OPTIMIZING BUILDING RETROFIT PROCESS WITH AI

Development of an AI-based surrogate model to identify optimal building envelope retrofit solutions considering the effects of heat waves in the Netherlands

P5 Presentation

Date
13/01/2025

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ARUP mentors
J. Ciurlanti, F. Nijenmanting

TU Delft ARUP

01 CONTEXT

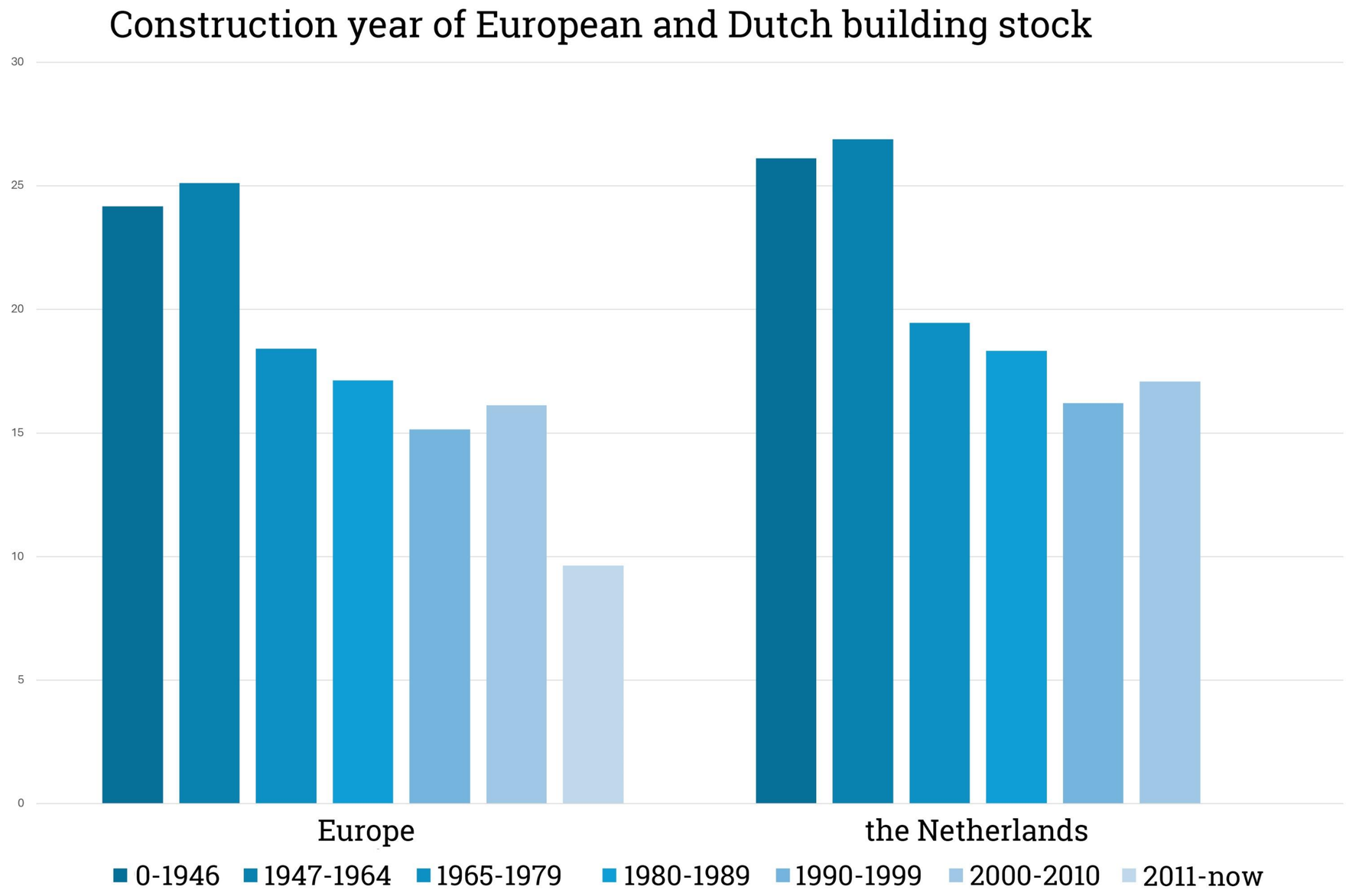
URGENT CLIMATE CRISIS

40 %

of global energy consumption

38 %

of global CO_2 emissions

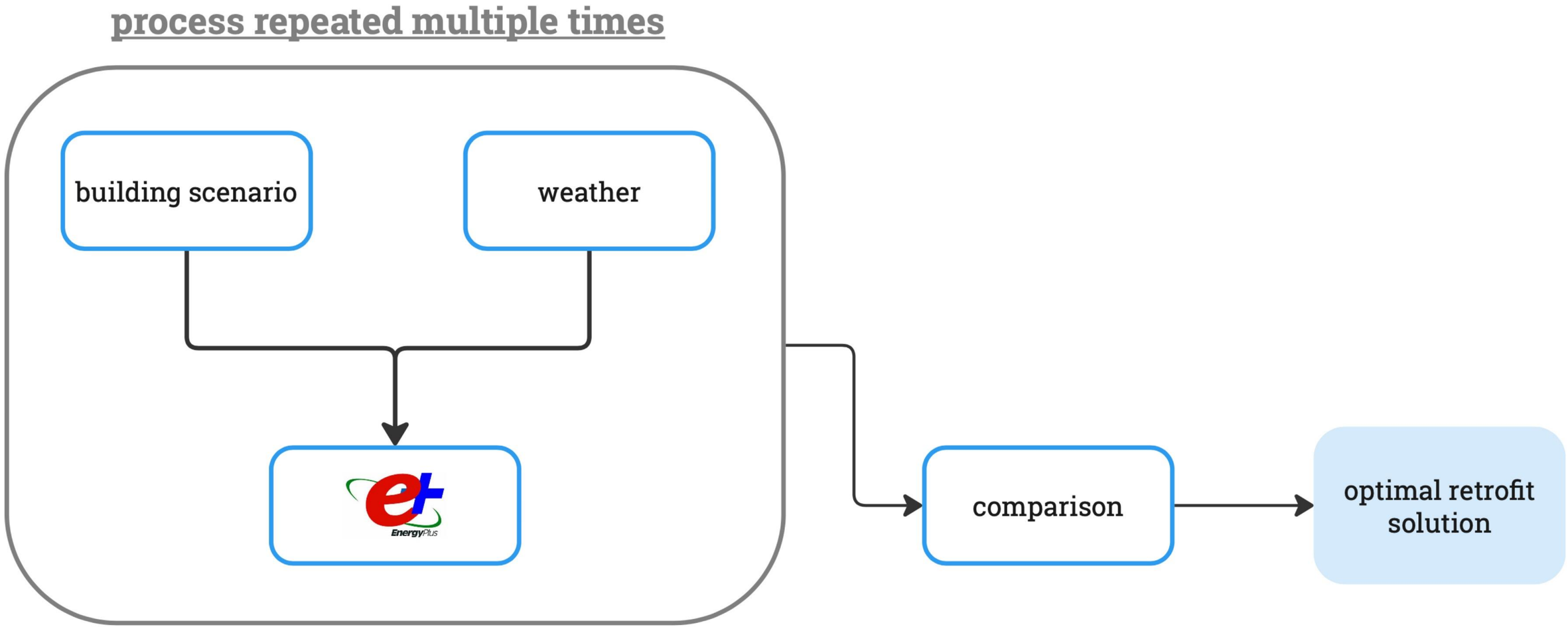

Construction year of European and Dutch building stock
30
25
20
15
10
5
0
Europe
the Netherlands
0-1946
1947-1964
1965-1979
1980-1989
1990-1999
2000-2010
2011-now

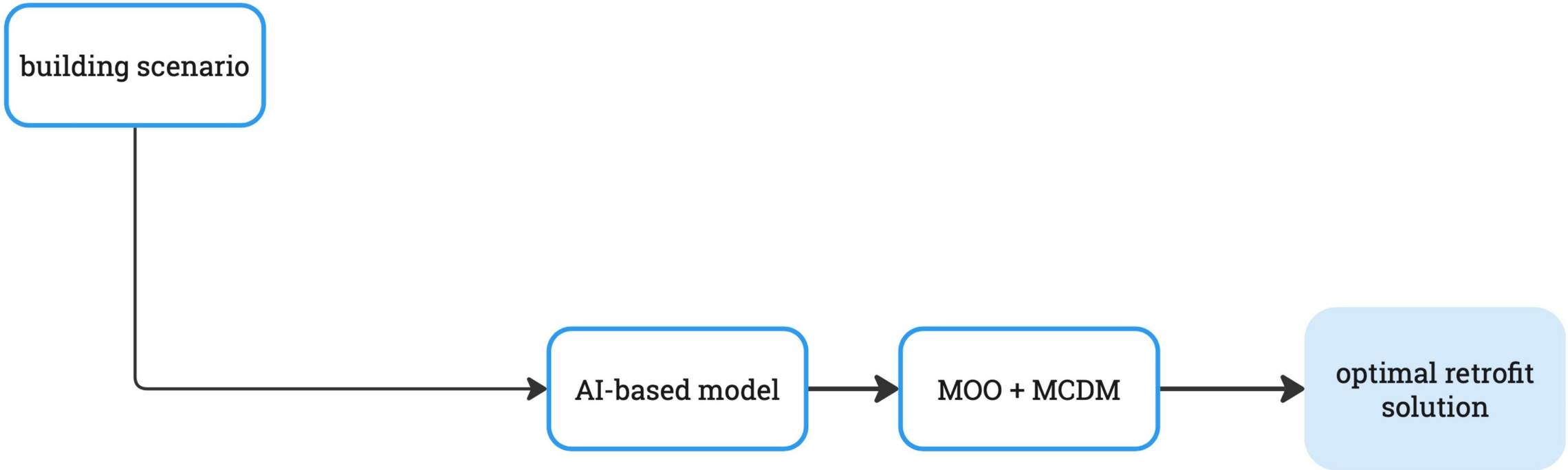
Reduce net greenhouse gas emissions by at least 55% by 2030 (compared to 1990 levels)

Support vulnerable households and micro-enterprises during the green transition

Include building sector from 2026 on

Achieve climate neutrality by 2050


process repeated multiple times
building scenario
weather
EnergyPlus
comparison
optimal retrofit solution


building scenario
AI-based model
MOO + MCDM
optimal retrofit solution

How to develop an **AI-based surrogate model** to select optimal building envelope **retrofit solutions** in the Netherlands considering the effect of **heat waves** in future weather?

