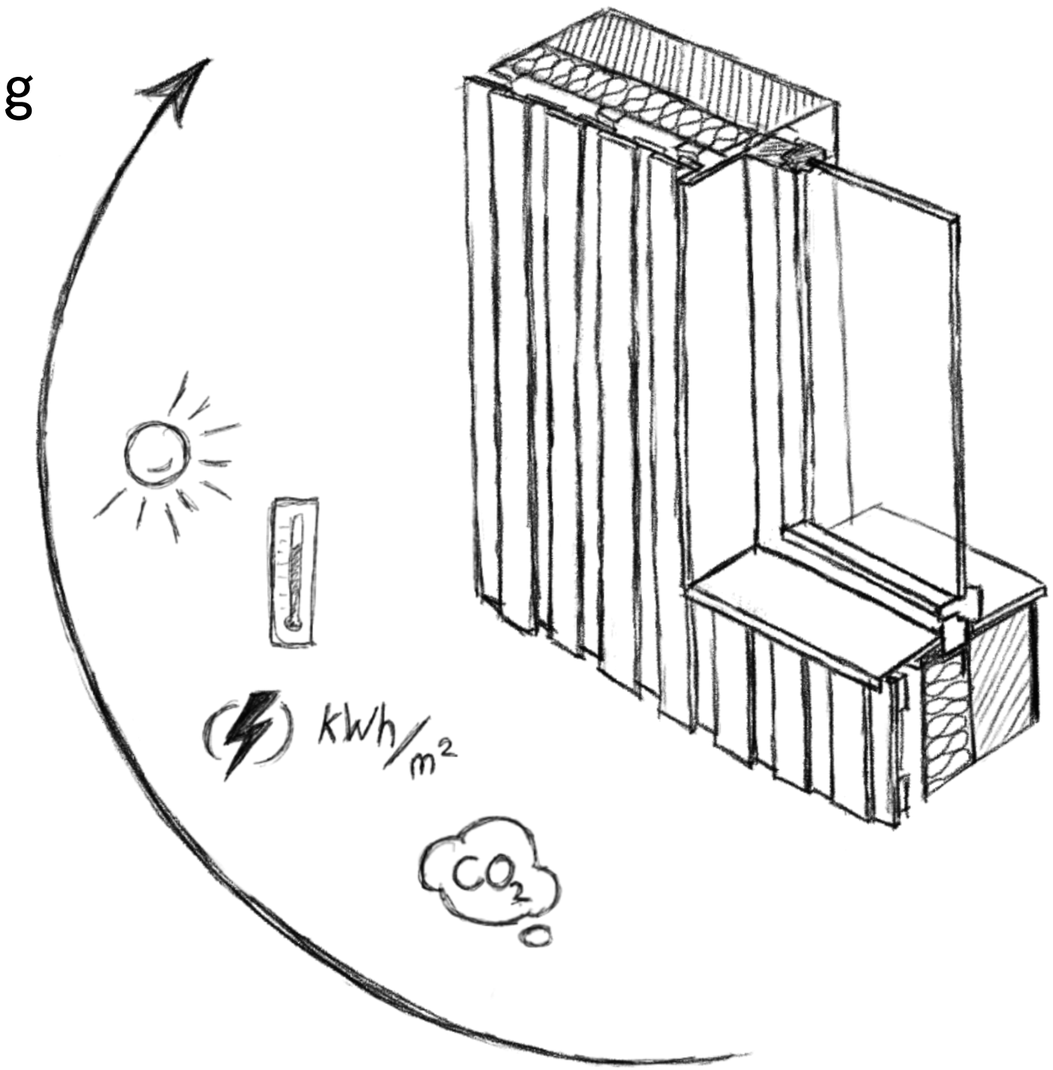
Retrofitting for Heat Resilience

A Dutch case study integrating overheating mitigation into cost-benefit analysis



MSc Thesis in Building Technology

P5 Presentation - 03.07.2025

Tamara Lalyko | 6075797

mentors

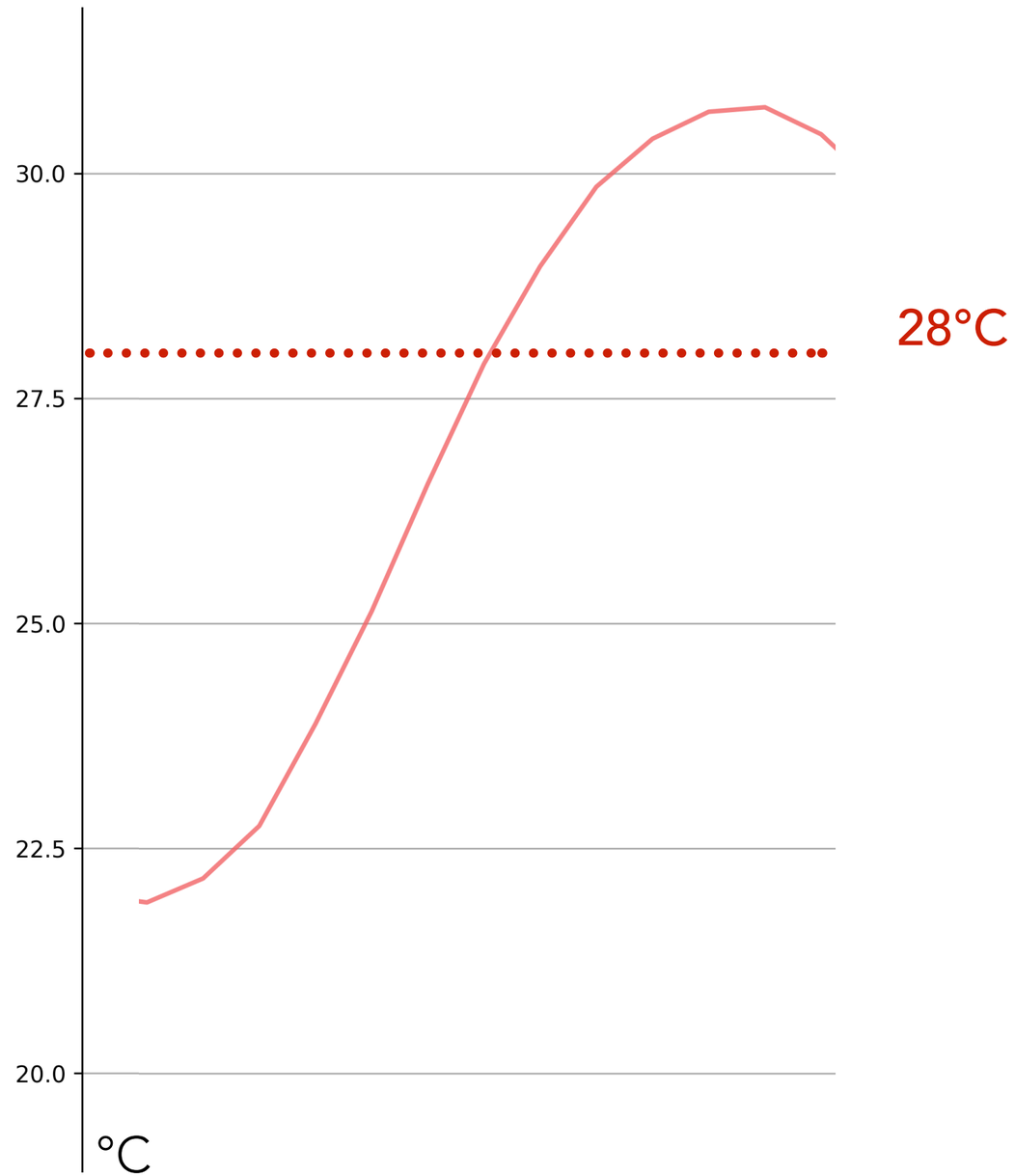
Dr. Simona Bianchi, Structural Design & Mechanics, TU Delft

Dr. Alessandra Luna Navarro, Facade & Product Design, TU Delft

third advisor

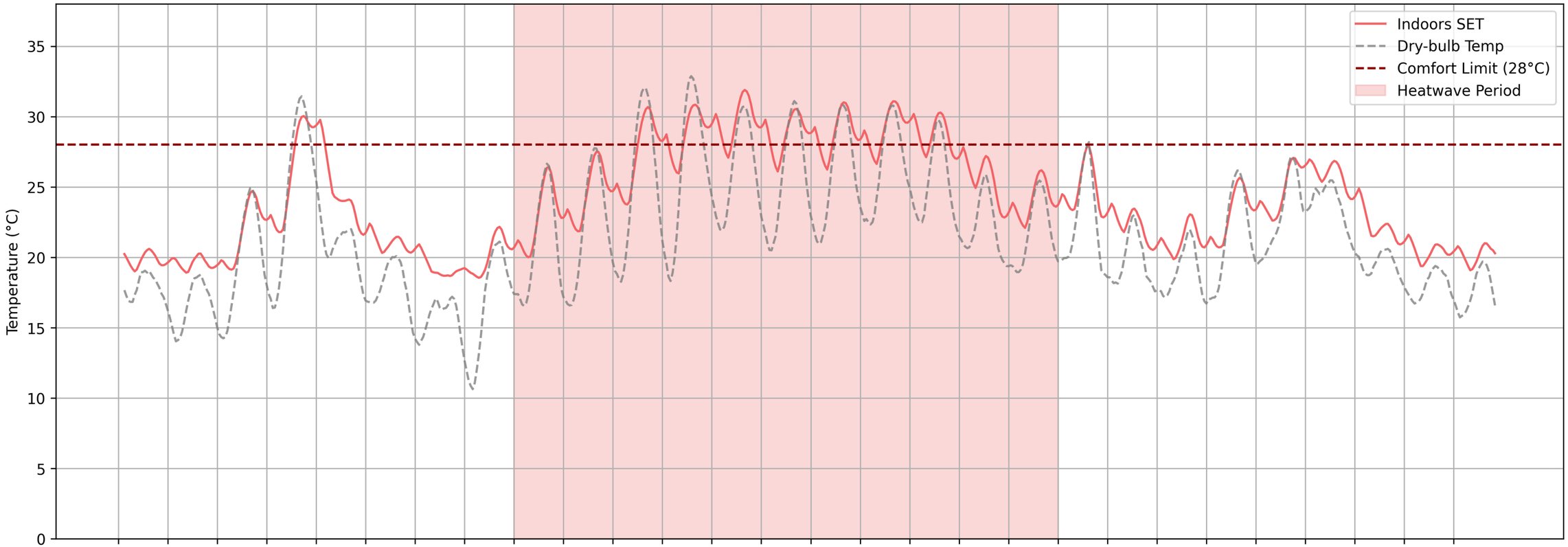
Diletta Ricci, PhD candidate, Design & Construction Management, TU Delft

Background



Background

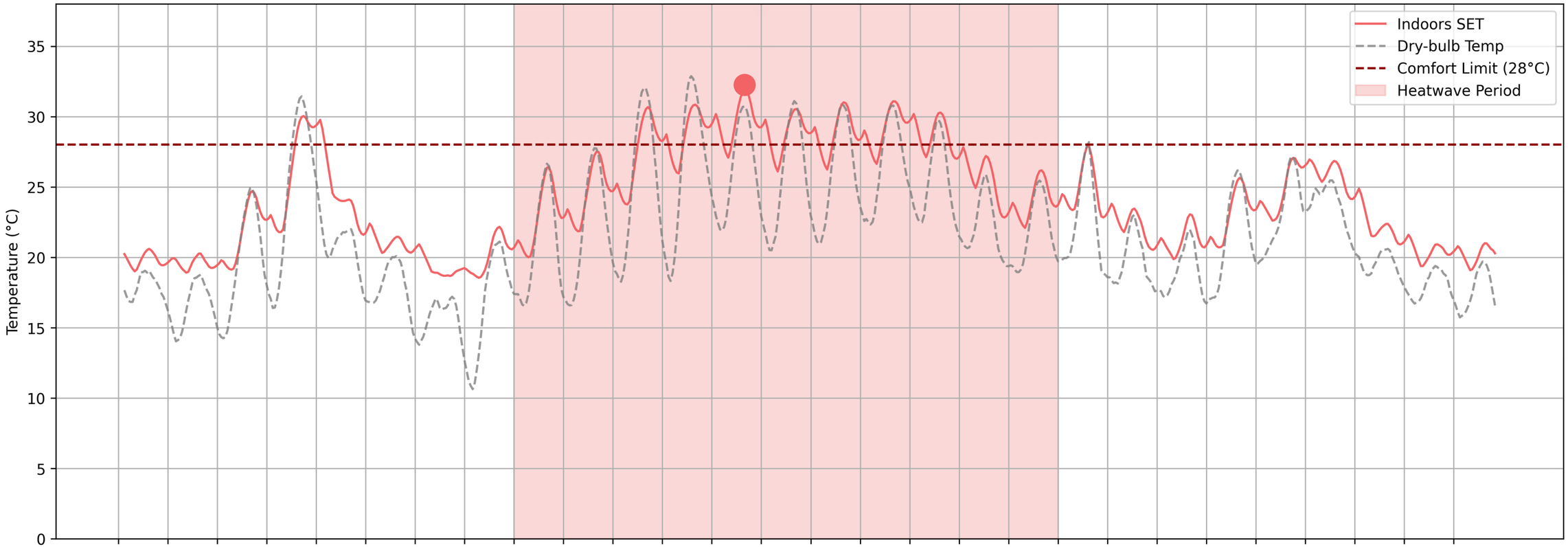
Prolonged Period of Heat



Background

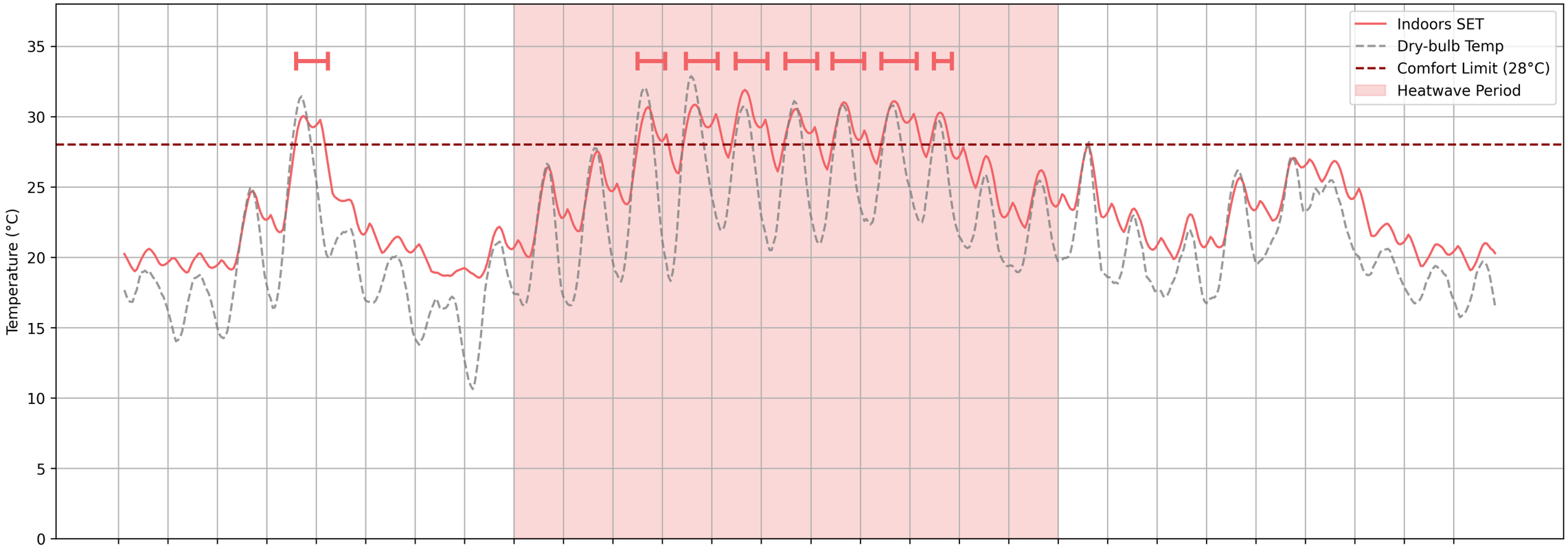
Prolonged Period of Heat

Peak above 32°C



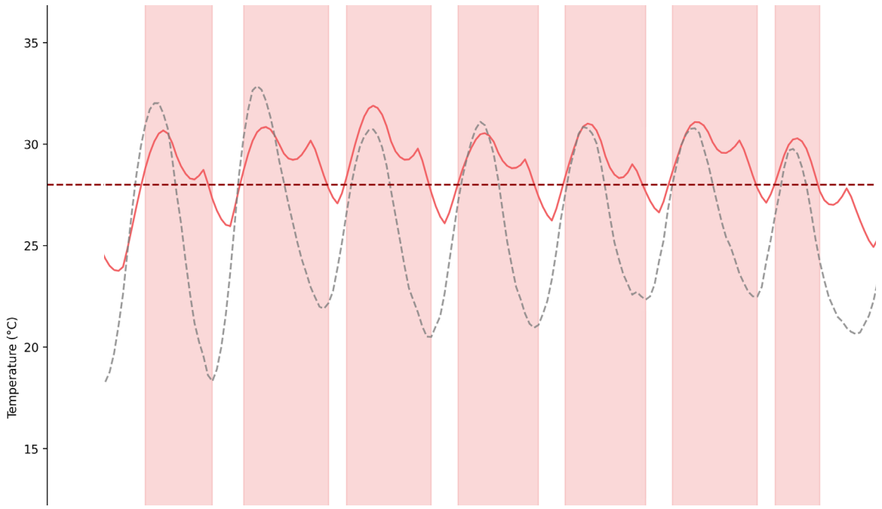
Background

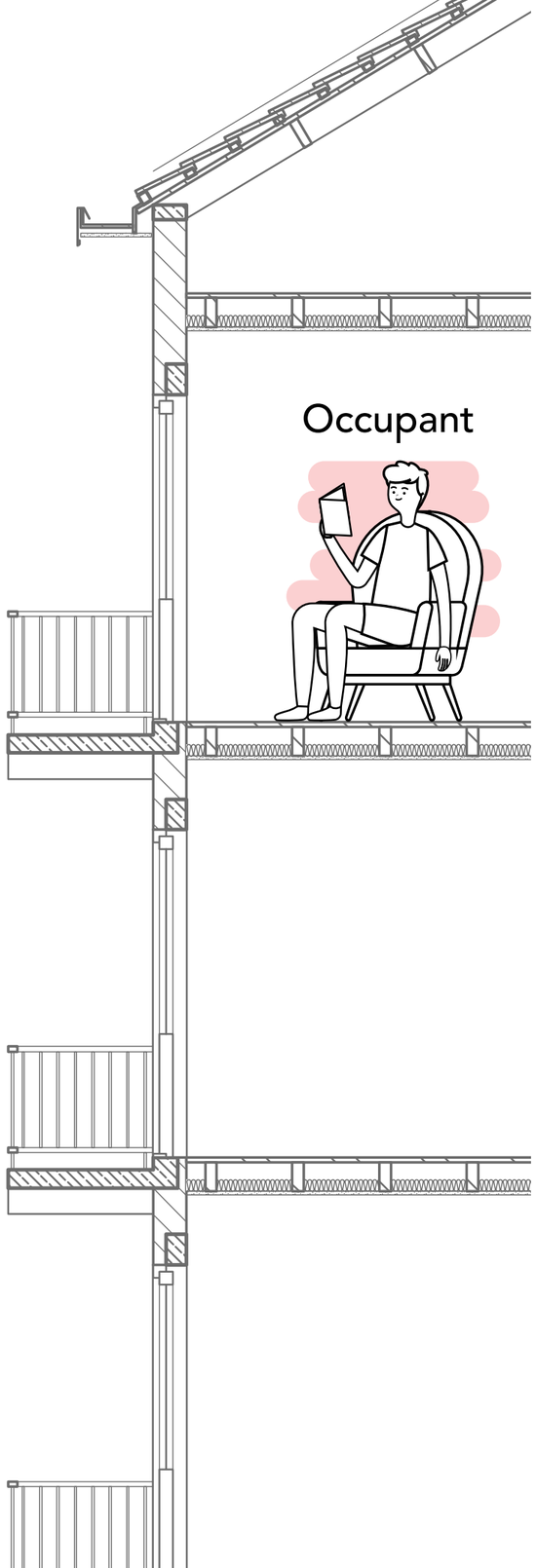
Prolonged Period of Heat

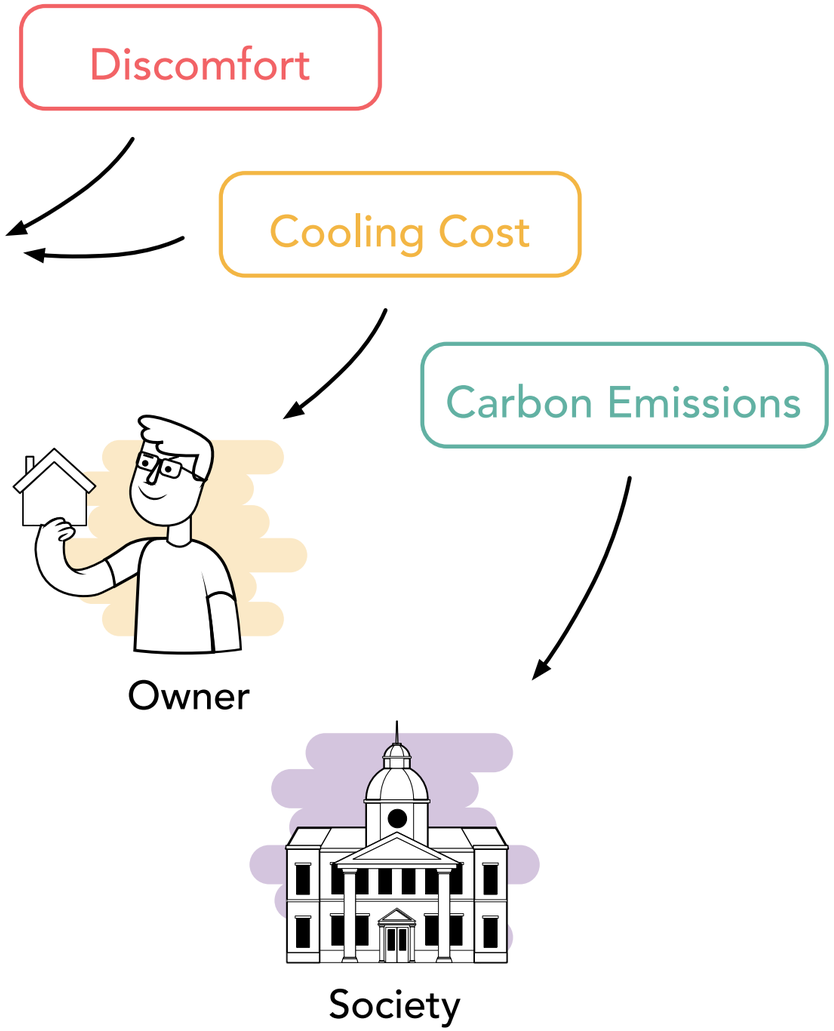


126 hours

Background

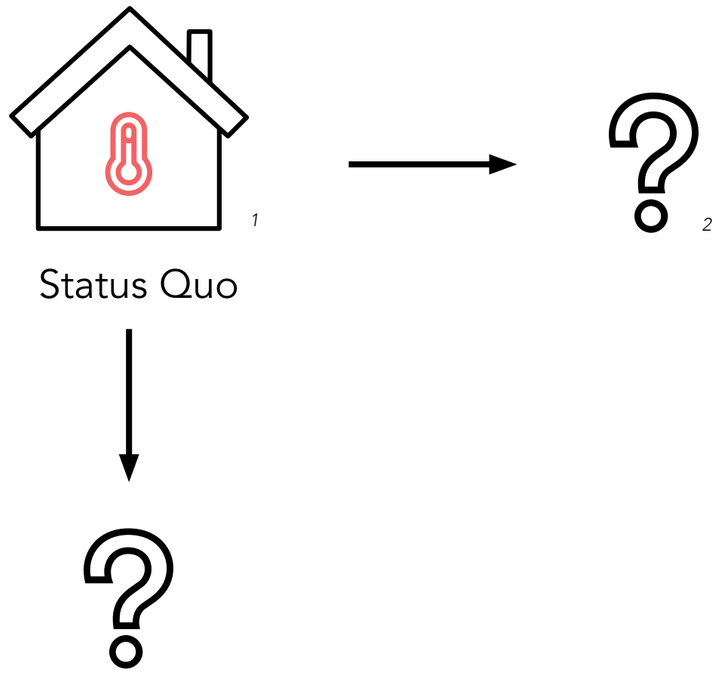

35
30
25
20
15
Temperature (°C)


Occupant


Discomfort
Cooling Cost
Carbon Emissions
Owner
Society

Resilience corresponds to mitigating loss before, during, and after heat hazard.

Can you mitigate through renovating?



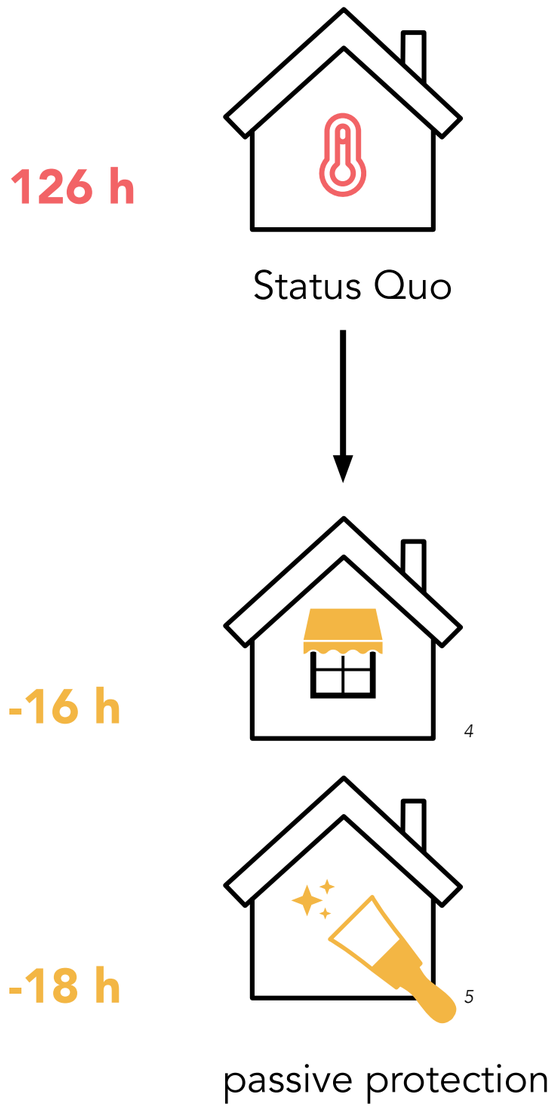
Can you mitigate through renovating?

Status Quo

Qualitative benefits

passive protection

Can you mitigate through renovating?



Can you mitigate through renovating?

Status Quo

active cooling

Can you mitigate through renovating?

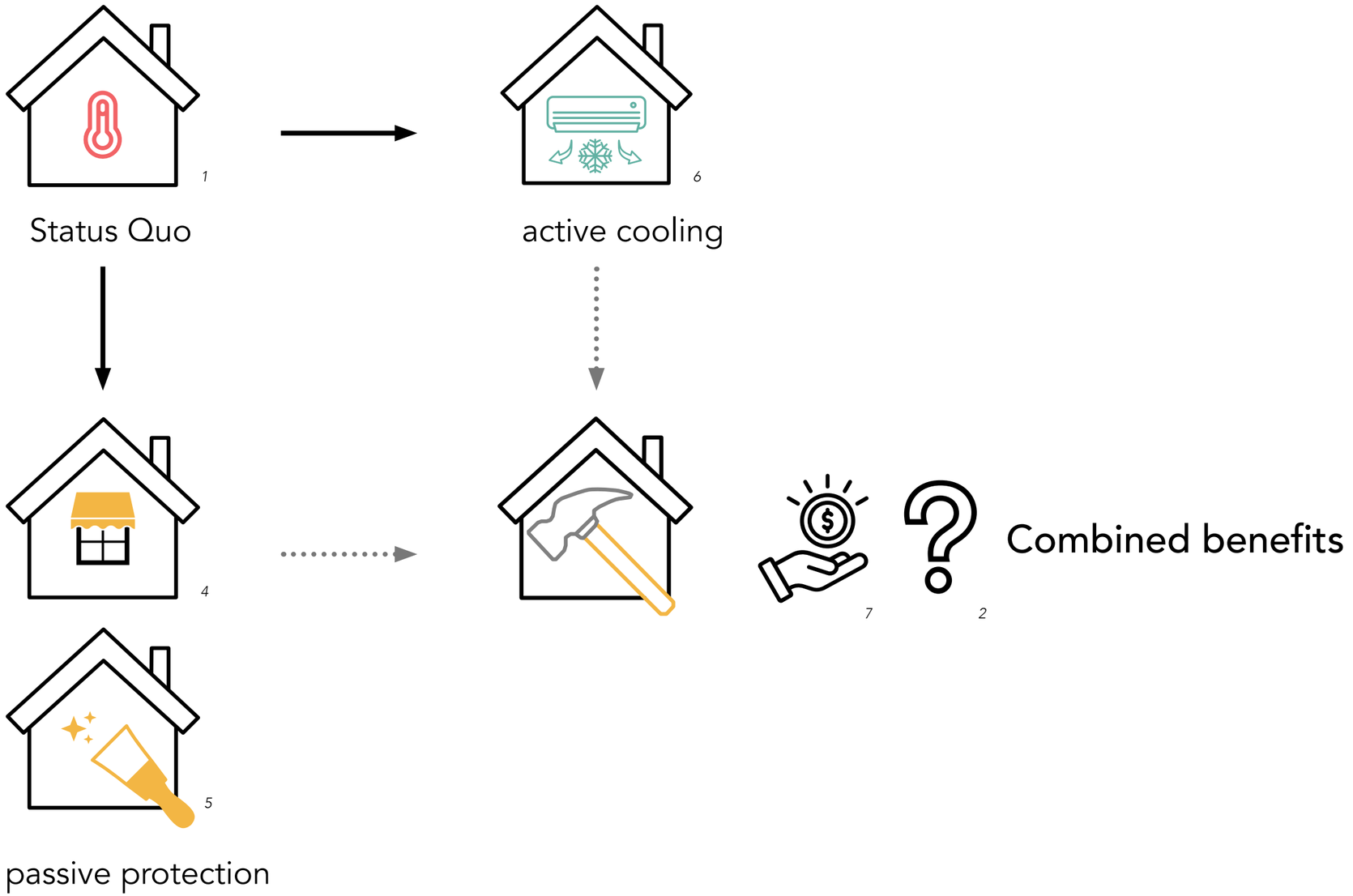
126 h

Status Quo

active cooling

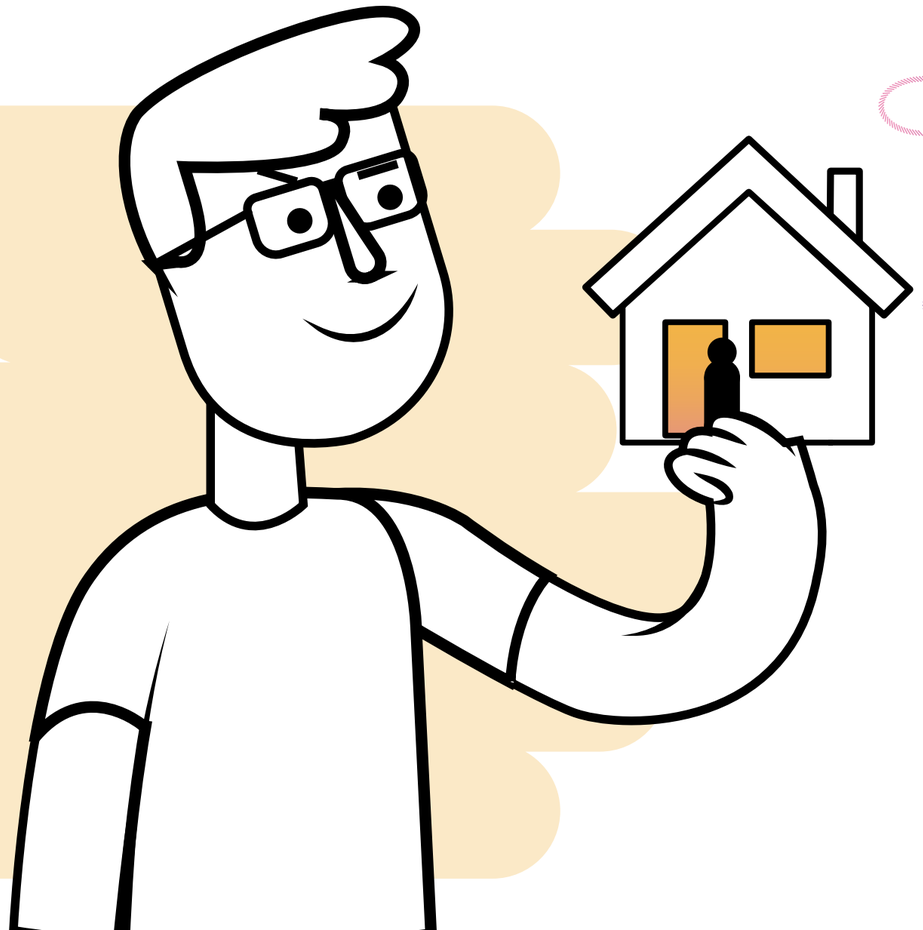
+14,077 kWh **+ 1,180 Euro**

Can you mitigate through renovating?



Research Gap

But is really worth it?



How much will heat hazards drive up cost?

Will the savings pay off my investment?

Does climate uncertainty affect financial feasibility?

How can thermal resilience be integrated in cost-benefit analysis to inform decision-making of envelope retrofitting scenarios?

Research Outline

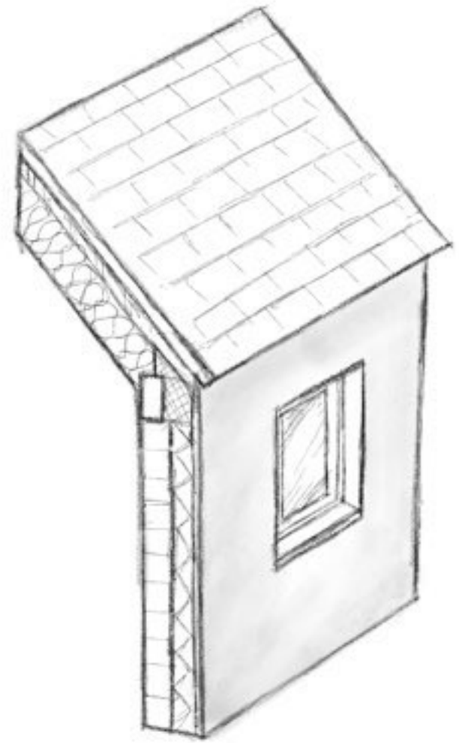
The Four Main Challenges

Cost for heat hazard long term

Climate uncertainty in cost-benefit

Outline extreme scenarios in cost-benefit

Informing renovation design

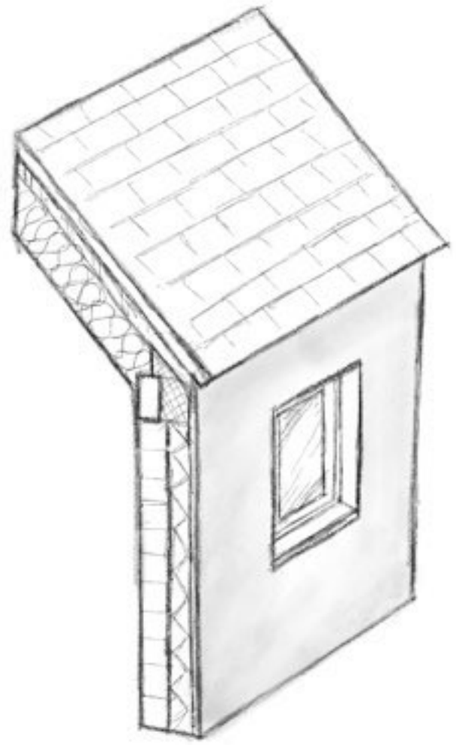


The Purpose of Renovating

Reduced Costs

Higher Profits

Gain Competitive Advantage



Increase Quality of Living

Increase Productivity

Reduce Ecological Impact

Sustainable Development

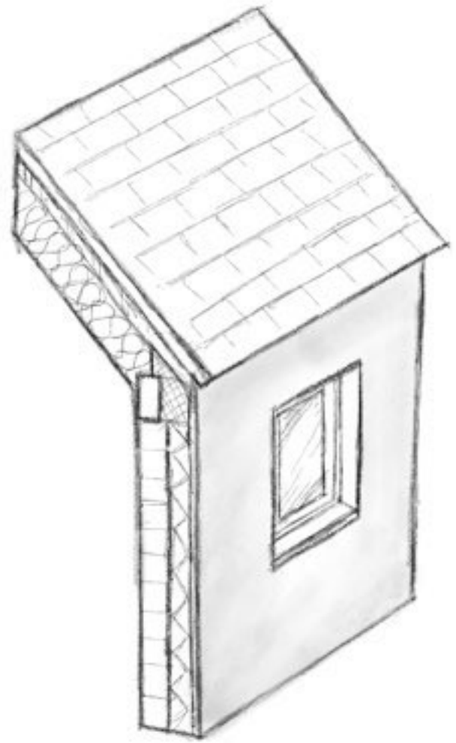
The Purpose of Renovating

Renovation endorsed by policy

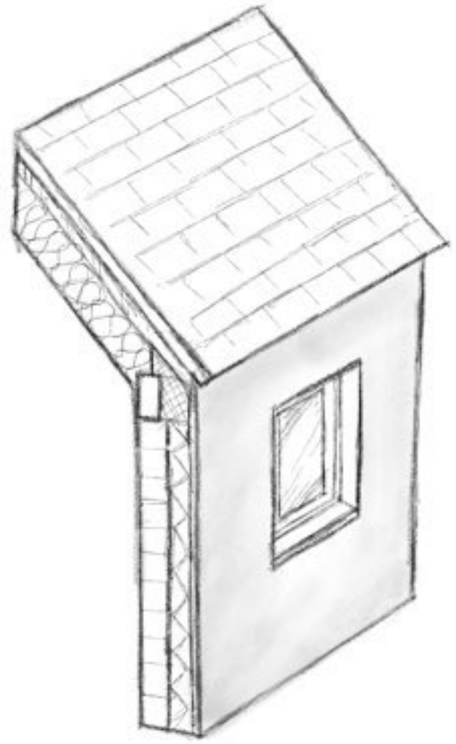
Energy Performance of Buildings Directive
increase efficiency
-16% by 2030

Renovation Wave
renovate 35 million buildings by 2030

Heating Transition



Energy retrofitting without overheating?



Overheating Mitigation

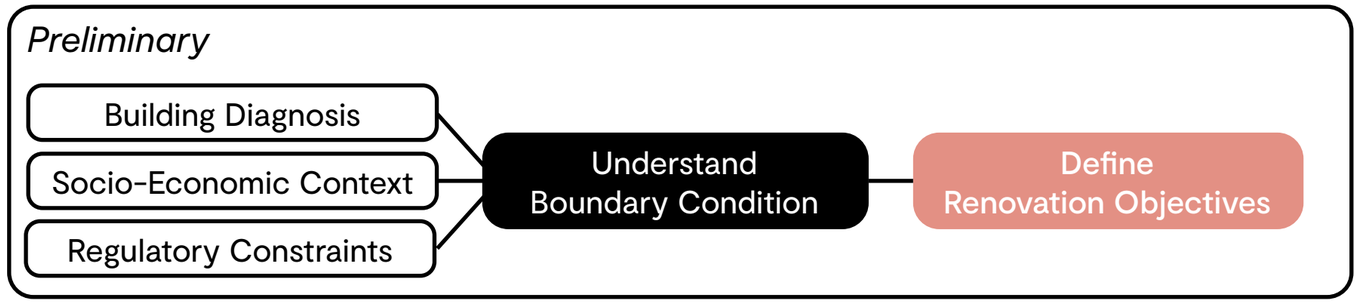
Heat wave loss reduction

Robustness for future climate

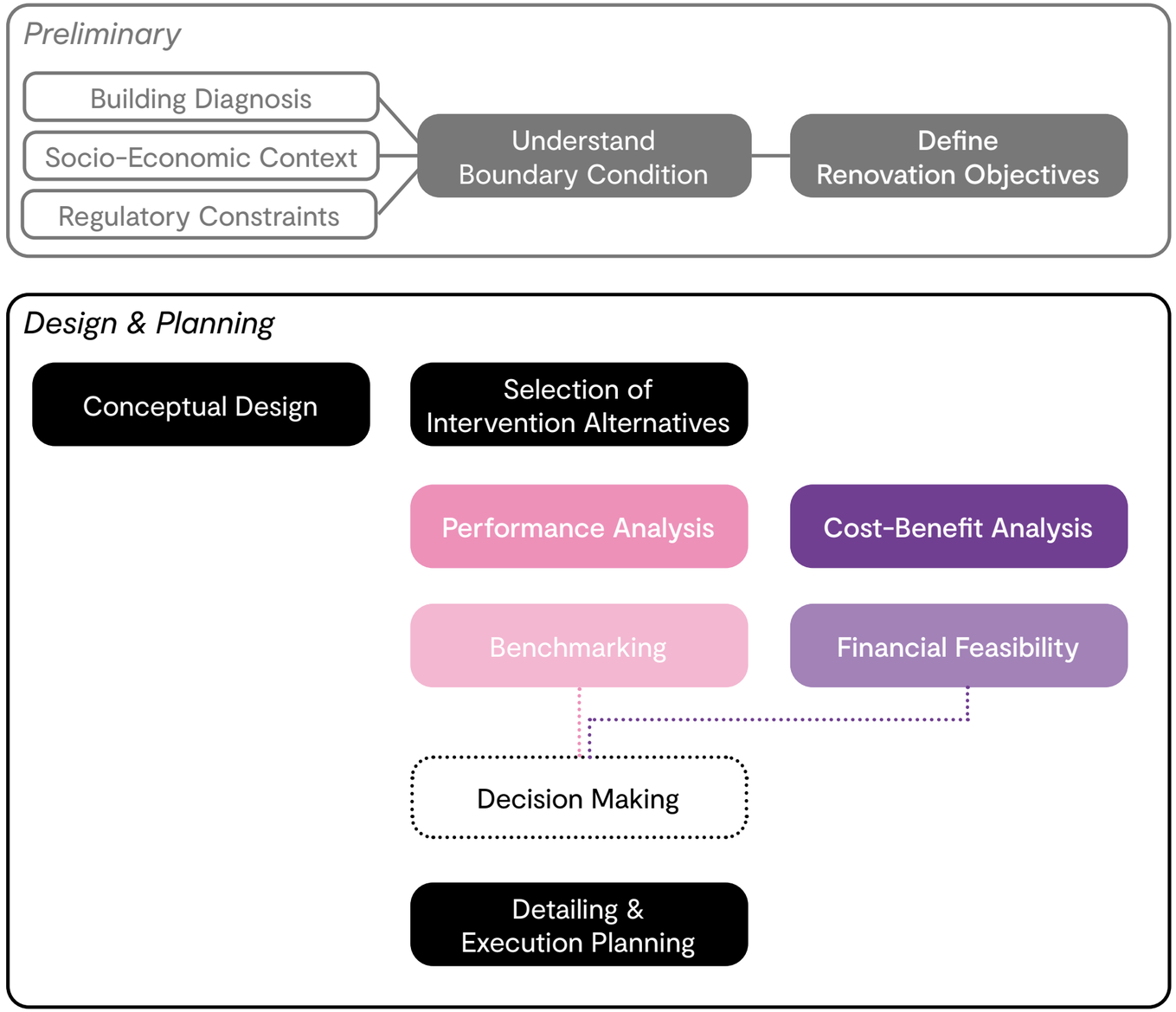
Where does overheating come in?

What does the renovation process look like?

