From thermal comfort to heat mitigation action

Informed Strategies for Mitigating PET Heat Stress in Public Spaces for Vulnerable Groups
– A Rotterdam Case Study

MSc Thesis Urbanism and Geomatics
Marieke van Esch

P5 17th of April 2024

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Prologue

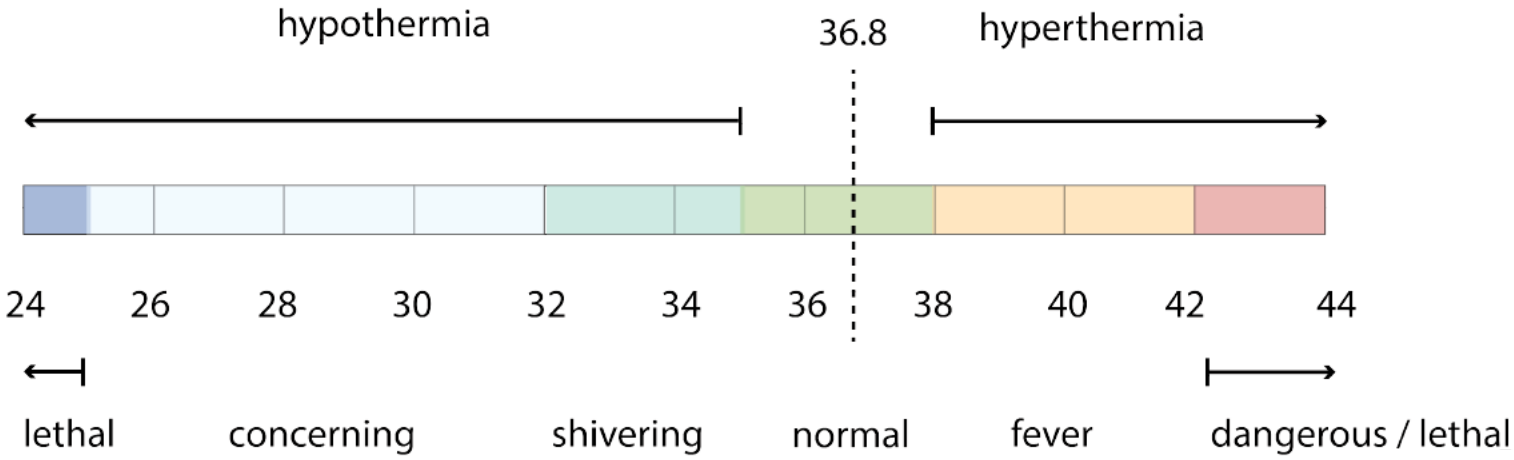
Spain braced for record April temperature of 39C as extreme heat causes misery

Government warns people to take precautions amid drought and heat 7C-11C above average for time of year

A woman gives water from a fountain to her dog in Seville as Spain experiences unseasonal temperatures. Photograph: Jorge Guerrero/AFP/Getty Images