02

BASE BUILDING SELECTION

TERRACED HOUSE

03

RETROFIT SOLUTIONS SELECTION

ENVELOPE COMPONENTS

Window

ENVELOPE COMPONENTS

Window

Facade

ENVELOPE COMPONENTS

Window

Facade

Roof

ENVELOPE COMPONENTS

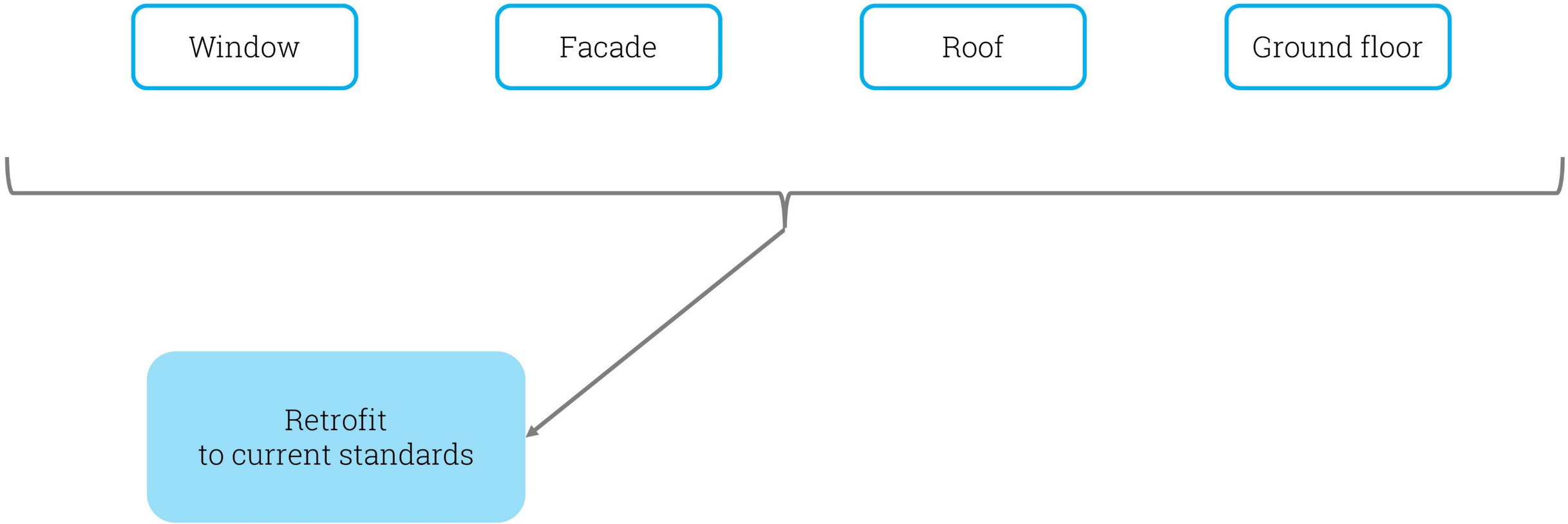
Window

Facade

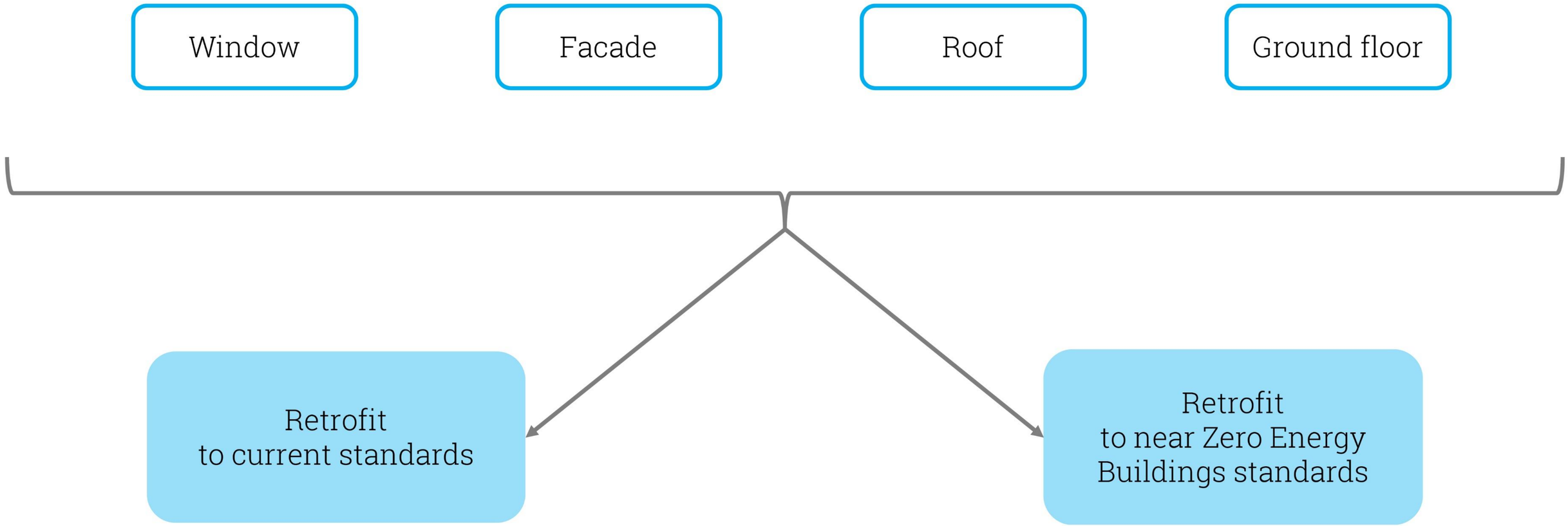
Roof

Ground floor

ENVELOPE COMPONENTS



ENVELOPE COMPONENTS



	Retrofit type	U value (W/m^2K)	Carbon value	Intervention	Cost (€/m^2)	Embodied carbon ($kgCO_2/m^2$)
Window	Current standards	1,20	Typical	HR++ double glazing, plastic frame	184	70
			Low	Hemp fiber insulation	485	50
	nZEB standards	0,80	Typical	Triple glazing, plastic frame	295	150
			Low	Hemp fiber insulation	622	120
Façade	Current standards	0,25	Typical	EPS insulation	182	9
			Low	Hemp fiber insulation	179	4
	nZEB standards	0,18	Typical	EPS insulation	200	17
			Low	Hemp fiber insulation	222	8
Roof	Current standards	0,25	Typical	Mineral wool	140	23
			Low	Hemp fiber insulation	105	4
	nZEB standards	0,15	Typical	PIR insulation	185	18
			Low	Hemp fiber insulation	139	10
Ground floor	Current standards	0,26	Typical	RESOL insulation	100	10
			Low	Hemp fiber insulation	174	5
	nZEB standards	0,18	Typical	PIR insulation	100	11
			Low	Hemp fiber insulation	206	7

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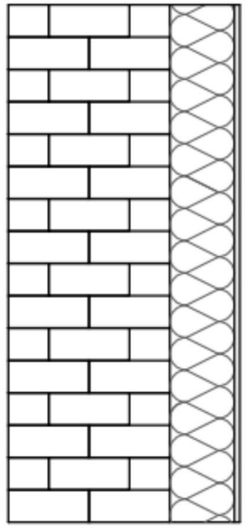
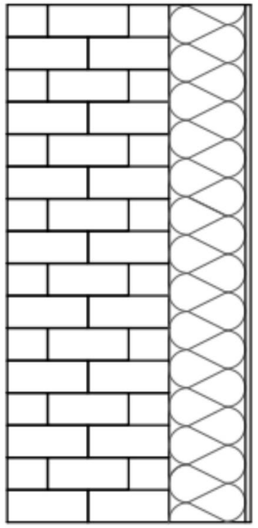