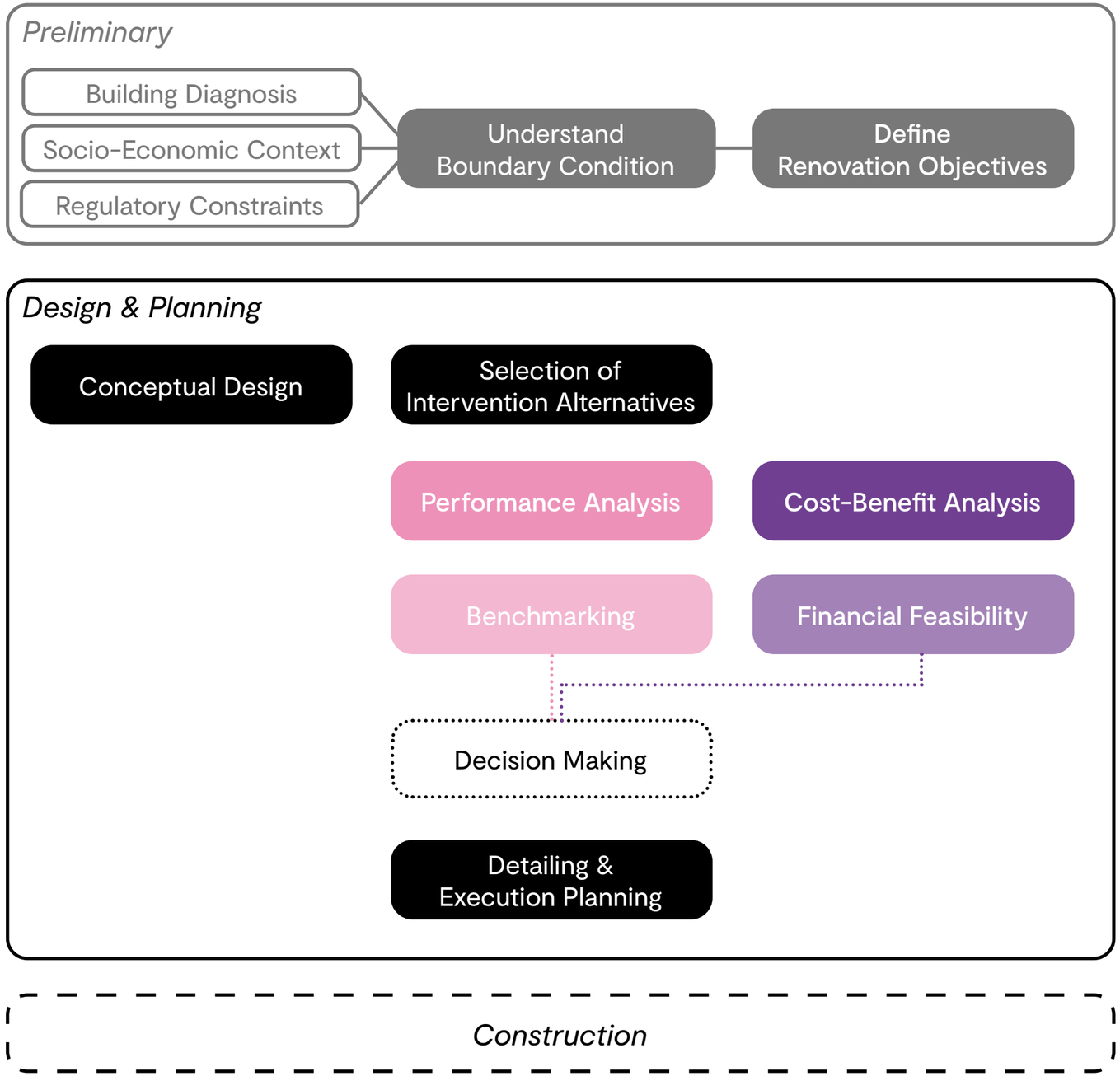
Renovation Process



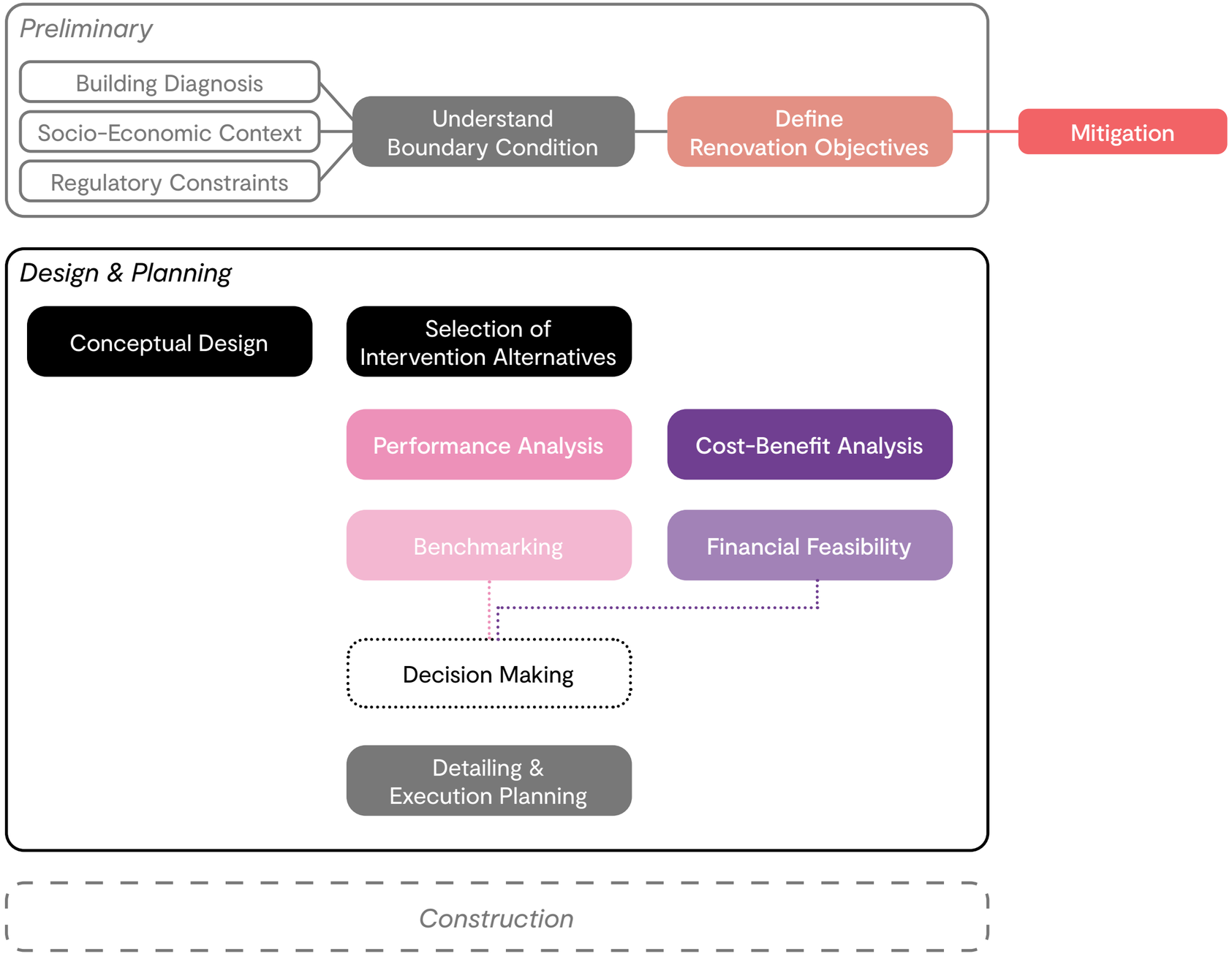
Renovation Process



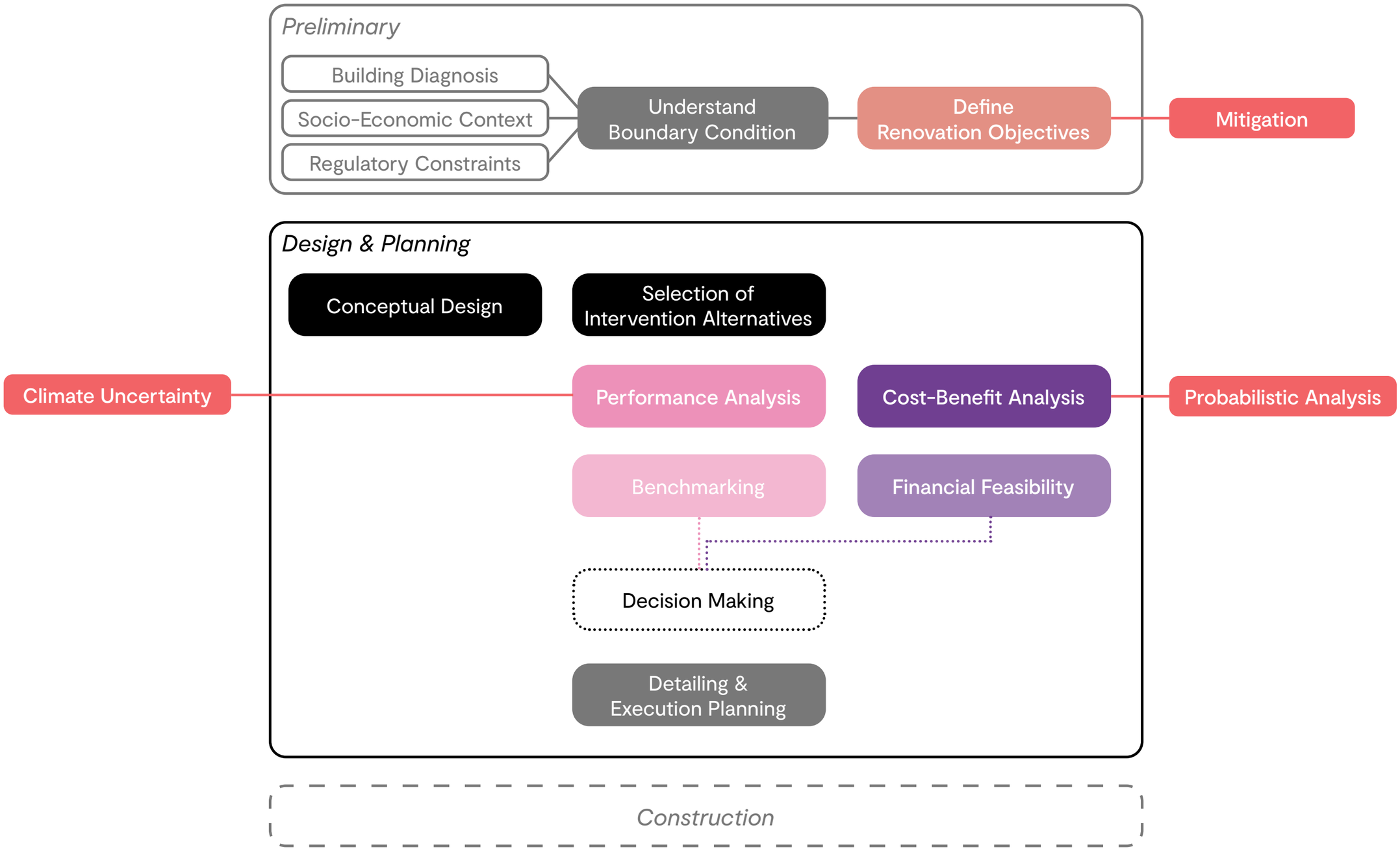
Renovation Process



Renovation Process



Renovation Process



CASE STUDY

Preliminary

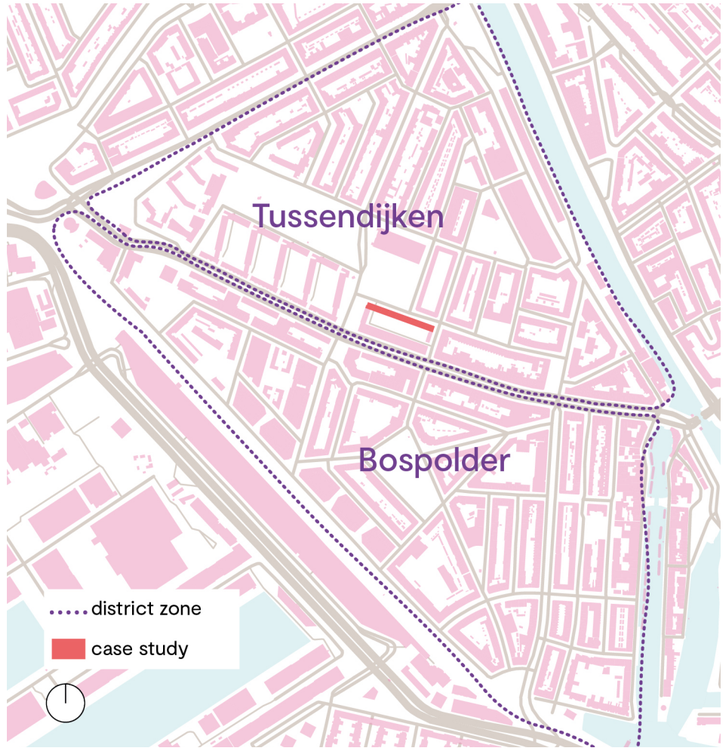
Design & Planning

Performance

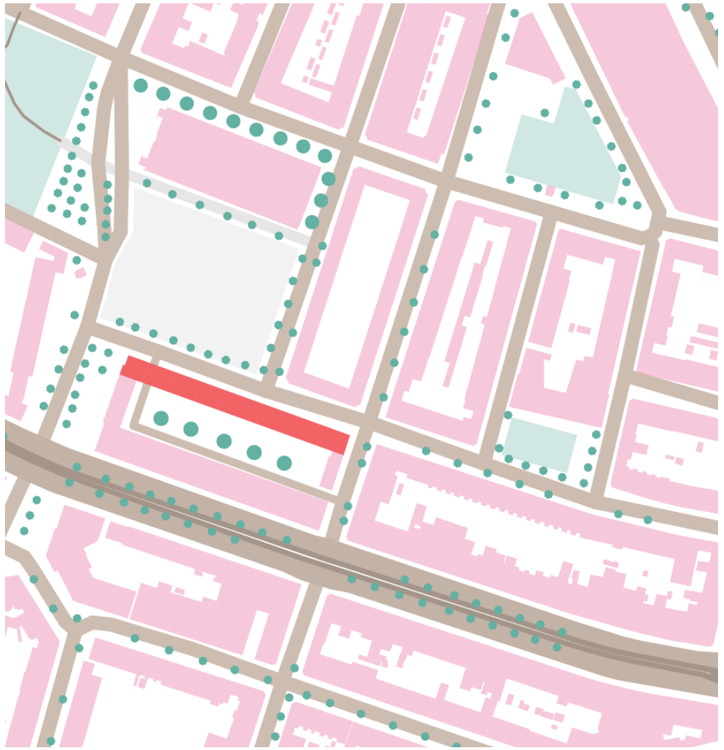
Cost-Benefit

Decision-making

Case study building



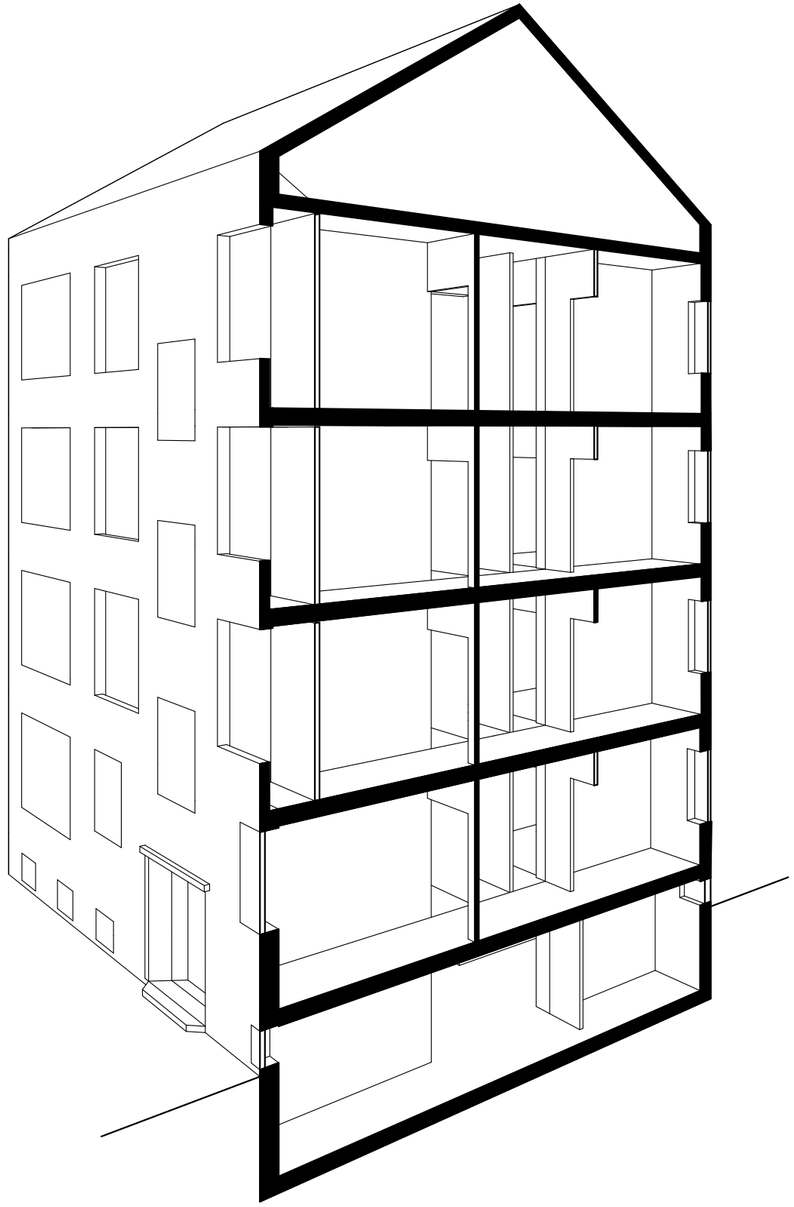
District Map

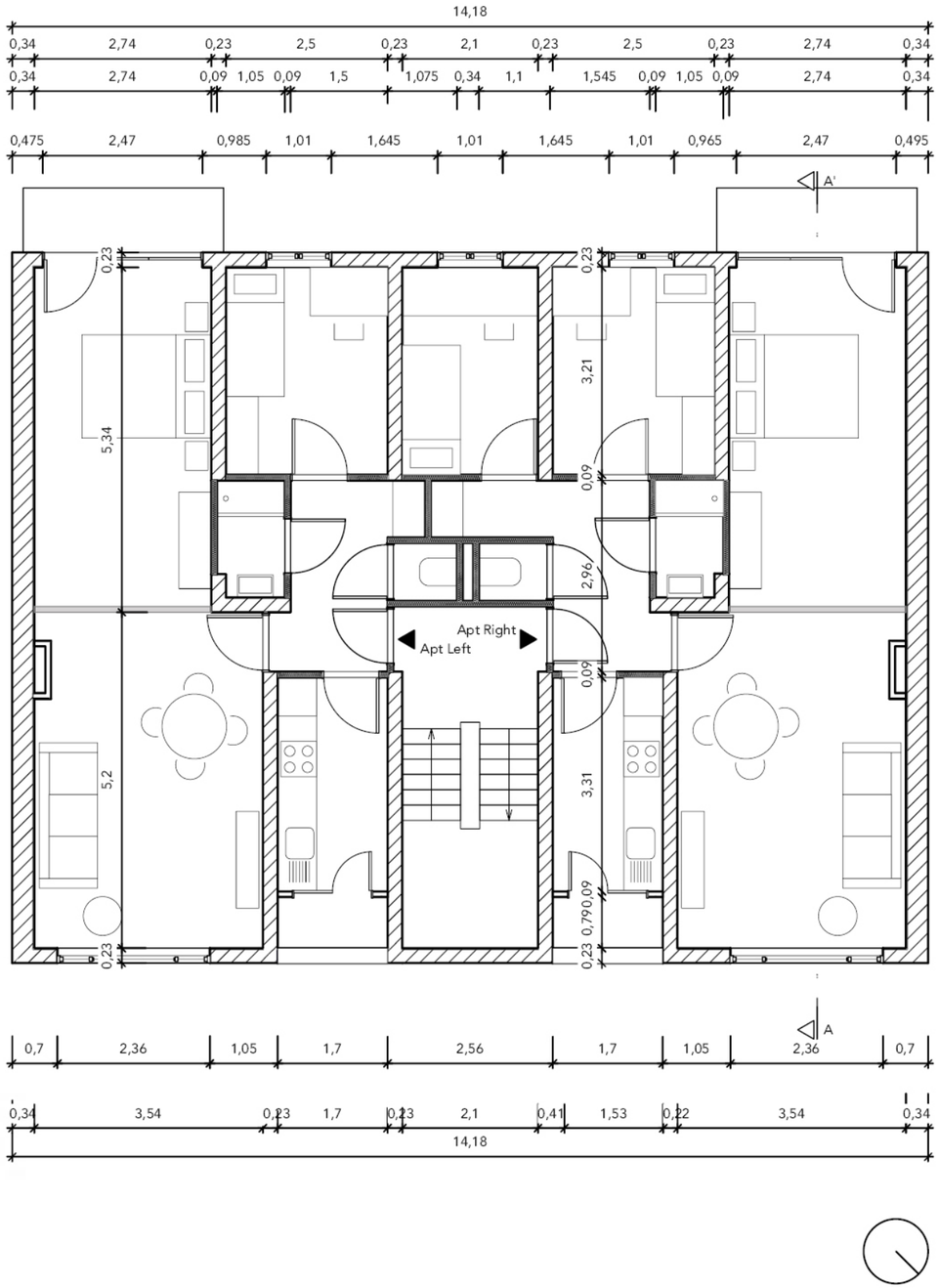


Neighbourhood Map

Gijsingstraat Porch Houses

Case study building

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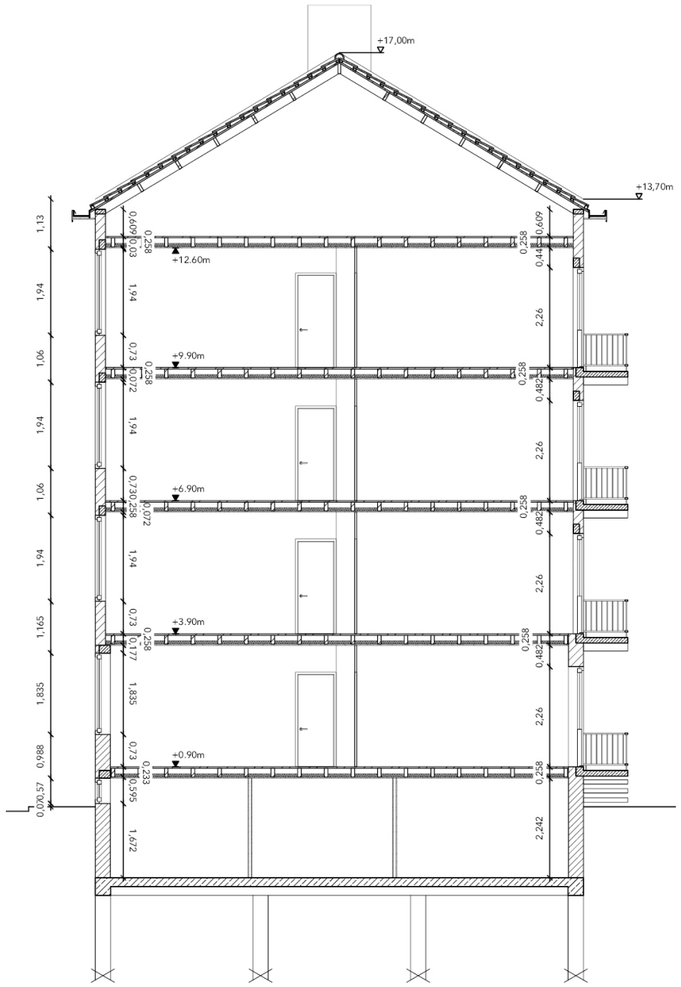
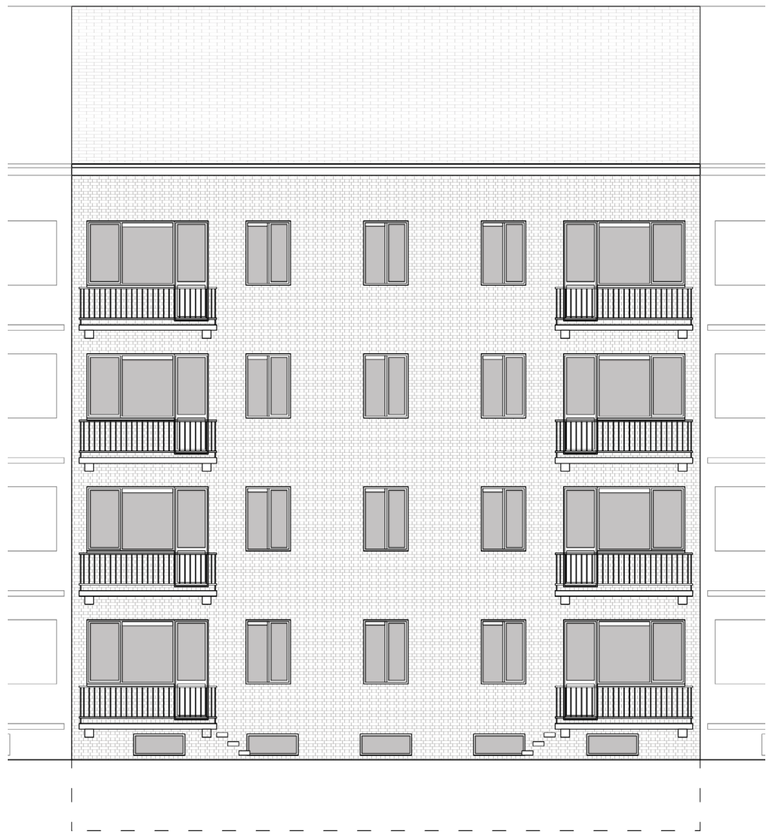
0,34 2,74 0,23 2,5 0,23 2,1 0,23 2,5 0,23 2,74 0,34
0,34 2,74 0,09 1,05 0,09 1,5 1,075 0,34 1,1 1,545 0,09 1,05 0,09 2,74 0,34
0,475 2,47 0,985 1,01 1,645 1,01 1,645 1,01 0,965 2,47 0,495
A'
0,23
5,34
3,21
0,09
2,96
Apt Right
Apt Left
0,09
5,2
3,31
0,23 0,79 0,09
0,23
A
0,7 2,36 1,05 1,7 2,56 1,7 1,05 2,36 0,7
0,34 3,54 0,23 1,7 0,23 2,1 0,41 1,53 0,22 3,54 0,34
14,18

Case Study

North-East





South-West

Preliminary

Design & Planning

Performance

Cost-Benefit

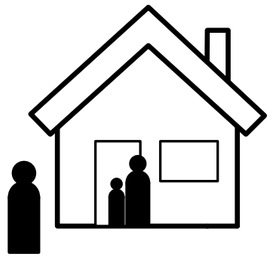
Decision-making

Preliminary

Stakeholders

Occupant/Resident

Owner/Investor



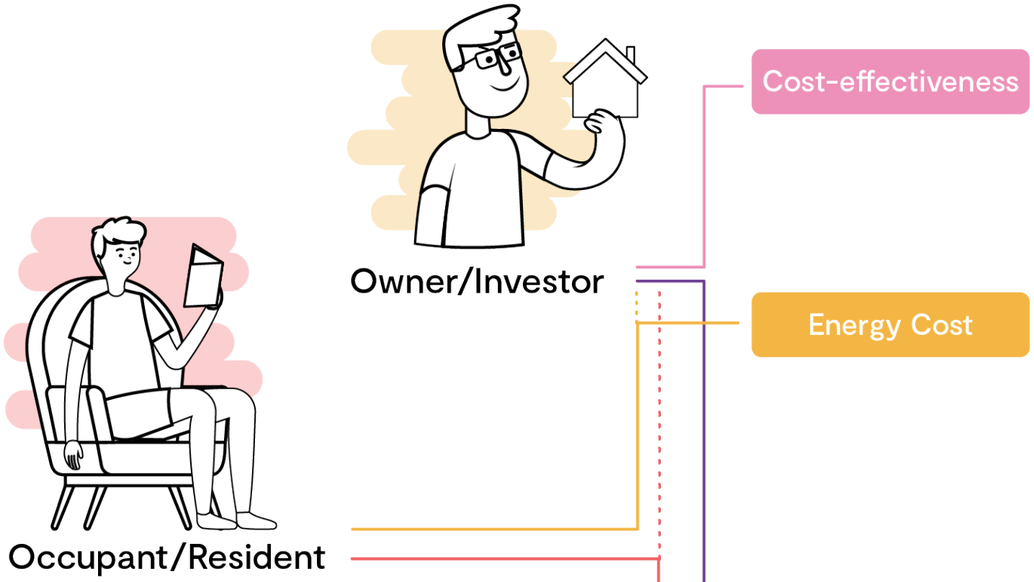
Private Rental

Owner-occupied

MIX

Preliminary

Renovation interest of stakeholders



Preliminary

Hazard loss connection to renovation interest?

Occupant/Resident

Owner/Investor

Cost-effectiveness

Energy Cost

Health

Comfort

Regulation

GHG emissions

Thermal Comfort

Cooling Energy

Environmental Impact

Preliminary

Hazard loss connection to renovation interest?

Occupant/Resident

Owner/Investor

policymaker

Cost-effectiveness

Energy Cost

Health

Comfort

Regulation

GHG emissions

Thermal Comfort

Cooling Energy

Environmental Impact

Preliminary

What are the renovation objectives?

Objective	*Criteria*
Reduce Energy Cost	Heating Efficiency
	Cooling Efficiency
Increase Thermal Comfort	Mitigate Overheating
Minimize Carbon Footprint	Reduce Emissions

Preliminary

What are the renovation objectives?

Objective

Criteria

Reduce Energy Cost

Heating Efficiency

Cooling Efficiency

Increase Thermal Comfort

Mitigate Overheating

Minimize Carbon Footprint

Reduce Emissions

Financial Feasibility

=> cost-recovery

Preliminary

Diagnosis - Heating Efficiency

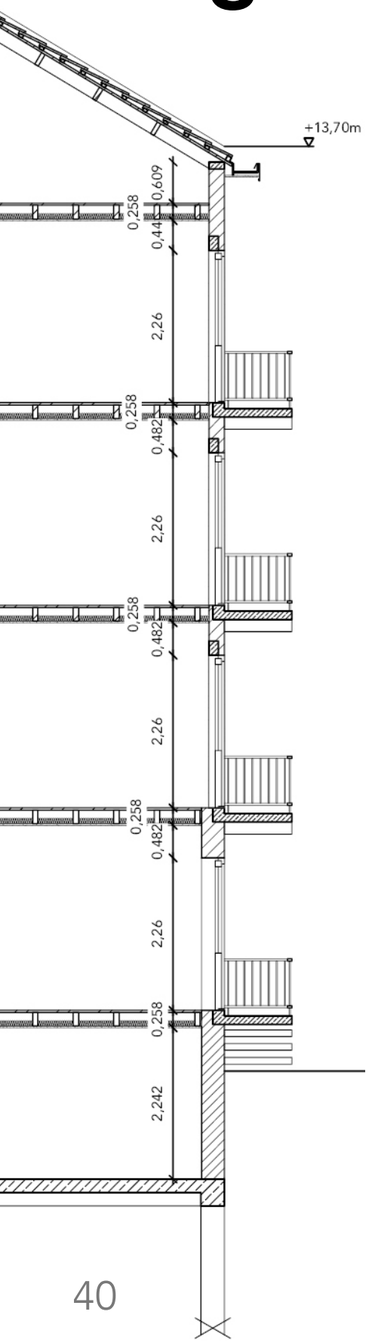
Apartment Floor	*Energy Label*	*Heating Demand*
03 Third Floor	G	312 kWh/m²
	F	265.26 kWh/m²
	E	-
	D	-
02 Second Floor	3x D	192.42 kWh/m²
	C	149,75 kWh/m²
01 First Floor	C	141.65 kWh/m²
	D	-
	E	-
00 Ground floor	4x C	173.17 kWh/m²

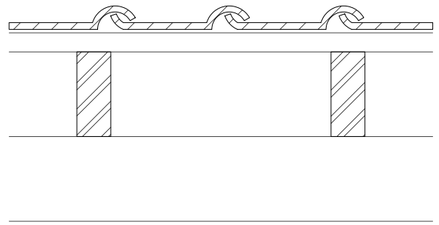
Average value **205.33 kWh/m²**

Up-to standard: **50,8 kWh/m²**

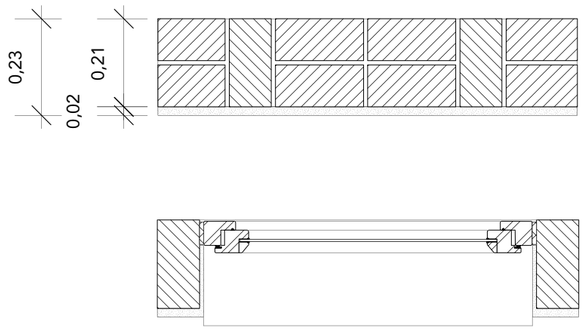
Preliminary

Diagnosis



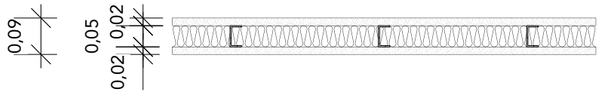


Uninsulated Timber
Joist Roof

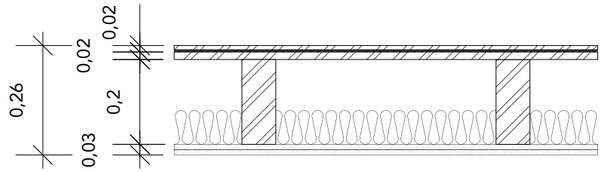


External Wall Type 230
210 mm brick masonry
20 mm cement plaster

Single-glazing timber framed



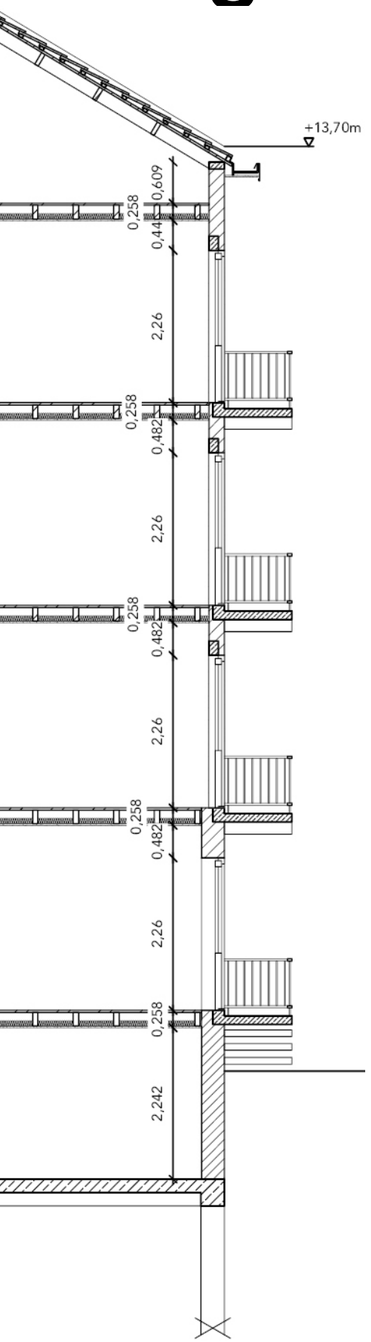
Interior Wall Type 90

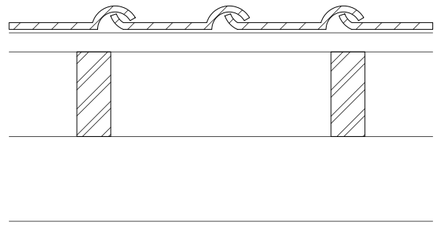


Interior Floor 258

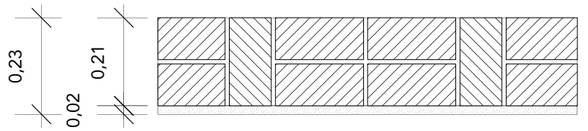
Preliminary

Diagnosis





Uninsulated Timber
Joist Roof



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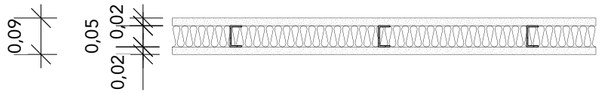
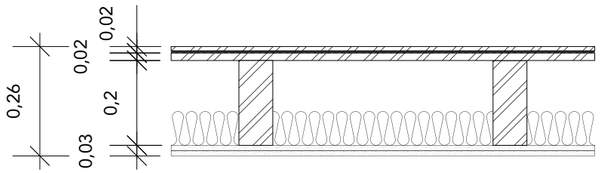


Interior Wall Type 90



Interior Floor 258

Preliminary

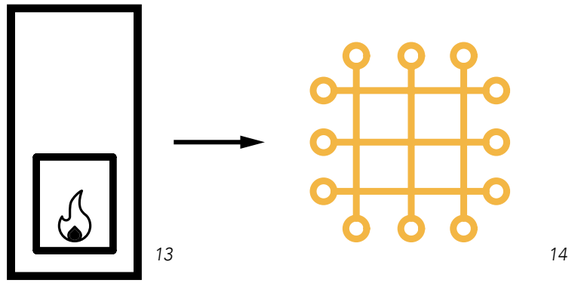
Heating Retrofitting Solutions

Active Solutions

Passive Solutions

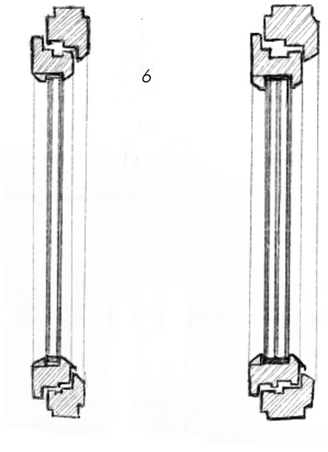
Preliminary

Heating Retrofitting Solutions



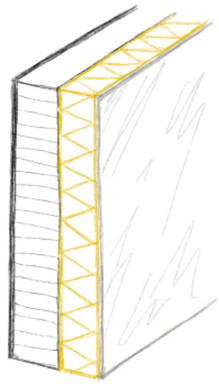
13 14

Heating source/system
- District Heating

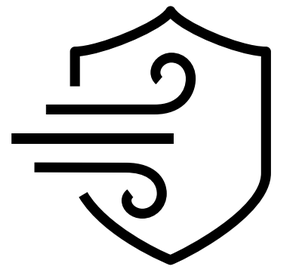


6

Double/ Triple Glazing



Insulation



15

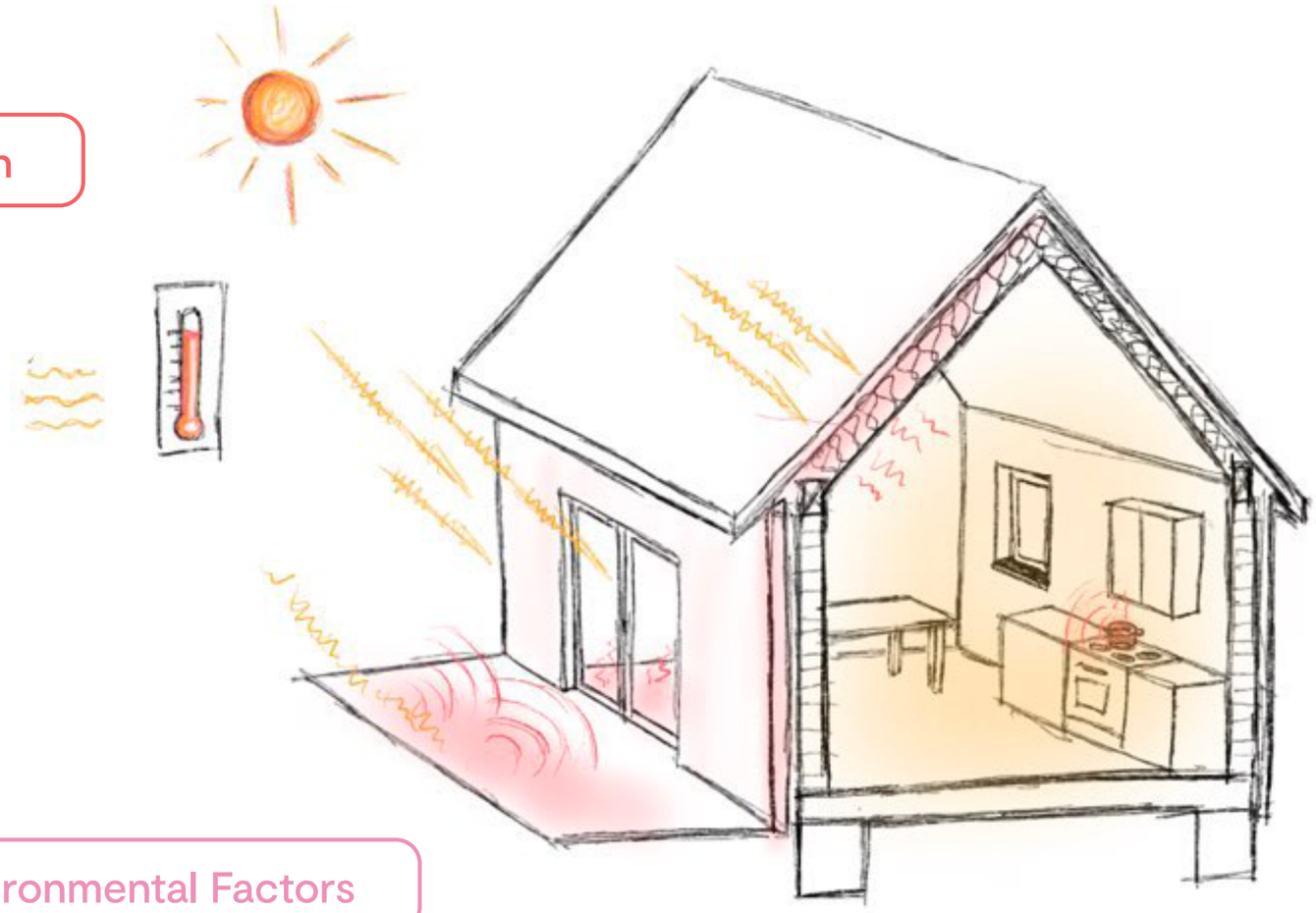
Air-tightening

Preliminary

Overheating Sources

Solar Radiation

Outdoor Temperature

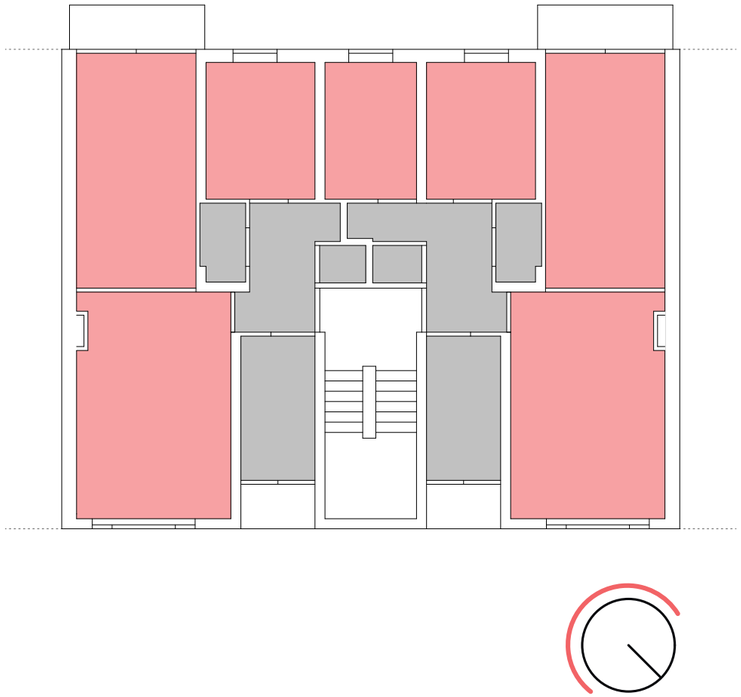


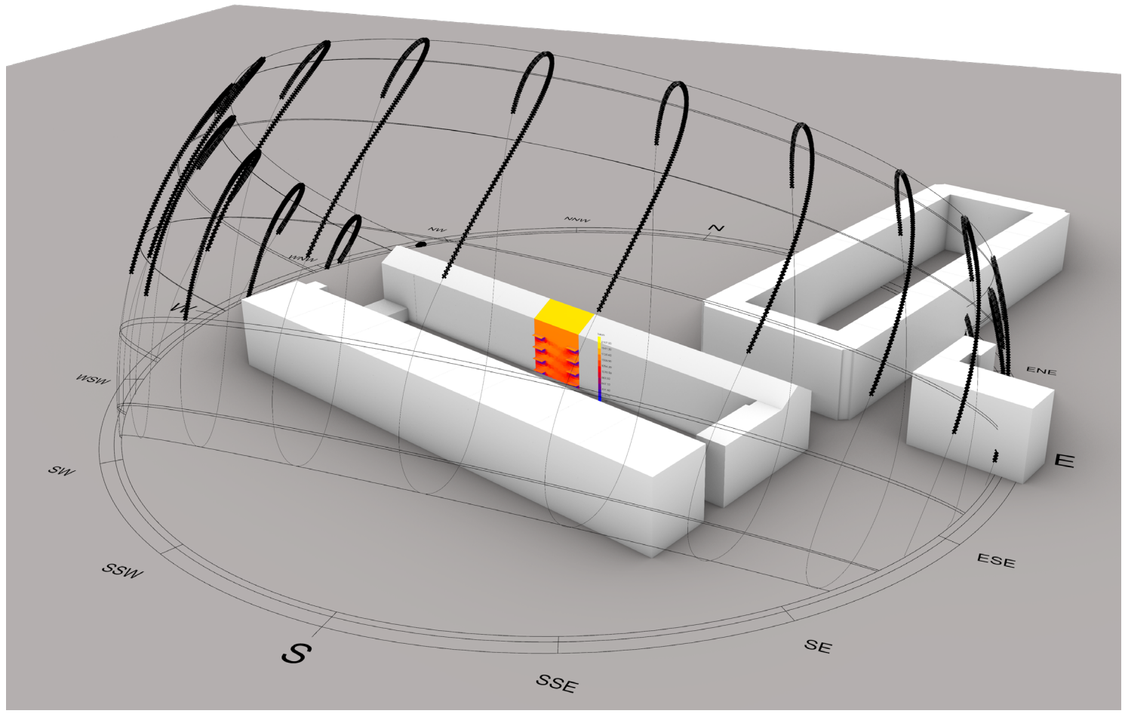
Internal Gains

Environmental Factors

Preliminary

Diagnosis - Sun Exposure





32% window to wall ratio

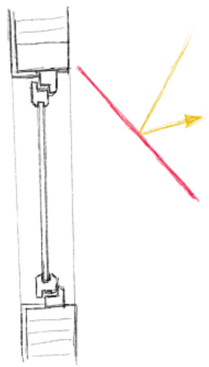
Overheating Mitigation

Heat Protection

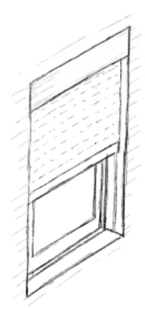
Heat Control

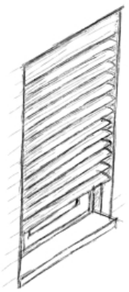
Heat Removal

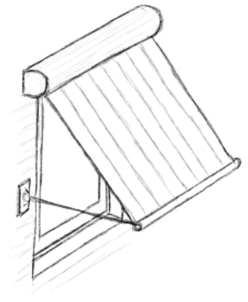
12

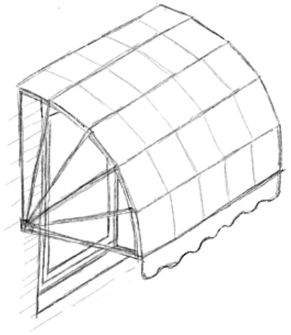


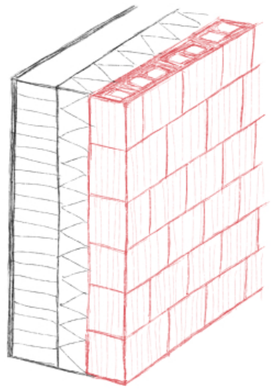
Shading



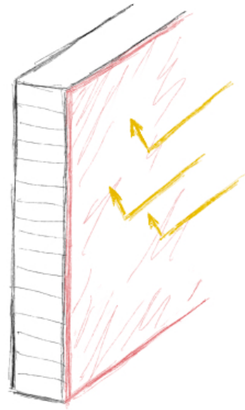




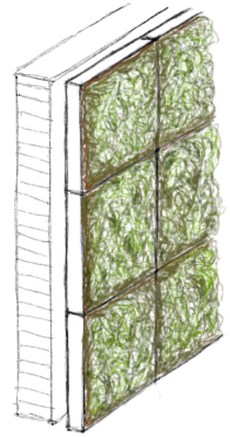




Thermal Mass

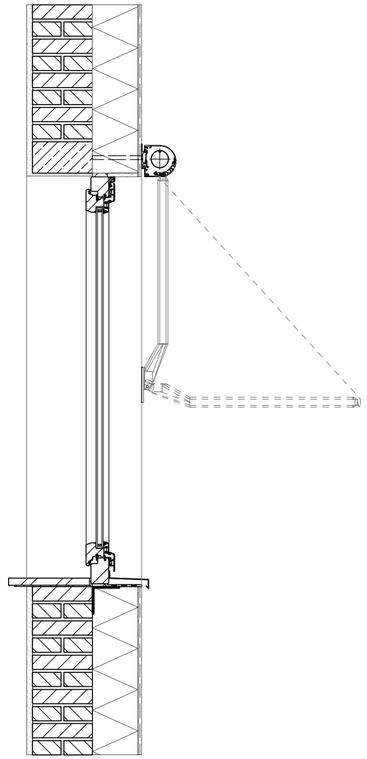


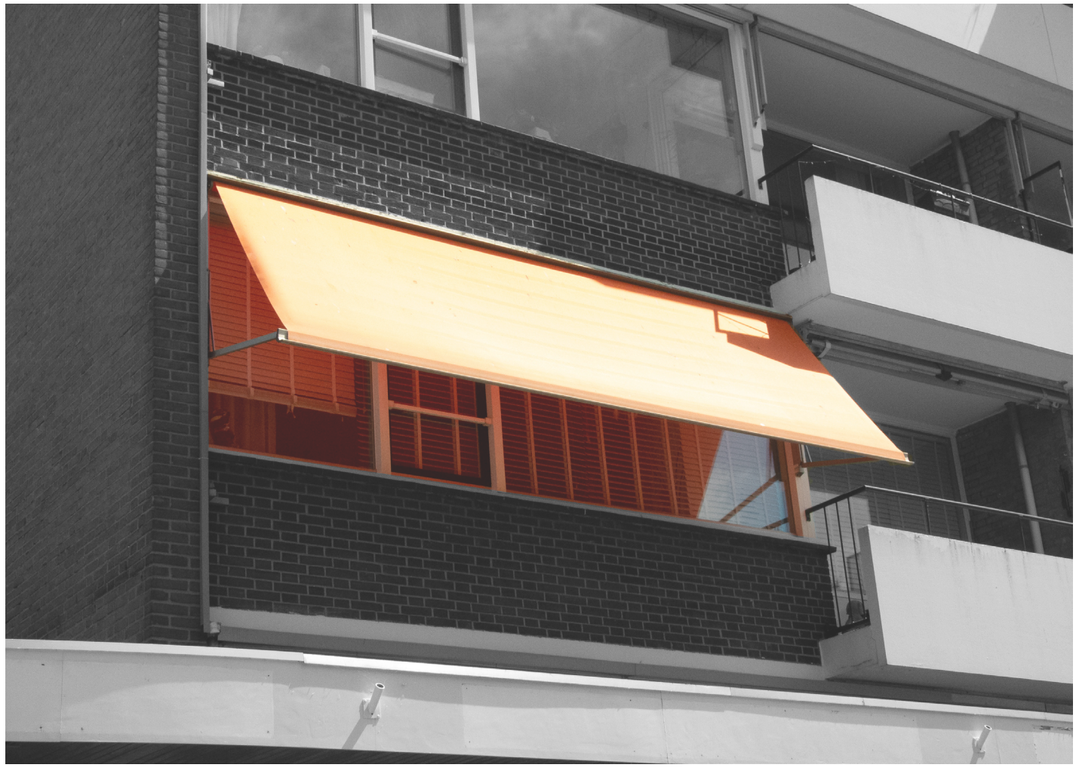
High-Albedo



Green Facade

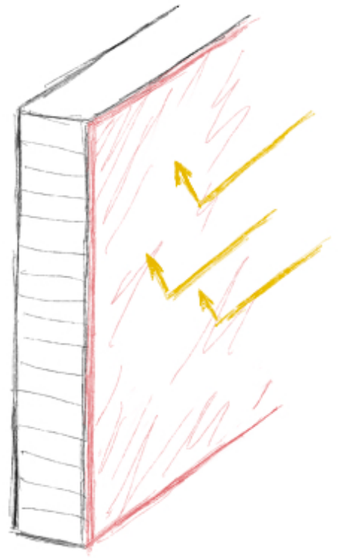
Shading





Renovation Design

High-Albedo Facade



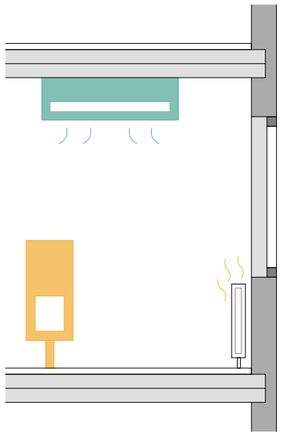
17

Intervention Depth

Simple	District Heating	Shading	White Paint
Medium	Double-Glazing		
Deep	Exterior Insulation		

