Scenario-based energy simulation: Modelling tree planting strategy to reduce heating and cooling demand under 2050 climate conditions

Prepared for Thesis Public Defense, 30 October 2025
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Outline

01 Introduction

02 Research questions

03 Method and Experiment

04 Result & Analysis

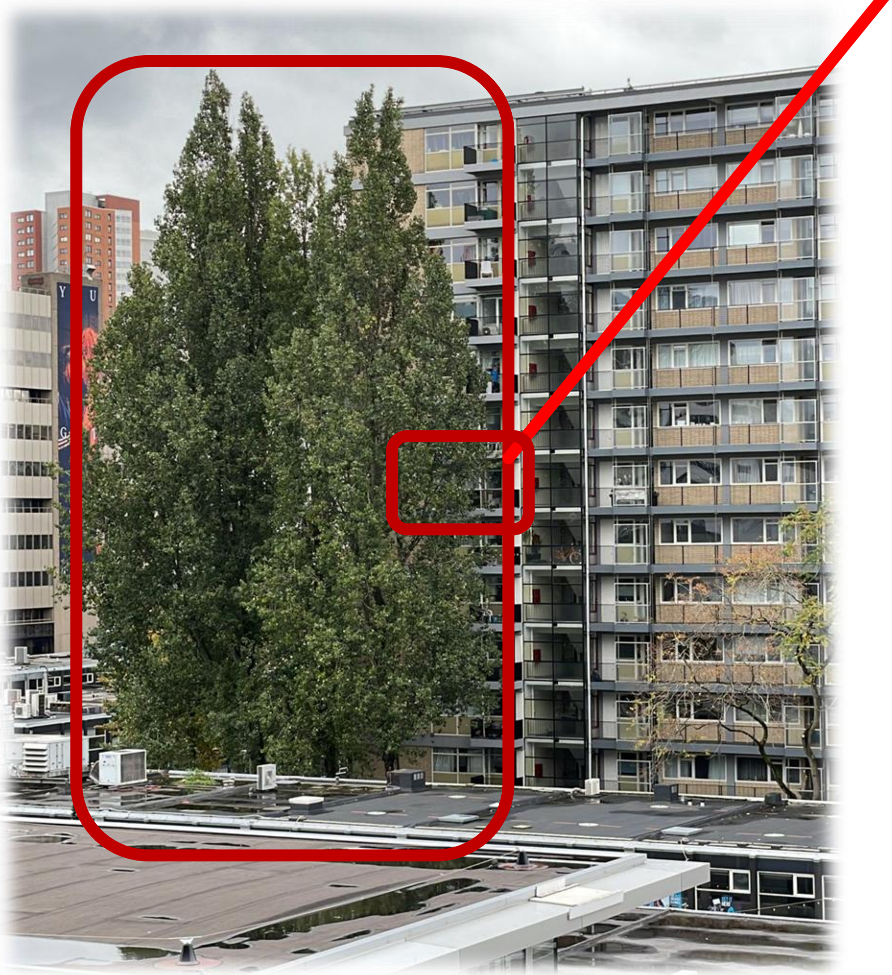
05 Conclusion

01

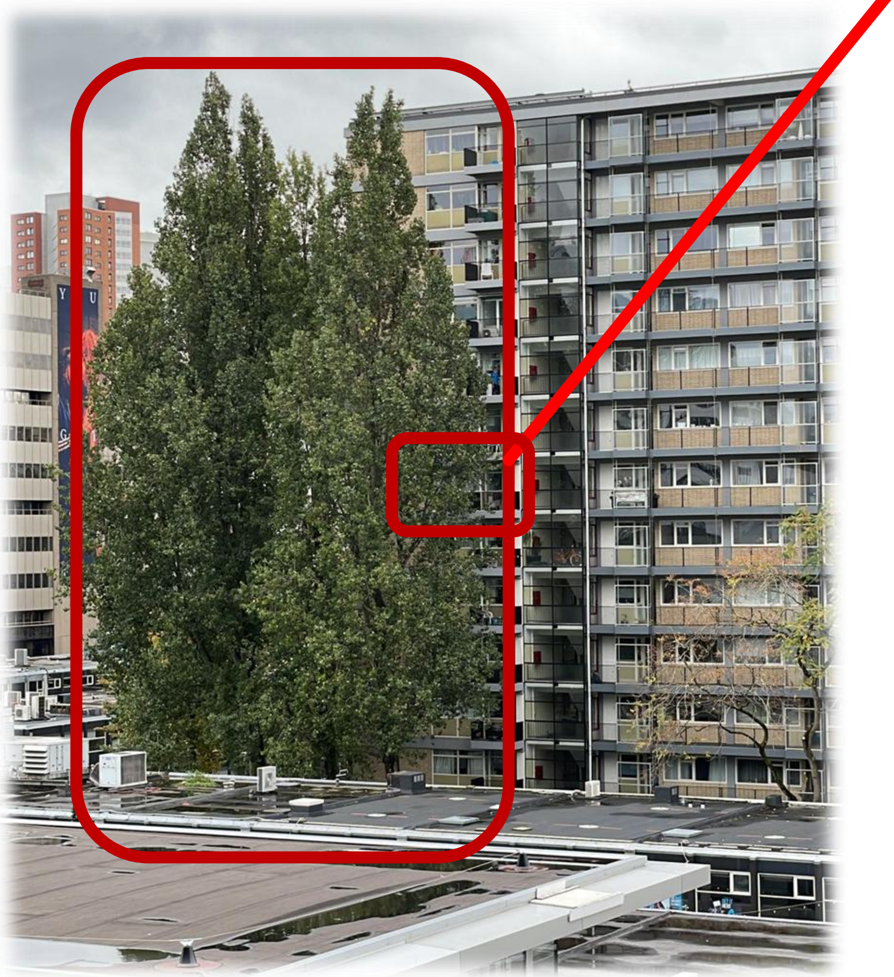
Introduction

First, try to imagine you live in this unit...

This unit has **an evergreen tree**, or tree that doesn’t shed its leaves throughout the year, right in front of it.

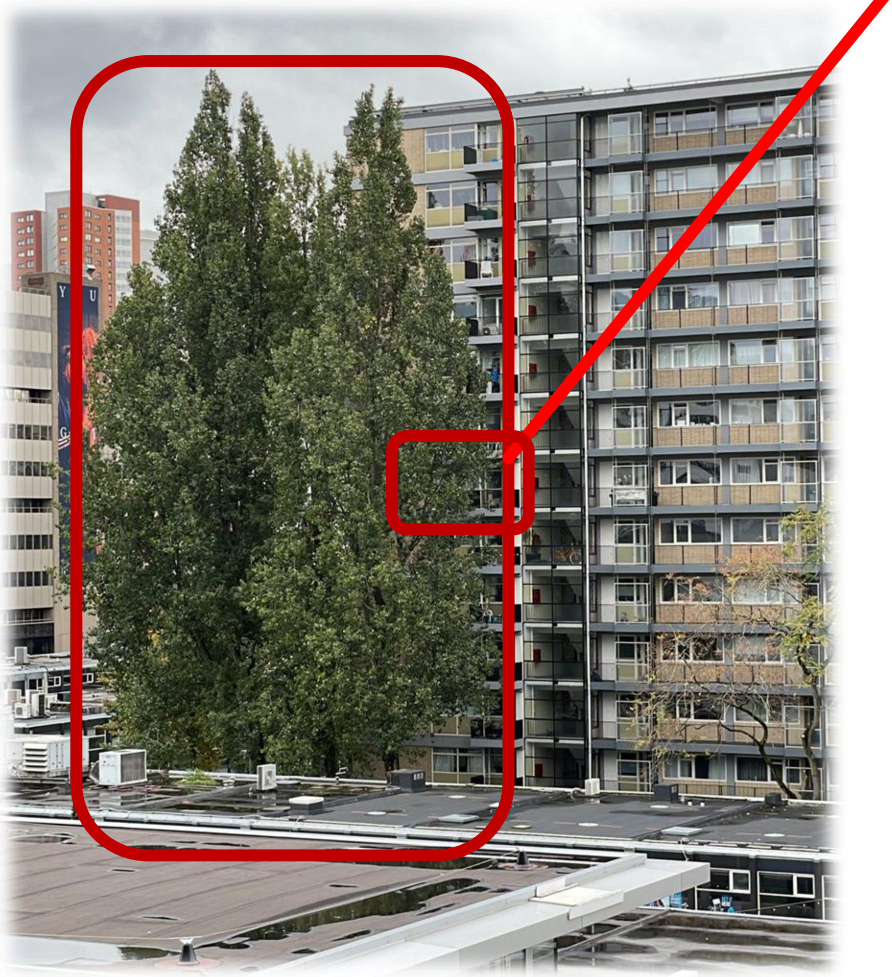


You would like the view of the tree in general



You would like the view of **the tree** in general

In summer, you'd appreciate the coolness **the tree** brings



🥰 You would like the view of
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☀ In summer, you'd appreciate
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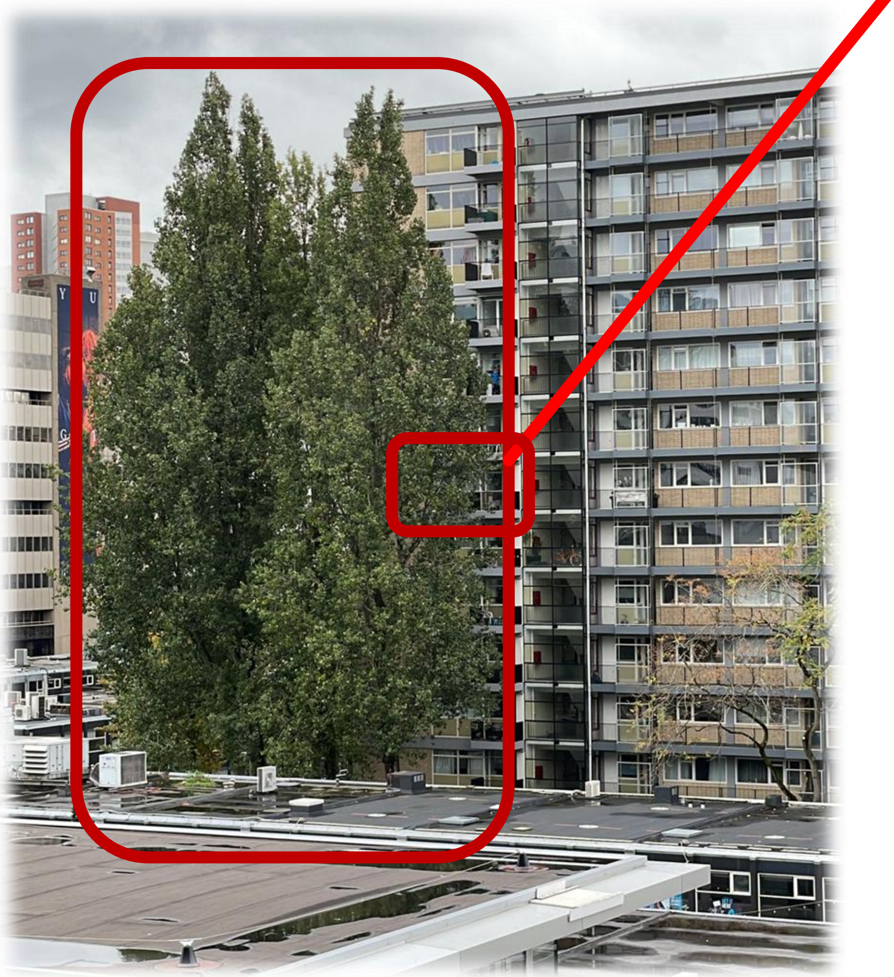
😟 But in winter, the tree
blocks the warmth you long for

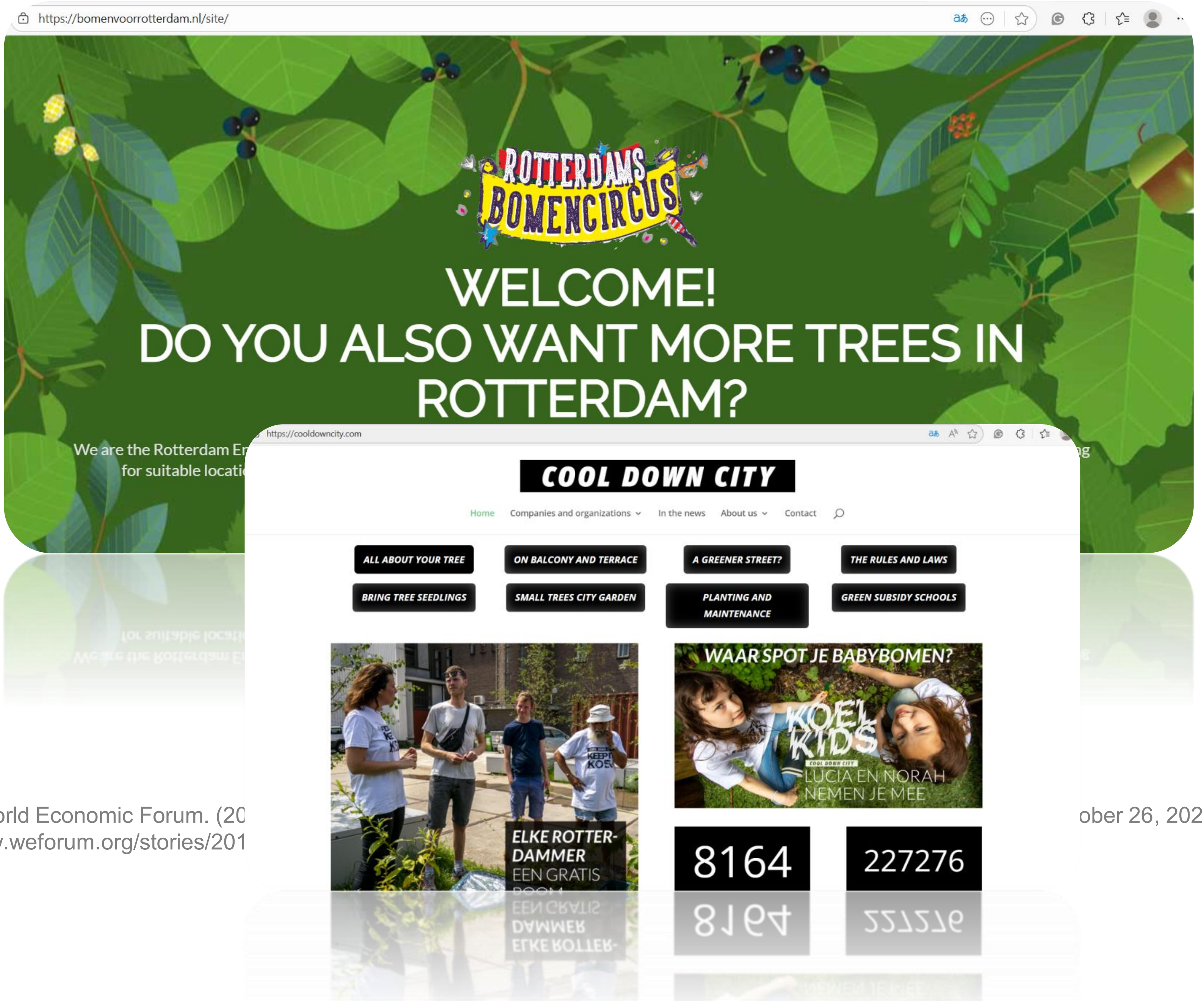


You would like the view of **the tree** in general

In summer, you'd appreciate the coolness **the tree** brings

But in winter, **the tree** blocks the warmth you long for

The tree causes higher electricity costs due to higher usage of heater



https://bomenvoorrotterdam.nl/site/

ROTTERDAMS BOMENCIRCUS

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DO YOU ALSO WANT MORE TREES IN ROTTERDAM?

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for suitable locati

https://cooldowncity.com

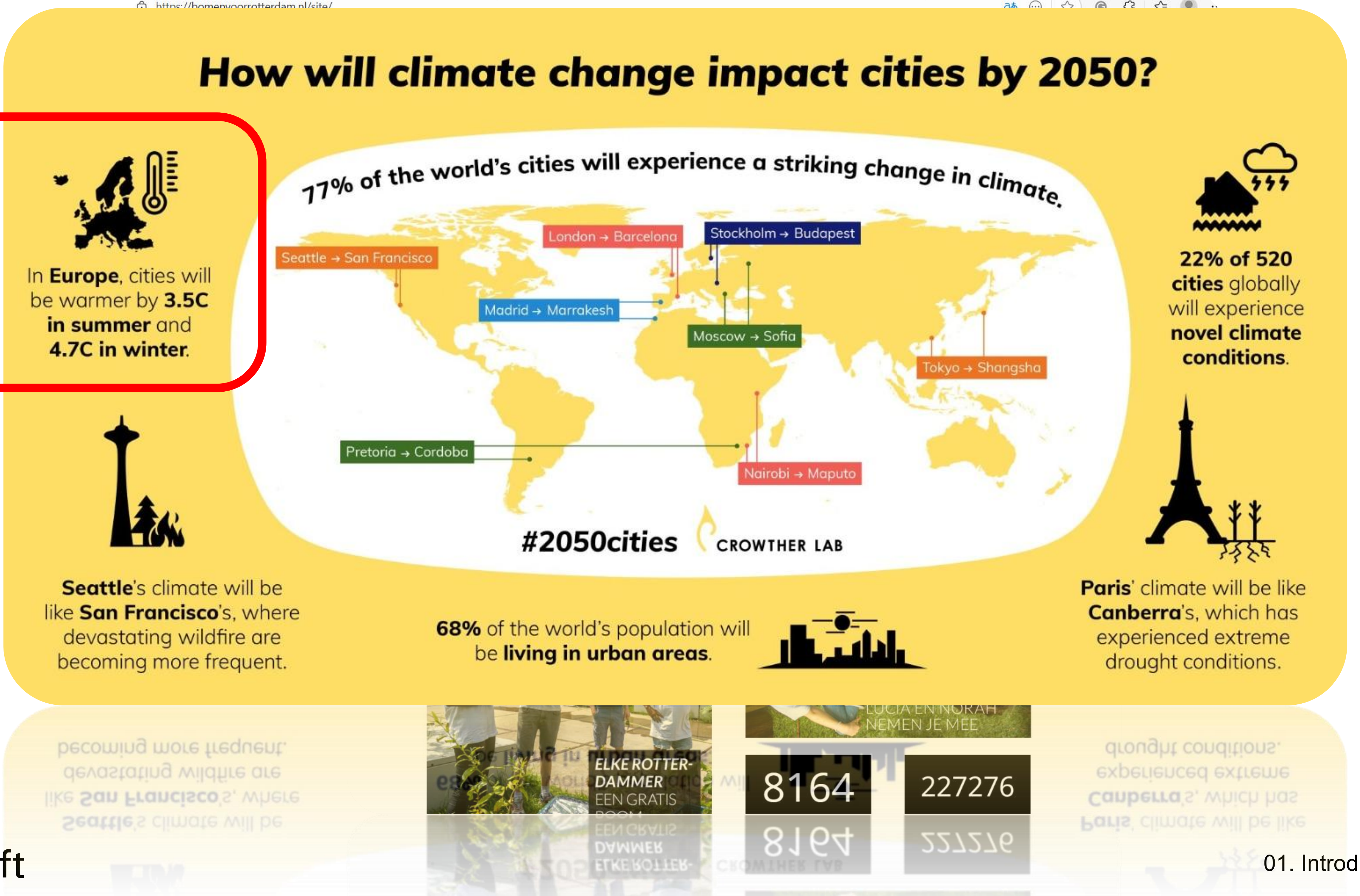
COOL DOWN CITY

8164

227276

Source: World Economic Forum. (20 ober 26, 2025, from
https://www.weforum.org/stories/201

Source: World Economic Forum. (2019). World's major cities to face 'unknown' climate conditions by 2050. Retrieved October 26, 2025, from https://www.weforum.org/stories/2019/07/worlds-major-cities-to-face-unknown-climate-conditions-by-2050/



How will climate change impact cities by 2050?

77% of the world's cities will experience a striking change in climate.

In **Europe**, cities will be warmer by **3.5C in summer** and **4.7C in winter**.

22% of 520 cities globally will experience **novel climate conditions**.

Seattle's climate will be like **San Francisco**'s, where devastating wildfire are becoming more frequent.

68% of the world's population will be **living in urban areas**.

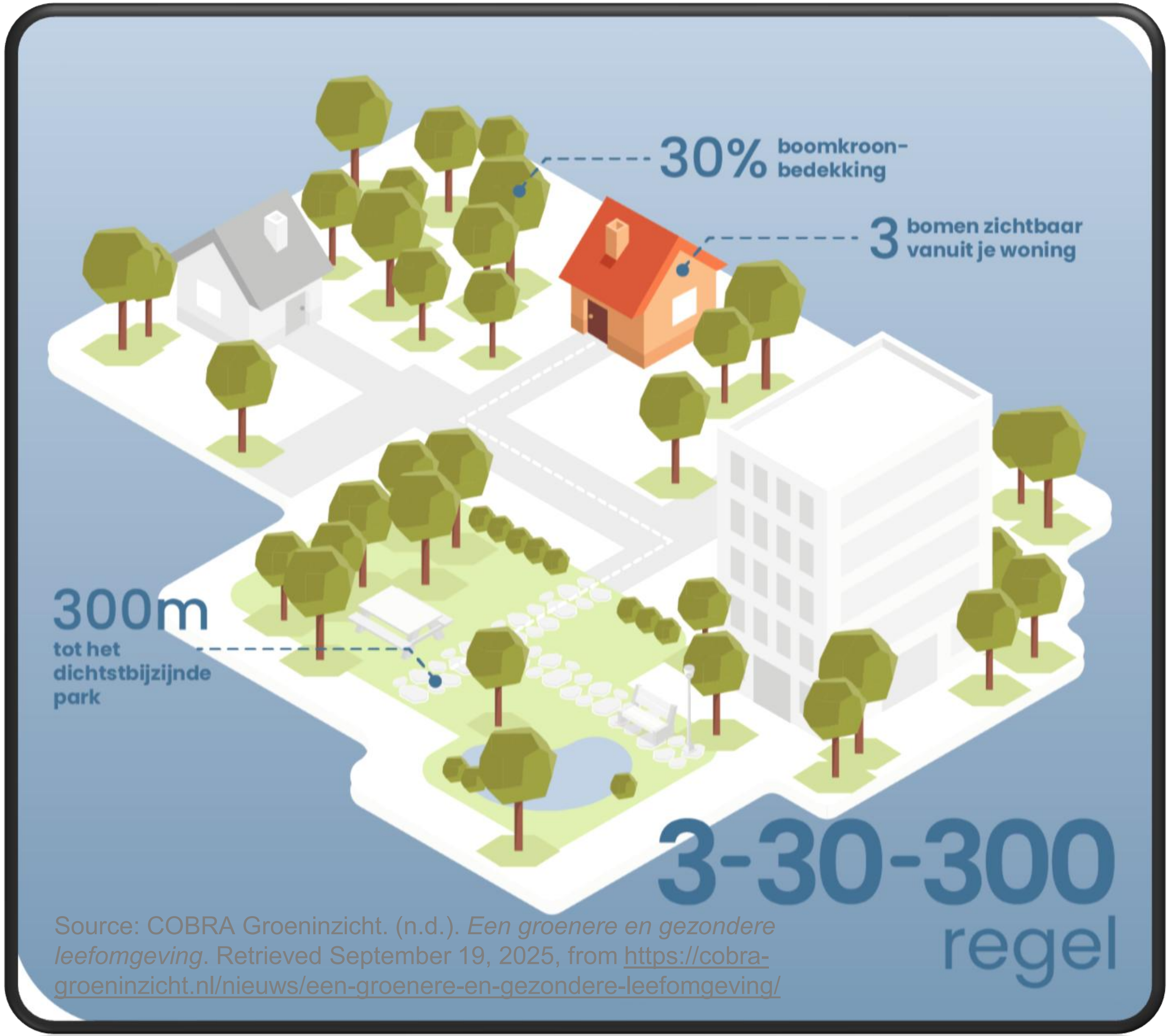
Paris' climate will be like **Canberra**'s, which has experienced extreme drought conditions.

3-30-300 rule

Every person should see 3 trees from their home, **have 30% tree canopy cover in their neighborhood,** and live within 300 meters of a green space

Benefits:

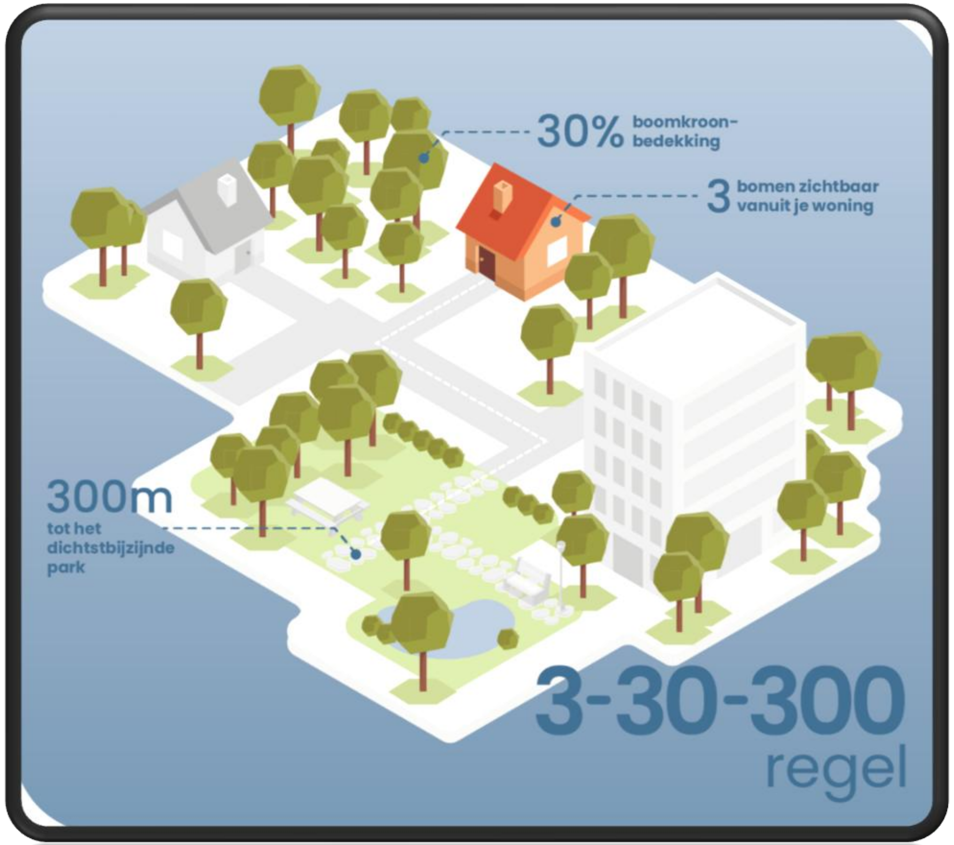
Boosts mental health, encourage physical activity, and it helps lower heat stress



Source: COBRA Groeninzicht. (n.d.). *Een groenere en gezondere leefomgeving*. Retrieved September 19, 2025, from https://cobra-groeninzicht.nl/nieuws/een-groenere-en-gezondere-leefomgeving/

But, still remember this house?

£ The tree might cause higher electricity costs due to higher usage of heater



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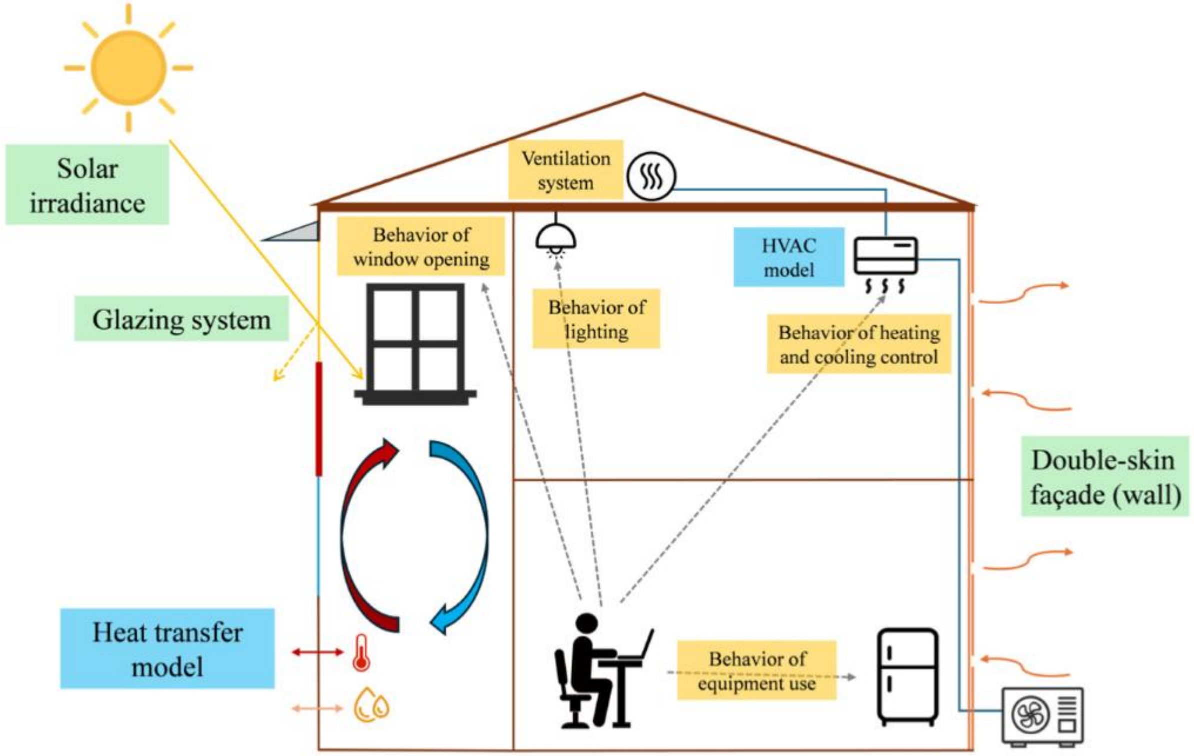
But in winter, that same tree blocks the warmth you long for

More heater use = higher electricity bill

Can we support the **3-30-300 rule** to help reduce the effects of **climate change, without unintentionally increasing electricity bills** across neighbourhoods?

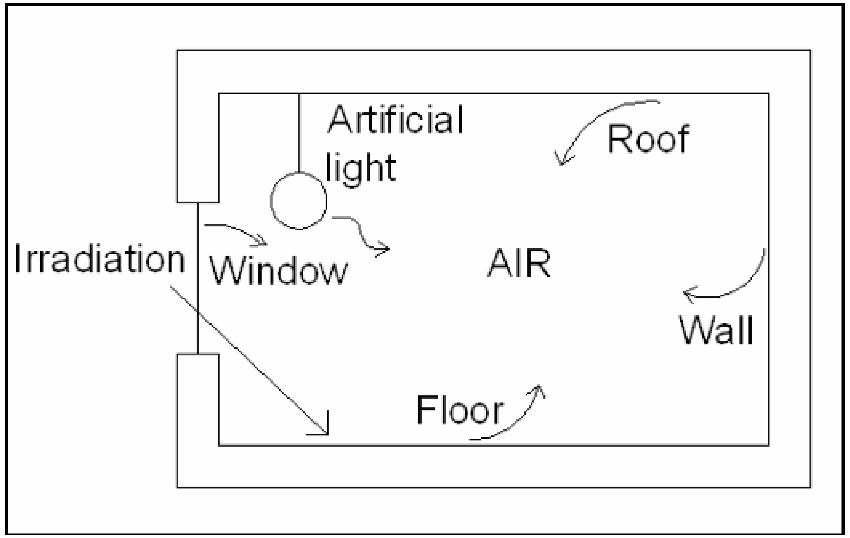
Building energy modelling



System diagram of building energy simulation modules
Source: Chen et al. (2024), Energies, *17*(17), 4313. Licensed under CC BY 4.0 (https://doi.org/10.3390/en17174313)

BEM → A **physics-based computational method** for representing how buildings use and transfer energy

Heat balance method



Heat balance representation
Source: Melo, A.P. & Lamberts, R. (2009).
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(https://www.ibpsa.org/proceedings/BS2009/BS09_2243_2250.pdf)

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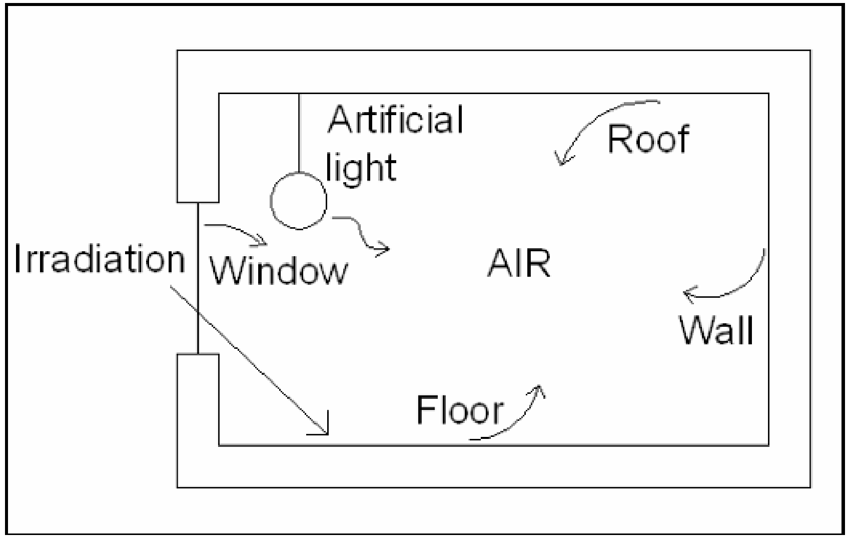

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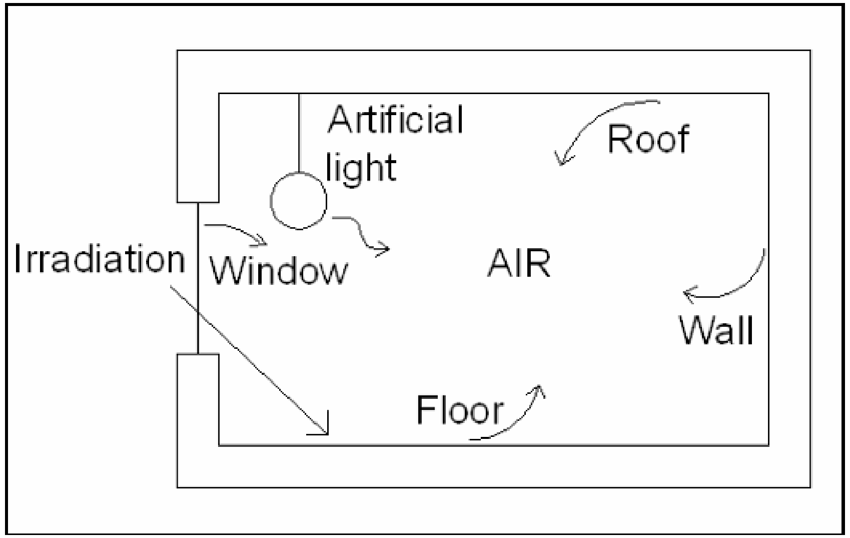

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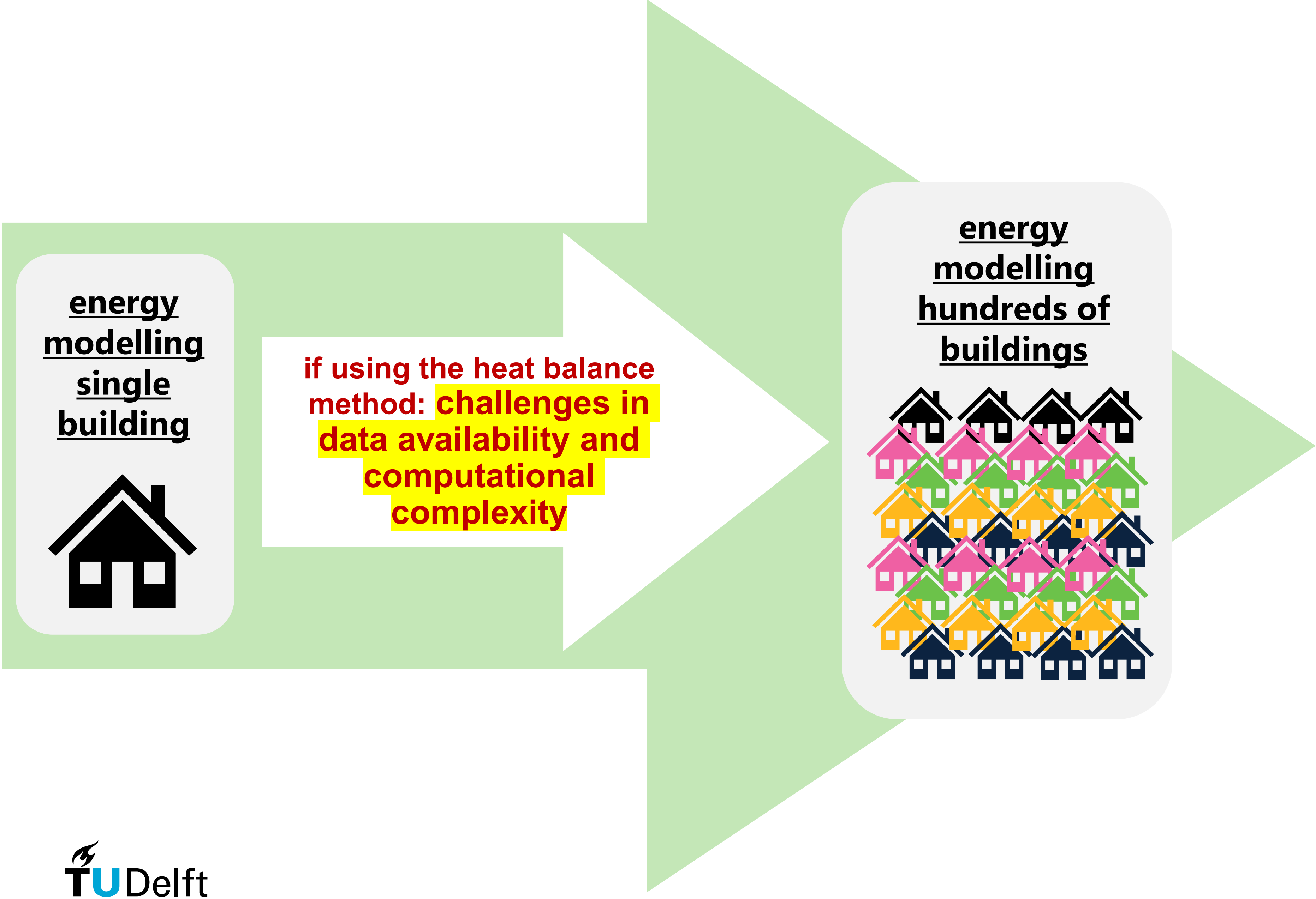
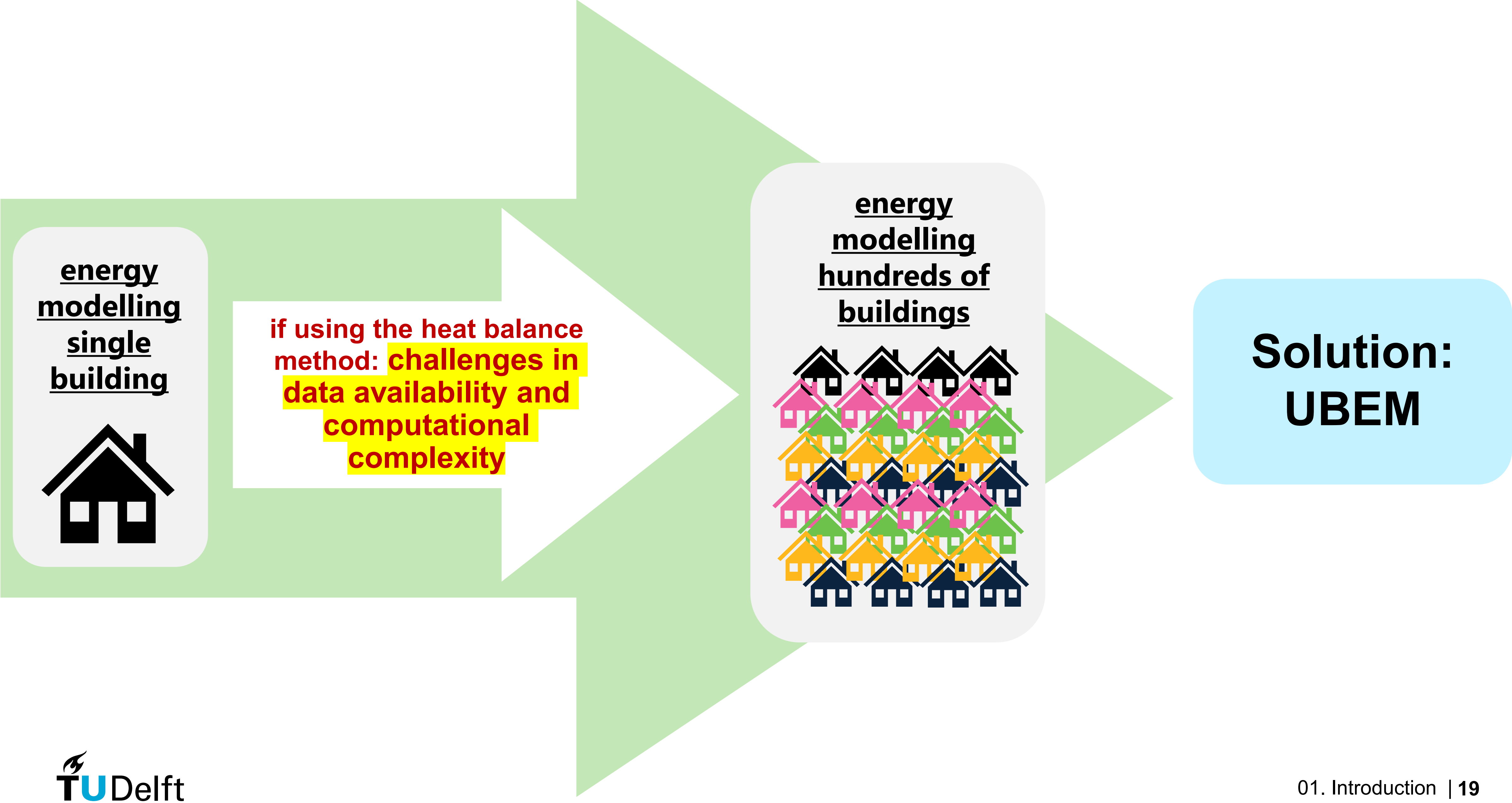
Gains: solar irradiation, artificial lighting, and internal heat from occupants and equipment.
Losses: conduction through the envelope, ventilation, and radiation exchange.



energy modelling single building

if using the heat balance method: challenges in data availability and computational complexity

energy modelling hundreds of buildings



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Solution: UBEM

UBEM approaches and their characteristics

Approach (Example Tools)	Strengths	Limitations
Top-down (e.g., LEAP, EnergyPLAN, TIMES)	• Captures **long-term** and **socioeconomic** trends • Integrates **policy and techno-economic** factors	• Based on **aggregated data** • **Generalizes** current conditions • Lacks detail on **individual end-uses**
Data-driven (Bottom-up) (e.g., ANN models, Regression, Random Forests)	• Provides **detailed depiction** of urban energy use • Efficient in **time and computation** • Considers **occupancy** and **socioeconomic patterns**	• **Depends on historical data** • Limited when data are **unavailable** • Low flexibility for **design changes**
Simulation-based (Bottom-up) (e.g., SimStadt, CitySim, CEA)	• Independent of historical datasets • Captures **end-use detail** • Integrates with **BIM/3DCM** • based on **physics-based modelling**	• Requires **detailed input** • **Computationally intensive** • Simplifies **complex urban factors**