Typical solution

+ 120 mm EPS insulation

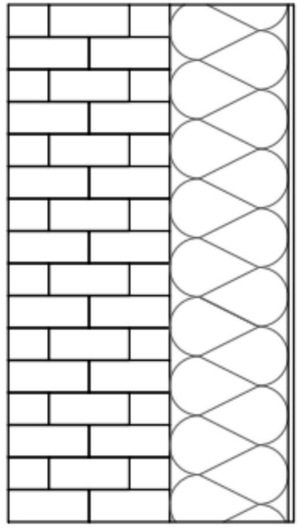
U = 0,25 W/m²K



Low carbon solution

+ 140 mm hemp fiber insulation

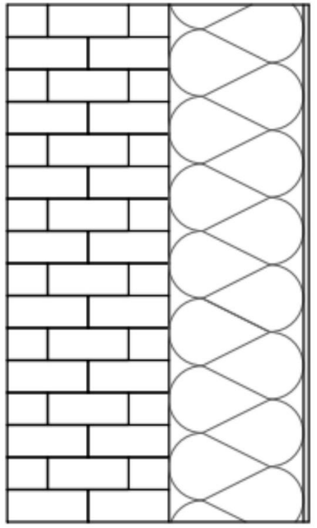
U = 0,25 W/m²K



Typical solution

+ 220 mm EPS insulation

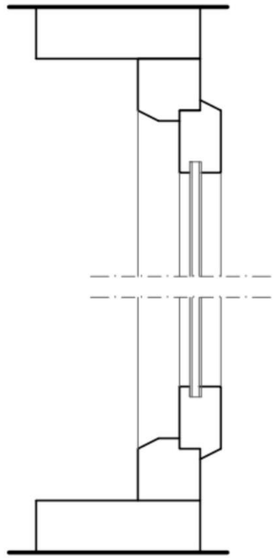
U = 0,18 W/m²K



Low carbon solution

+ 240 mm hemp fiber insulation

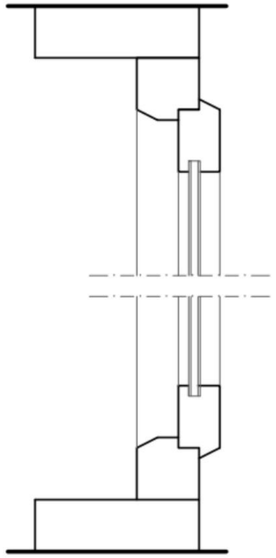
U = 0,18 W/m²K



Typical solution

Double glazing HR++, plastic frame

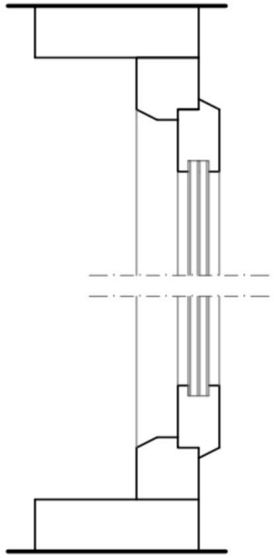
U = 1,2 W/m²K



Low carbon solution

Double glazing HR++, wooden frame

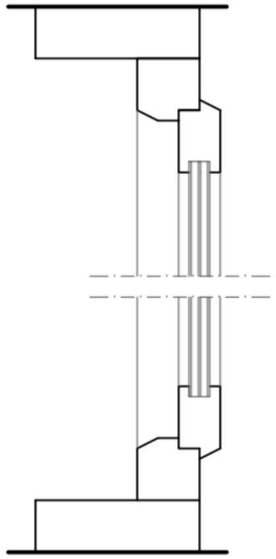
U = 1,2 W/m²K



Typical solution

Triple glazing, plastic frame

U = 0,8 W/m²K



Low carbon solution

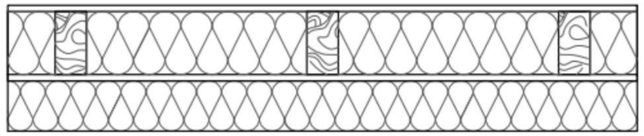
Triple glazing, wooden frame

U = 0,8 W/m²K

Typical solution

+ 100 mm of PIR insulation

U = 0,26 W/m²K



Low carbon solution

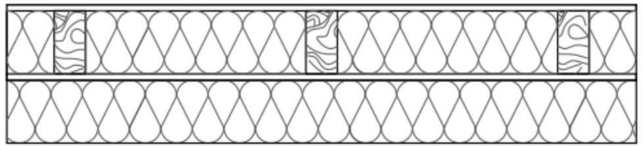
+ 180 mm hemp fiber insulation

U = 0,26 W/m²K

Typical solution

+ 100 mm resol insulation

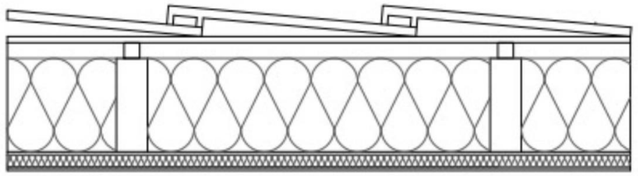
U = 0,18 W/m²K



Low carbon solution

+ 200 mm hemp fiber insulation

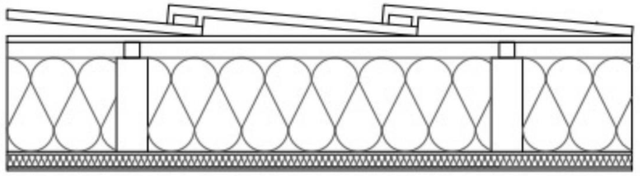
U = 0,18 W/m²K



Typical solution

+ 120 mm mineral wool insulation

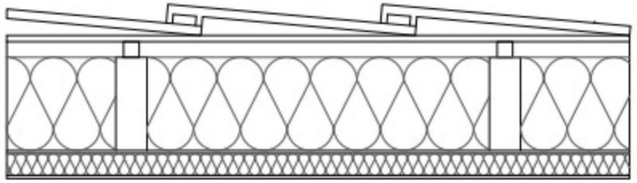
U = 0,25 W/m²K



Low carbon solution

+ 140 mm hemp fiber insulation

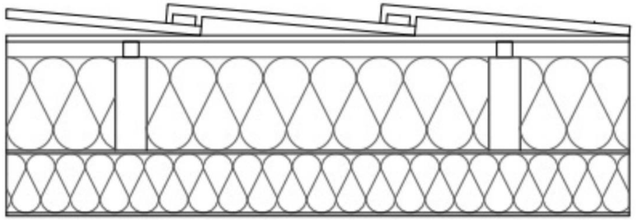
U = 0,25 W/m²K



Typical solution

+ 185 mm PIR insulation

U = 0,15 W/m²K



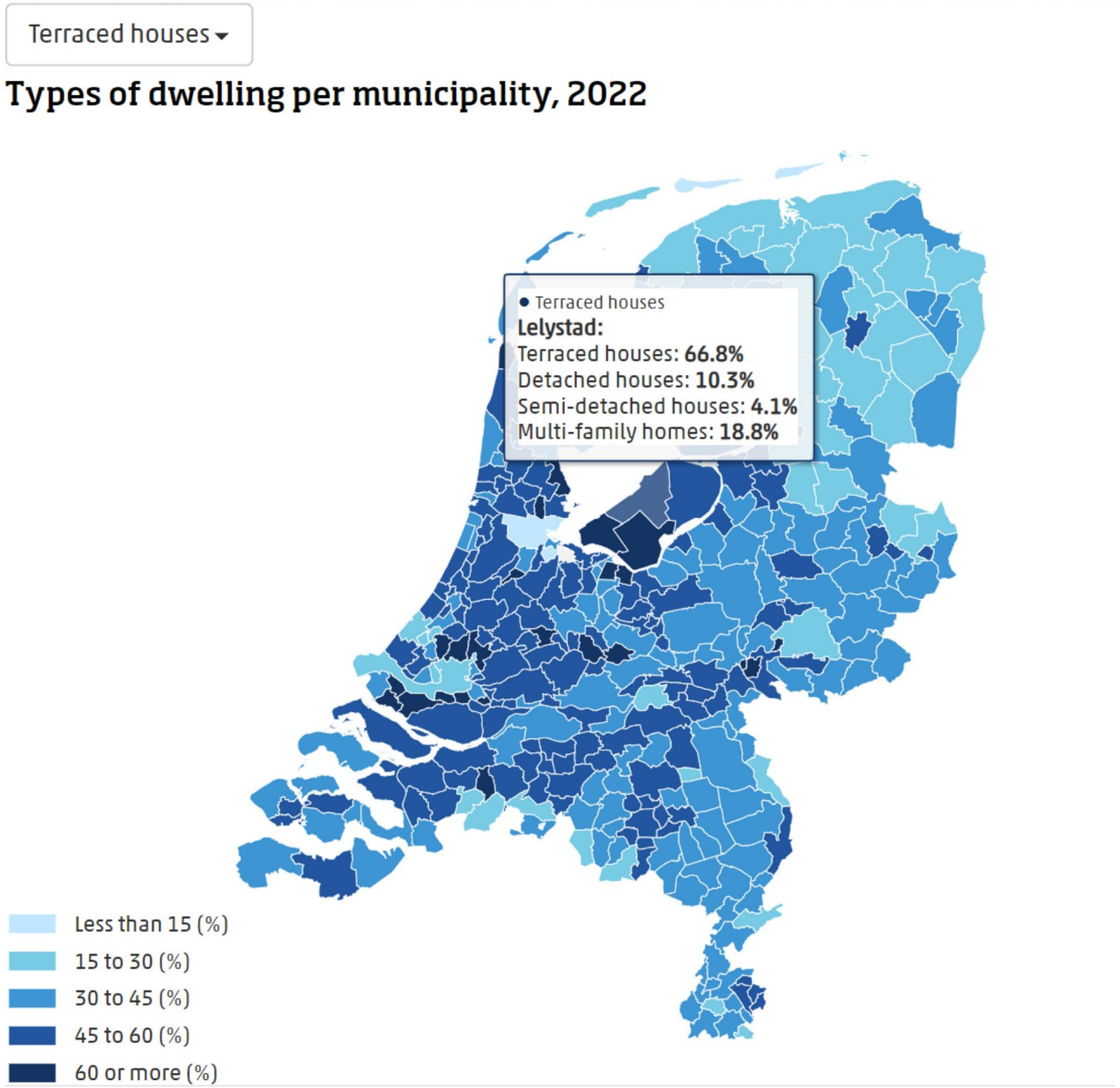
Low carbon solution

+ 300 mm hemp fiber insulation

U = 0,15 W/m²K

04

WEATHER PREDICTIONS

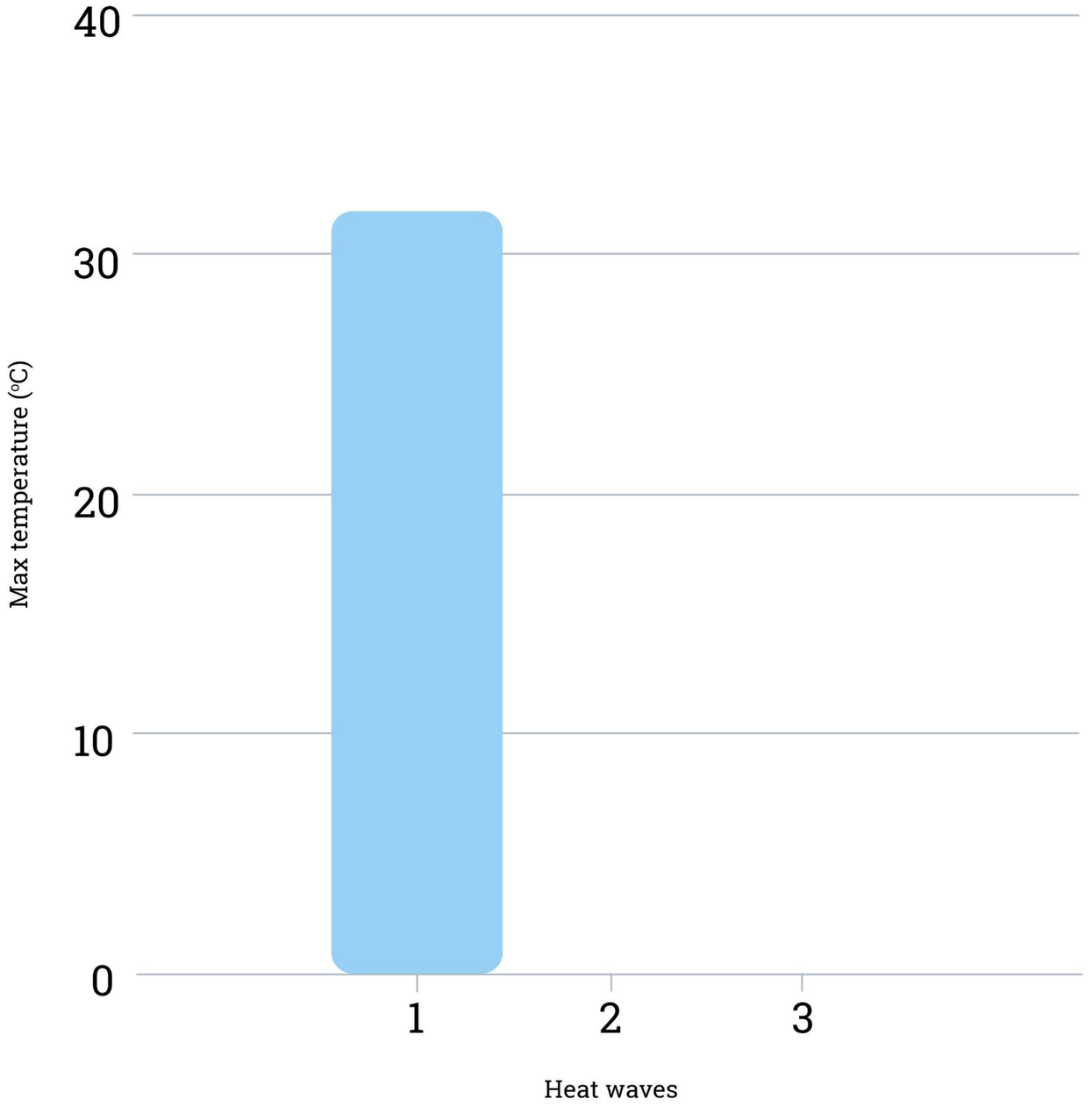


Types of dwellings per municipality in the Netherlands (Source: Centraal Bureau voor de Statistiek, 2023)