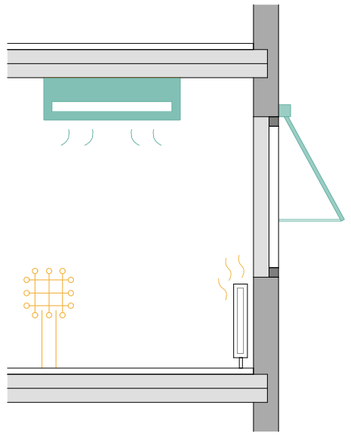
Renovation Design

BASELINE



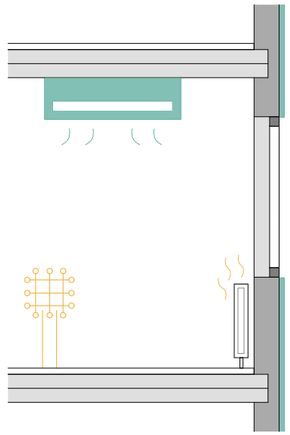
Air-condition
Gas Boiler
No insulation
No shading
Single glazing

SIMPLE 01 - SHADING



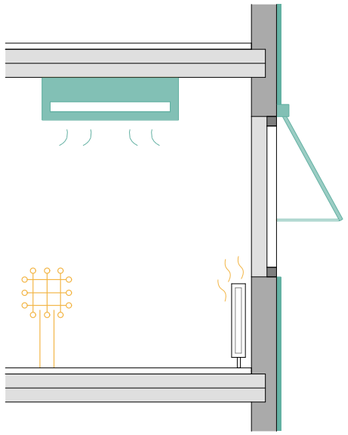
Air-condition
District-Heating
No insulation
Exterior shading

SIMPLE 02 - PAINT



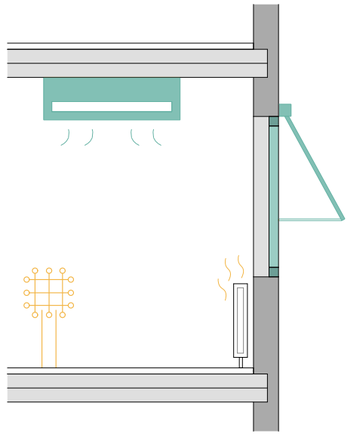
Air-condition
District-Heating
No insulation
No shading
White paint

SIMPLE 04 COMBINATION



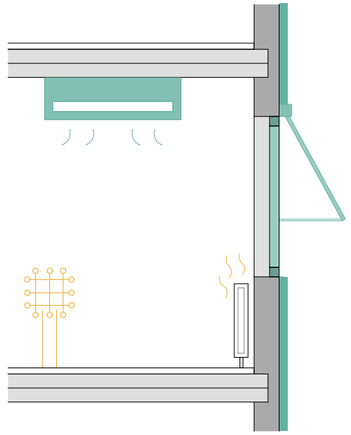
Air-condition
District-Heating
No insulation
Exterior shading
White paint

MEDIUM + SHADING



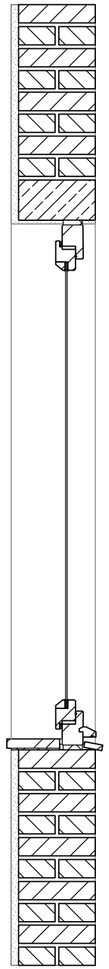
Air-condition
District-Heating
No insulation
Exterior shading
Double glazing

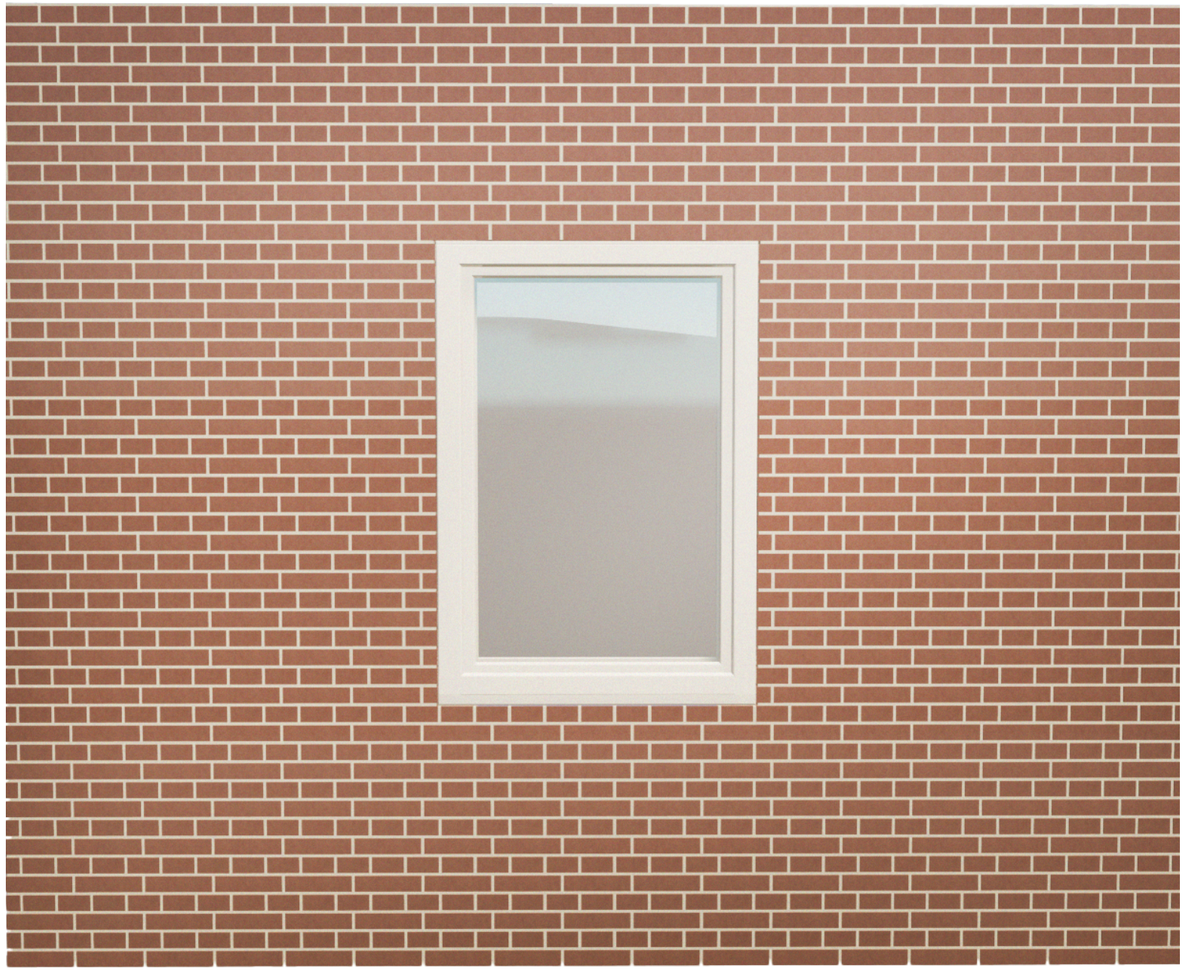
DEEP + SHADING & PAINT



Air-condition
District-Heating
Insulation-stucco wall
Exterior shading
Double glazing
White paint

Baseline



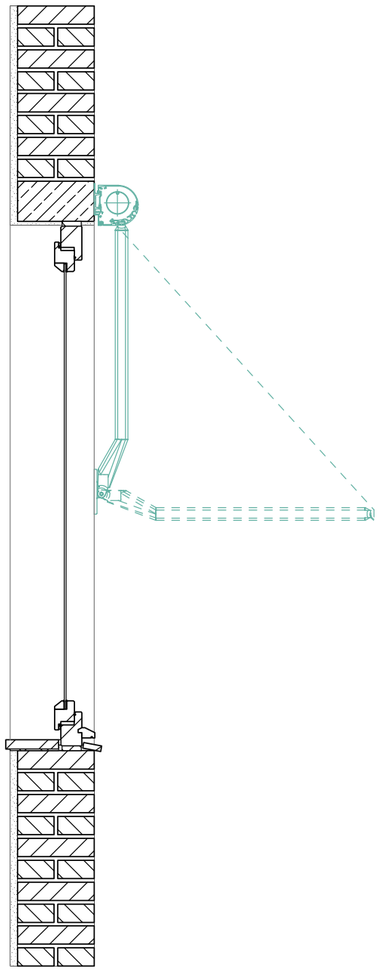


Air-conditioning
Gas Boiler

No insulation
Single glazing
No shading

Renovation Design

Simple Shading

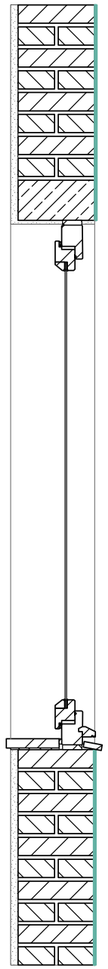


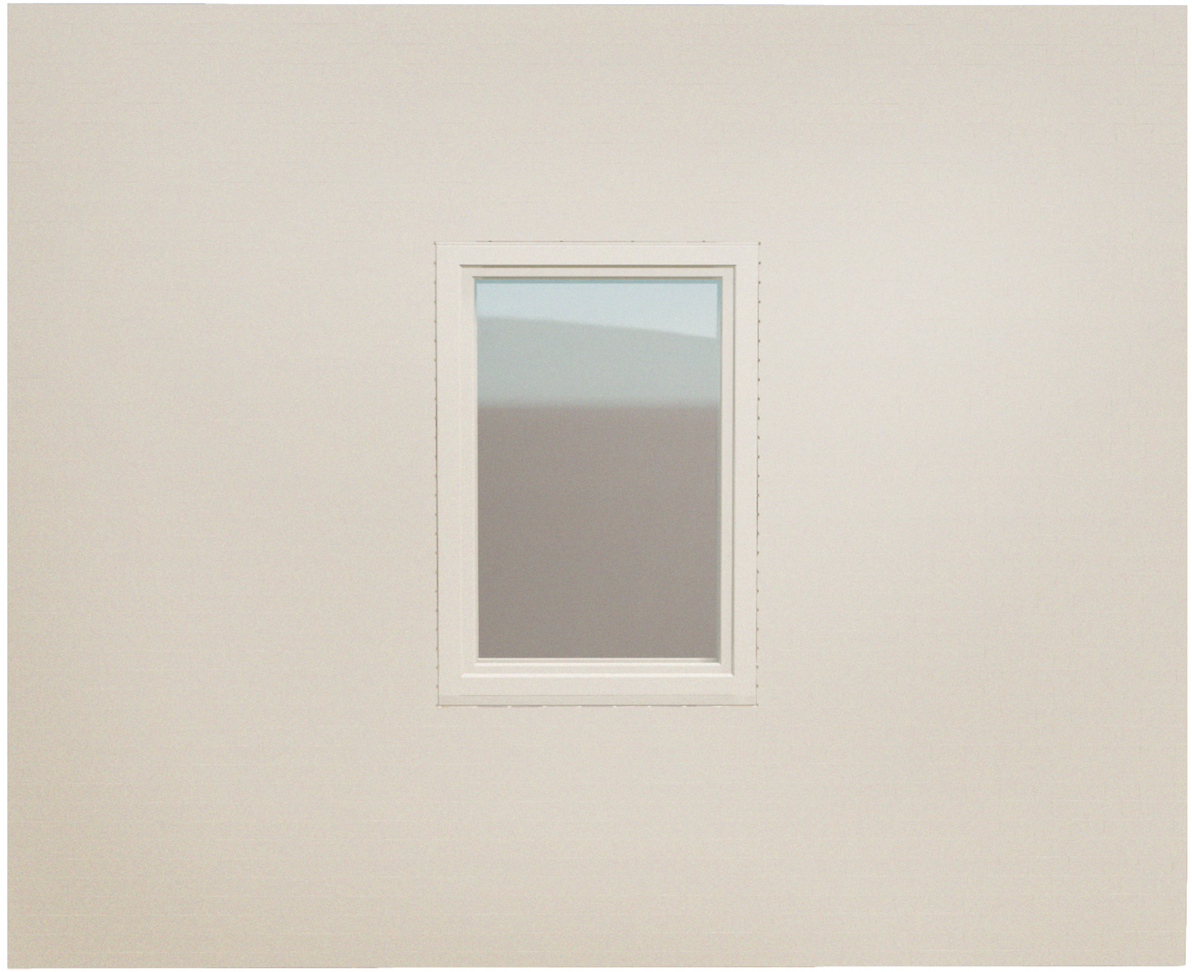
Air-conditioning
District heating

No insulation
Single glazing
Shading

Renovation Design

Simple Paint

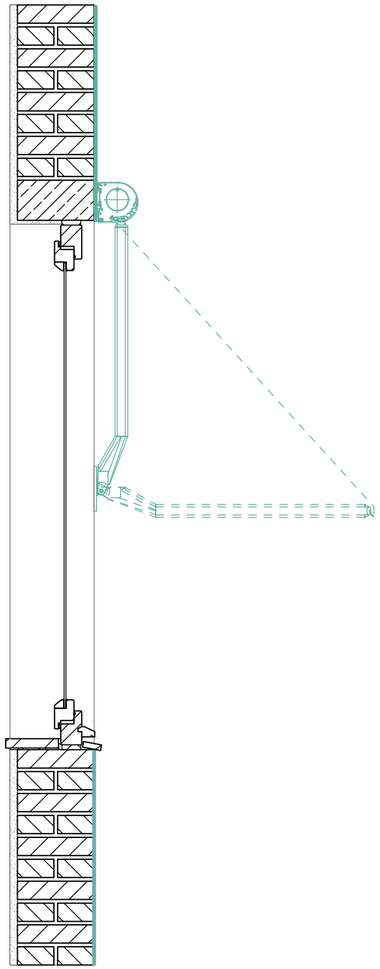




Air-conditioning
District heating
No insulation
White paint
Single glazing
No shading

Renovation Design

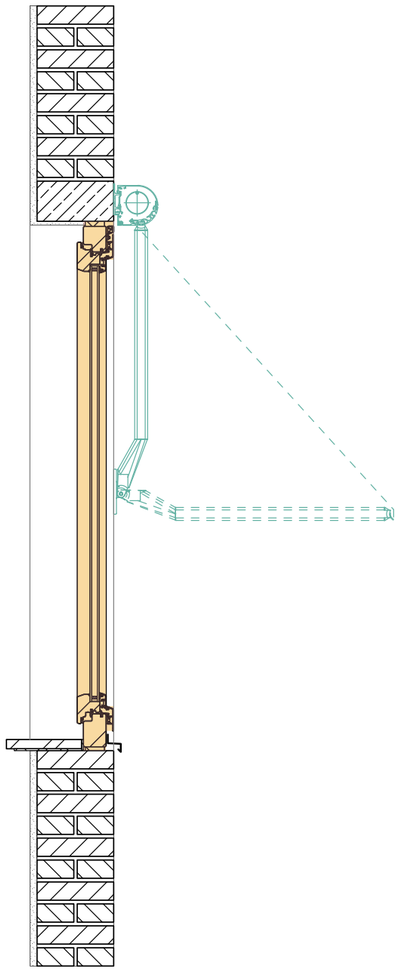
Simple Combination



Air-conditioning
District heating
No insulation
White paint
Single glazing
Shading

Renovation Design

Medium shading

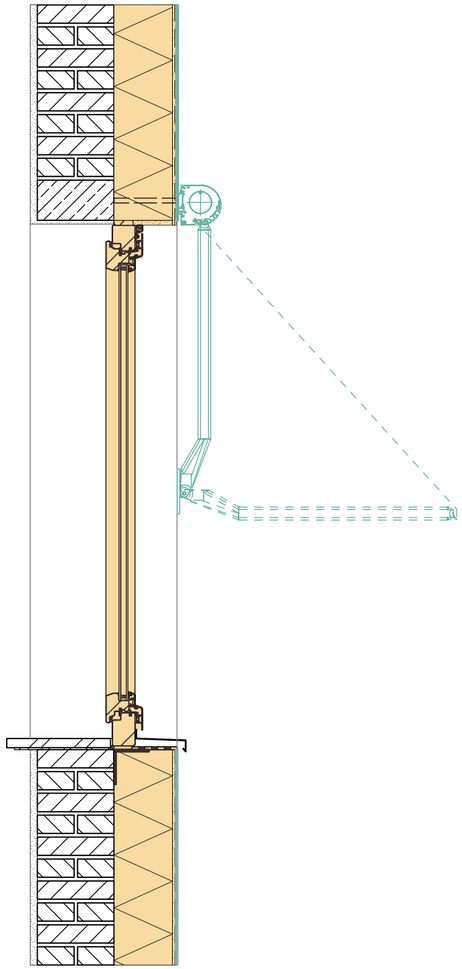


Air-conditioning
District heating

No insulation
Double glazing
Shading

Renovation Design

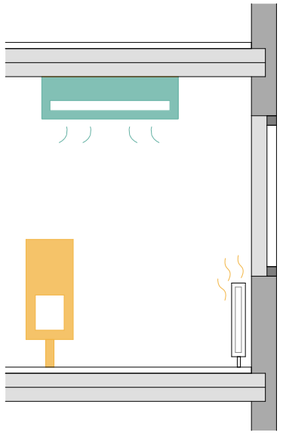
Deep combination



Air-conditioning
District heating
Exterior insulation
White paint
Double glazing
Shading

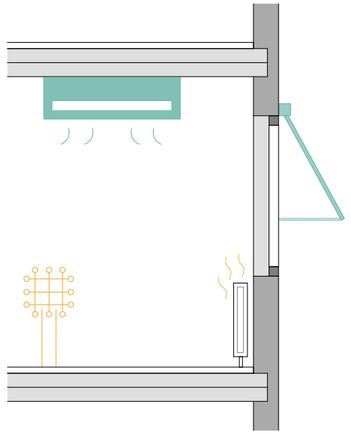
Renovation Design

BASELINE



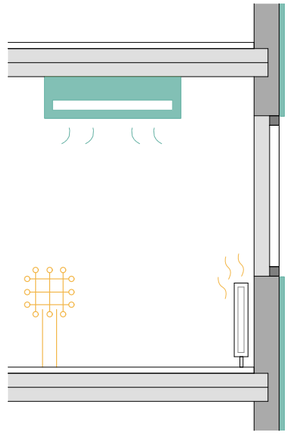
Air-condition
Gas Boiler
No insulation
No shading
Single glazing

SIMPLE 01 - SHADING



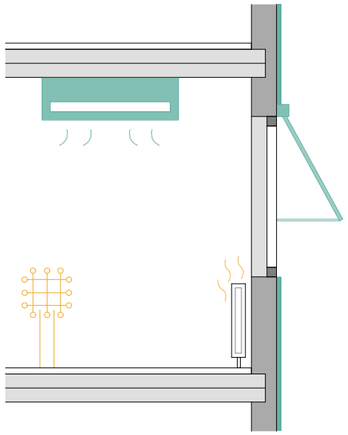
Air-condition
District-Heating
No insulation
Exterior shading

SIMPLE 02 - PAINT



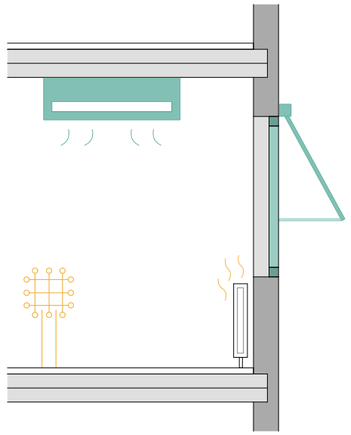
Air-condition
District-Heating
No insulation
No shading
White paint

SIMPLE 04 COMBINATION



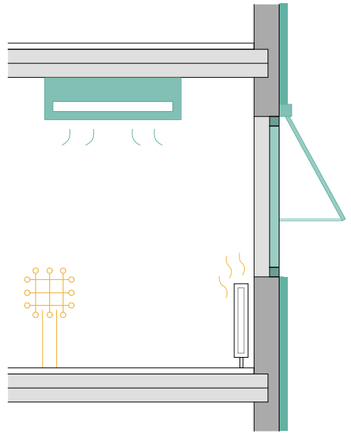
Air-condition
District-Heating
No insulation
Exterior shading
White paint

MEDIUM + SHADING



Air-condition
District-Heating
No insulation
Exterior shading
Double glazing

DEEP + SHADING & PAINT



Air-condition
District-Heating
Insulation-stucco wall
Exterior shading
Double glazing
White paint

Preliminary

Design & Planning

Performance

Cost-Benefit

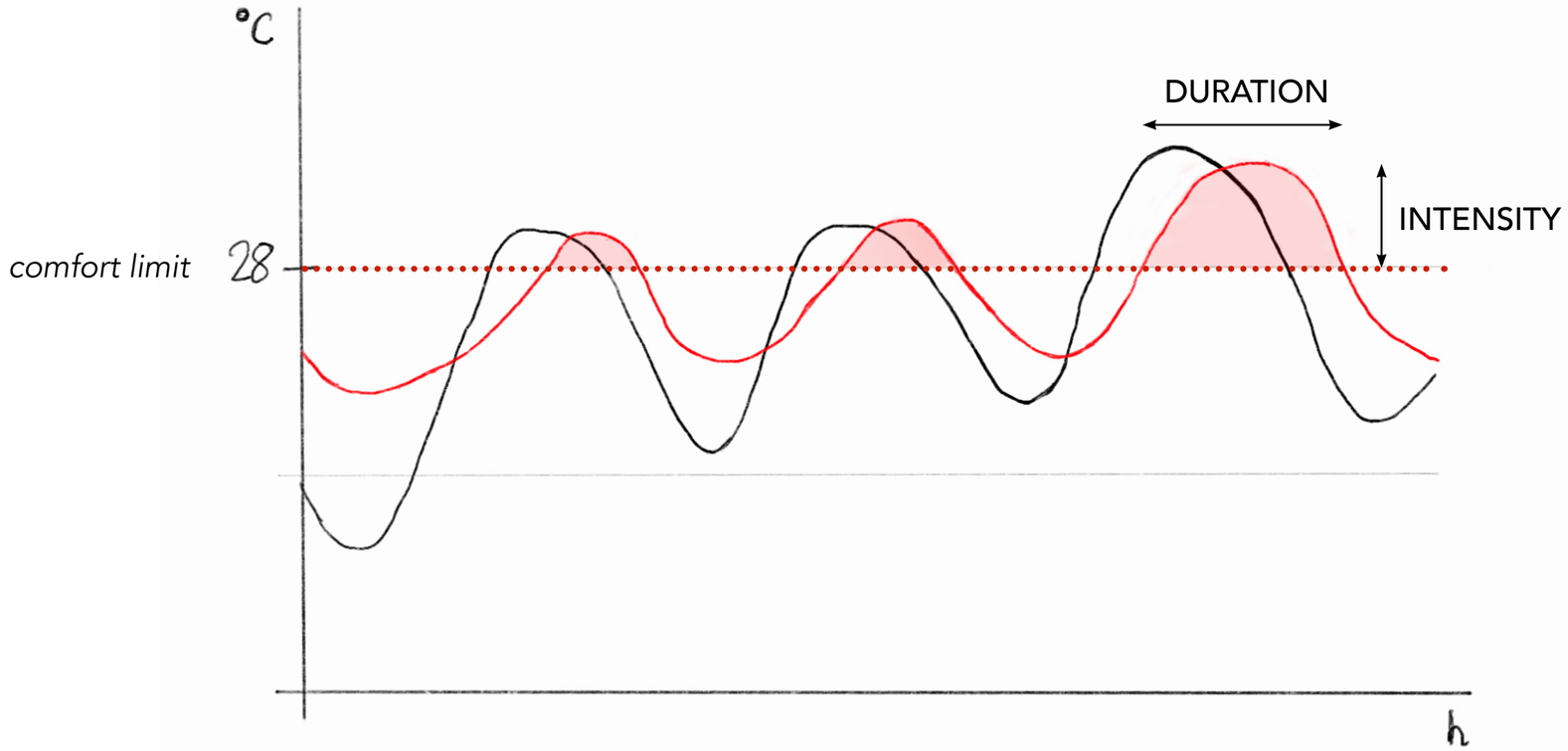
Decision-making

Performance Analysis

Quantify how?

Objective	*Criteria*	*Key Performance Indicator*
Reduce Energy Cost	Heating Efficiency	Energy Use Intensity
	Cooling Efficiency	
Increase Thermal Comfort	Mitigate Overheating	???
Minimize Carbon Footprint	Reduce Emissions	Carbon Emission Intensity

Resiliences relates to duration and intensity



indoor temperature

outdoor temperature

Performance Analysis

Heat Resilience Metrics

Overheated Hours	Degree Hours	Overheating Escalation Factor
Counting Hours >28°C	Counting Hours & Intensity >28°C	Counting Hours & Intensity >28°C divided by outdoor climate

Performance Analysis

Key Performance Indicator

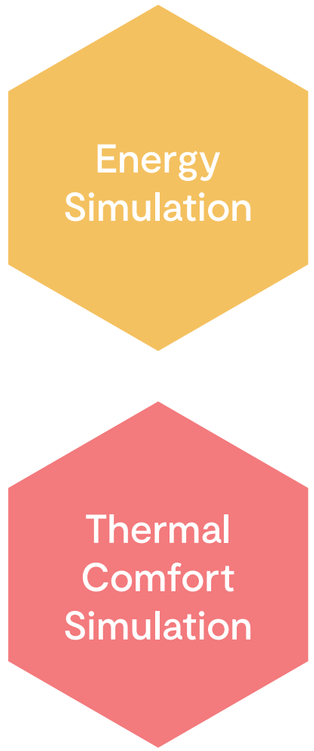
Energy Use Intensity

Carbon Emission Intensity

Overheated Hours

Degree Hours

Degree Hours



Performance Analysis

Quantification needs a climate reference

Key Performance Indicator

Energy Use Intensity

Carbon Emission Intensity

Energy Simulation

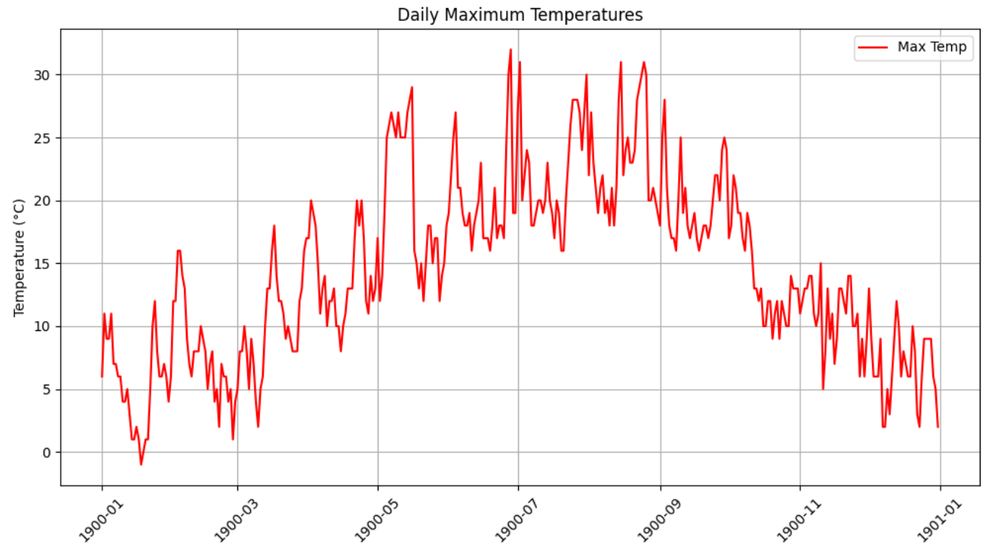
Overheated Hours

Degree Hours

Degree Hours

Thermal Comfort Simulation

Climate Reference



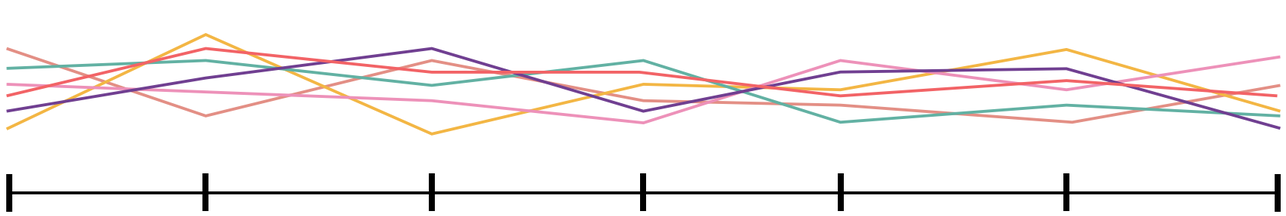
Cost for **heat hazard long term**

Climate uncertainty in cost-benefit

Outline **extreme scenarios** in cost-benefit

Informing renovation design

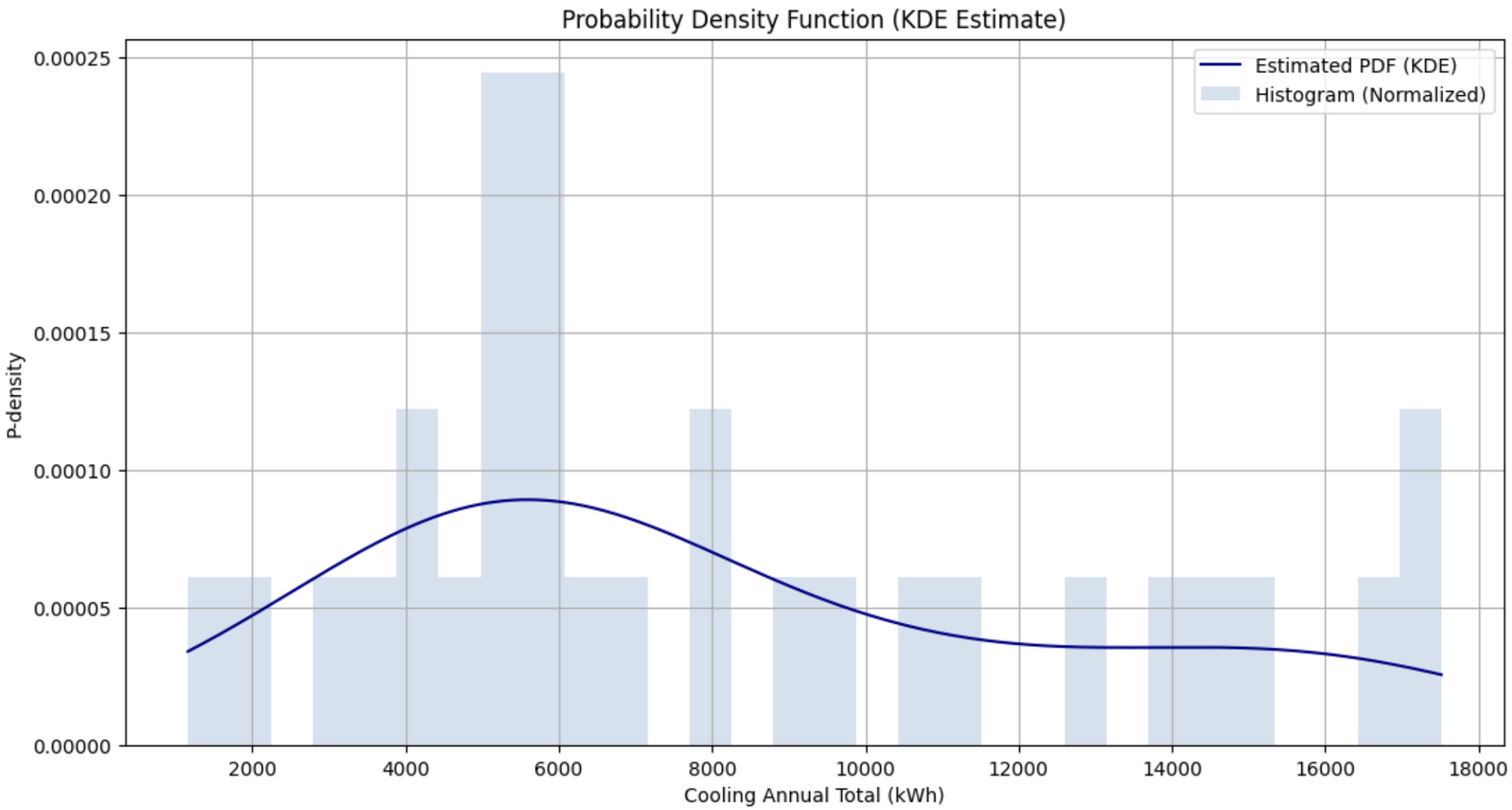
Variability of thermal performance



*Historical years 1995-2024

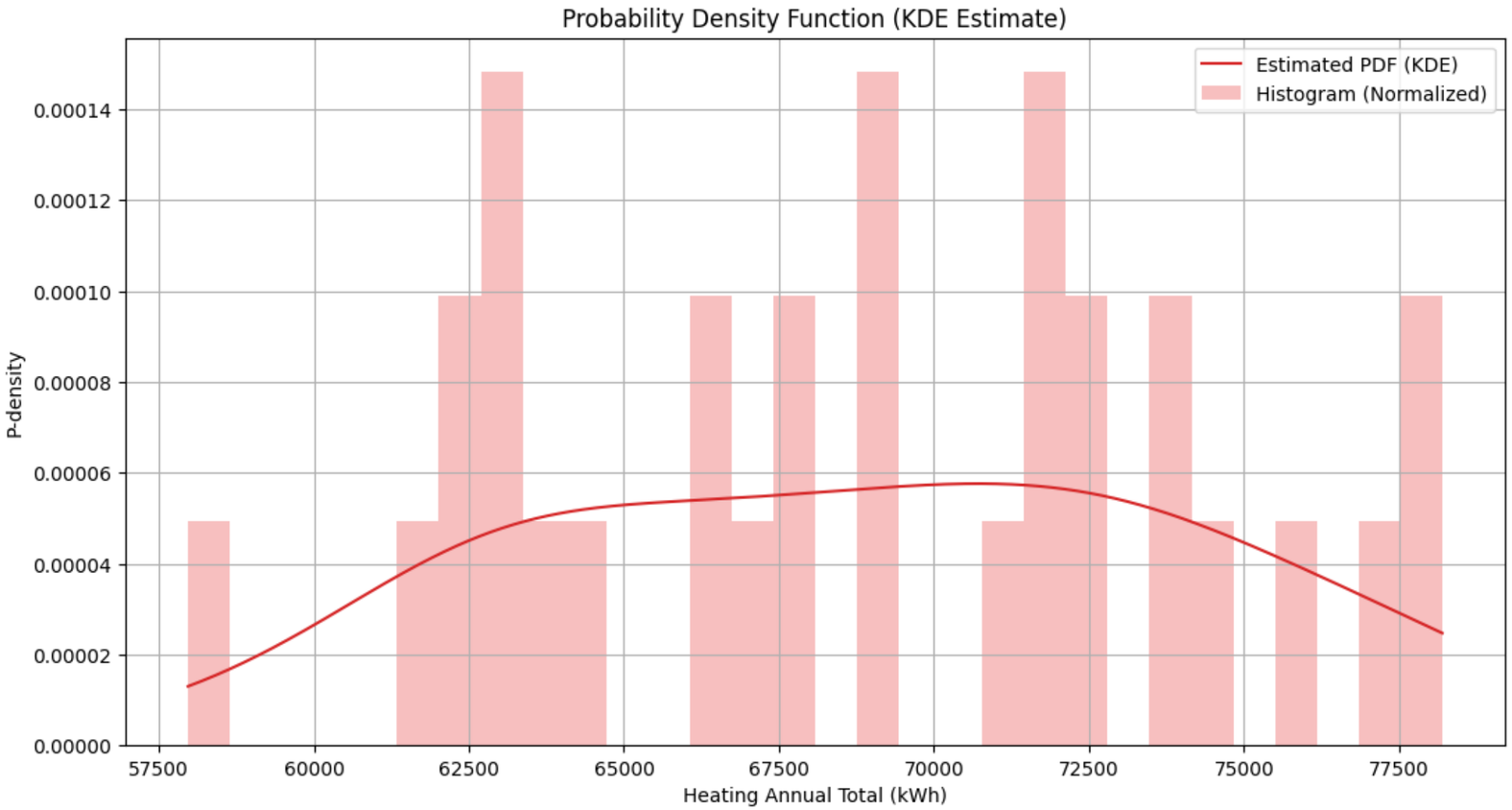
Performance Analysis

How does annual energy demand variate?



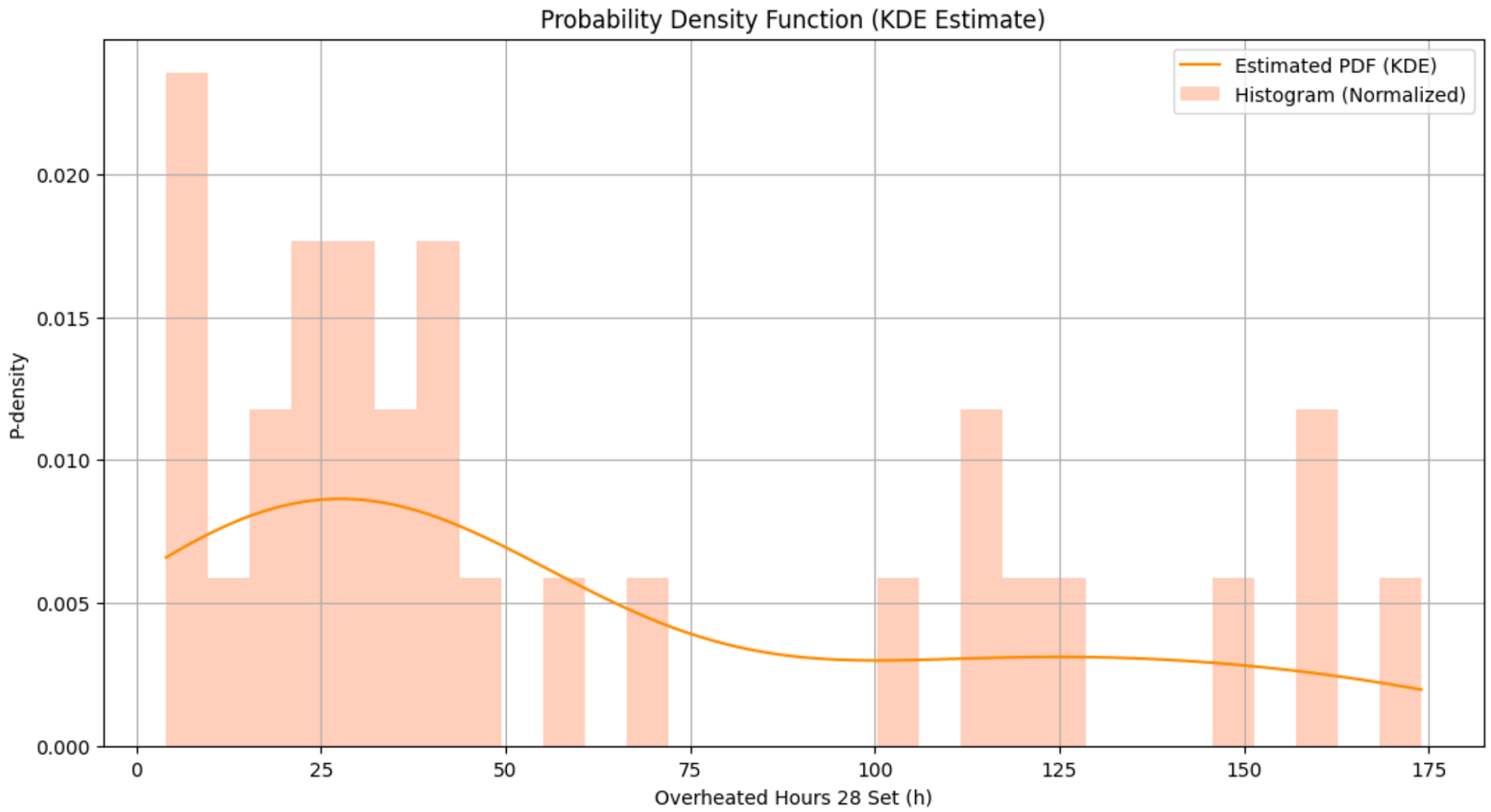
Performance Analysis

Heating demand distribution



Performance Analysis

Distribution of overheating



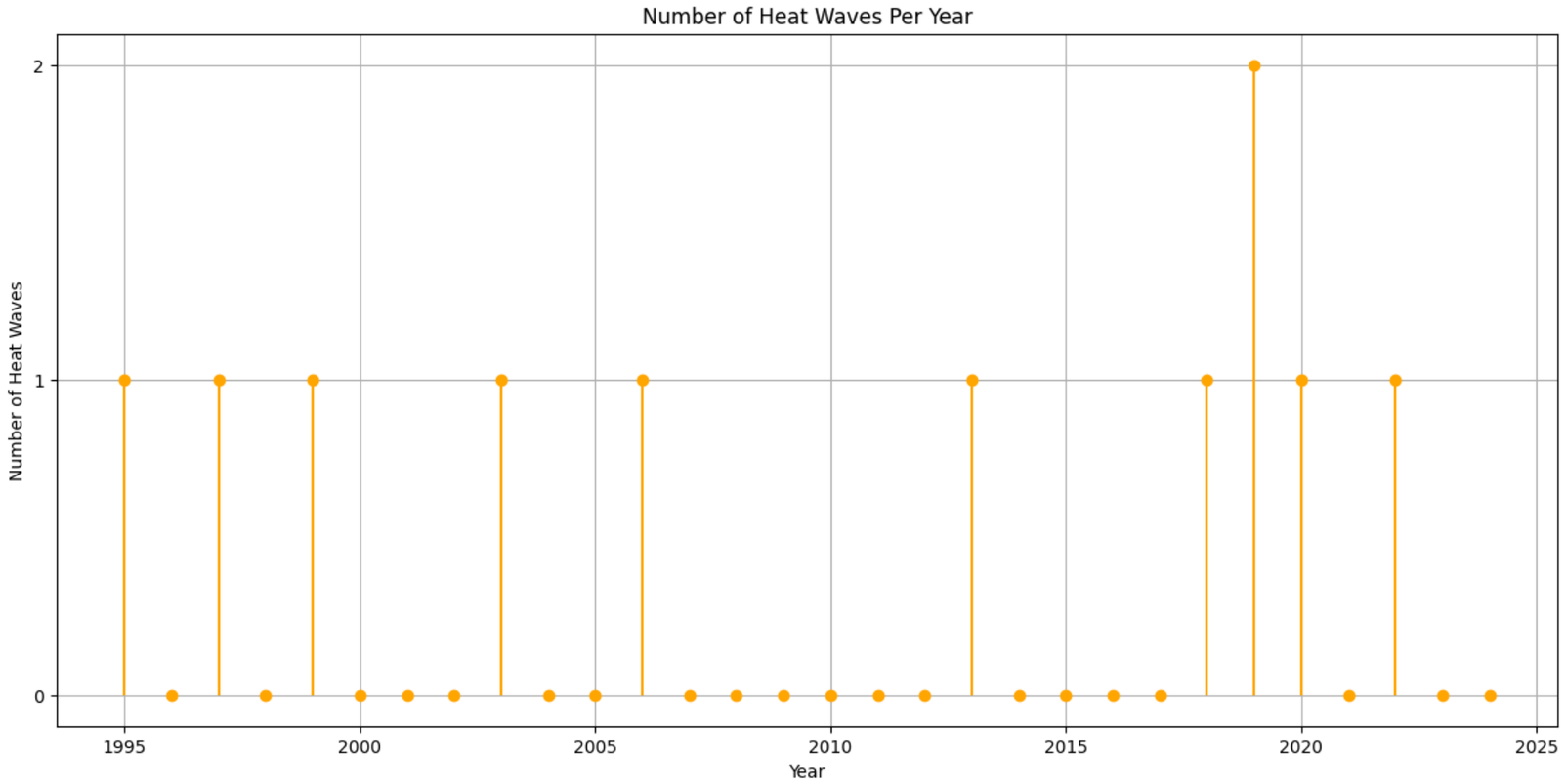
What is now considered extreme?

KNMI Heat wave definition

a heat wave is a period
of at least 5 days with a daily maximum
temperature above 25°C
including at least 3 days above 30°C.