Adapted from: Abbasabadi, N., & Ashayeri, M. (2019). *Urban energy use modelling methods and tools: A review and an outlook.* https://doi.org/10.1016/j.buildenv.2019.106270

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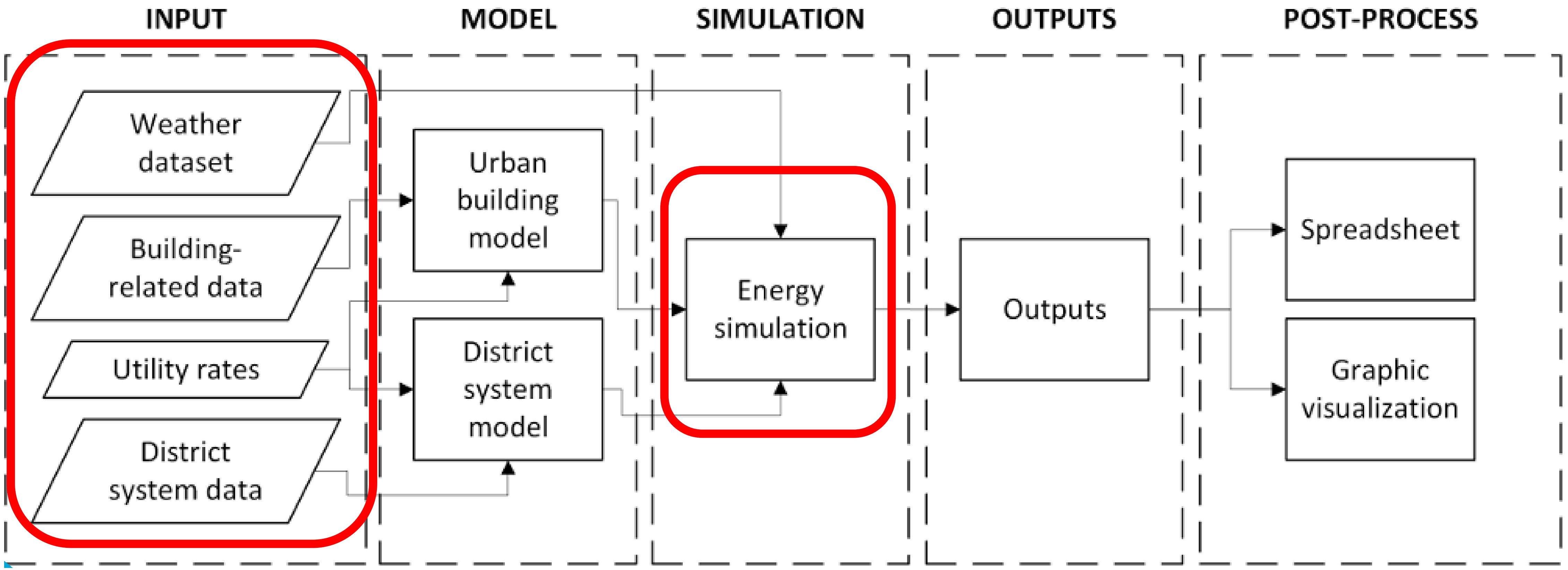
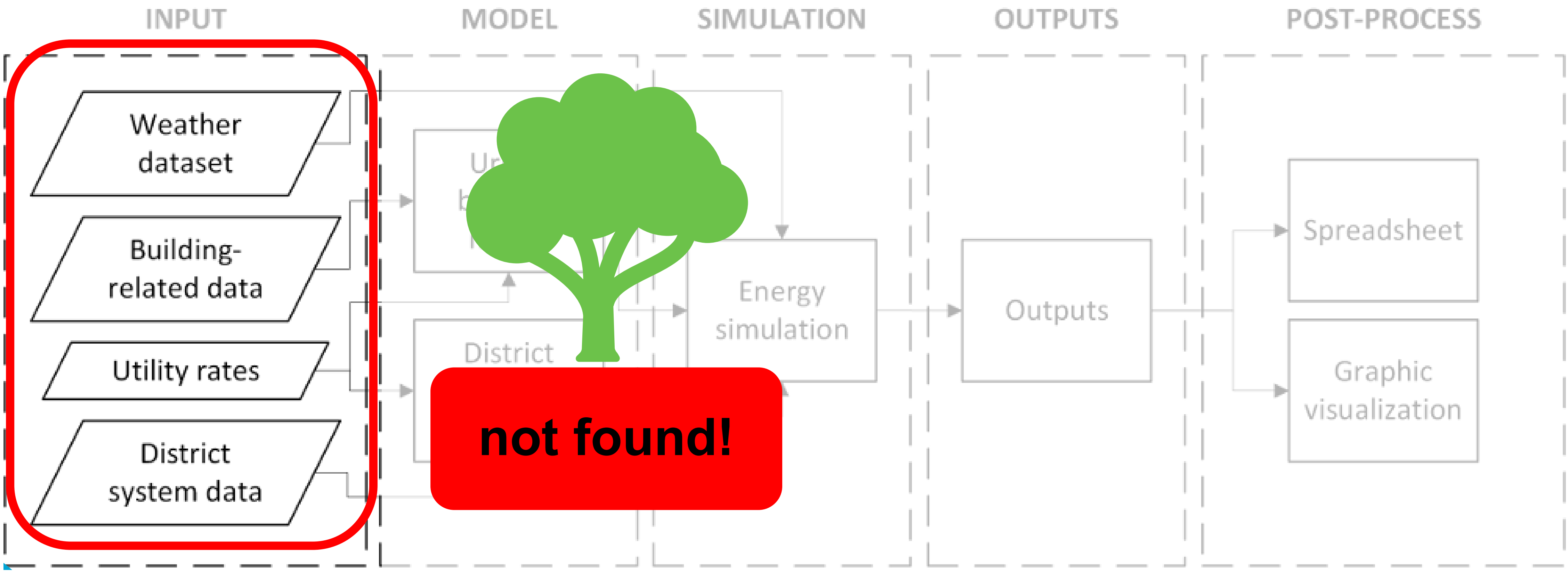
Physics-based UBEM workflow



Physics-based UBEM workflow in general (adapted from [Ferrando et al., 2020]

Physics-based UBEM workflow



Physics-based UBEM workflow in general (adapted from [Ferrando et al., 2020]

Representation of trees in physics-based UBEM

Approach	Main Tools	Tree Representation	Scale
1. Radiative + BEM	CitySim	Trees as canopy layers filtering short- & long-wave radiation	100 × 200 m site (~40 000 m² floor area)
2. Coupled Microclimate + UBEM	ENVI-met + CEA (Zurich) / ENVI-met + EnergyPlus (Thessaloniki)	Trees defined by height, LAD, albedo, transmittance; affect microclimate (T, RH, wind)	Zurich: 522 × 498 m (+100 m buffer) Thessaloniki: 40 000 m² residential area
3. Direct Tree Integration	GIS + Grasshopper + UMI	1 142 trees as simplified shading objects	Capitol East, Des Moines — neighbourhood scale

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rely on multiple tools rather than a single modelling platform

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Except for the 2nd approach, these studies are also limited to a small neighbourhood scale.

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no methods currently exist for incorporating vegetation at the large neighbourhood or district scale **within a single modelling platform**.

02

Research questions

Research question:

How can the spatial representation of tree planting be integrated into UBEM to assess its effectiveness in reducing heating and cooling demand under projected 2050 climate conditions?

Objectives

SRQ1

Method to integrate spatial tree data into UBEM workflows to quantify neighbourhood-scale energy impacts.

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SRQ2

A set of modelling assumptions and simplifications for representing tree shading under varying climates

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SRQ1 Method to integrate spatial tree data into UBEM workflows to quantify neighbourhood-scale energy impacts.

SRQ2 A set of modelling assumptions and simplifications for representing tree shading under varying climates

SRQ3 Framework for interpreting simulation results to guide urban planning and climate adaptation decisions.

Positive Energy District (PED)

European initiatives to design urban areas that cut energy use, produce surplus renewable energy, and reach net zero emissions. One of PED goals is **Reducing energy demand** through efficiency and smart urban management.

URBAN EUROPE

Home > Positive Energy Districts (PED)

Source: JPI Urban Europe. (n.d.). *Positive Energy Districts (PED)*. Retrieved September 19, 2025, from https://jpi-urbaneurope.eu/ped/

03

Method and Experiment

Study Area

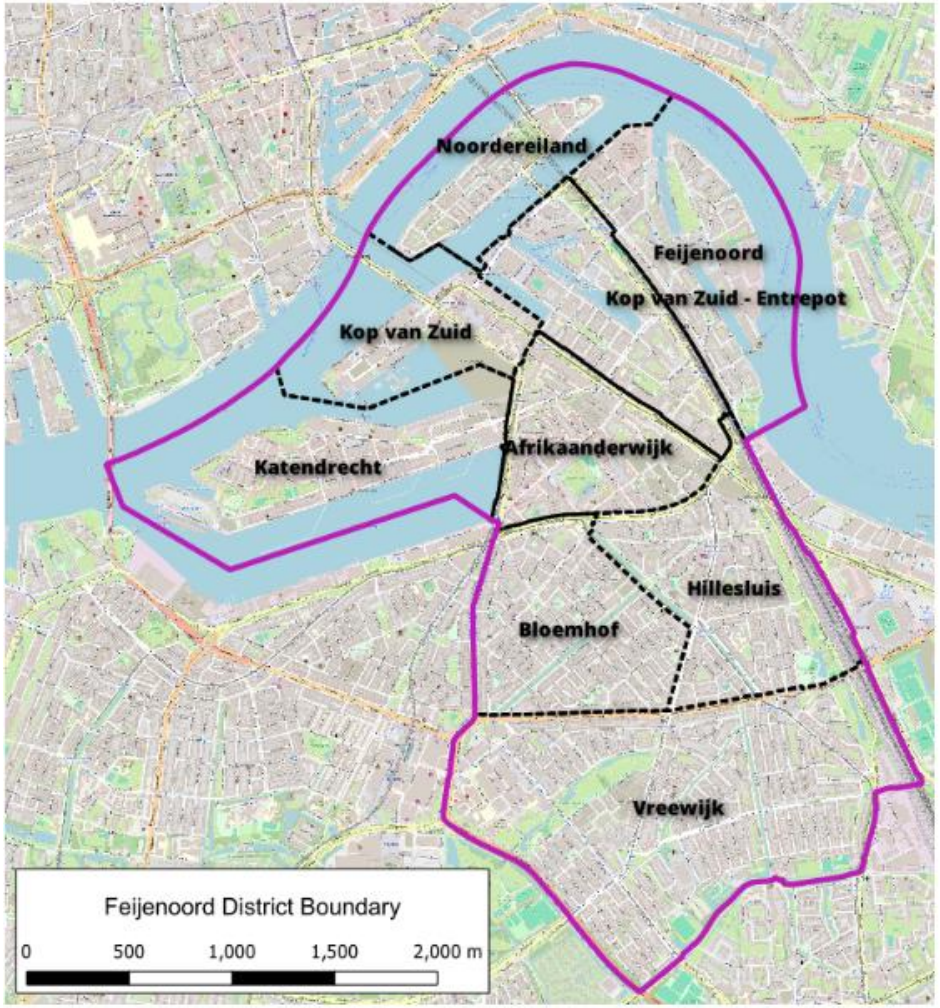
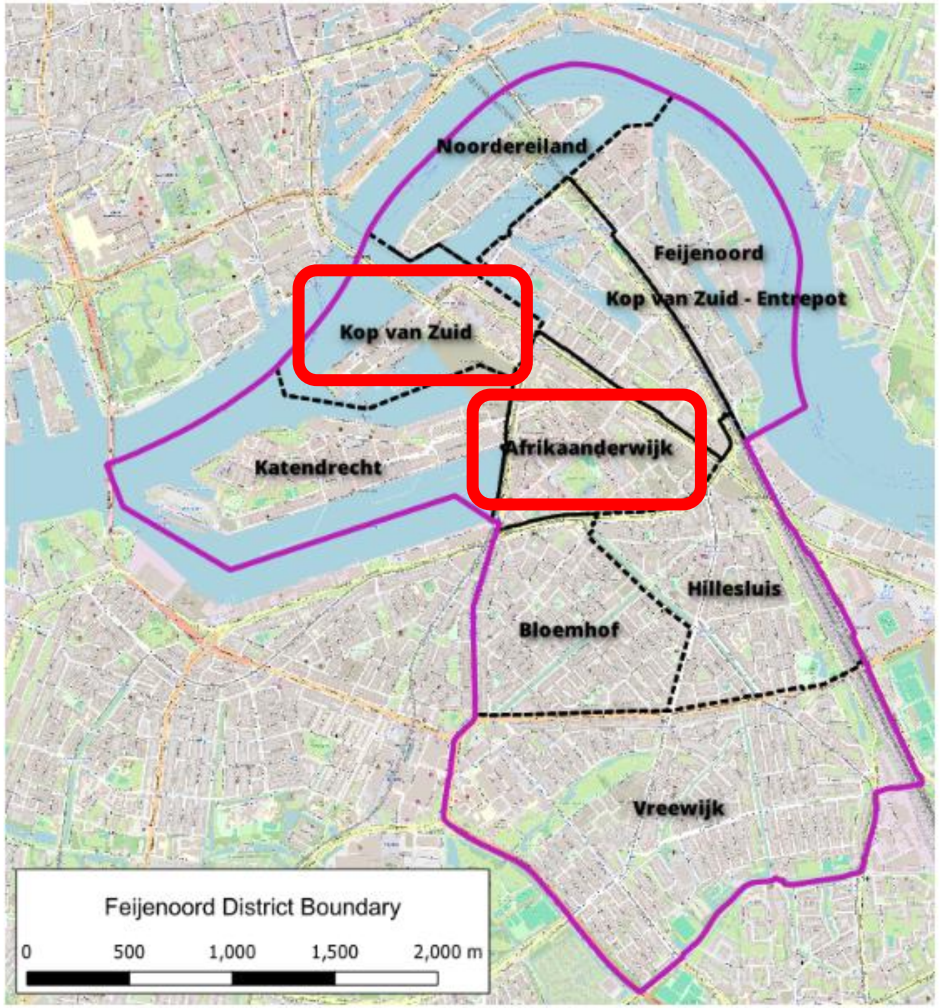


Figure 4.1.: Feijenoord District

Feijenoord district

“most ‘stony’ or not green neighborhood in Rotterdam”

Study Area



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“most ‘stony’ or not green neighborhood in Rotterdam”

Has 9 neighborhoods

But only 2 were chosen due to computational and time limitations. The areas are **Kop van Zuid and Afrikaanderwijk**.

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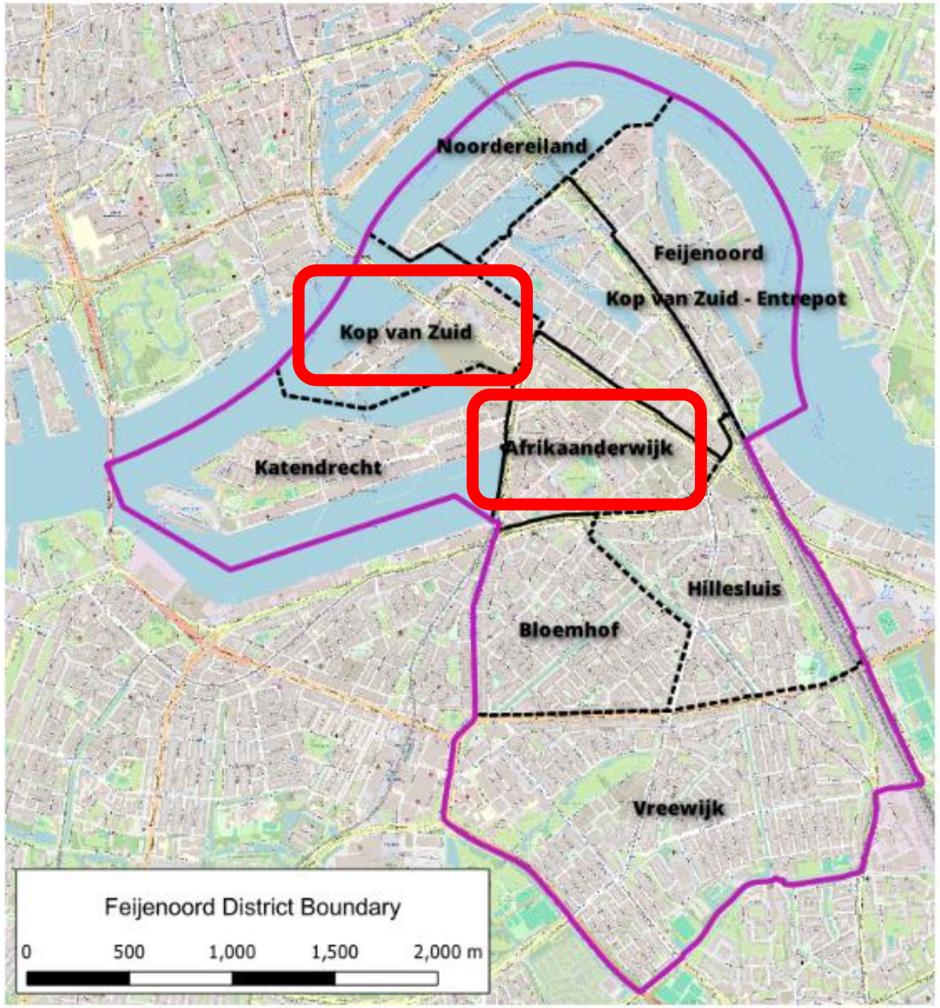

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Feijenoord district

“most ‘stony’ or not green neighborhood in Rotterdam”

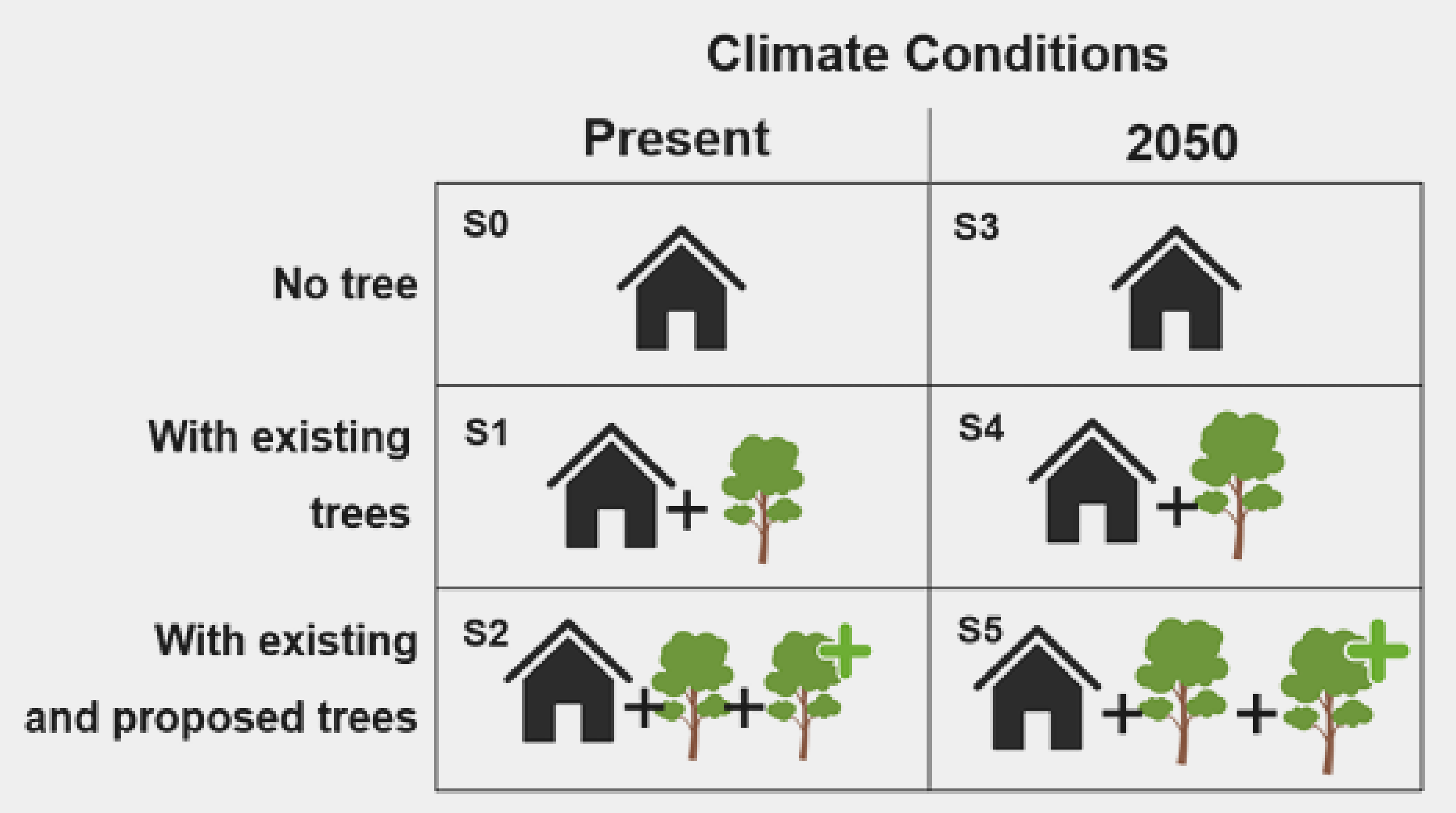
Has 9 neighborhoods

But only 2 were chosen due to computational and time limitations. The areas are **Kop van Zuid and Afrikaanderwijk**.
Even though only two areas were analyzed, they still show useful variation between a waterfront zone and a dense inner-city area.

Method

- Scenarios development
- Simulation tool and data requirements identification
- Modelling simplifications and assumptions
- Model configuration
- Simulation, post-processing, analysis and visualization

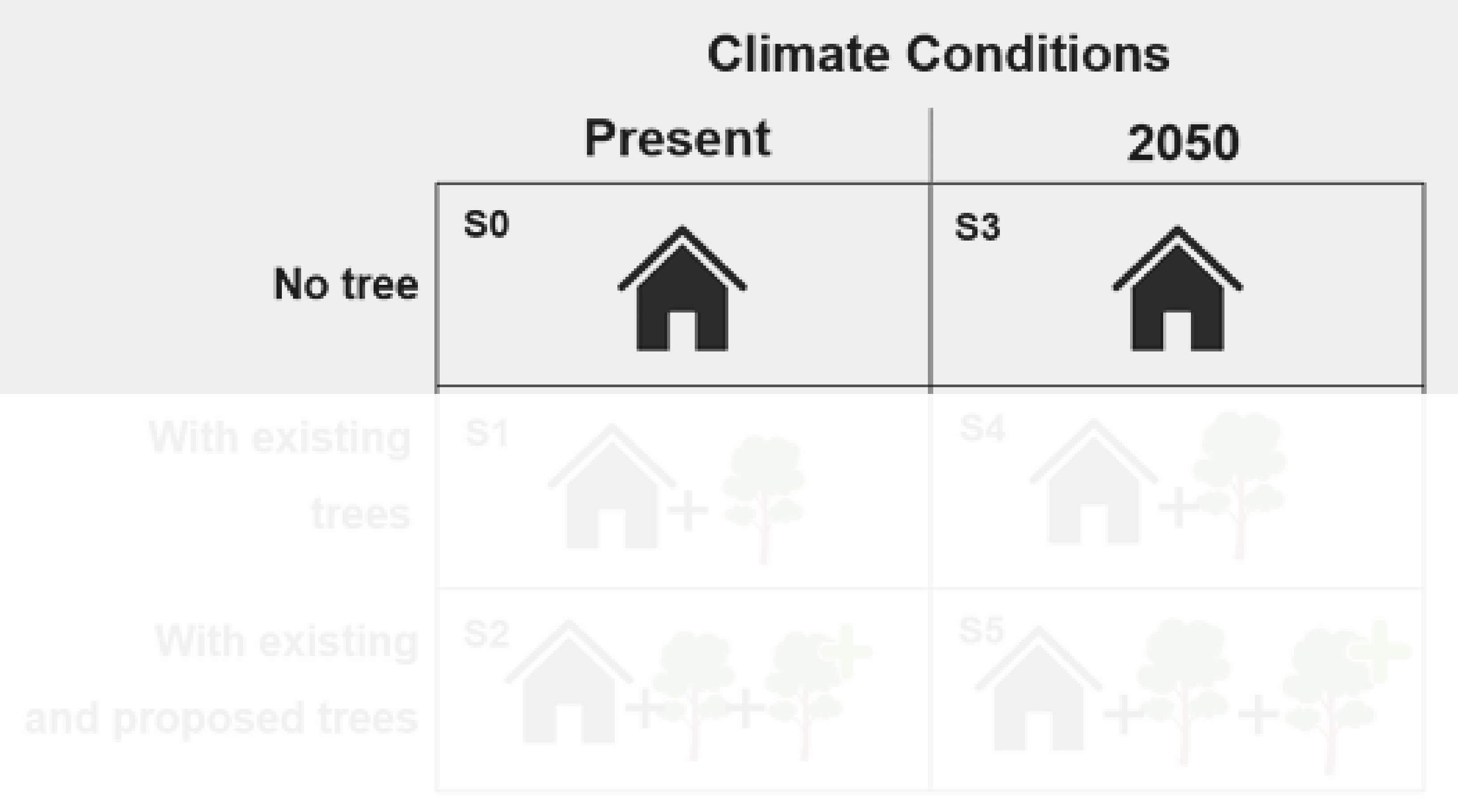
1. Scenarios developments



	Climate Conditions	
	Present	2050
No tree	S0	S3
With existing trees	S1	S4
With existing and proposed trees	S2	S5

Structured to isolate the individual and combined effects of vegetation and climate change on building energy demand

1. Scenarios developments



Climate Conditions

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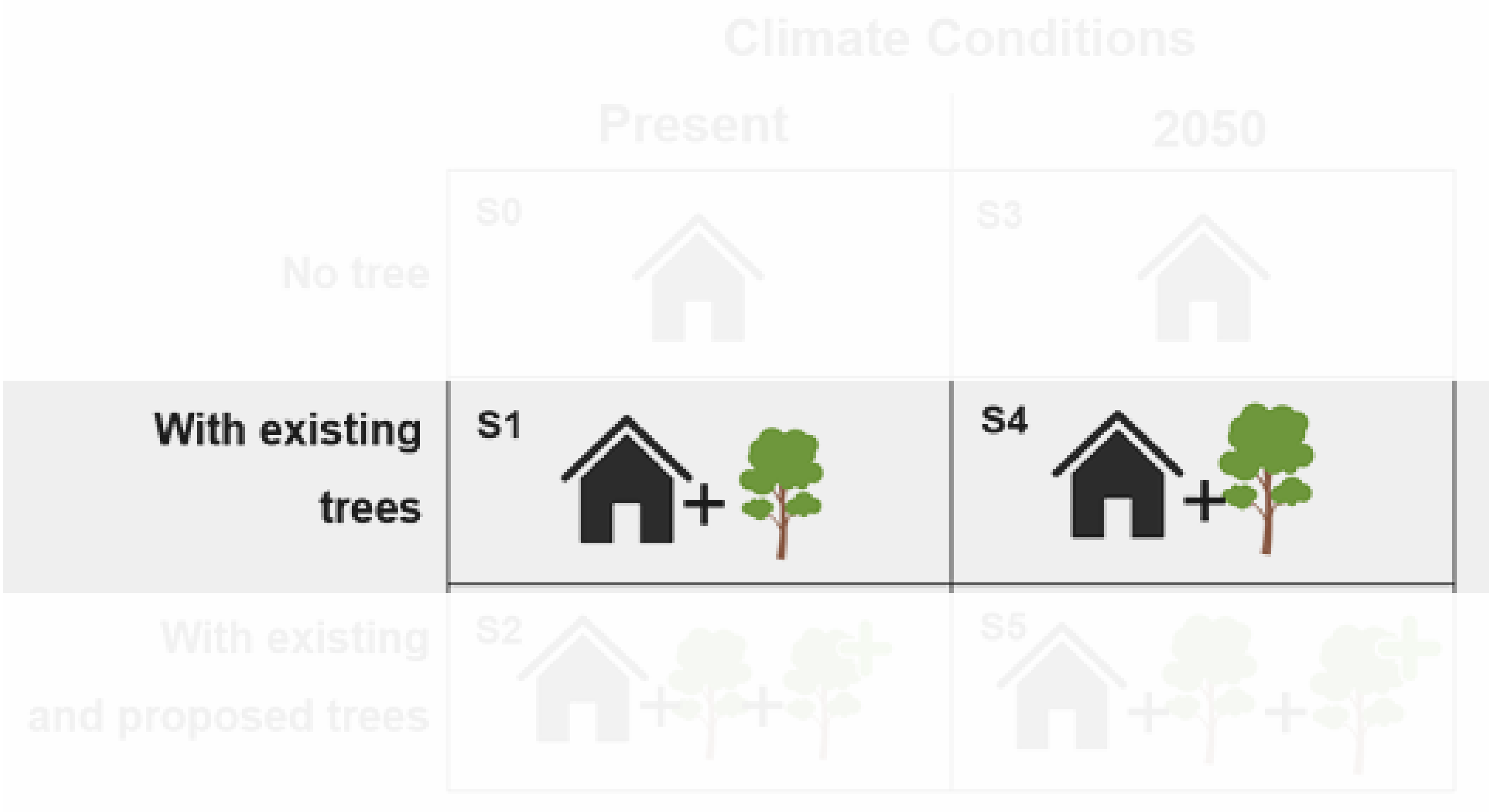
Begin with a reference case containing only buildings

1. Scenarios developments



	Climate Conditions	
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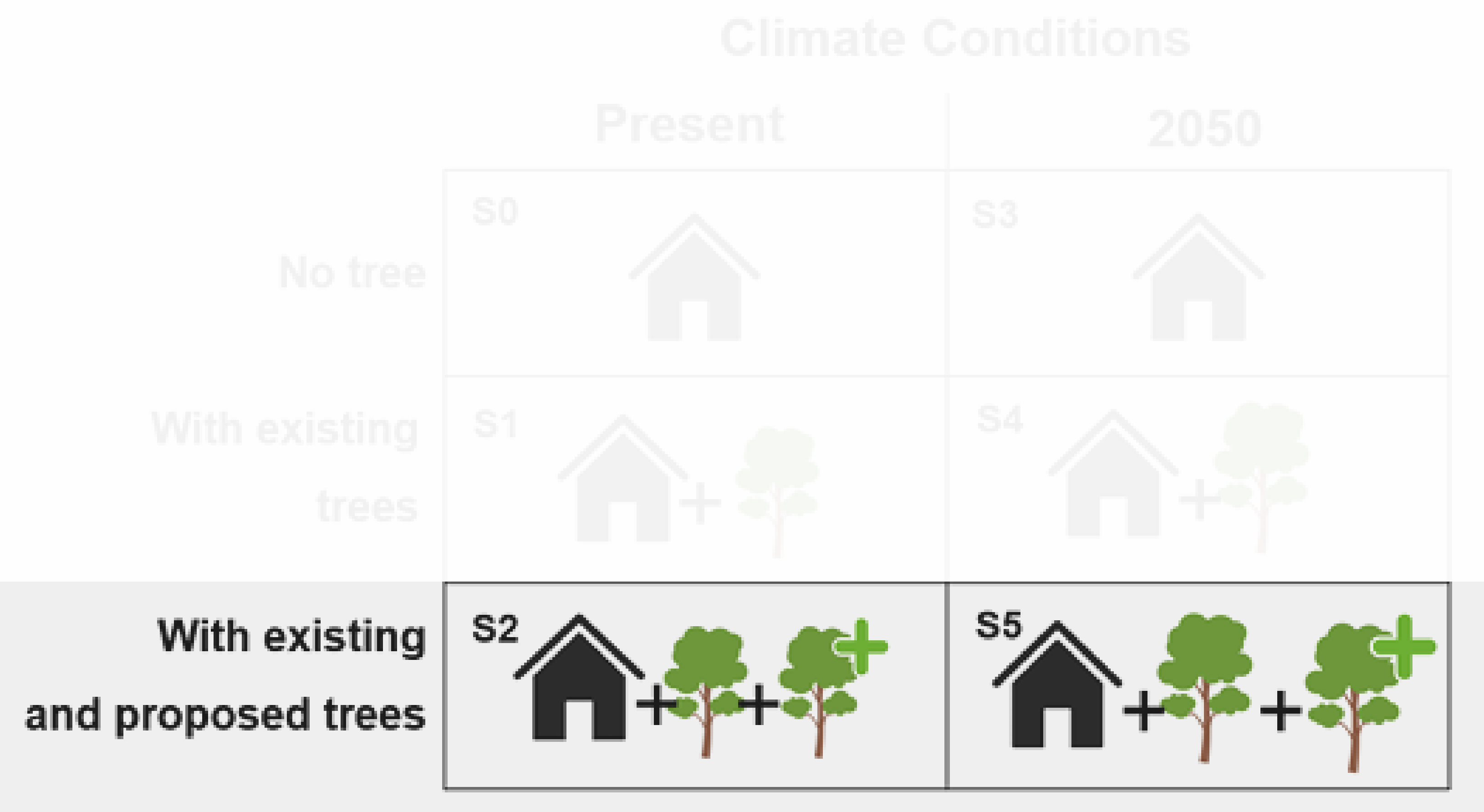
then introduce existing trees

Scenarios developments



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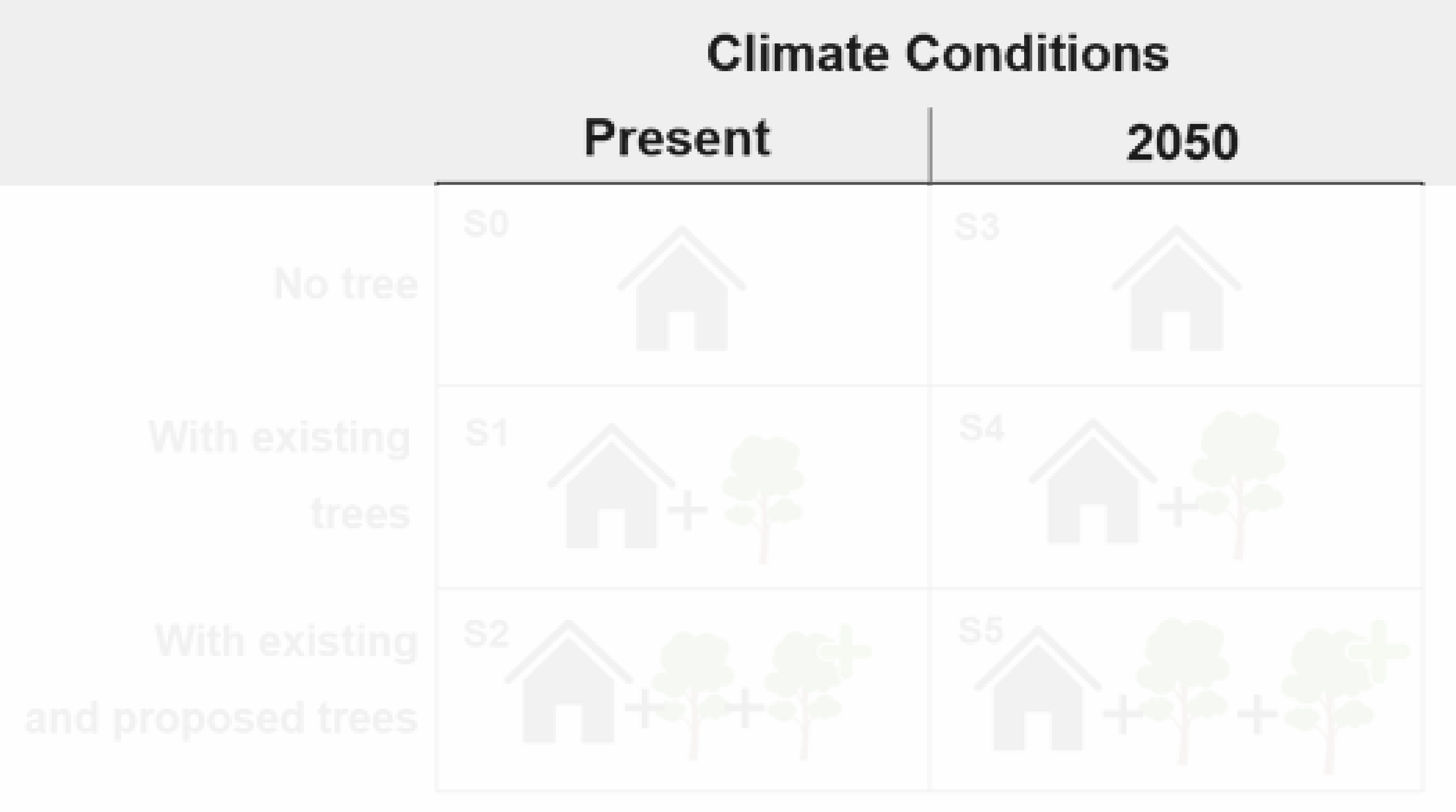
and finally include proposed trees.

1. Scenarios developments



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These cases are run under both present and projected 2050 climate conditions.

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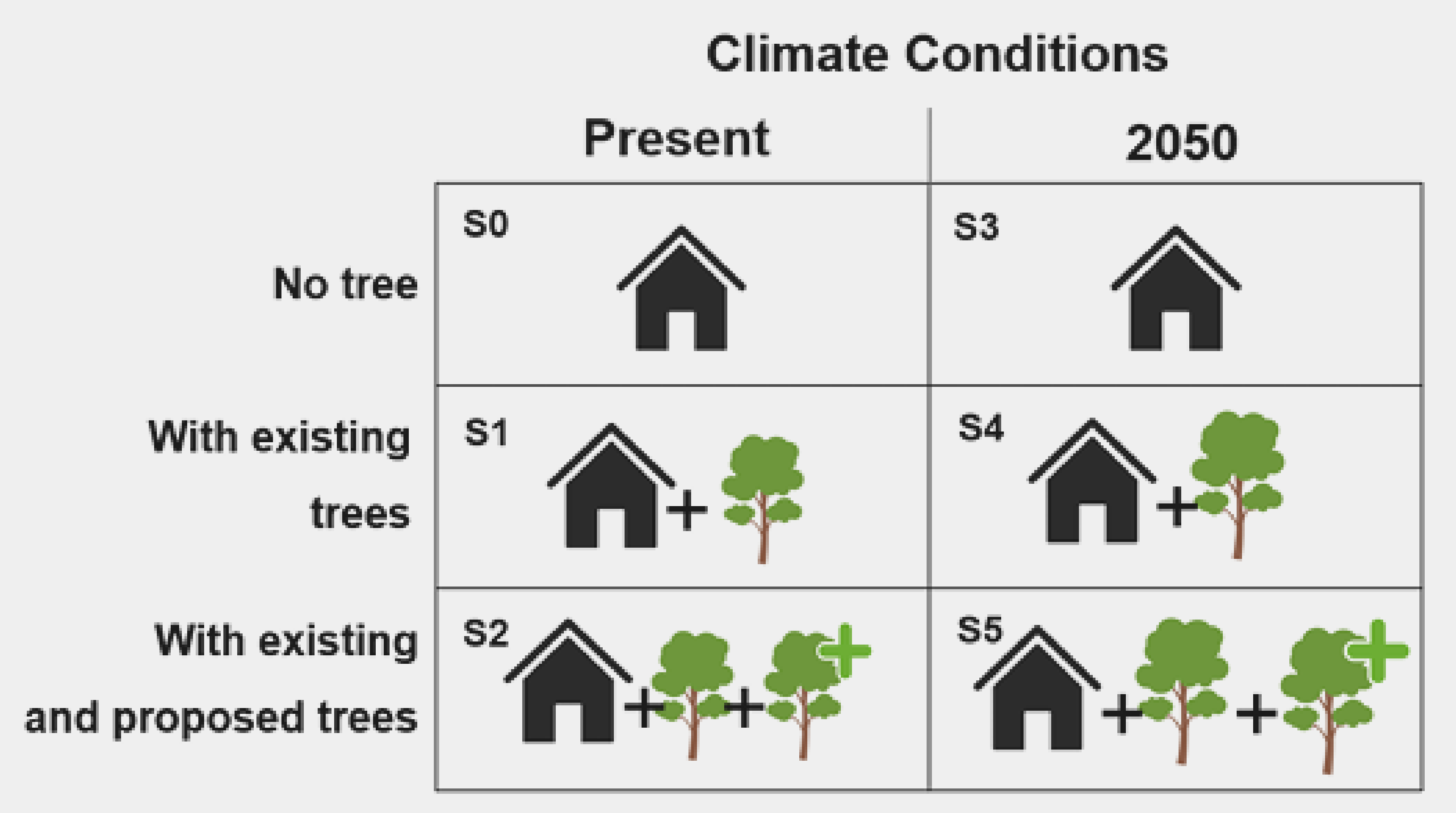

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This approach will allow us to systematically compare how each factor influences heating and cooling demand

Method

Scenarios development

Simulation tool and data requirements identification

Modelling simplifications and assumptions

Model configuration

Simulation, post-processing, analysis and visualization

2. Simulation Tool and Data Requirements Identification

Assessed based on:

modelling approach and simulation engine: reduced-order RC model

GIS integration: has CityGML integration

computational requirements: PC-based

Applicability: city scale

2. Simulation Tool and Data Requirements Identification

Energy simulation tool:

SimStadt

Urban simulation environment developed at **HFT Stuttgart, Germany**

Assessed based on:

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Supporting tools:

FME by Safe Software

QGIS

2. Simulation Tool and Data Requirements Identification

Data needed:

Buildings → to capture geometry and energy characteristics
Vegetation (existing and proposed) → to represent additional shading
Weather Data (Current and Future)
Urban Context → District boundaries
Land use layers → to generate proposed trees

Method

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3. Modelling Simplifications and Assumptions

Simulation tool:

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Limitations:

- Only reads CityGML building geometries
- Needs weather data in specific format (at least contains GHI + temperature)

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Modelling simplifications and assumptions are needed to keep the model workable while still capturing the dynamics we wanted to study

3. Modelling Simplifications and Assumptions

Tree Representation:

- Trees modeled as **cylinders**
- Each tree given **generic construction year** + building type to stay in workflow

Foliage Density:

- **Full foliage** in summer (1 × Dc), **reduced foliage** in winter (0.64 × Dc)
- Only differentiates **deciduous vs. evergreen based on trees genus and** not species-specific details

Proposed Trees:

- Trees are placed in ‘suitable planting areas’, at least 3 meters from buildings and 5 meters apart. All new trees are deciduous, with uniform height and diameter.