2020

1 HEAT WAVE

12 DAYS UNDER HEAT WAVE



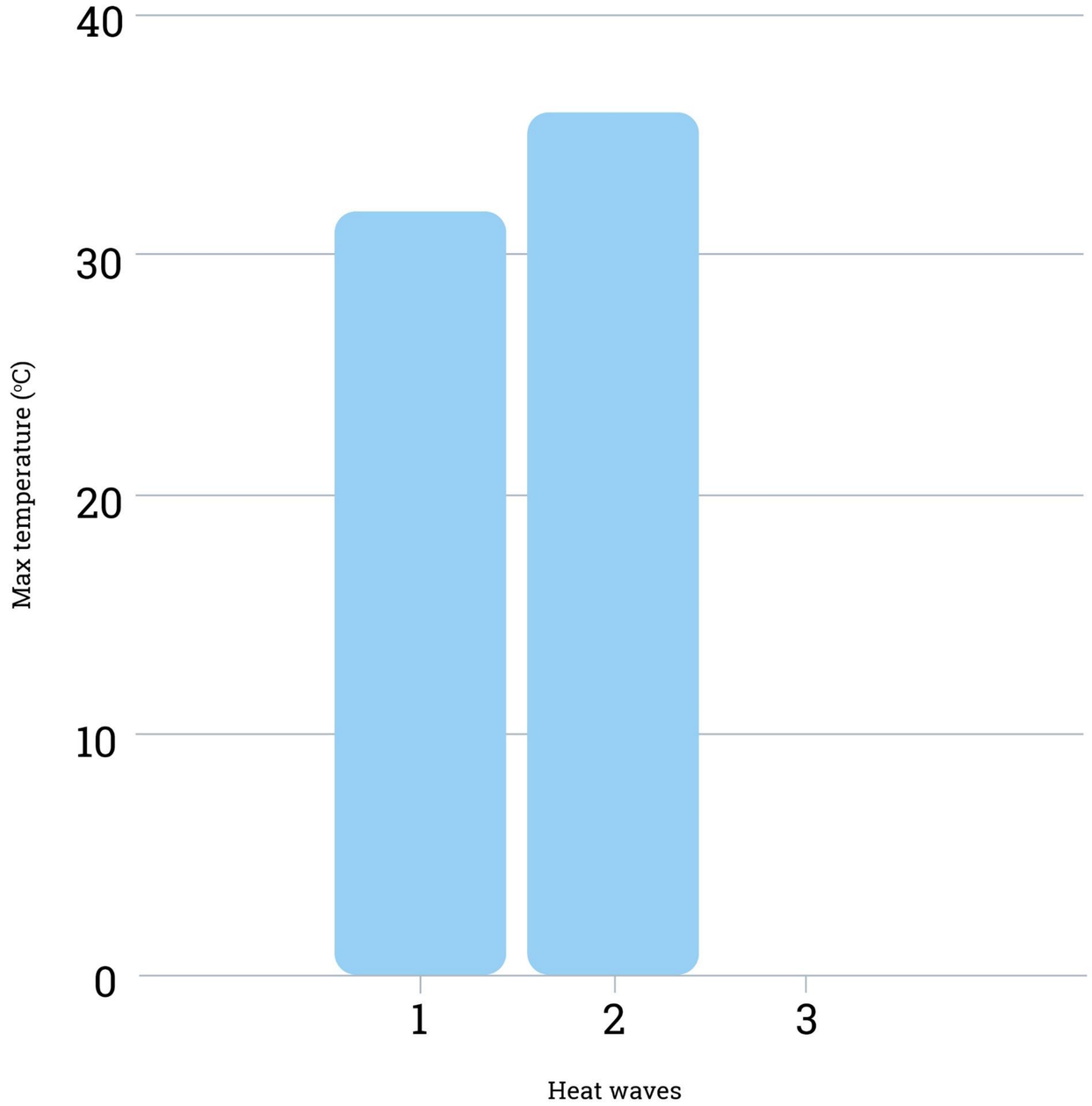
2050

+ 100%

2 HEAT WAVES

+ 83%

22 DAYS UNDER HEAT WAVE



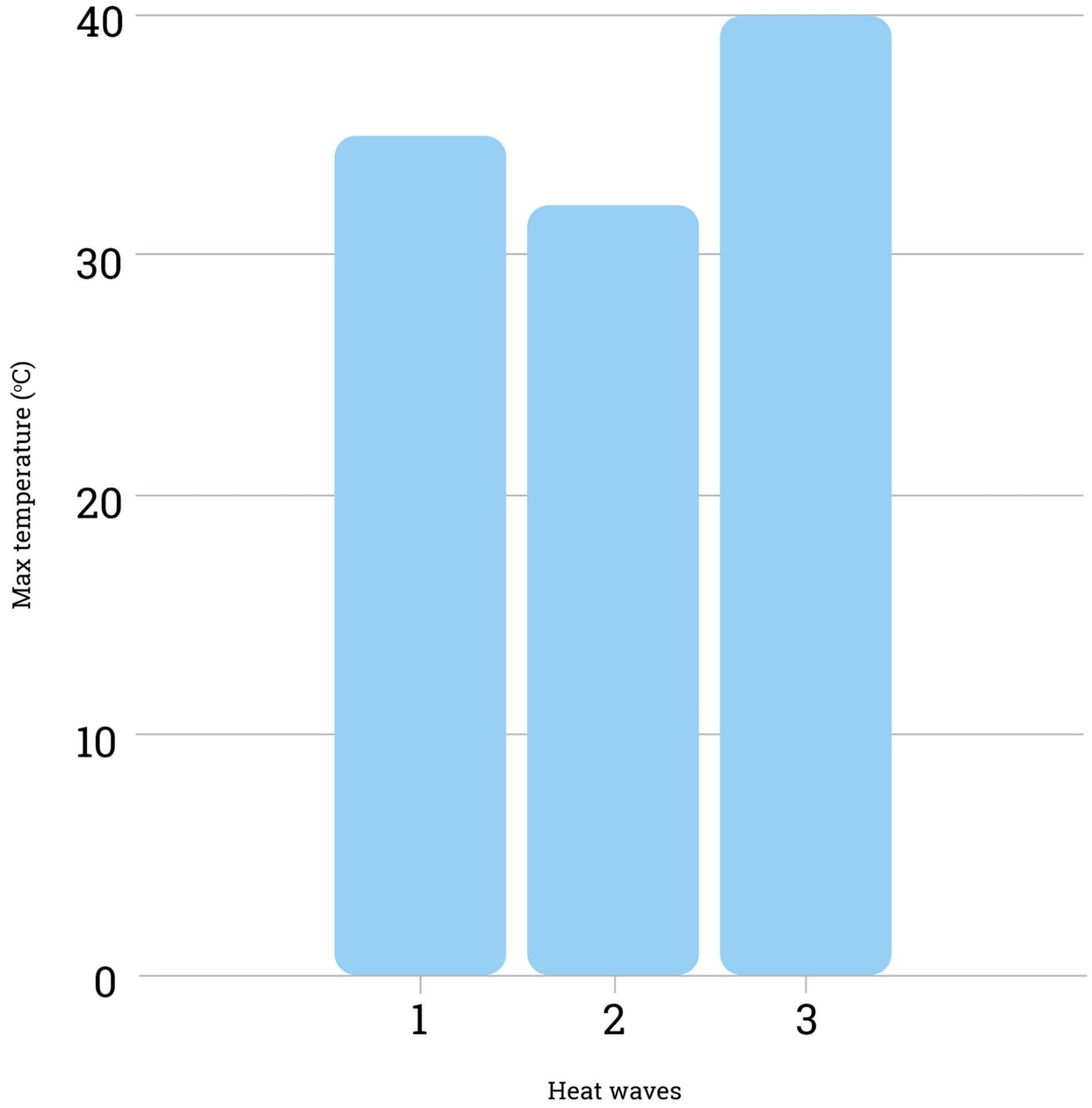
2100

+ 200%

3 HEAT WAVES

+ 266%

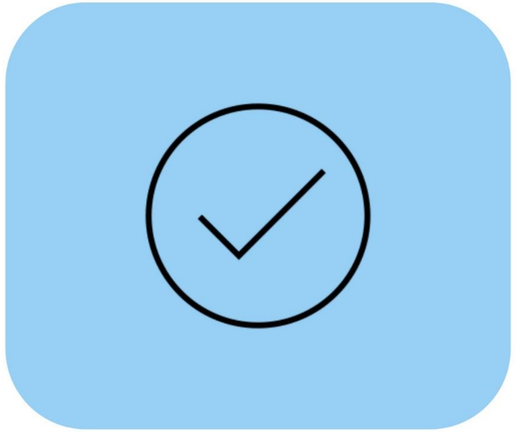
44 DAYS UNDER HEAT WAVE



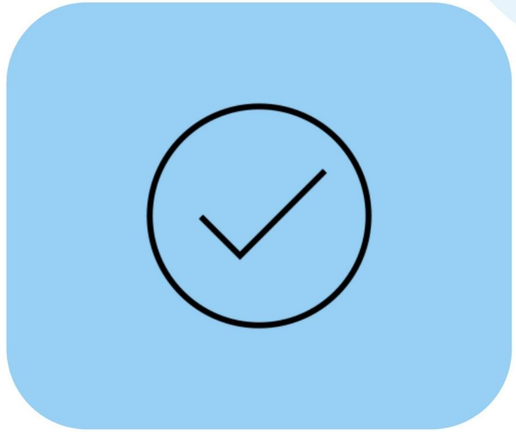
05

ENERGYPLUS SIMULATIONS

Weather files



Retrofit scenarios

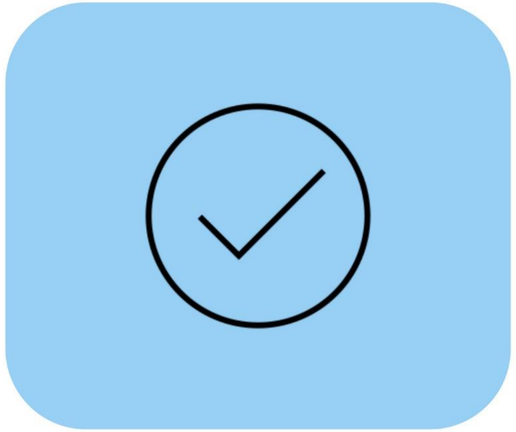


IDF file

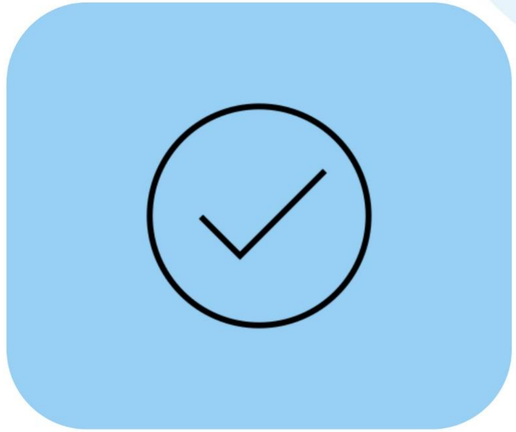
To run the simulations

INPUTS

Weather files



Retrofit scenarios



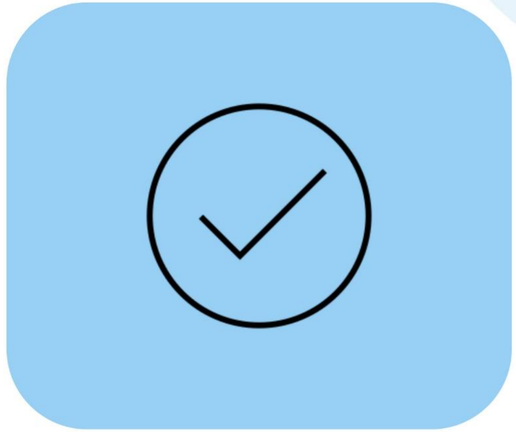
IDF file

To run the simulations

INPUTS

Weather files

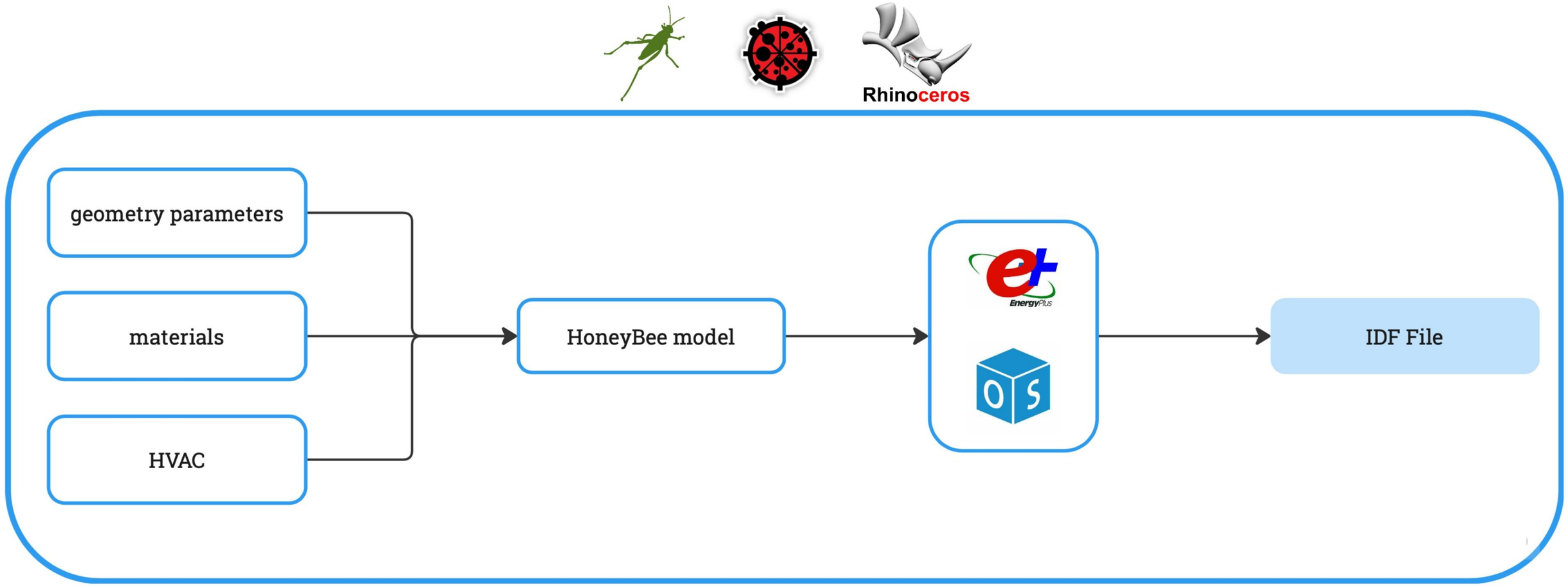
Retrofit scenarios



IDF file

To run the simulations

INPUTS


Rhinoceros
geometry parameters
materials
HVAC
HoneyBee model
EnergyPlus
O S
IDF File