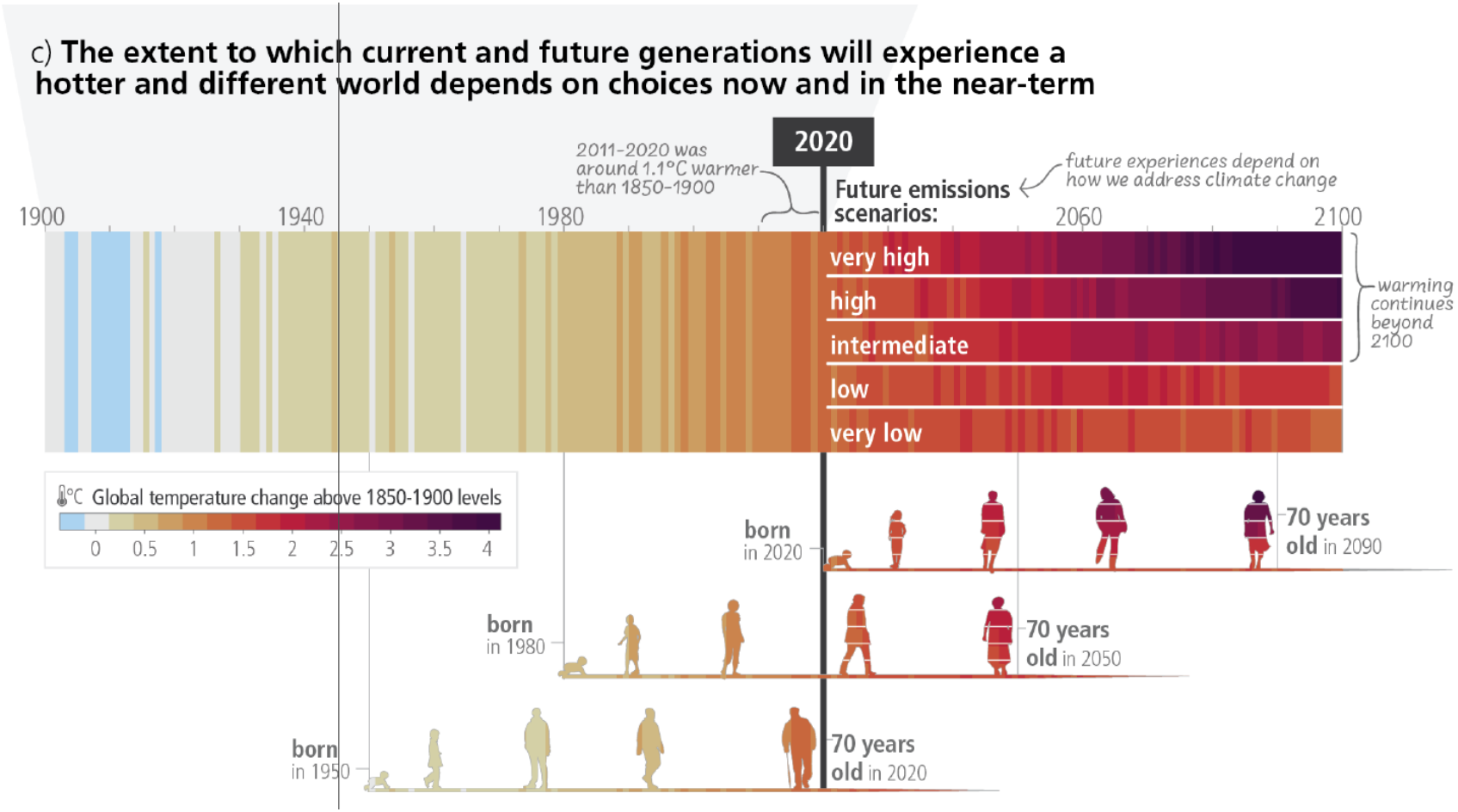
fig. x https://www.theguardian.com/world/2023/apr/27/spain-braced-for-record-april-temperature-of-

Health jeopardised



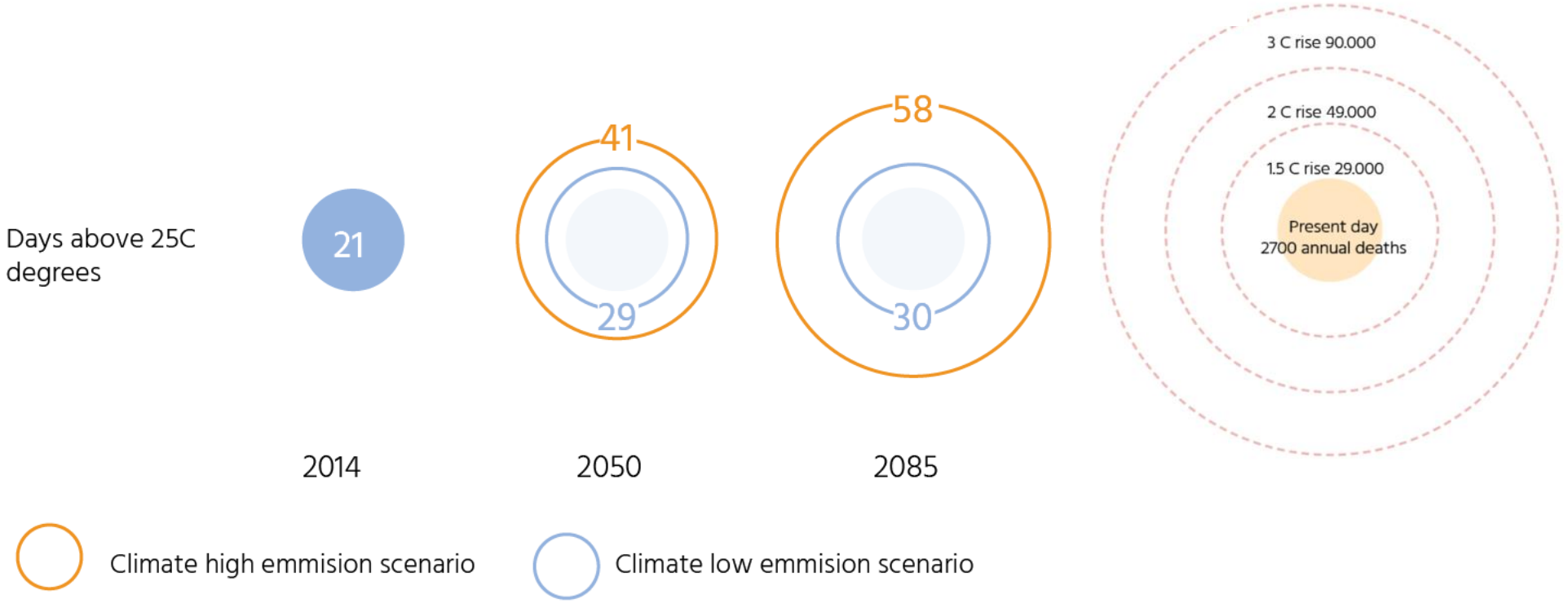
(Martin et al., 2017)

