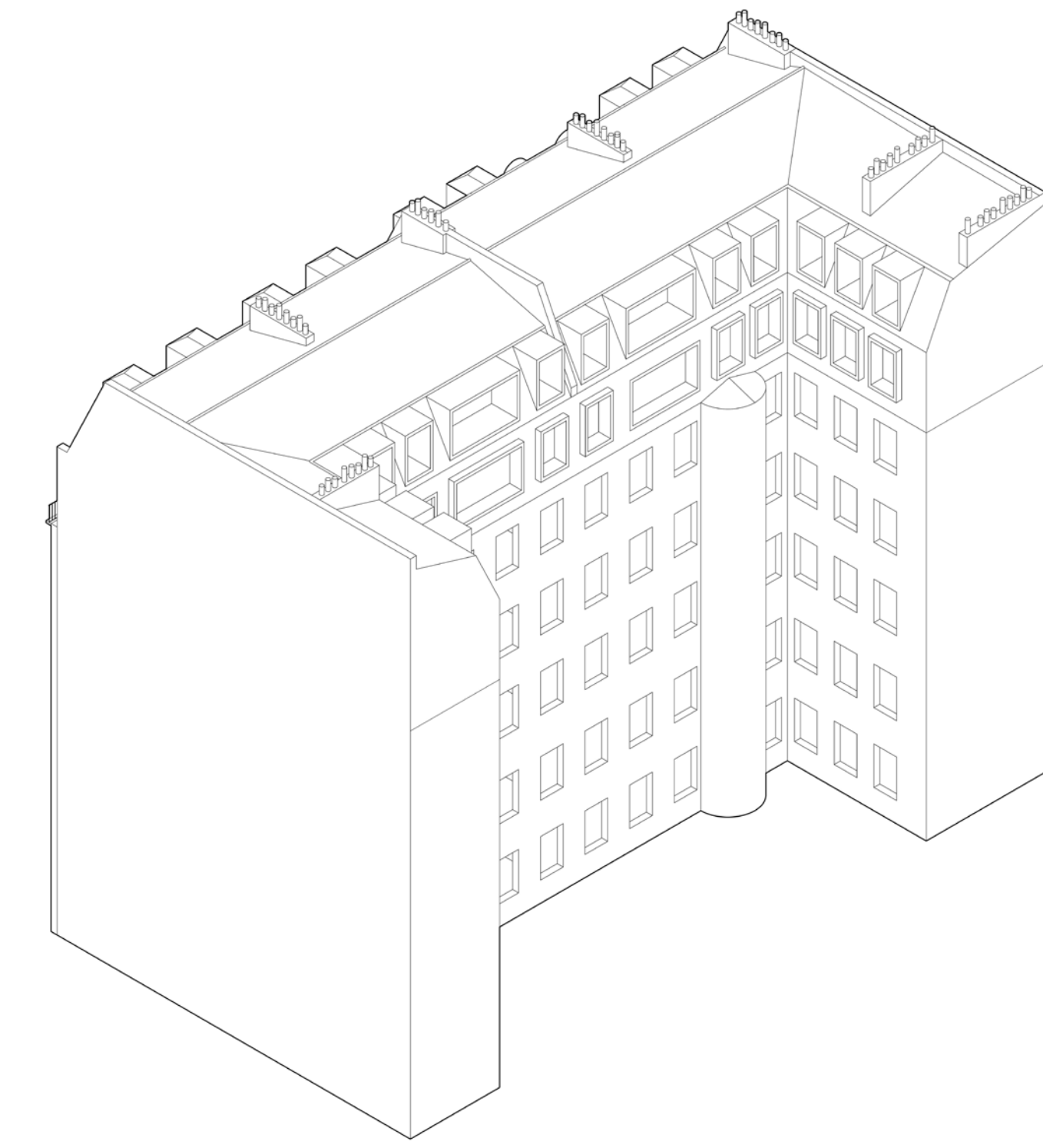