Performance Analysis

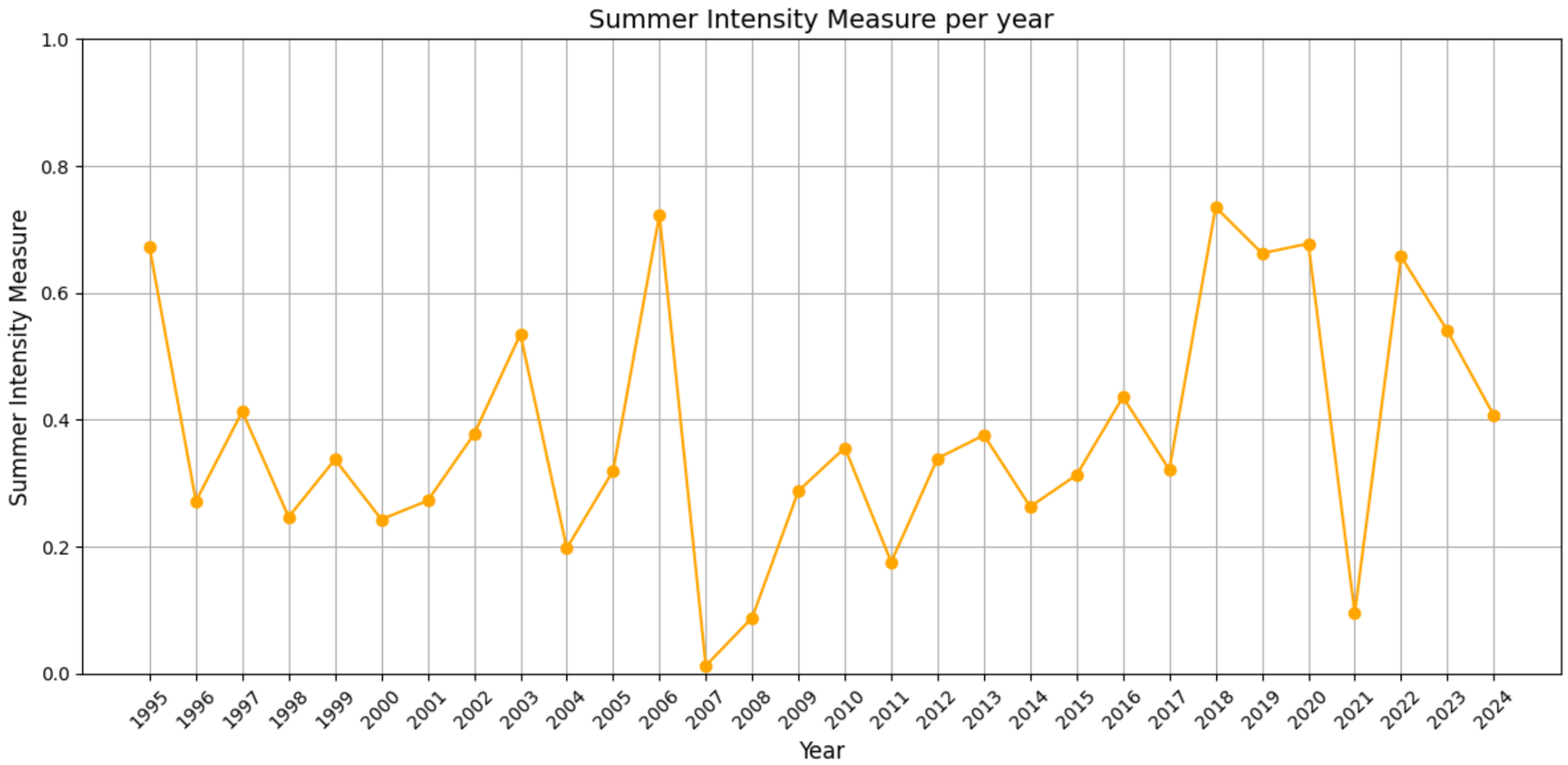
Past Heat Waves



>5 days >25°C daily maximum temperature
>3 days >30°C daily maximum temperature

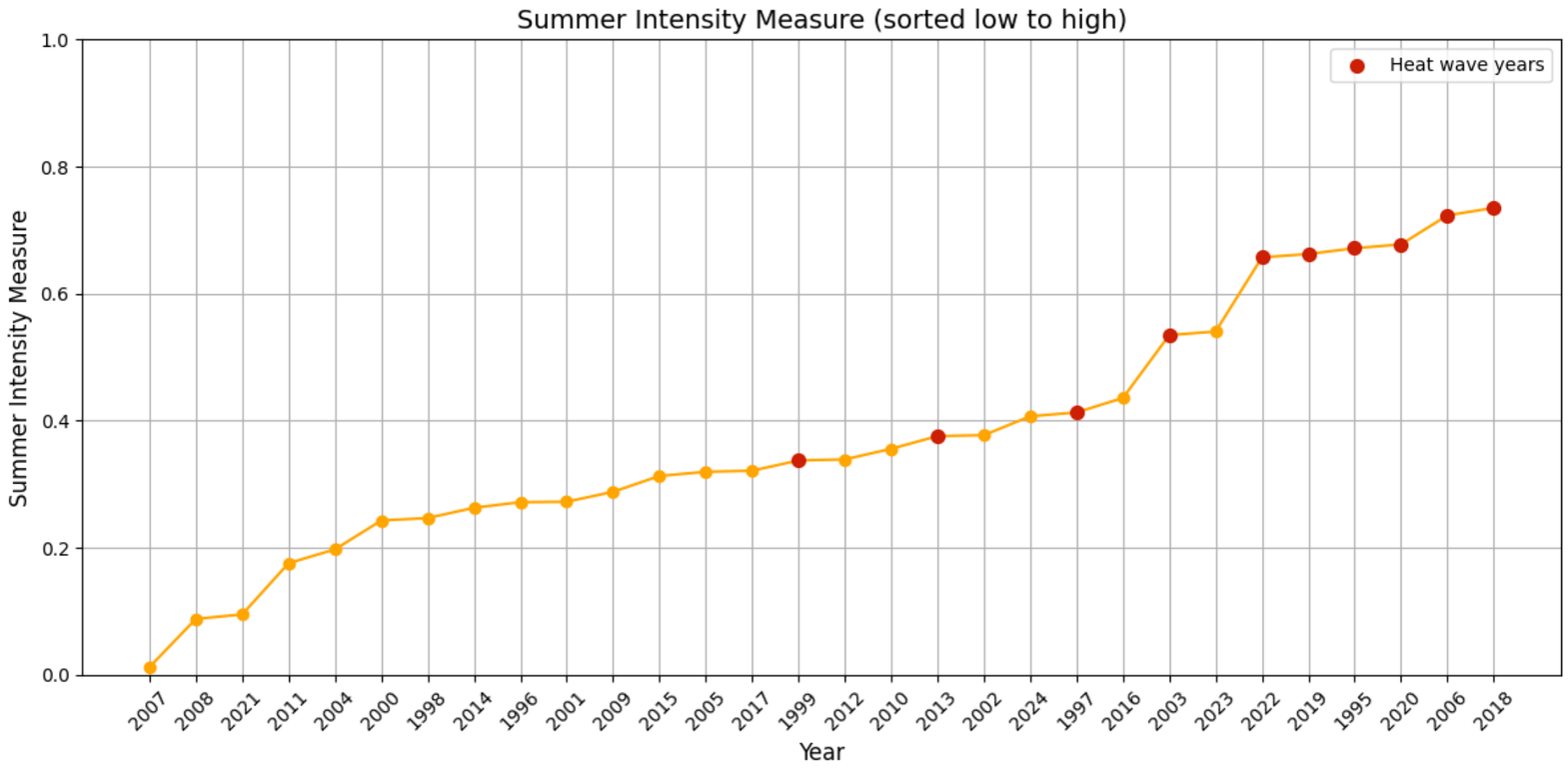
Performance Analysis

Past Heat Waves



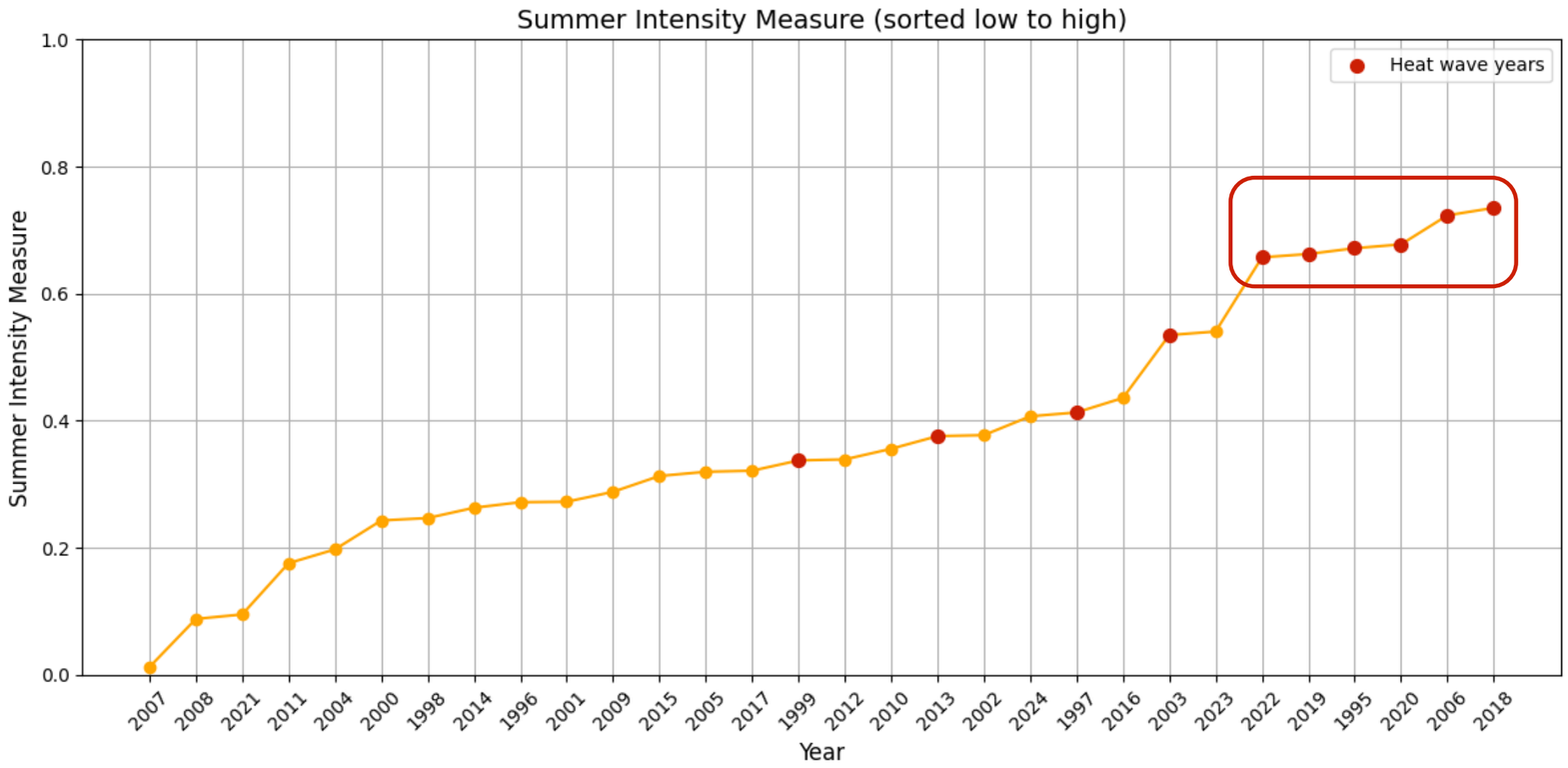
Performance Analysis

Summer heat



Performance Analysis

Summer heat



The impact of heat extremes

1995

2006

2018

2019

2020

2022

Performance Analysis

Heat Wave Contribution - Energy

1995

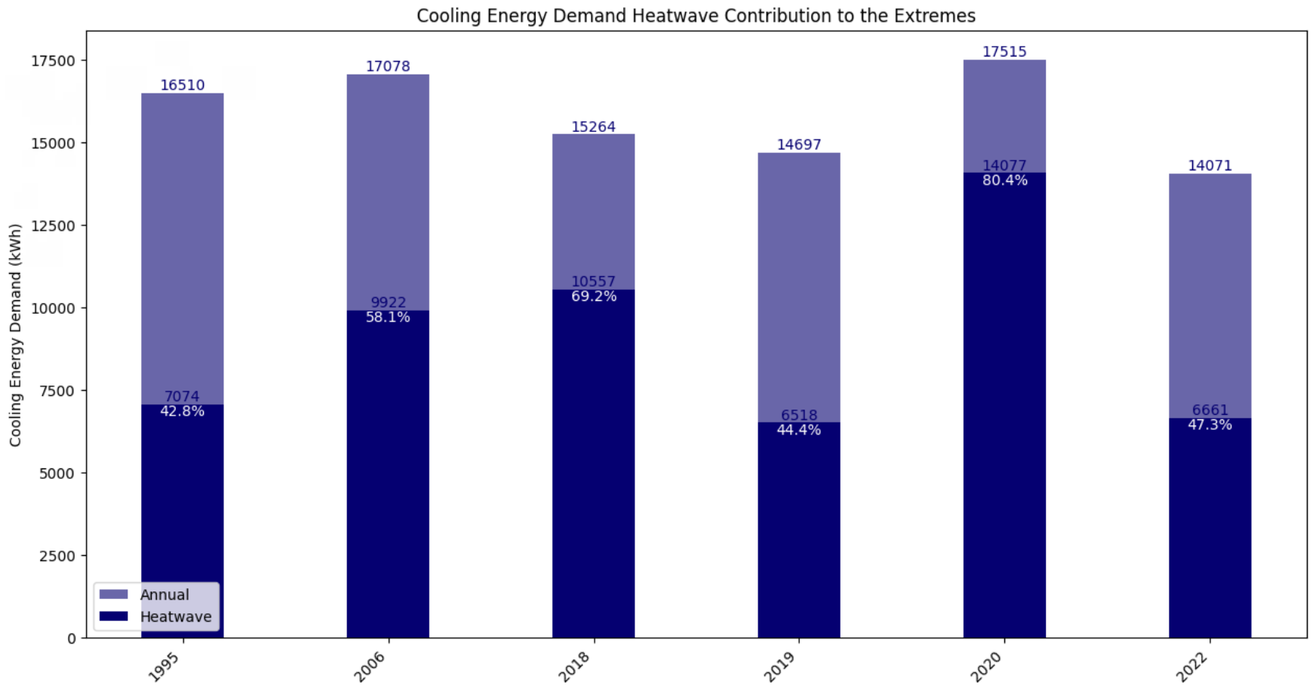
2006

2018

2019

2020

2022



Performance Analysis

Heat Wave Contribution - Overheating

1995

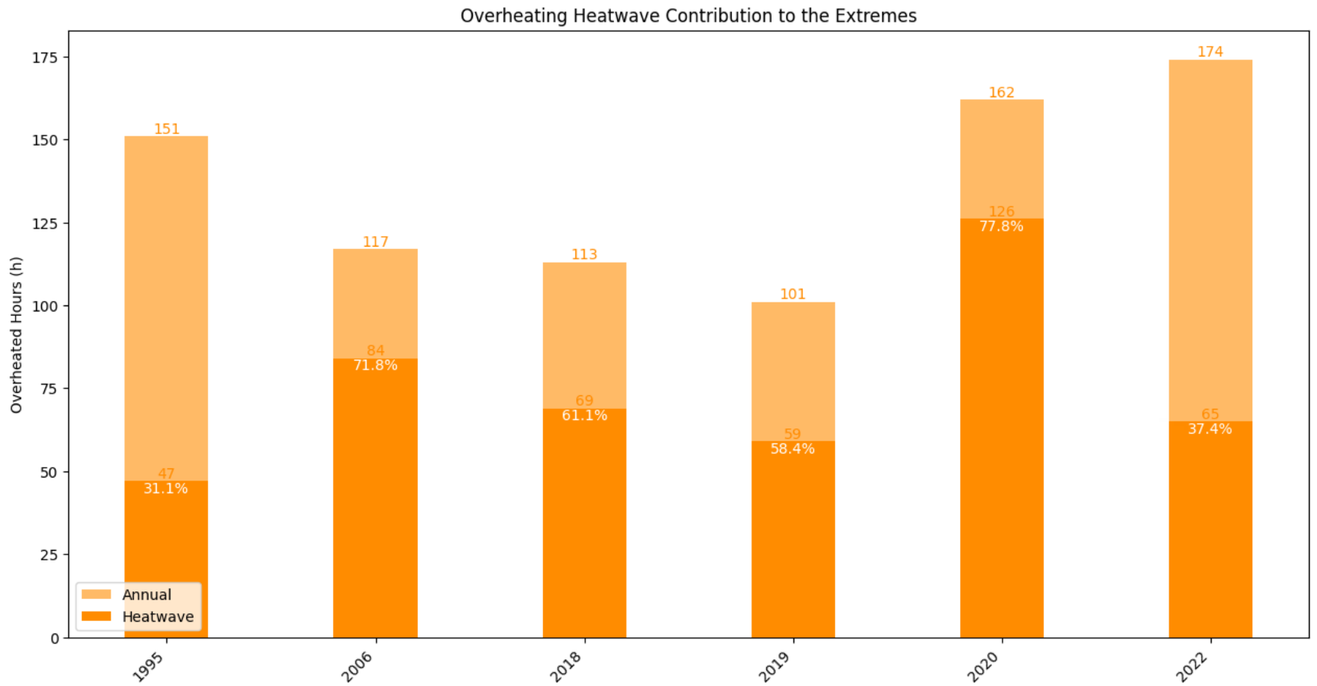
2006

2018

2019

2020

2022



Heat extremes

1995

2006

2018

2019

2020

2022

Performance Analysis

Extremes on the distribution

1995

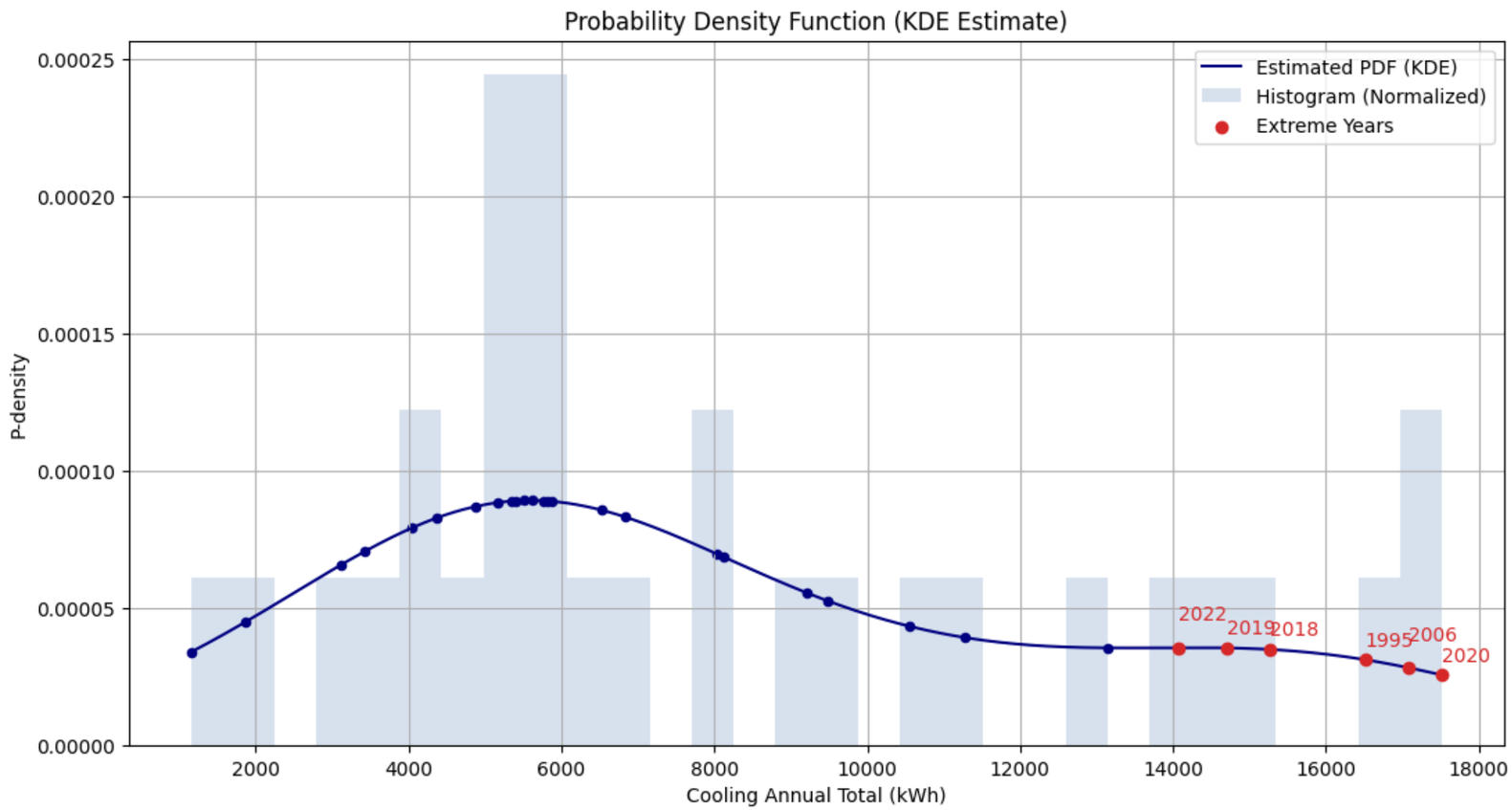
2006

2018

2019

2020

2022



Performance Analysis

The Extreme Range

1995

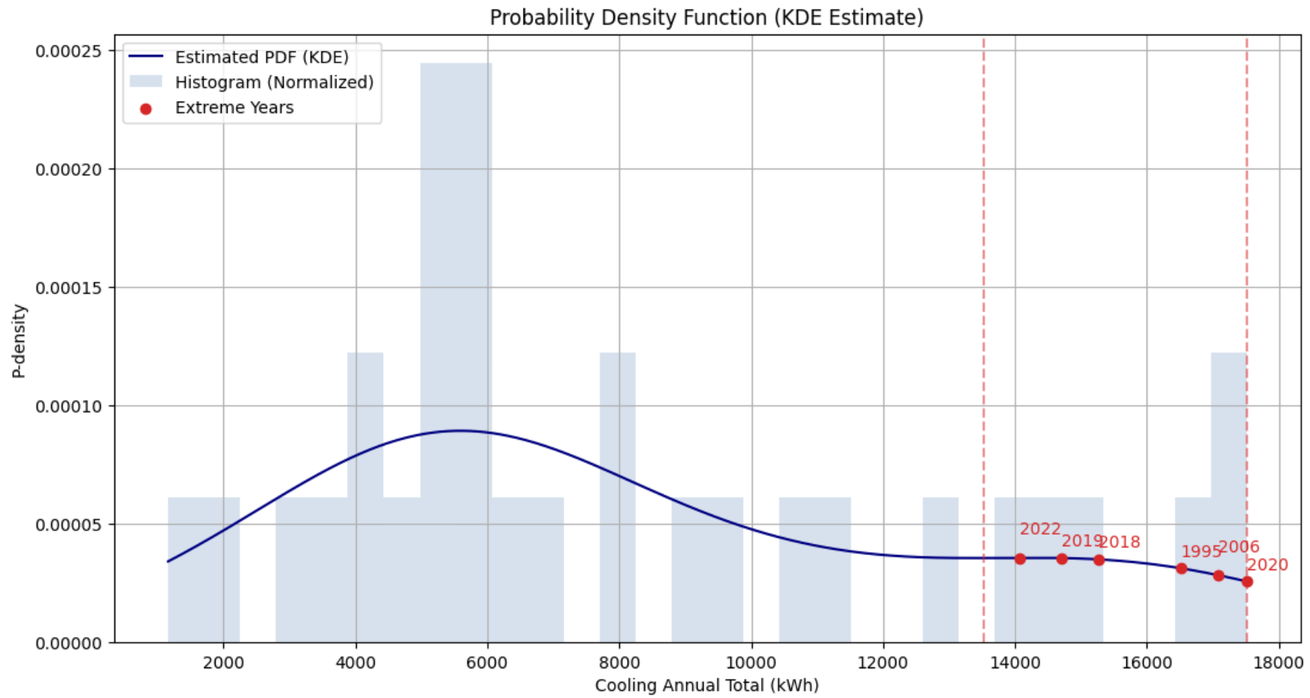
2006

2018

2019

2020

2022



15% extreme range

Performance Analysis

The Extreme Range

1995

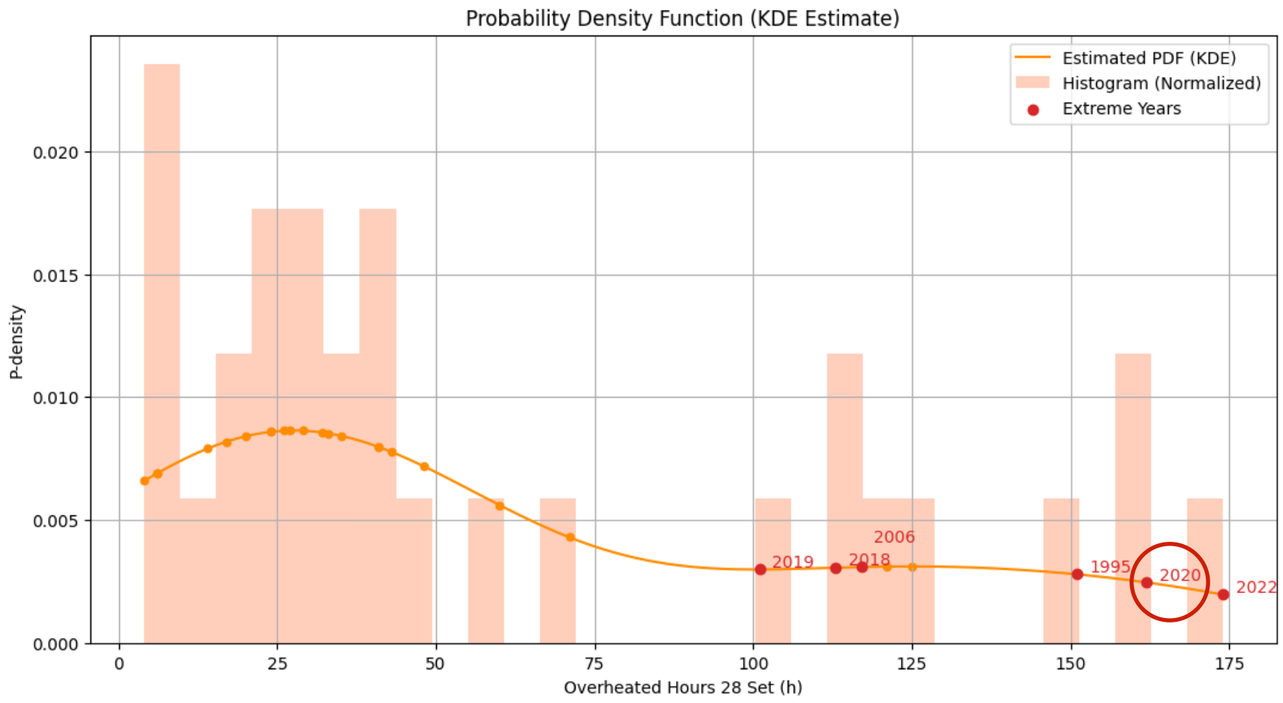
2006

2018

2019

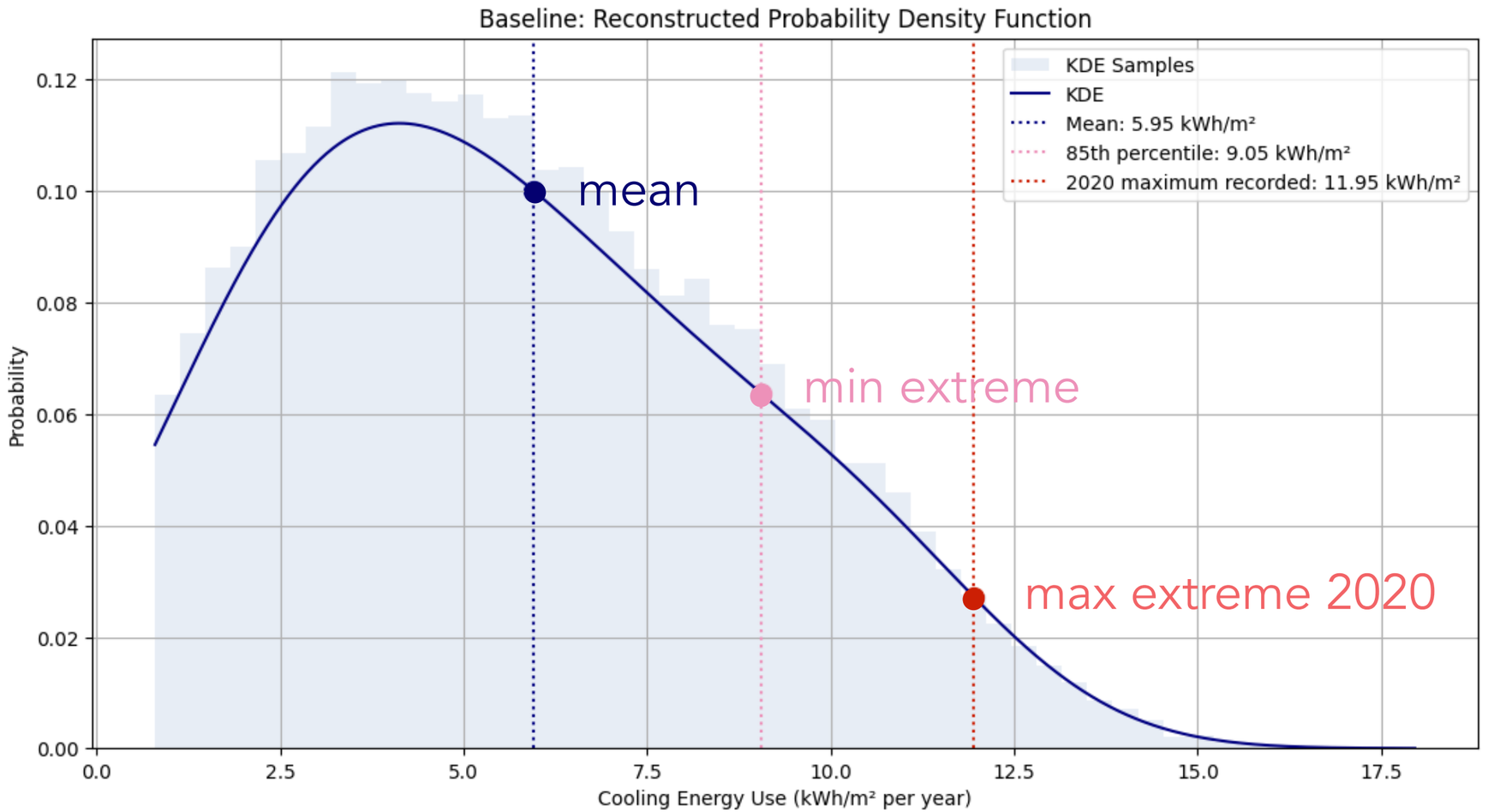
2020

2022



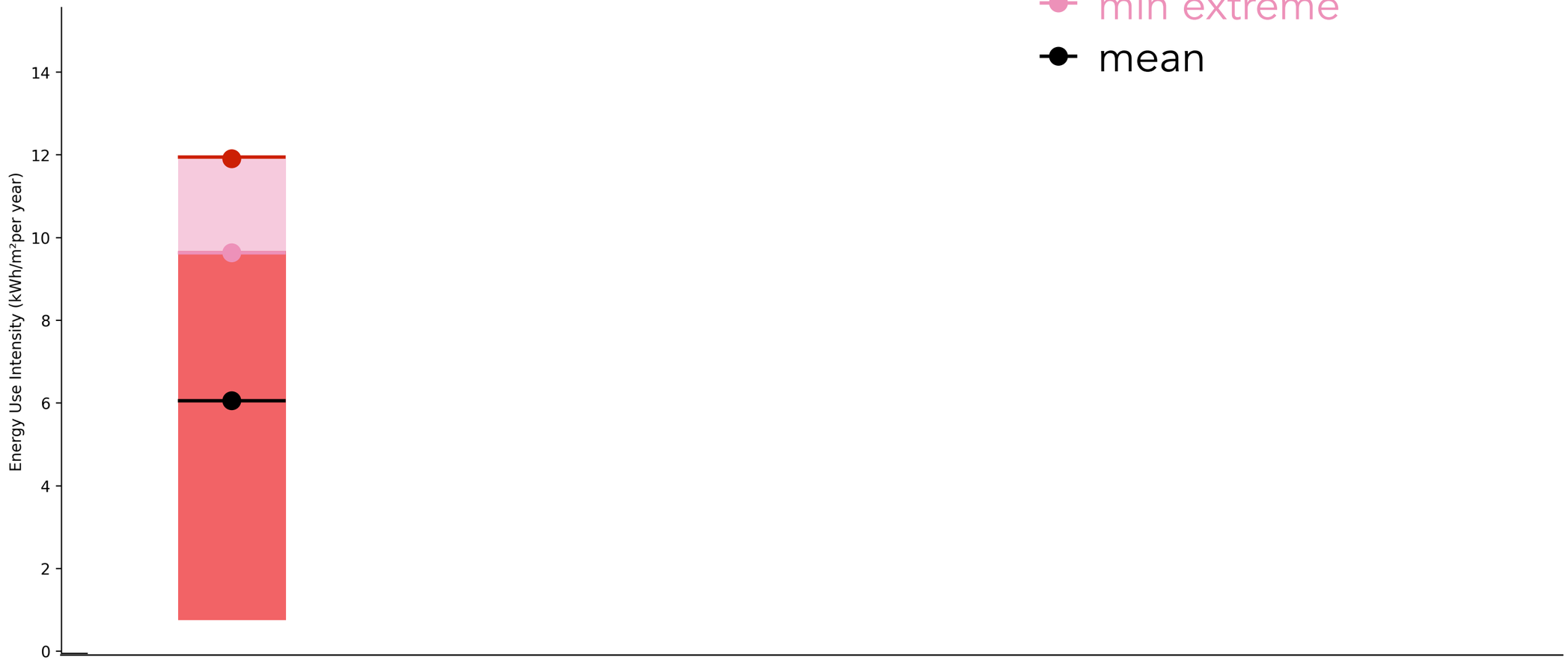
15% extreme range

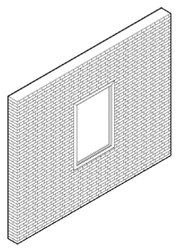
Probabilistic Analysis



Let‘s look at the results!