Future Tree Growth:

- Linear growth until **2050** for known planting years
- Max growth limits: **+2 m diameter**, **+2.5 m height** to reflect pruning limits

Future Climate Conditions:

Monthly changes in **temperature** + **radiation** included for **2050 scenarios → due to data availability (KNMI ’23)**

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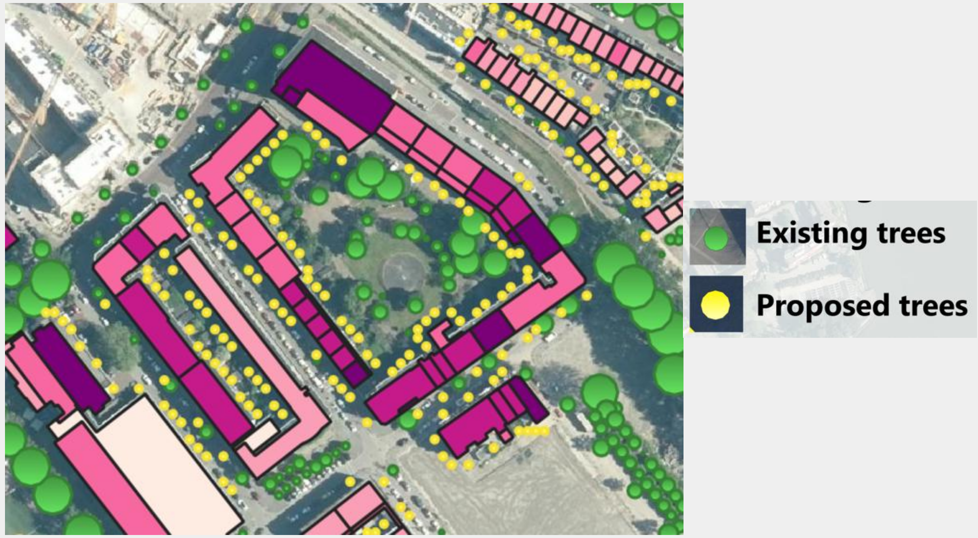

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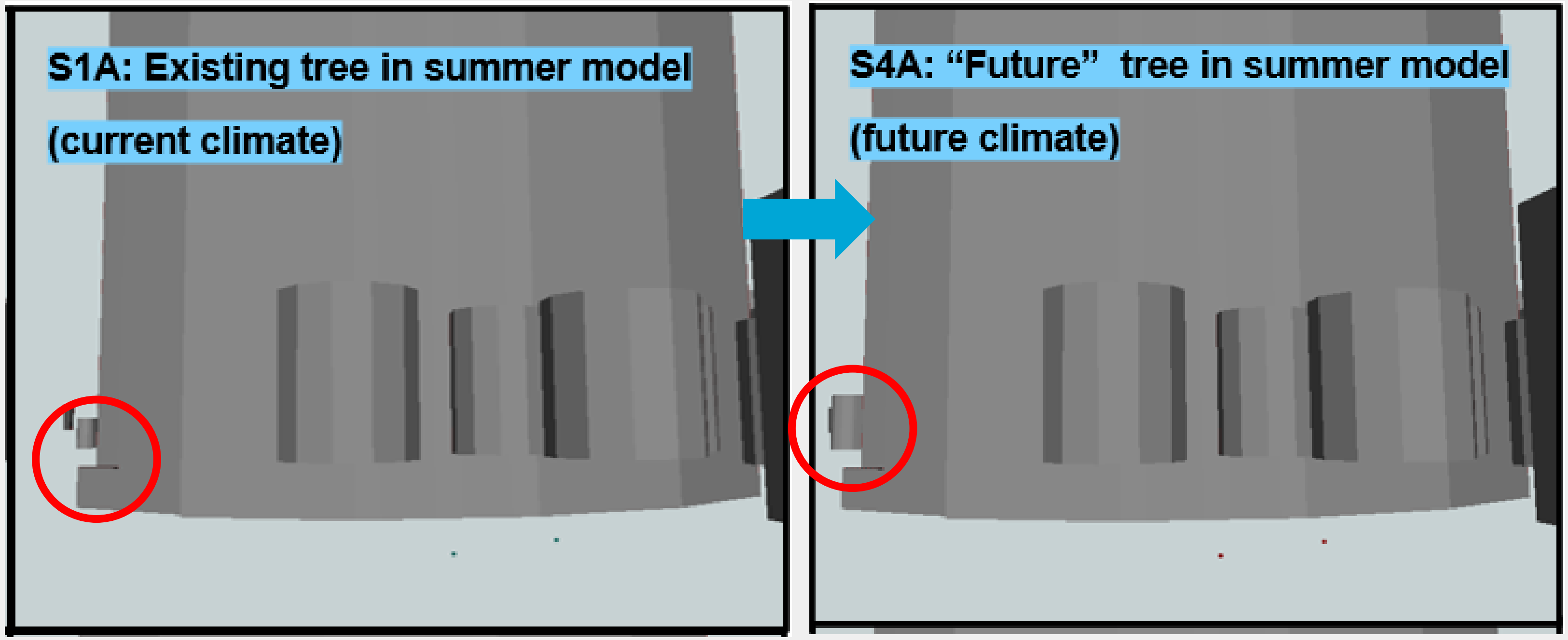

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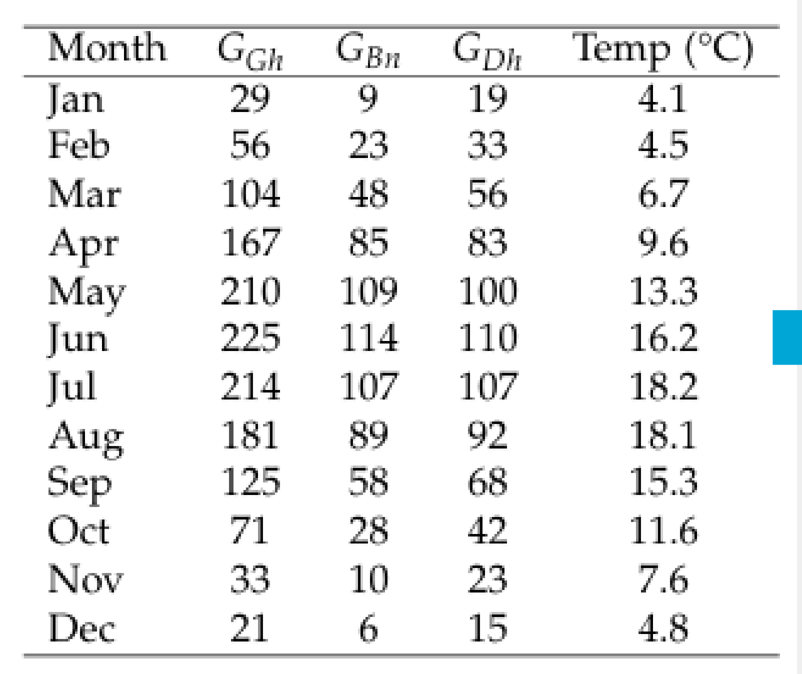
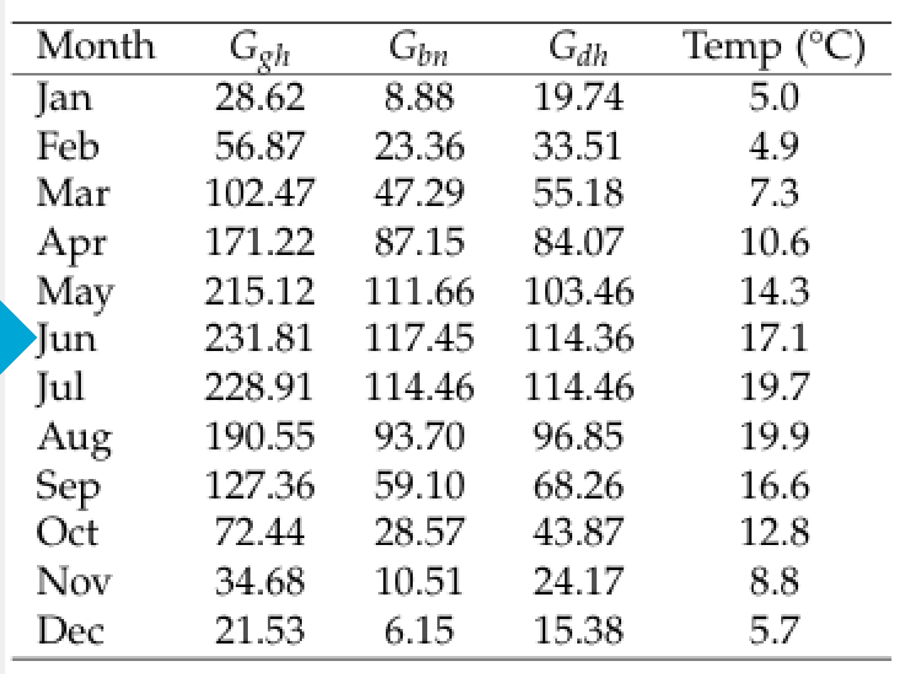
- Max growth limits: **+2 m diameter**, **+2.5 m height** to reflect pruning limits

3. Modelling Simplifications and Assumptions



Month	G_{Gh}	G_{Bn}	G_{Dh}	Temp (°C)
Jan	29	9	19	4.1
Feb	56	23	33	4.5
Mar	104	48	56	6.7
Apr	167	85	83	9.6
May	210	109	100	13.3
Jun	225	114	110	16.2
Jul	214	107	107	18.2
Aug	181	89	92	18.1
Sep	125	58	68	15.3
Oct	71	28	42	11.6
Nov	33	10	23	7.6
Dec	21	6	15	4.8

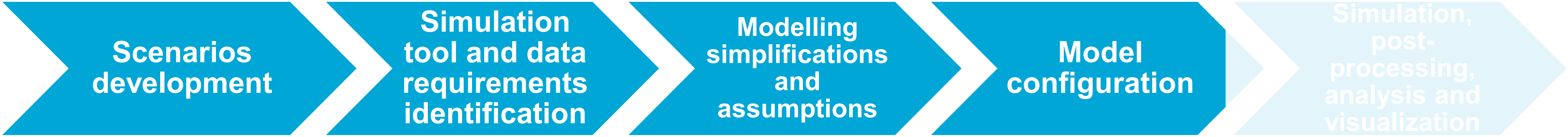


Month	G_{gh}	G_{bn}	G_{dh}	Temp (°C)
Jan	28.62	8.88	19.74	5.0
Feb	56.87	23.36	33.51	4.9
Mar	102.47	47.29	55.18	7.3
Apr	171.22	87.15	84.07	10.6
May	215.12	111.66	103.46	14.3
Jun	231.81	117.45	114.36	17.1
Jul	228.91	114.46	114.46	19.7
Aug	190.55	93.70	96.85	19.9
Sep	127.36	59.10	68.26	16.6
Oct	72.44	28.57	43.87	12.8
Nov	34.68	10.51	24.17	8.8
Dec	21.53	6.15	15.38	5.7

Future Climate Conditions:

Monthly changes in **temperature** + **radiation** included for **2050 scenarios → due to data availability (KNMI ’23)**

Method



Scenarios development

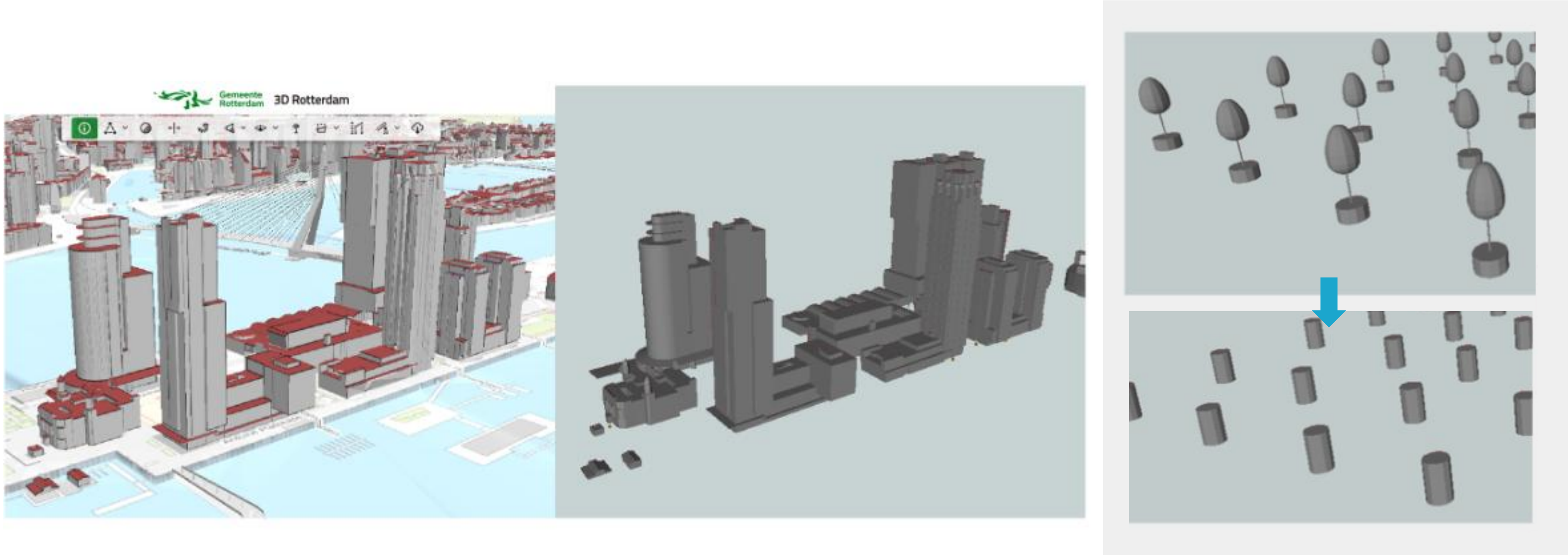
Simulation tool and data requirements identification

Modelling simplifications and assumptions

Model configuration

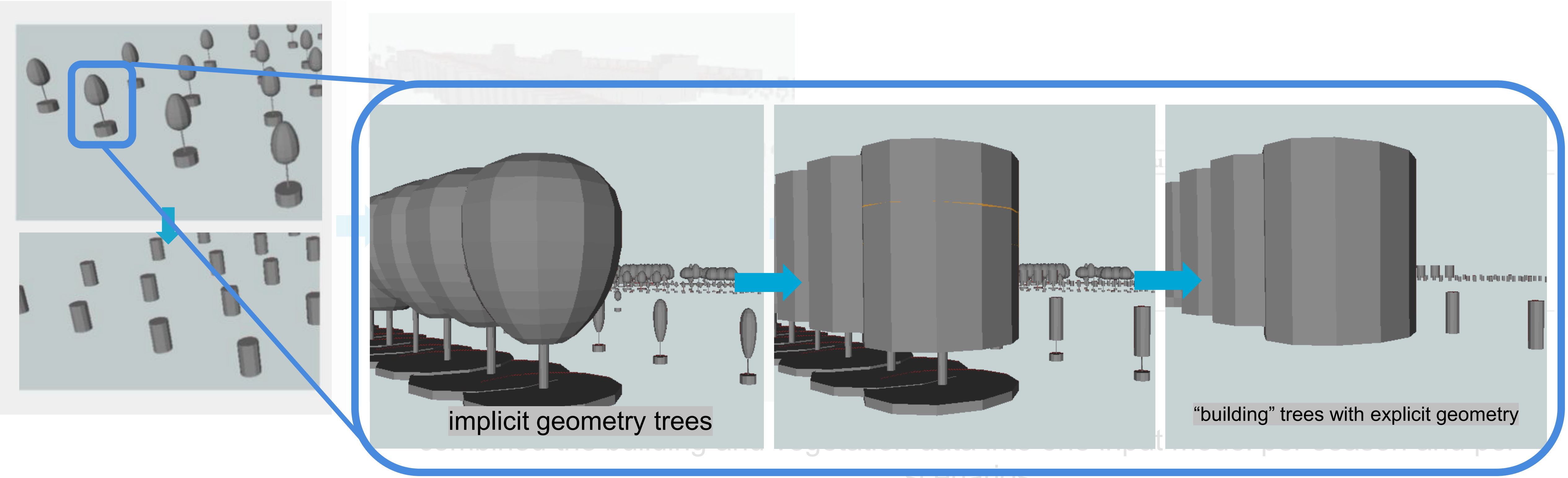
Simulation, post-processing, analysis and visualization

4. Model configuration

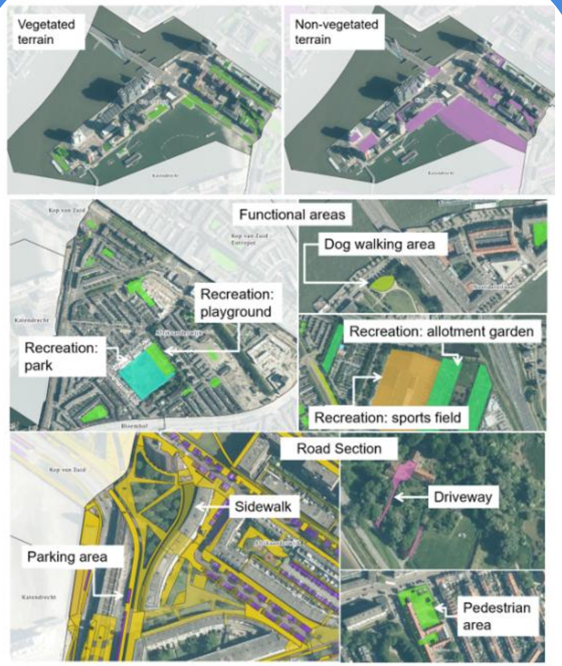


1. Preprocessed the building and tree data using the assumptions and simplifications defined earlier

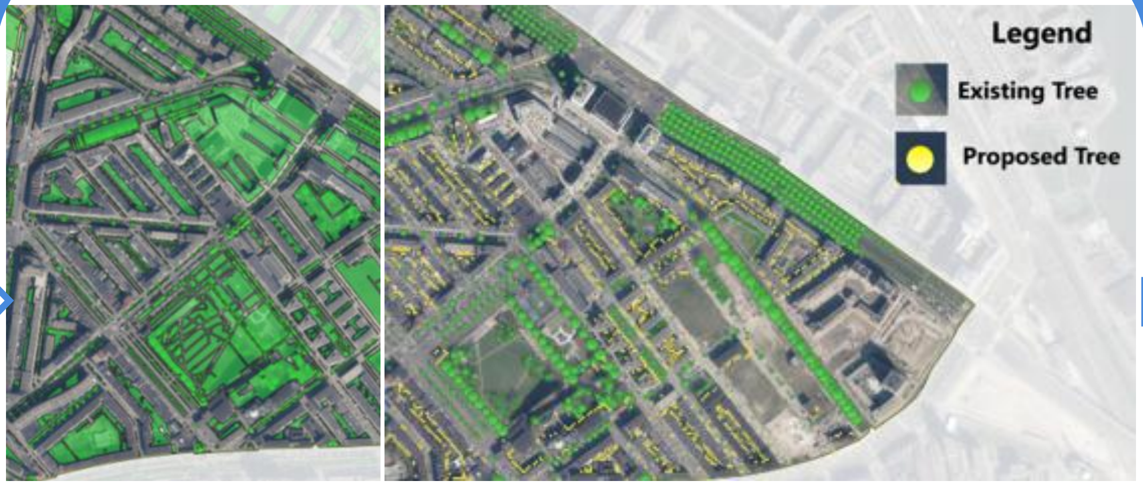
4. Model configuration: existing trees



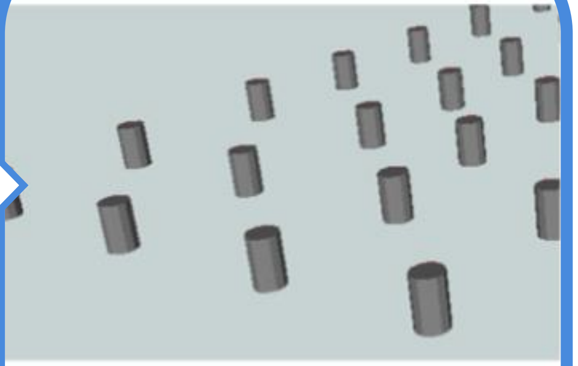
4. Model configuration: proposed trees



Process land use data

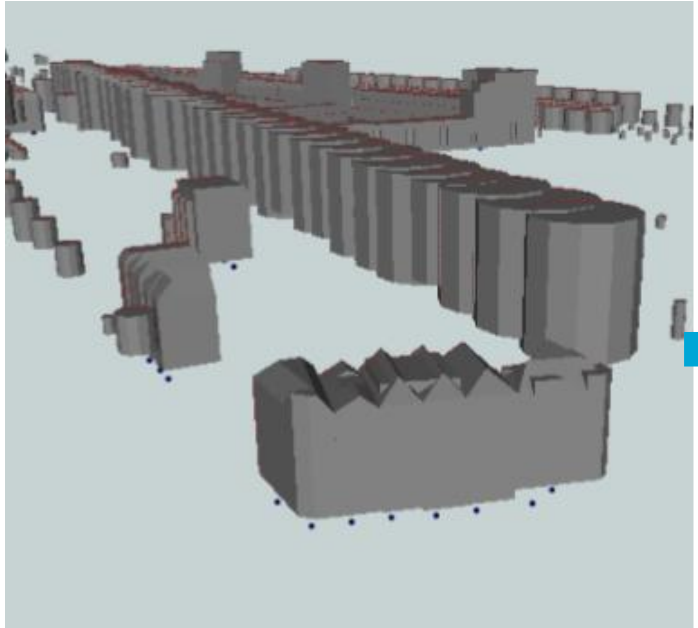


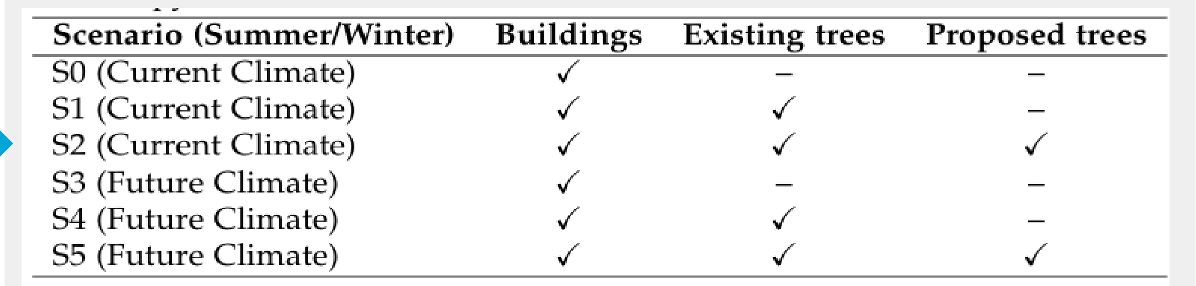
To generate potential planting areas and then generate the proposed tree points on it



Cyllindrical proposed trees

4. Model configuration

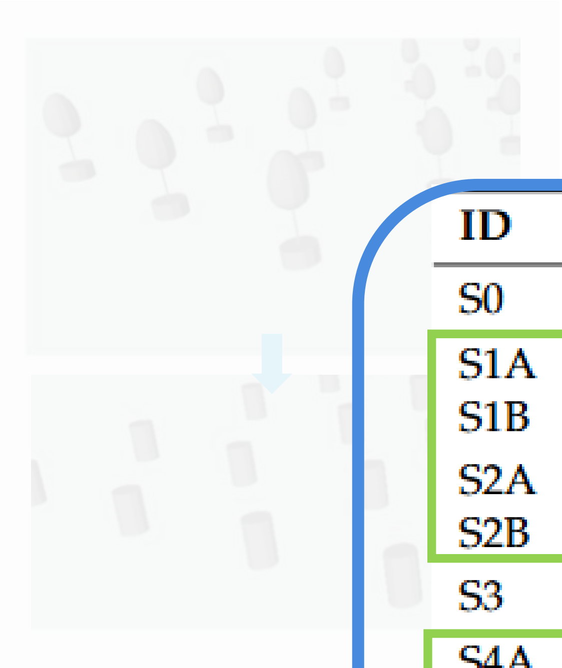




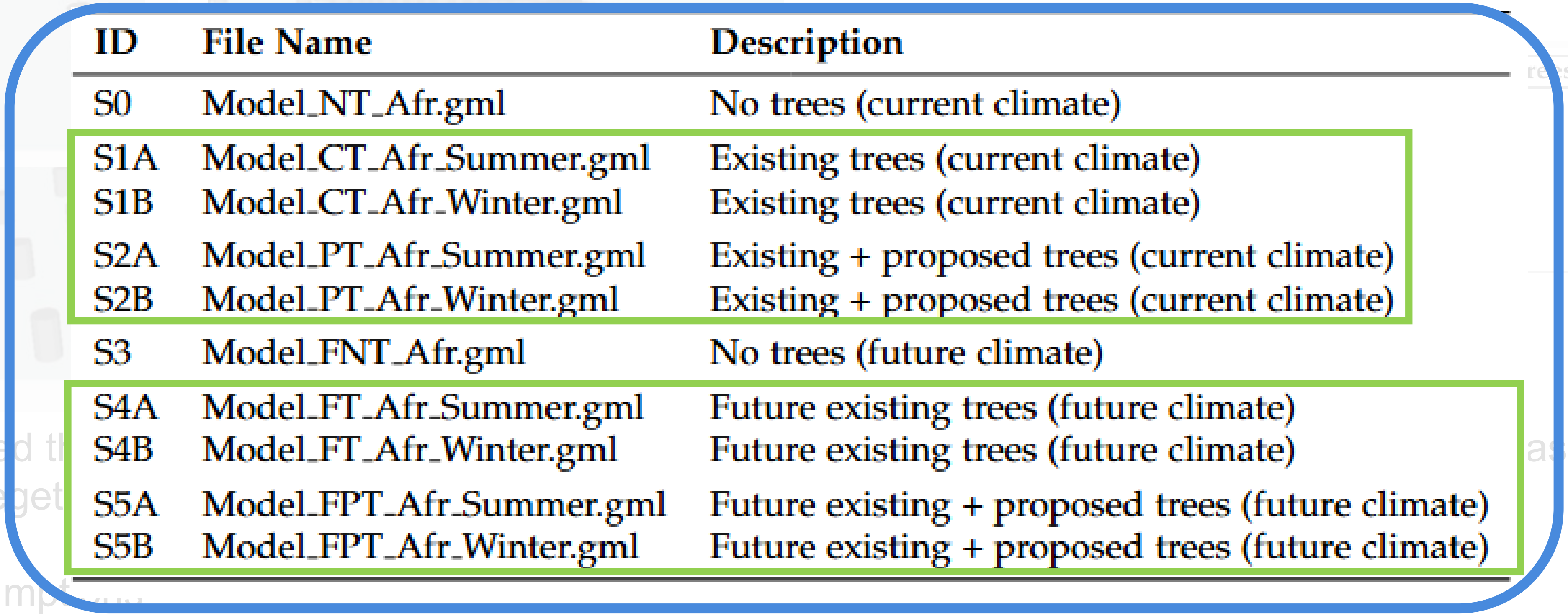
Scenario (Summer/Winter)	Buildings	Existing trees	Proposed trees
S0 (Current Climate)	✓	–	–
S1 (Current Climate)	✓	✓	–
S2 (Current Climate)	✓	✓	✓
S3 (Future Climate)	✓	–	–
S4 (Future Climate)	✓	✓	–
S5 (Future Climate)	✓	✓	✓

2. Combined the building and vegetation data into one input model per season and per scenarios

4. Model configuration



Each area → 12 models and simulation runs:

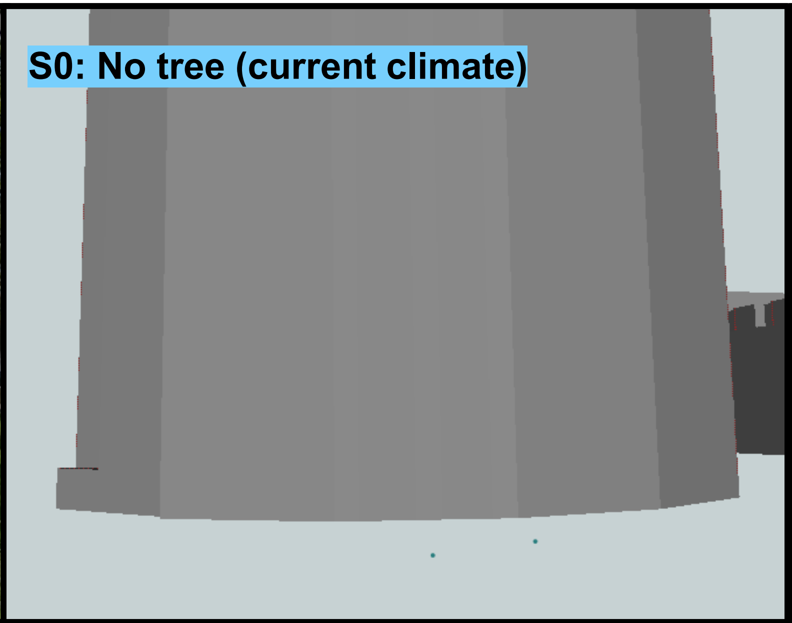


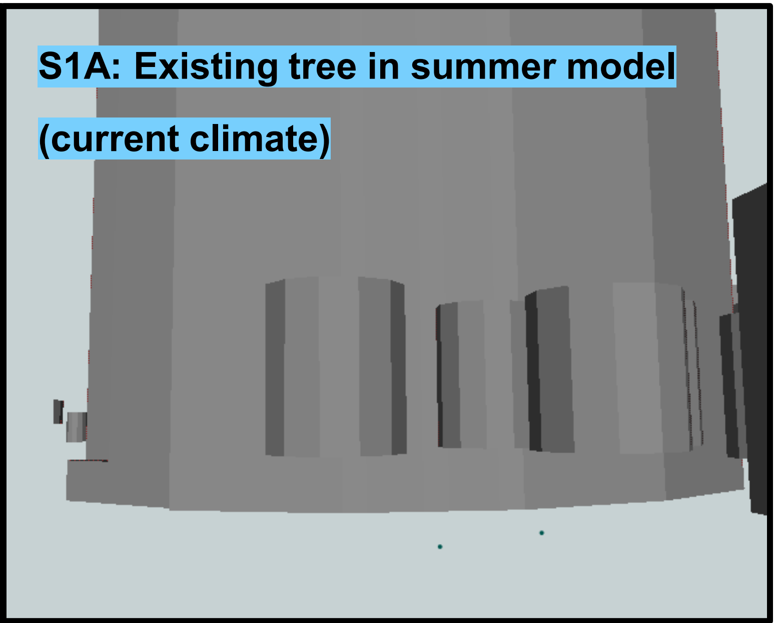
ID	File Name	Description
S0	Model_NT_Afr.gml	No trees (current climate)
S1A	Model_CT_Afr_Summer.gml	Existing trees (current climate)
S1B	Model_CT_Afr_Winter.gml	Existing trees (current climate)
S2A	Model_PT_Afr_Summer.gml	Existing + proposed trees (current climate)
S2B	Model_PT_Afr_Winter.gml	Existing + proposed trees (current climate)
S3	Model_FNT_Afr.gml	No trees (future climate)
S4A	Model_FT_Afr_Summer.gml	Future existing trees (future climate)
S4B	Model_FT_Afr_Winter.gml	Future existing trees (future climate)
S5A	Model_FPT_Afr_Summer.gml	Future existing + proposed trees (future climate)
S5B	Model_FPT_Afr_Winter.gml	Future existing + proposed trees (future climate)

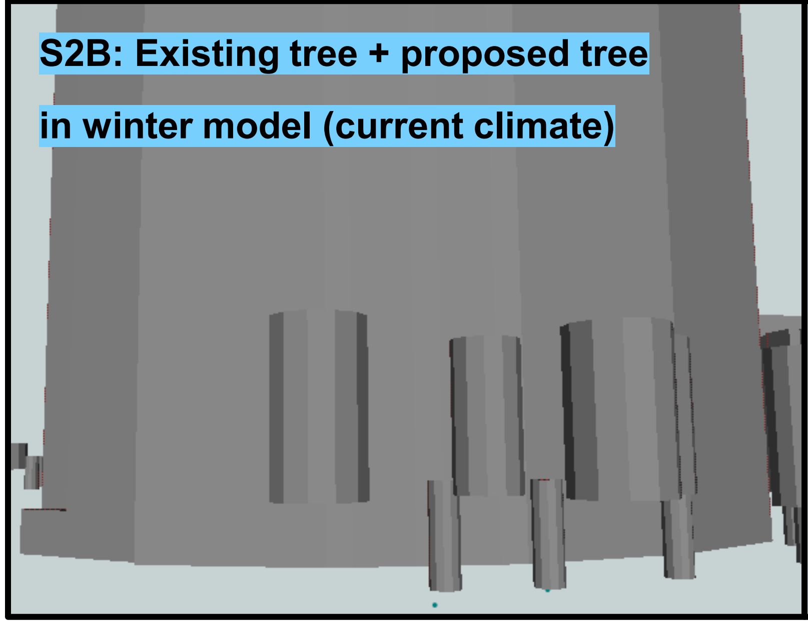
Preprocessed th
building and veget
data
using the assump
and simplifications
defined earlier

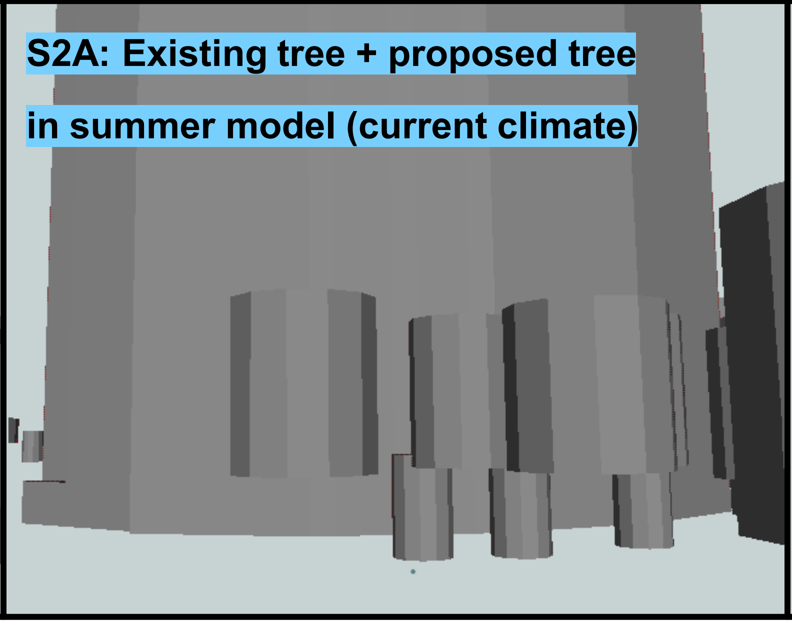
ason and per

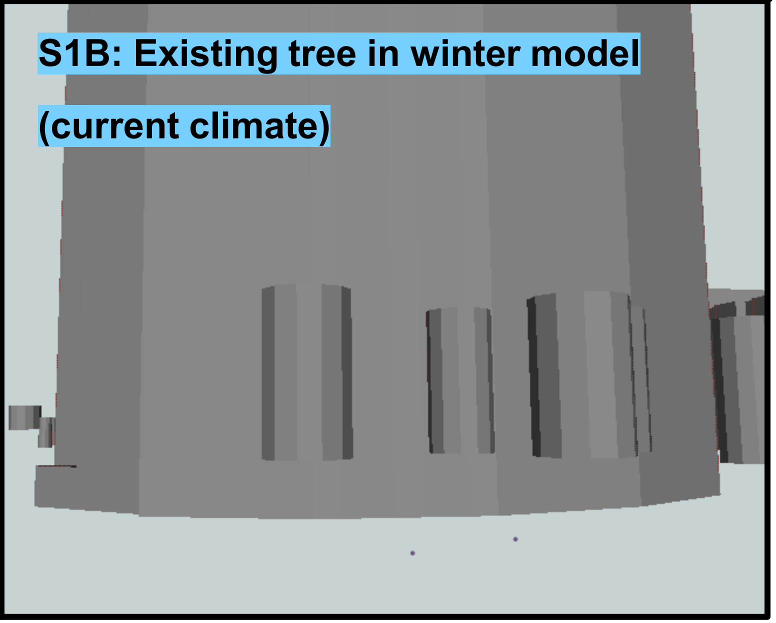

Streetview


S0: No tree (current climate)

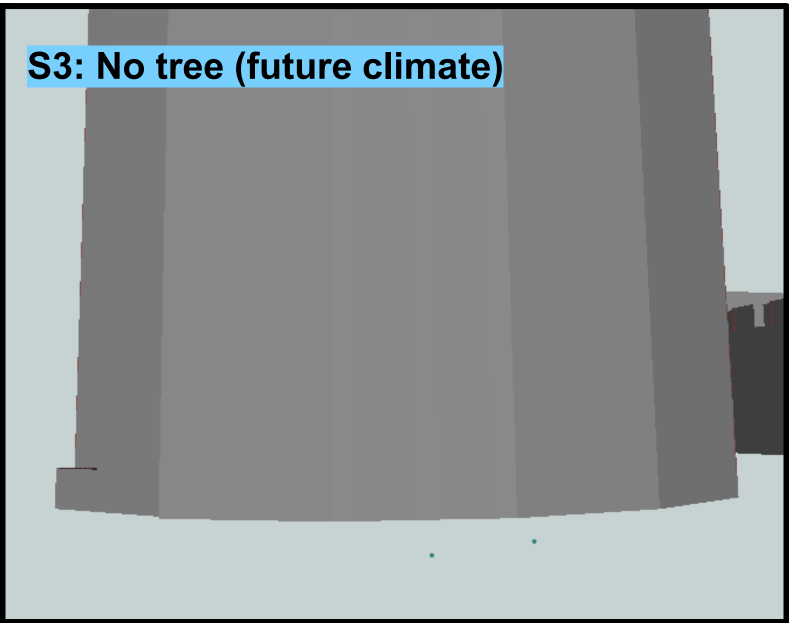

S1A: Existing tree in summer model (current climate)

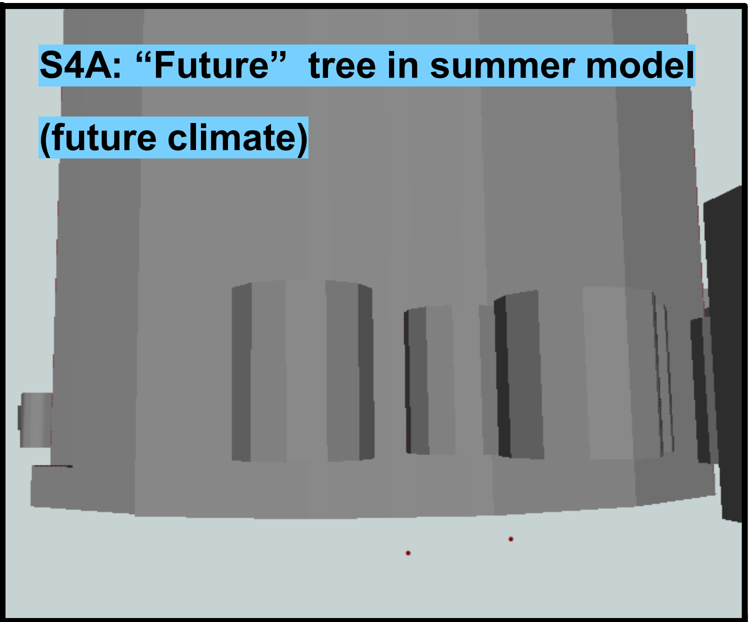

S2B: Existing tree + proposed tree in winter model (current climate)

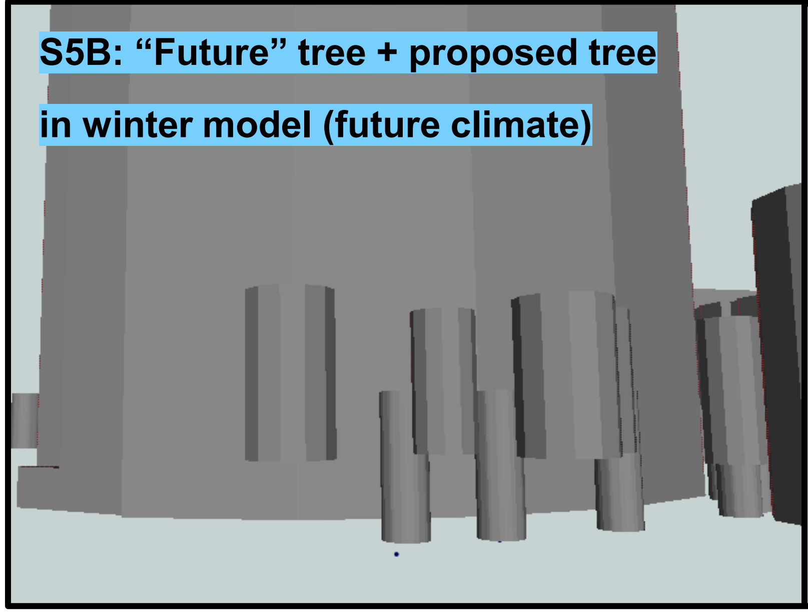

S2A: Existing tree + proposed tree in summer model (current climate)


S1B: Existing tree in winter model (current climate)

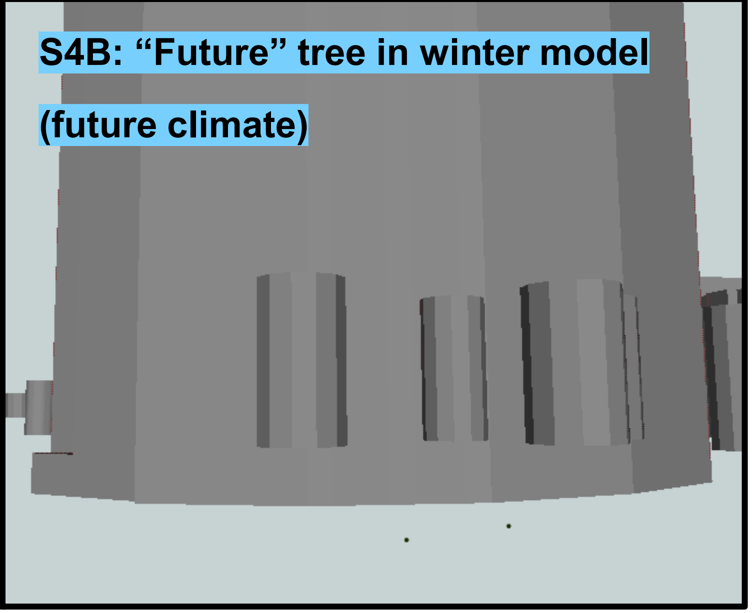

Streetview


S3: No tree (future climate)


S4A: “Future” tree in summer model (future climate)


S5B: “Future” tree + proposed tree in winter model (future climate)


S5A: “Future” tree + proposed tree in summer model (future climate)


S4B: “Future” tree in winter model (future climate)

Method

Scenarios development

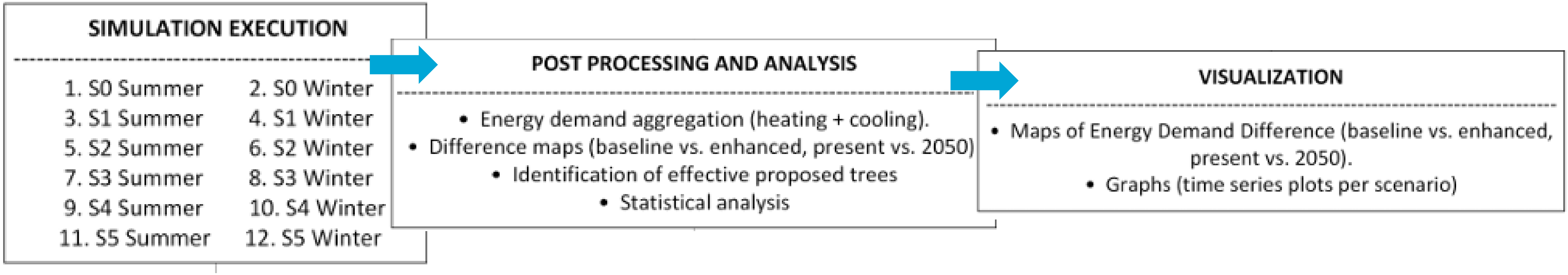
Simulation tool and data requirements identification

Modelling simplifications and assumptions

Model configuration

Simulation, post-processing, analysis and visualization

5. Simulation, Post-Processing, Analysis, and Visualisation



SIMULATION EXECUTION

1. S0 Summer
2. S0 Winter
3. S1 Summer
4. S1 Winter
5. S2 Summer
6. S2 Winter
7. S3 Summer
8. S3 Winter
9. S4 Summer
10. S4 Winter
11. S5 Summer
12. S5 Winter