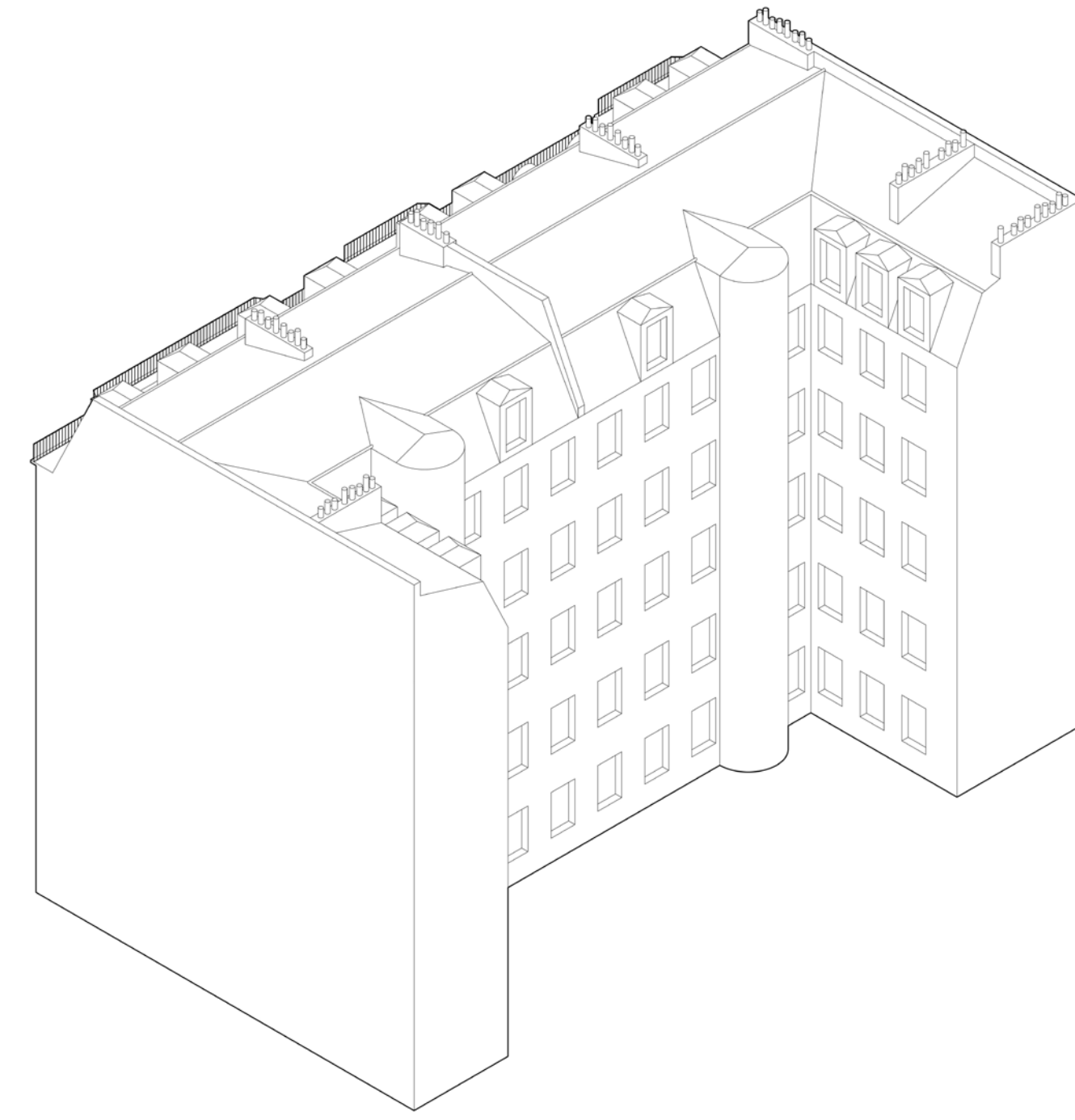