Daily energy consumption

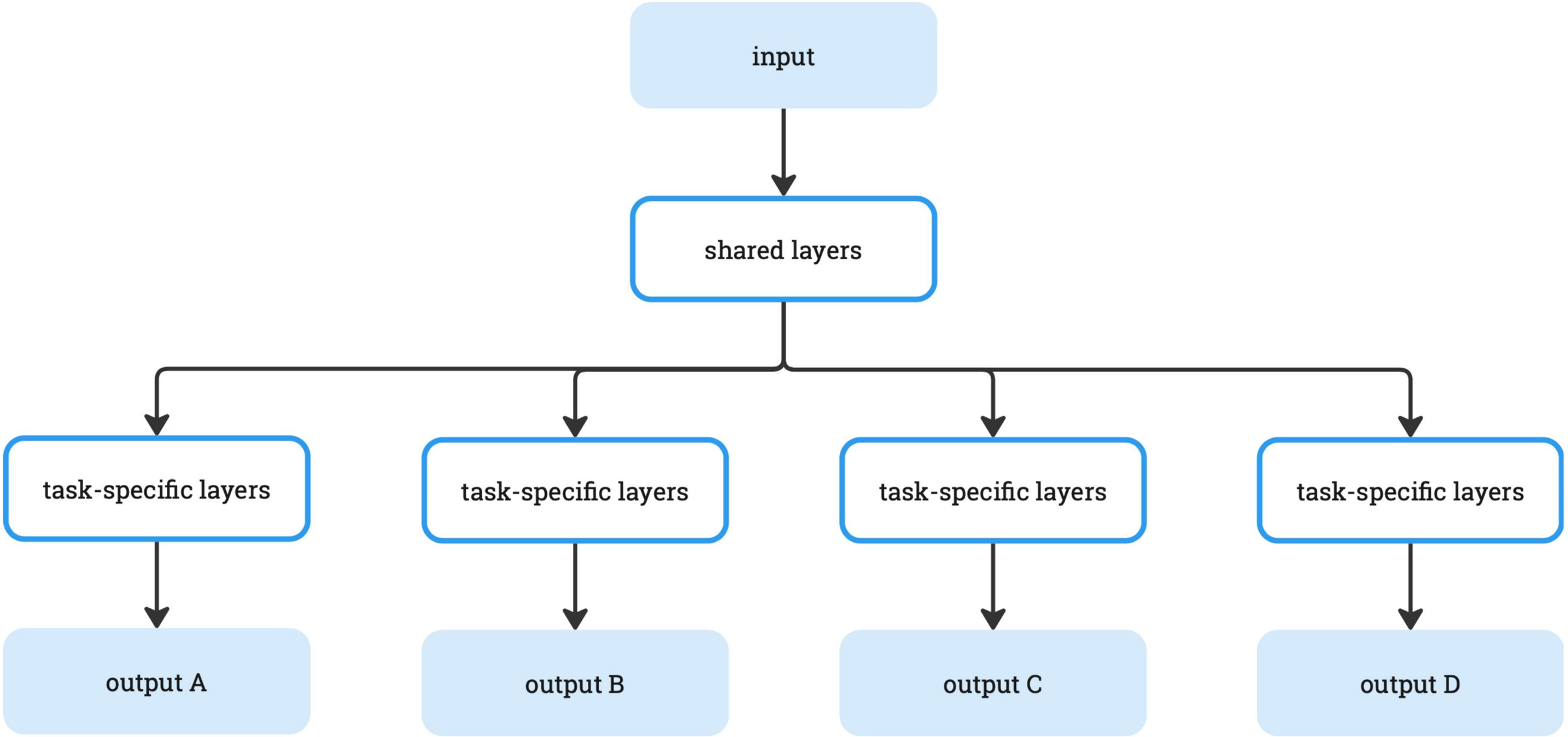
Maximum indoor temperature

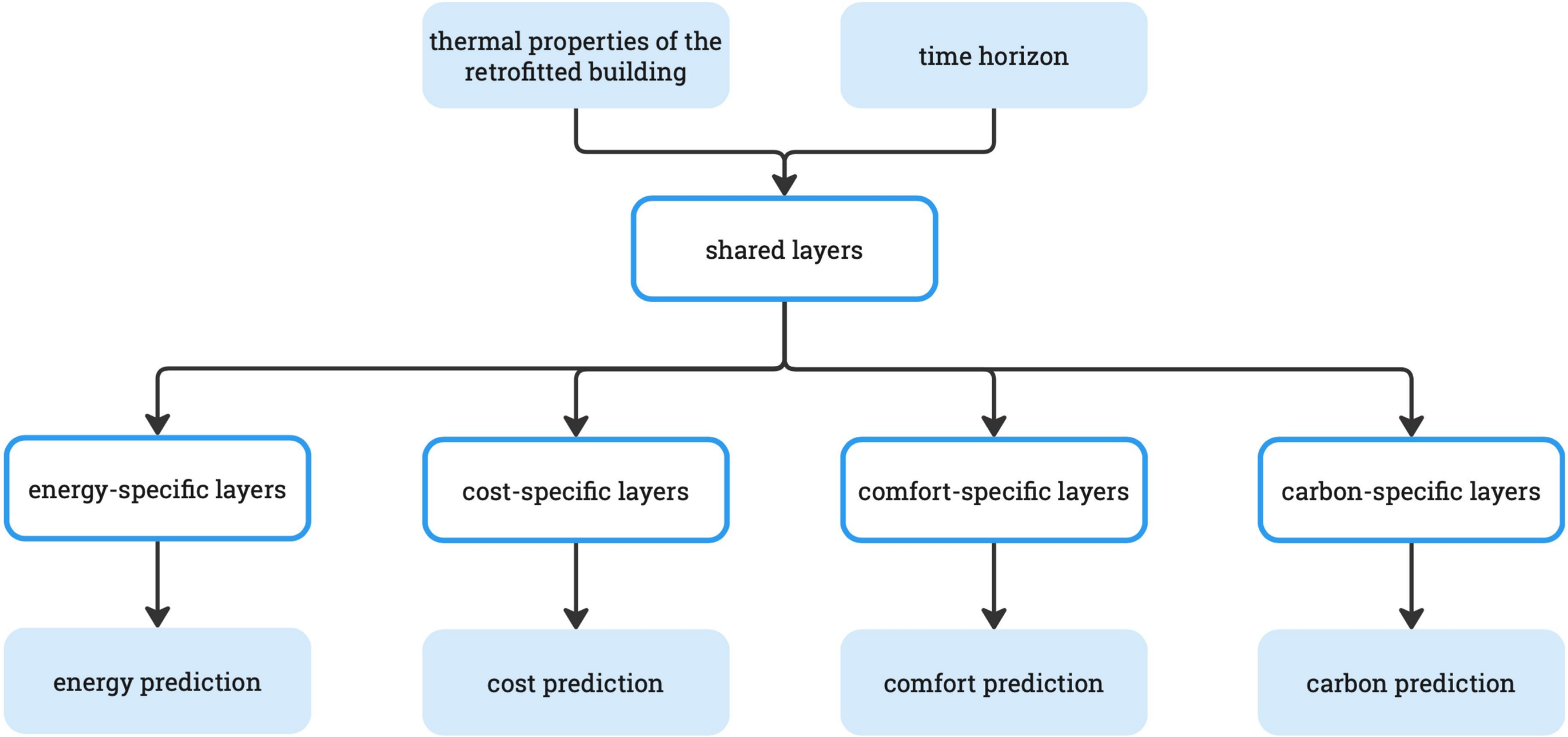
Of the simulations

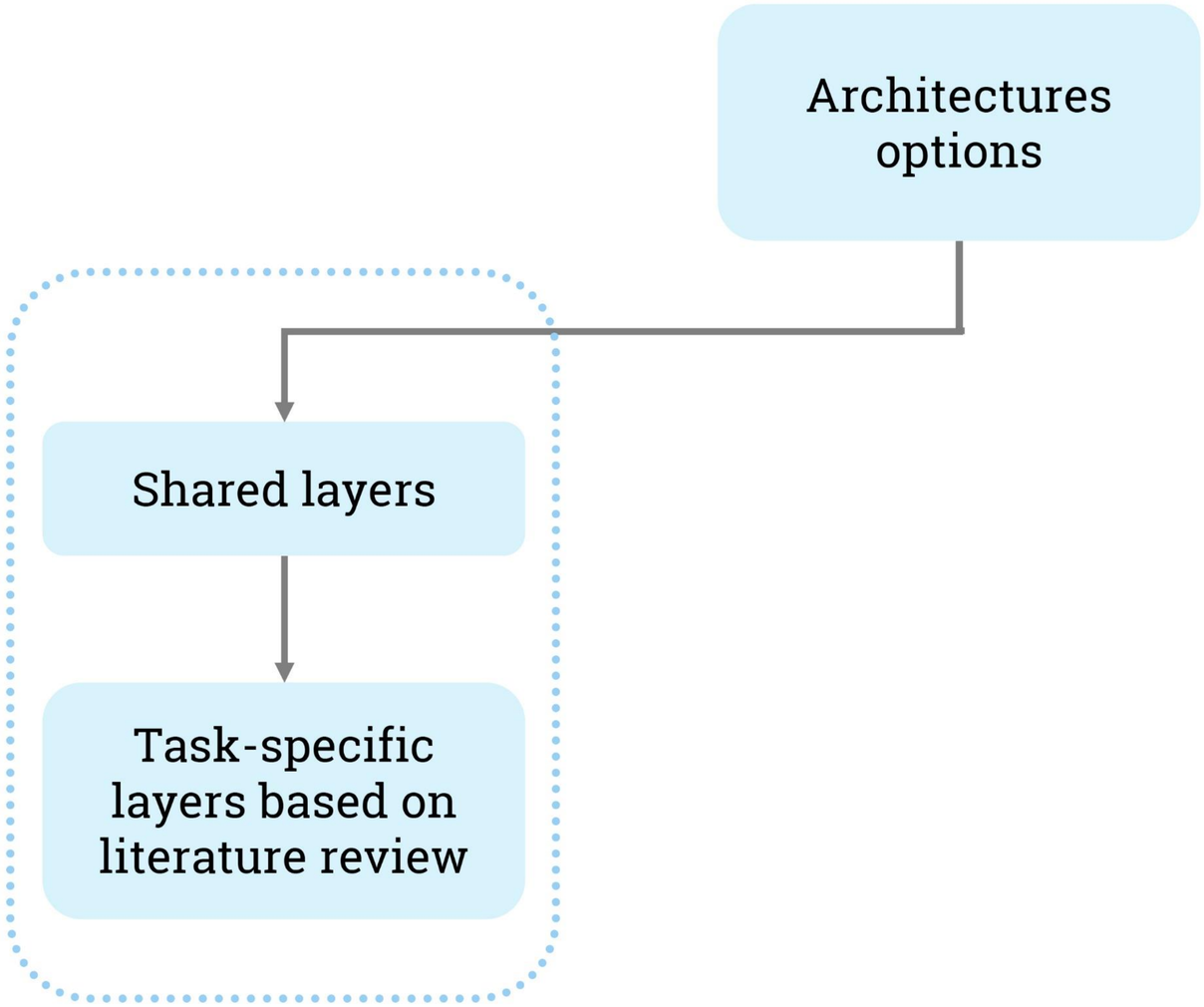
OUTPUTS

06

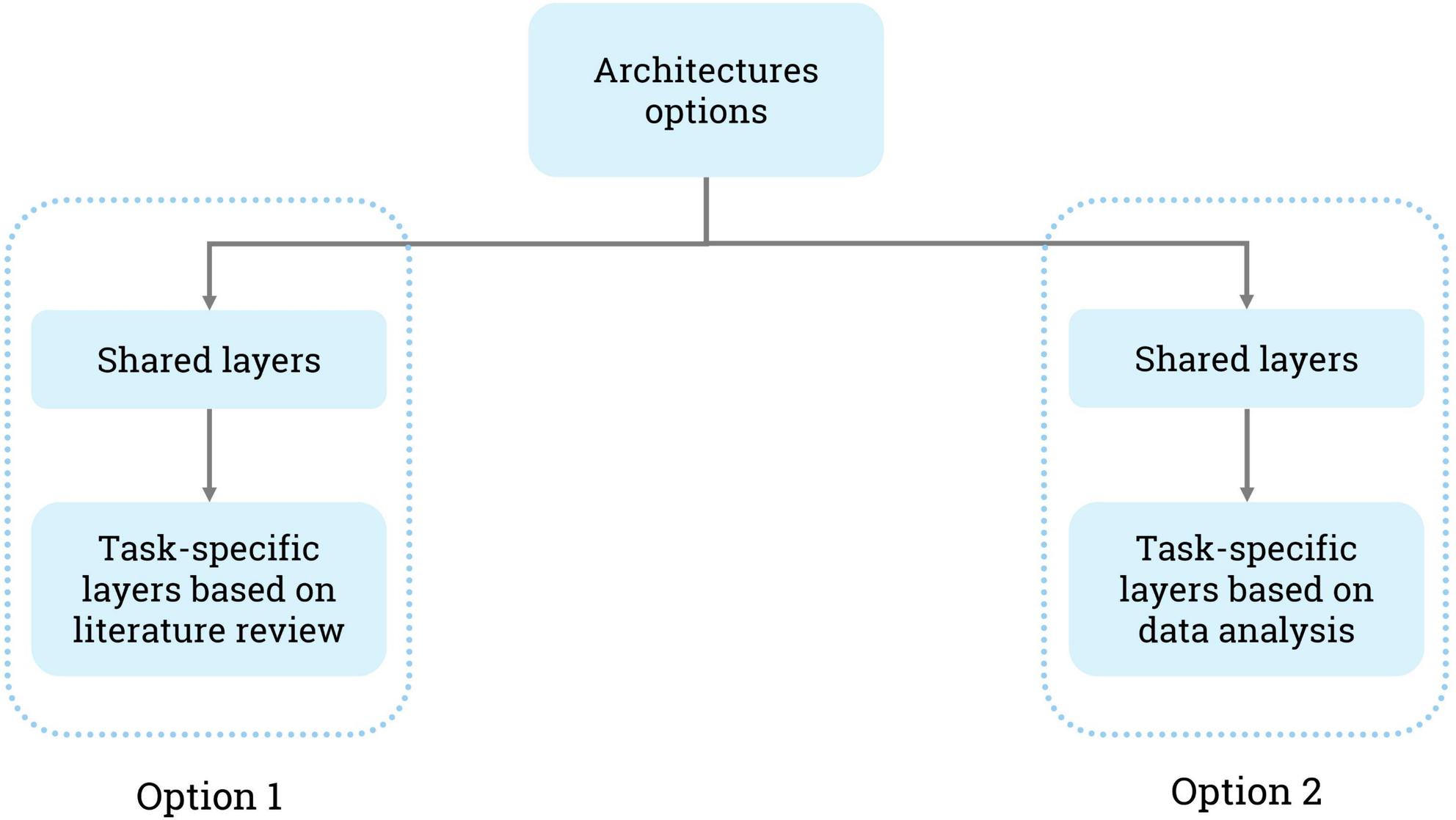
AI-BASED SURROGATE MODEL

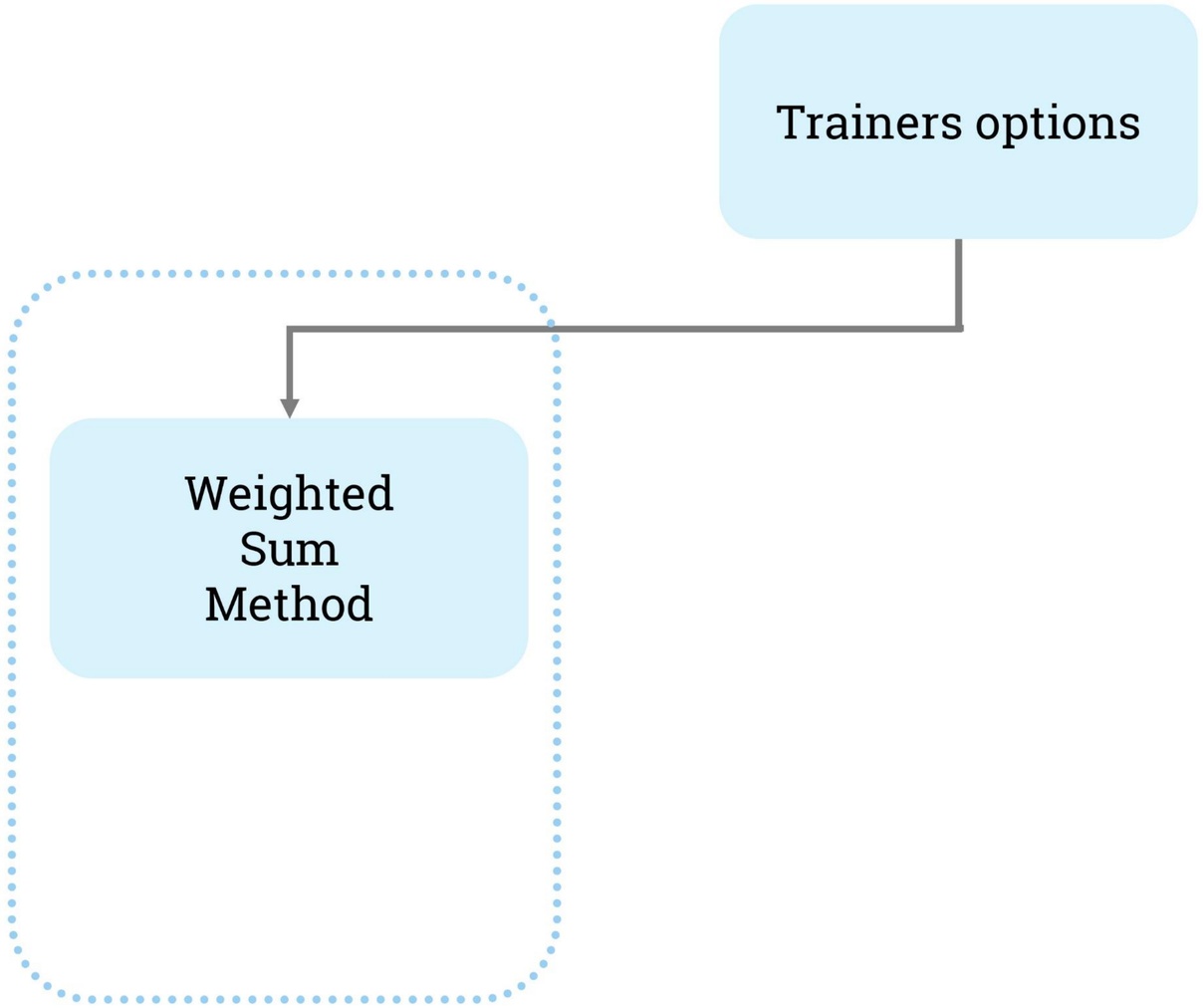

input
shared layers
task-specific layers
task-specific layers
task-specific layers
task-specific layers
output A
output B
output C
output D


thermal properties of the retrofitted building
time horizon
shared layers
energy-specific layers
cost-specific layers
comfort-specific layers
carbon-specific layers
energy prediction
cost prediction
comfort prediction
carbon prediction