Cooling Energy

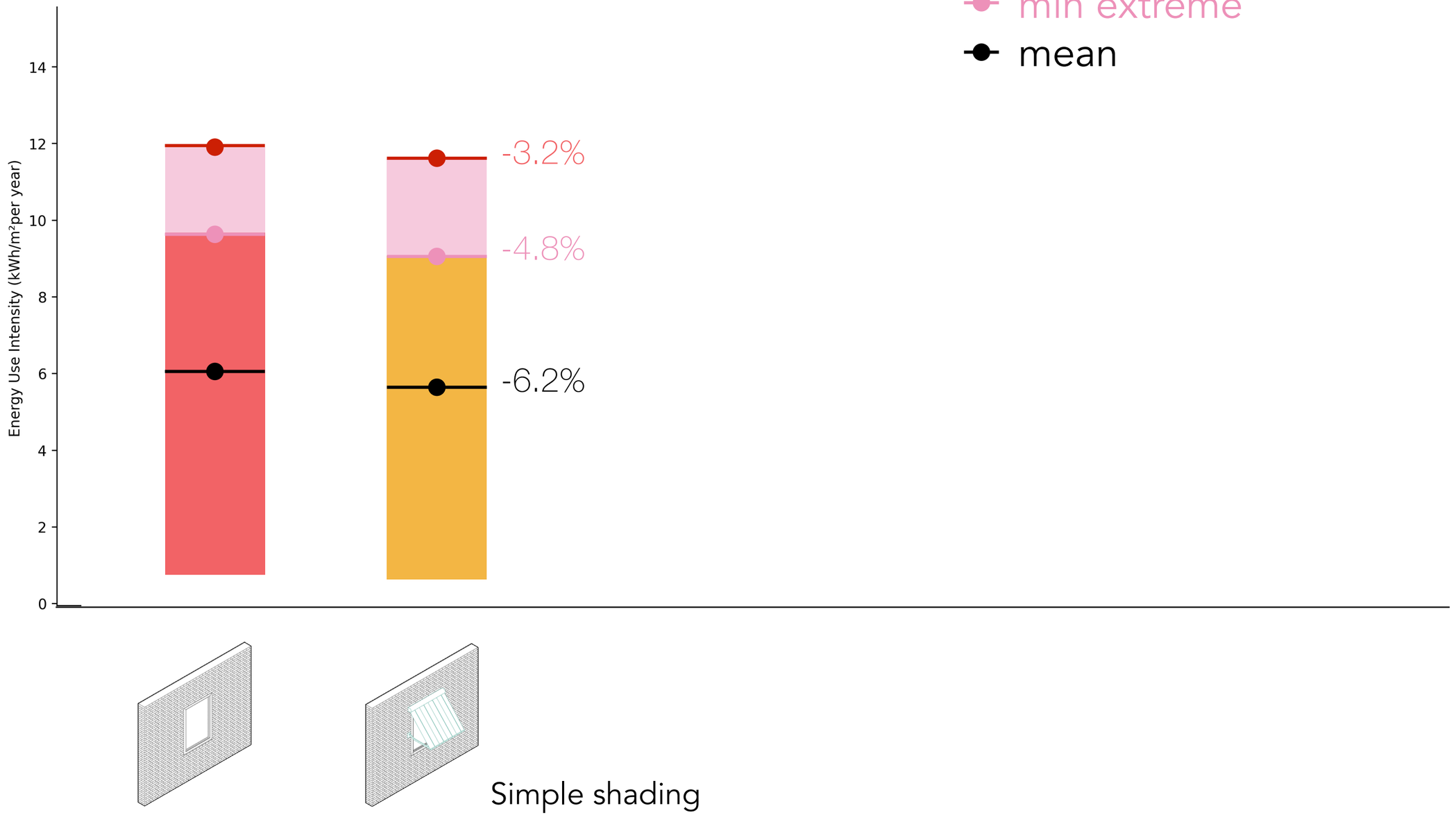




Baseline

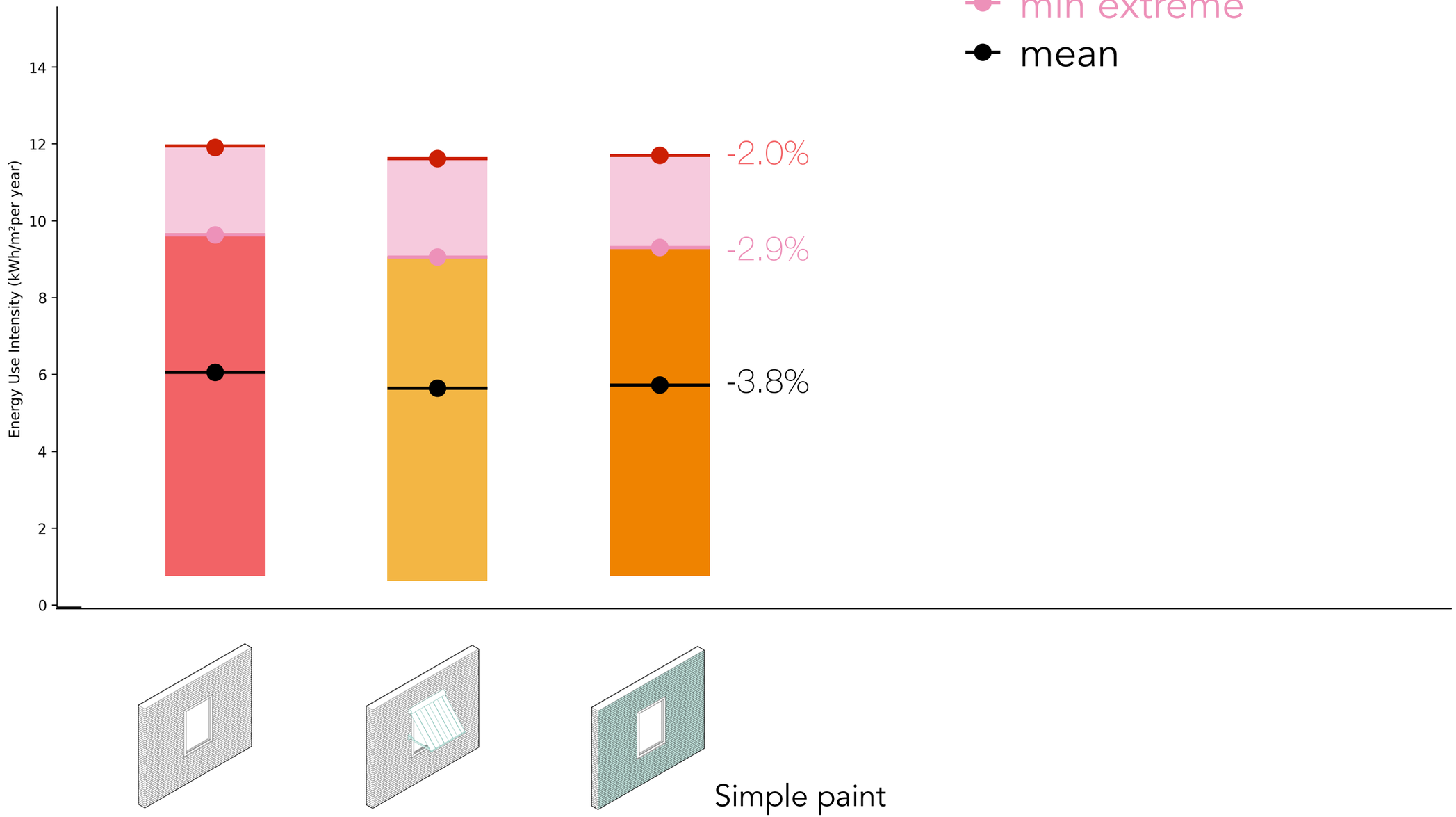
Performance Analysis

Cooling Energy



Simple shading

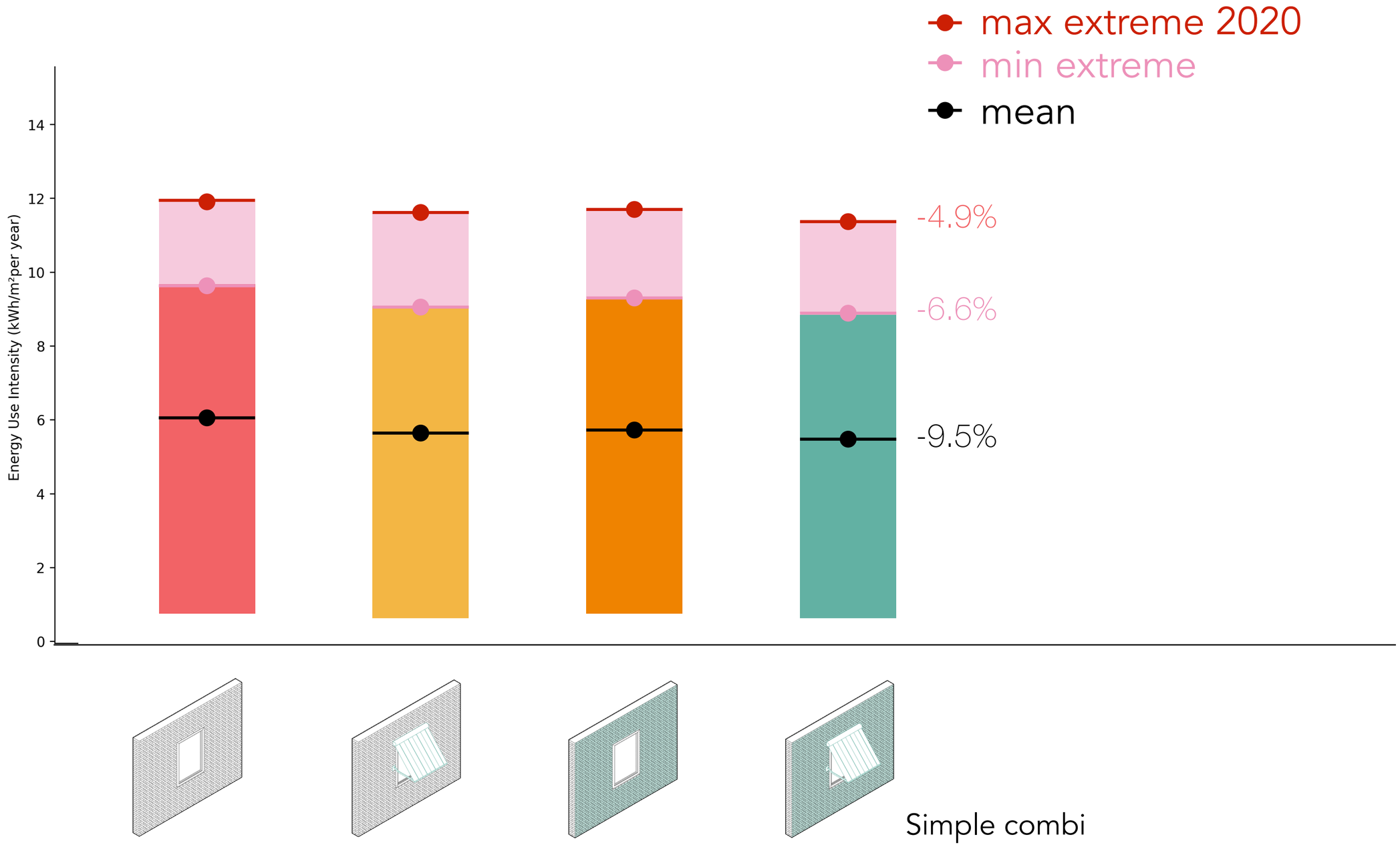
Cooling Energy



Simple paint

Performance Analysis

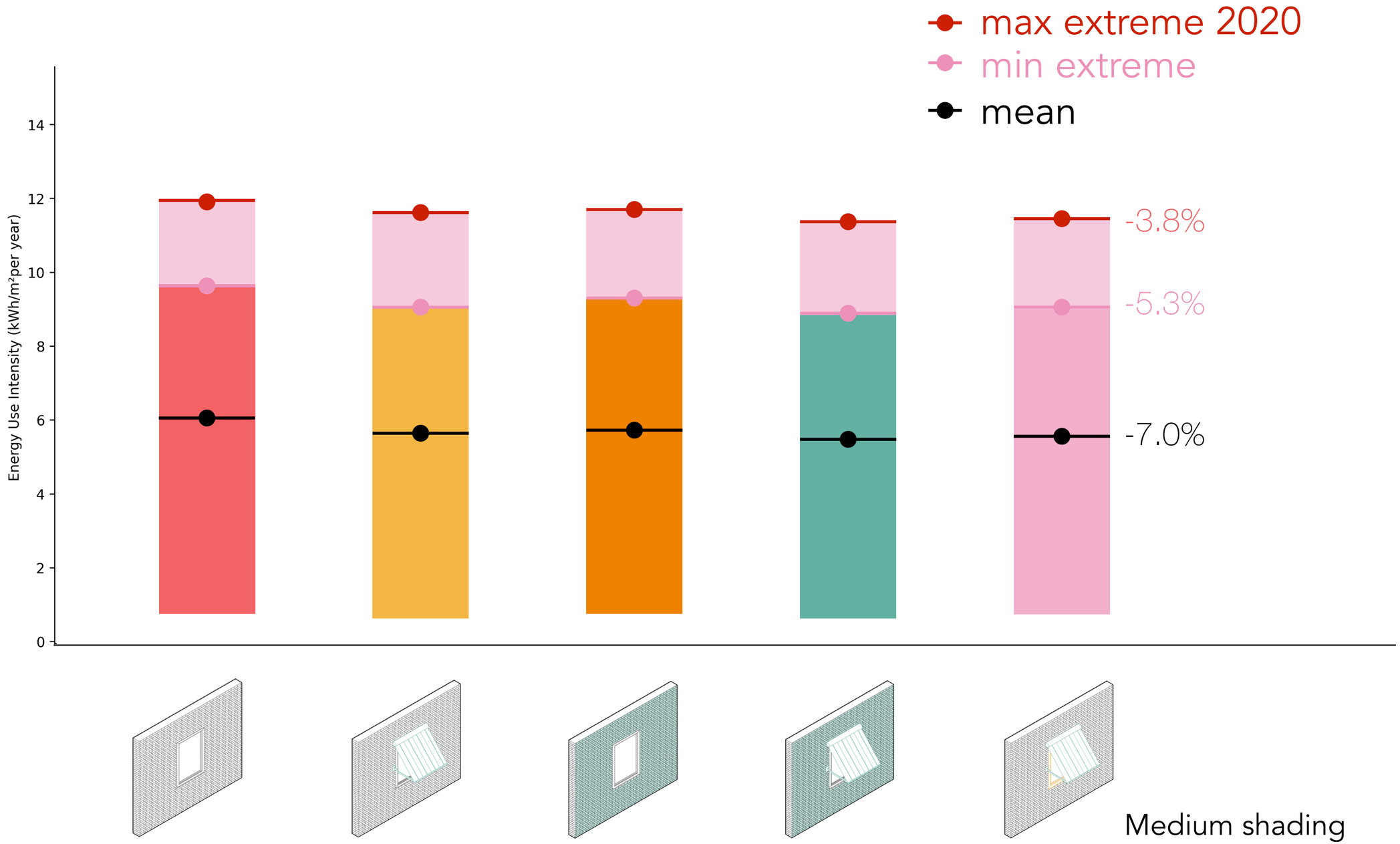
Cooling Energy



Simple combi

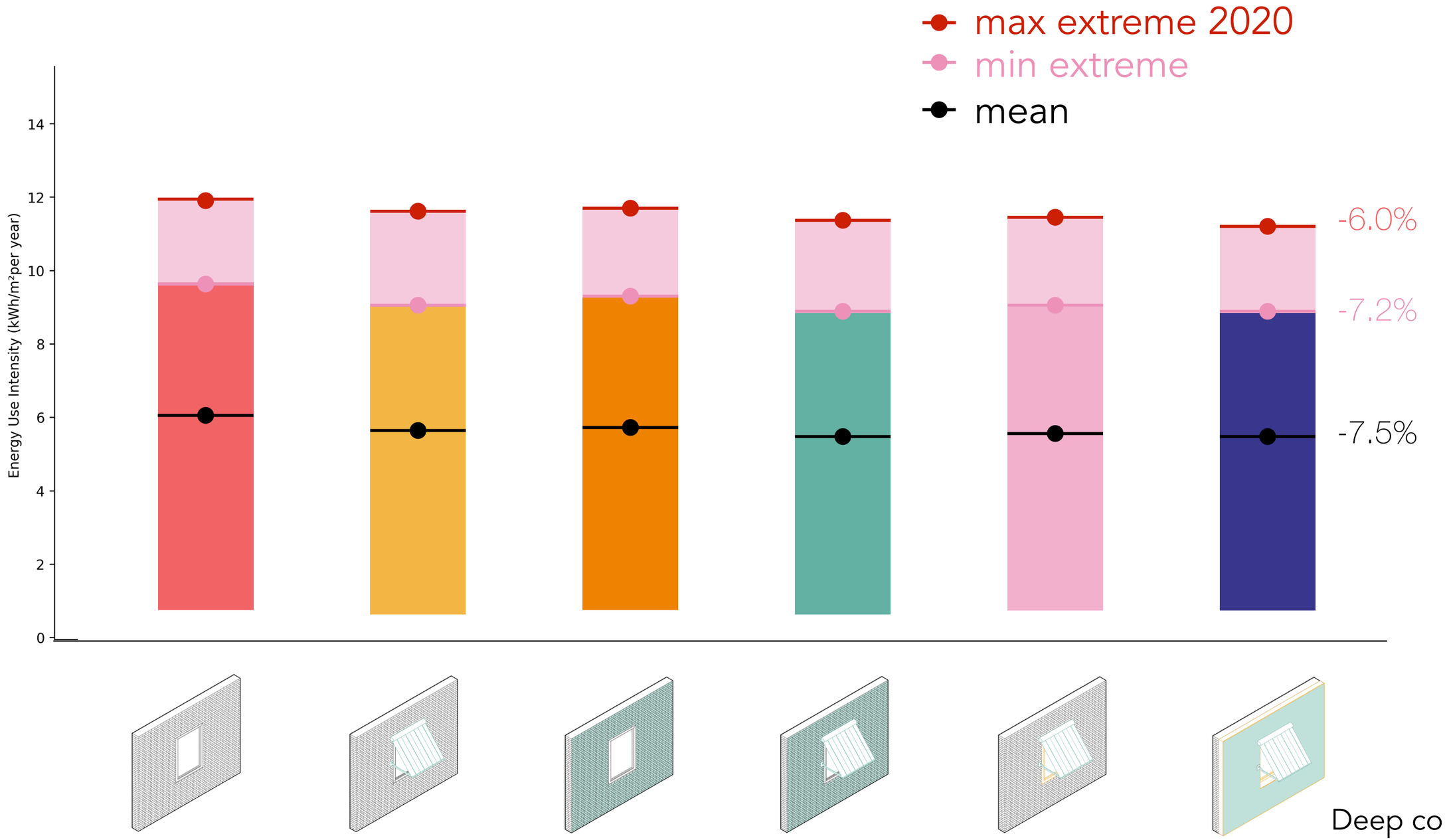
Performance Analysis

Cooling Energy

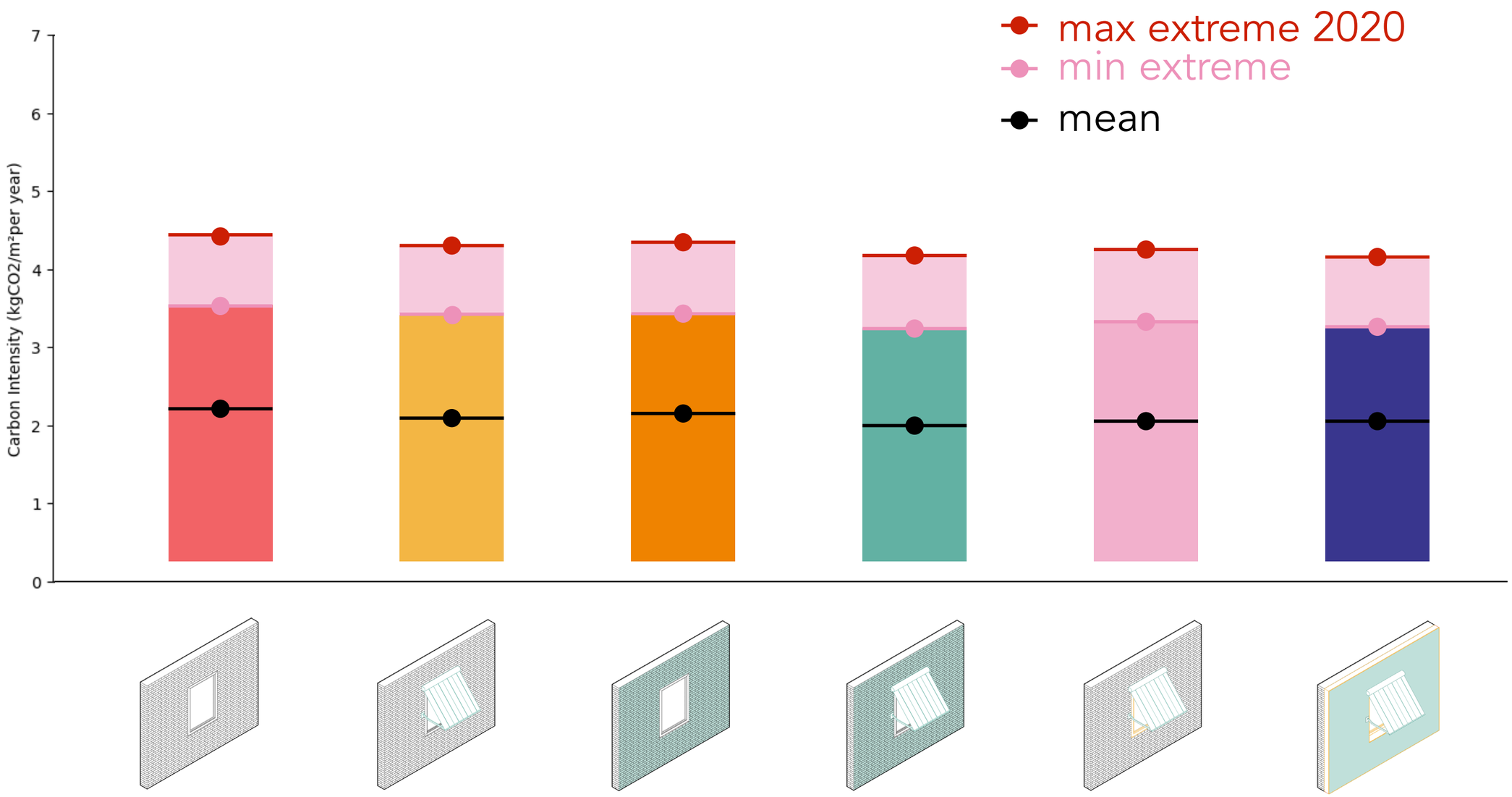


Performance Analysis

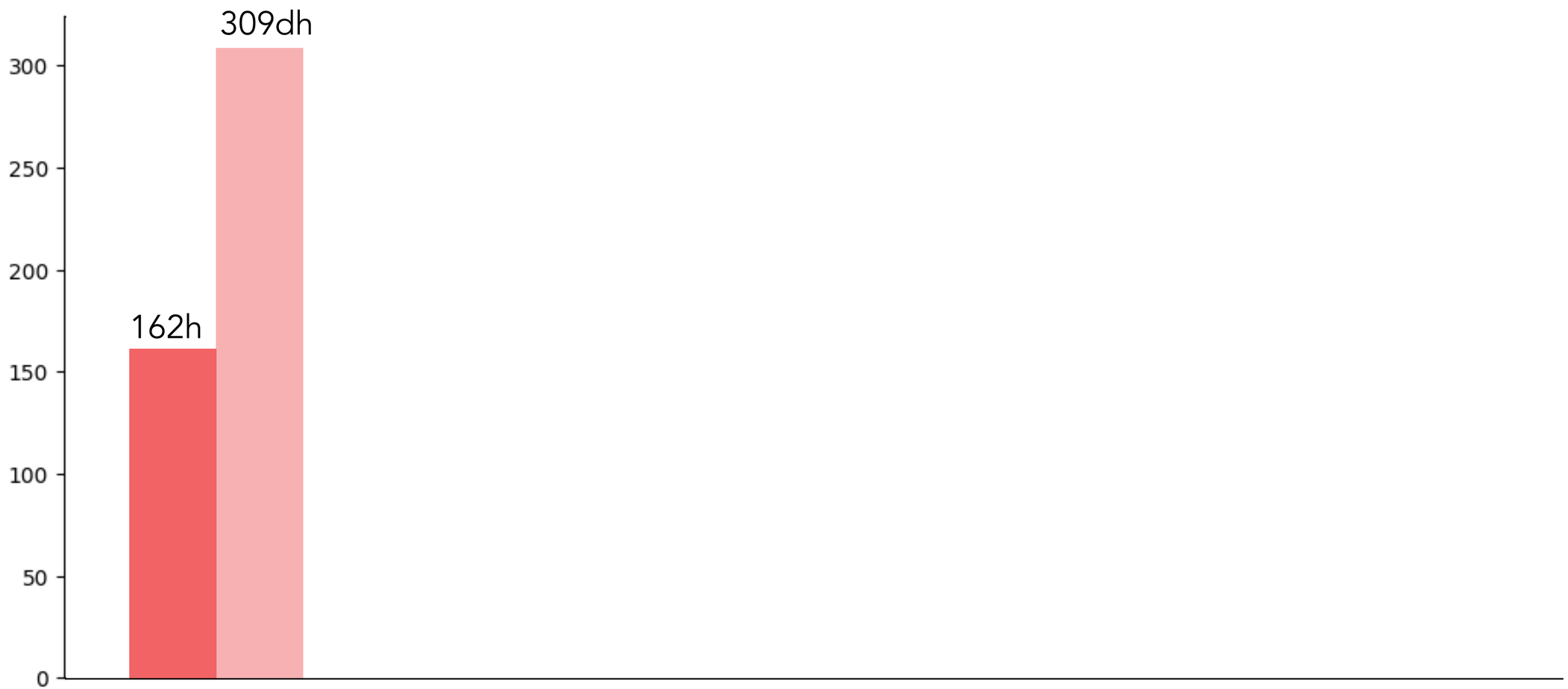
Cooling Energy

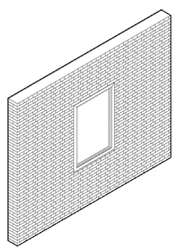


Carbon emission intensity - Cooling



Overheating Duration & Intensity

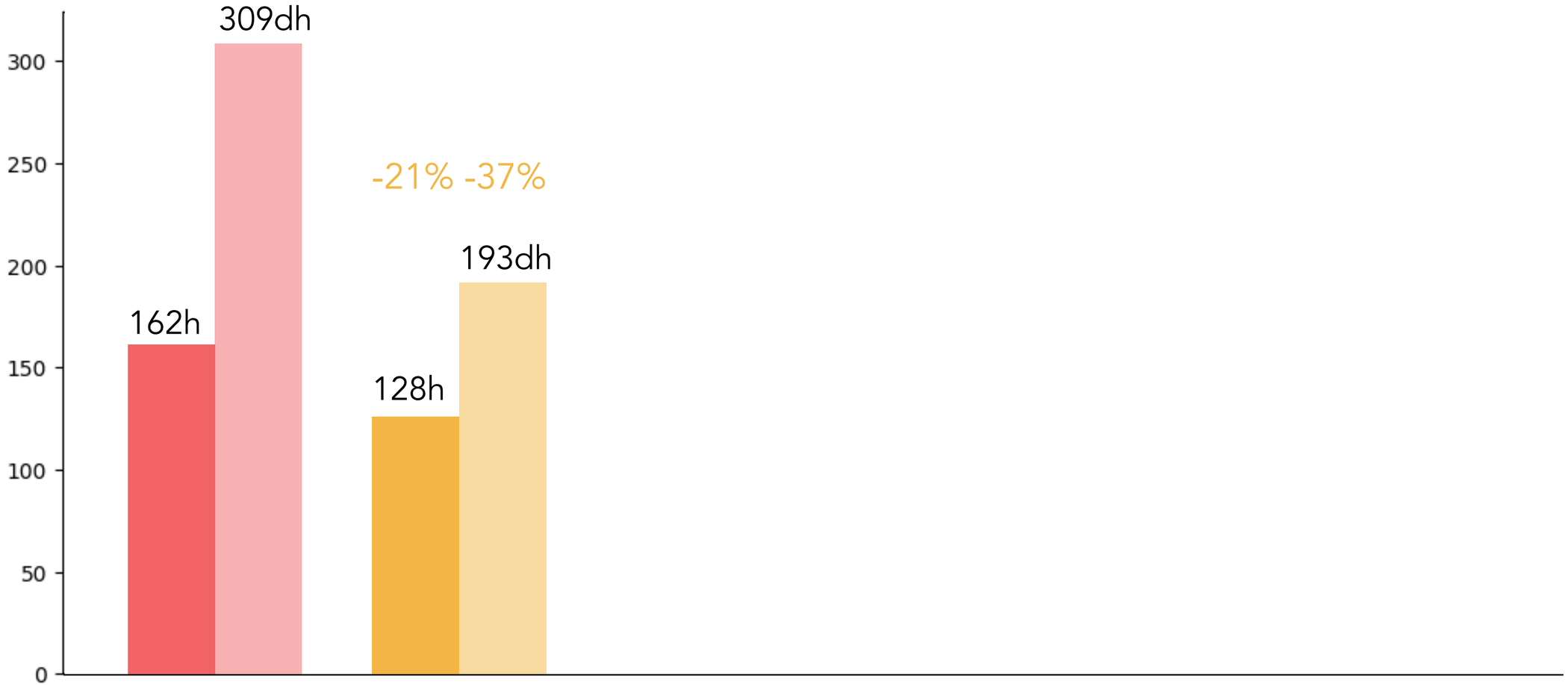


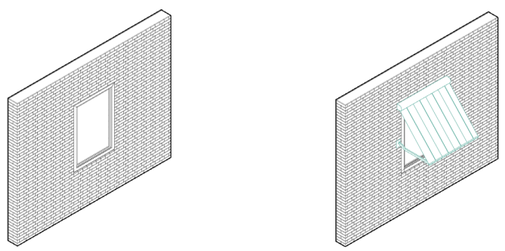


Baseline

Performance Analysis

Overheating Duration & Intensity

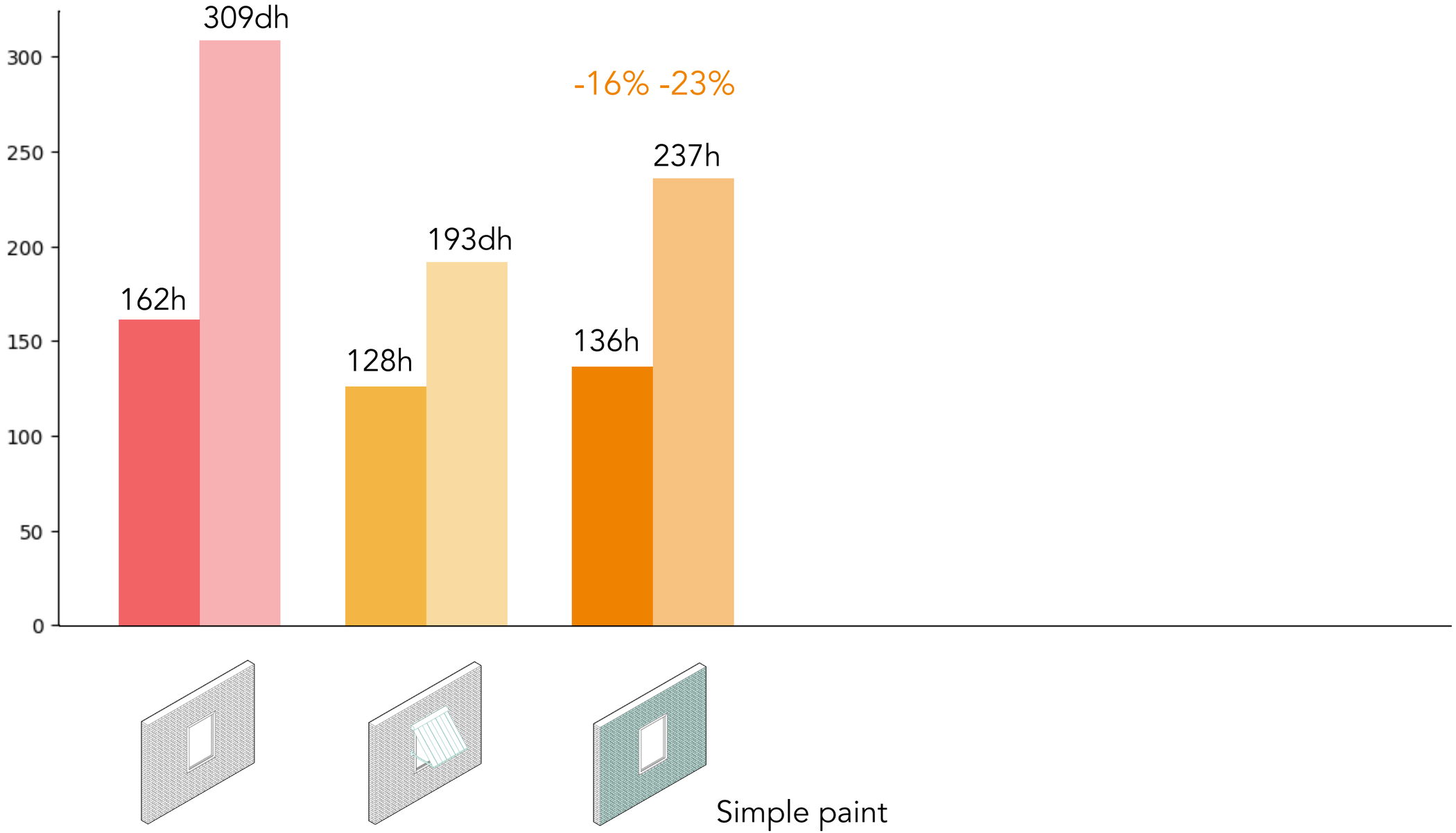




Simple shading

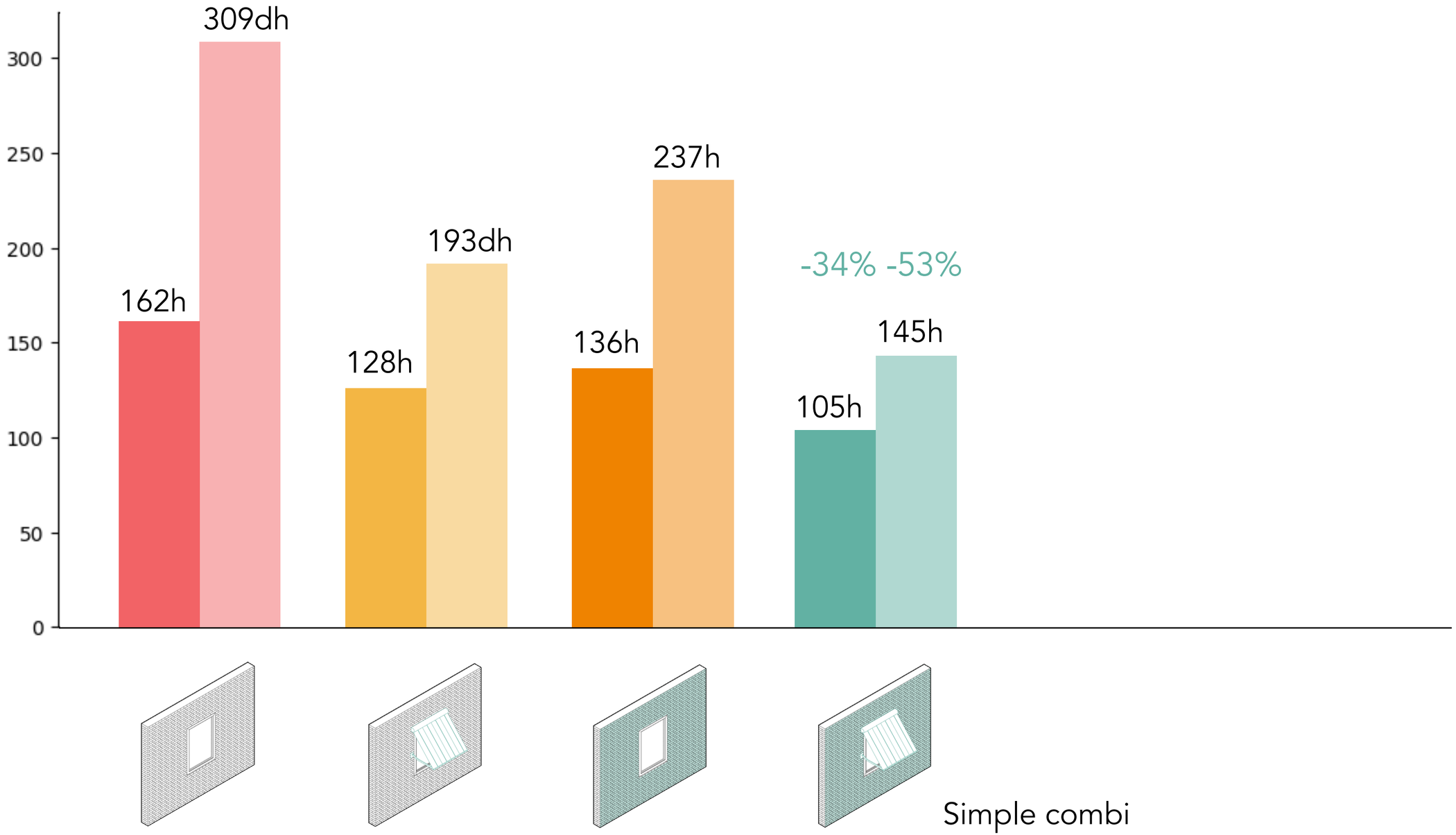
Performance Analysis

Overheating Duration & Intensity



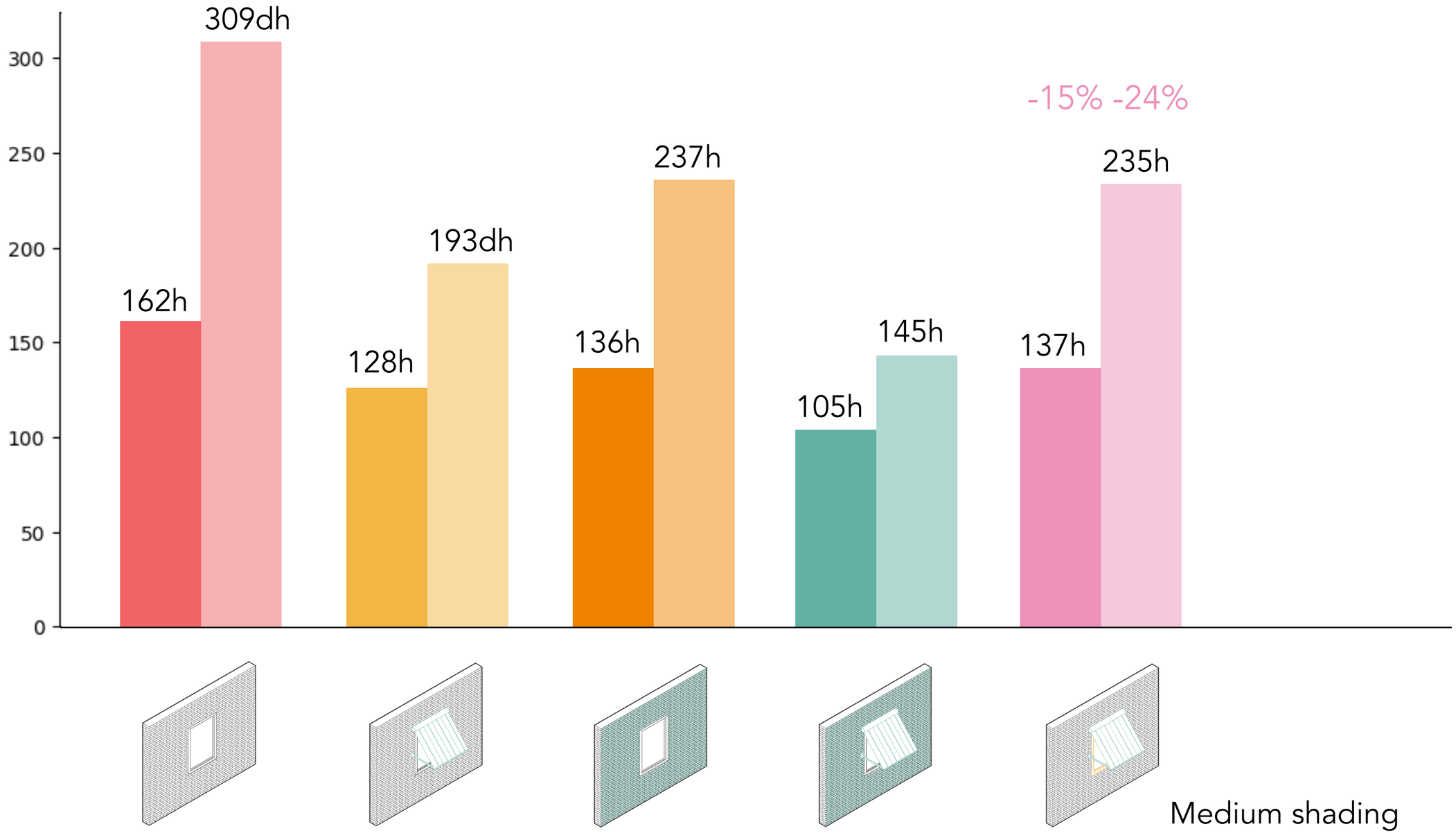
Performance Analysis

Overheating Duration & Intensity



Performance Analysis

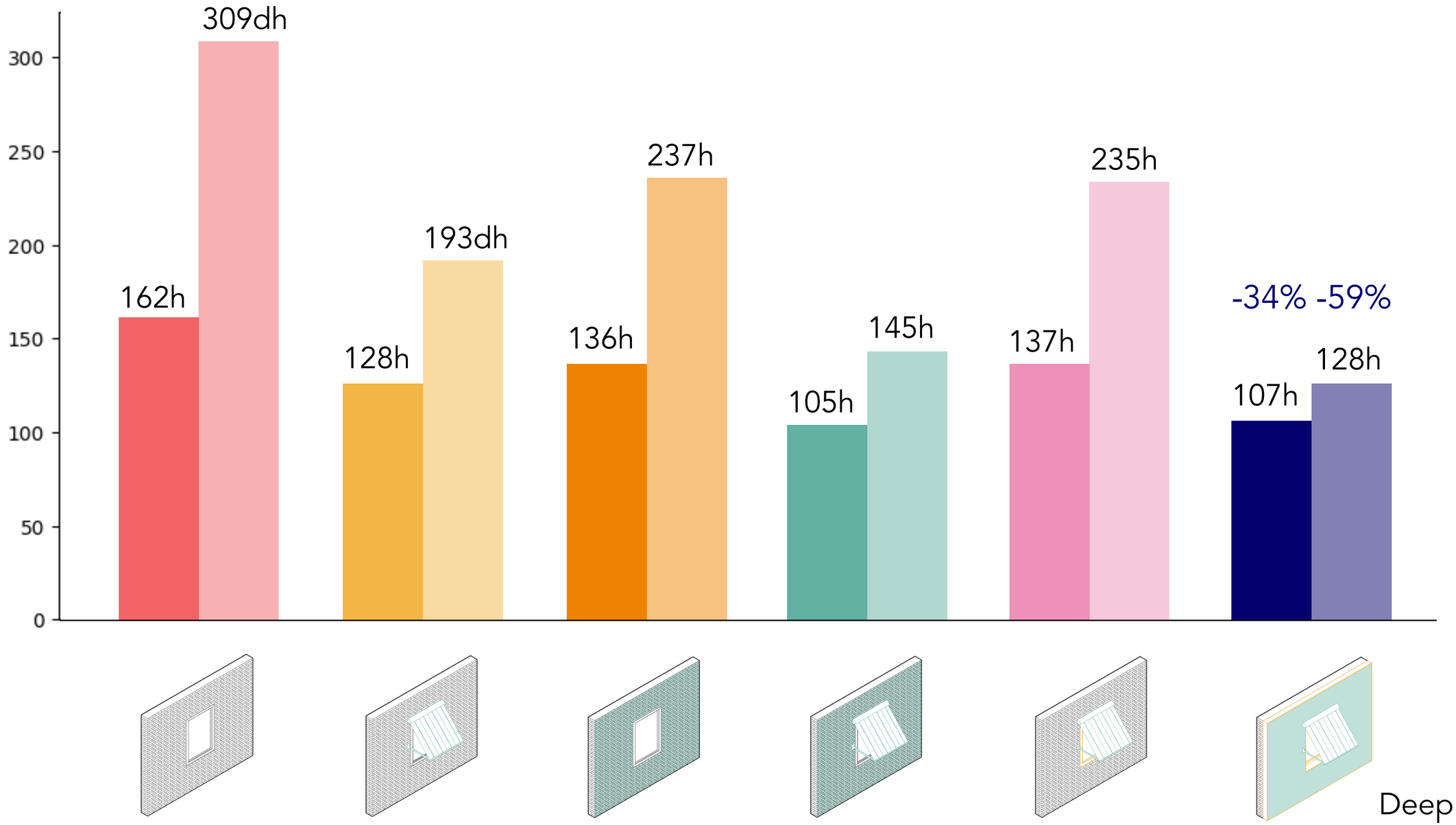
Overheating Duration & Intensity



Medium shading

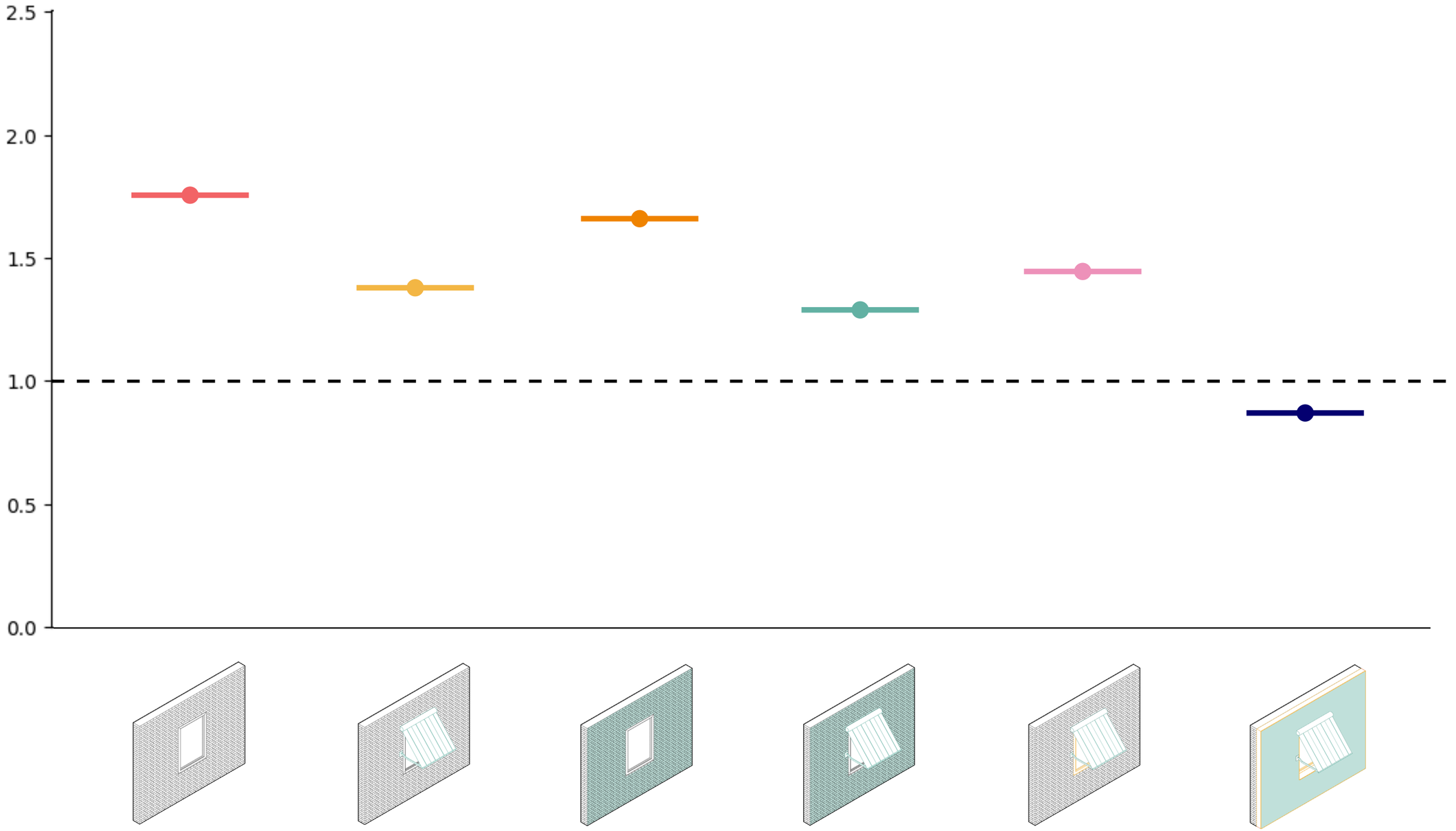
Performance Analysis

Overheating Duration & Intensity

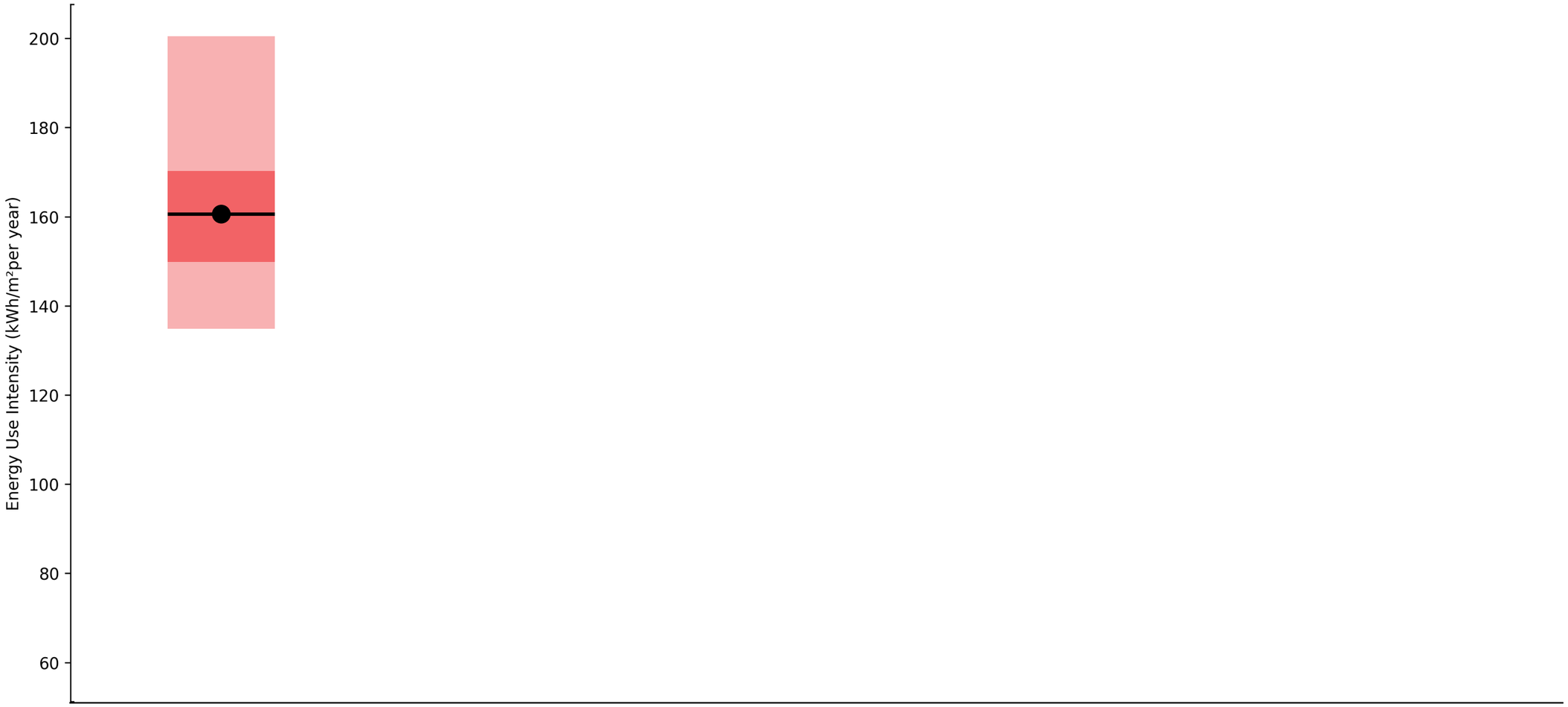


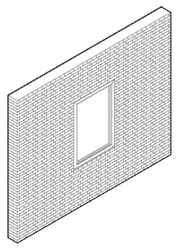
Performance Analysis

Overheating Escalation Factor



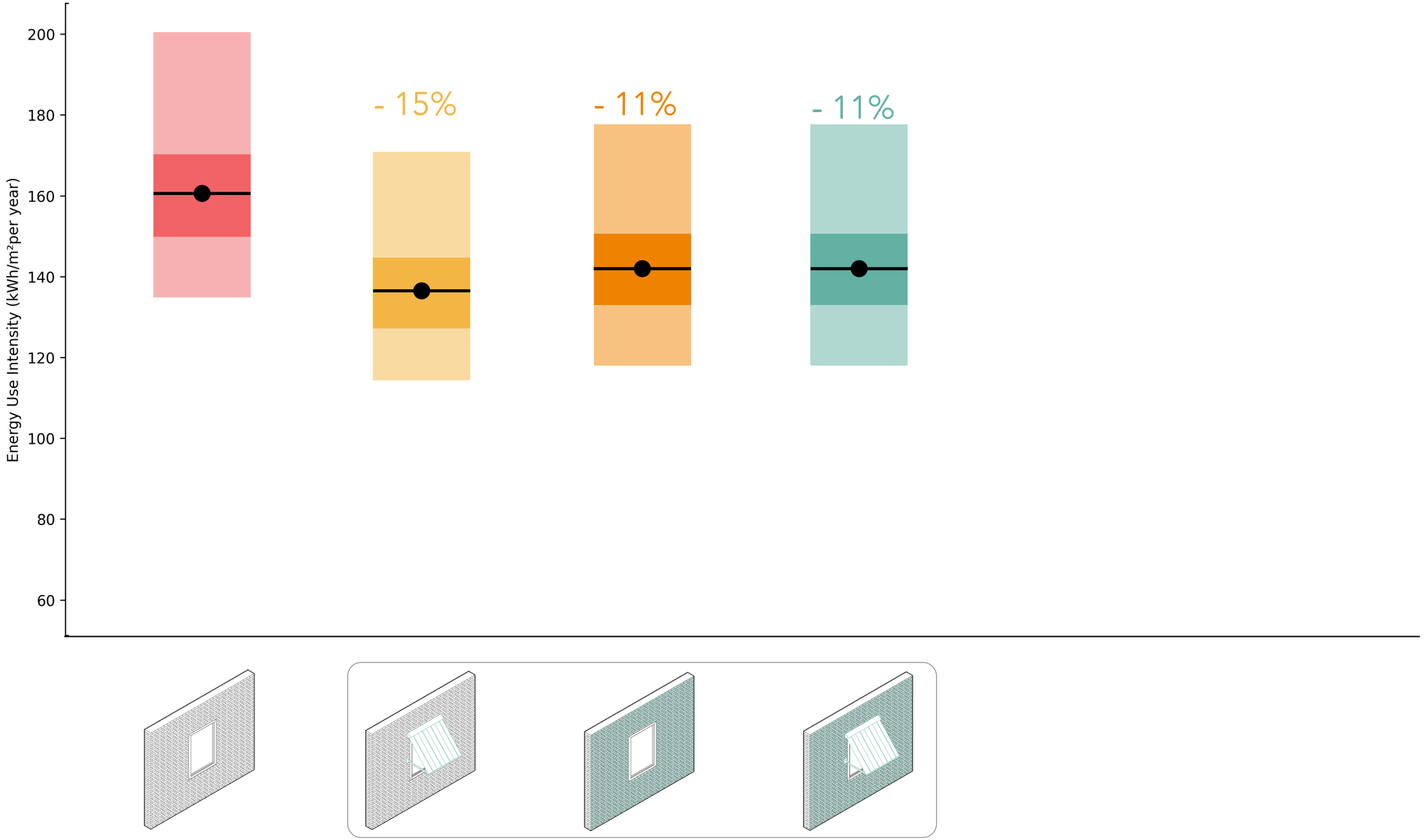
Energy use intensity - Heating





Performance Analysis

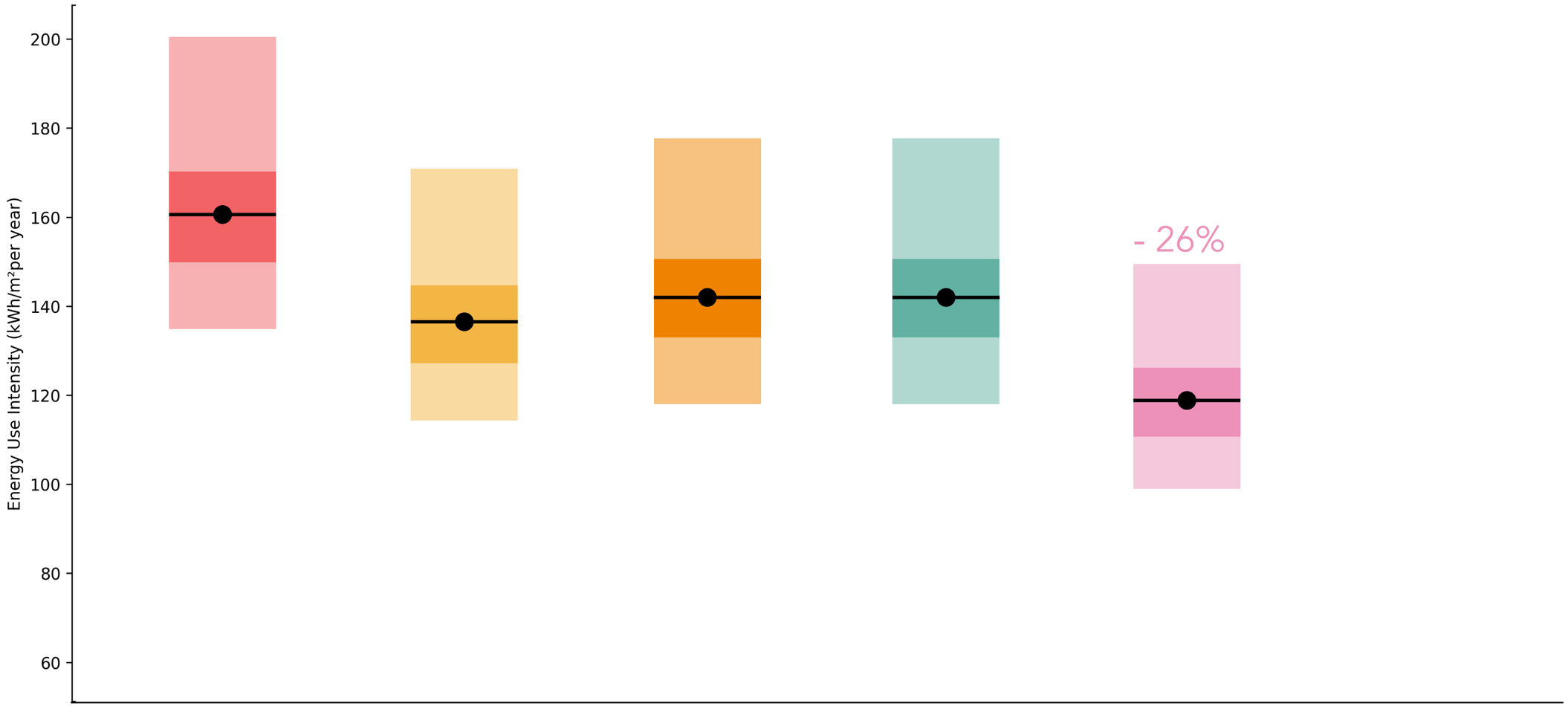
Energy use intensity - Heating

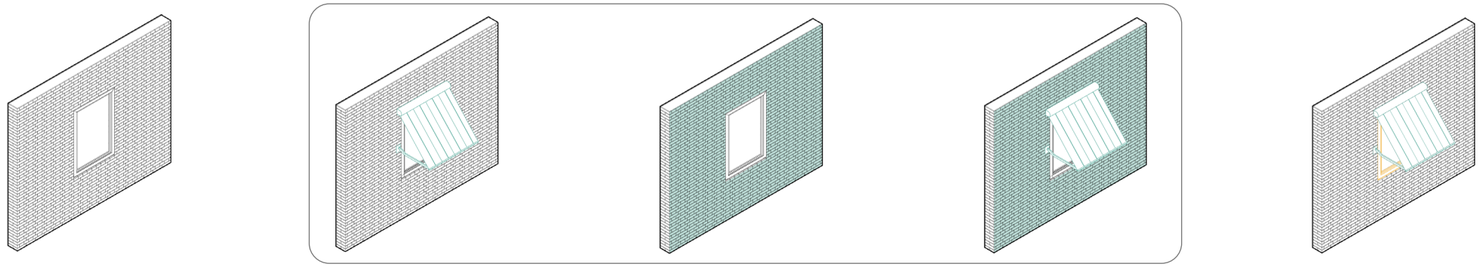


Simple Distict Heating

Performance Analysis

Energy use intensity - Heating



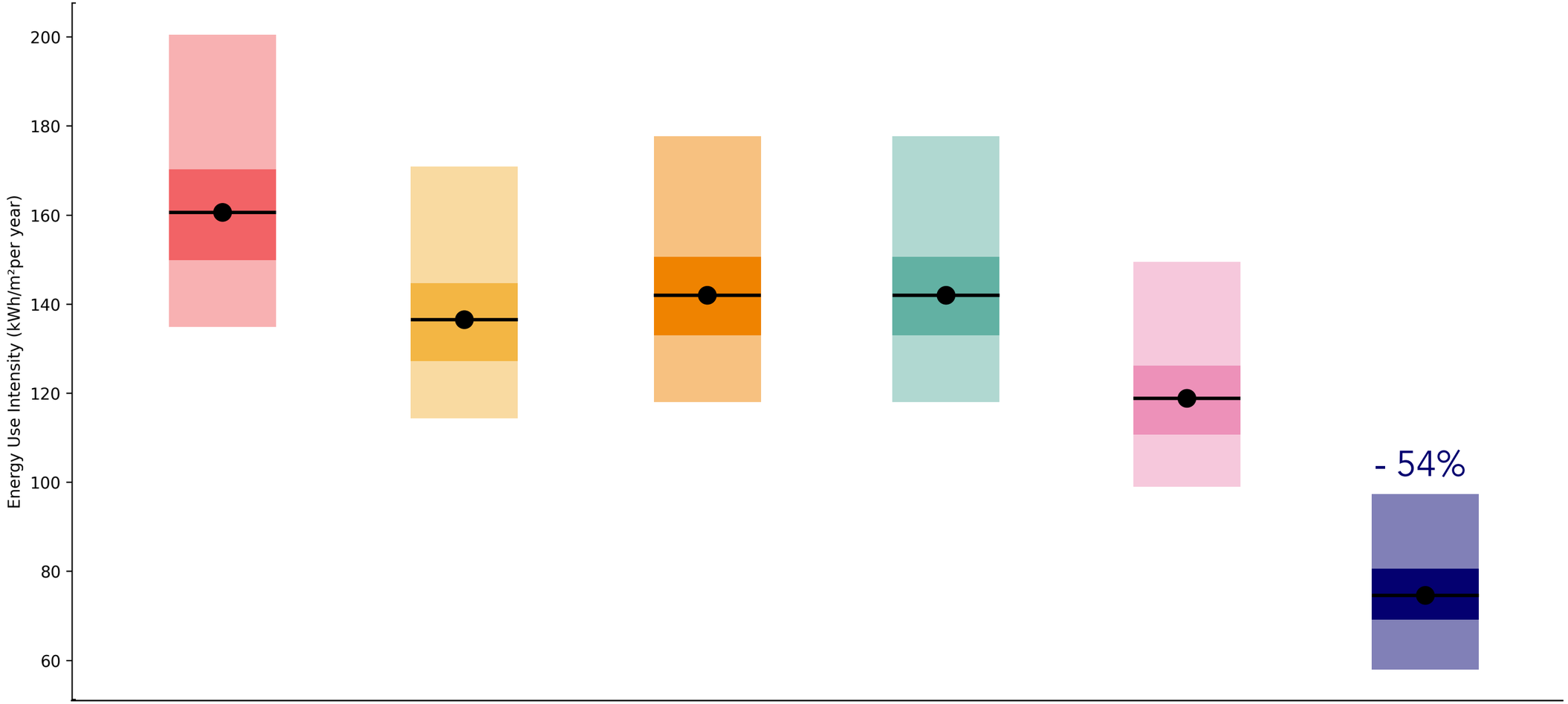


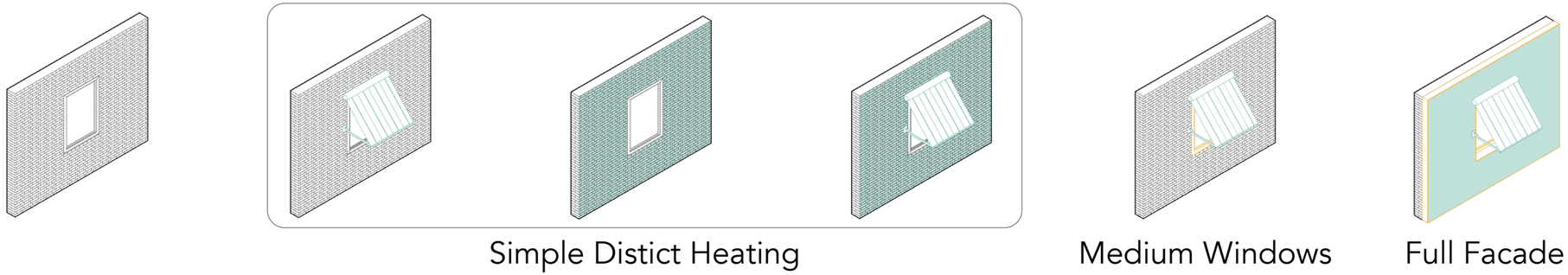
Simple Distict Heating

Medium Windows

Performance Analysis

Energy use intensity - Heating





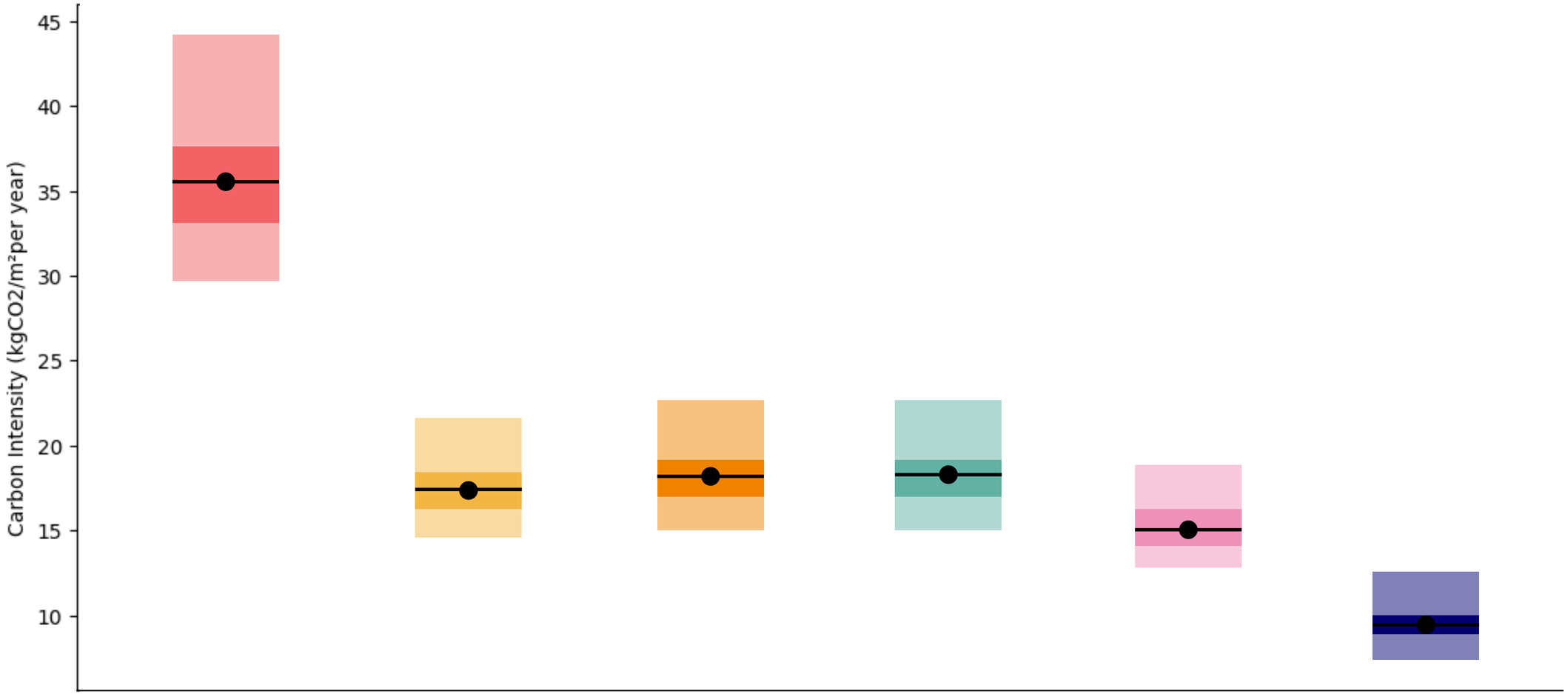
Simple Distict Heating

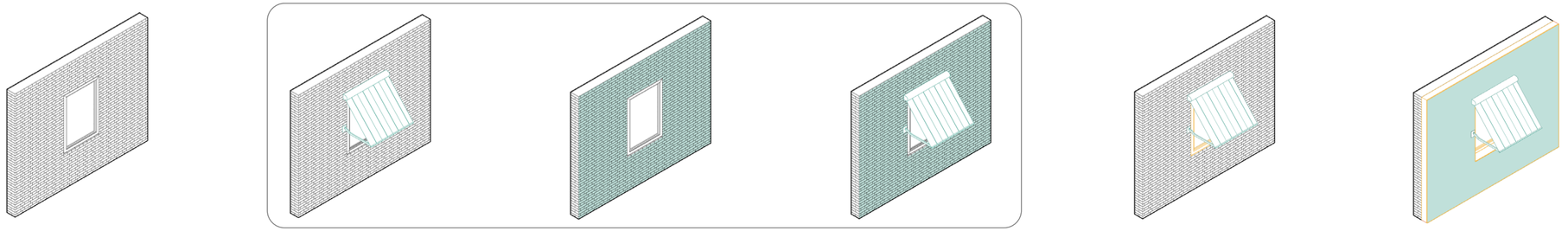
Medium Windows

Full Facade

Performance Analysis

Carbon emission intensity - Heating





Simple Distict Heating | Medium Windows | Full Facade

Let‘s recap!

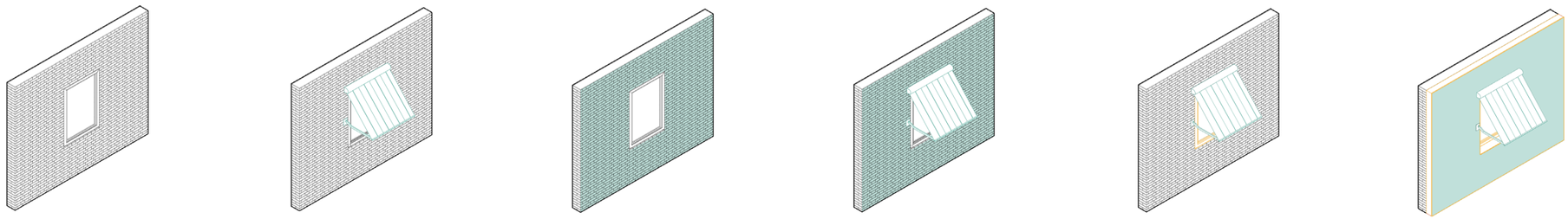
Objective

Heating

Cooling

Overheating

Carbon

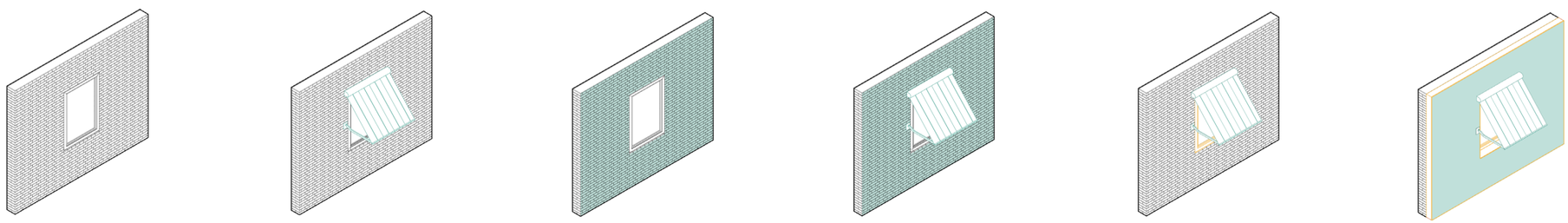


Performance Analysis

Let‘s recap!

Objective

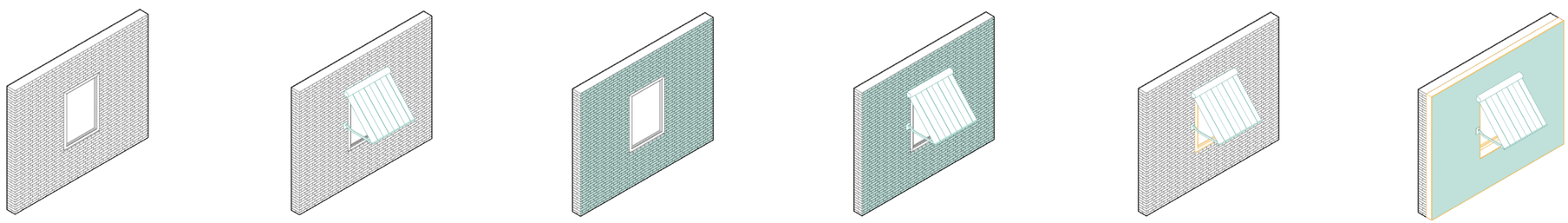
Heating						
Cooling	5.99 kWh/m²	- 6%	- 4%	- 10%	- 7%	- 8%
	11.57 kWh/m²	- 3%	- 2%	- 5%	- 4%	- 6%
Overheating	309dh	- 37%	-23%	- 53%	- 24%	- 59%
Carbon						



Let‘s recap!

Objective

Heating	160.7 kWh /m²	- 15%	- 11%	- 11%	- 26%	- 54%
Cooling	5.99 kWh/m²	- 6%	- 4%	- 10%	- 7%	- 8%
Overheating						
Carbon						



Performance Analysis

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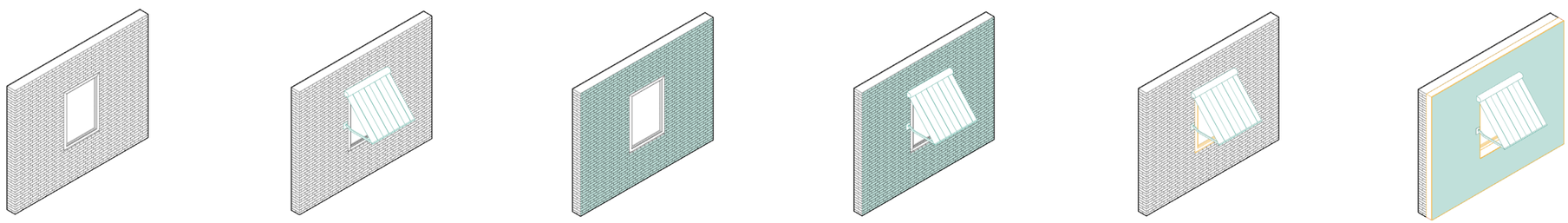
Cooling	5.99 kWh/m²	- 6%	- 4%	- 10%	- 7%	- 8%
Overheating						
Carbon	37.15 kg/m²	-48%	-46%	- 47%	- 55%	- 70%



Performance Analysis

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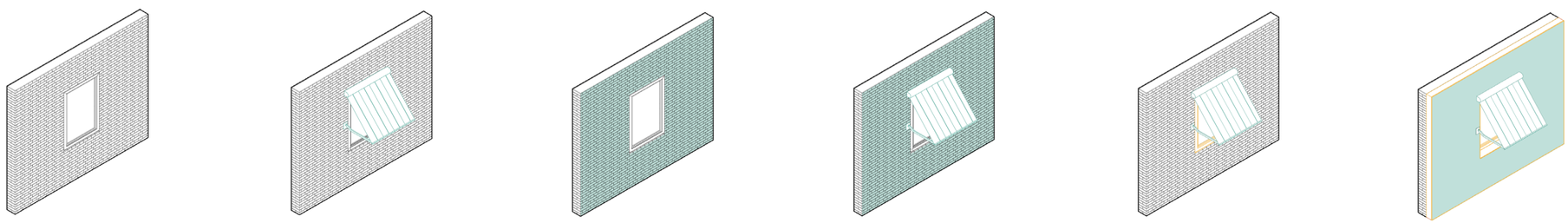


Preliminary

Design & Planning

Performance

Cost-Benefit

Decision-making