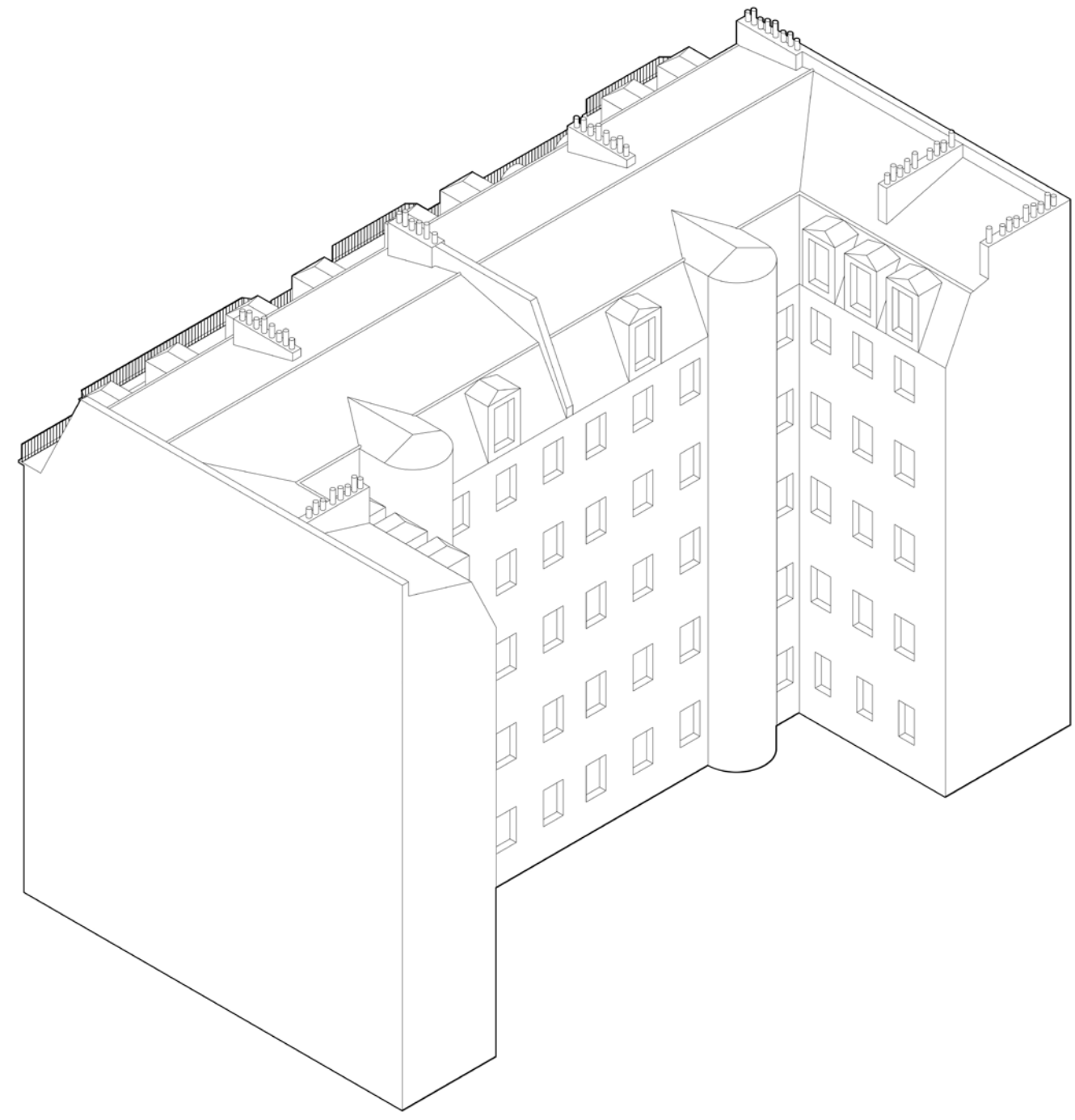
Renovation