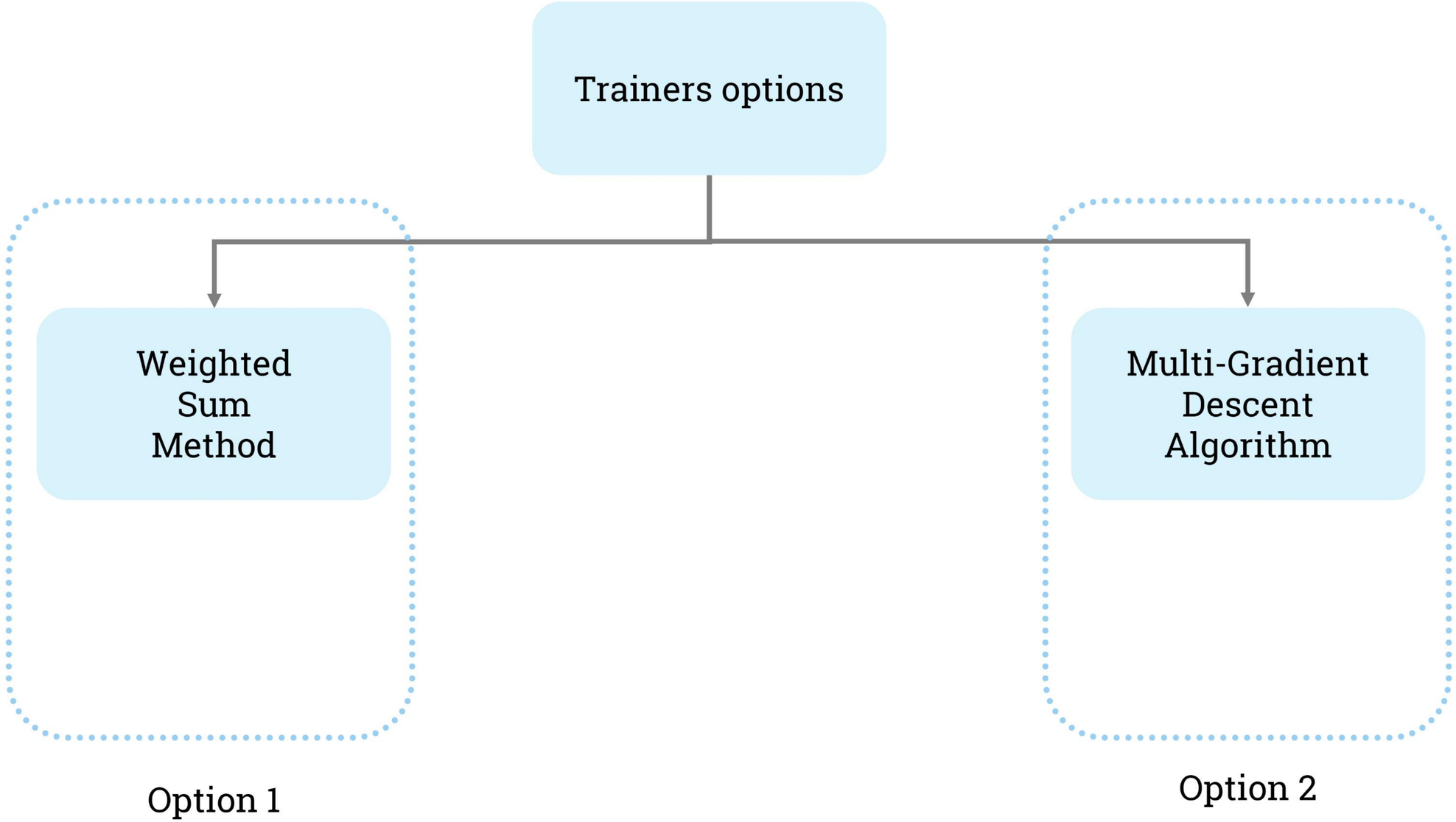

Architectures options
Shared layers
Task-specific layers based on literature review

Option 1

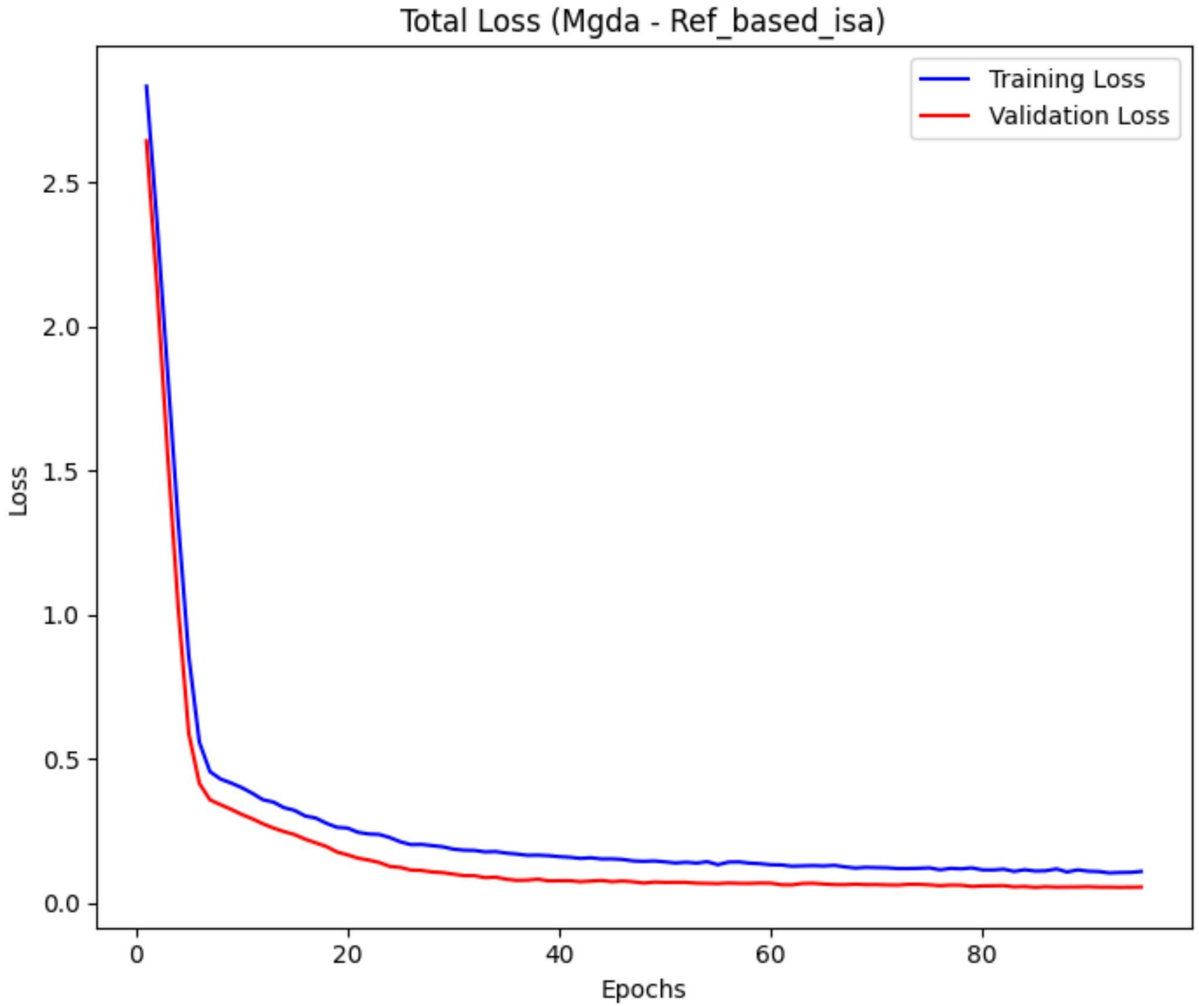

Architectures options
Shared layers
Task-specific layers based on literature review
Shared layers
Task-specific layers based on data analysis
Option 1
Option 2