Financial Feasibility

3

Performance

7

monetary value
of benefits

9

project cost

Financial Feasibility

3

Performance

10

9

project cost

7

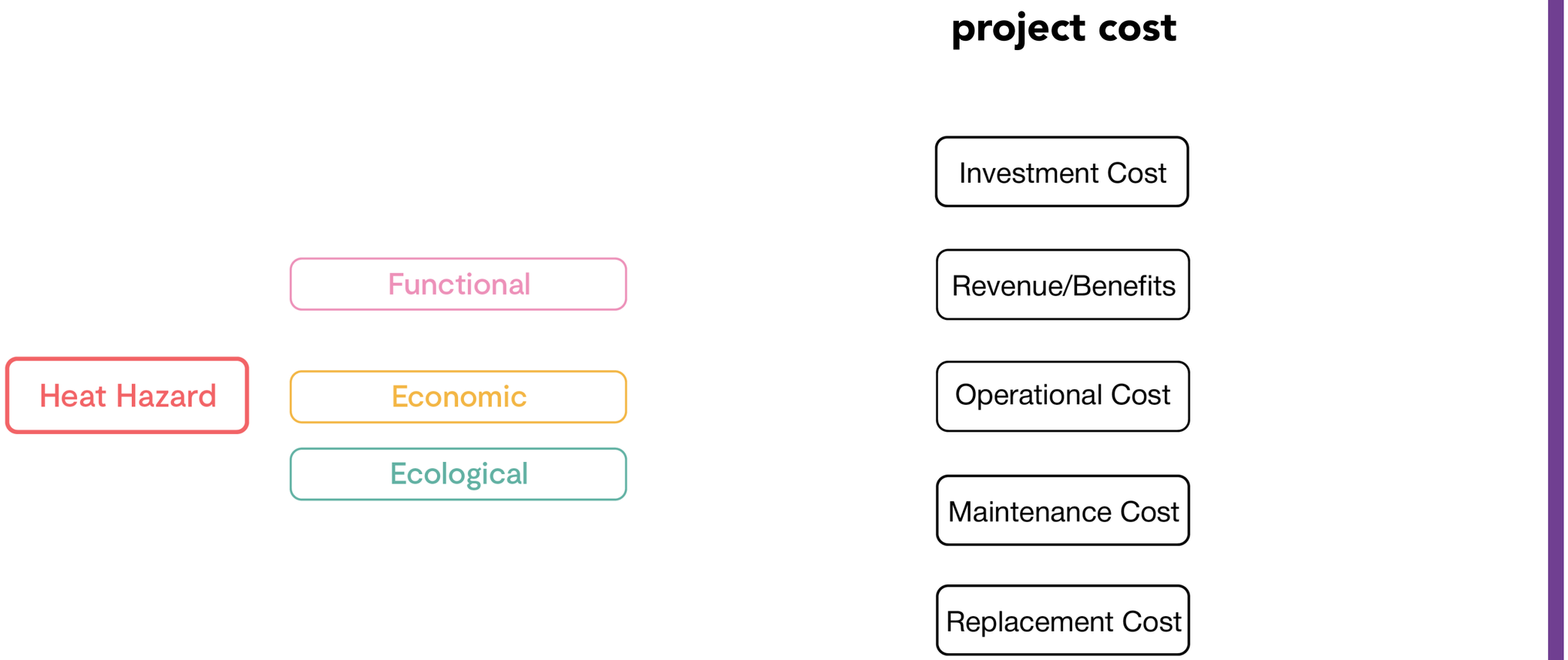
monetary value
of benefits

What are cost and benefits?

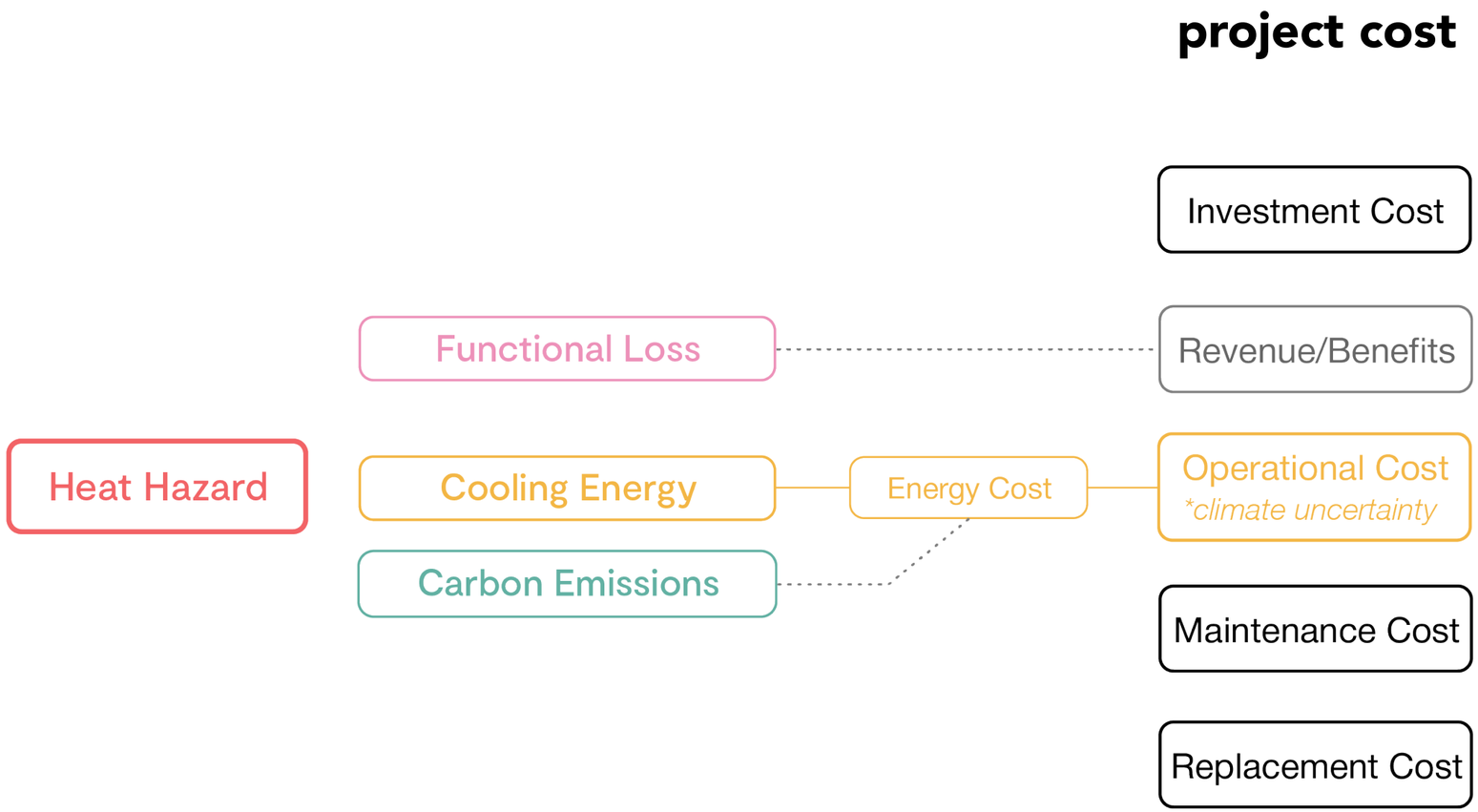
project cost

- Investment Cost
- Revenue/Benefits
- Operational Cost
- Maintenance Cost
- Replacement Cost

Hazard loss affecting project cost



Hazard loss affecting project cost



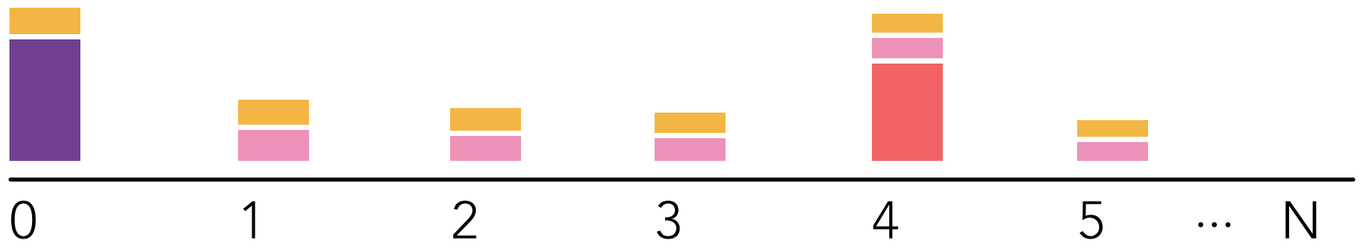
How to estimate a project‘s cost?

Investment Cost

Operational Cost

Maintenance Cost

Replacement Cost



Discounted Cashflows

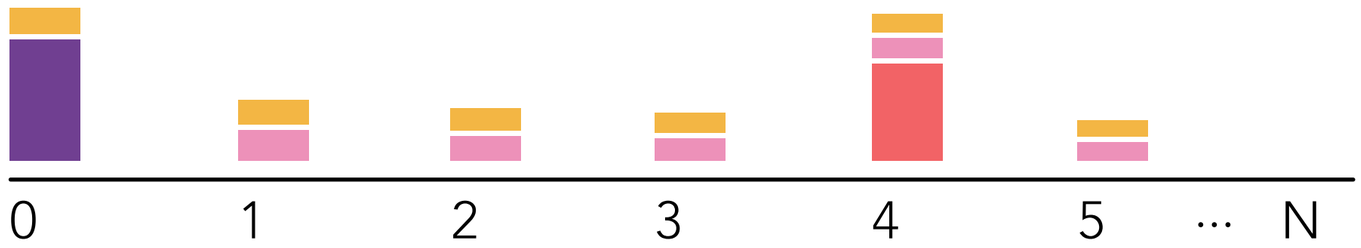
Cashflows over time

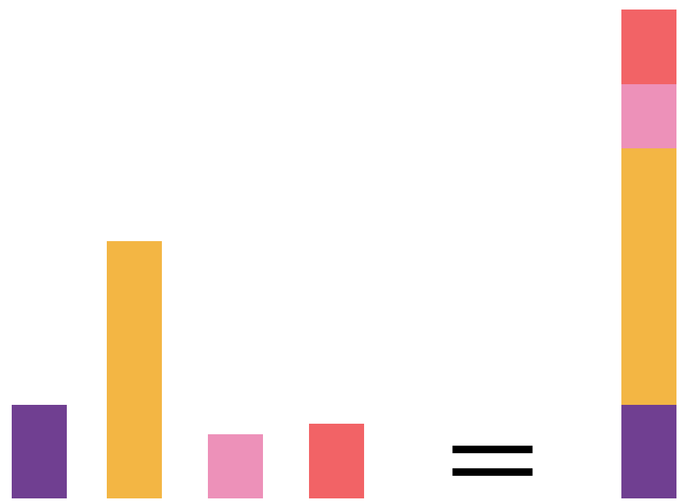
Investment Cost

Operational Cost

Maintenance Cost

Replacement Cost

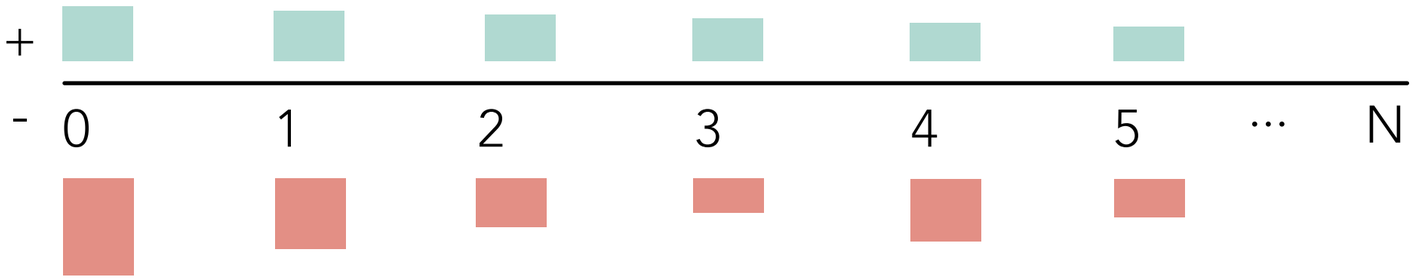


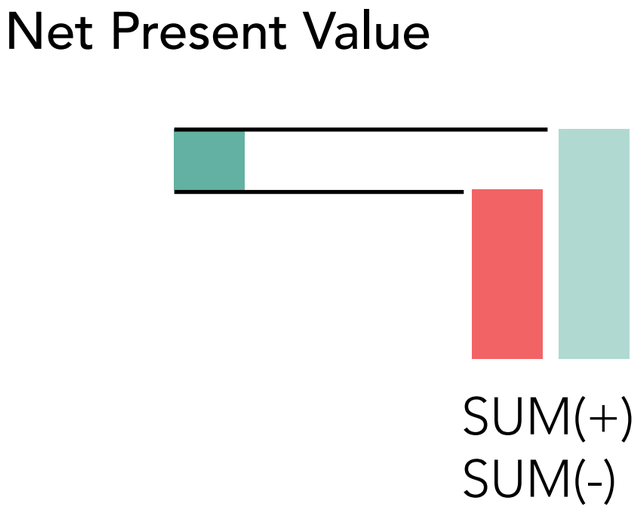


Total Cost

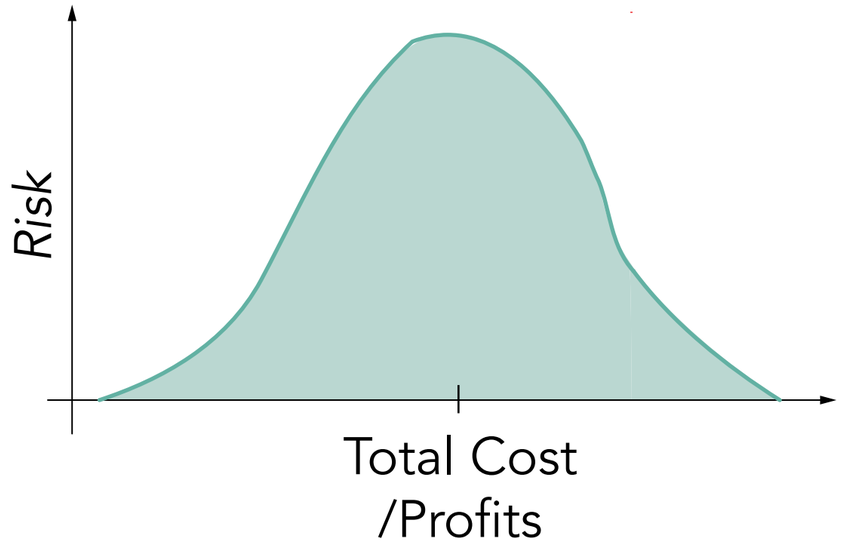
Cost-Benefit Analysis

Indicate Financial Feasibility



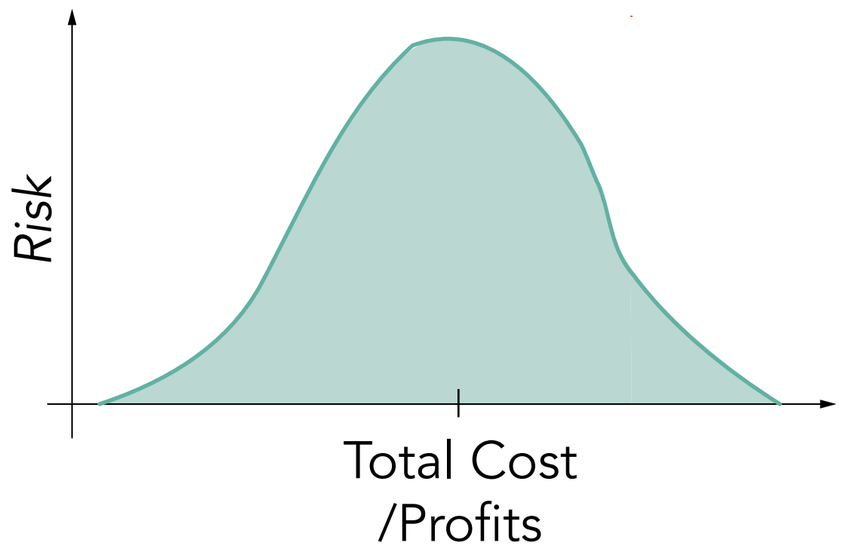


How to assess risk in cost-benefit?



How to assess risk in cost-benefit?

based on climate uncertainty



Risk assessment

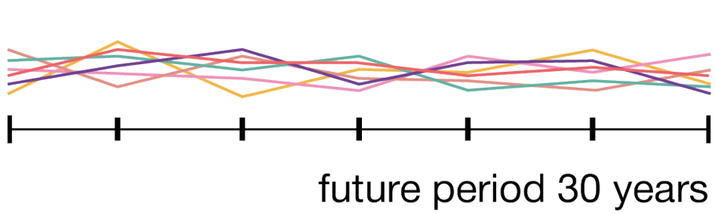
Investment Cost

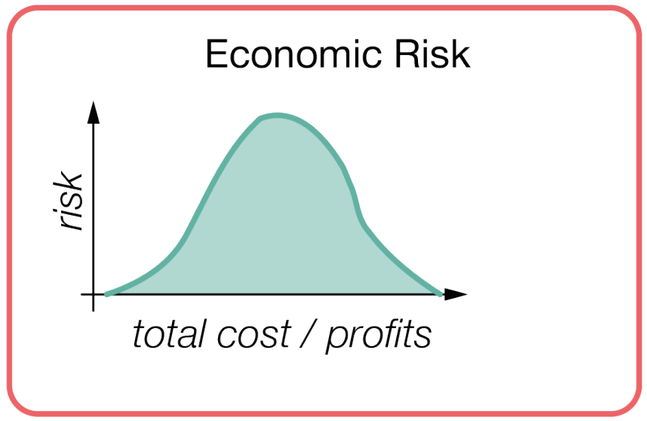
Revenue/Benefits

Operational Cost
**climate uncertainty*

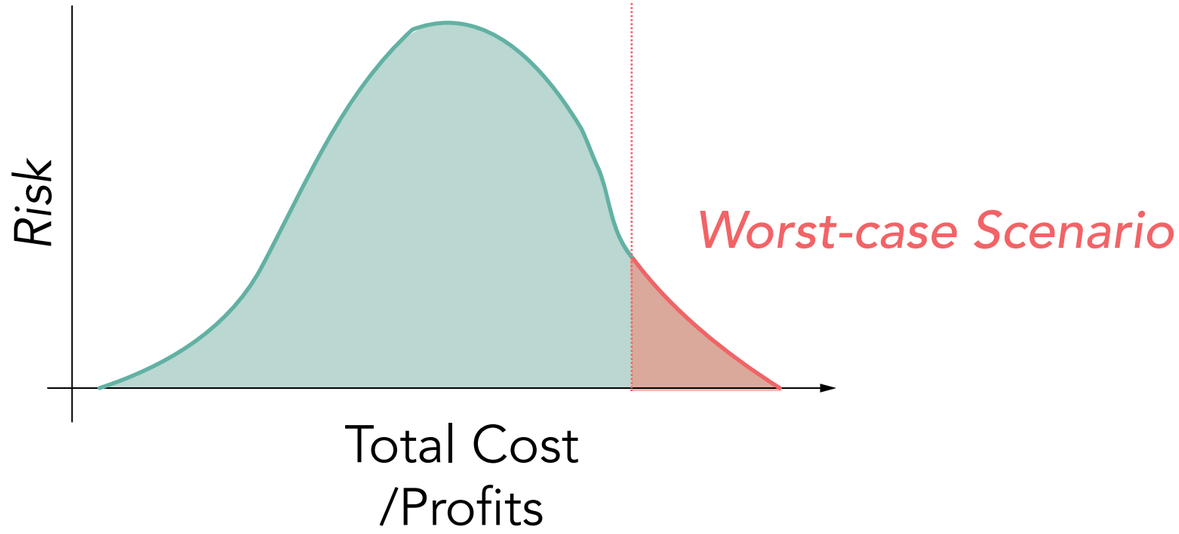
Maintenance Cost

Replacement Cost





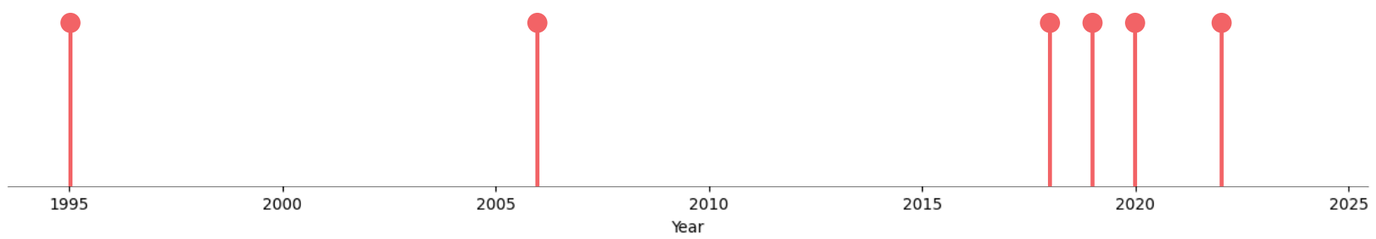
Economic Risk - Worst-case



But what is the worst case?

But what is the worst case?

15% chance for an extreme

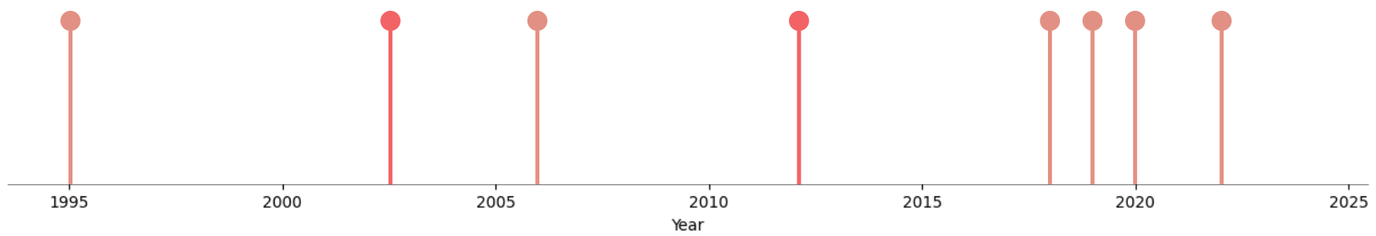


6 out of 30 years

But what is the worst case?

15% chance for an extreme

Worst-case Scenario



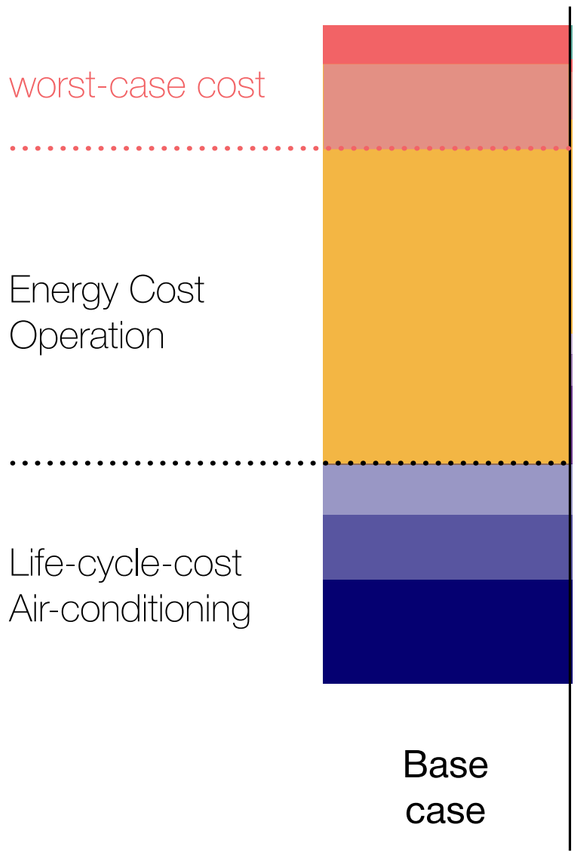
8 out of 30 years

Exceptionally frequent extremes

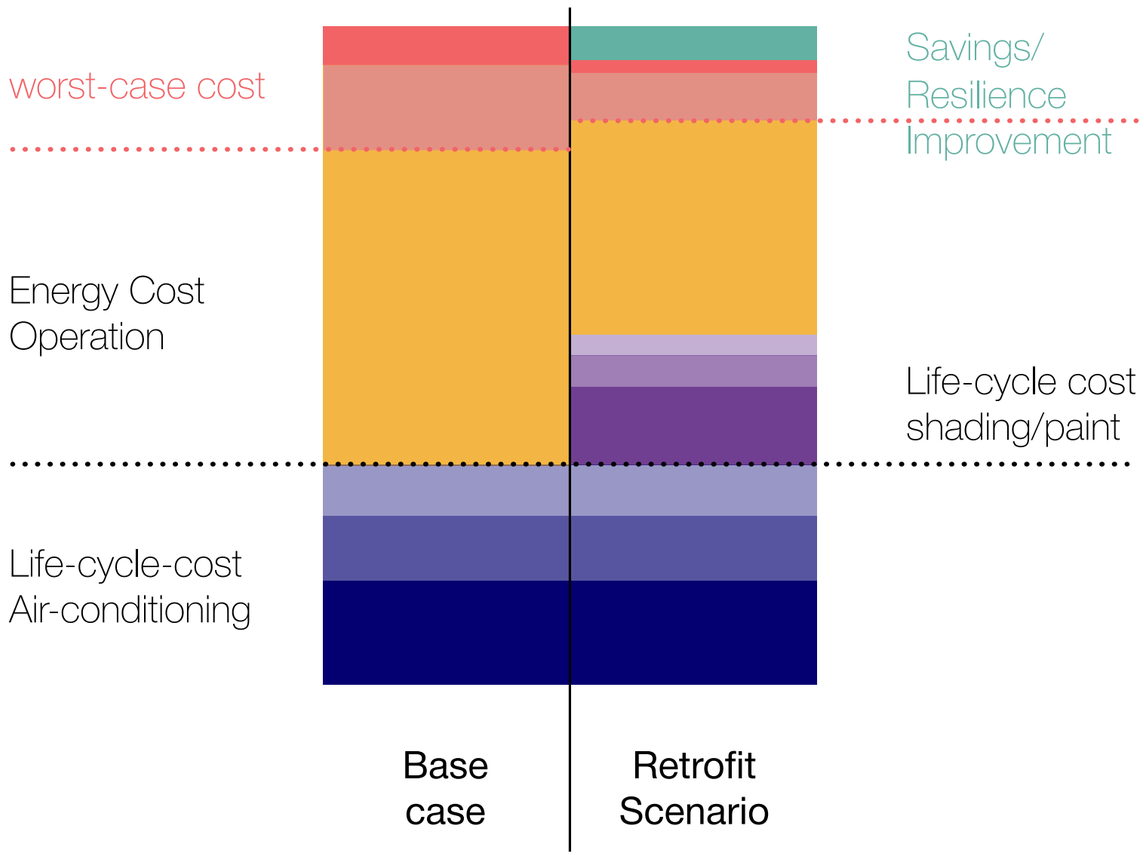
Indicators

Total Cost of Ownership	Net Present Value
Risk for total cost going up Risk for added cost worst-case	Risk for no profits Risk for worst-case outcome

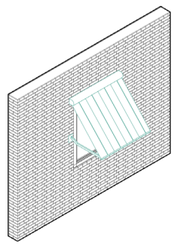
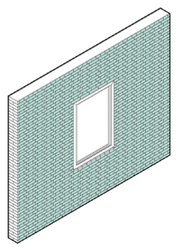
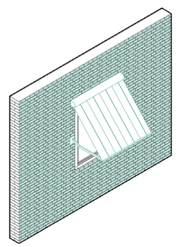
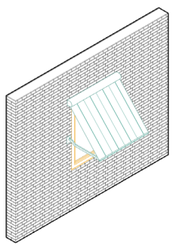
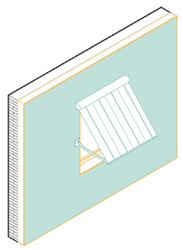
Analysis Outline



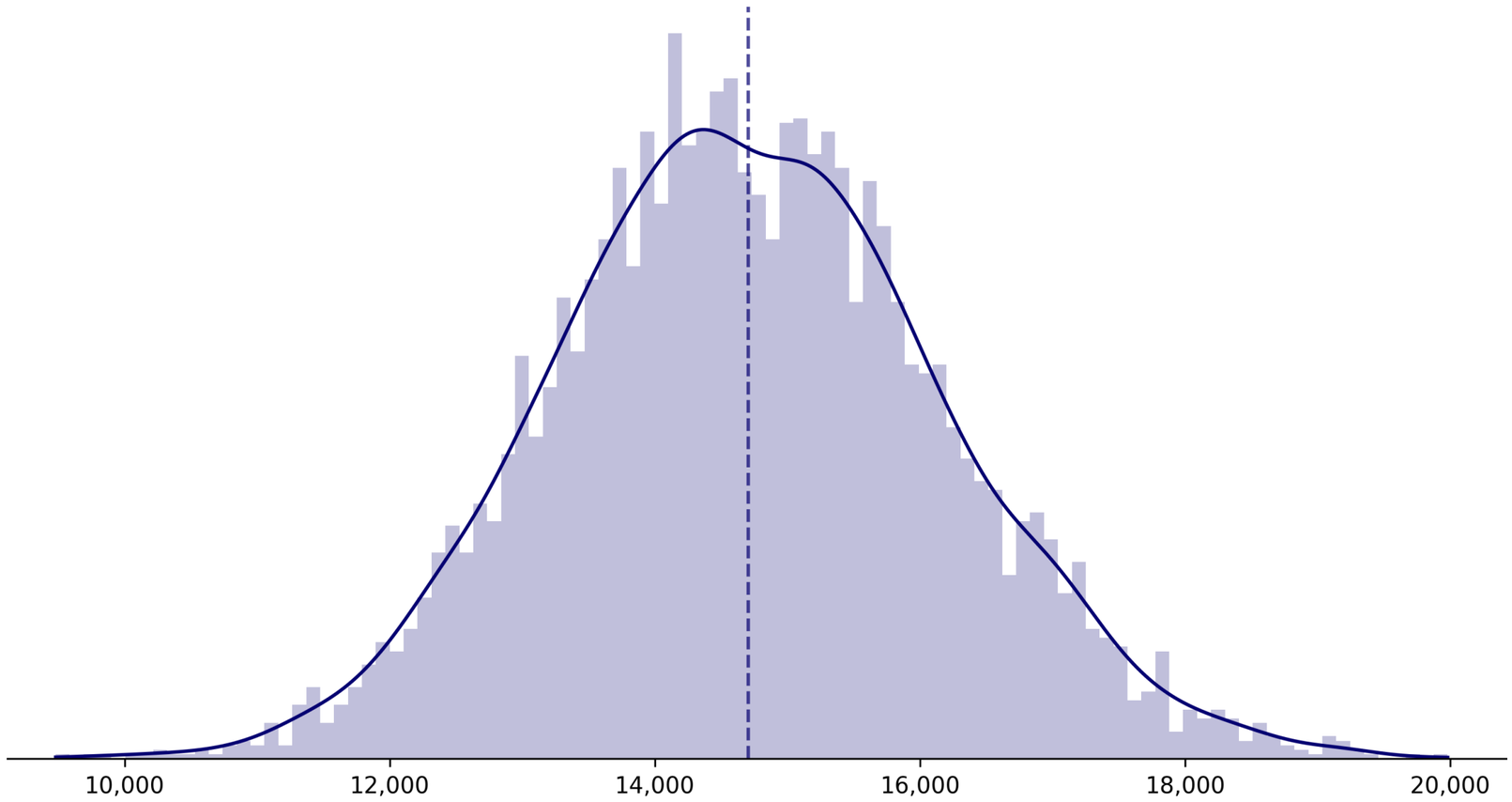
Analysis Outline



Added project cost for retrofitting

					
Investment Cost					
Heating	8,300.00 EUR	6,000.00 EUR	14,300.00 EUR	8,300.00 EUR	8,300.00 EUR
Cooling	12,149.00 EUR	12,149.00 EUR	12,149.00 EUR	54,849.00 EUR	96,349.00 EUR
Maintenance Cost					
items	470.00 EUR	0.00 EUR	470.00 EUR	470.00 EUR	470.00 EUR
	5 years	0 years			
cycles			5 years	5 years	5 years
Replacement Cost					
items	0.00 EUR	6000.00 EUR	6000.00 EUR	0.00 EUR	6000.00 EUR
cycles	0 years	15 years	15 years	0 years	15 years
Total Cost	**22,185.00 Eur**	**22,000.00 Eur**	**31,035.00 Eur**	**64,884.00 Eur**	**110,235.00 Eur**

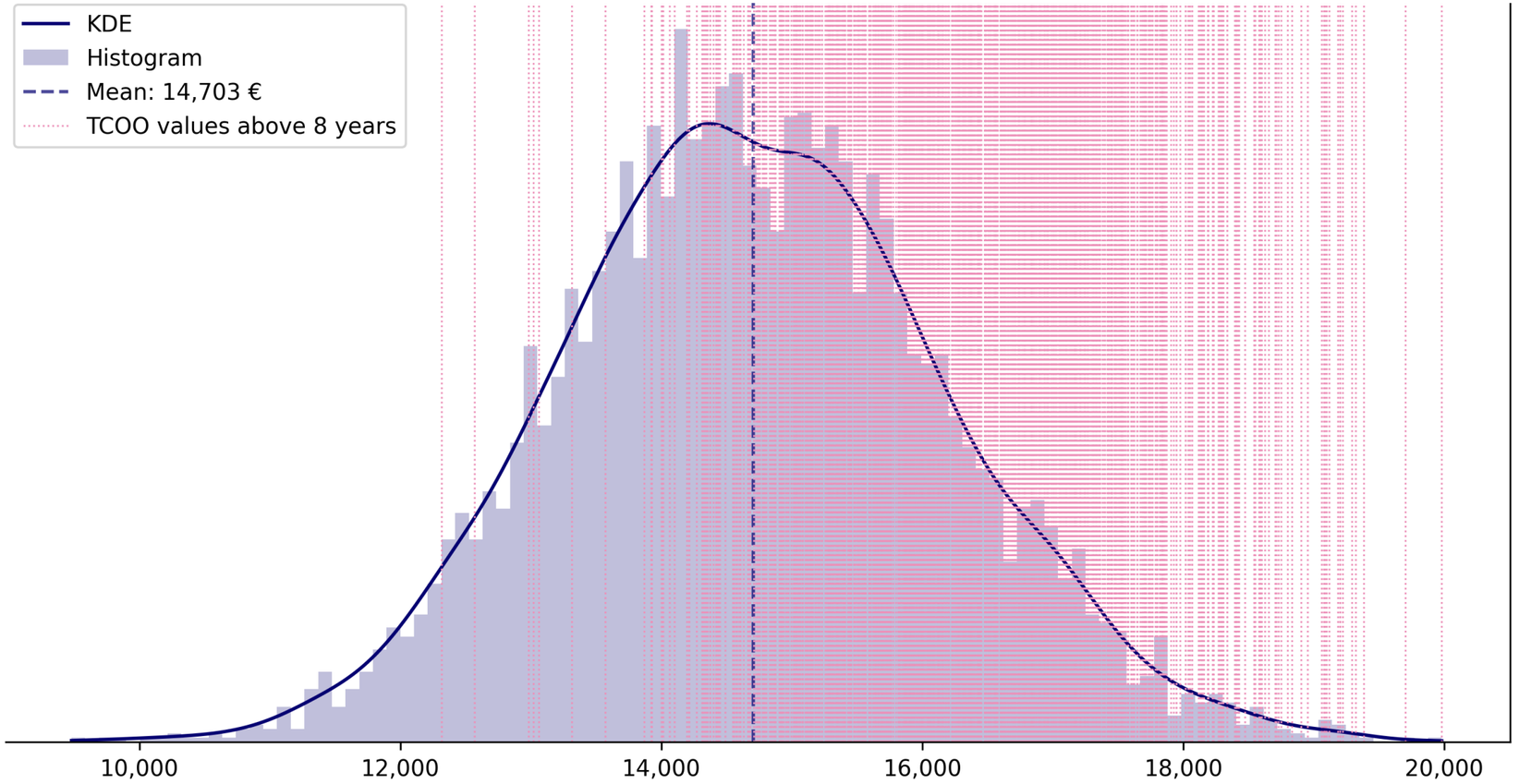
Total Cost



Baseline Total Cost - Cooling

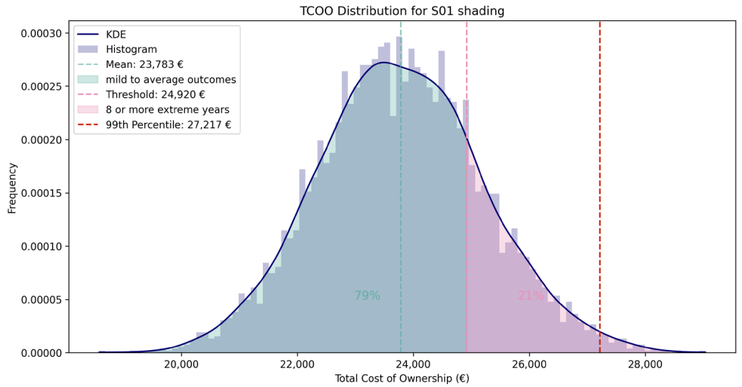
Total cost for the baseline just operational cost

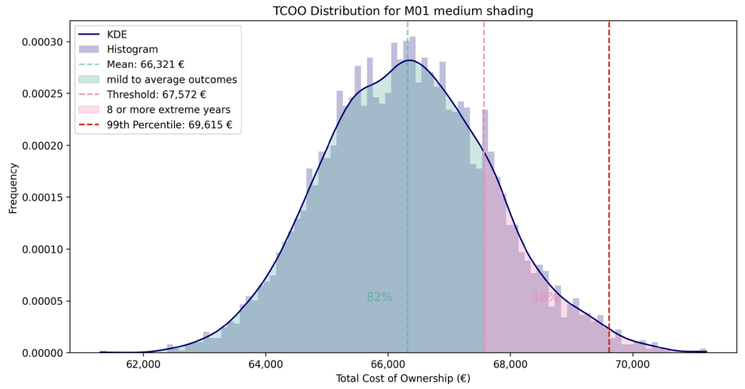
Where are the worst-case results?