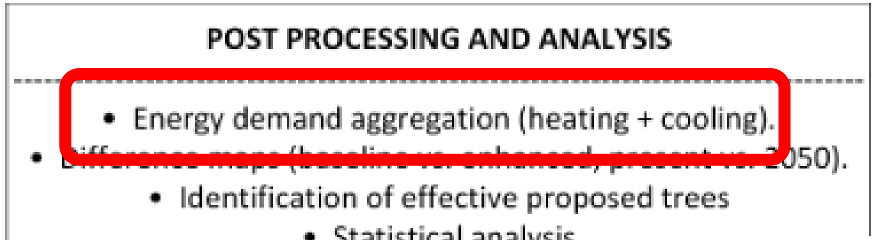
POST PROCESSING AND ANALYSIS

- Energy demand aggregation (heating + cooling).
- Difference maps (baseline vs. enhanced, present vs. 2050)
- Identification of effective proposed trees
- Statistical analysis

VISUALIZATION

- Maps of Energy Demand Difference (baseline vs. enhanced, present vs. 2050).
- Graphs (time series plots per scenario)

5. Simulation, Post-Processing, Analysis, and Visualisation



POST PROCESSING AND ANALYSIS

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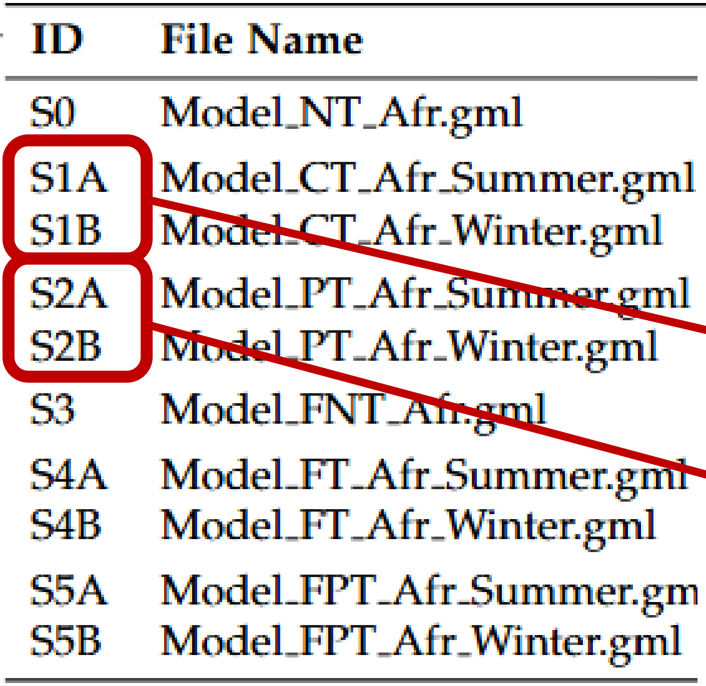

ID	File Name
S0	Model_NT_Afr.gml
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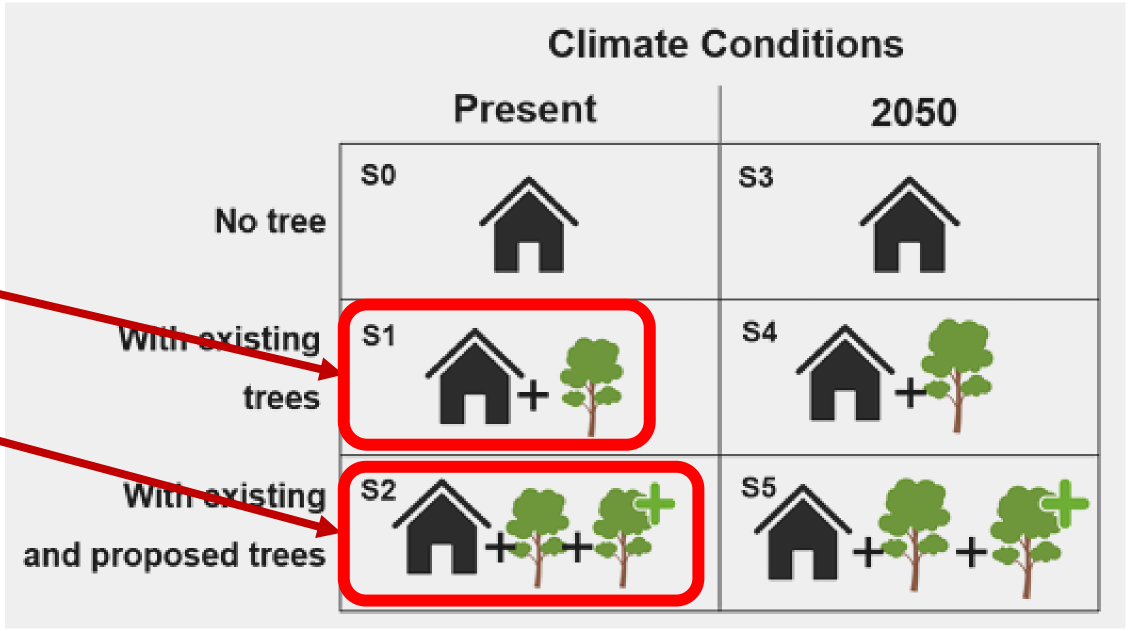
S1B	Model_CT_Afr_Winter.gml
S2A	Model_PT_Afr_Summer.gml
S2B	Model_PT_Afr_Winter.gml
S3	Model_FNT_Afr.gml
S4A	Model_FT_Afr_Summer.gml
S4B	Model_FT_Afr_Winter.gml
S5A	Model_FPT_Afr_Summer.gm
S5B	Model_FPT_Afr_Winter.gml



5. Simulation, Post-Processing, Analysis, and Visualisation

POST PROCESSING AND ANALYSIS

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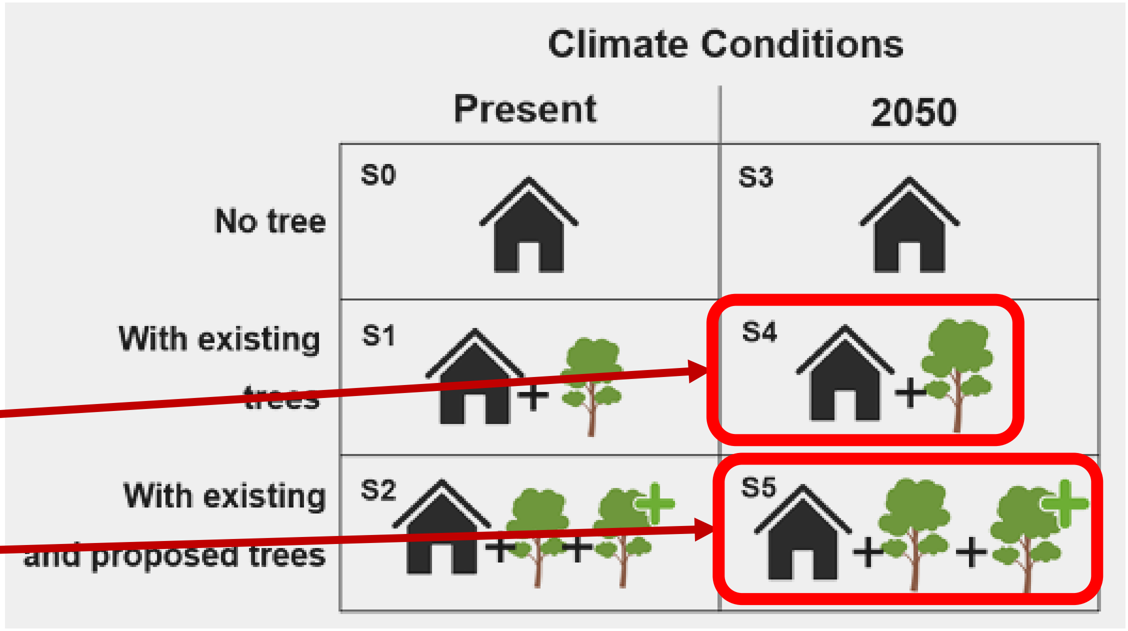
S4A	Model_FT_Afr_Summer.gml
S4B	Model_FT_Afr_Winter.gml
S5A	Model_FPT_Afr_Summer.gml
S5B	Model_FPT_Afr_Winter.gml



5. Simulation, Post-Processing, Analysis, and Visualisation

S0

S1

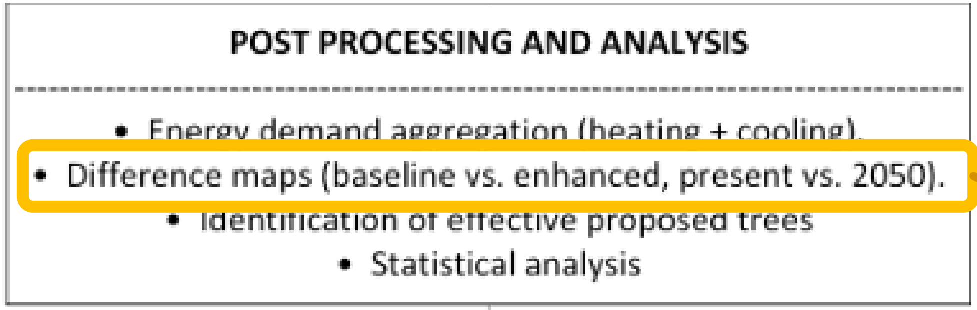
S2

S3

S4

S5

5. Simulation, Post-Processing, Analysis, and Visualisation



POST PROCESSING AND ANALYSIS

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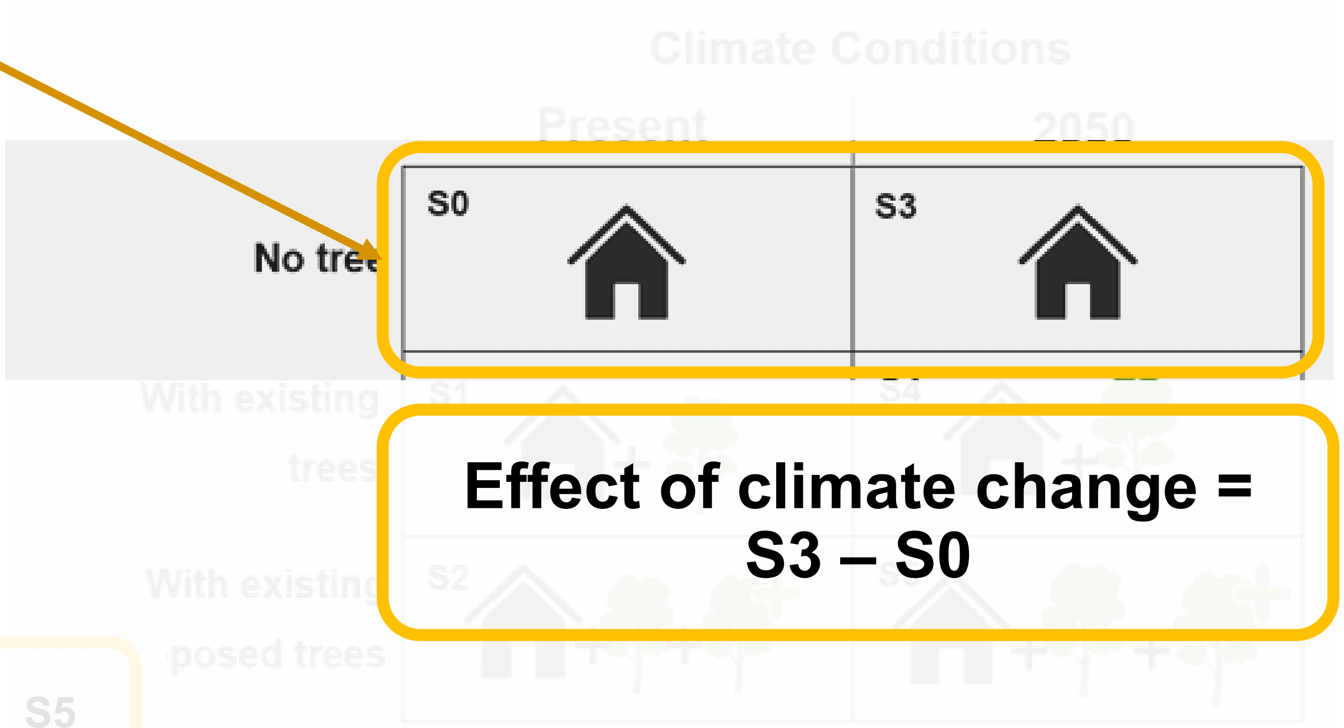
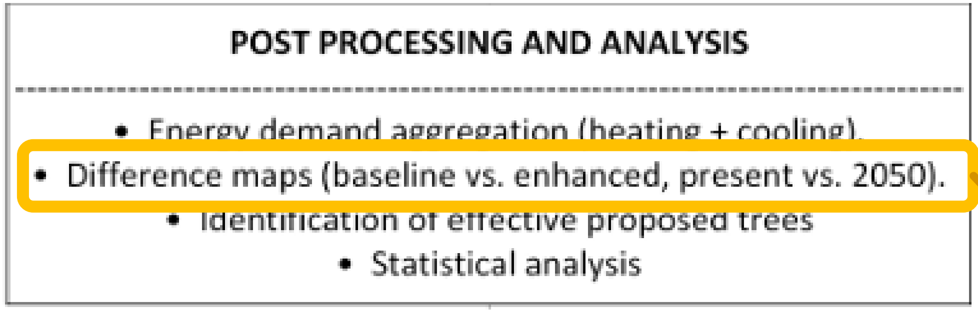


Effect of climate change = S3 – S0

S0 S1 S2 **S3** S4 S5

5. Simulation, Post-Processing, Analysis, and Visualisation



POST PROCESSING AND ANALYSIS

- Energy demand aggregation (heating + cooling).
- Difference maps (baseline vs. enhanced, present vs. 2050).
- Identification of effective proposed trees
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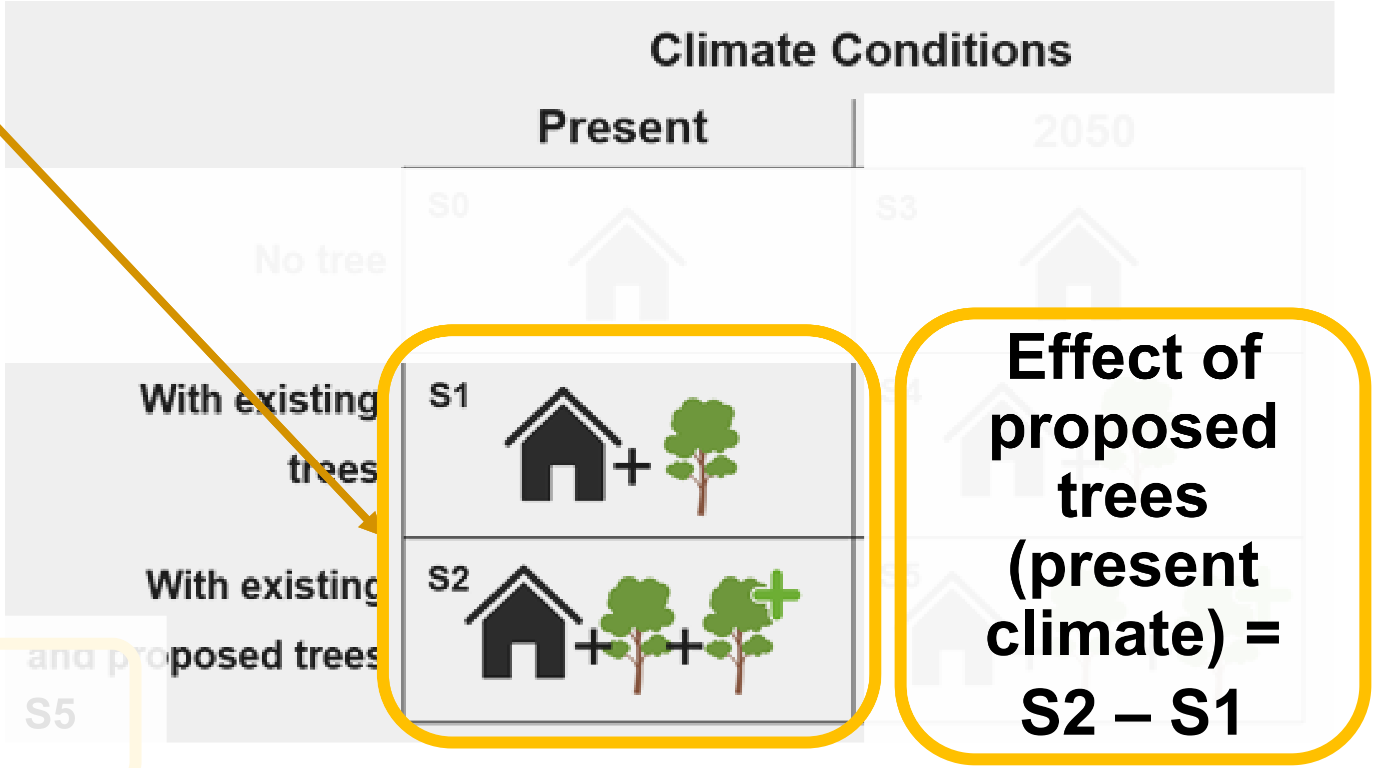
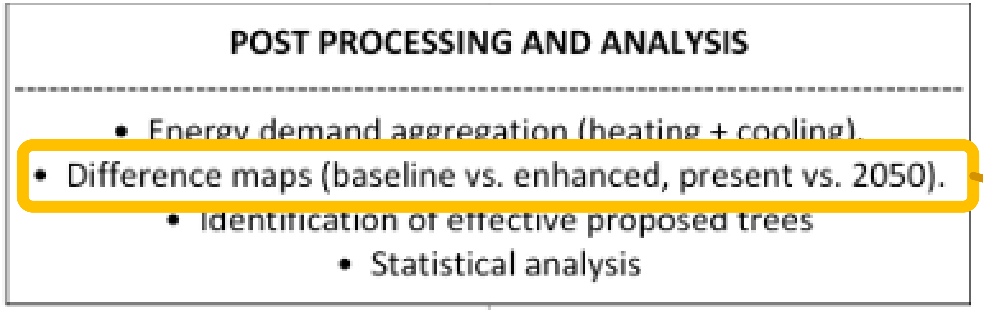


	Climate Conditions	
	Present	2050
No tree	S0	S3
With existing trees	S1	S4
With existing and proposed trees	S2	S5

Effect of proposed trees (present climate) = S2 – S1

S0 S1 S2 S3 S4 S5

5. Simulation, Post-Processing, Analysis, and Visualisation



POST PROCESSING AND ANALYSIS

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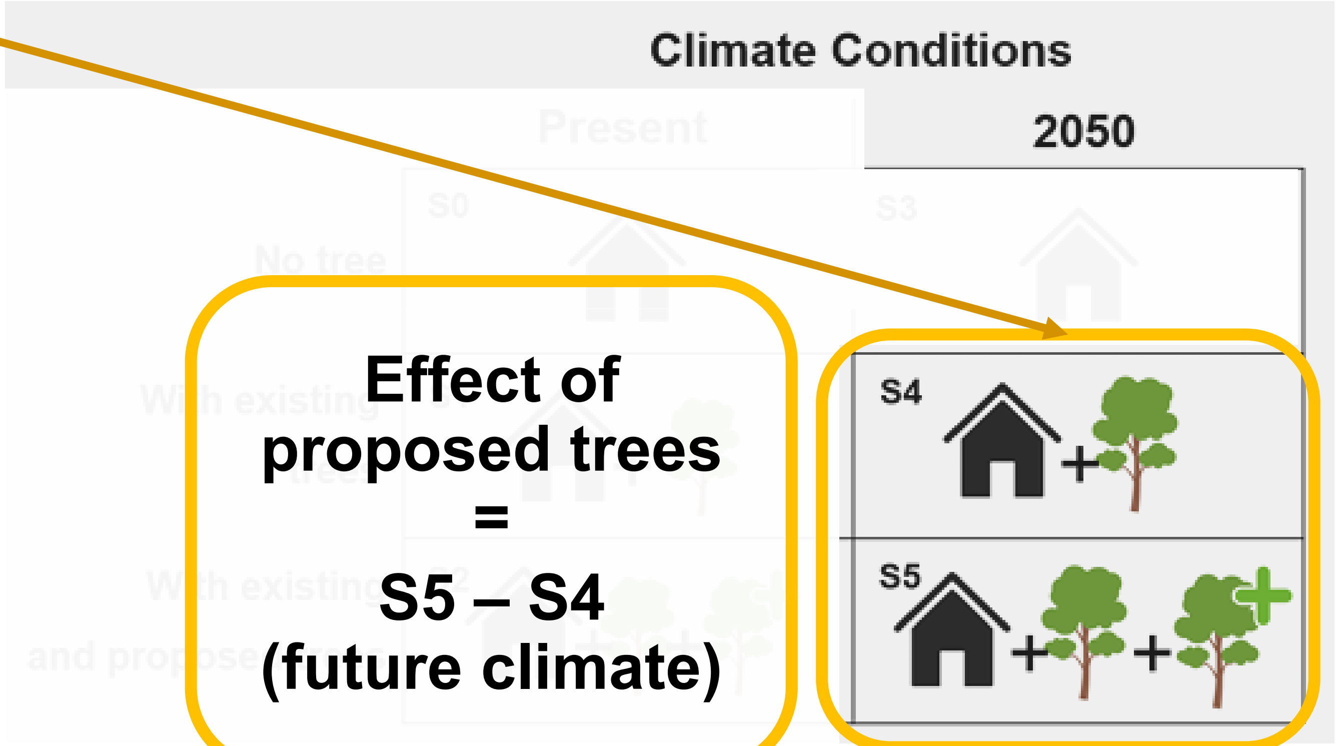
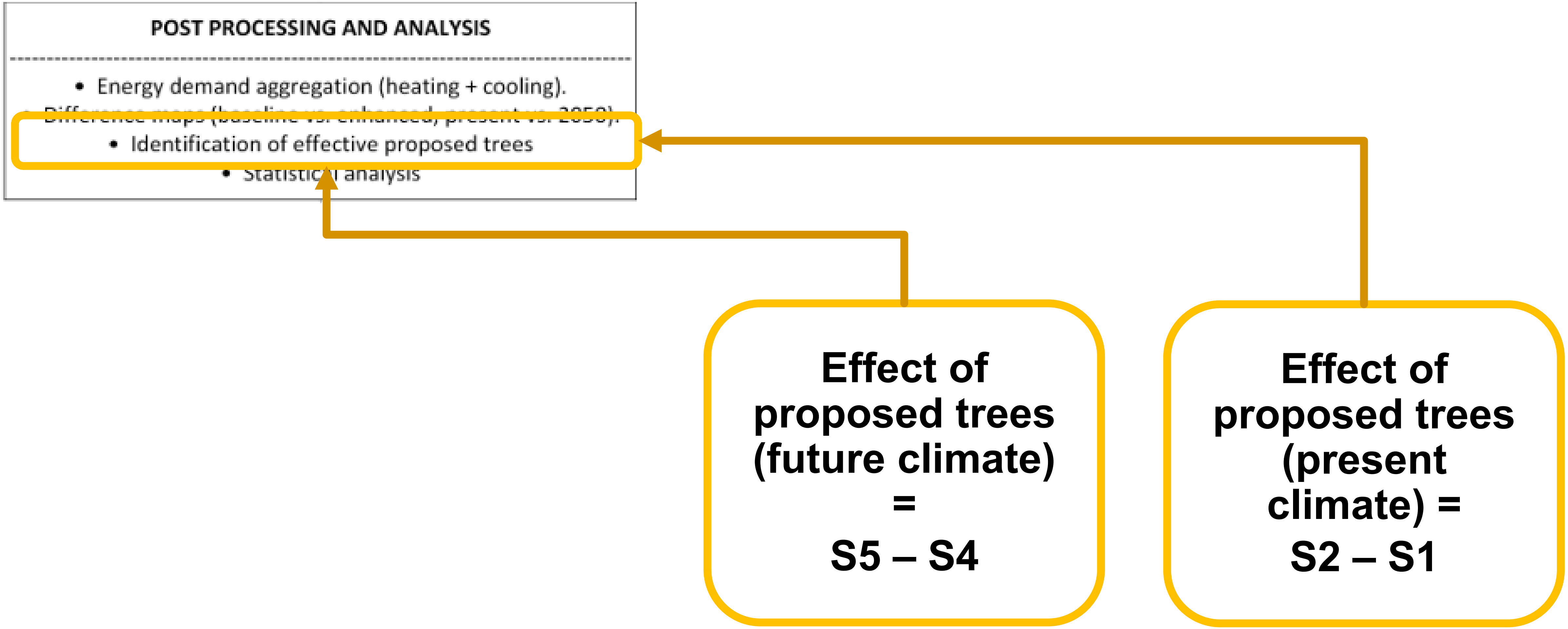


Effect of proposed trees
=
S5 – S4
(future climate)

5. Simulation, Post-Processing, Analysis, and Visualisation



POST PROCESSING AND ANALYSIS

- Energy demand aggregation (heating + cooling).
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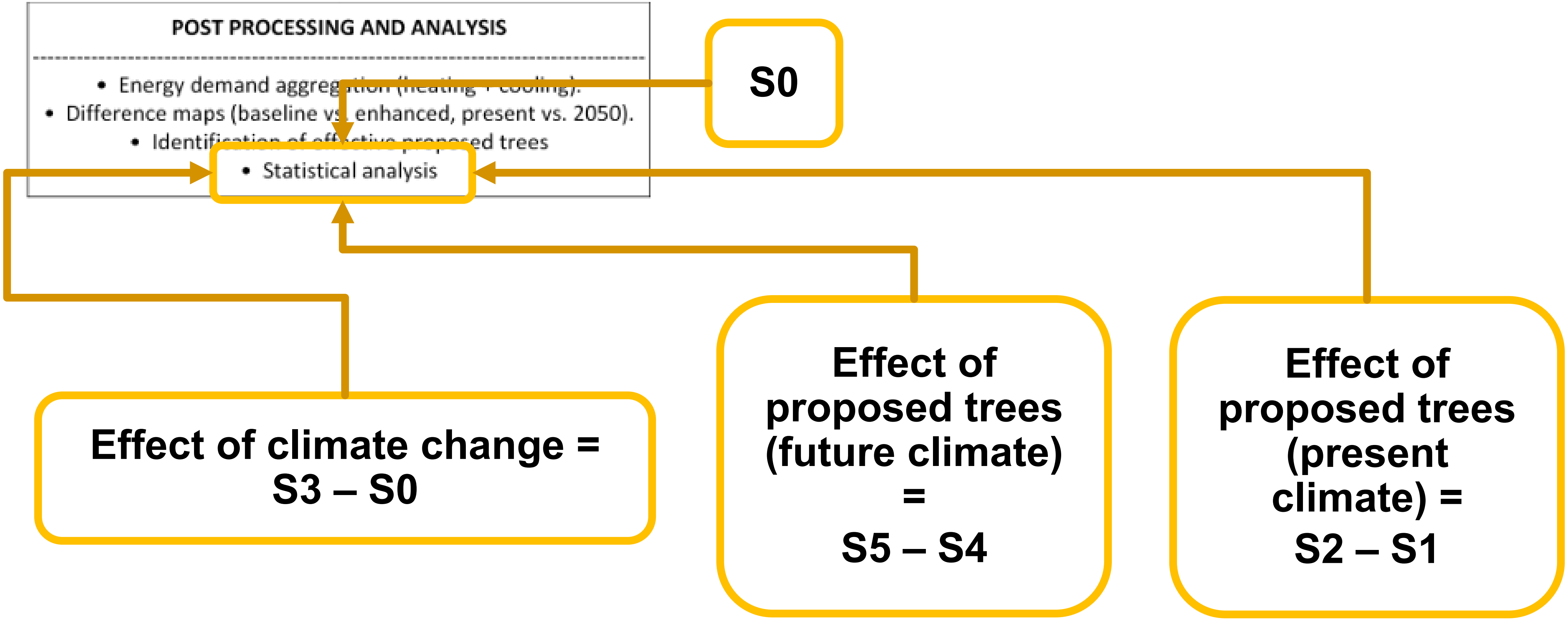
- Statistical analysis

Effect of proposed trees (future climate) = S5 – S4

Effect of proposed trees (present climate) = S2 – S1

5. Simulation, Post-Processing, Analysis, and Visualisation



POST PROCESSING AND ANALYSIS

- Energy demand aggregation (heating + cooling).
- Difference maps (baseline vs. enhanced, present vs. 2050).
- Identification of effective proposed trees
- Statistical analysis

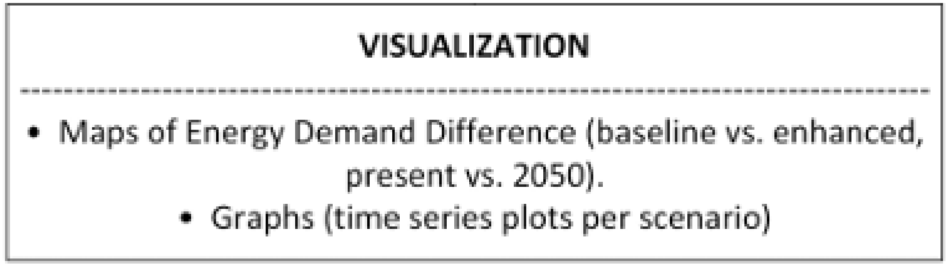
S0

Effect of climate change = S3 – S0

Effect of proposed trees (future climate) = S5 – S4

Effect of proposed trees (present climate) = S2 – S1

5. Simulation, Post-Processing, Analysis, and Visualisation



VISUALIZATION

- Maps of Energy Demand Difference (baseline vs. enhanced, present vs. 2050).
- Graphs (time series plots per scenario)