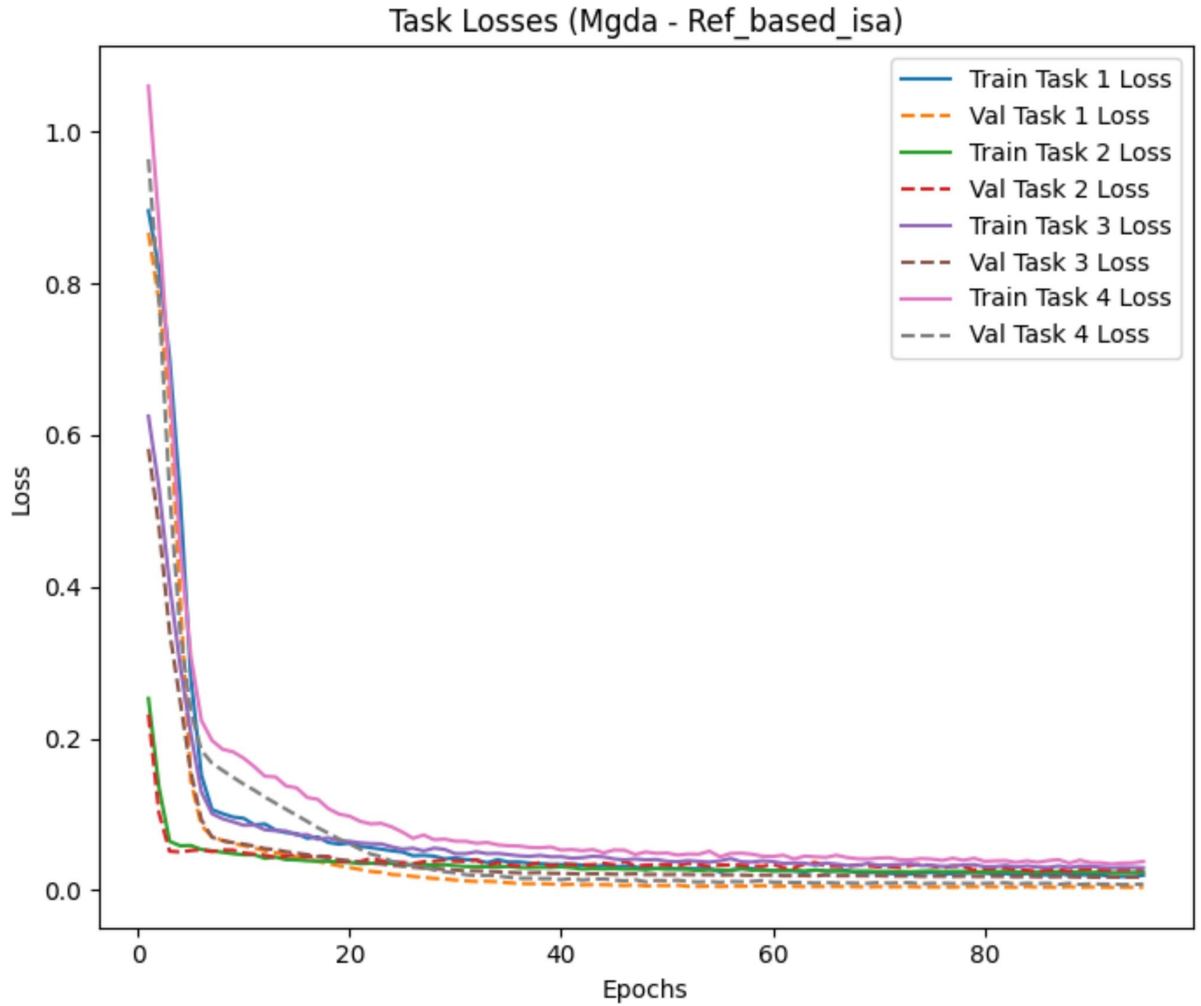


Option 1

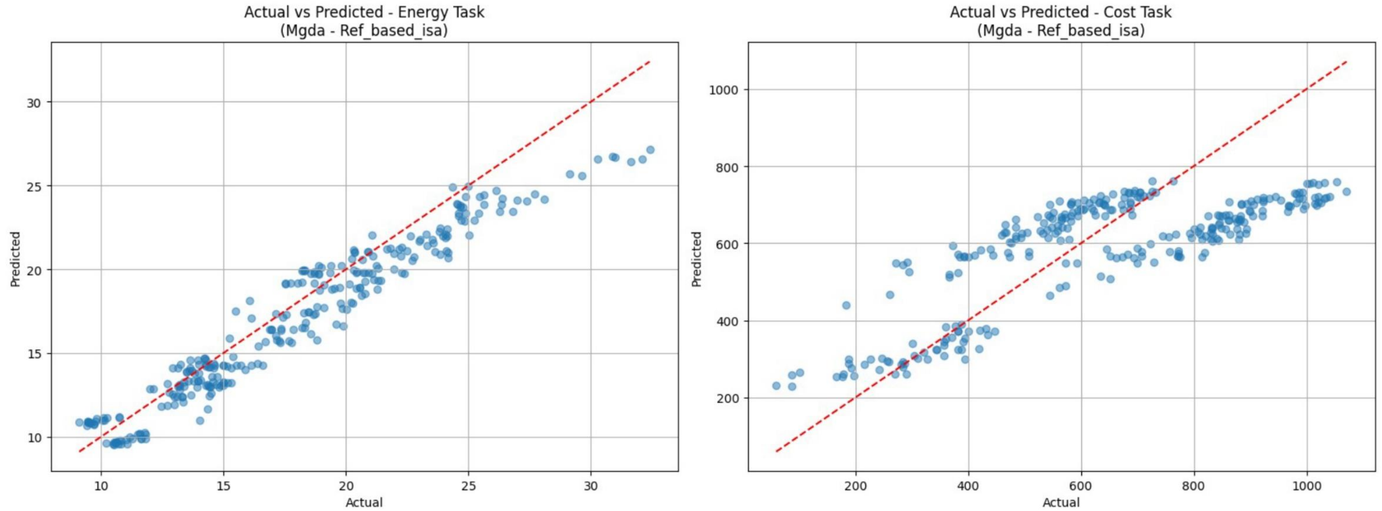

Trainers options
Weighted Sum Method
Multi-Gradient Descent Algorithm
Option 1
Option 2

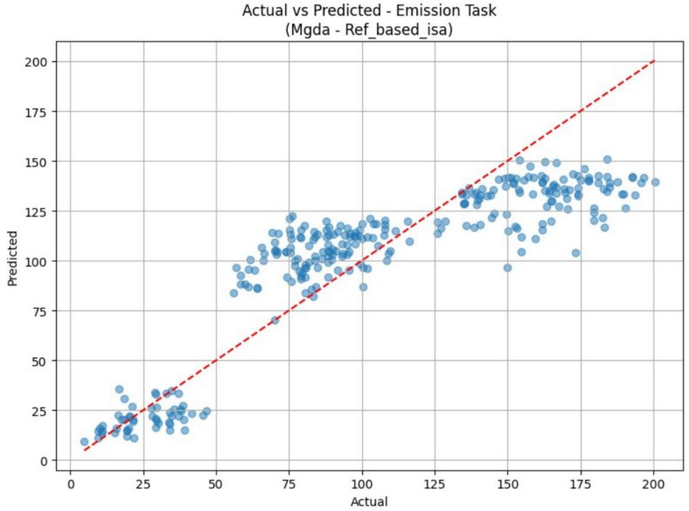
Architectures based on literature-review using MDGA

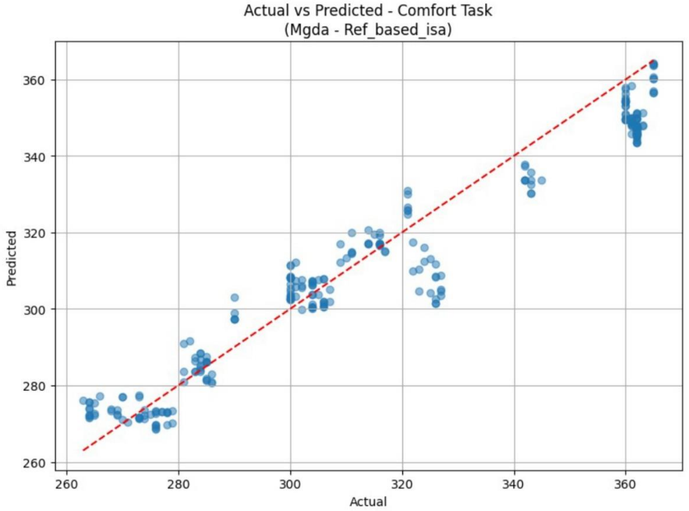




Architectures based on literature-review using MDGA







98% time reduction

compared to usual retrofit process

07

OPTIMIZATION PROCESS

Optimization based on dataset

MULTI-OBJECTIVES OPTIMIZATION

OBJECTIVES

- minimise energy consumption
- minimise cost
- minimise embodied carbon
- maximise comfort days

↓

PARETO OPTIMAL SOLUTIONS

→

MULTI-CRITERIA DECISION MAKING

OBJECTIVES WEIGHTS

↓

✓ **BEST SOLUTION SELECTION**

Optimization
based on constraints

MULTI-OBJECTIVES OPTIMIZATION

INPUT CONSTRAINTS

↓

OBJECTIVES

- minimise energy consumption
- minimise cost
- minimise embodied carbon
- maximise comfort days

↓

PARETO OPTIMAL SOLUTIONS

→

MULTI-CRITERIA DECISION MAKING

OBJECTIVES WEIGHTS

↓

✓ **BEST SOLUTION SELECTION**

08

RESULTS & DISCUSSION

PRIORITIZING ENERGY CONSUMPTION

74% energy reduction

high cost

PRIORITIZING ENERGY CONSUMPTION

74% energy reduction

high cost

PRIORITIZING COST

10% energy reduction

PRIORITIZING ENERGY CONSUMPTION

74% energy reduction

high cost

PRIORITIZING COST

10% energy reduction

PRIORITIZING EMBODIED CARBON

40% energy reduction

PRIORITIZING ENERGY CONSUMPTION

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10% energy reduction

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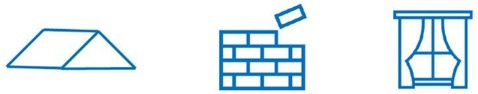
40% energy reduction

PRIORITIZING COMFORT



63% energy reduction

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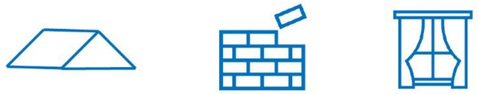


63% energy reduction

high cost

TREATING ALL OBJECTIVES EQUALLY

47% energy reduction

INSULATION IMPACT

Highly effective at low Rc values

KEY PARAMETERS

Windows & Facade

OVERHEATING

If insulation level is high

2020

326 days in comfort

2020

326 days in comfort

2050

318 days in comfort

2020

326 days in comfort

2050

318 days in comfort

2100

308 days in comfort

COMFORT DAYS DECLINE

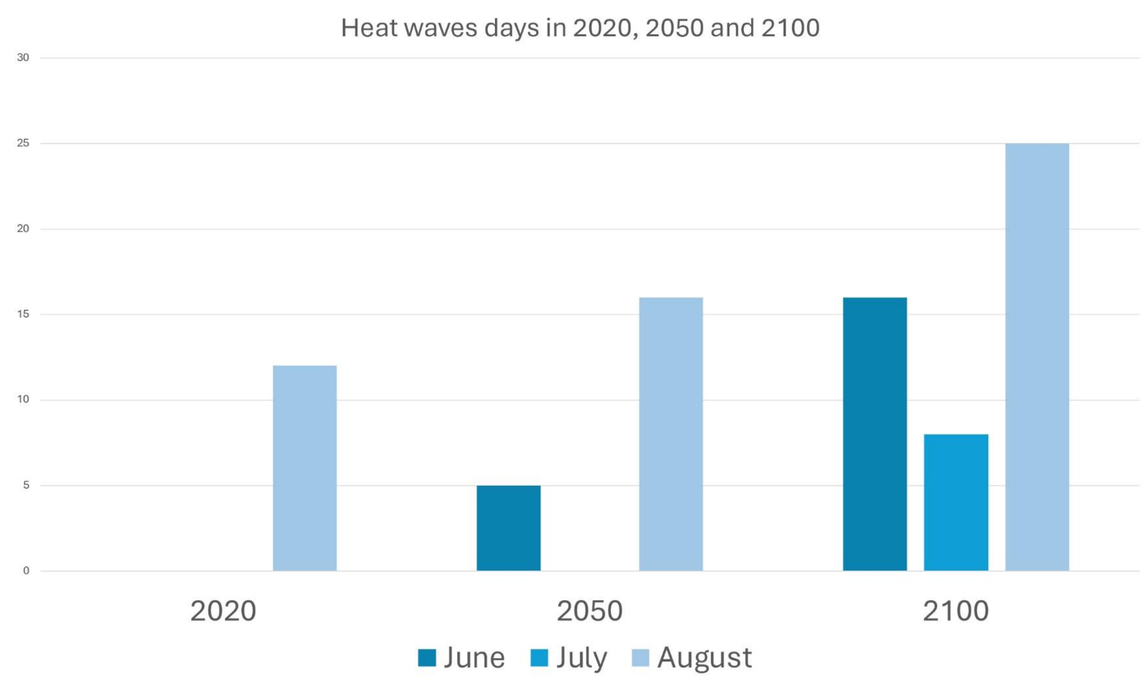
- 22 days in comfort from 2020 to 2100

09

CONCLUSIONS

How to develop an **AI-based surrogate model** to select optimal building envelope **retrofit solutions** in the Netherland considering the effect of **heat waves** in future weather?

Which are **heat waves prediction** for future weather?



Which type of **AI is it better to implement** for a surrogate model that identifies optimal building envelope retrofit solutions?

Multi-tasks Learning model

Multi-Gradient Descent Algorithm

Task-specific architectures

98% time reduction

compared to usual retrofit process

Which are **key consideratins** when selecting building envelope **retrofit solutions**?

Need for trade-off solutions

Insulation has its strongest influence at low R_c levels

Prioritize windows and facade retrofit

High potential of improvements

THANK YOU!

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