Climate change



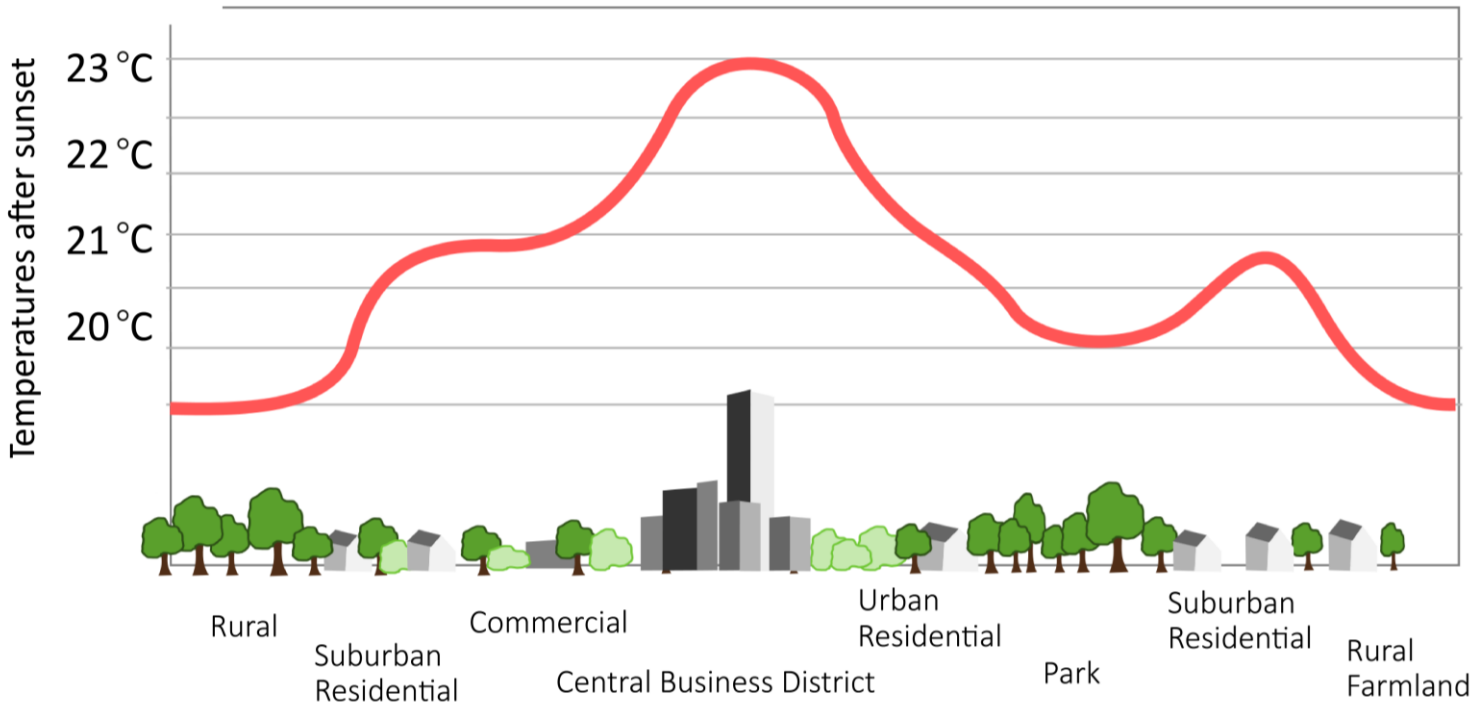
IPCC retrieved from https://www.ipcc.ch/report/ar6/syr/figures/summary-for-policymakers/figure-spm-1 port/ar6/syr/figures/summary-for-policymakers/figure-spm-1