S0 **S1** **S2** **S3** **S4** **S5**

Effect of climate change = S3 – S0

Effect of proposed trees (future climate) = S5 – S4

Effect of proposed trees (present climate) = S2 – S1

04

Results and analysis

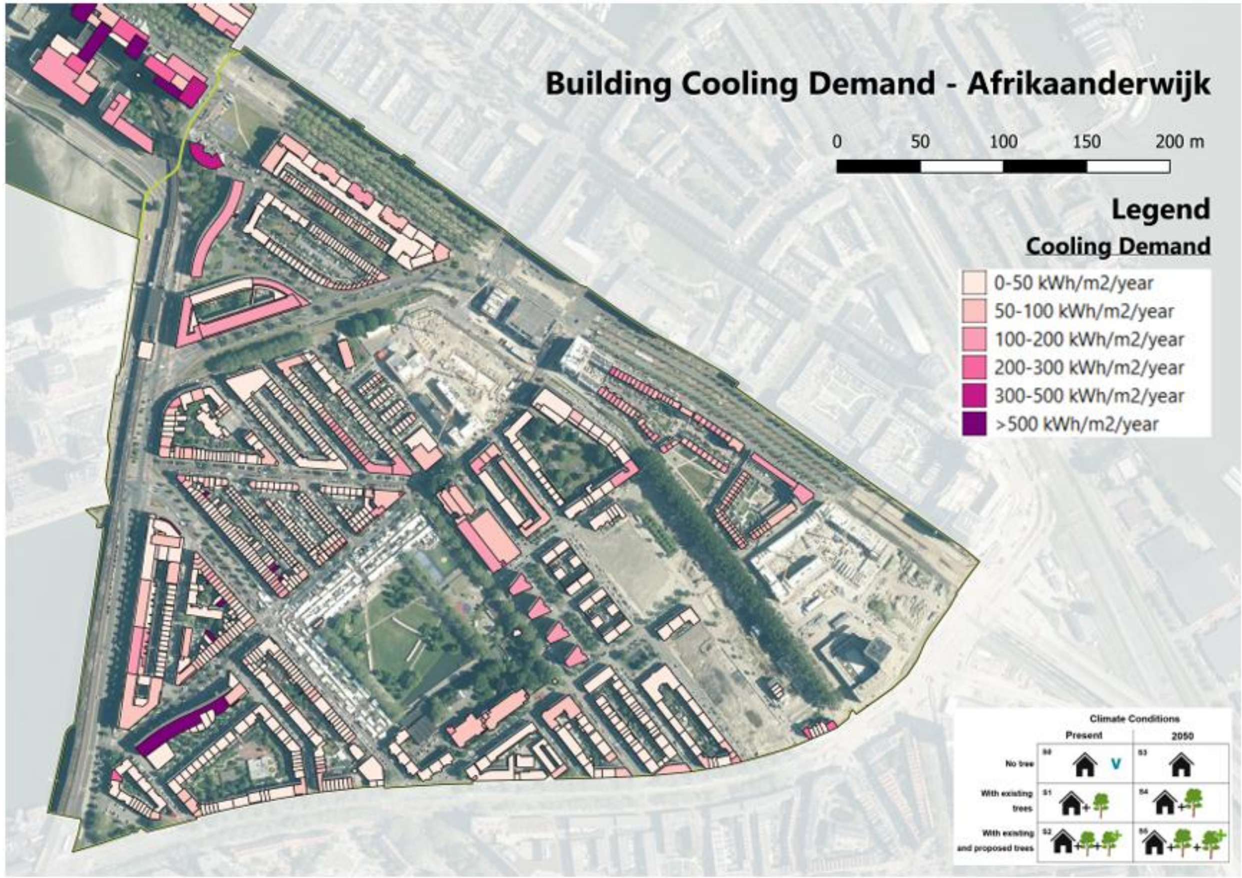
S0

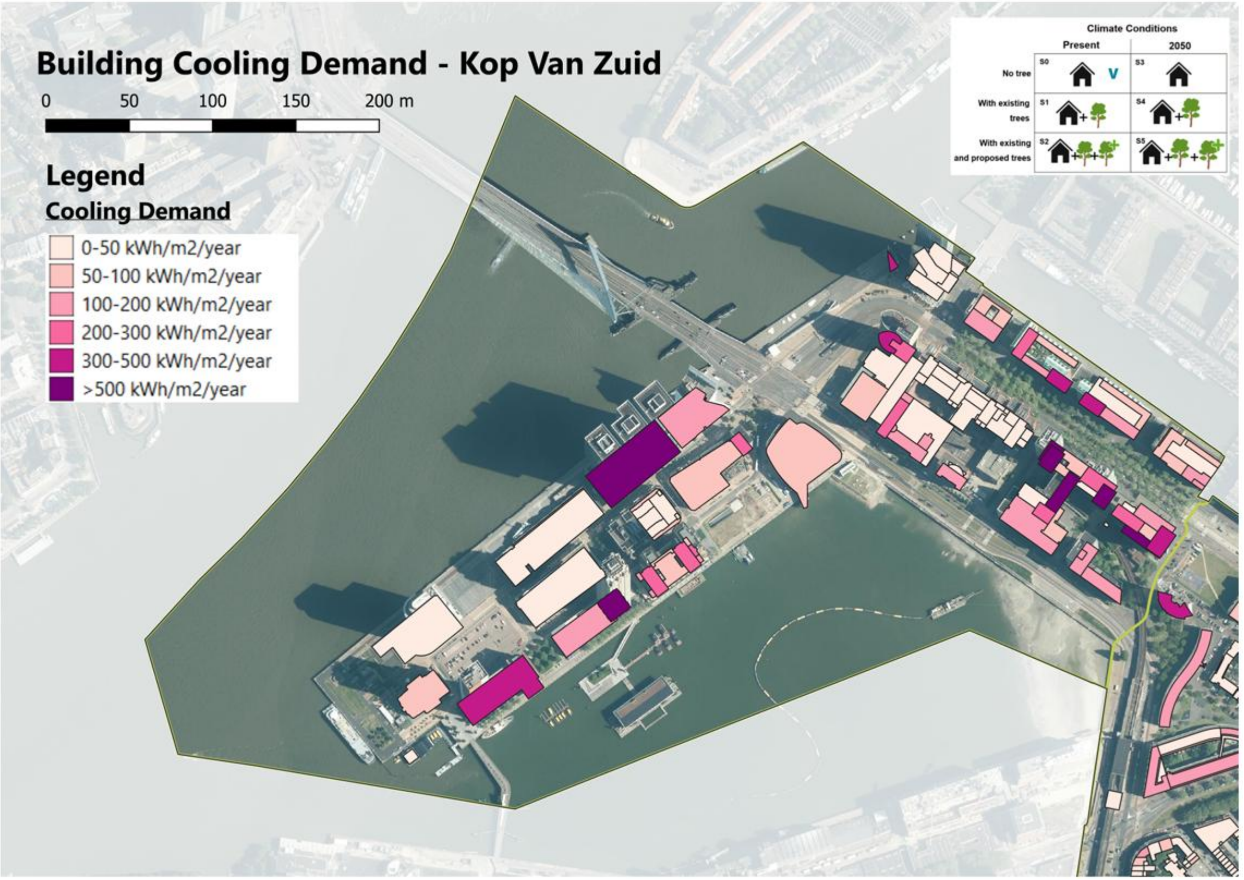
Climate change effect

Effect of proposed trees

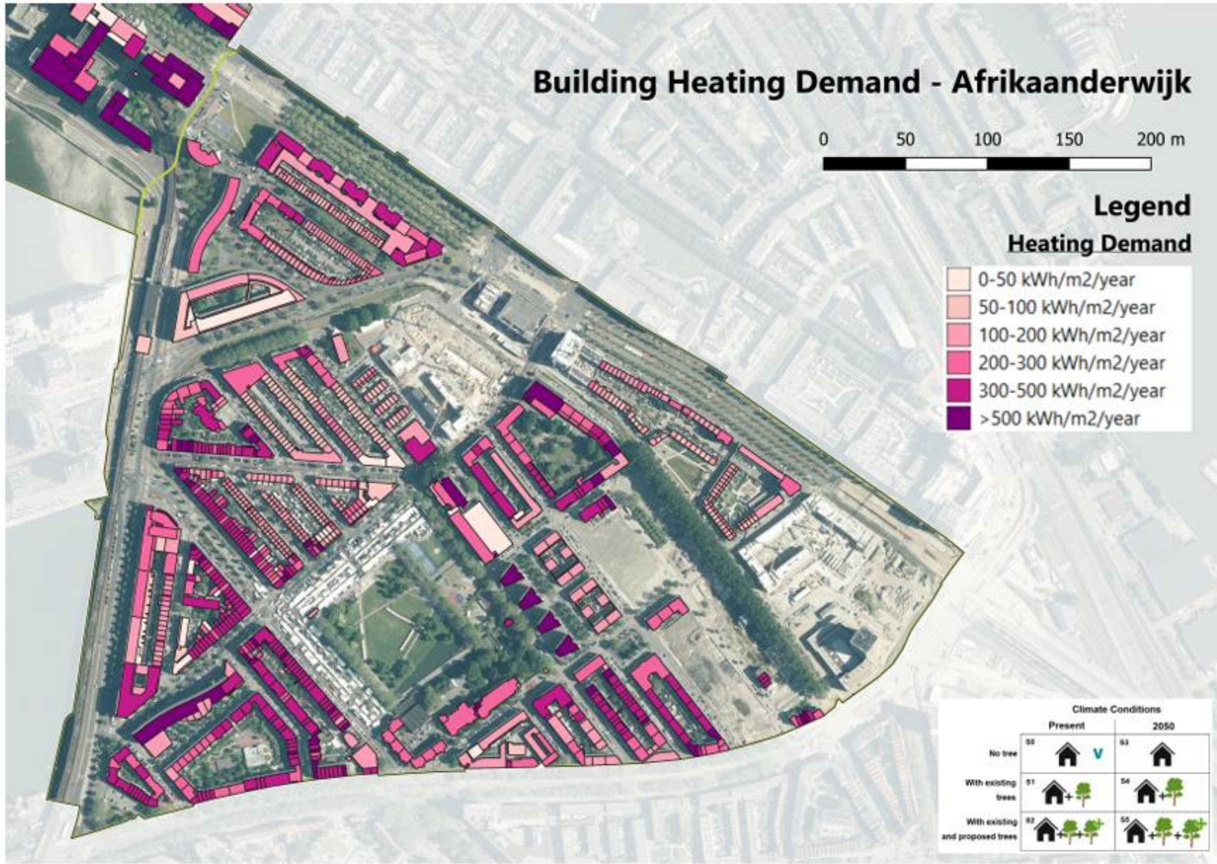
Urban vegetation assesment

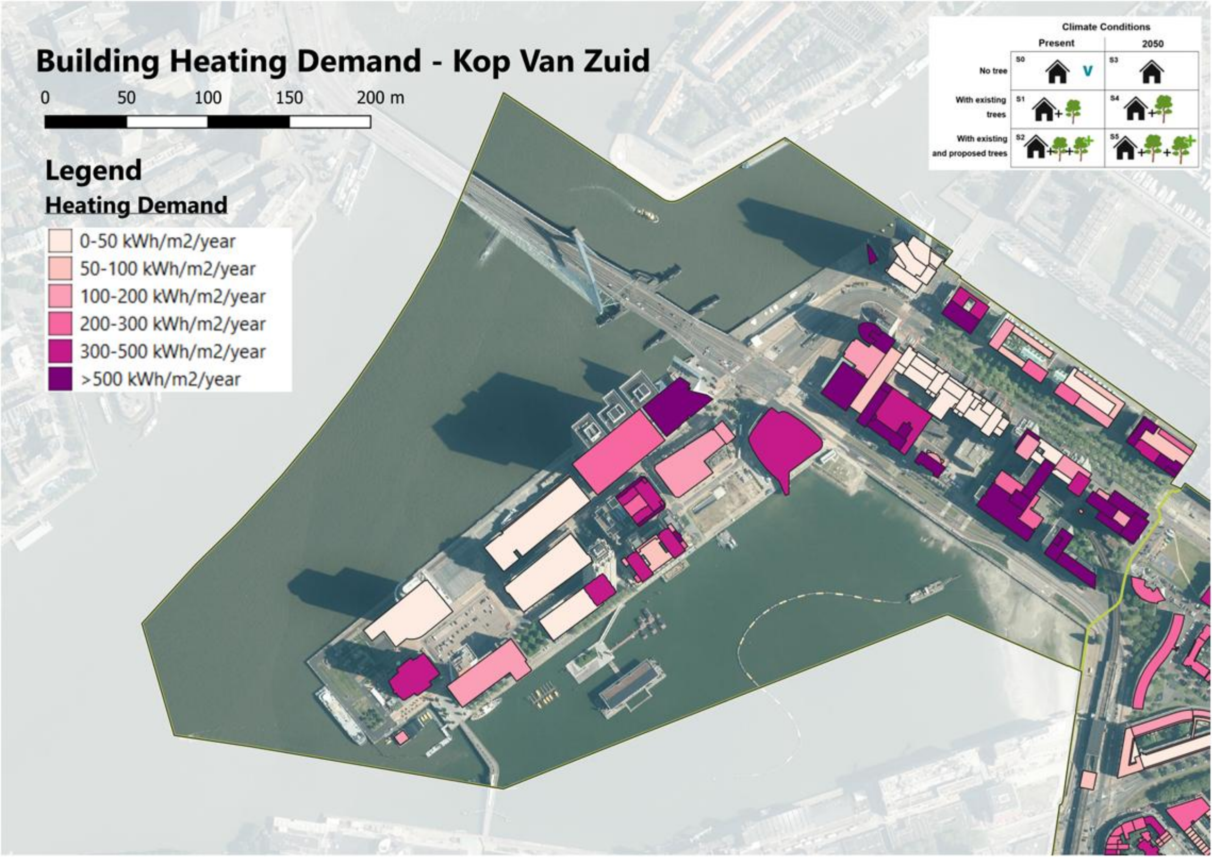
Cooling demand under current climate



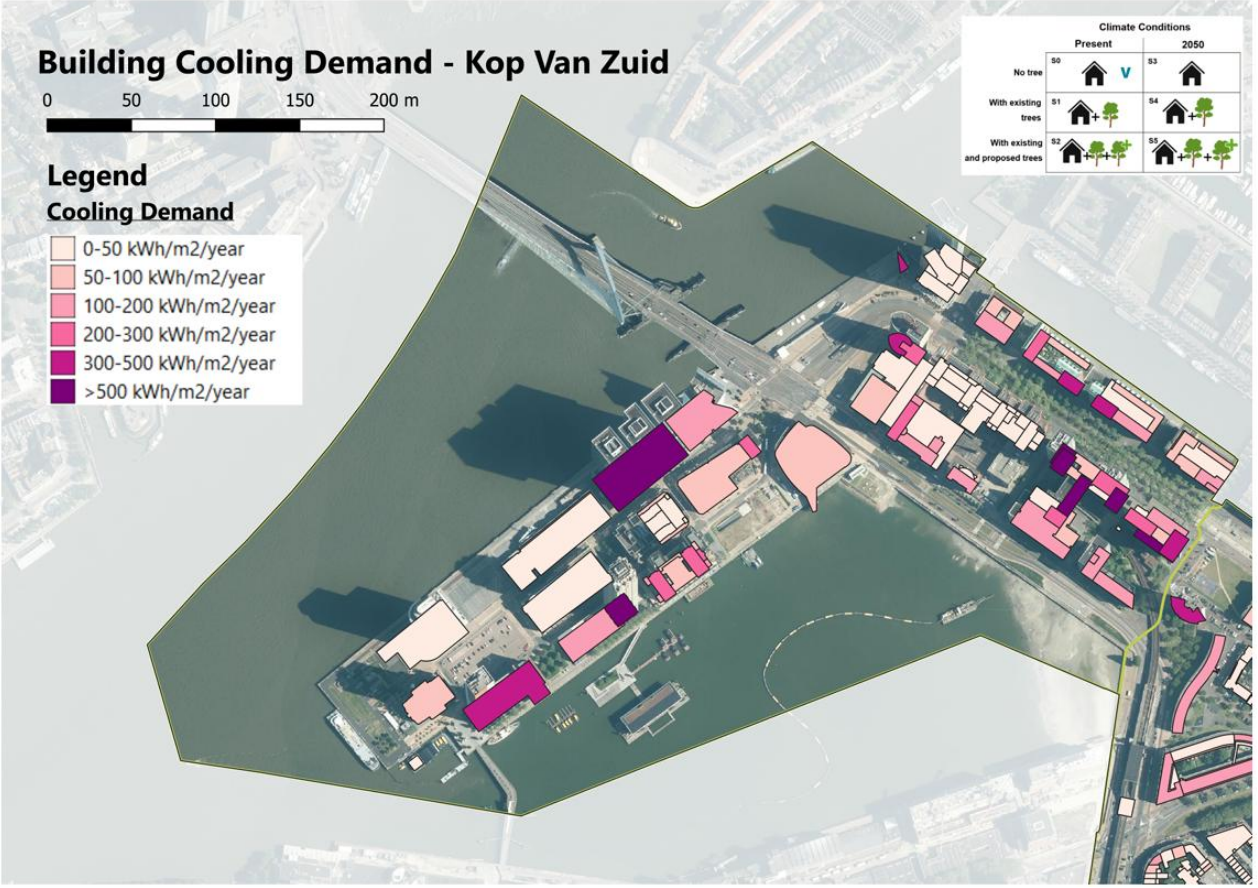


Heating demand under current climate





Statistical Check: Kop van Zuid S0 Results



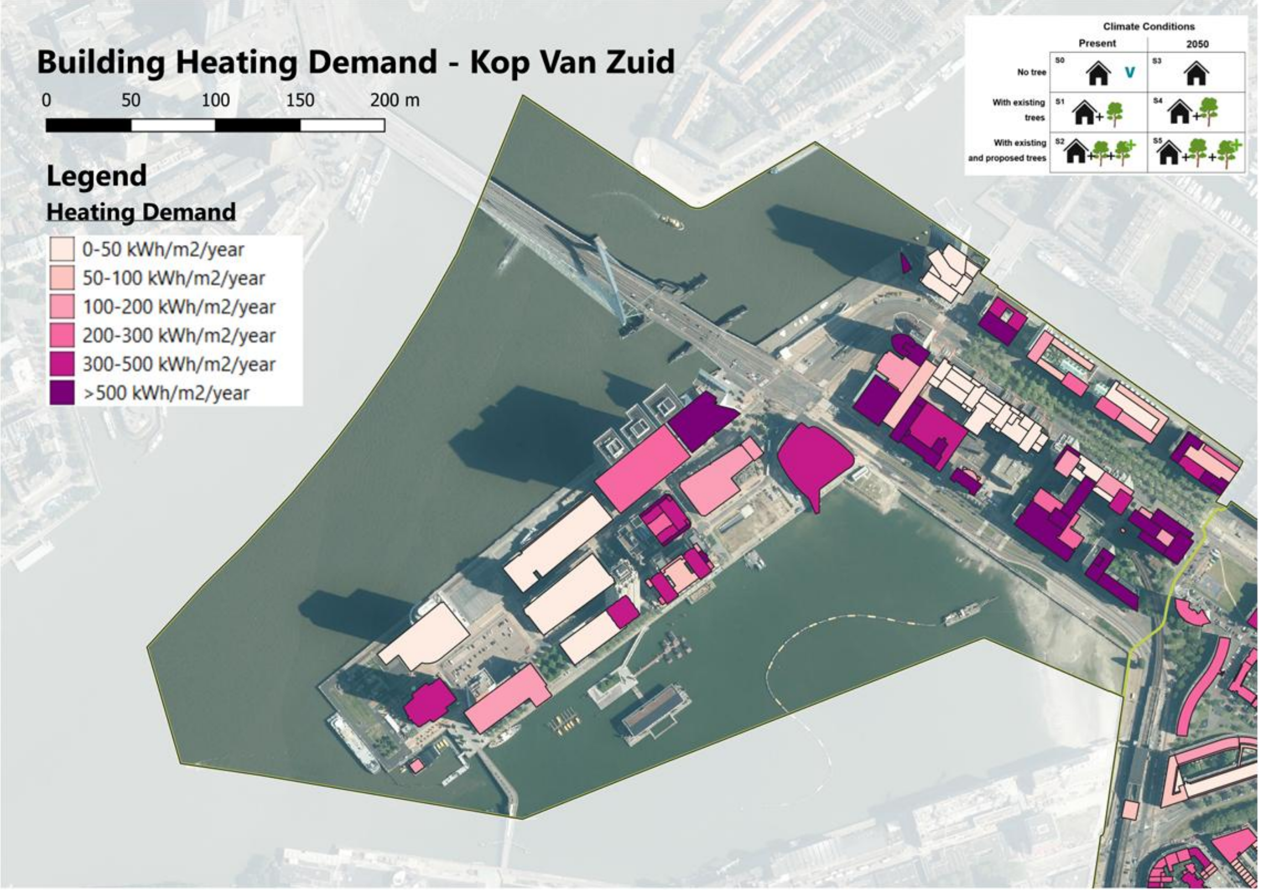
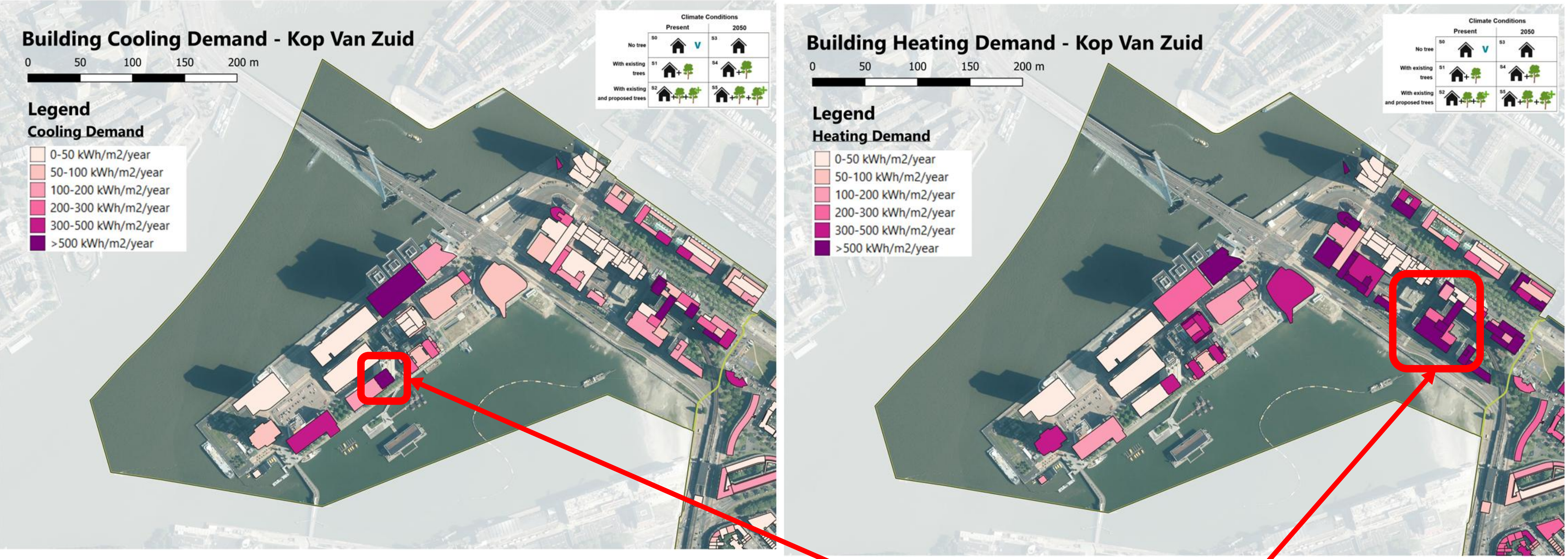
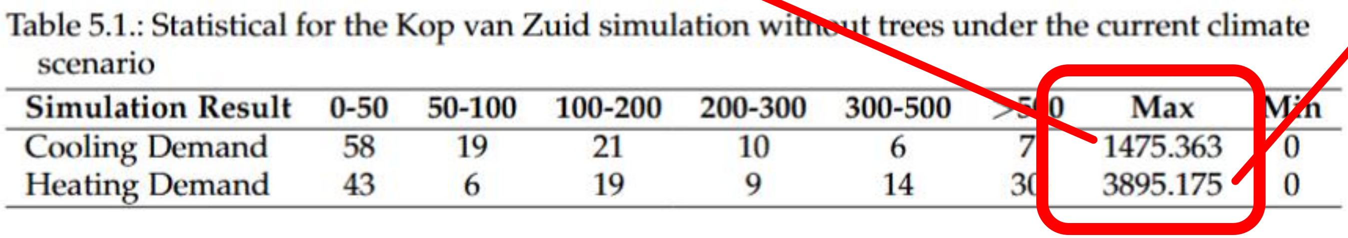


Table 5.1.: Statistical for the Kop van Zuid simulation without trees under the current climate scenario

Simulation Result	0-50	50-100	100-200	200-300	300-500	>500	Max	Min
Cooling Demand	58	19	21	10	6	7	1475.363	0
Heating Demand	43	6	19	9	14	30	3895.175	0

Statistical Check: Kop van Zuid S0 Results





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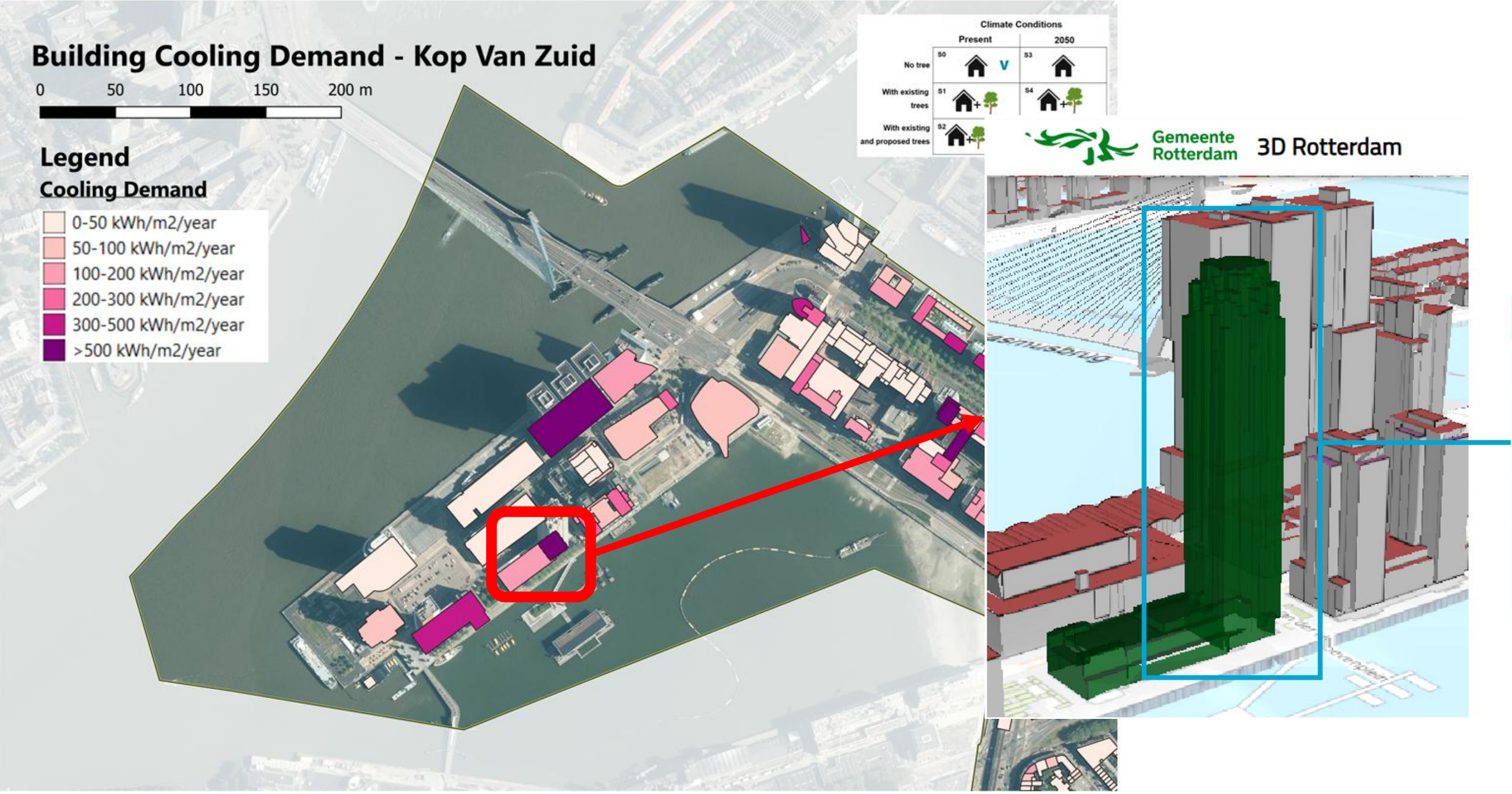
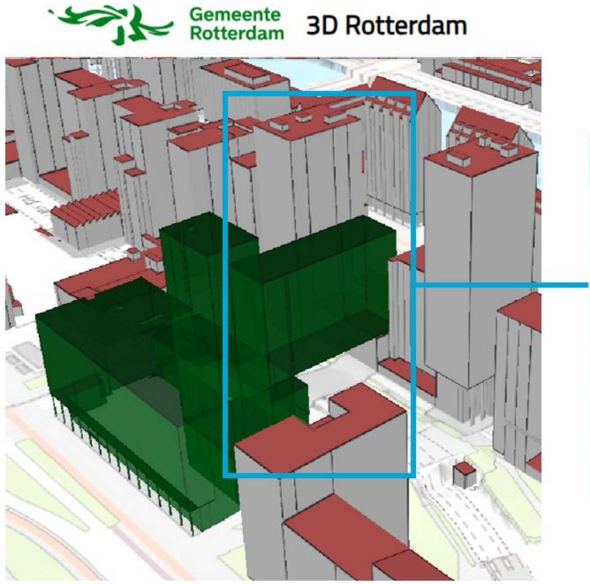
Building with highest cooling demand



Building with highest value in N_YCD

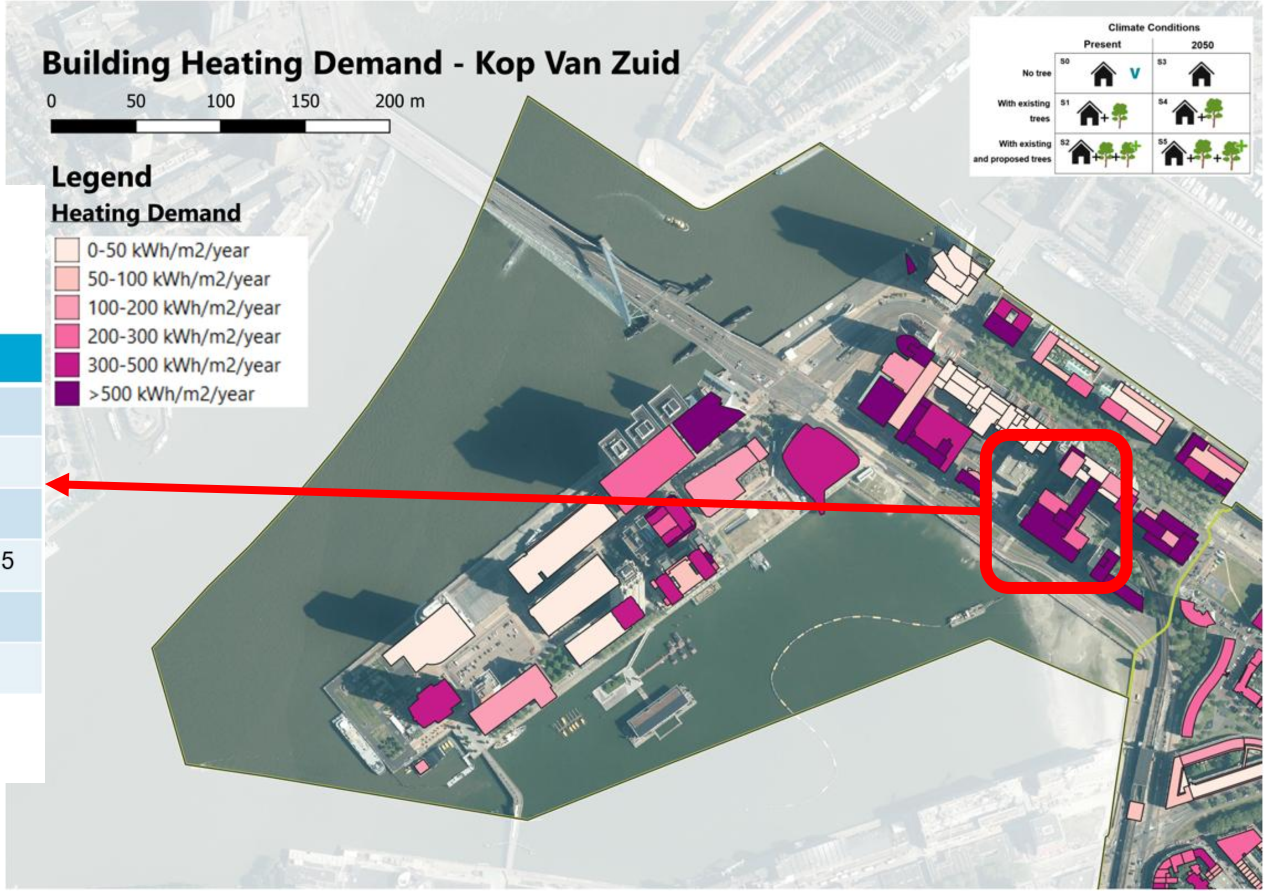
Attribute	Value
Street	Van der Hoevenplein
N_YHD (kWh/m²/year)	374.555
N_YCD (kWh/m²/year)	1475.363
Gml_parent_id	BAG_0599100000753300
PrimaryUsageZoneType	industry
SecondaryUsageZoneType	residential

Building with highest heating demand

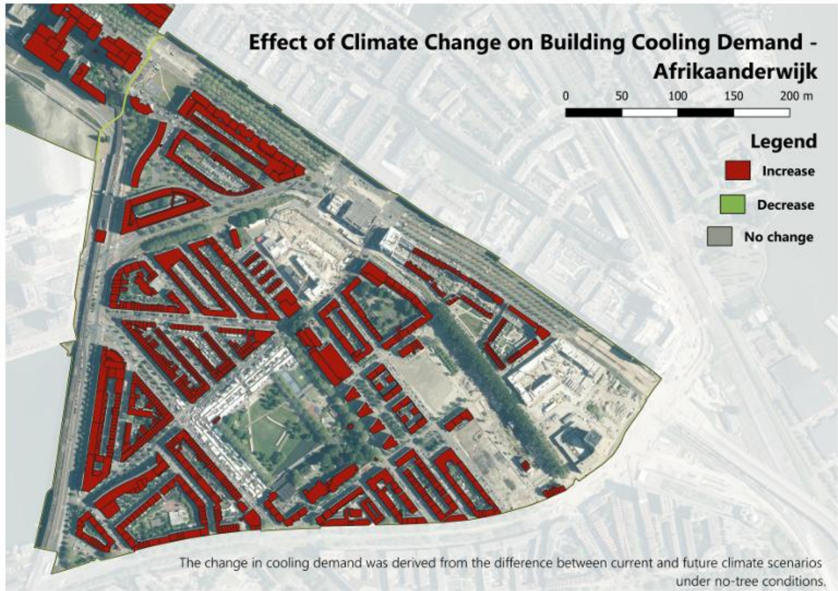


Building with highest value in N_YHD

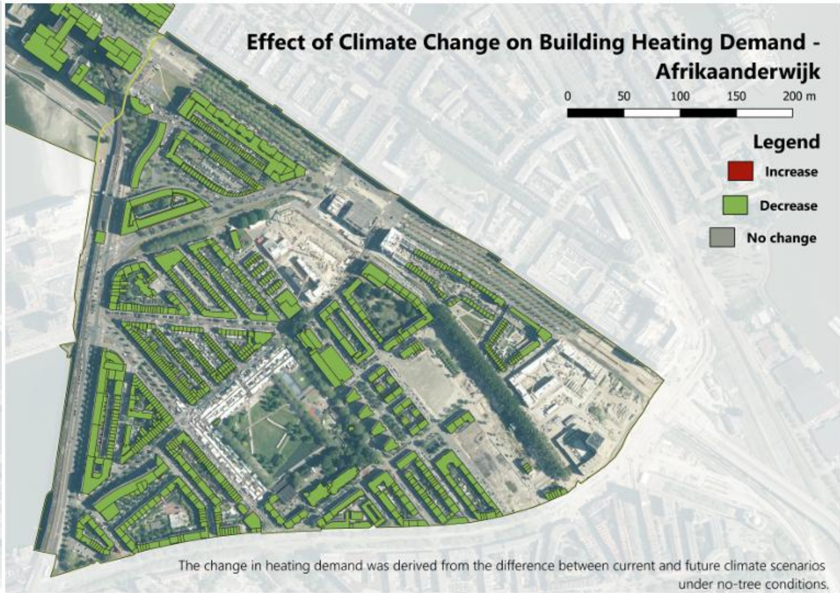
Attribute	Value
Street	Posthumalaan
N_YHD (kWh/m²/year)	3895.175
N_YCD (kWh/m²/year)	685.74
Gml_parent_id	BAG_0599100000359215
PrimaryUsageZoneType	education and research
SecondaryUsageZoneType	none



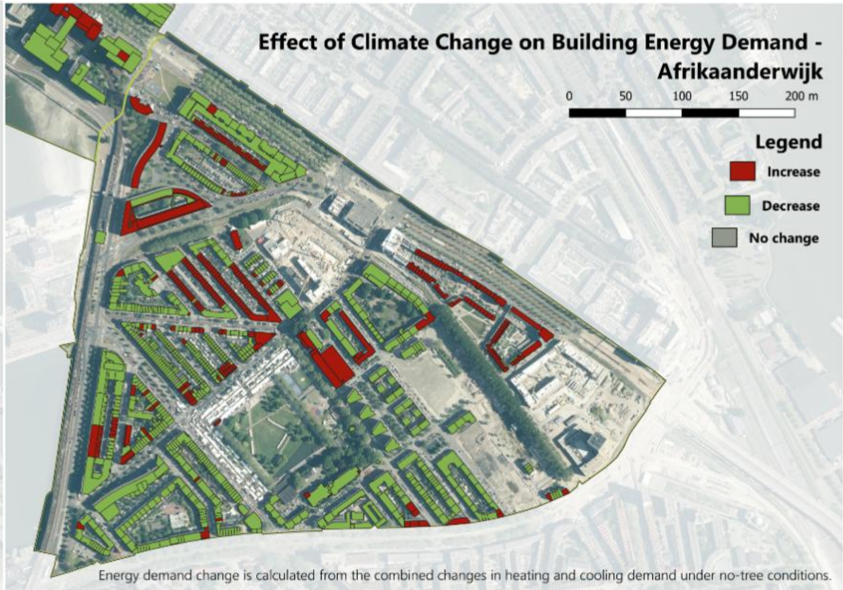
Climate change effect (S3-S0) Afrikaanderwijk


Effect of Climate Change on Building Cooling Demand - Afrikaanderwijk

The change in cooling demand was derived from the difference between current and future climate scenarios under no-tree conditions.

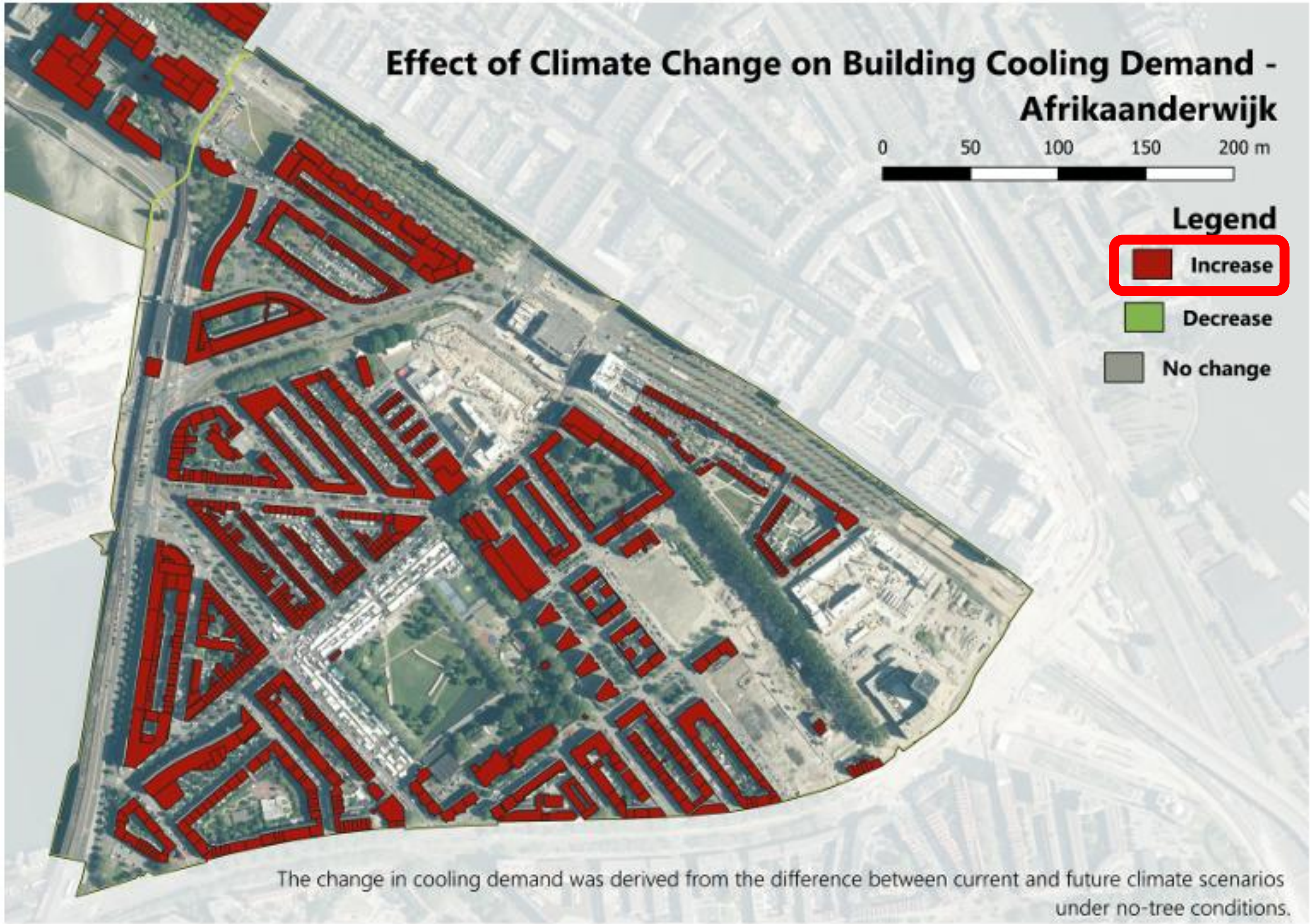

Effect of Climate Change on Building Heating Demand - Afrikaanderwijk

The change in heating demand was derived from the difference between current and future climate scenarios under no-tree conditions.


Effect of Climate Change on Building Energy Demand - Afrikaanderwijk

Energy demand change is calculated from the combined changes in heating and cooling demand under no-tree conditions.

Climate change effect (S3-S0) Afrikaanderwijk: On cooling demand



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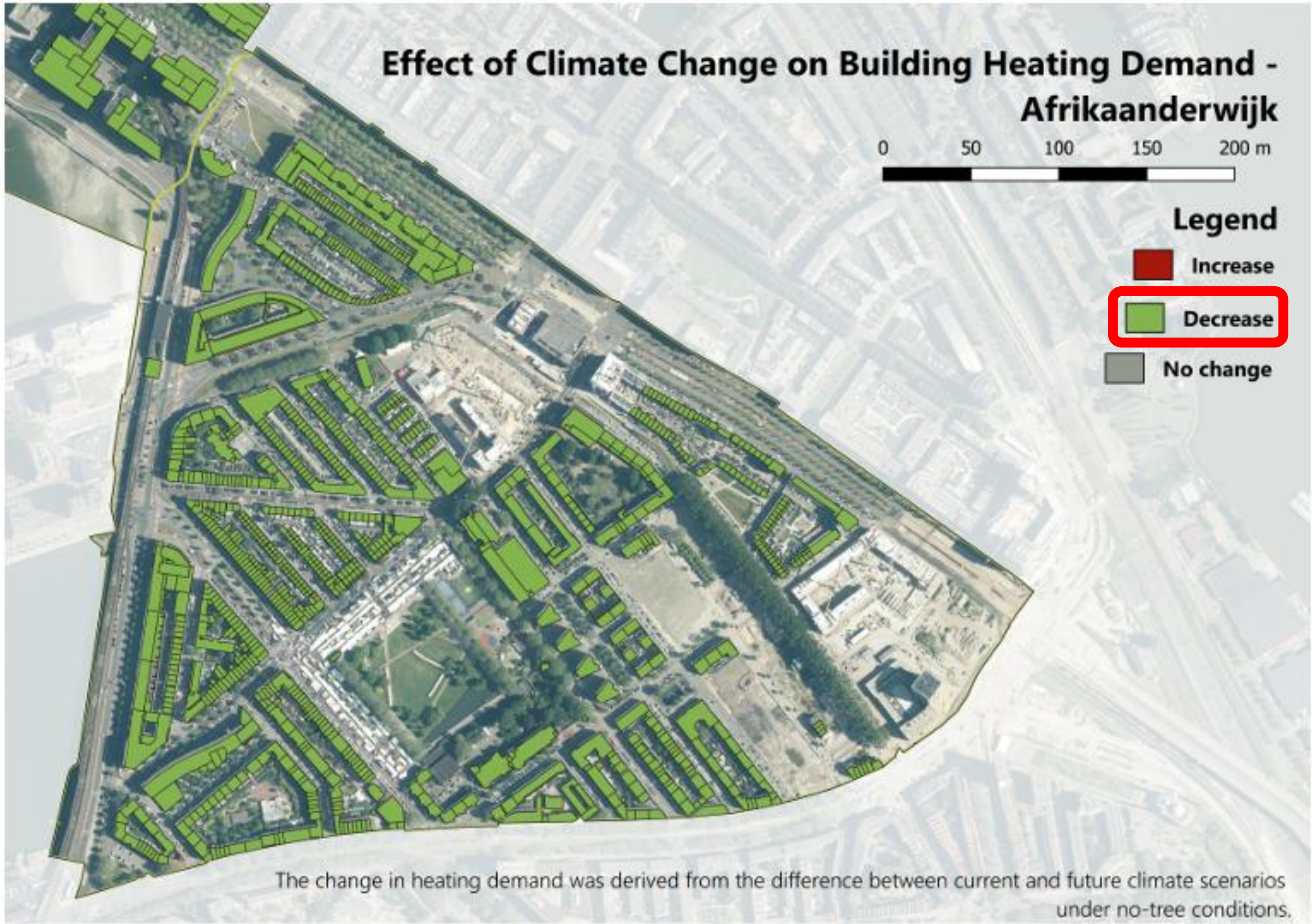
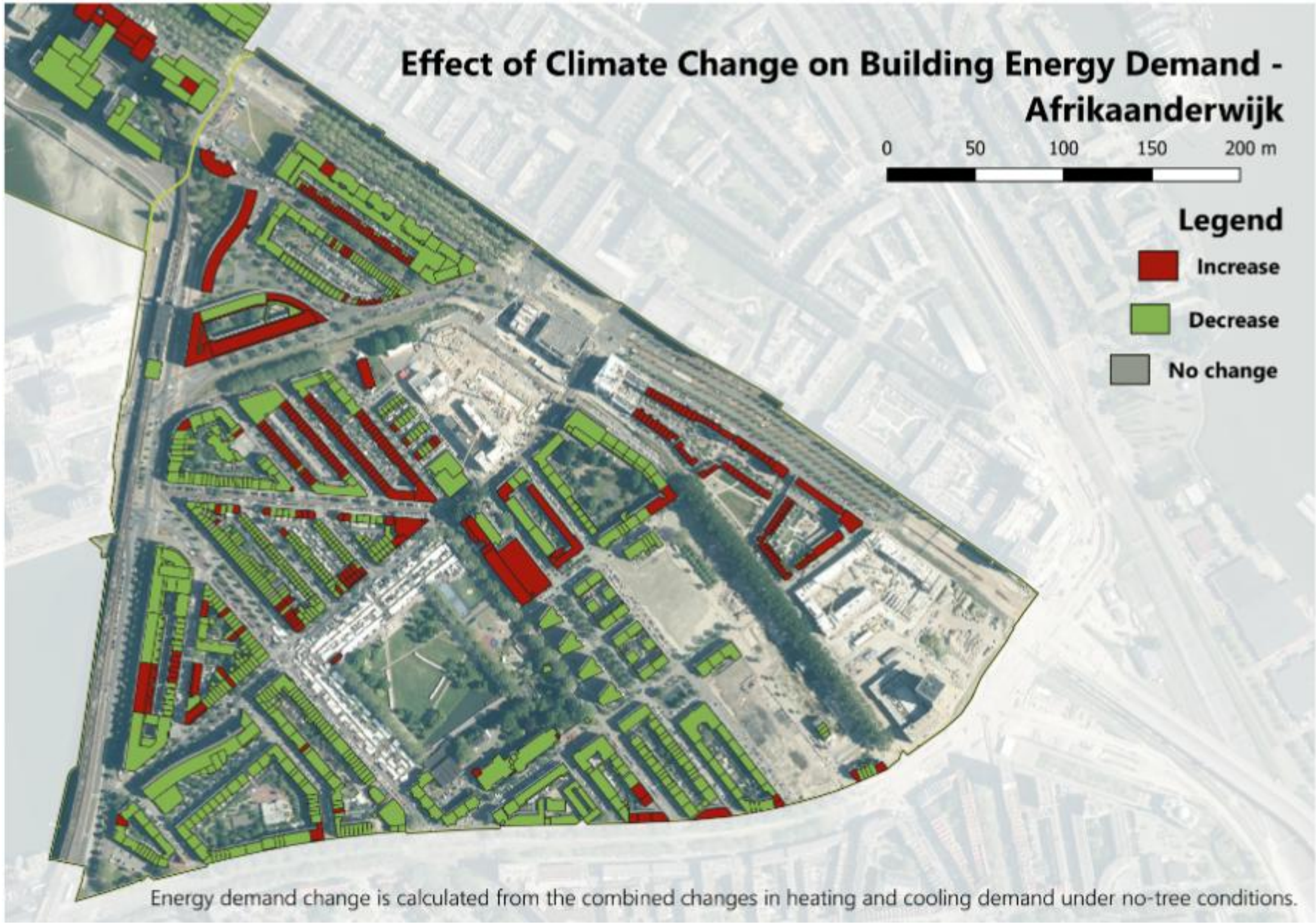
Climate change effect (S3-S0) Afrikaanderwijk: On heating demand



The change in heating demand was derived from the difference between current and future climate scenarios under no-tree conditions.

Climate change effect (S3-S0) Afrikaanderwijk: On cooling + heating demand



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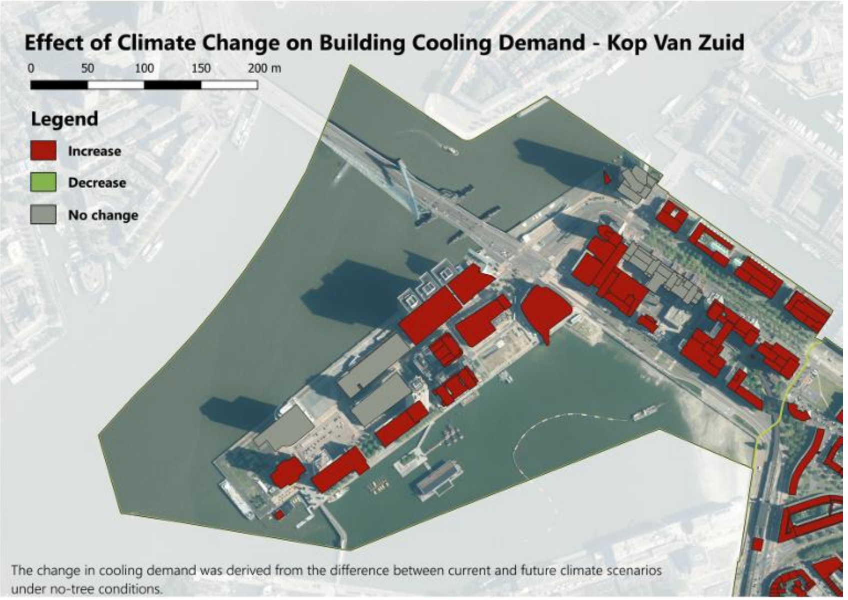
Climate change effect (S3-S0) Kop van Zuid



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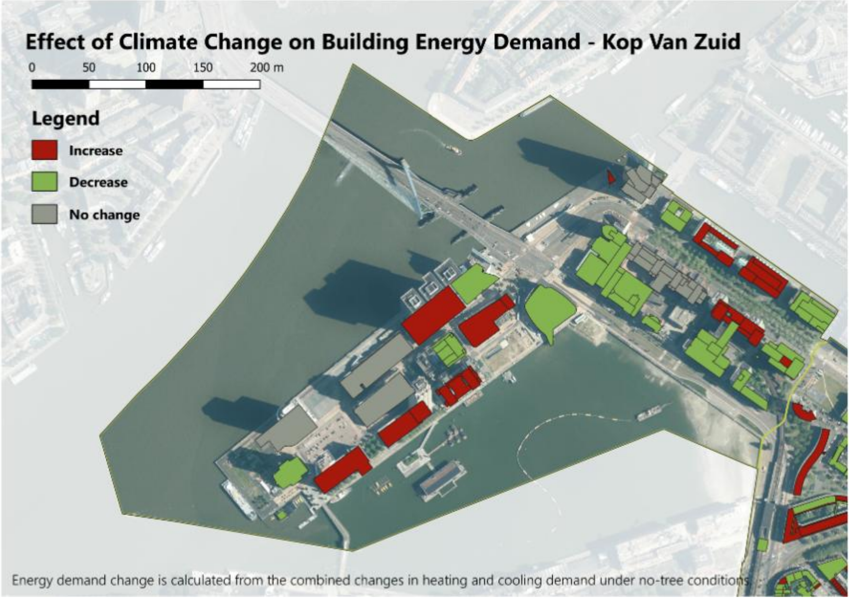

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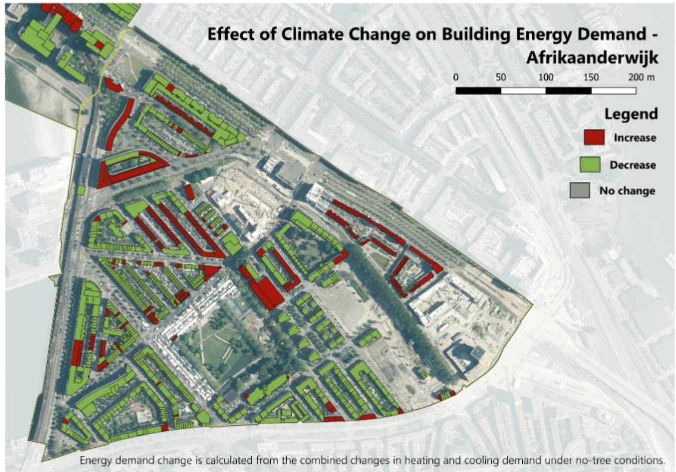
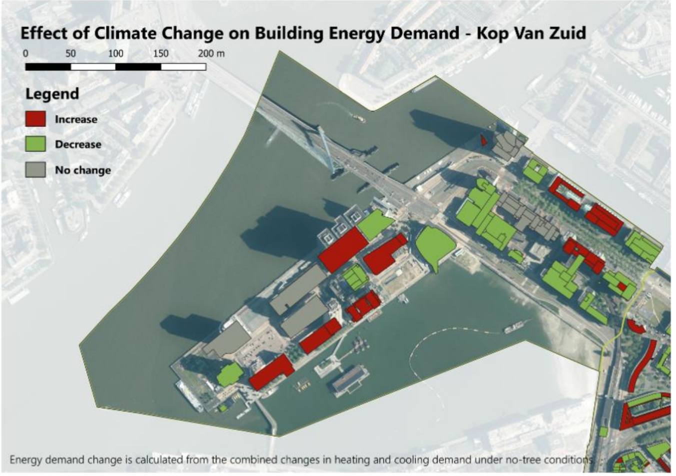




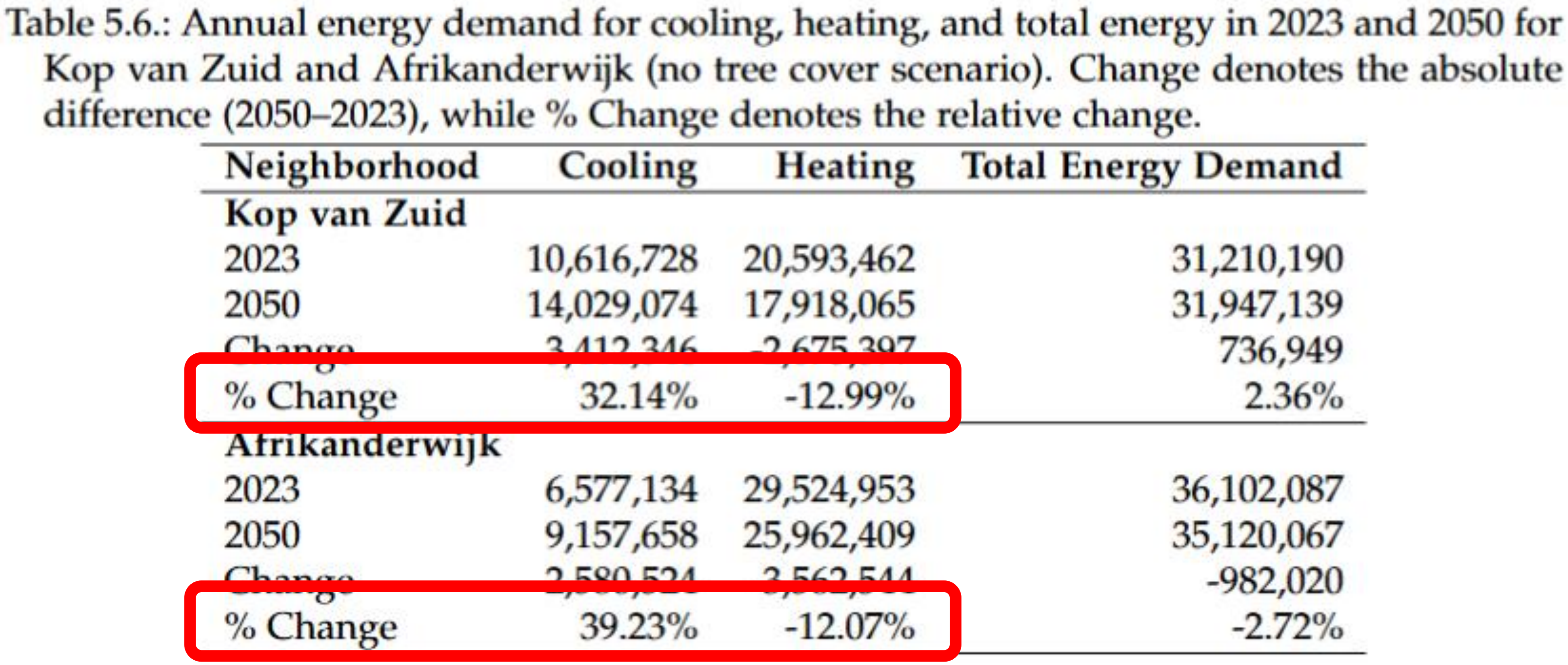
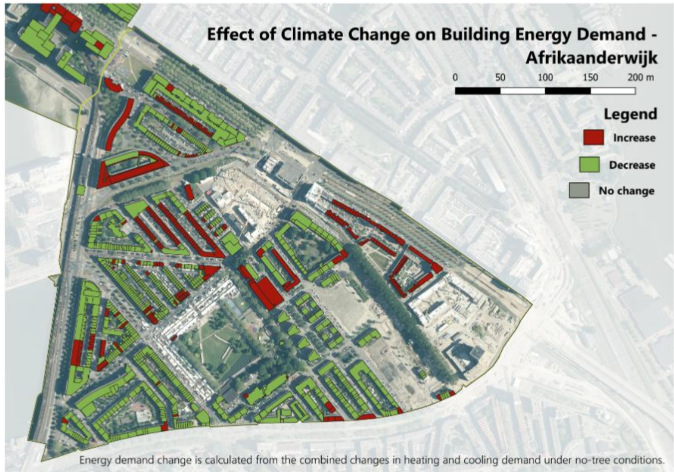


Table 5.6.: Annual energy demand for cooling, heating, and total energy in 2023 and 2050 for Kop van Zuid and Afrikanderwijk (no tree cover scenario). Change denotes the absolute difference (2050–2023), while % Change denotes the relative change.