sDA: **5.4%**
aV LUX lvl: **125 lx**



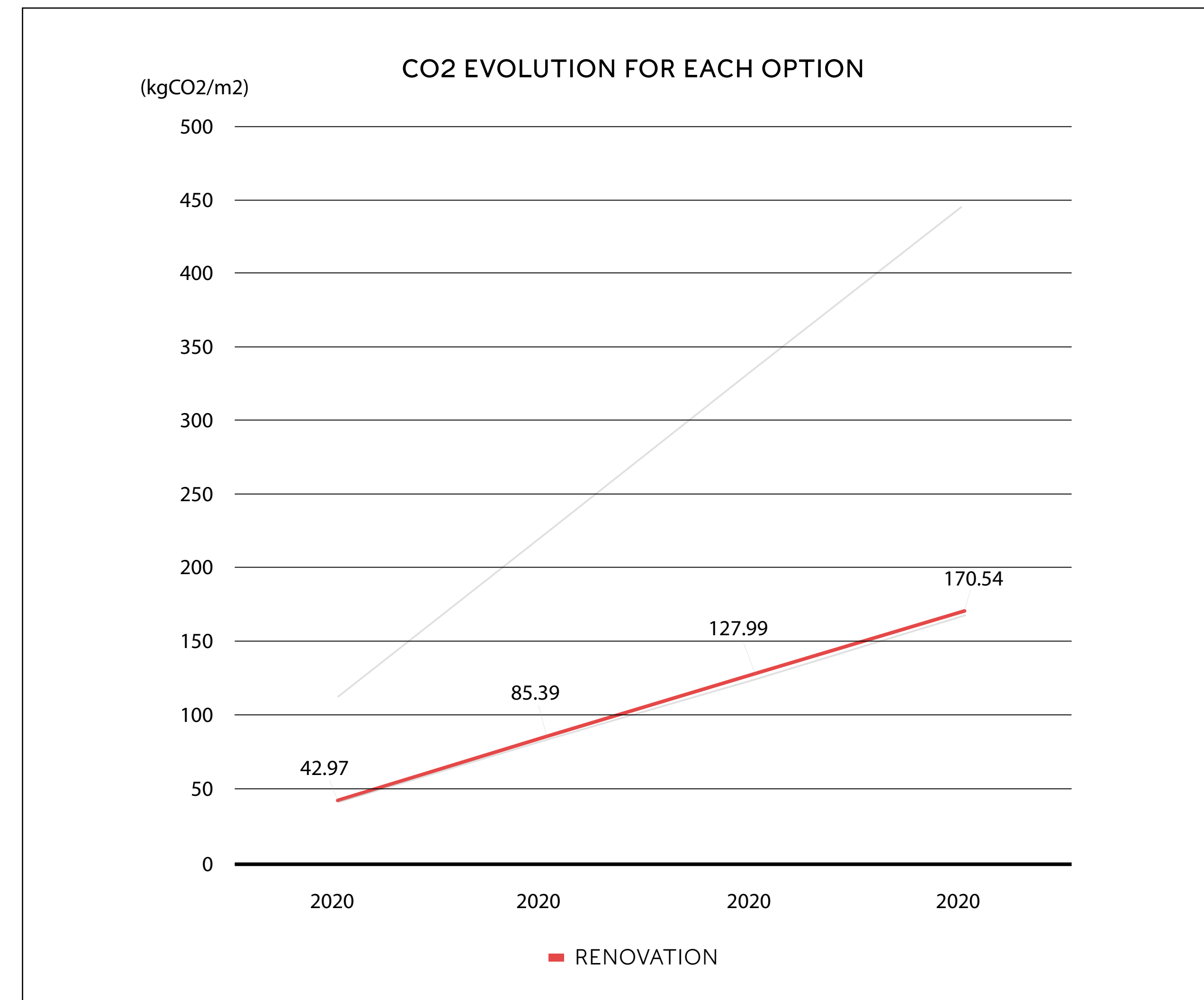
Sur-Elevation

sDA: **5.0%**
aV LUX lvl: **115 lx**