Increase of summer days…



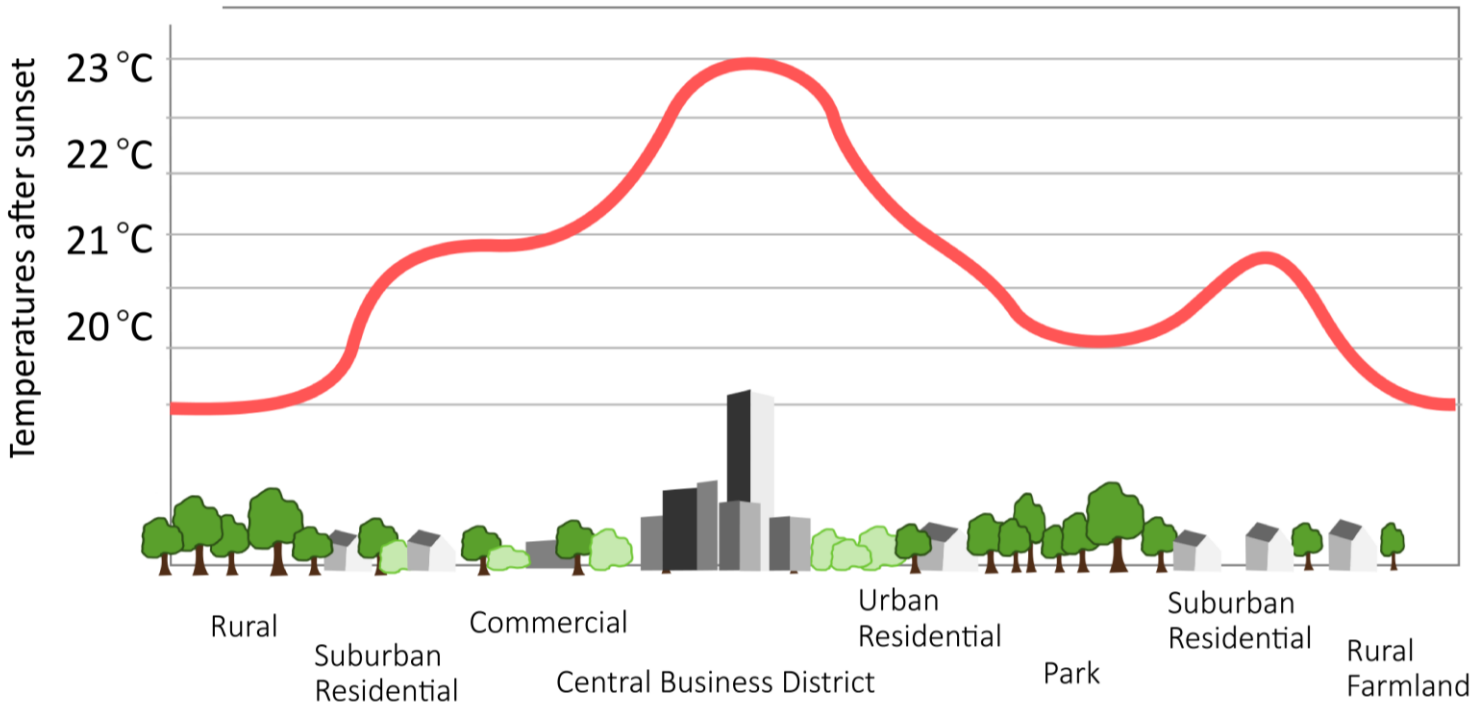
(KNMI, 2014)