Neighborhood	Cooling	Heating	Total Energy Demand
Kop van Zuid			
2023	10,616,728	20,593,462	31,210,190
2050	14,029,074	17,918,065	31,947,139
Change	3,412,346	-2,675,397	736,949
% Change	32.14%	-12.99%	2.36%
Afrikanderwijk			
2023	6,577,134	29,524,953	36,102,087
2050	9,157,658	25,962,409	35,120,067
Change	2,580,524	3,562,544	-982,020
% Change	39.23%	-12.07%	-2.72%

For both neighboorhood total annual energy use changes only slightly,



Effect of Climate Change on Building Energy Demand - Afrikaanderwijk

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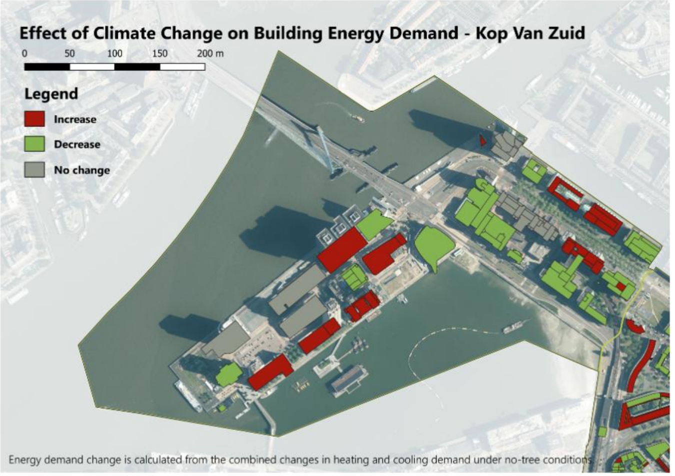

Effect of Climate Change on Building Energy Demand - Kop Van Zuid

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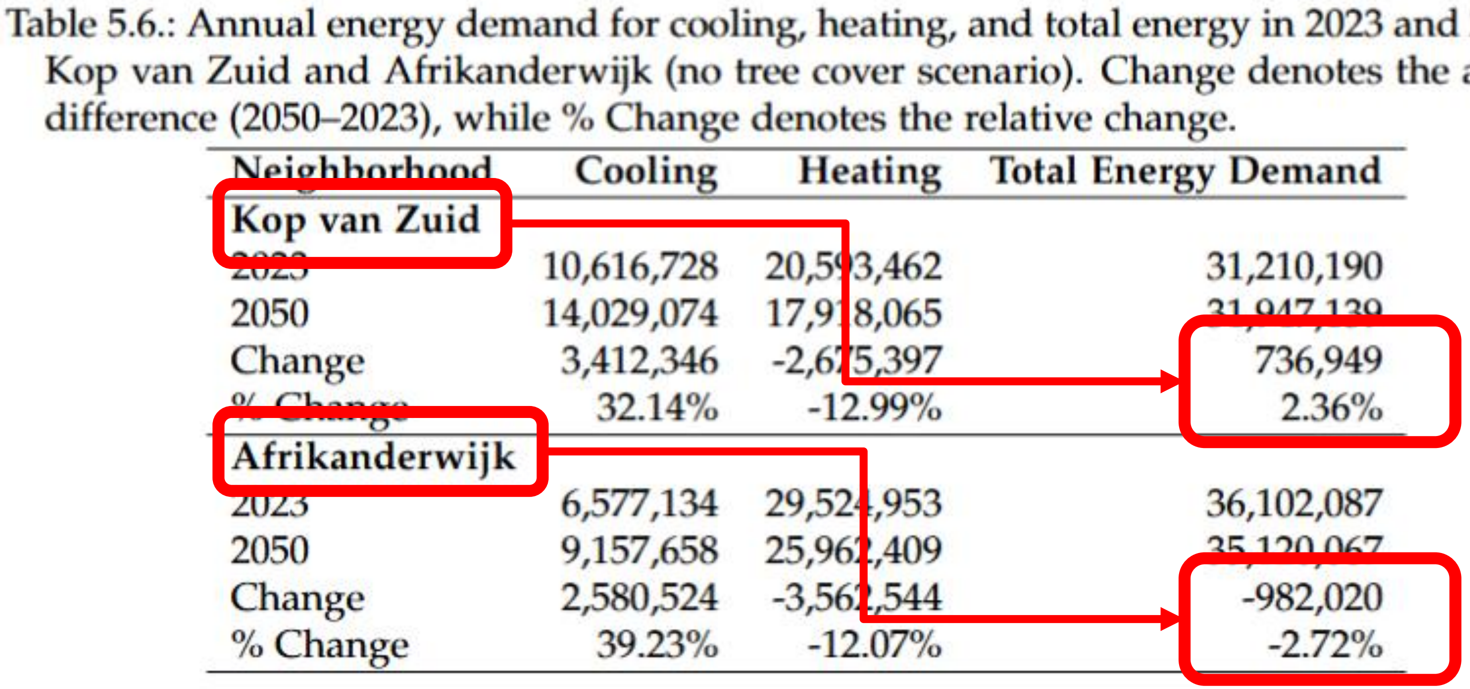

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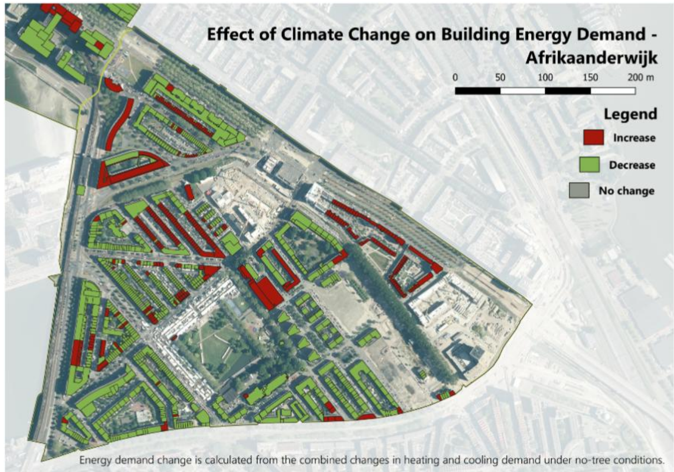

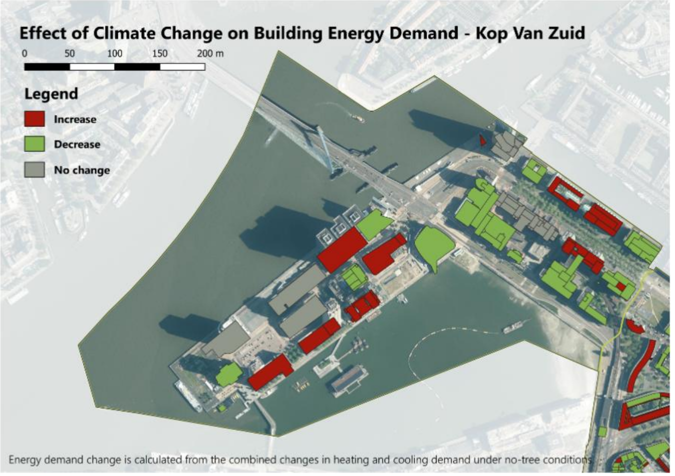

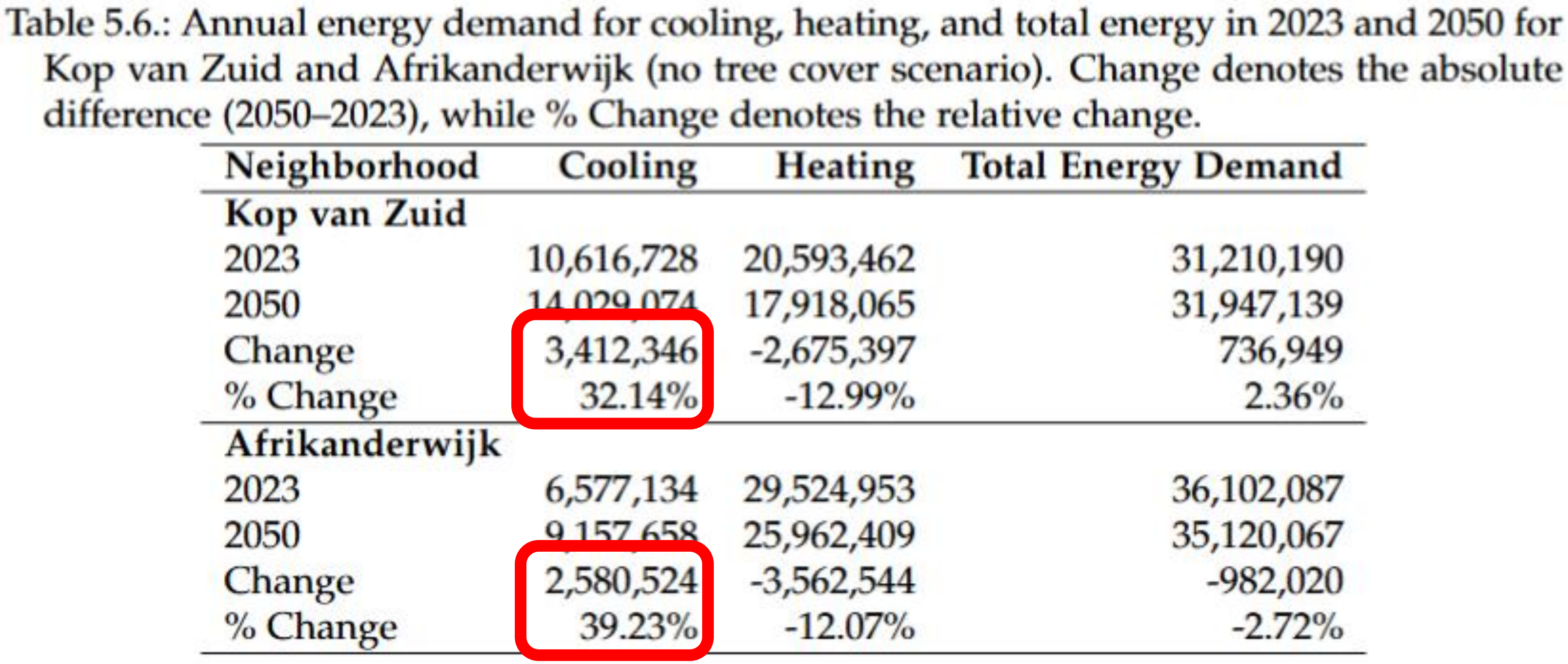
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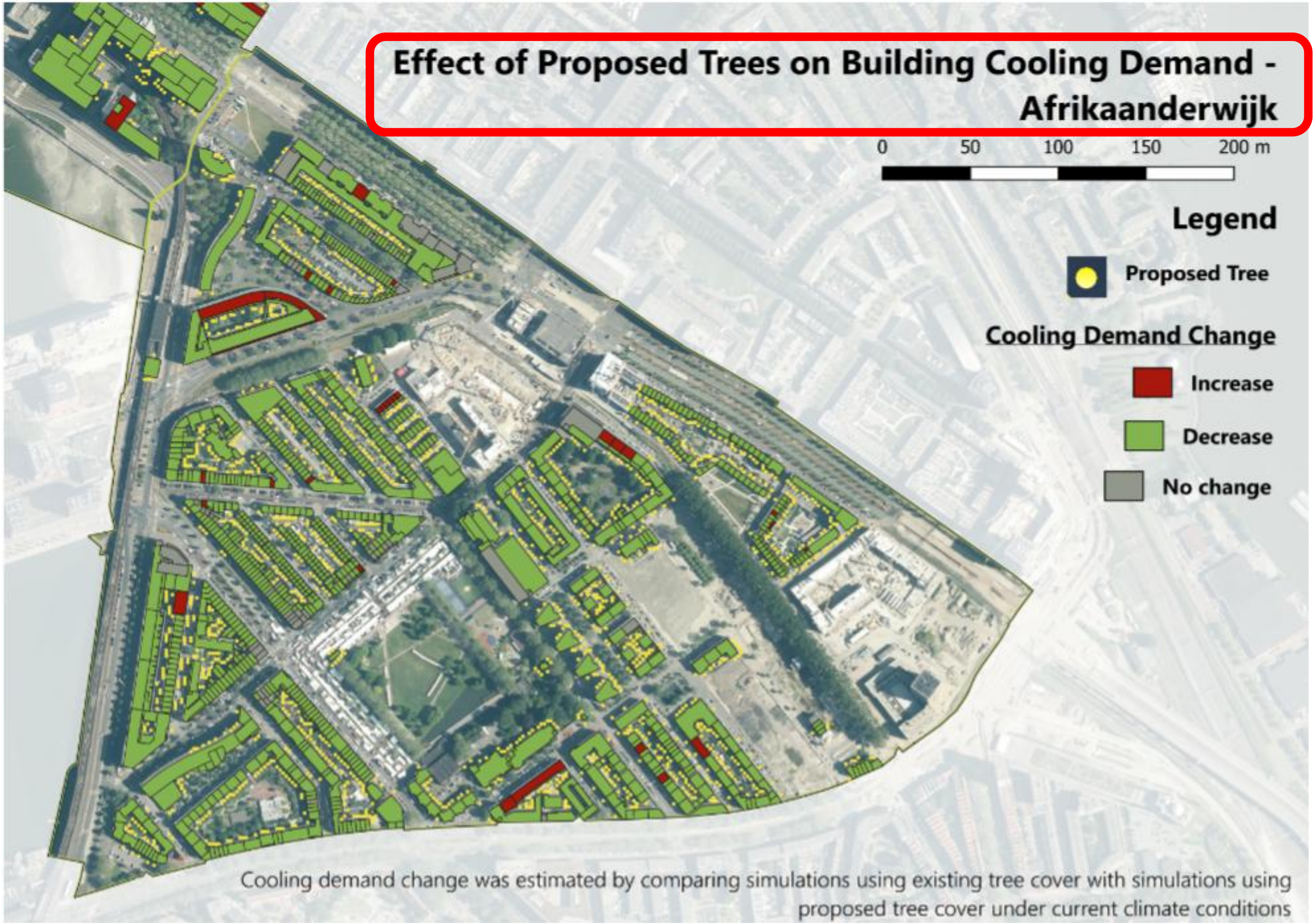
For both neighboorhood total annual energy use changes only slightly, but summer cooling is becoming much more dominant, suggesting potential challenges for peak electricity demand in the future.

Effectiveness of Proposed Tree Planting Strategies

Effectiveness of Proposed Tree Planting Strategies

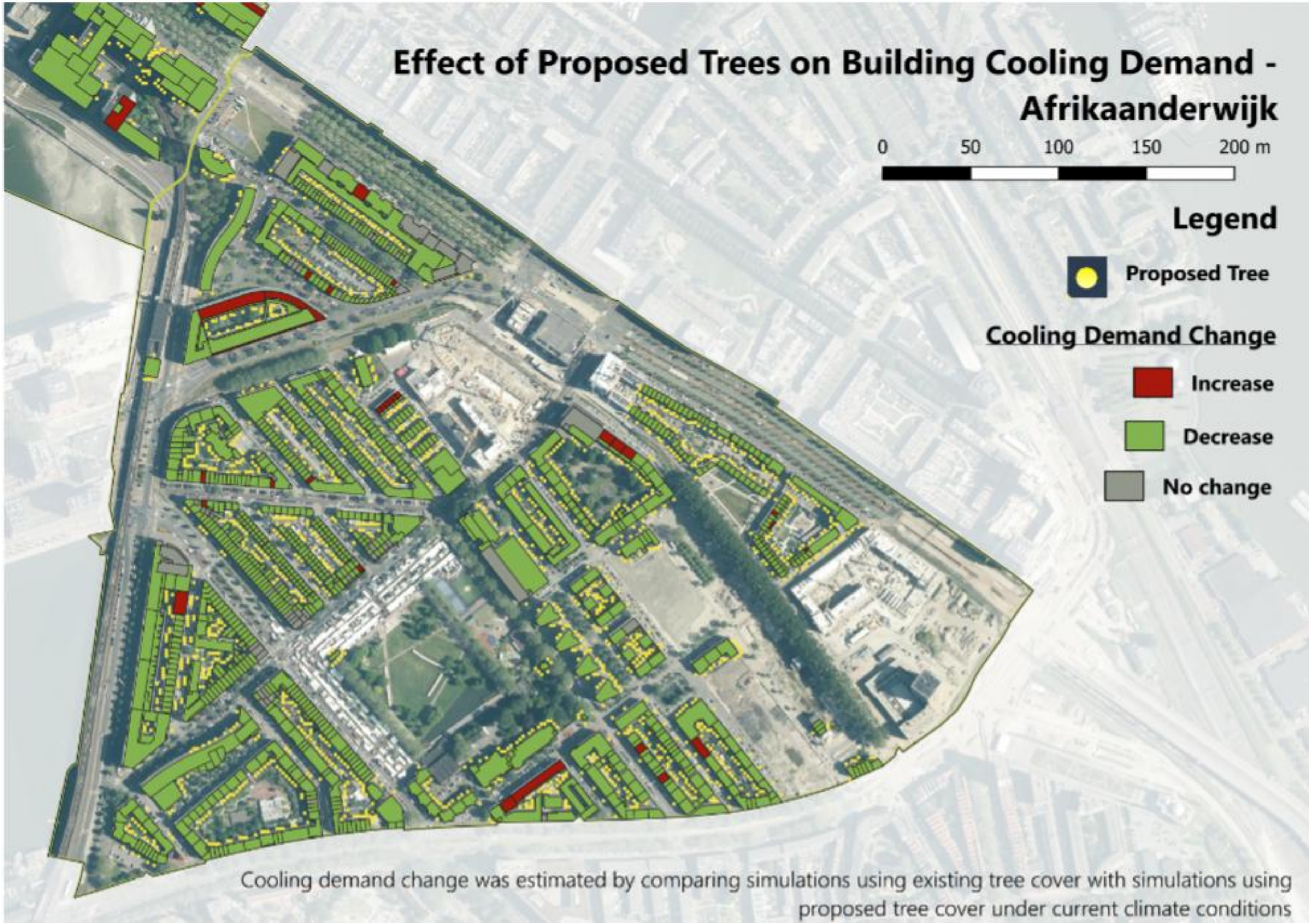


Cooling demand change was estimated by comparing simulations using existing tree cover with simulations using proposed tree cover under current climate conditions

Effectiveness of Proposed Tree Planting Strategies

Shading effect
→ Trees block solar radiation
→ Less heat enters buildings
→ Indoor temperatures stay cooler
→ Cooling demand decreases

More shade
= less solar heat gain
= lower need for air conditioning.



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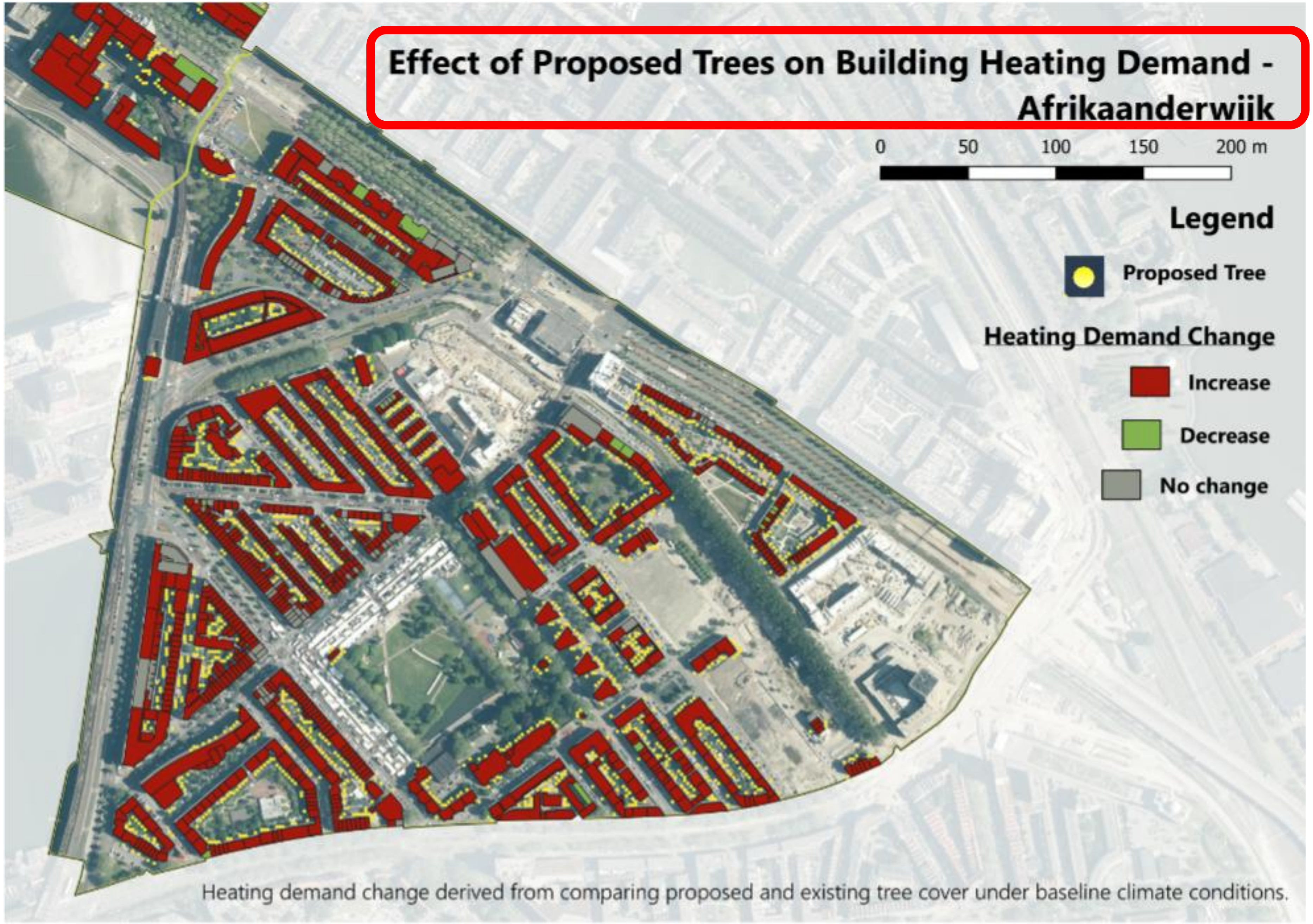
Effectiveness of Proposed Tree Planting Strategies

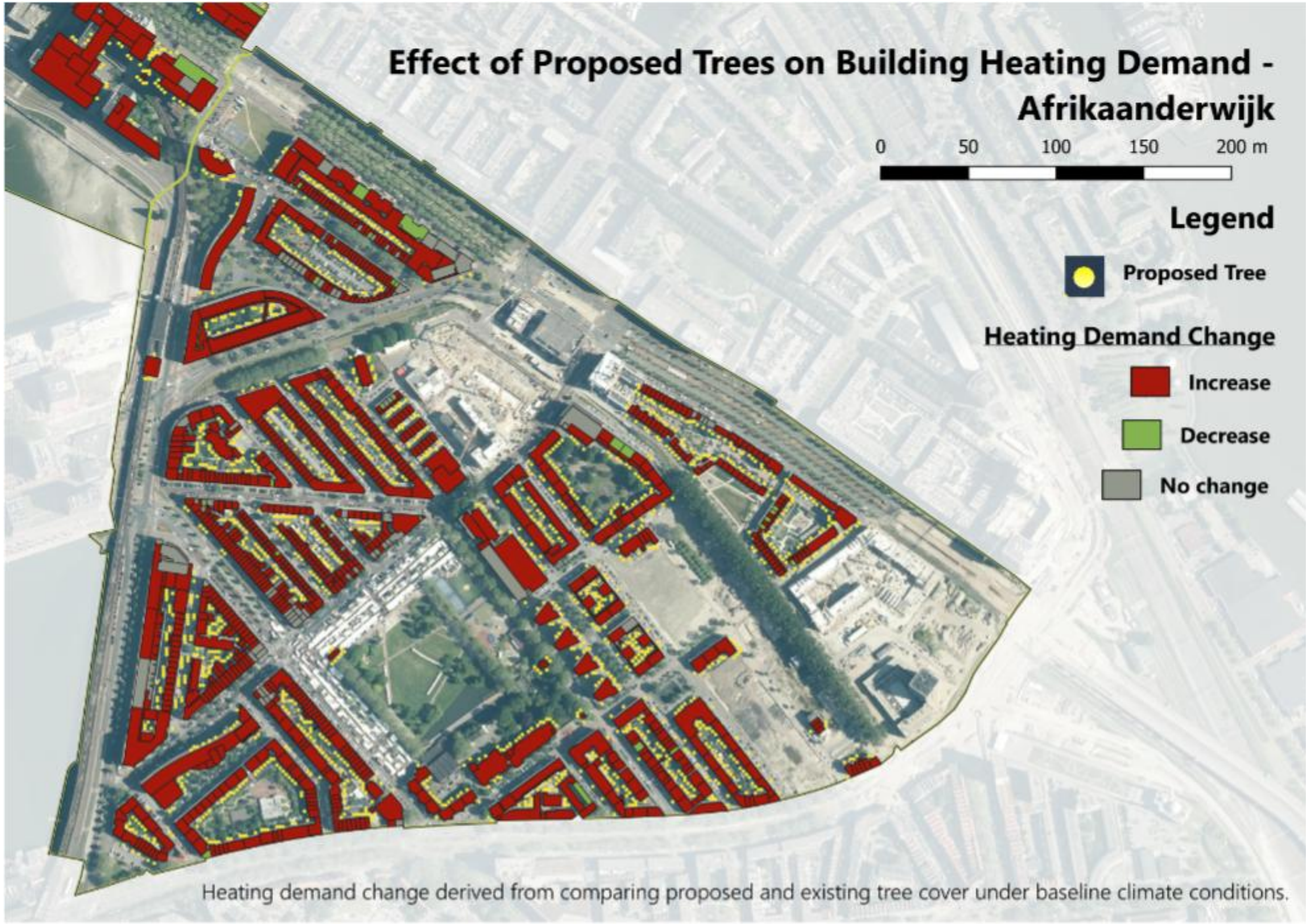


Heating demand change derived from comparing proposed and existing tree cover under baseline climate conditions.

Effectiveness of Proposed Tree Planting Strategies

Shading effect
→ Trees block solar radiation
→ Less heat enters buildings
→ Indoor temperatures drop
→ Heating demand increases

More shade = less free solar warmth in winter = higher need for heating.



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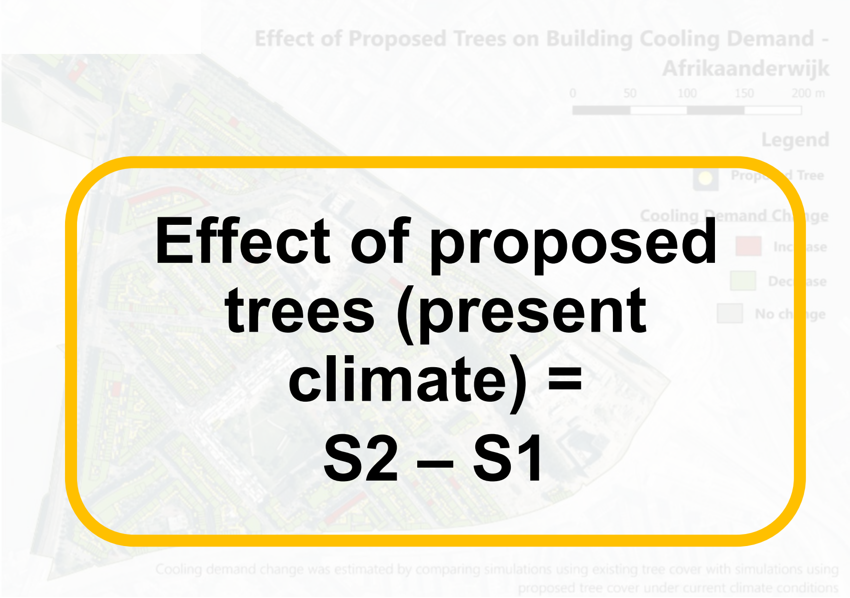
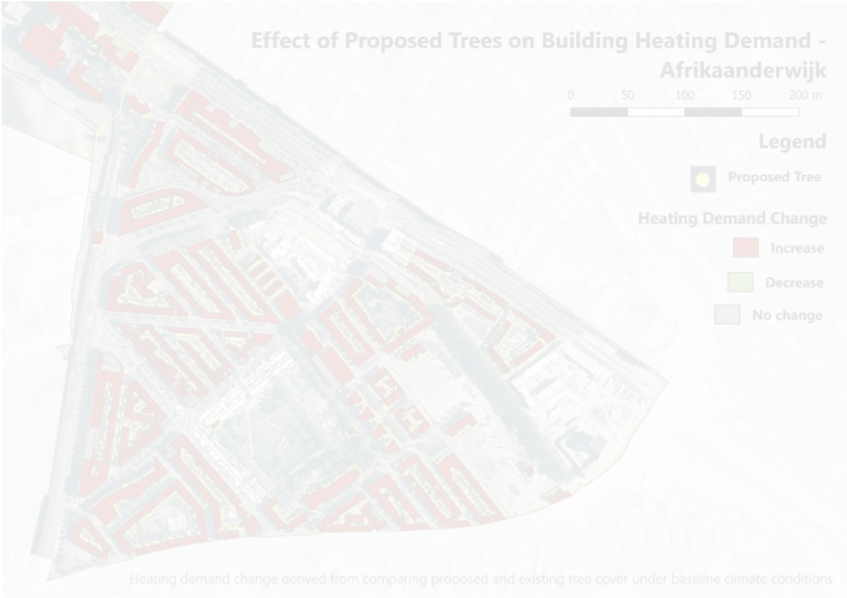
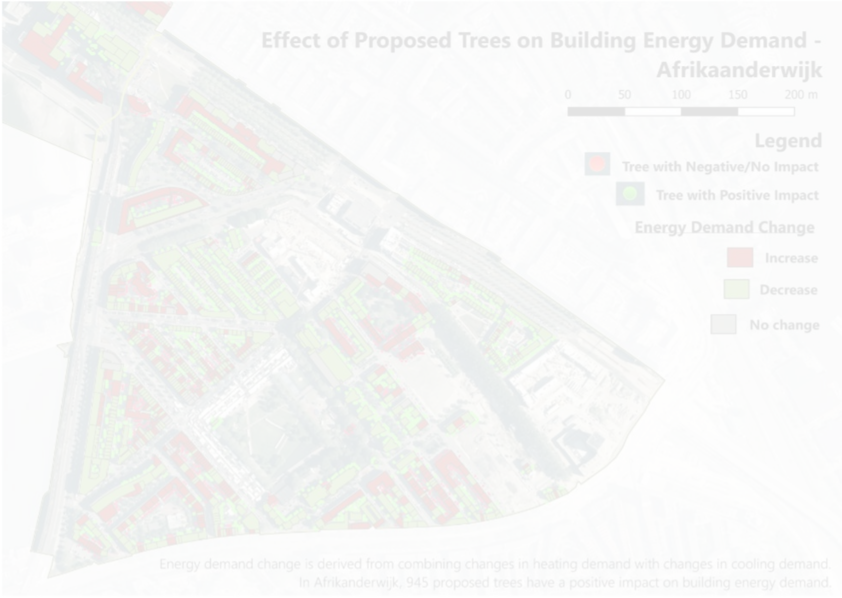
Effectiveness of Proposed Tree Planting Strategies



Effect of proposed trees (present climate) =
S2 – S1





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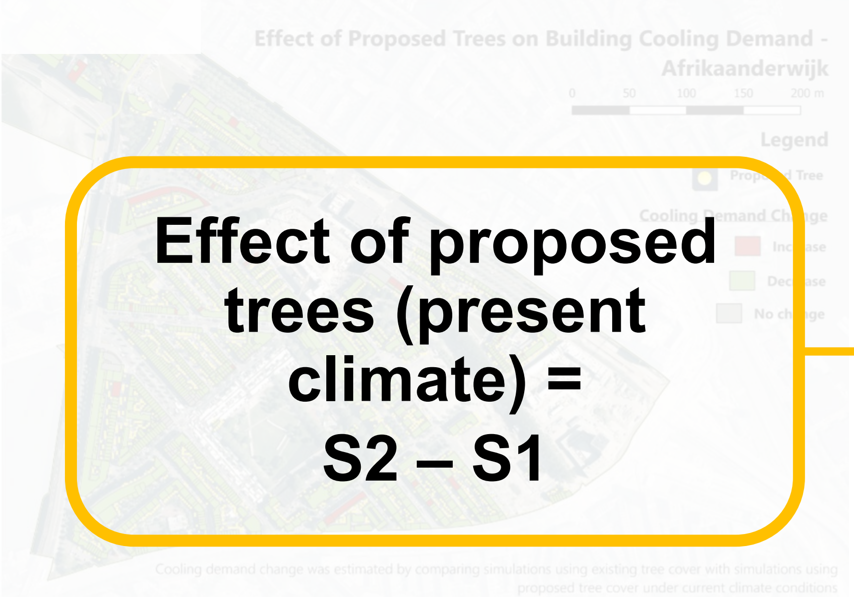
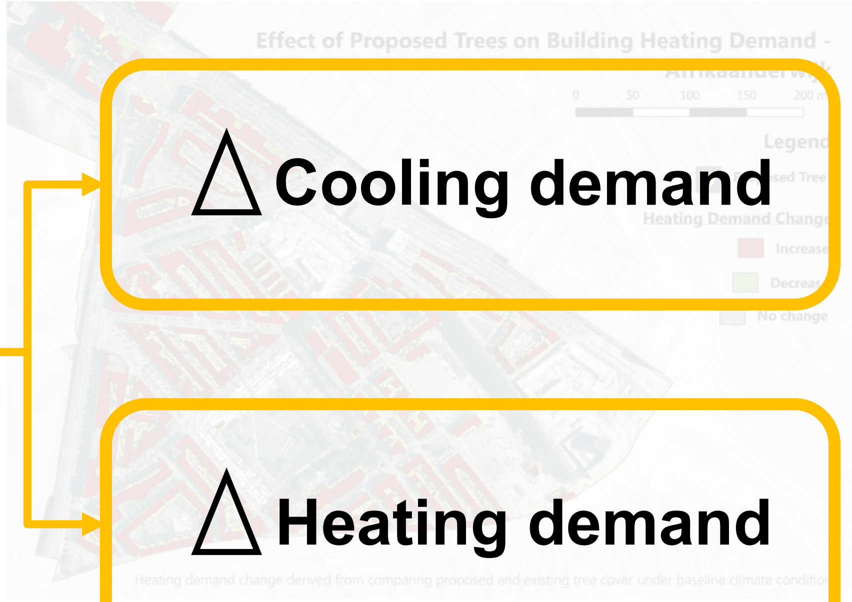
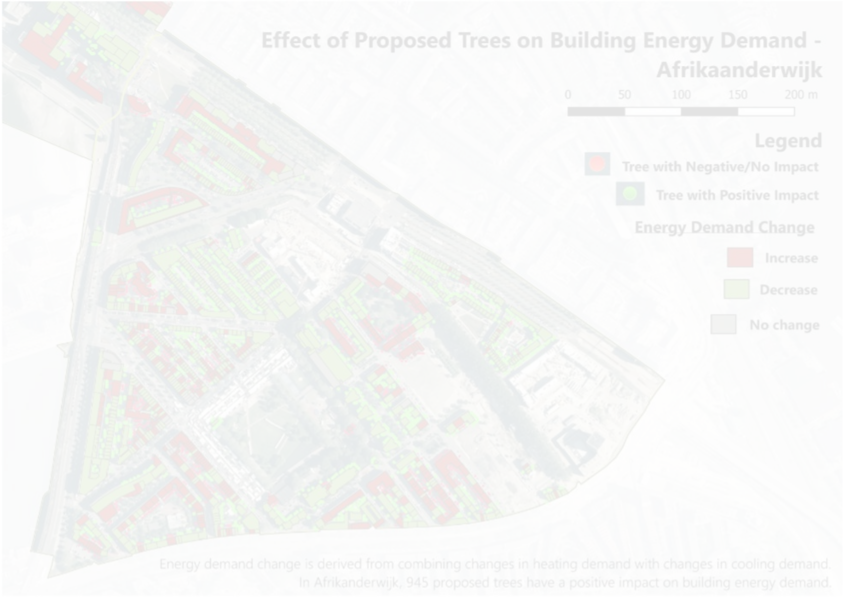


Cooling demand change was estimated by comparing simulations using existing tree cover with simulations using proposed tree cover under current climate conditions



Heating demand change derived from comparing proposed and existing tree cover under baseline climate condition



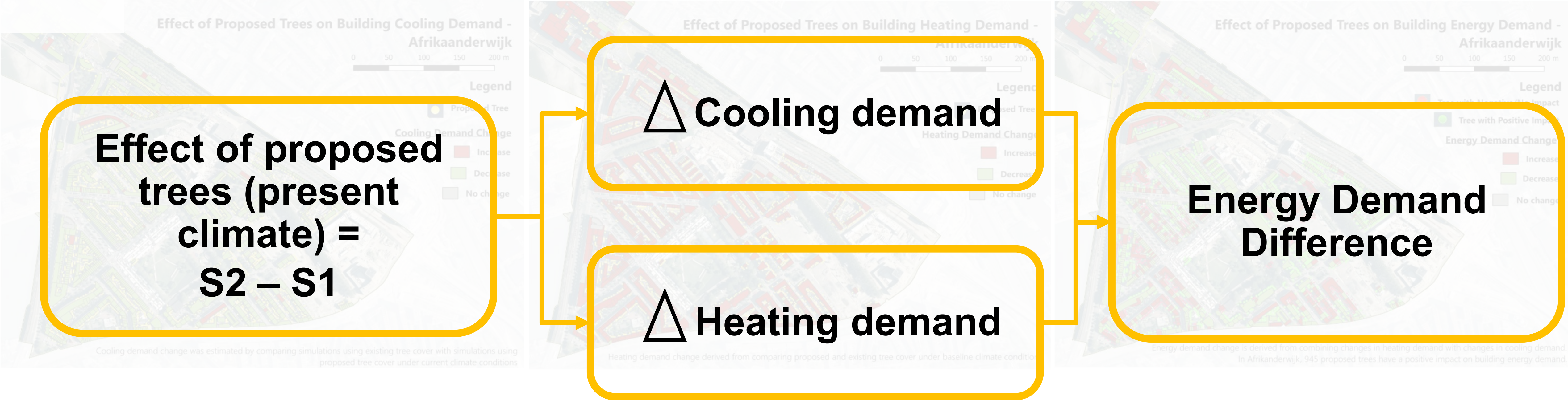
Energy demand change is derived from combining changes in heating demand with changes in cooling demand. In Afrikanderwijk, 945 proposed trees have a positive impact on building energy demand.