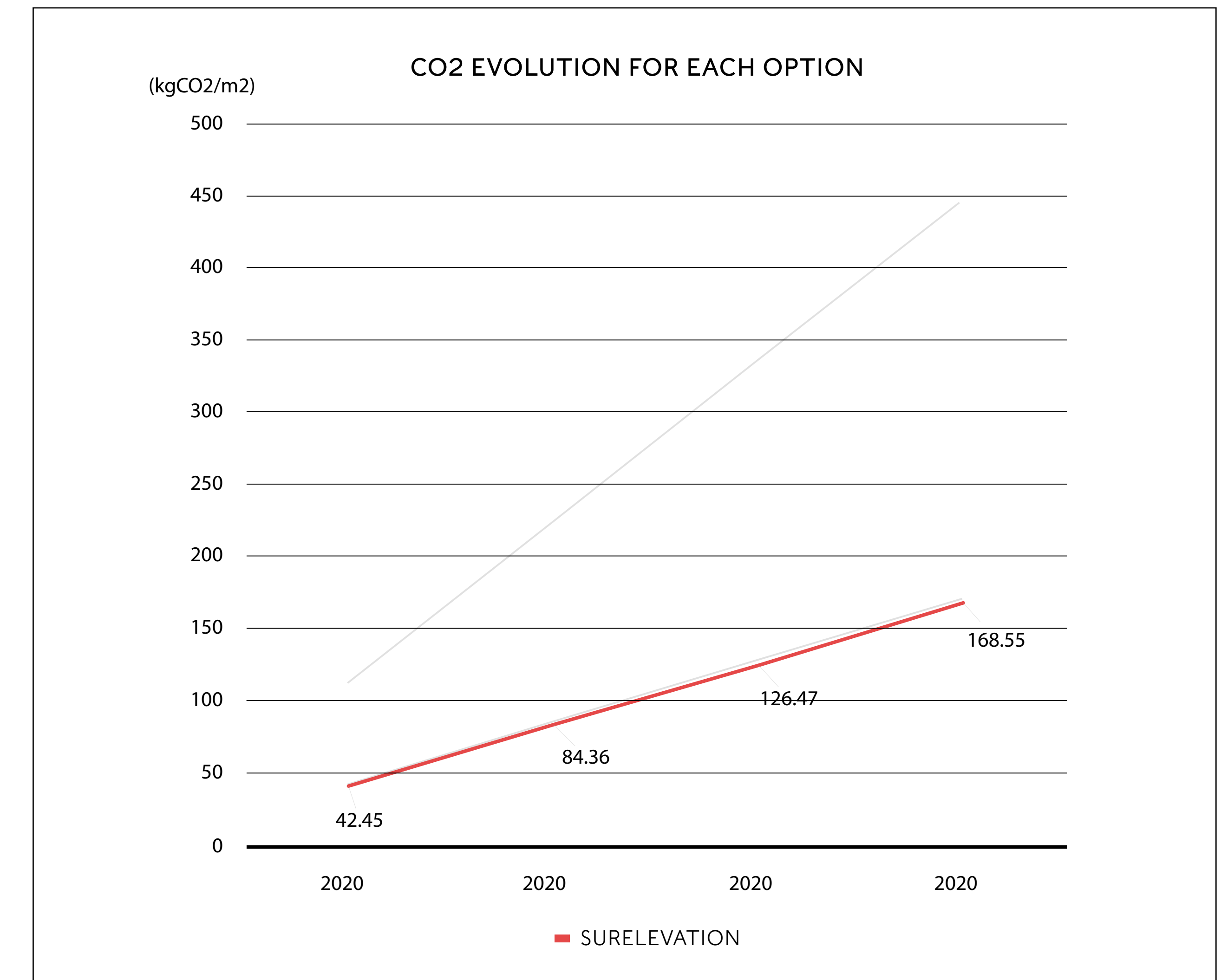
Baseline

EUI: **333 kW/m2**



Renovation

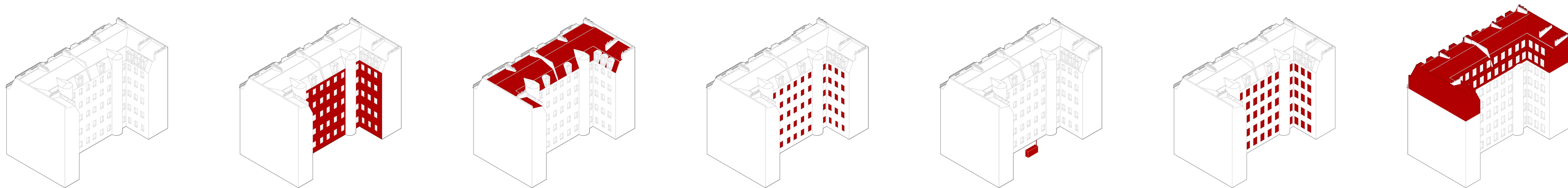
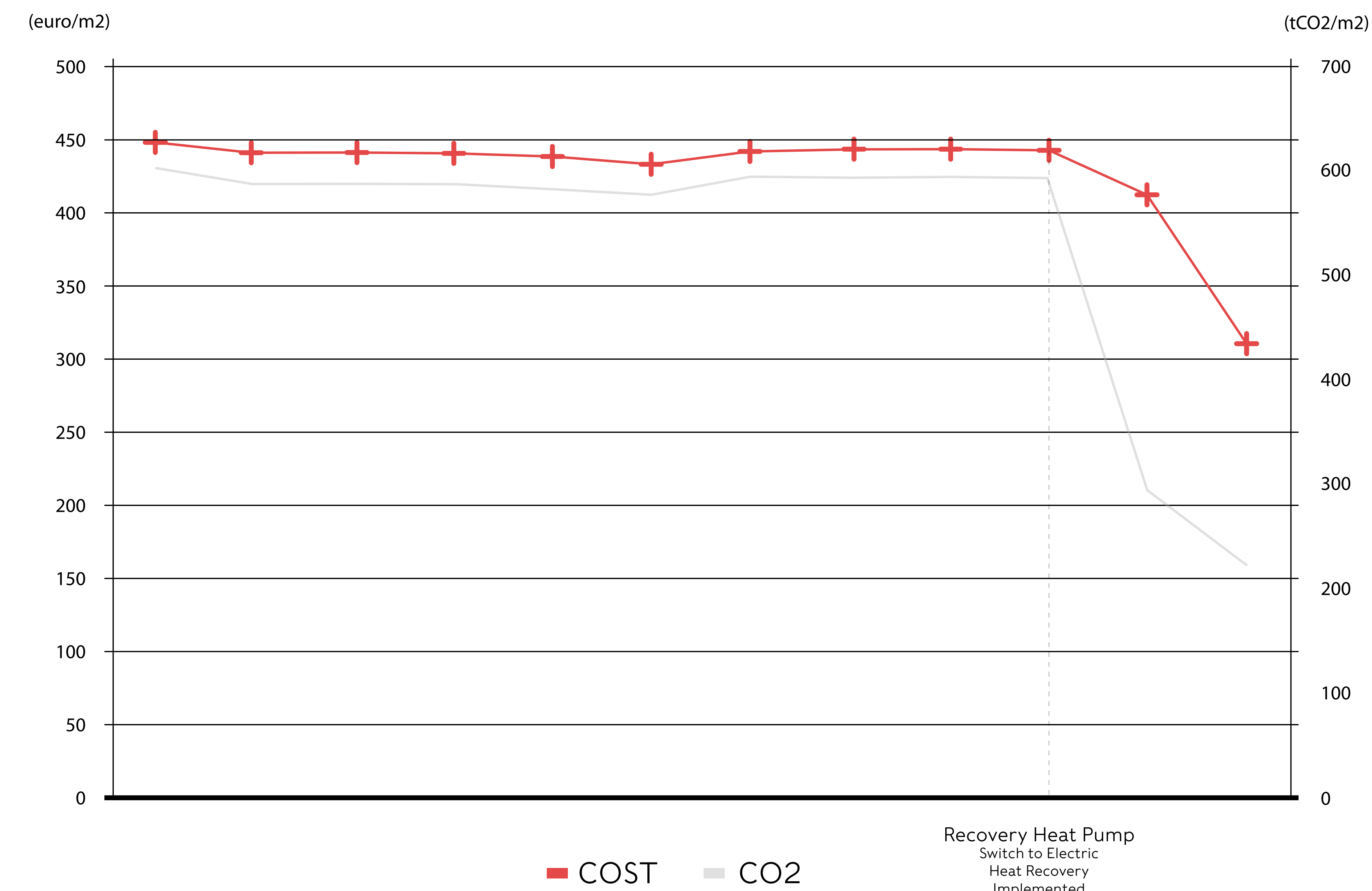
EUI: **101 kW/m2**



Sur-Elevation

EUI: **99 kW/m2**

IMPACT OF BUILDING CHANGES ON GRID ENERGY COSTS AND CO2 EMISSIONS



Energy Cost & CO2 emissions