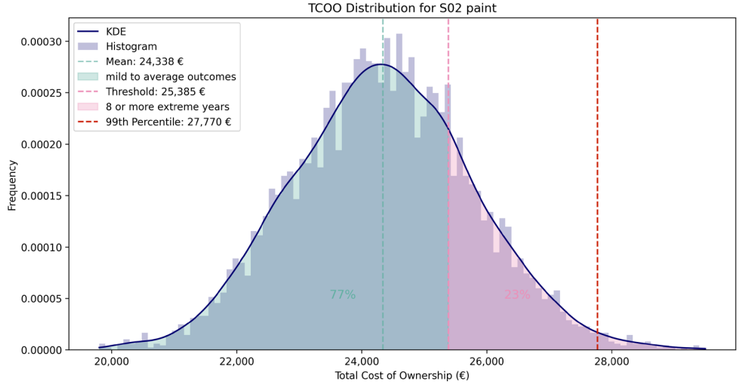


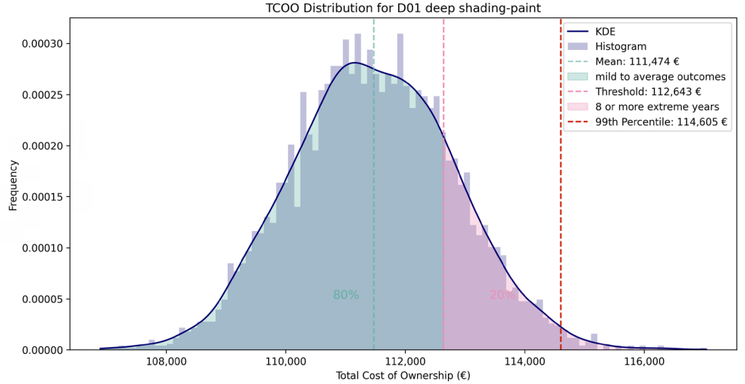
Defining a worst-case range

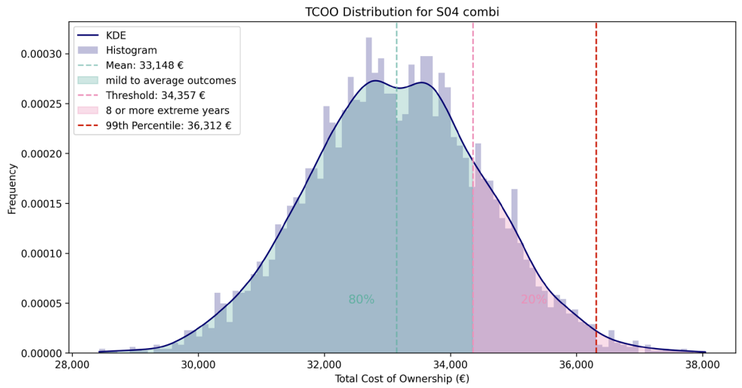
Scenario Total Cost Results





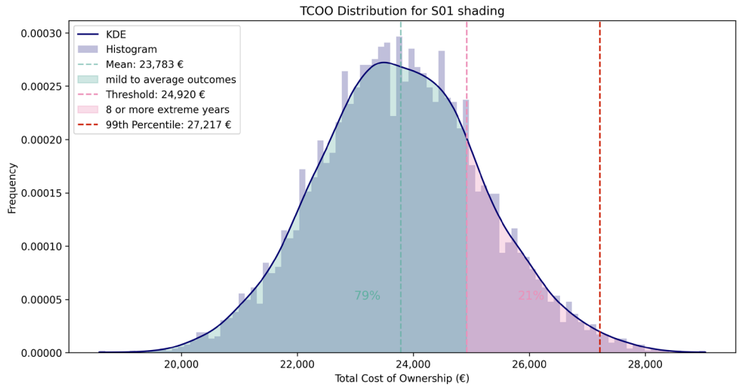


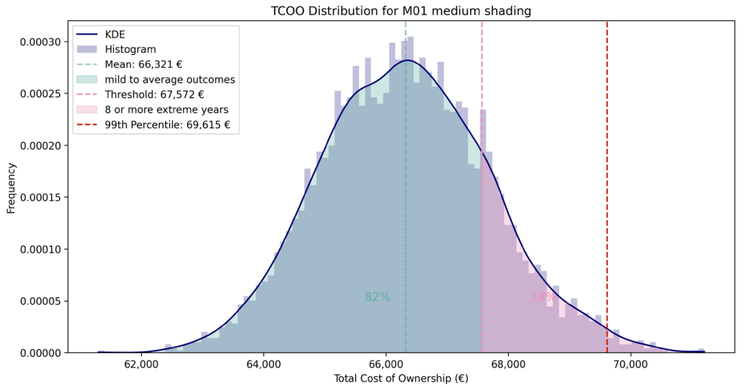


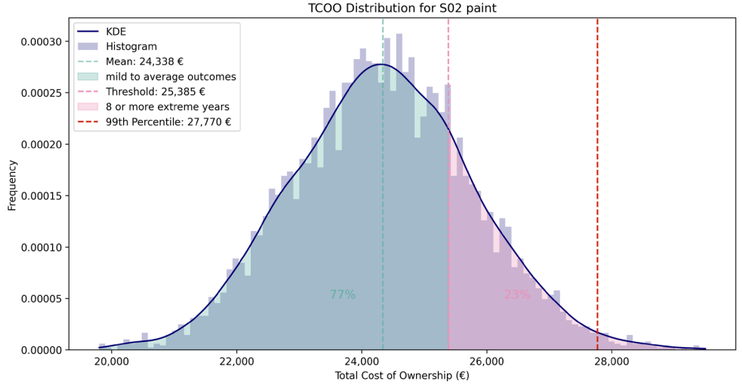


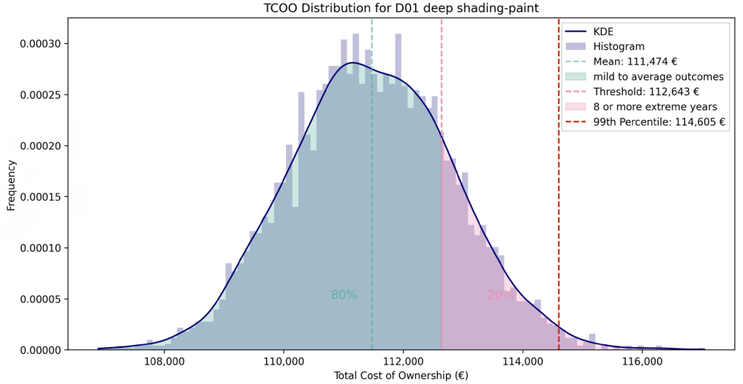
Cost-Benefit Analysis

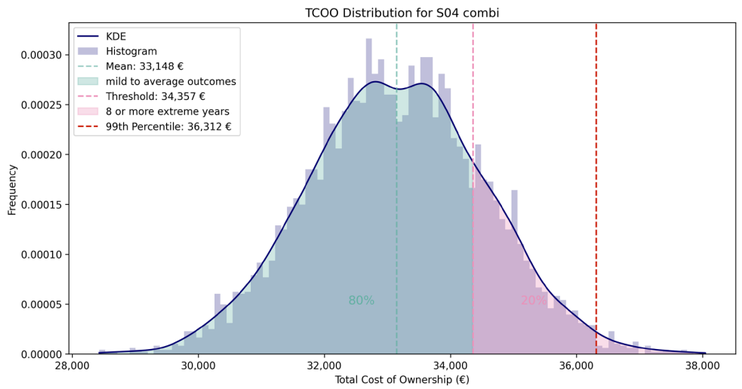
Scenario Total Cost Results





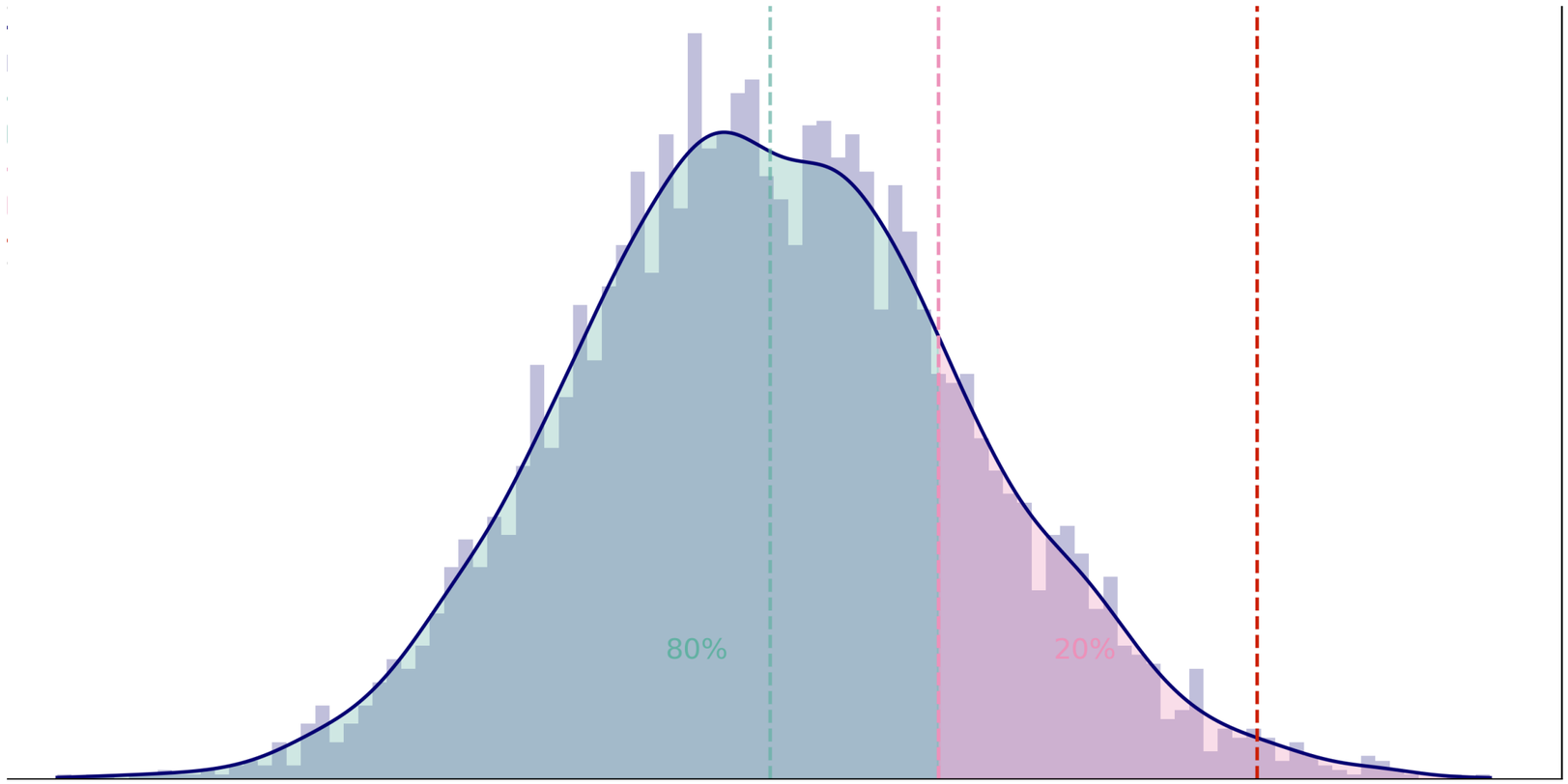






Now What?

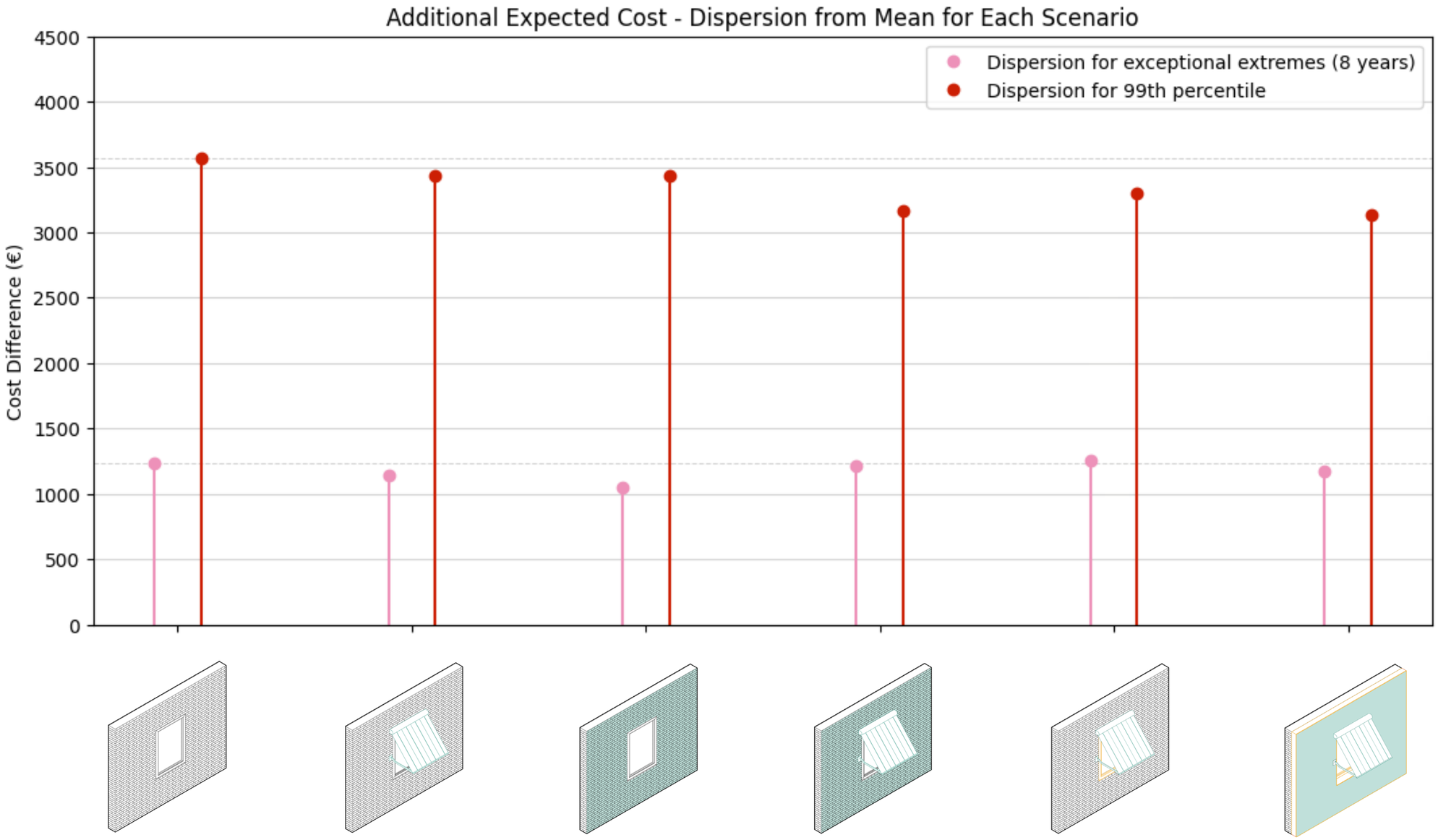
What is the added cost for the worst-case?



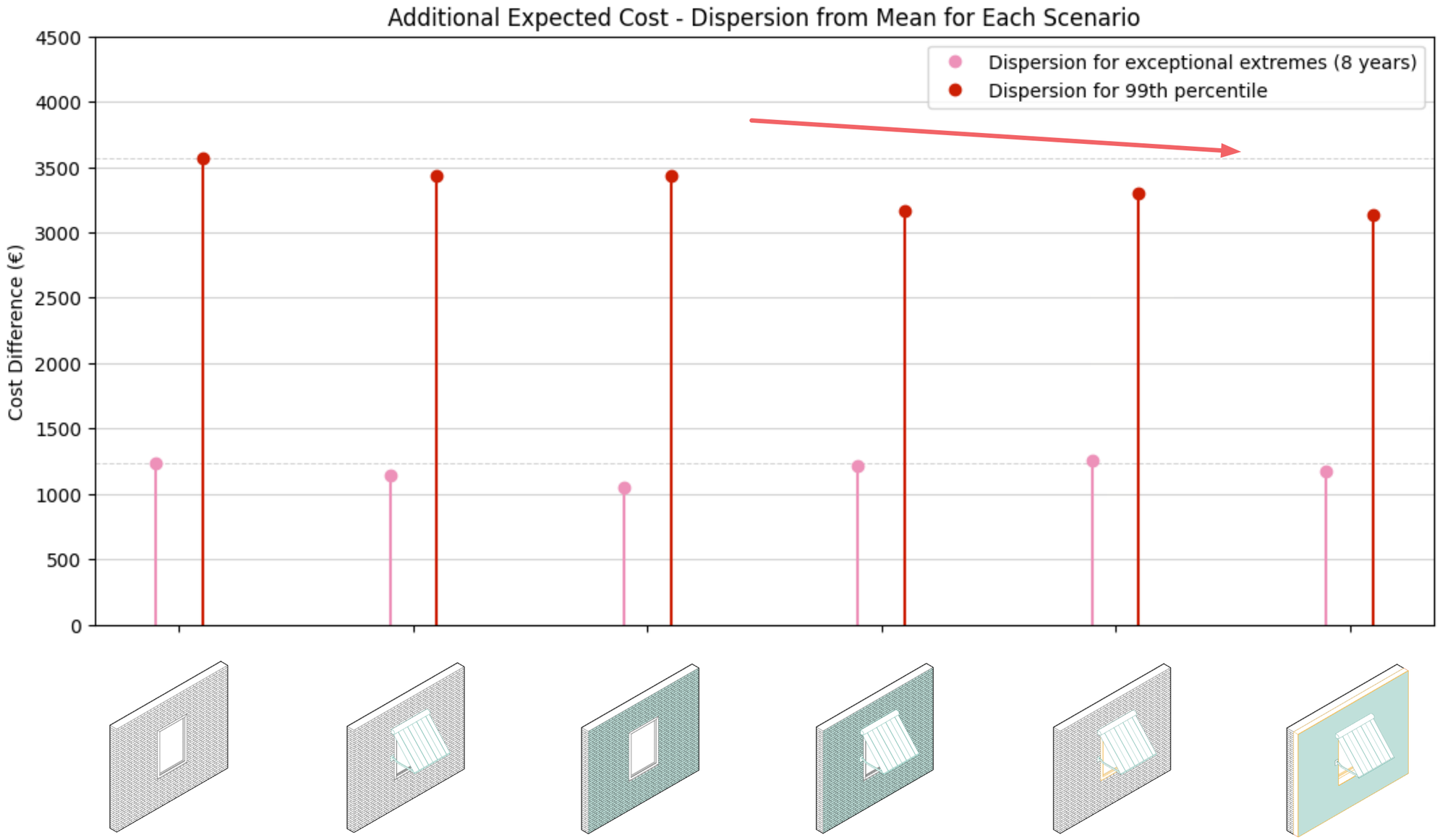
Added cost minimum

Added cost maximum

Comparing the added cost for the worst case

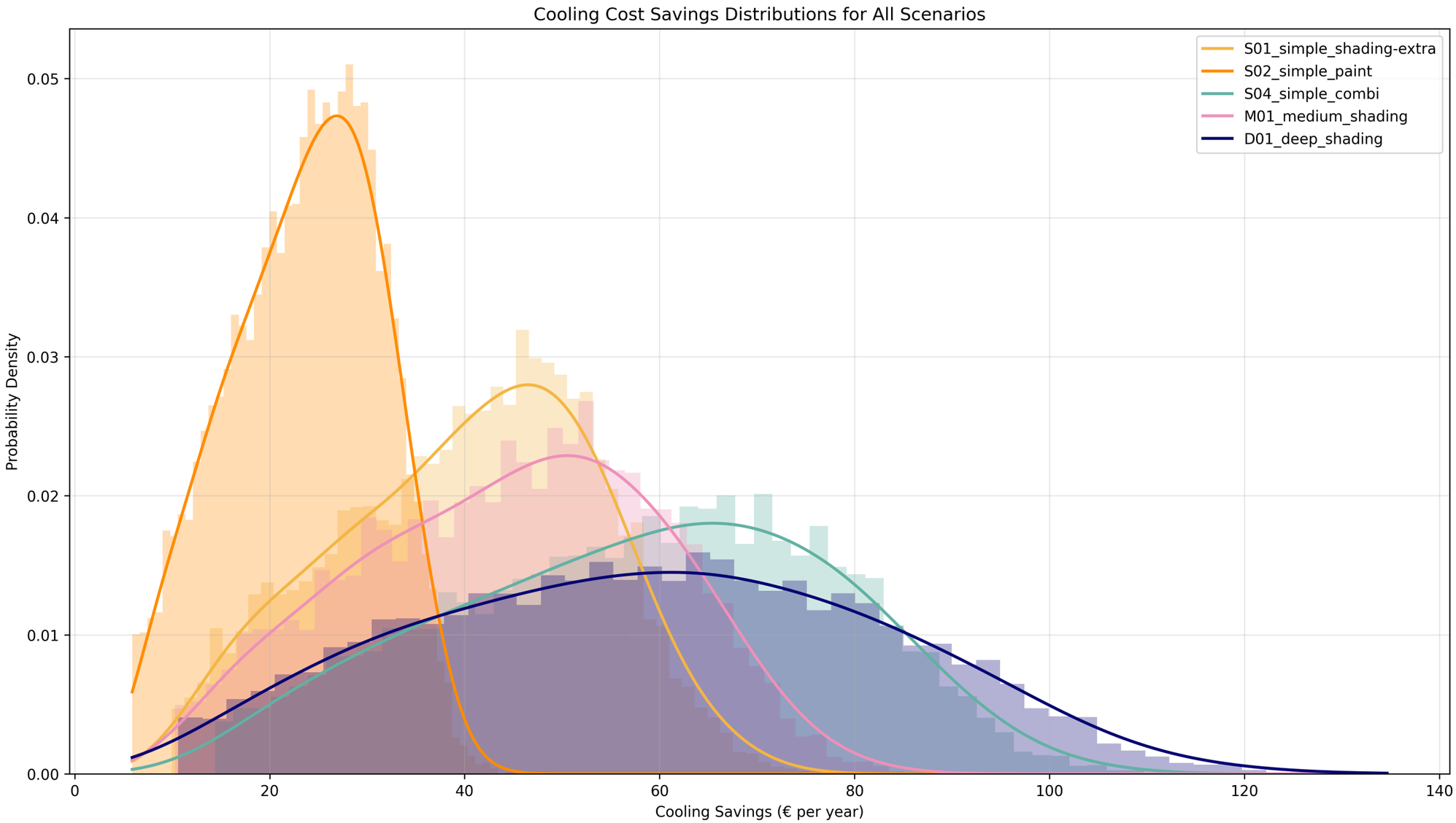


Comparing the added cost for the worst case

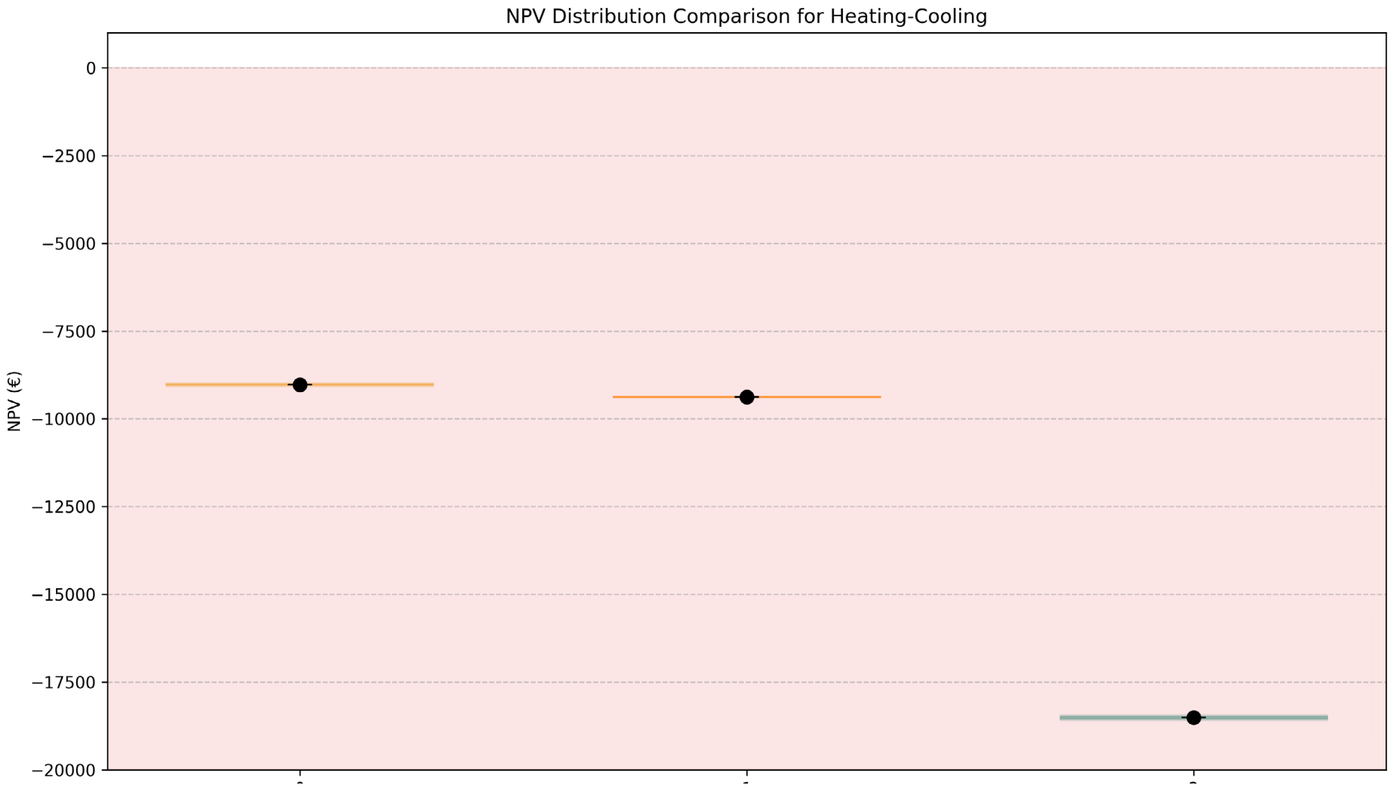


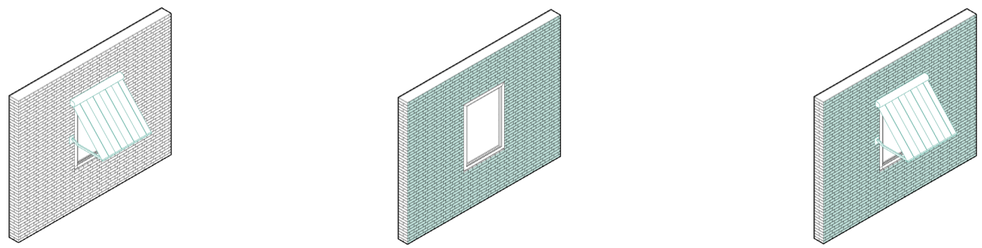
What is the potential for cost recovery?

Cooling Energy Savings



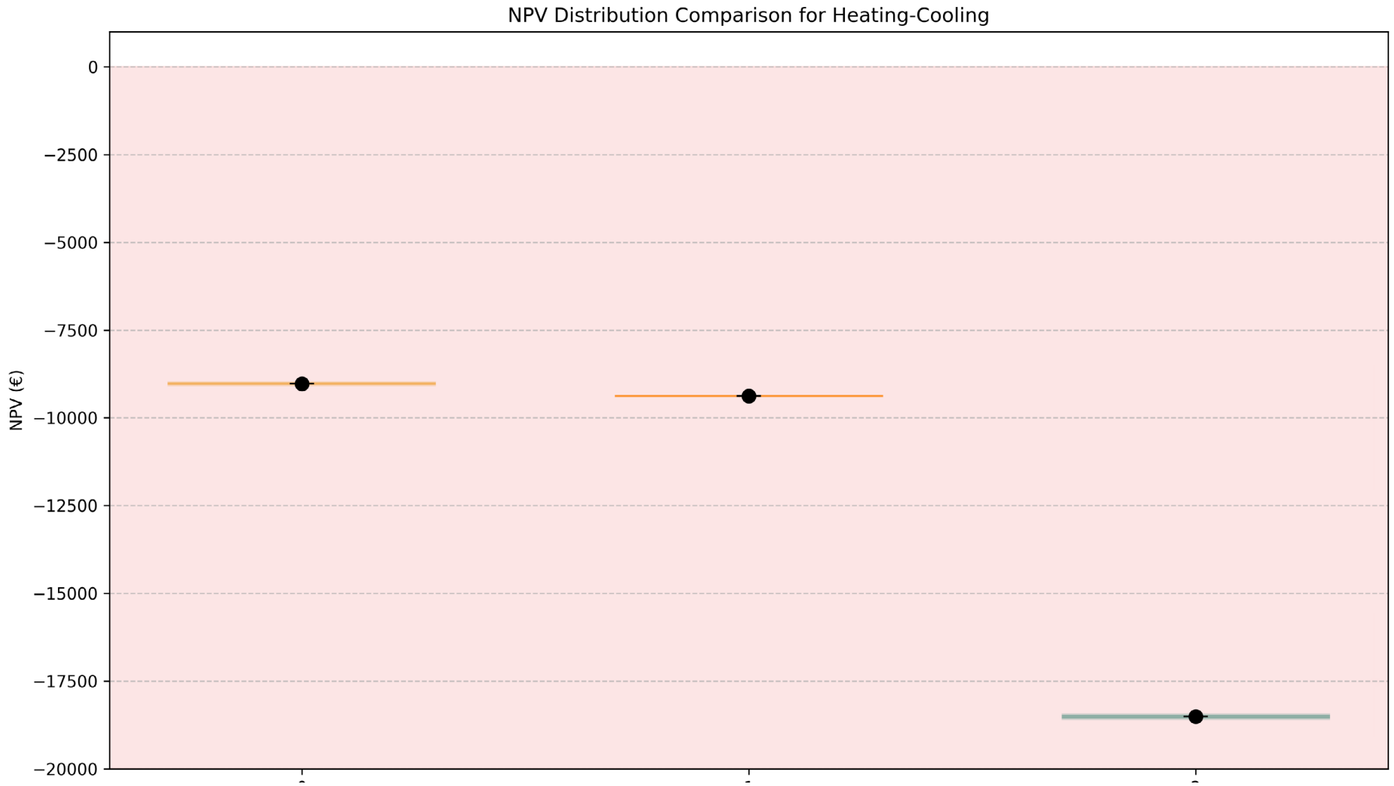
NPV Cooling

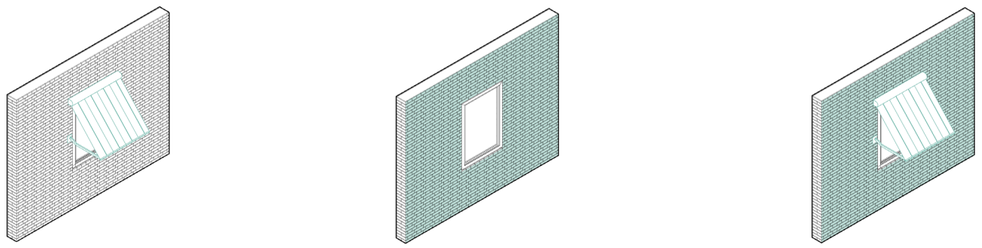

NPV Distribution Comparison for Heating-Cooling
NPV (€)
0
−2500
−5000
−7500
−10000
−12500
−15000
−17500
−20000

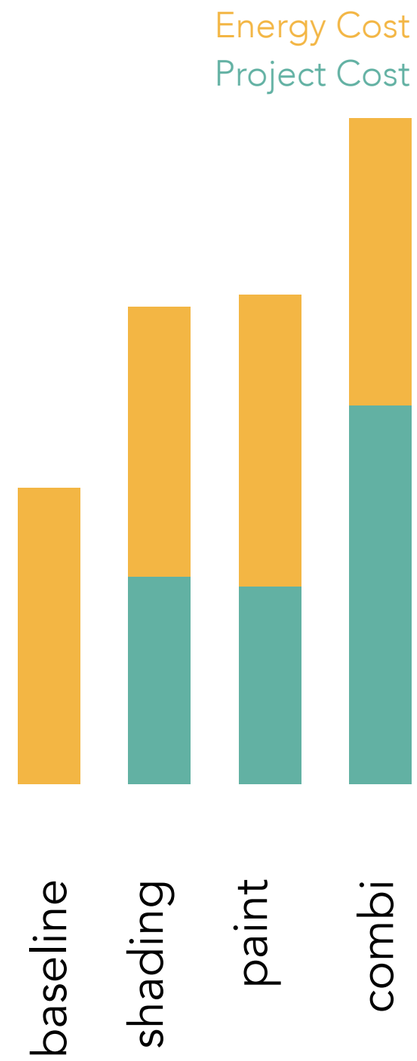


Cost-Benefit Results

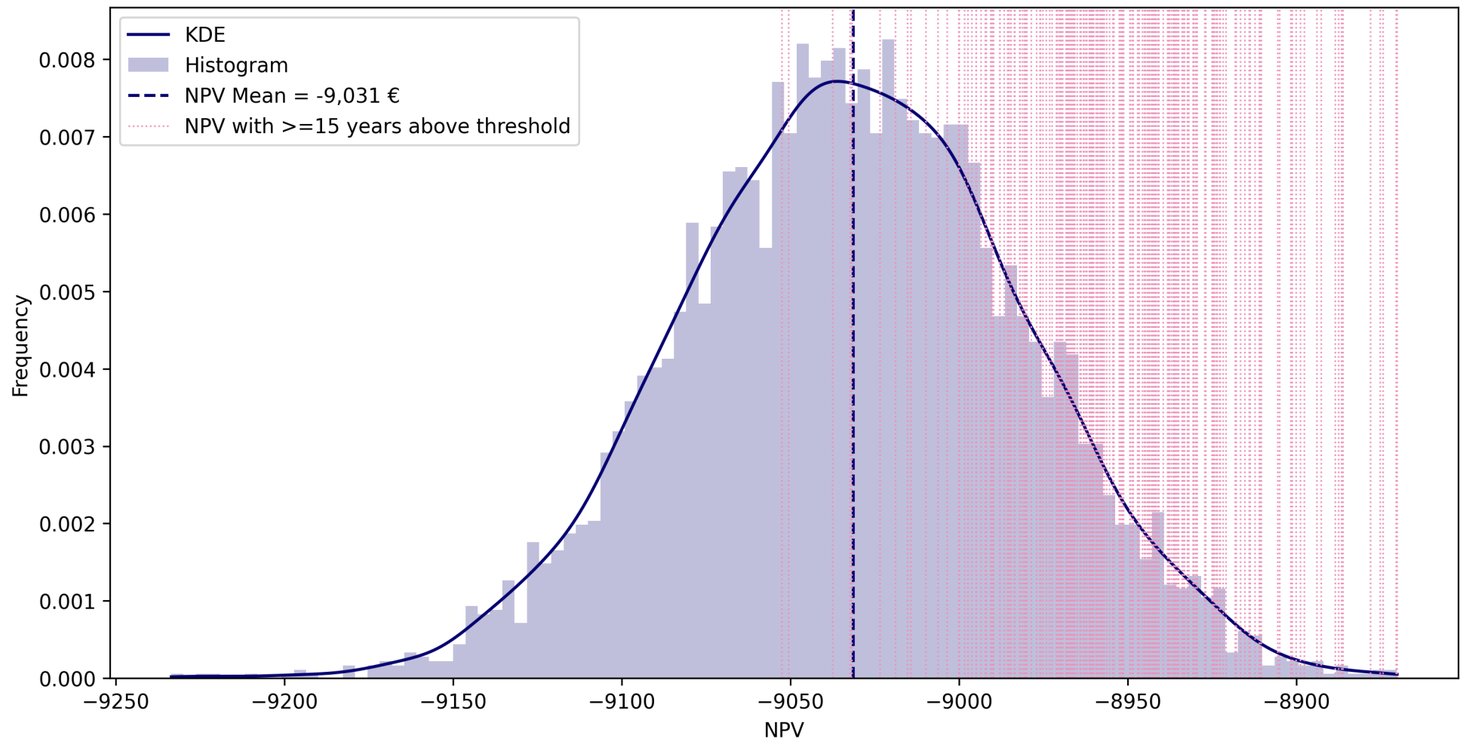
NPV Cooling





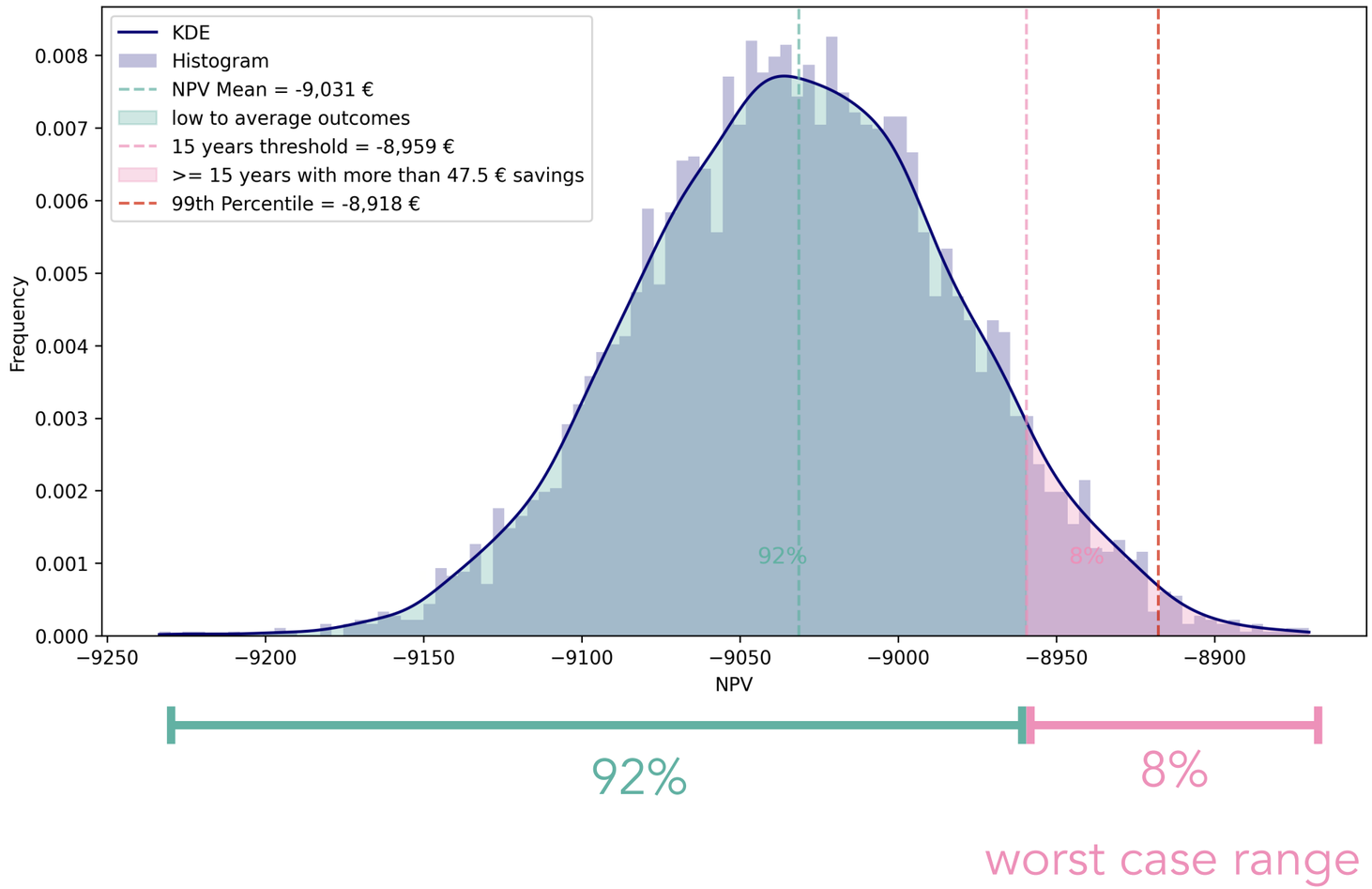


Does the worst-case affect cost recovery?



Cost-Benefit Results

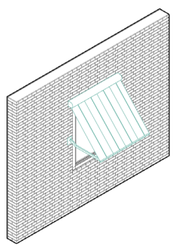
Does the worst-case affect cost recovery?

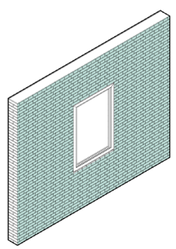


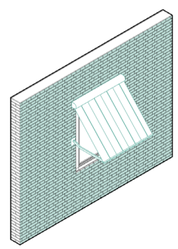
Cost-Benefit Results

Worst-case range for the scenarios?