Effect of proposed trees (present climate) = S2 – S1

△ Cooling demand

△ Heating demand

Effectiveness of Proposed Tree Planting Strategies



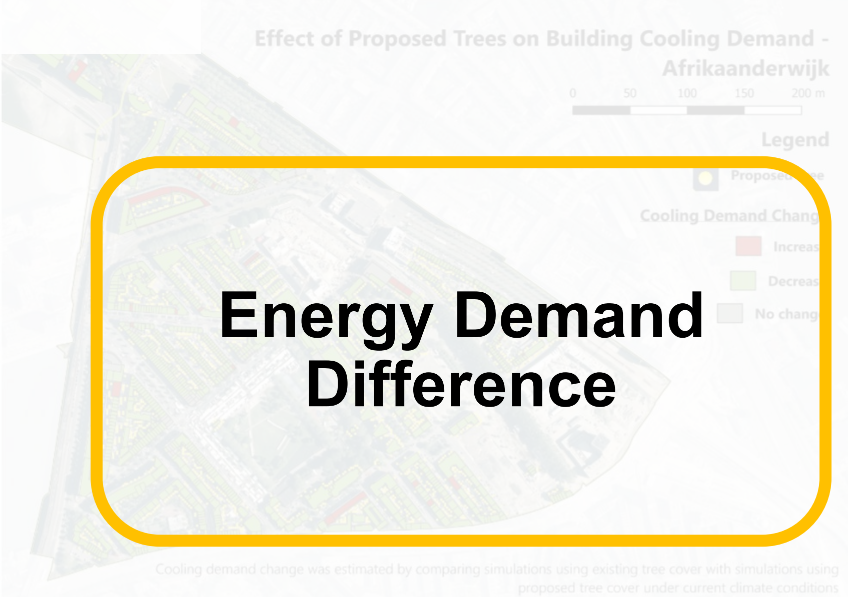
Effect of proposed trees (present climate) = S2 – S1

△ Cooling demand

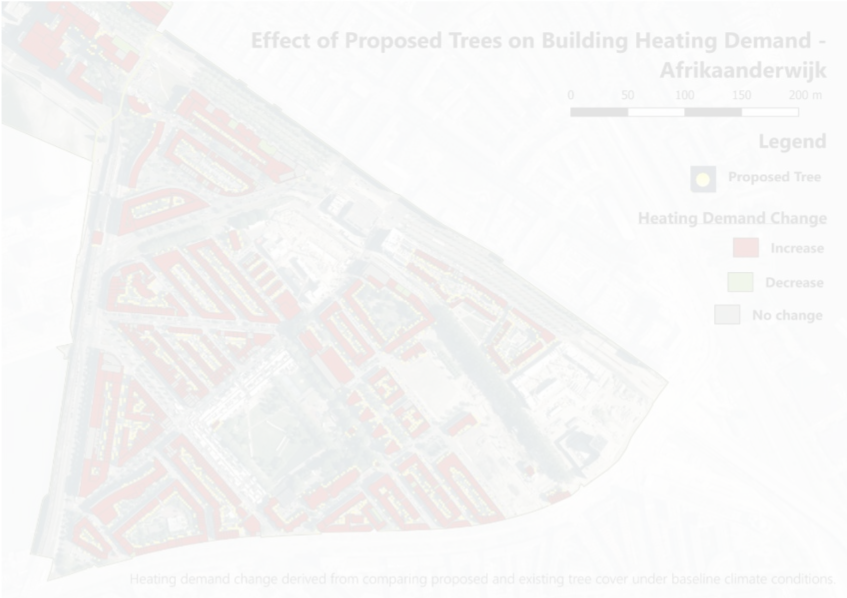
△ Heating demand

Energy Demand Difference

Effectiveness of Proposed Tree Planting Strategies



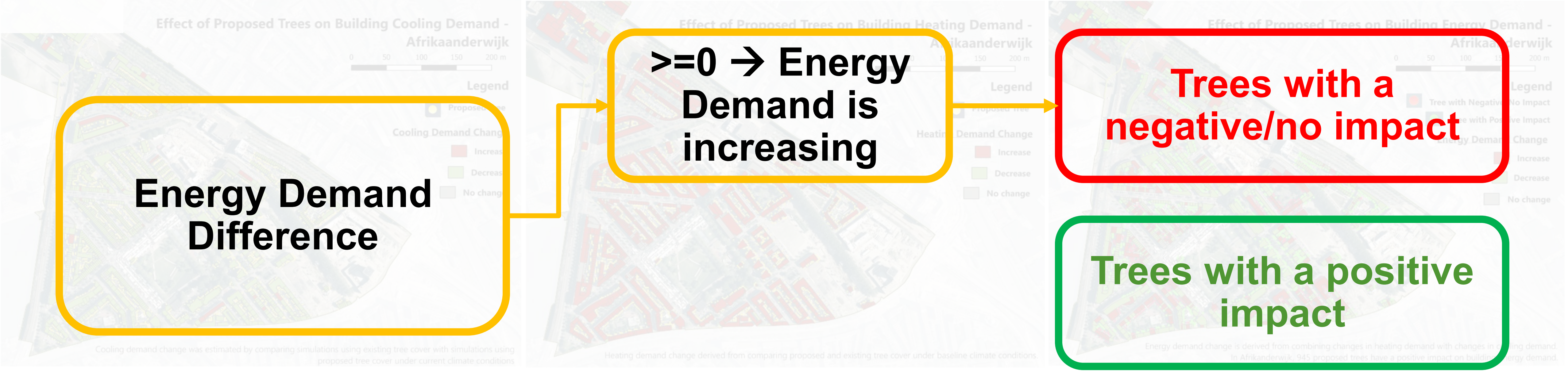
Energy Demand Difference



Trees with a negative/no impact

Trees with a positive impact

Effectiveness of Proposed Tree Planting Strategies



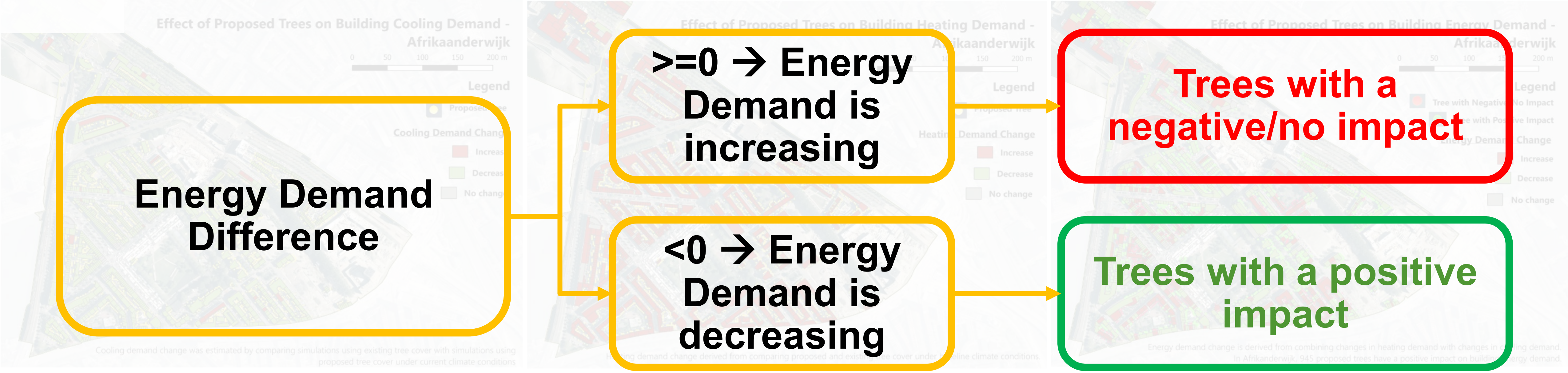
Energy Demand Difference

>=0 → Energy Demand is increasing

Trees with a negative/no impact

Trees with a positive impact

Effectiveness of Proposed Tree Planting Strategies



Energy Demand Difference

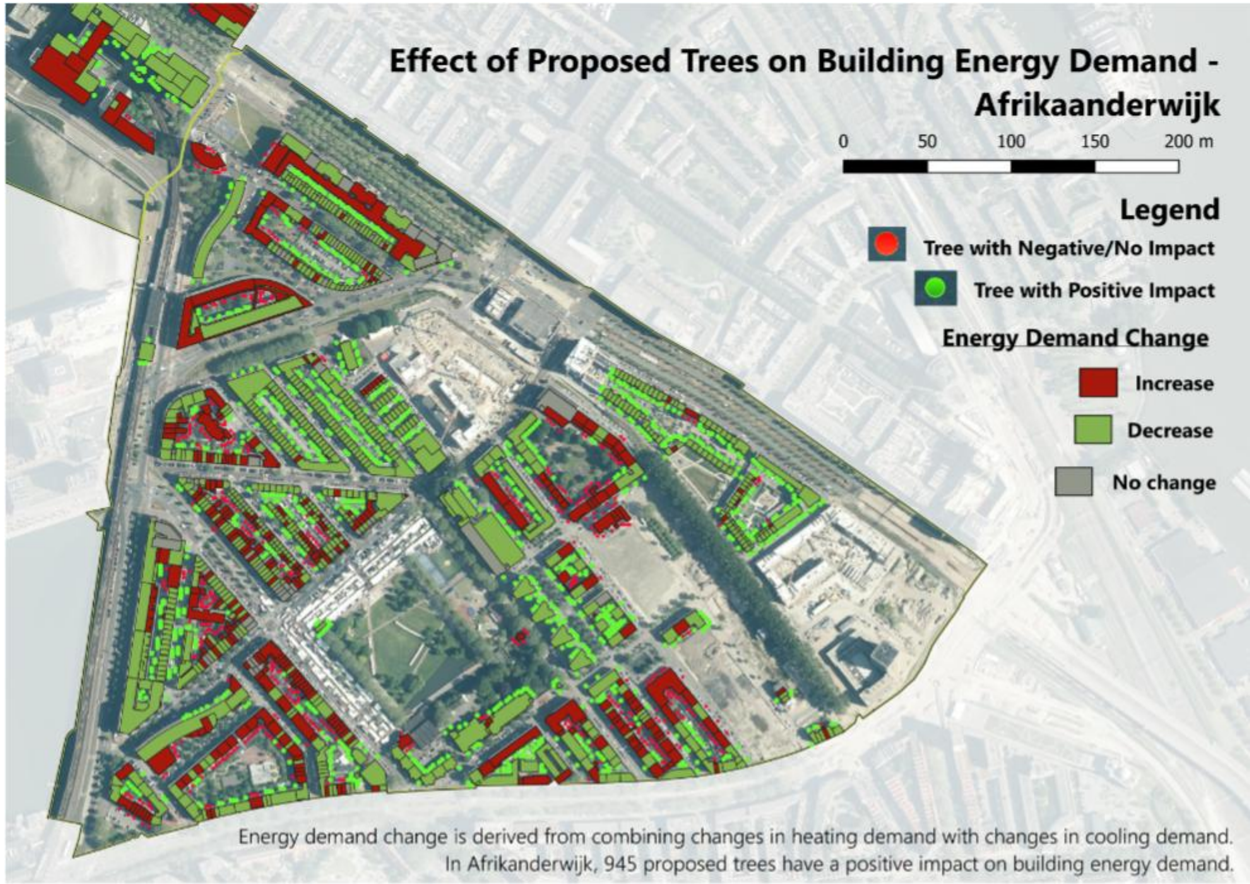
>=0 → Energy Demand is increasing

<0 → Energy Demand is decreasing

Trees with a negative/no impact

Trees with a positive impact

Effectiveness of proposed tree planting strategy under current climate



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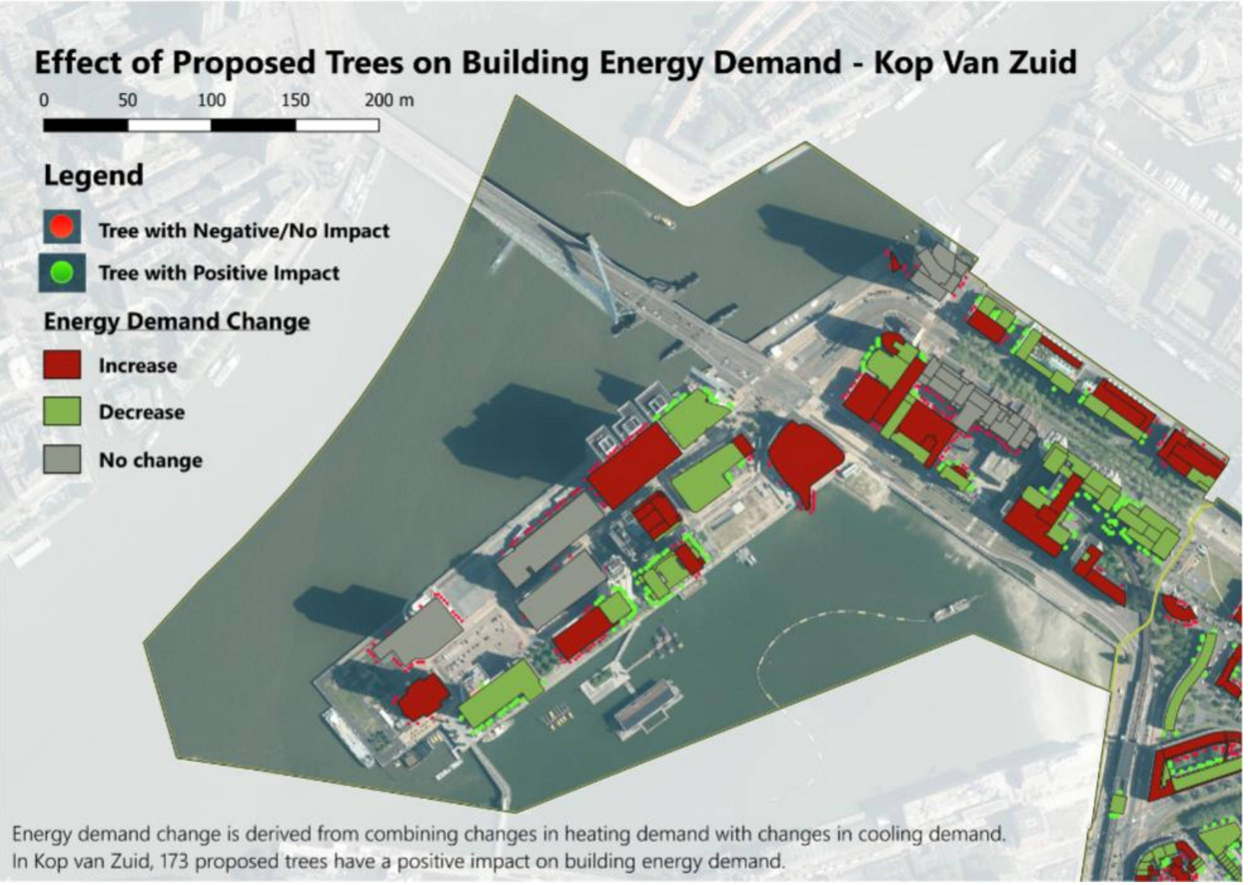
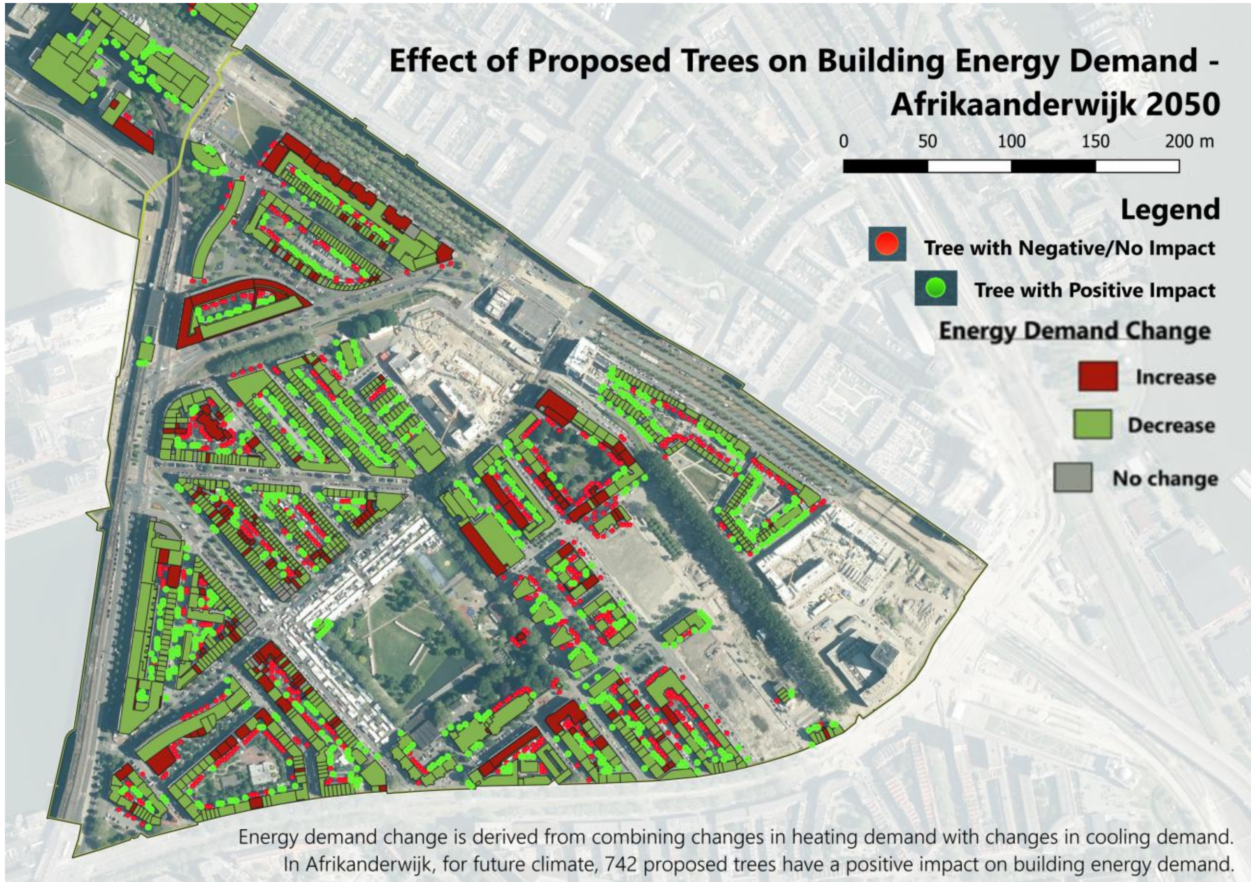
In Afrikanderwijk, 945 proposed trees have a positive impact on building energy demand.

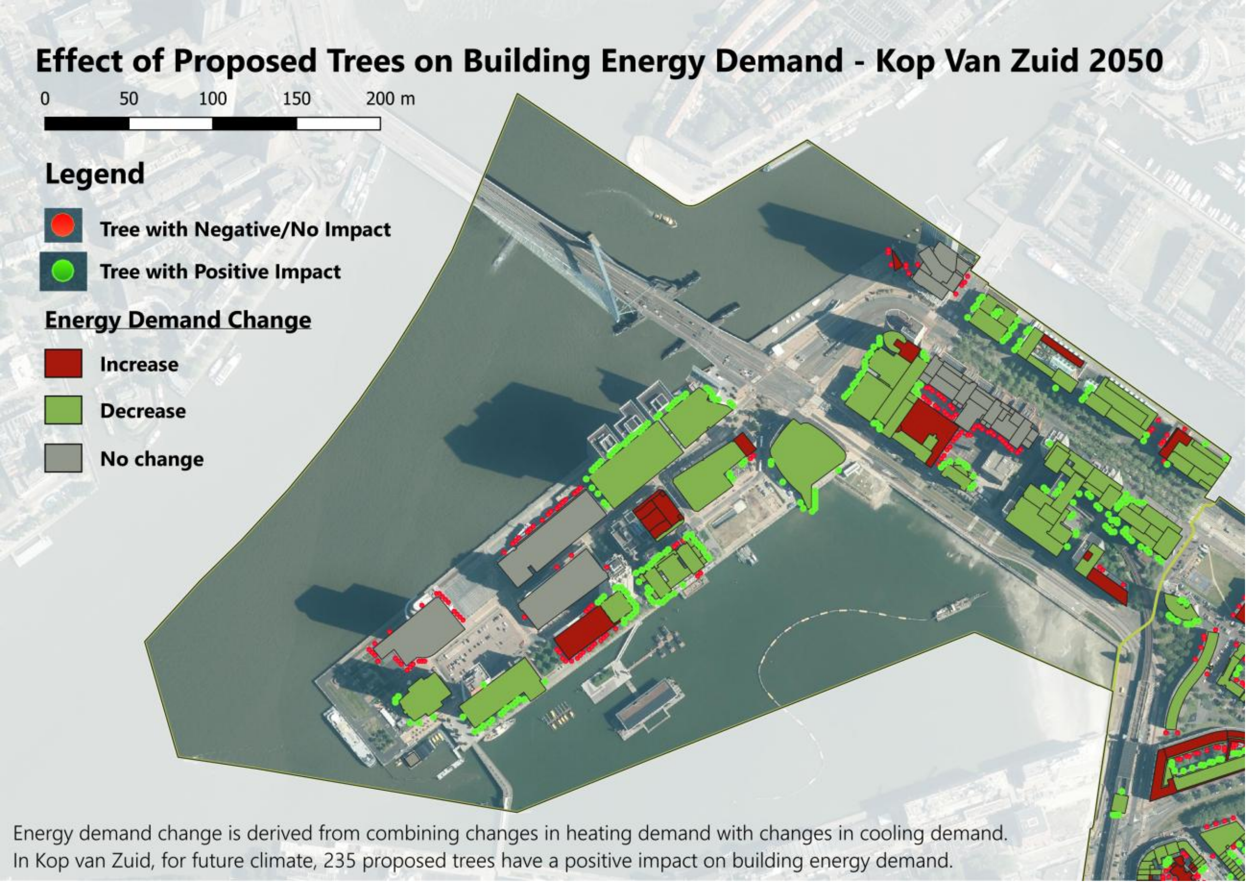


Energy demand change is derived from combining changes in heating demand with changes in cooling demand.
In Kop van Zuid, 173 proposed trees have a positive impact on building energy demand.

Effectiveness of proposed tree planting strategy under future climate

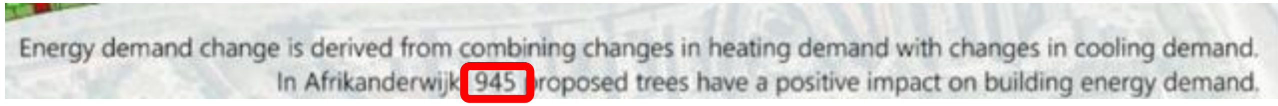


Energy demand change is derived from combining changes in heating demand with changes in cooling demand. In Afrikanderwijk, for future climate, 742 proposed trees have a positive impact on building energy demand.



Energy demand change is derived from combining changes in heating demand with changes in cooling demand. In Kop van Zuid, for future climate, 235 proposed trees have a positive impact on building energy demand.

Difference: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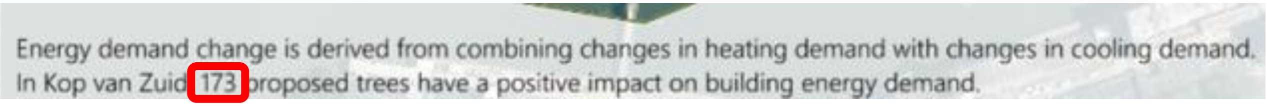
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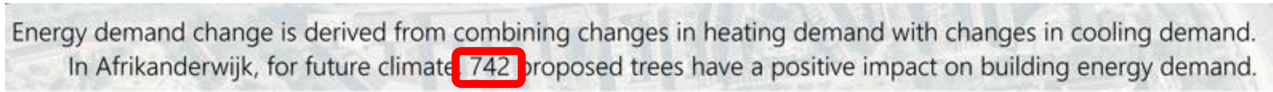
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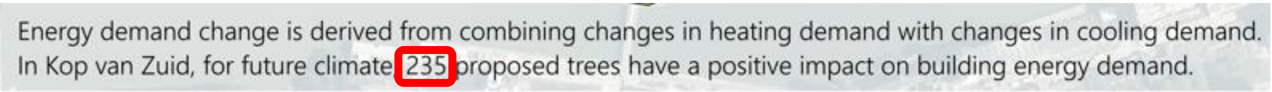
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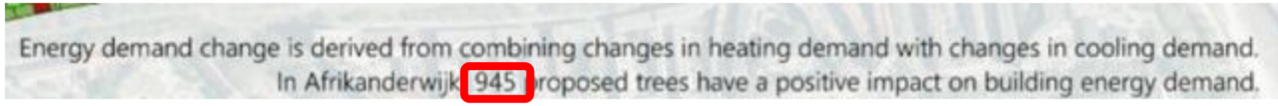
Afrikaanderwijk Beneficial trees: **945 under current climate → 742 under future climate**

Kop van Zuid Beneficial trees: **173 under current climate → 235 under future climate**

Difference:



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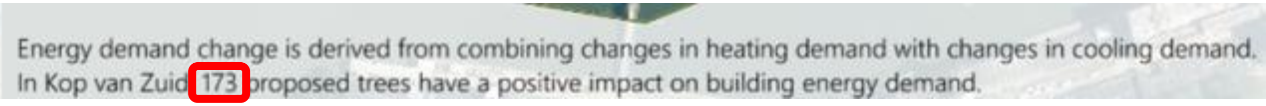

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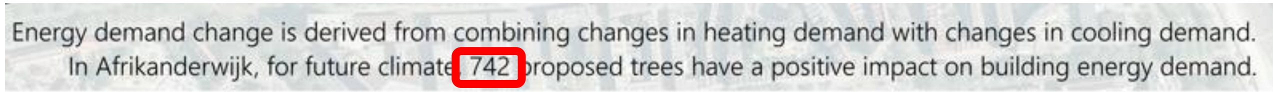

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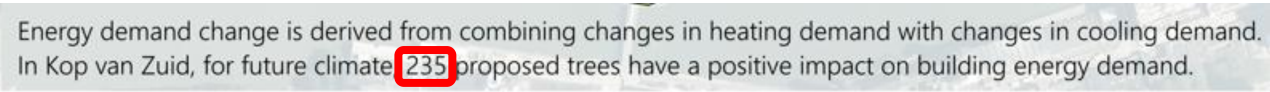

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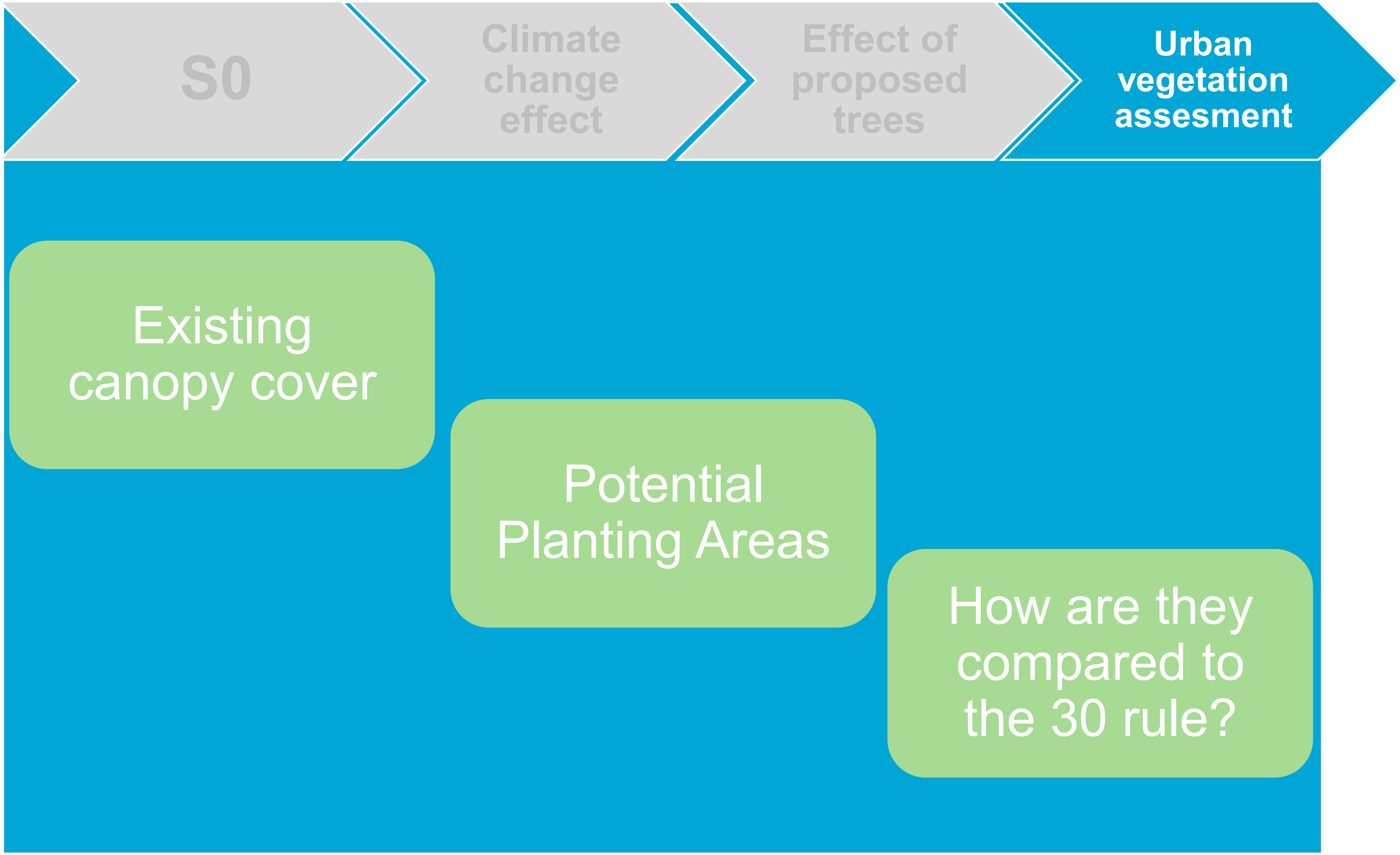
Afrikaanderwijk Beneficial trees: **945 under current climate → 742 under future climate**

Kop van Zuid Beneficial trees: **173 under current climate → 235 under future climate**

→ Climate warming changes the balance of tree energy benefits.
→ Local urban characteristics influence outcomes.



S0

Climate change effect

Effect of proposed trees

Urban vegetation assesment

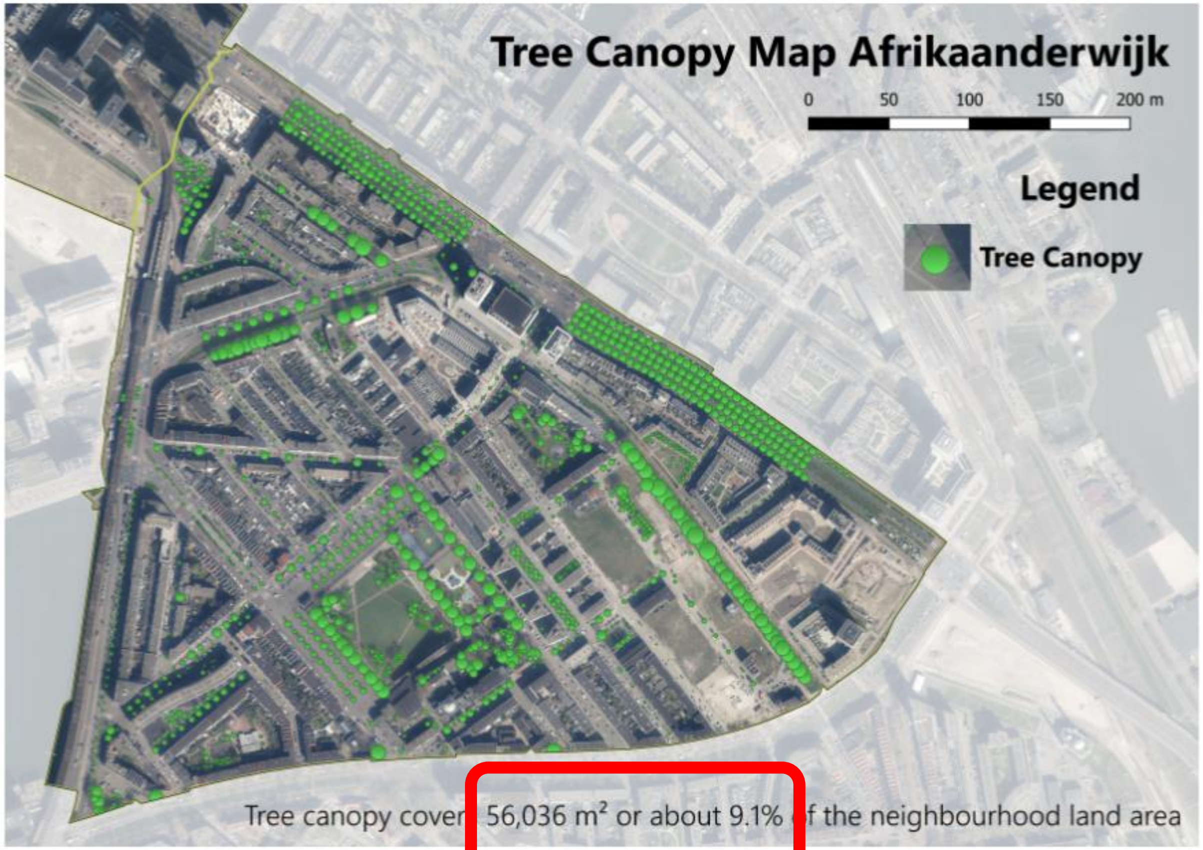
Existing canopy cover

Potential Planting Areas

How are they compared to the 30 rule?

Canopy cover maps

Tree canopy cove s 11,218 m^2 or about 4.3% f the neighbourhood land area



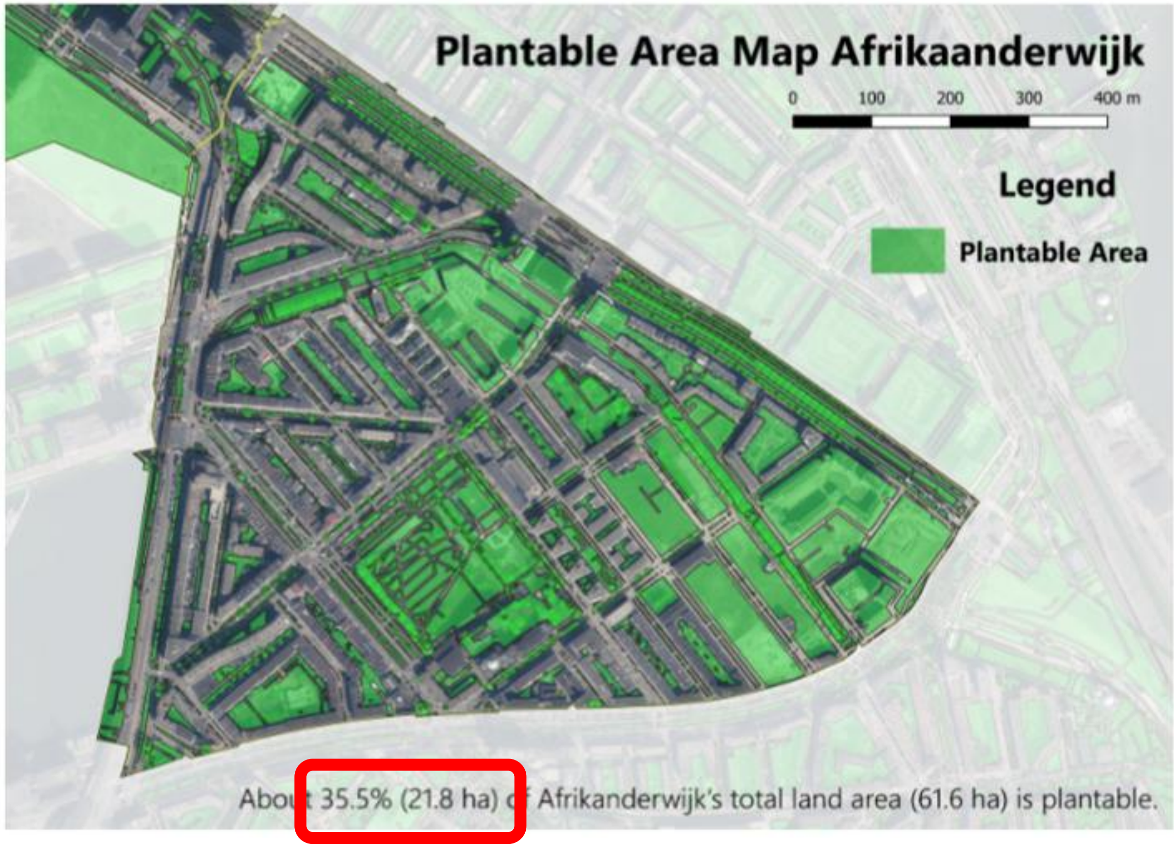
Tree canopy cover 56,036 m^2 or about 9.1% f the neighbourhood land area

Existing canopy cover far less than 30% canopy target.

GDPR COMPLIANCE → ROTTERDAM 3DCM ONLY CONTAINS PUBLIC TREES

Trees not represented near 📍 Christiaan de Wetstraat and 📍 De la Reystraat, Afrikaanderwijk

Potential planting area maps



About 35.5% (21.8 ha) of Afrikanderwijk's total land area (61.6 ha) is plantable.

About 45% (11.8 ha) of Kop van Zuid's total land area (26.1 ha) is plantable.

Potential planting areas exceed the 30% canopy target.

Effectiveness of Proposed Tree Planting Strategies

Energy demand change is derived from combining changes in heating demand with changes in cooling demand.
In Afrikanderwijk, 945 proposed trees have a positive impact on building energy demand.

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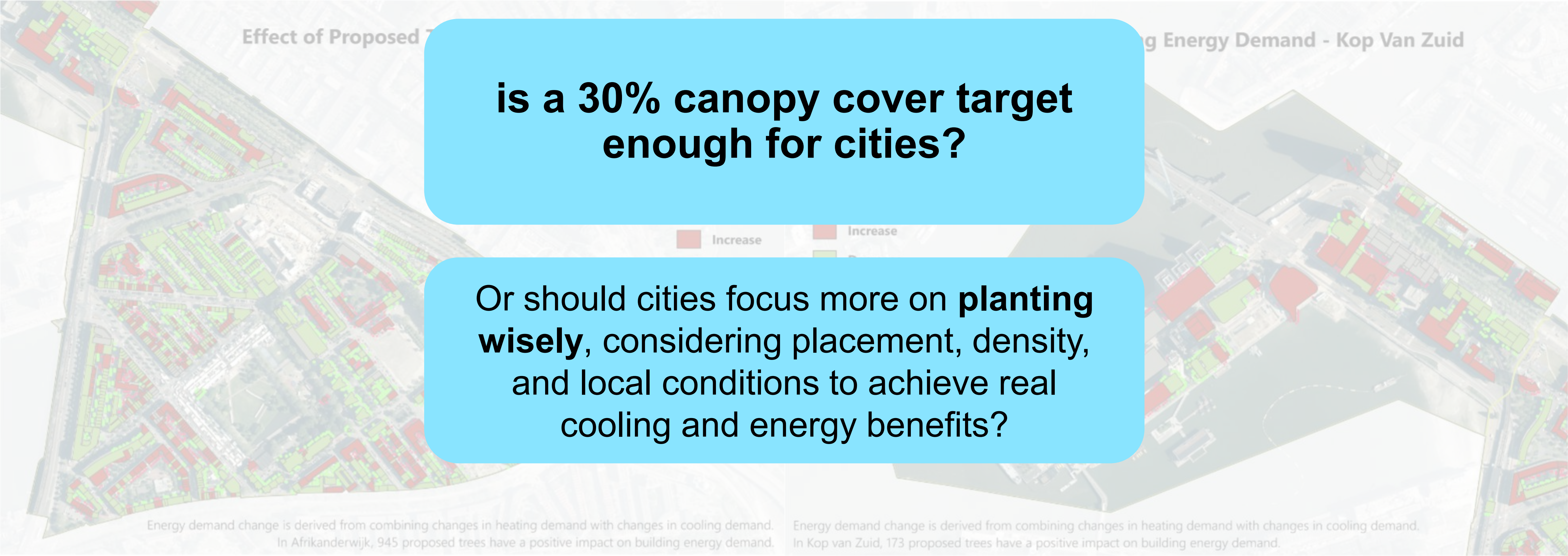
is a 30% canopy cover target enough for cities?

Effectiveness of Proposed Tree Planting Strategies



Energy demand change is derived from combining changes in heating demand with changes in cooling demand. In Afrikanderwijk, 945 proposed trees have a positive impact on building energy demand.

Energy demand change is derived from combining changes in heating demand with changes in cooling demand. In Kop van Zuid, 173 proposed trees have a positive impact on building energy demand.

is a 30% canopy cover target enough for cities?

Or should cities focus more on **planting wisely**, considering placement, density, and local conditions to achieve real cooling and energy benefits?

05

Conclusion

Research Questions & Objectives

How can tree planting scenarios, as nature-based strategies, be integrated into neighbourhood-scale simulation-based UBEM to evaluate their effectiveness in reducing heating and cooling demand under projected 2050 climate conditions?

SRQ1

Method to integrate spatial tree data into UBEM workflows to quantify neighbourhood-scale energy impacts.

SRQ2

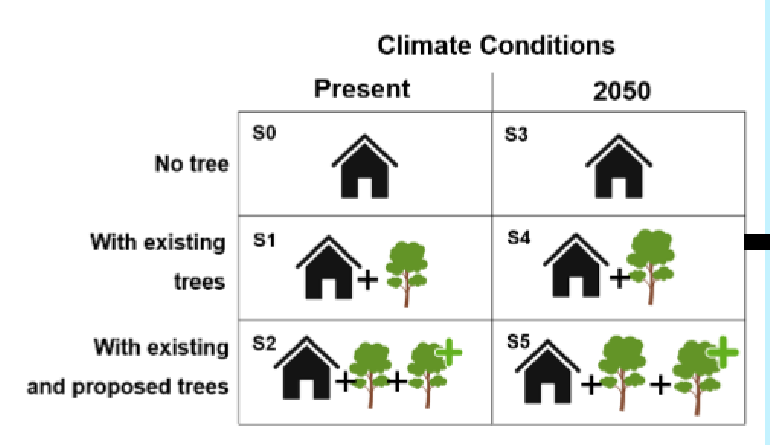
A set of modelling assumptions and simplifications for representing tree shading under varying climates

SRQ3

Framework for interpreting simulation results to guide urban planning and climate adaptation decisions.

Research Questions & Objectives

How can tree planting scenarios, as nature-based strategies, be integrated into neighbourhood-scale simulation-based UBEM to evaluate their effectiveness in reducing heating and cooling demand under projected 2050 climate conditions?