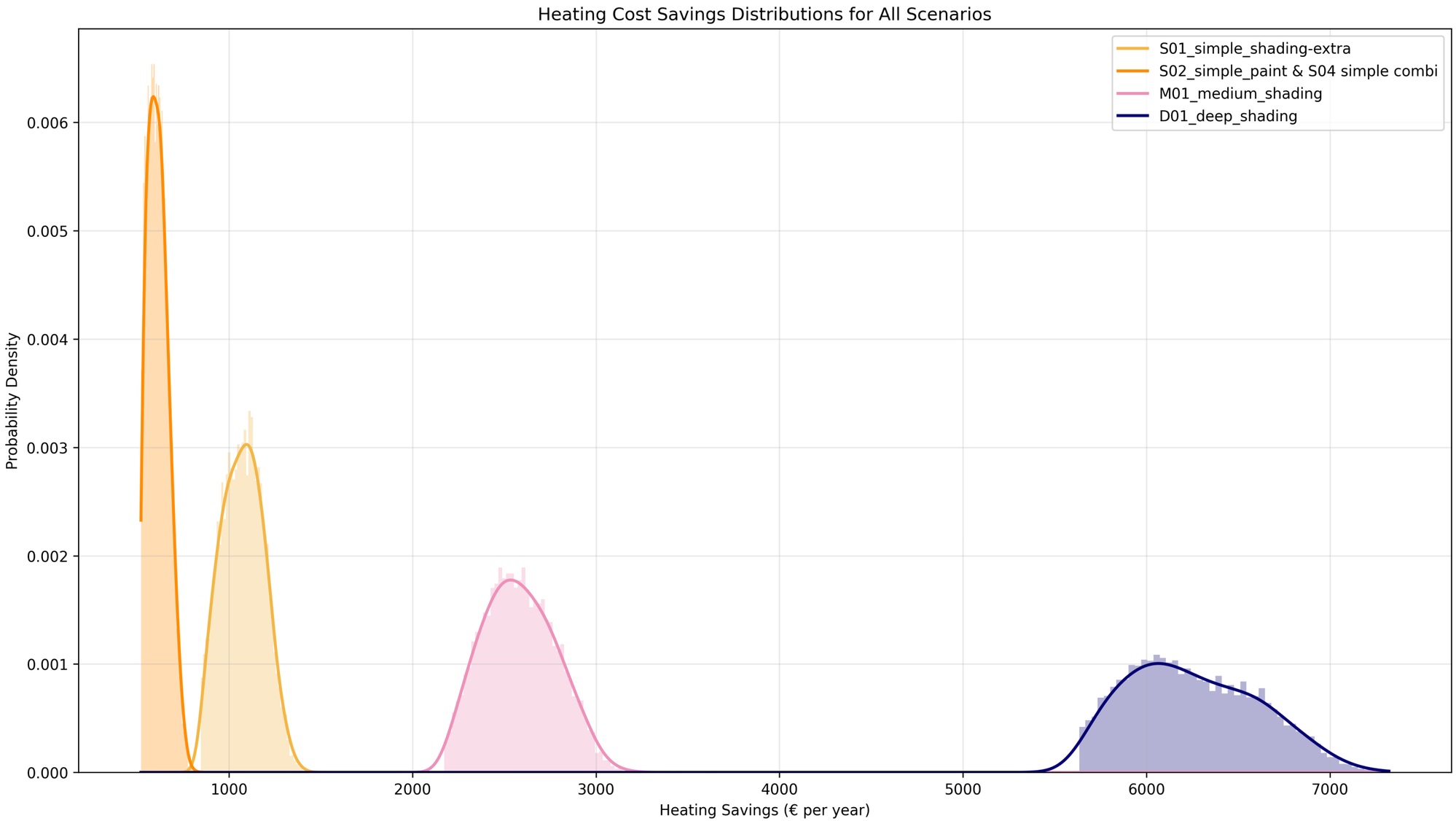
mean	-9,031 Eur		-9376 Eur		-18,513 Eur	
min worst case	-8,959 Eur	**+ 72 Eur**	-9,331 Eur	**+ 45 Eur**	-18,404 Eur	**+109 Eur**
max worst-case	-8,918 Eur	**+113 Eur**	-9,309 Eur	**+ 67 Eur**	-18,344 Eur	**+169 Eur**





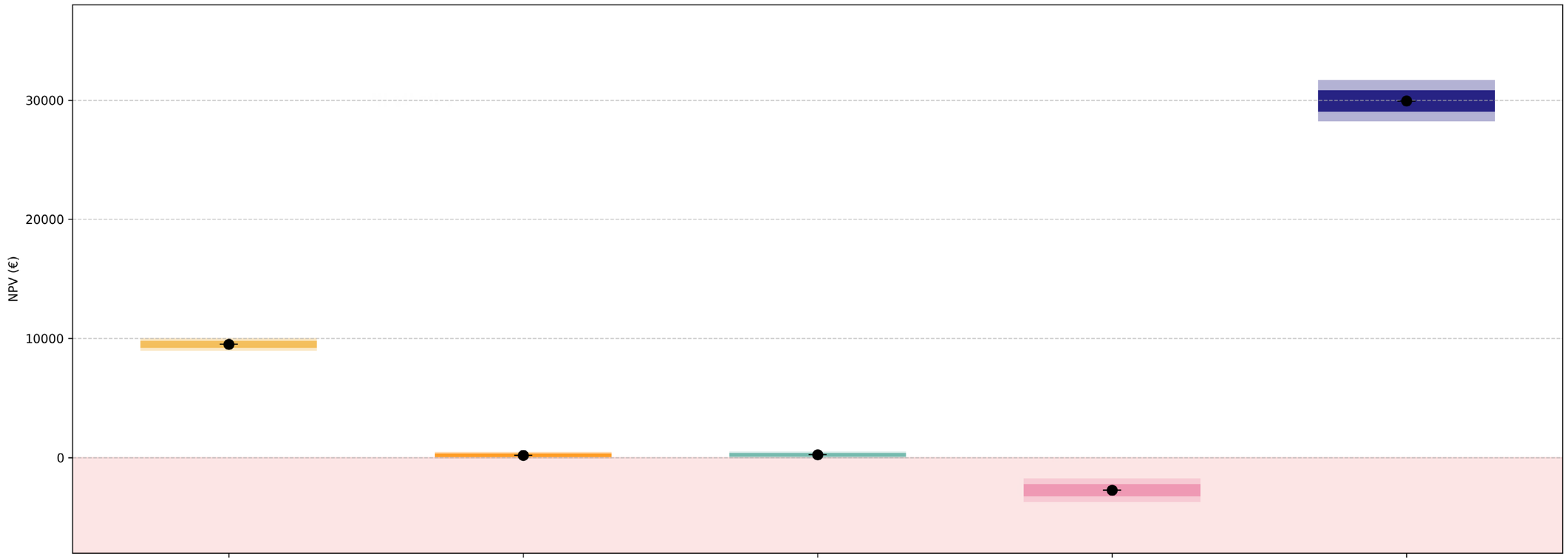


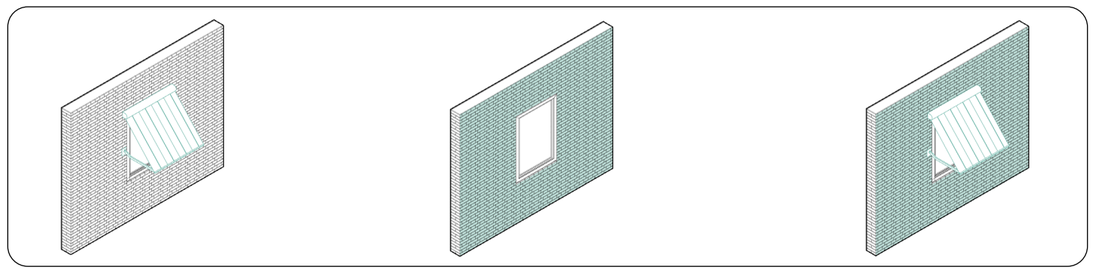
Heating Savings



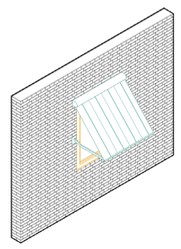
Cost-Benefit Results

Heating Only NPV

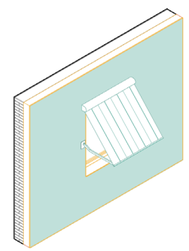




Distict Heating



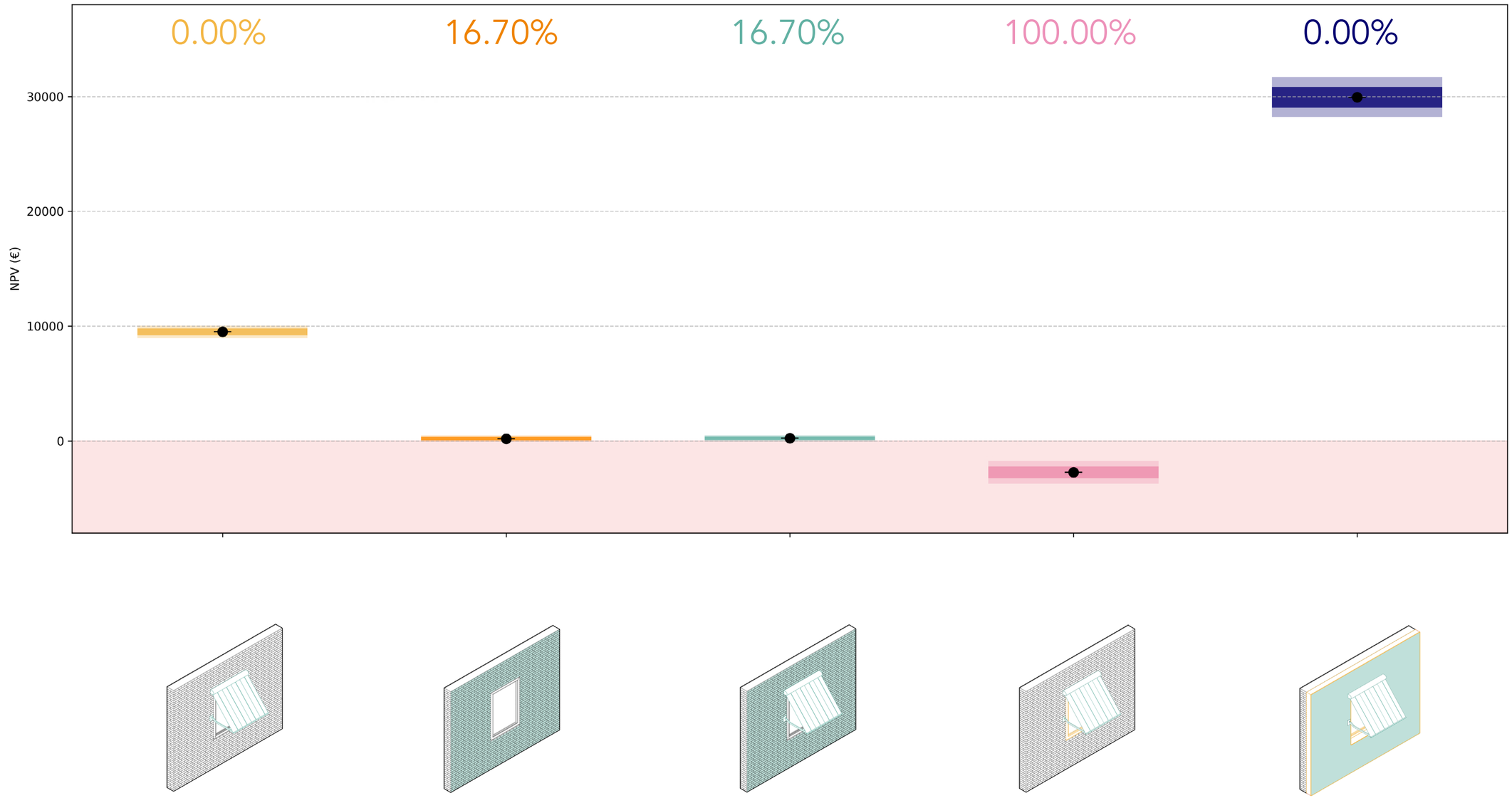
Windows



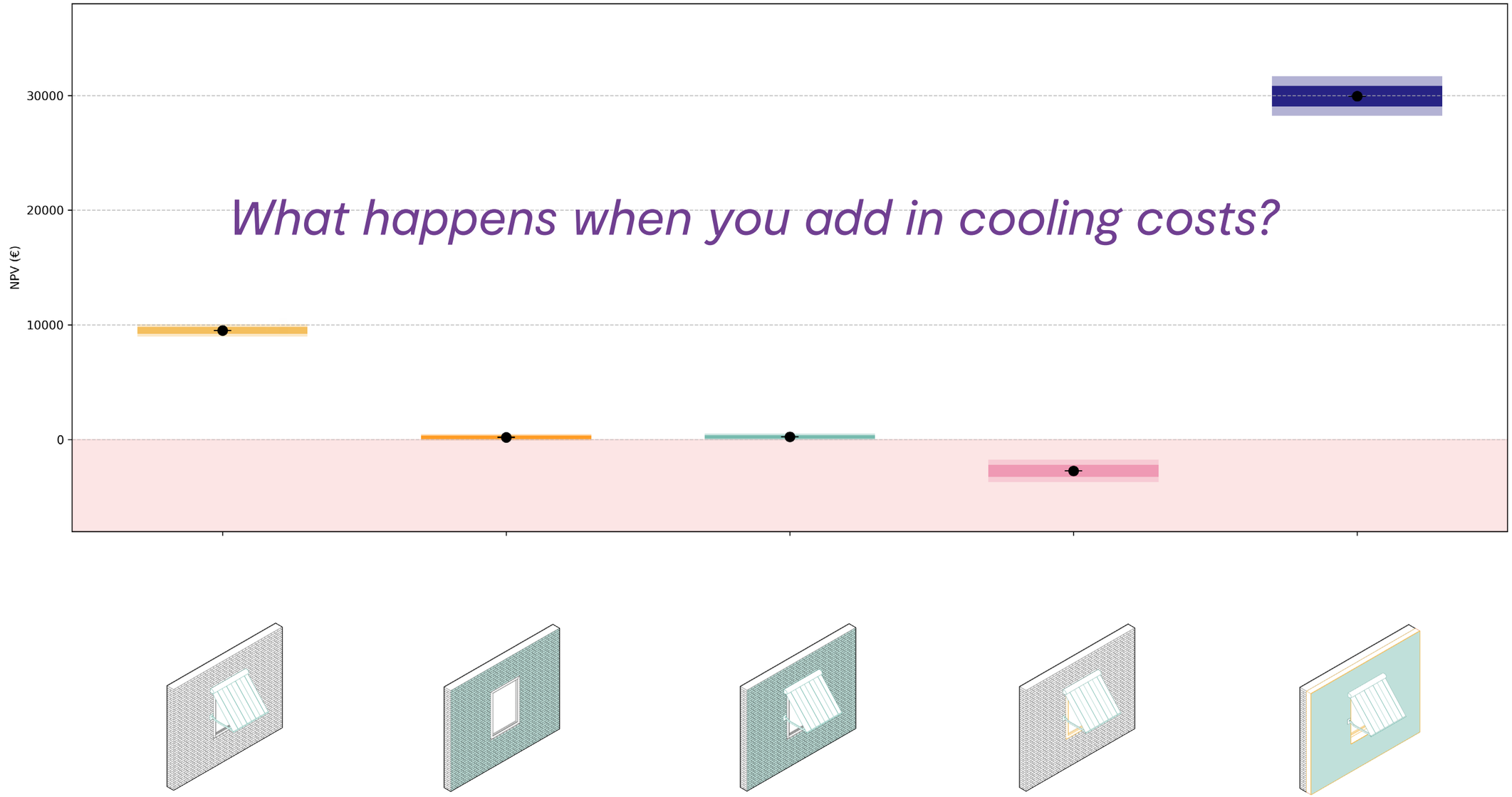
Full Facade

Cost-Benefit Results

Heating Only NPV

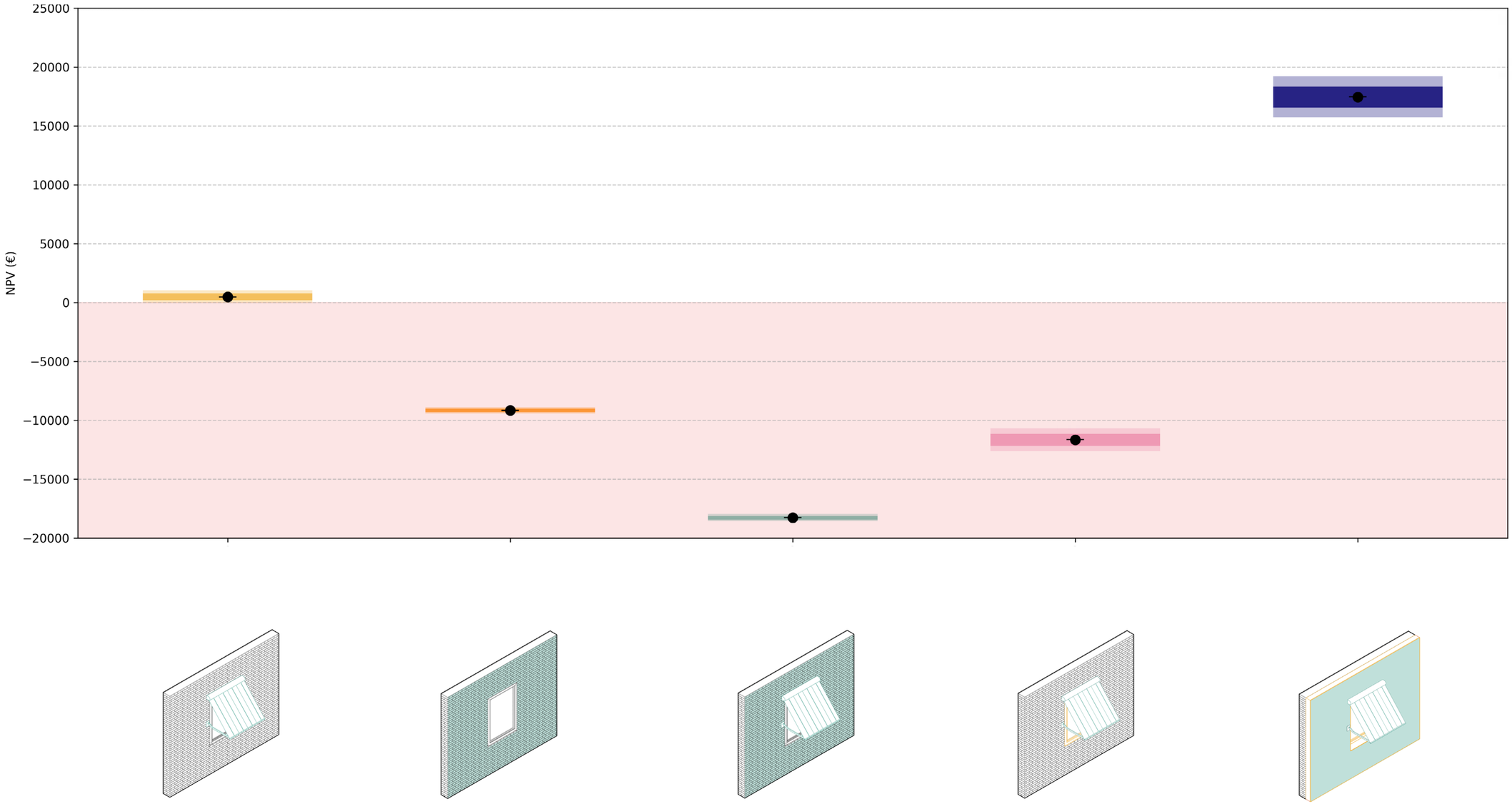


Heating Only NPV



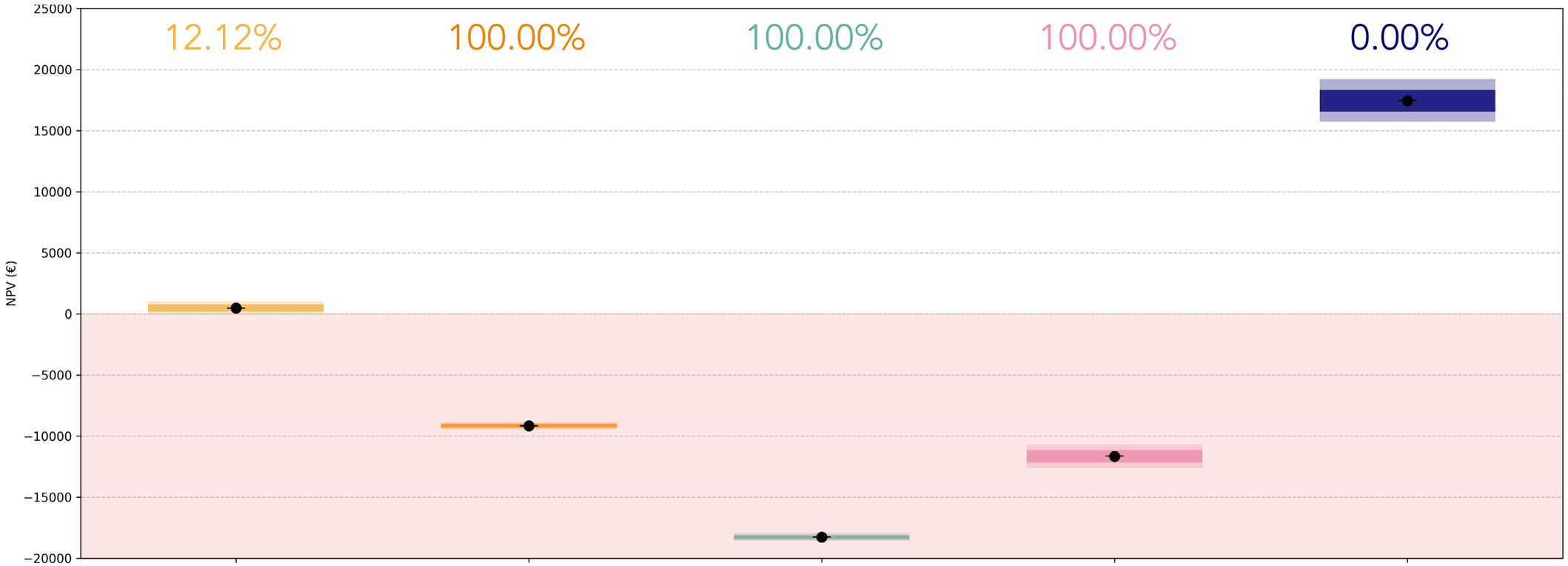
Cost-Benefit Results

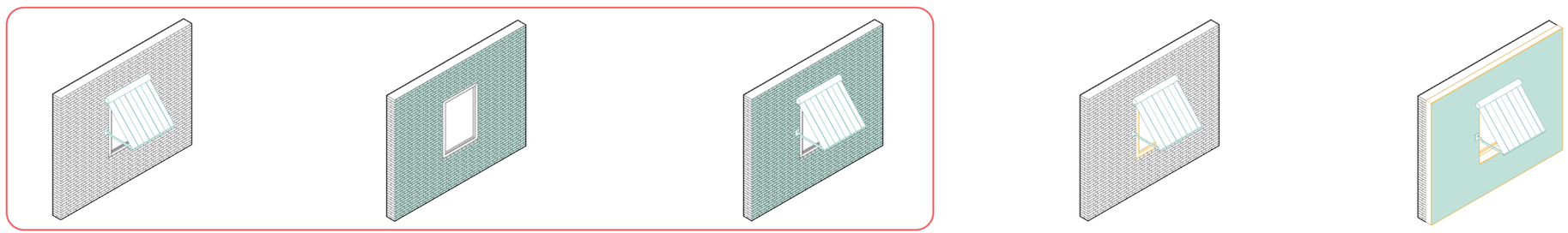
Heating & Cooling Integration



Cost-Benefit Results

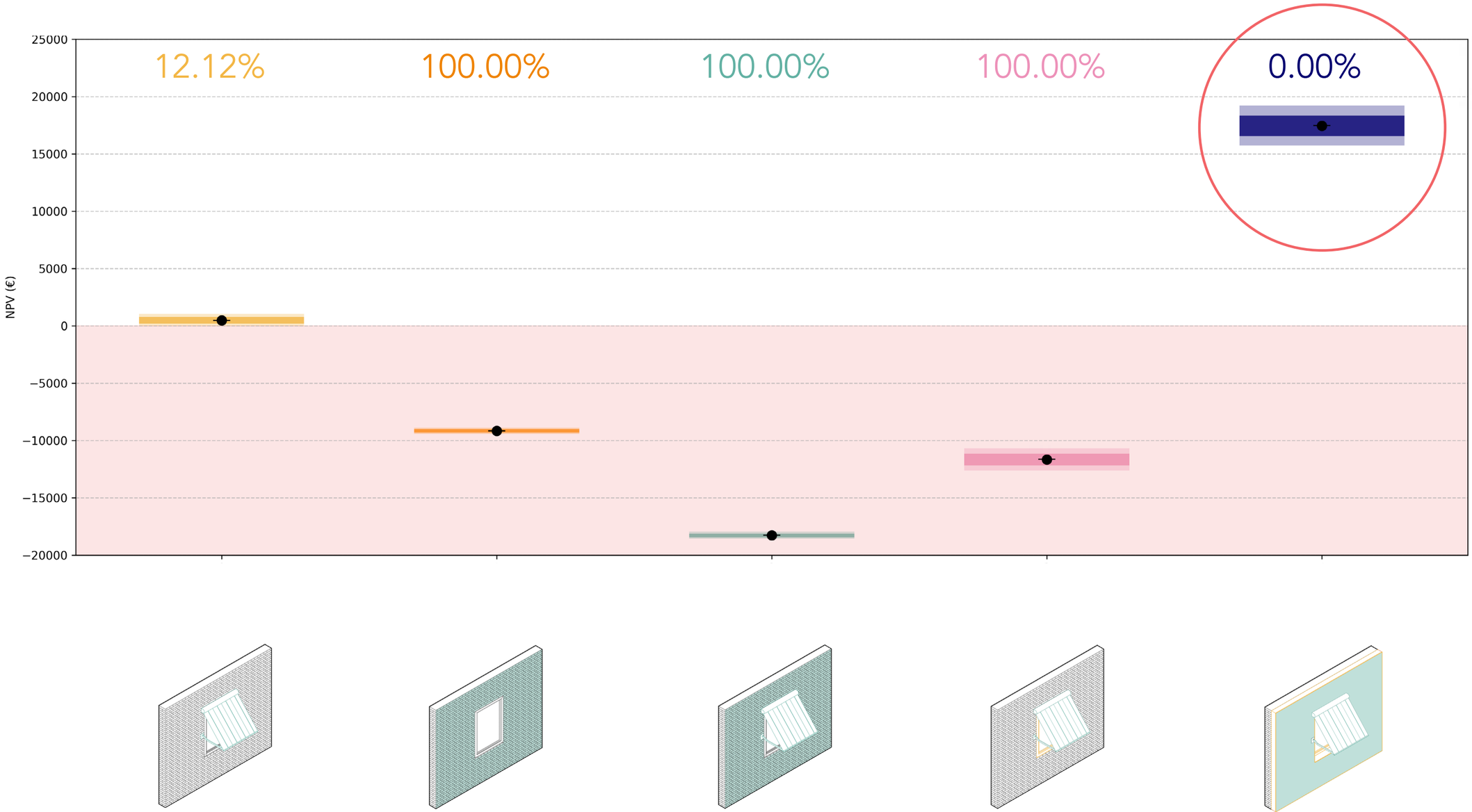
Heating & Cooling Integration



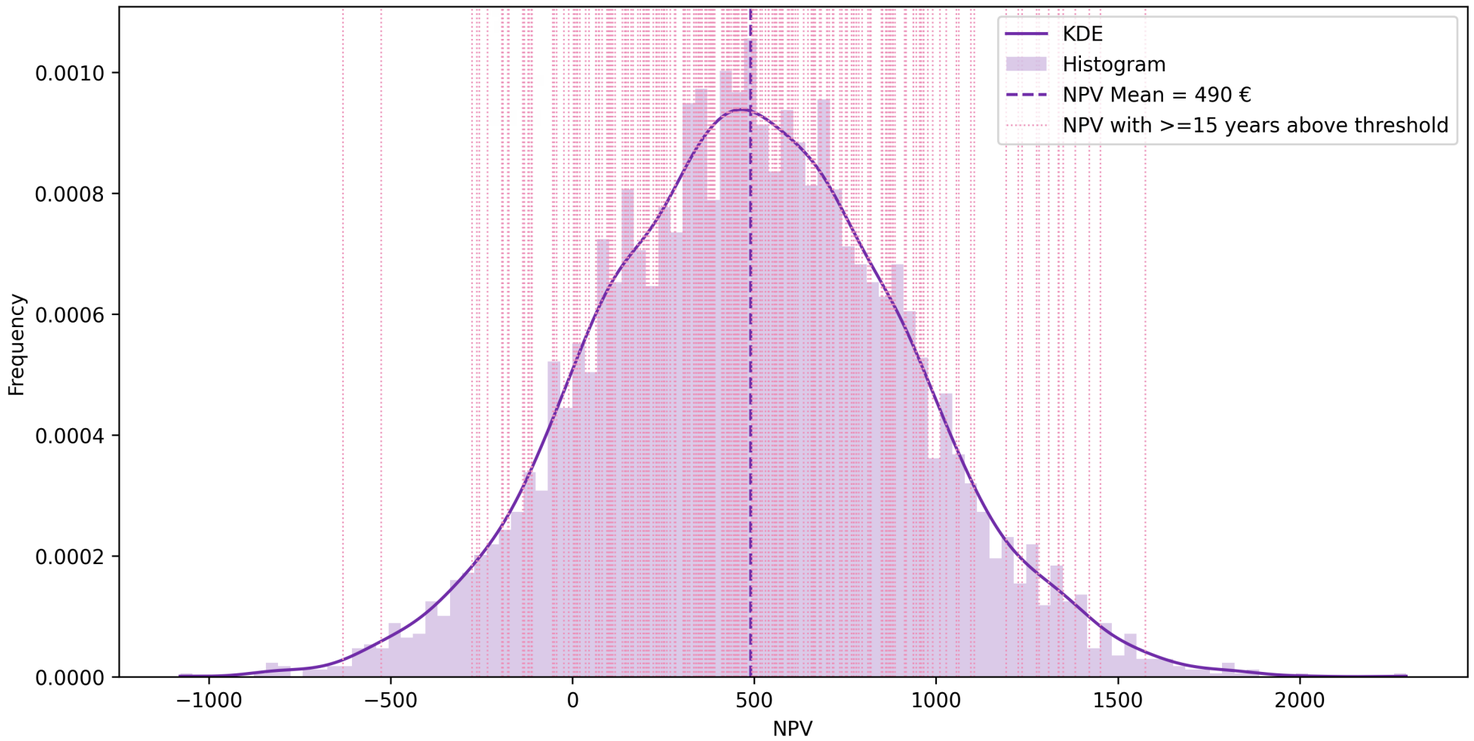


Cost-Benefit Results

Heating & Cooling Integration

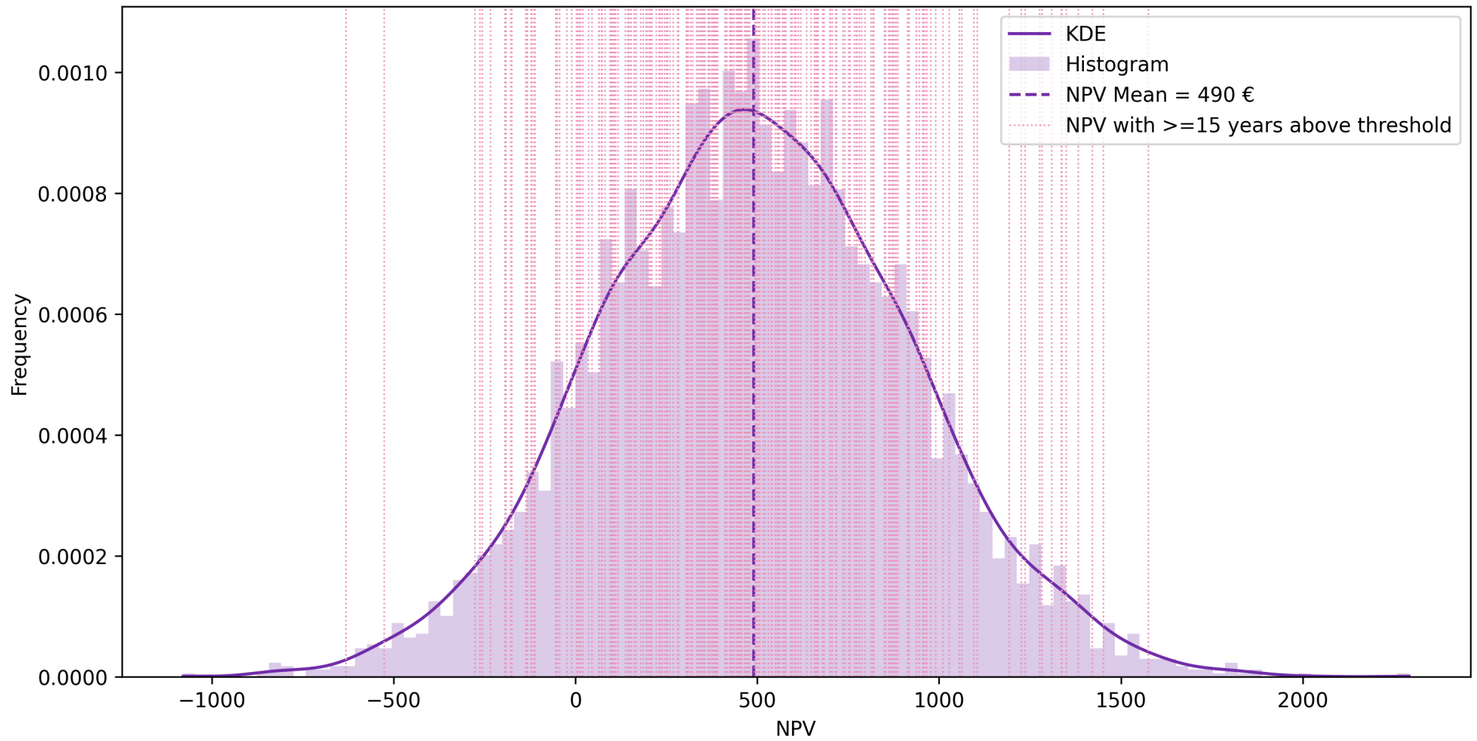


What was the influence of the worst-case?



NPV Results for Simple Shading

What was the influence of the worst-case?



Worst-case for cooling had no significant influence on the outcome.

Preliminary

Design & Planning

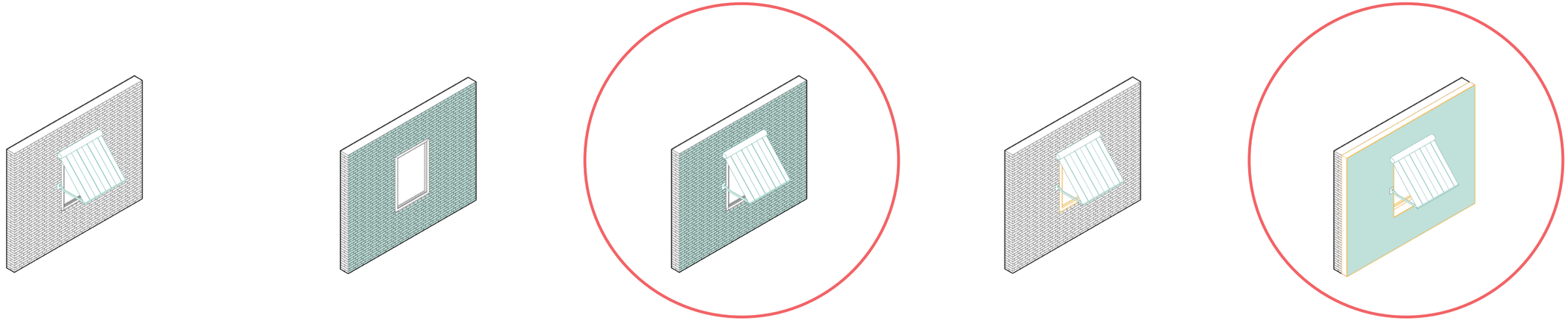
Performance

Cost-Benefit

Decision-making

What did we learn?

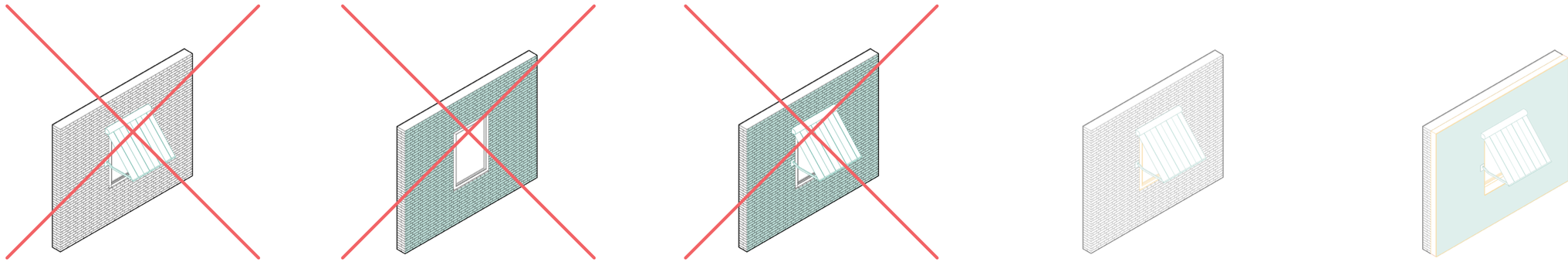
Evaluation of Results



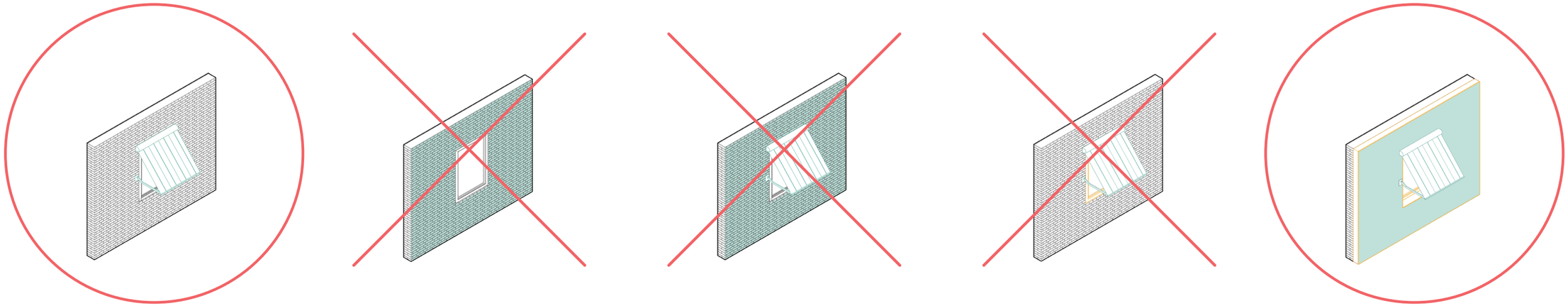
Combining passive measures has the highest impact on mitigation.

With larger qualitative than monetary benefit.

Evaluation of Results



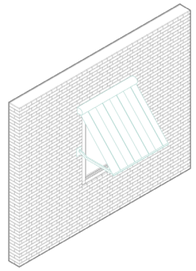
However, cost-recovery is not possible with cooling savings.

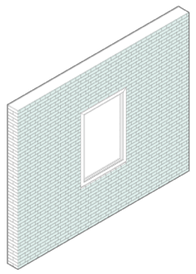


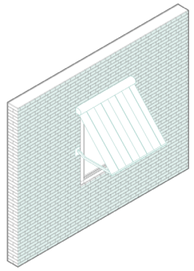
Integrating Heating & Cooling

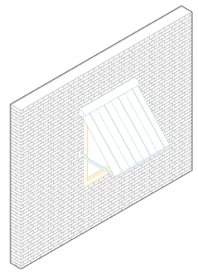
Still, heating savings can compensate for cooling measures.

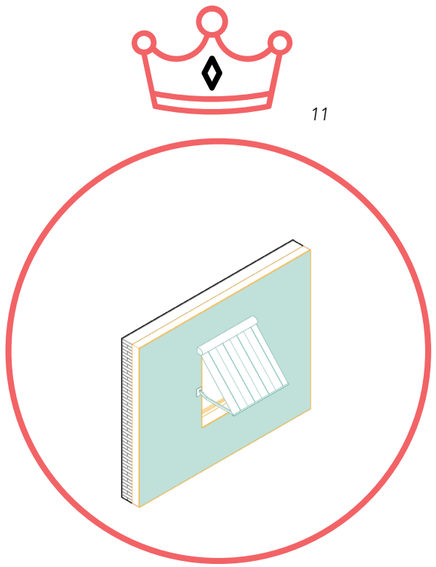
Evaluation of Results







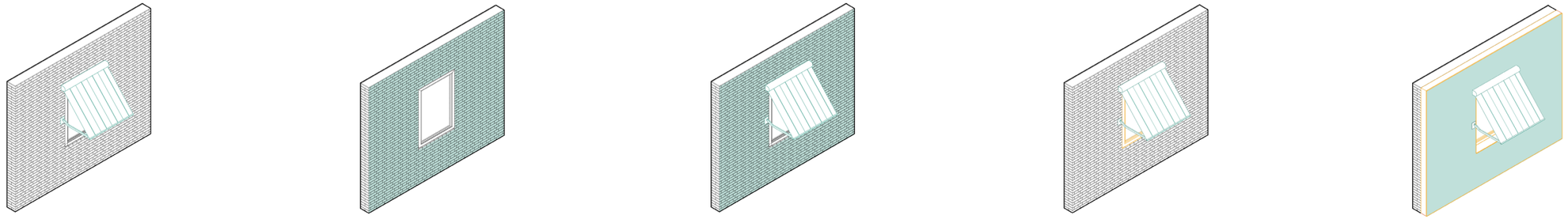




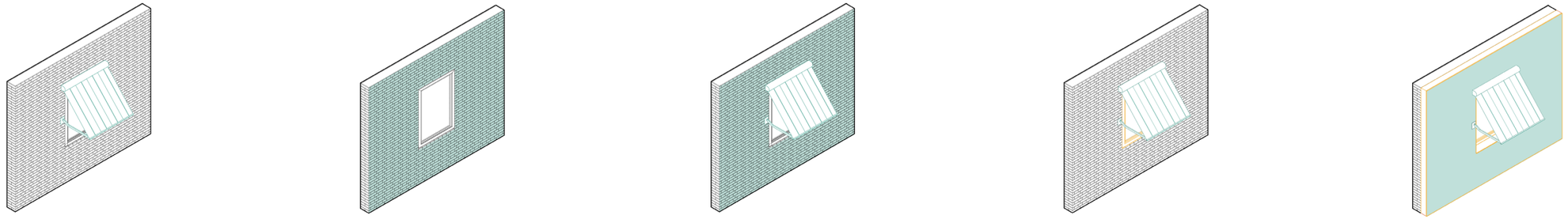
11

Making the deep retrofit the most effective and profitable option!

Evaluation of Results



What did we learn about resilience for the long-term?



Mitigating cost long-term indicates resilience improvement.

Improvement depends on the level of cost or savings.

However, it is hard to pin point with probabilistic simulation.

Reflecting on the framework

8

Cost for heat hazard long term

Climate uncertainty in cost-benefit

Outline extreme scenarios in cost-benefit

Informing renovation design

Reflecting on the framework

Estimate Energy Cost
-> might not align with functional loss

Climate uncertainty in cost-benefit

Outline extreme scenarios in cost-benefit

Informing renovation design

Reflecting on the framework

Estimate Energy Cost
-> might not align with functional loss

Adopt a probabilistic approach
to analyze the full range of outcomes

Outline extreme scenarios in cost-benefit

Informing renovation design

Reflecting on the framework

Estimate Energy Cost
-> might not align with functional loss

Adopt a probabilistic approach
to analyze the full range of outcomes

Define extremes for hazard years
Outline a worst-case scenario

Informing renovation design

Reflecting on use of outcome

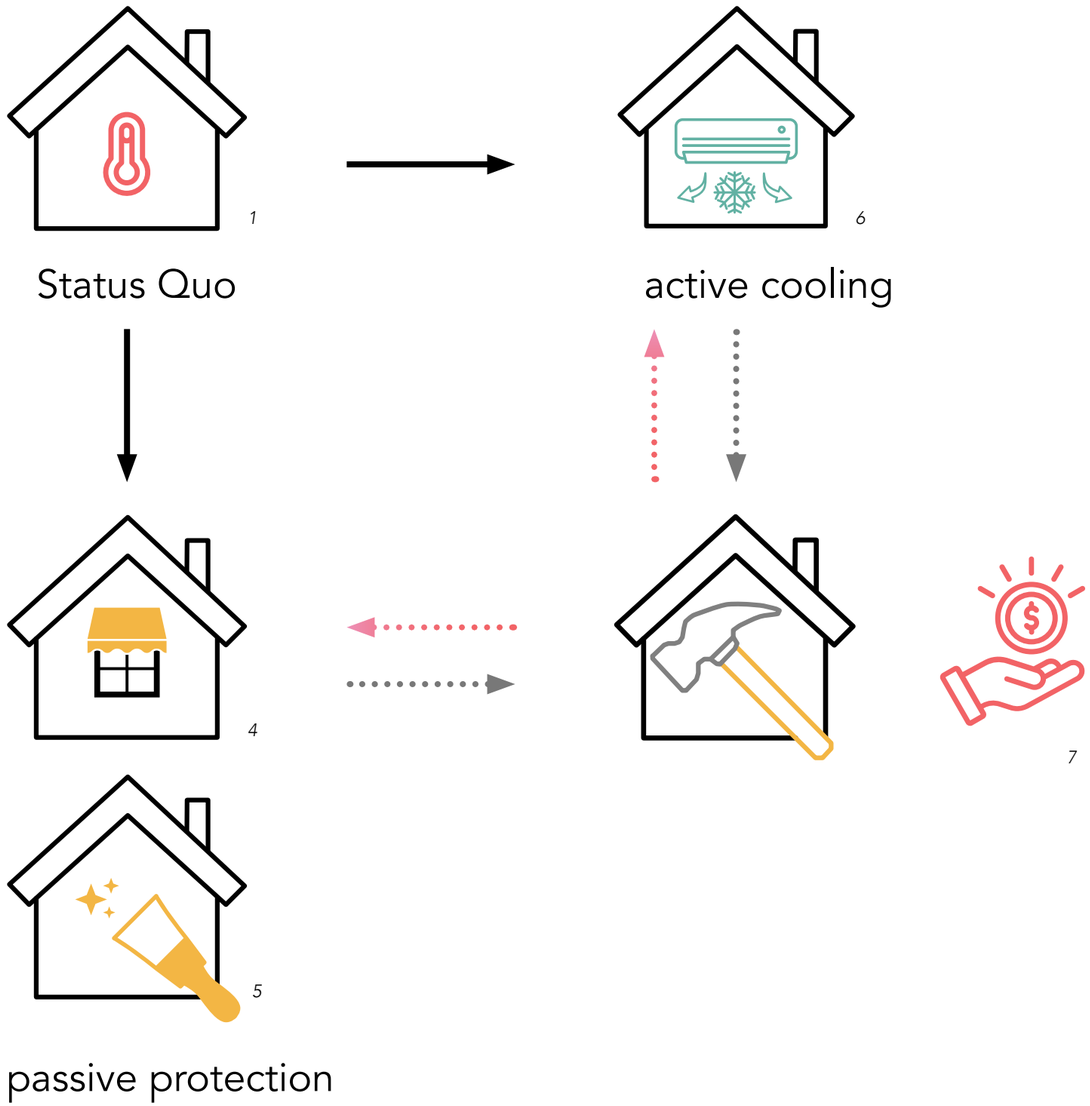
Estimate Energy Cost
-> might not align with functional loss

Adopt a probabilistic approach
to analyze the full range of outcomes

Define extreme hazard years
Outline a worst-case scenario

Ensure cost-recovery including risk assessment
Understand long term financial impact of choices
Verifying combined benefits or adverse effects

Reflecting on use of outcome



What can be explored next?

The effect of **global warming** on **heat exposure and impact.**

As well as the **cost for greenhouse gas emissions**.

Resilience corresponds to mitigating loss before, during, and after heat hazard.

Resilience corresponds to **mitigating risks long term**
to **prevent added costs** *from functionality loss*
in case of heat hazard.

Thank You!

References for icons

1	*thermometer*	*Side Project the noun project*
2	*question mark*	*YURR.studio, the noun project*
3	*performance measure*	*the noun project*
4	*window*	*Laymik, the noun project*
5	*paintbrush*	*bastian vieri & Trident, the noun project*
6	*airconditioning*	*ainul muttaqin, the noun project*
7	*financial value*	*nangicon, the noun project*
8	*challenge*	*the noun project*
9	*cost*	*Fran Couto, the noun project*
10	*scale*	*Larea Design the noun project*
11	*crown*	*ainul muttaqin, the noun project*
12	*ventilation*	*Candy Design, the noun project*
13	*flame*	*the noun project*
14	*grid*	*Muhammad Syaifuddin, the noun project*
15	*windproof*	*faldan, the noun project*
16	*future city*	*generated with Dall-E from ChatGPT*
17	*mykonos*	*danielaelenatentis-2743349, pixabay*