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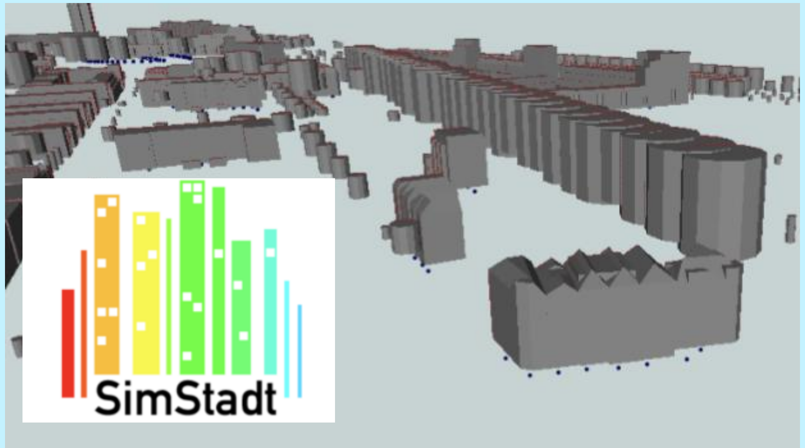

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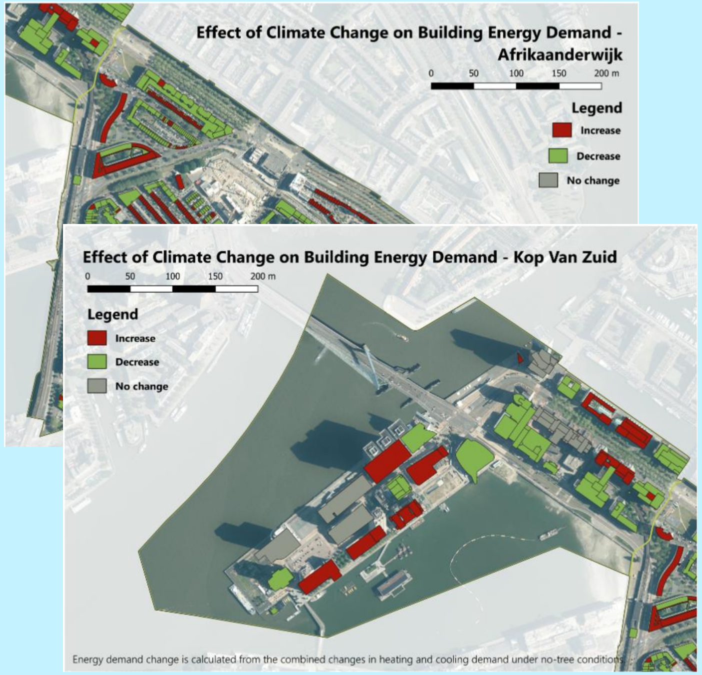


Limitations

The climate data had limited temporal resolution, as monthly inputs were used

The building energy model relied on the **DIN V 18599 standard** with monthly energy balances and predefined archetypes, which may not fully reflect local practices

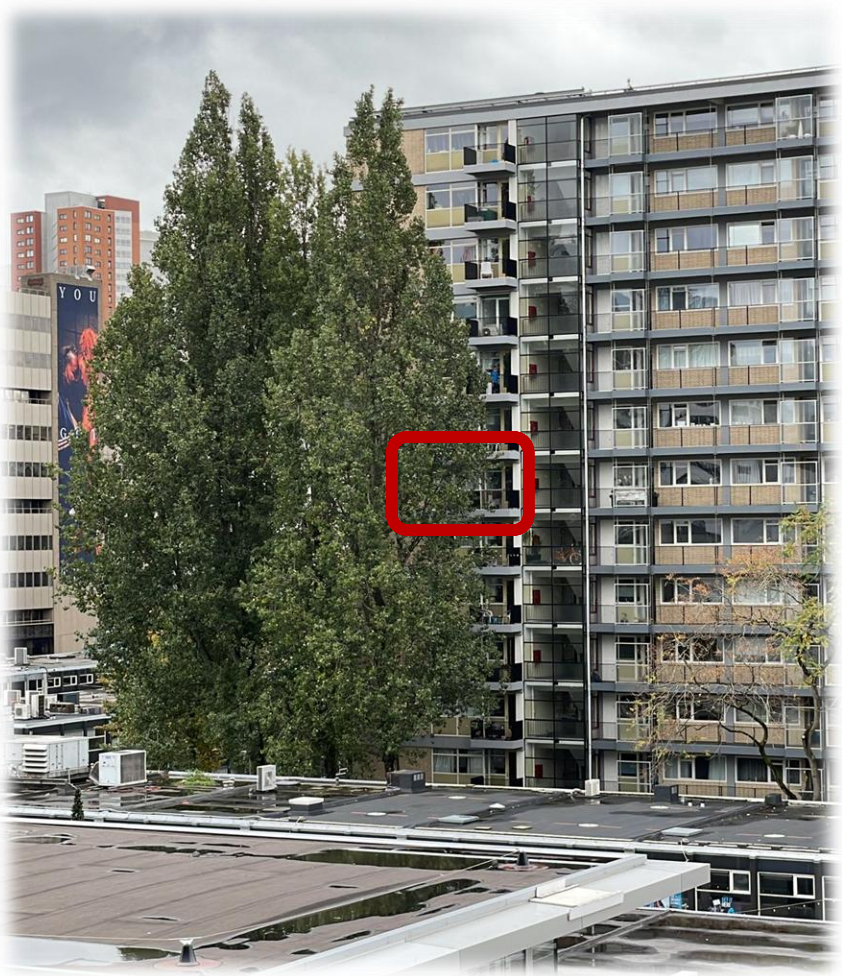
Vegetation was simplified by modelling trees as static cylinders with fixed seasonal factors and generic species assumptions, thereby oversimplifying shading and cooling effects

Limitations

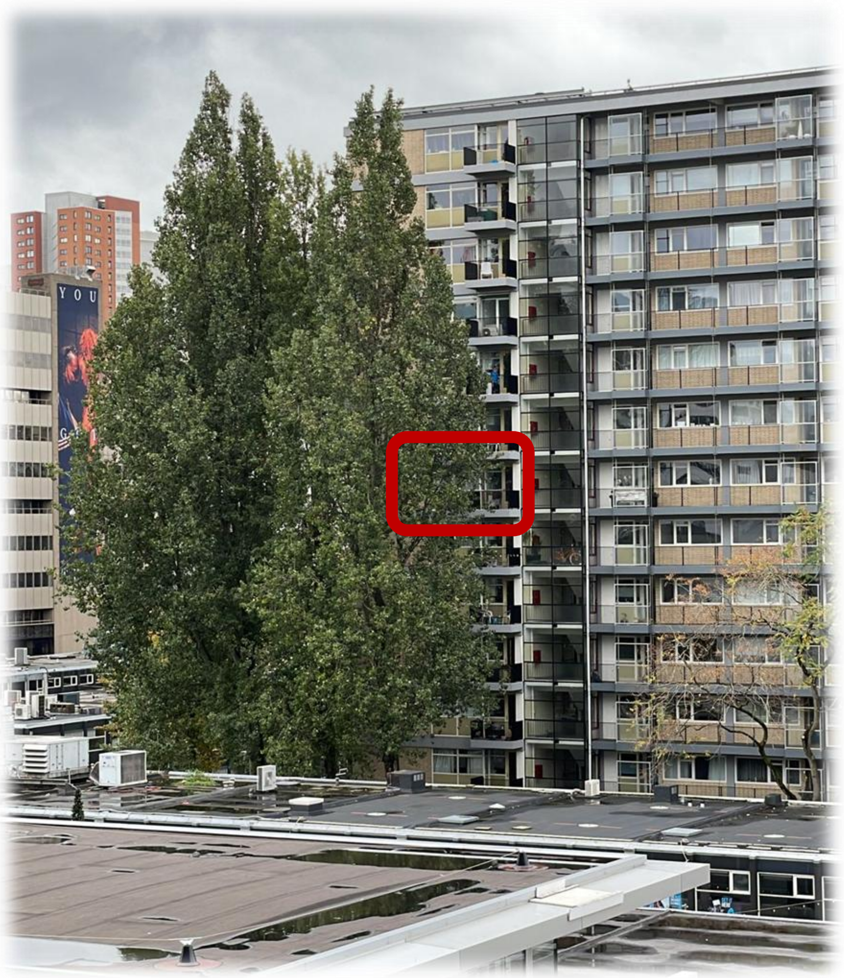
Due to **computational limitations**, the analysis was limited to two neighbourhoods, preventing the exploration of additional urban typologies and densities and limiting applicability to other urban forms.

Finally, **the modelling framework assumed a static building stock** over time, without accounting for future retrofitting, insulation upgrades, or system replacements.

Still remember this apartment unit???

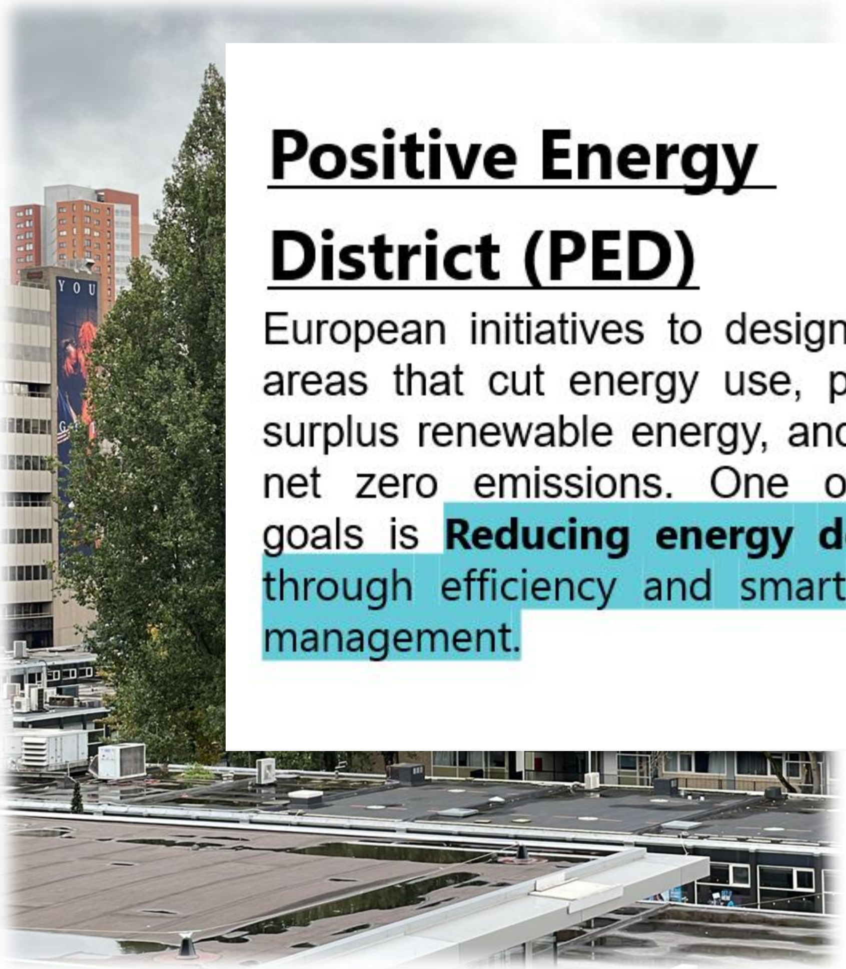


Still remember this apartment unit???



It’s probably a good idea to think about how planting **new trees** might affect energy use before deciding to plant them.

Still remember this apartment unit???



Positive Energy District (PED)

European initiatives to design urban areas that cut energy use, produce surplus renewable energy, and reach net zero emissions. One of PED goals is **Reducing energy demand** through efficiency and smart urban management.

URBAN EUROPE

Home > Positive Energy Districts (PED)

Source: JPI Urban Europe. (n.d.). *Positive Energy Districts (PED)*. Retrieved September 19, 2025, from https://jpi-urbaneurope.eu/ped/

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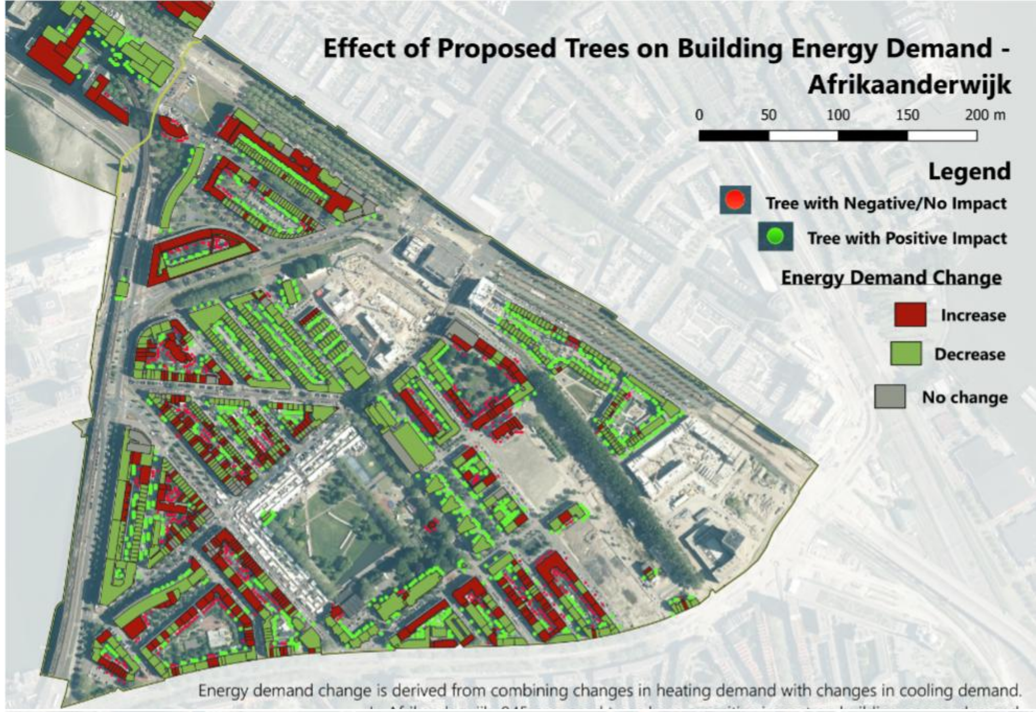
Conclusion

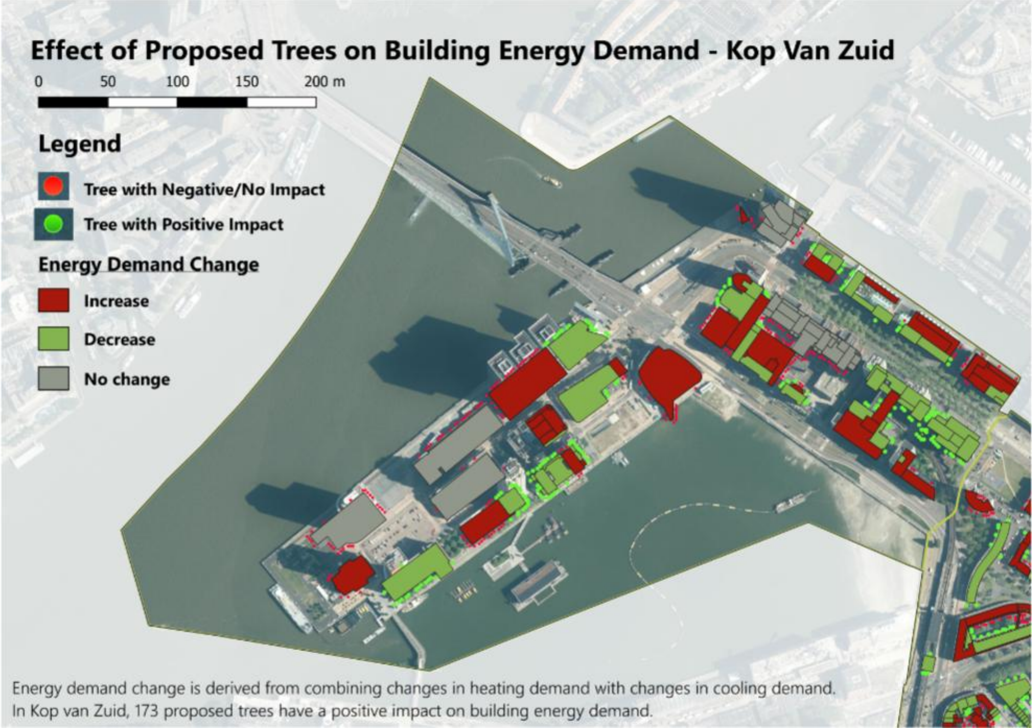
The study demonstrates that **energy-aware and site-specific tree planting** can effectively reduce cooling demand and contribute to urban climate adaptation.

TU Delft



Effect of Proposed Trees on Building Energy Demand - Afrikaanderwijk

Energy demand change is derived from combining changes in heating demand with changes in cooling demand.

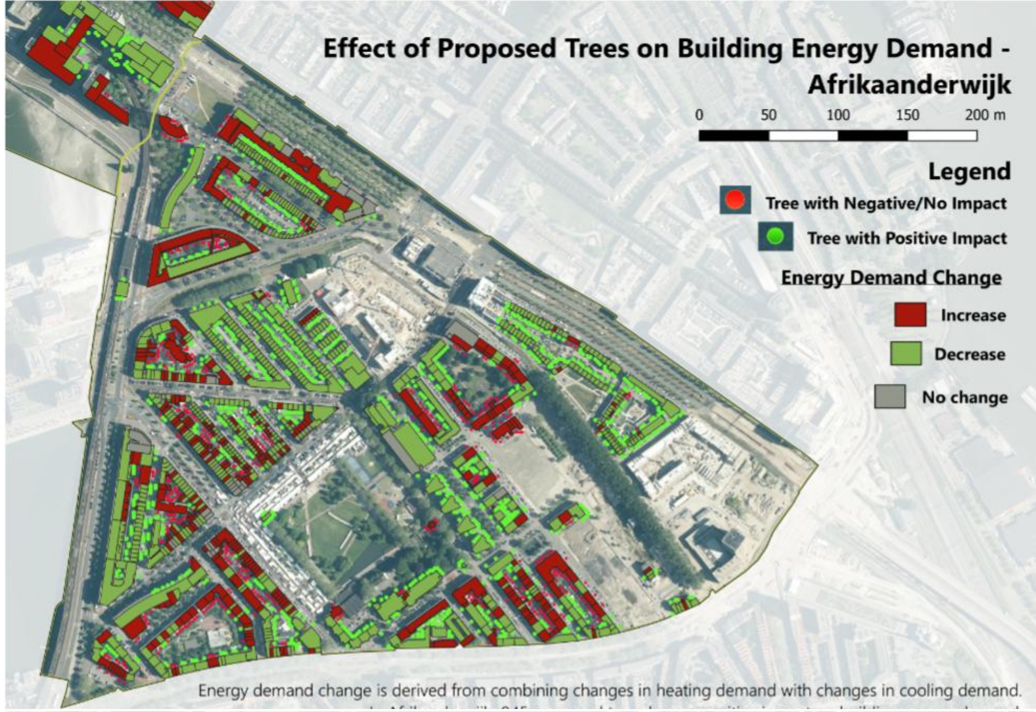


Effect of Proposed Trees on Building Energy Demand - Kop Van Zuid

Energy demand change is derived from combining changes in heating demand with changes in cooling demand.
In Kop van Zuid, 173 proposed trees have a positive impact on building energy demand.

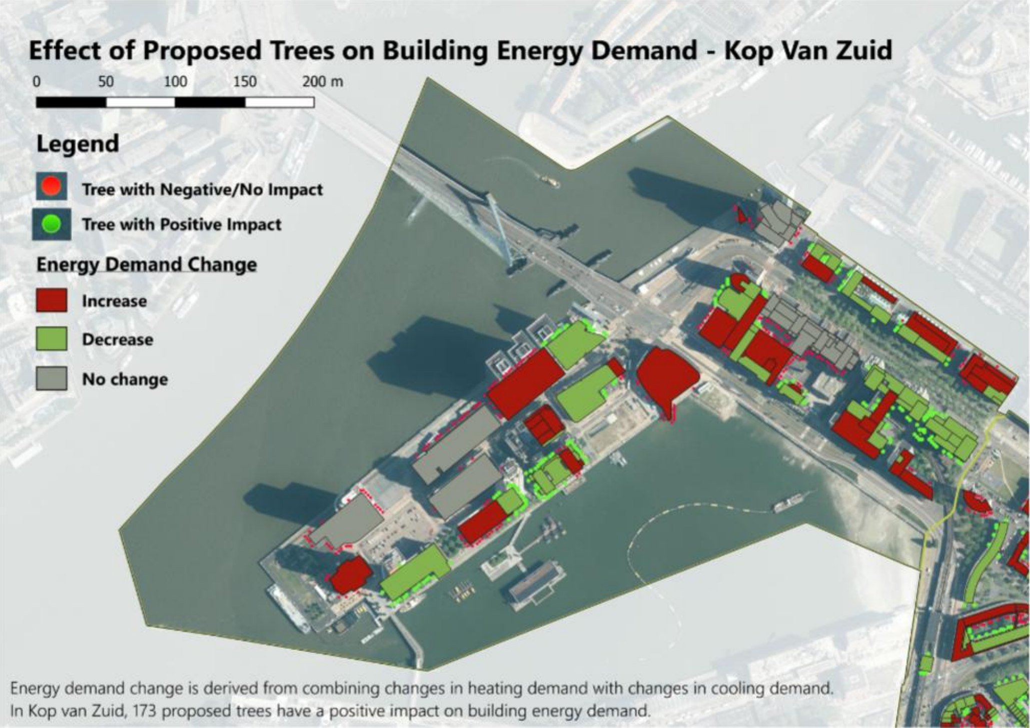
Conclusion

The study demonstrates that **energy-aware and site-specific tree planting** can effectively reduce cooling demand and contribute to urban climate adaptation.
However, **uniform canopy targets** are less effective, as the benefits of trees depend on **local conditions, building layout, and seasonal shading effects**.



Effect of Proposed Trees on Building Energy Demand - Afrikaanderwijk

Energy demand change is derived from combining changes in heating demand with changes in cooling demand.



Effect of Proposed Trees on Building Energy Demand - Kop Van Zuid

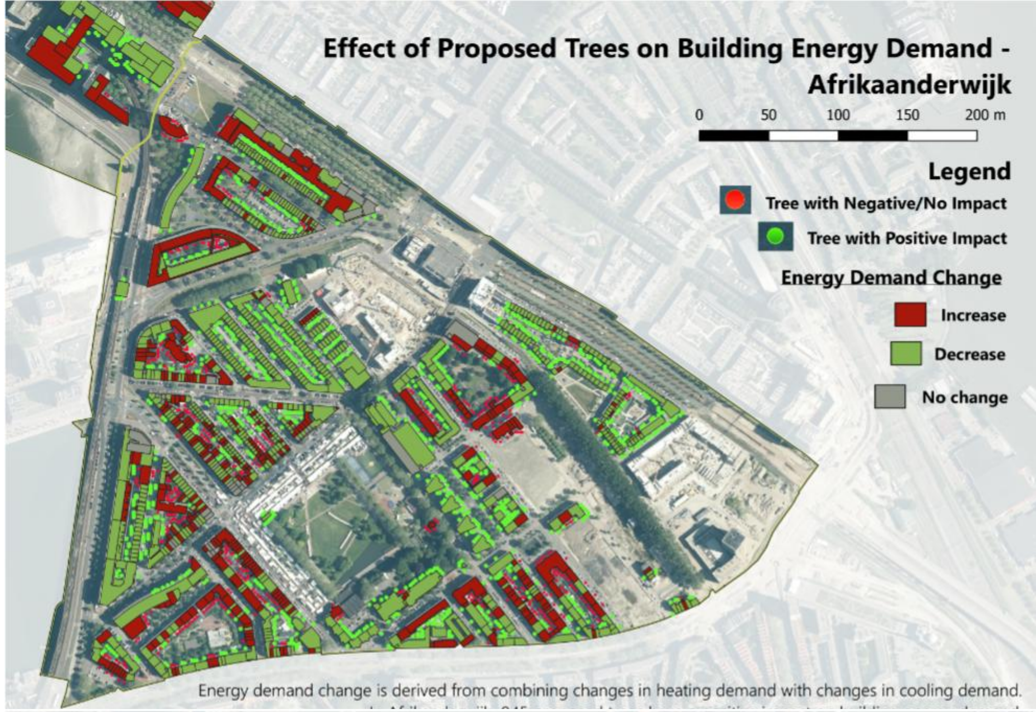
Energy demand change is derived from combining changes in heating demand with changes in cooling demand.
In Kop van Zuid, 173 proposed trees have a positive impact on building energy demand.

Conclusion

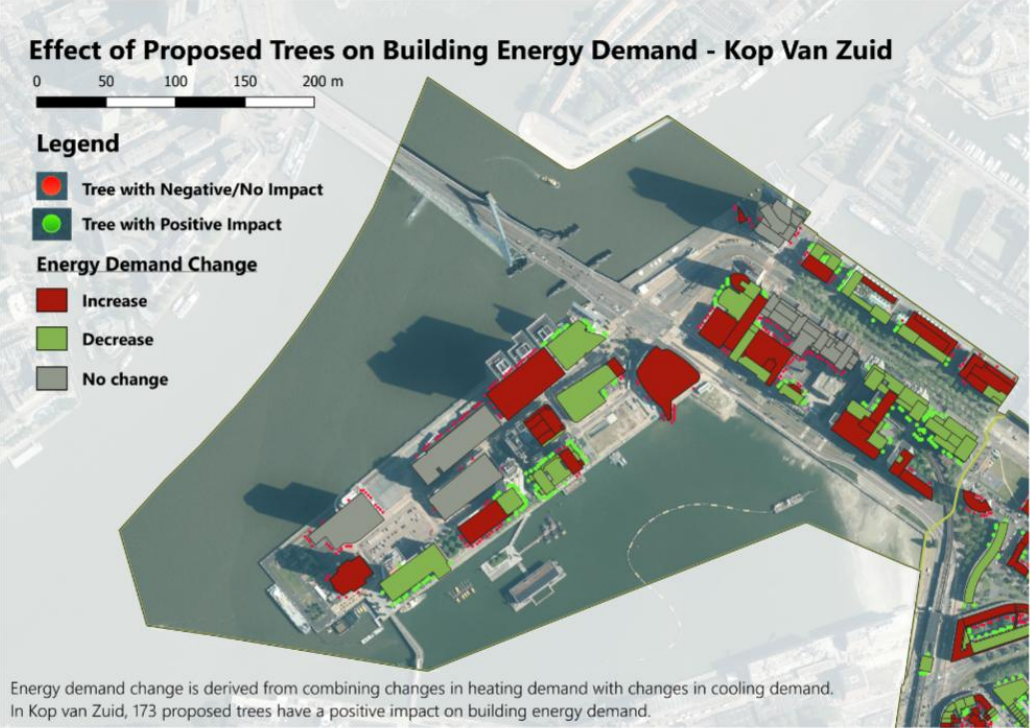
The study demonstrates that **energy-aware and site-specific tree planting** can effectively reduce cooling demand and contribute to urban climate adaptation.

However, **uniform canopy targets** are less effective, as the benefits of trees depend on **local conditions, building layout, and seasonal shading effects**.

Therefore, cities should aim not just to plant more trees, but to **plant wisely** — in the right places and for the right purposes.

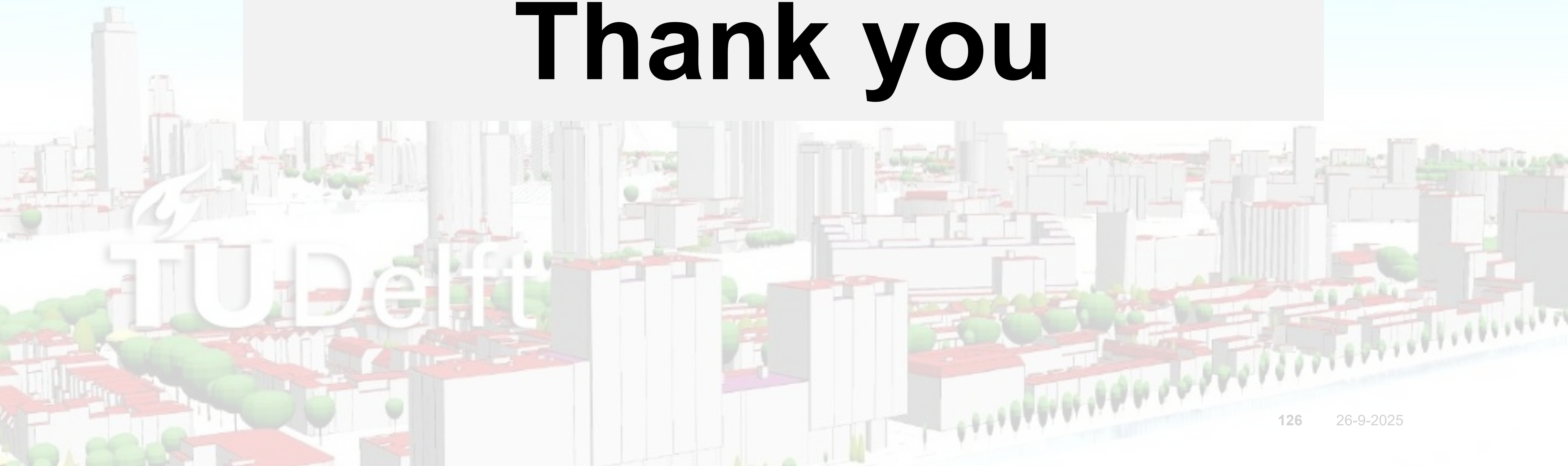


Energy demand change is derived from combining changes in heating demand with changes in cooling demand.

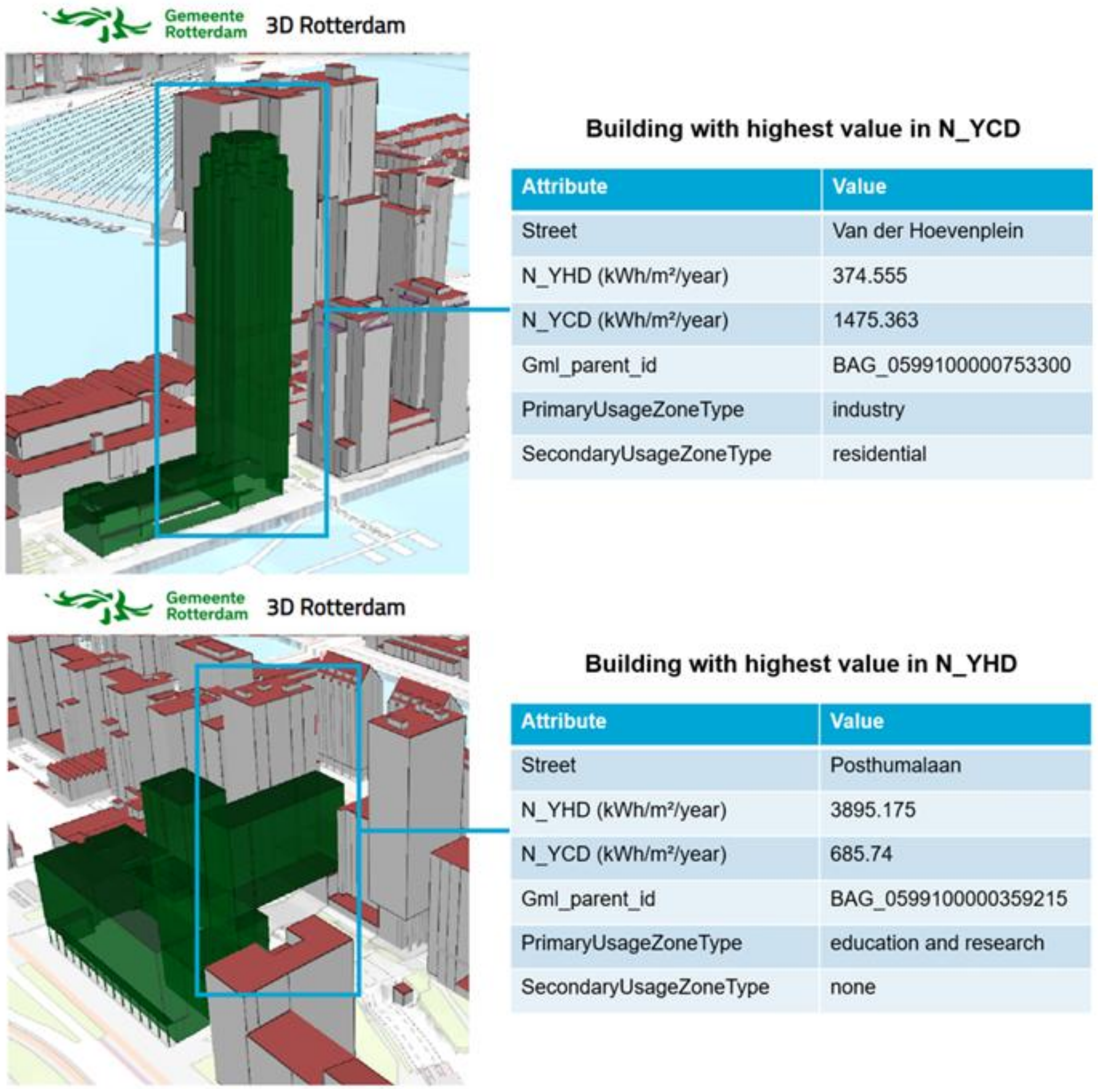


Energy demand change is derived from combining changes in heating demand with changes in cooling demand.
In Kop van Zuid, 173 proposed trees have a positive impact on building energy demand.

Thank you



Additional Analysis



Building with highest value in N_YCD

Attribute	Value
Street	Van der Hoevenplein
N_YHD (kWh/m²/year)	374.555
N_YCD (kWh/m²/year)	1475.363
Gml_parent_id	BAG_0599100000753300
PrimaryUsageZoneType	industry
SecondaryUsageZoneType	residential

Building with highest value in N_YHD

Attribute	Value
Street	Posthumalaan
N_YHD (kWh/m²/year)	3895.175
N_YCD (kWh/m²/year)	685.74
Gml_parent_id	BAG_0599100000359215
PrimaryUsageZoneType	education and research
SecondaryUsageZoneType	none

Figure 5.1.: Buildings with the highest simulated cooling (top) and heating (bottom) demand in Kop van Zuid.

Tree effects on neighbourhood under current climate

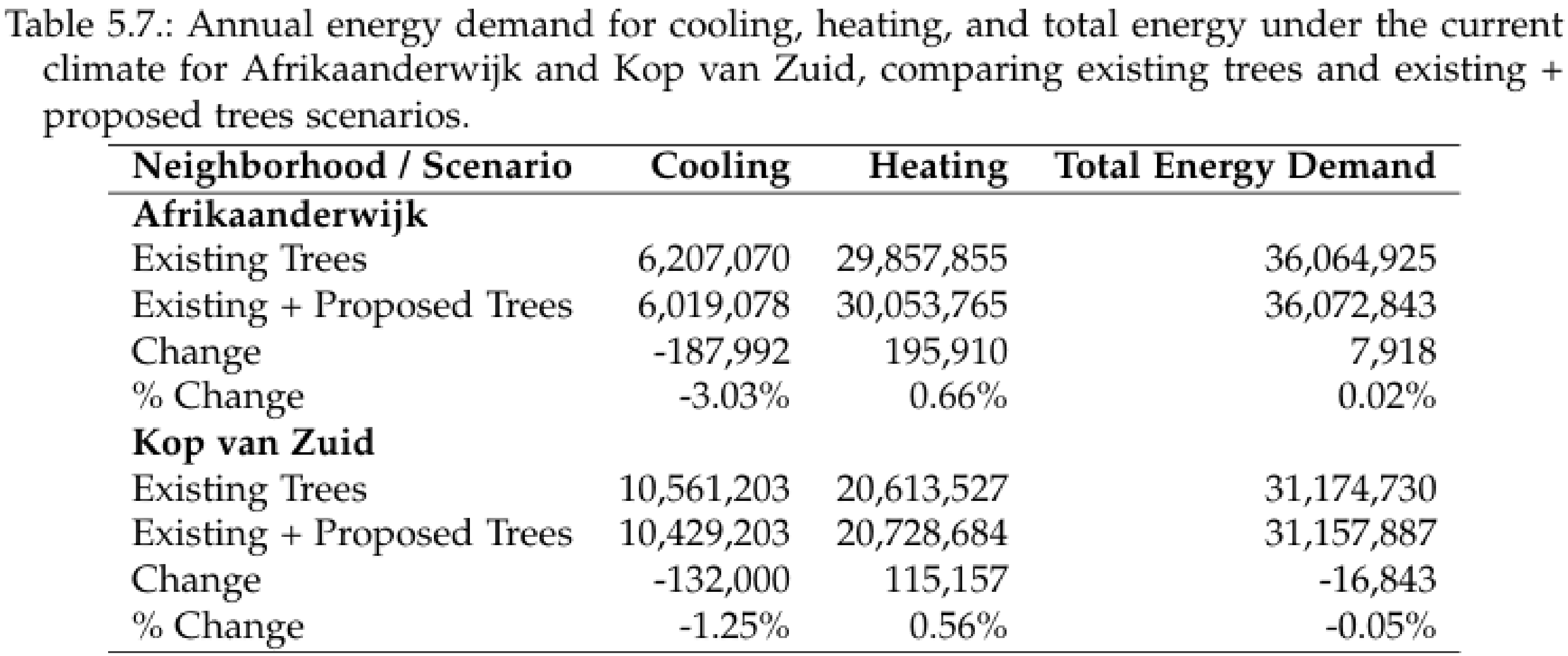


Table 5.7.: Annual energy demand for cooling, heating, and total energy under the current climate for Afrikaanderwijk and Kop van Zuid, comparing existing trees and existing + proposed trees scenarios.

Neighborhood / Scenario	**Cooling**	**Heating**	**Total Energy Demand**
Afrikaanderwijk			
Existing Trees	6,207,070	29,857,855	36,064,925
Existing + Proposed Trees	6,019,078	30,053,765	36,072,843
Change	-187,992	195,910	7,918
% Change	-3.03%	0.66%	0.02%
Kop van Zuid			
Existing Trees	10,561,203	20,613,527	31,174,730
Existing + Proposed Trees	10,429,203	20,728,684	31,157,887
Change	-132,000	115,157	-16,843
% Change	-1.25%	0.56%	-0.05%

Tree effects on neighbourhood under future climate

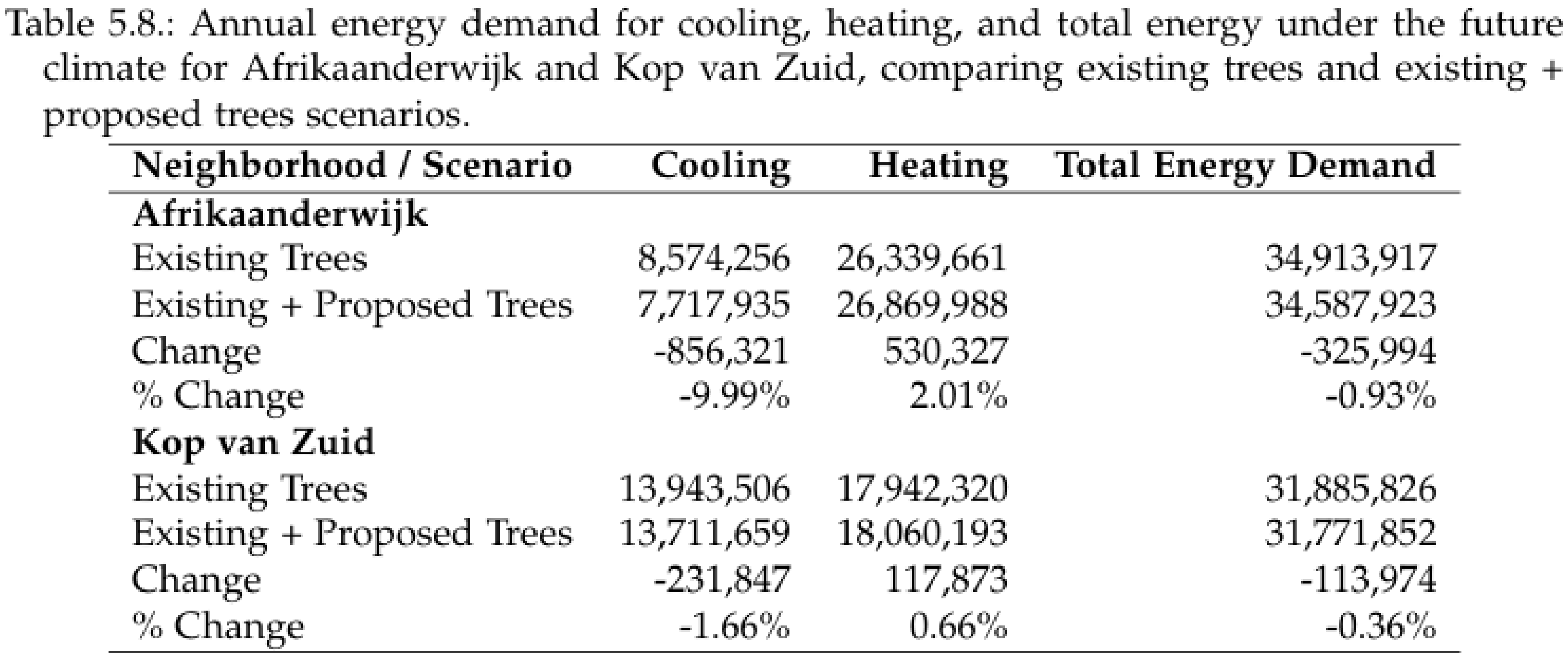


Table 5.8.: Annual energy demand for cooling, heating, and total energy under the future climate for Afrikaanderwijk and Kop van Zuid, comparing existing trees and existing + proposed trees scenarios.

Neighborhood / Scenario	**Cooling**	**Heating**	**Total Energy Demand**
Afrikaanderwijk			
Existing Trees	8,574,256	26,339,661	34,913,917
Existing + Proposed Trees	7,717,935	26,869,988	34,587,923
Change	-856,321	530,327	-325,994
% Change	-9.99%	2.01%	-0.93%
Kop van Zuid			
Existing Trees	13,943,506	17,942,320	31,885,826
Existing + Proposed Trees	13,711,659	18,060,193	31,771,852
Change	-231,847	117,873	-113,974
% Change	-1.66%	0.66%	-0.36%

Figure 5.16.: Highest net benefits building in Afrikaanderwijk

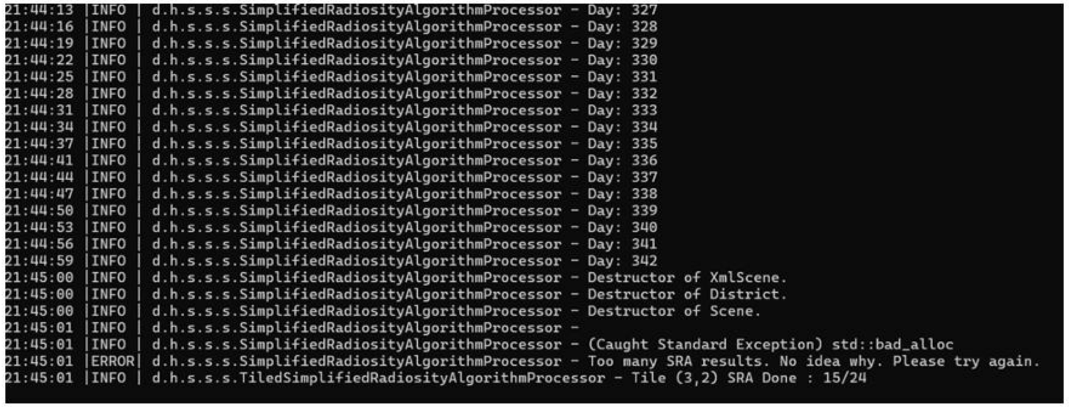
Figure 5.18.: Building with high cooling benefits but substantial heating penalties in Afrikaanderwijk

Figure 5.20.: Building heating penalties outweigh cooling benefits in Afrikaanderwijk.

Simulation runs

Table 4.10.: Simulation success for each neighbourhoods across scenarios. A tick (V) indicates successful completion; cells marked ’X’ indicate failed runs.

Neighbourhoods	**Today Trees (Summer)**	**Today Trees (Winter)**	**Proposed Trees (Summer)**	**Proposed Trees (Winter)**
Afrikaanderwijk	**V**	**V**	**V**	**V**
Bloemhof	V	V	X	X
Feijenoord	V	X	X	X
Hillesluis	**V**	**V**	**V**	**V**
Katendrecht	**V**	**V**	**V**	**V**
Kop van Zuid Entrepot	V	V	X	V
Kop van Zuid	**V**	**V**	**V**	**V**
Noordereiland	**V**	**V**	**V**	**V**
Vreewijk	V	X	X	V



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21:44:16 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Day: 328
21:44:19 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Day: 329
21:44:22 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Day: 330
21:44:25 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Day: 331
21:44:28 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Day: 332
21:44:31 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Day: 333
21:44:34 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Day: 334
21:44:37 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Day: 335
21:44:41 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Day: 336
21:44:44 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Day: 337
21:44:47 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Day: 338
21:44:50 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Day: 339
21:44:53 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Day: 340
21:44:56 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Day: 341
21:44:59 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Day: 342
21:45:00 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Destructor of XmlScene.
21:45:00 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Destructor of District.
21:45:00 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Destructor of Scene.
21:45:01 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor -
21:45:01 |INFO | d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - (Caught Standard Exception) std::bad_alloc
21:45:01 |ERROR| d.h.s.s.s.SimplifiedRadiosityAlgorithmProcessor - Too many SRA results. No idea why. Please try again.
21:45:01 |INFO | d.h.s.s.s.TiledSimplifiedRadiosityAlgorithmProcessor - Tile (3,2) SRA Done : 15/24
```

Figure 4.12.: Example of a memory allocation error (std::bad_alloc) encountered during the simulation.