Urban morphology and heat



https://www.metlink.org/fieldwork-resource/urban-heat-island-introduction/

Urban morphology and heat



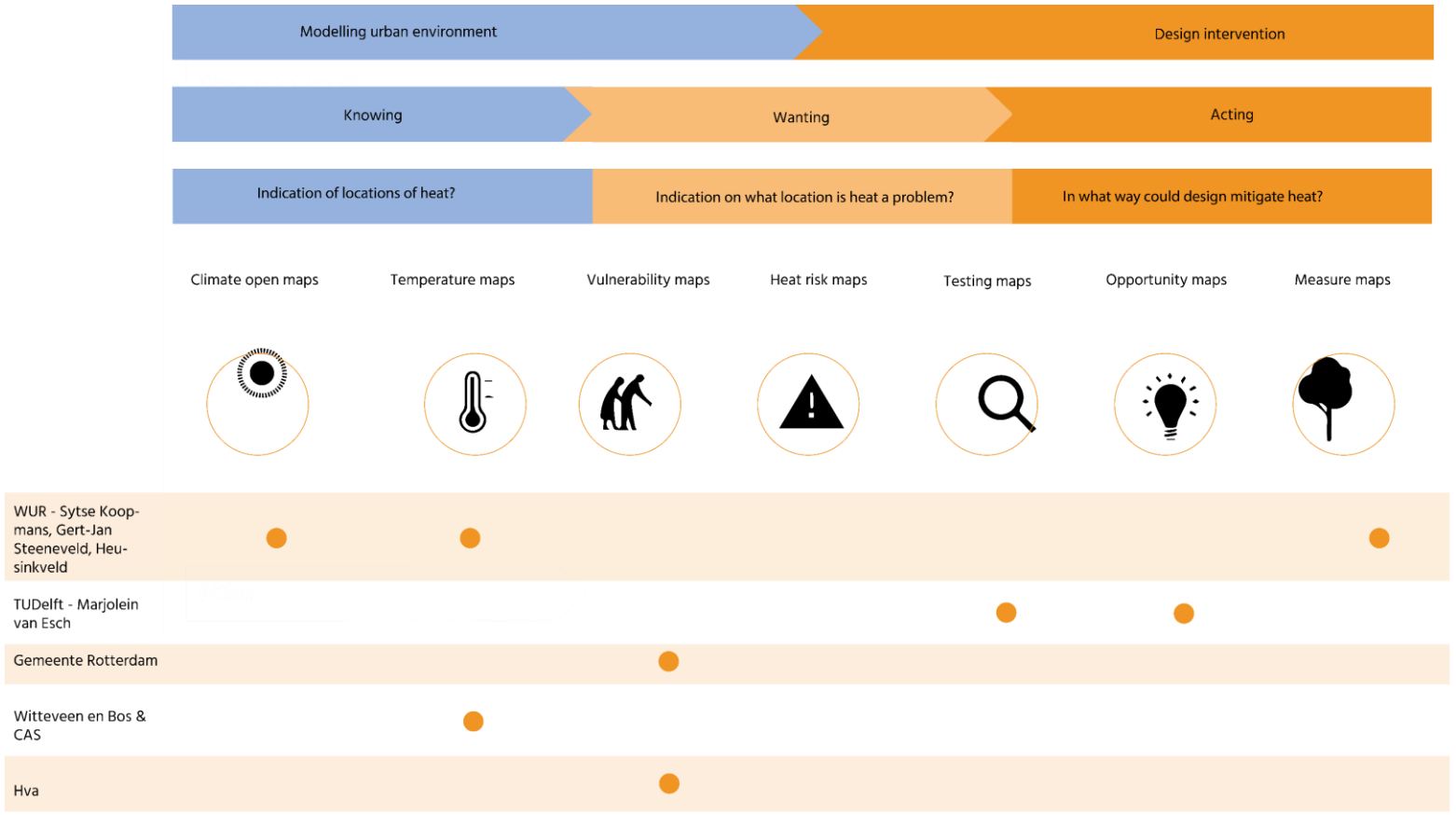
55% > 68%

Of the world population will live in cities in 2085

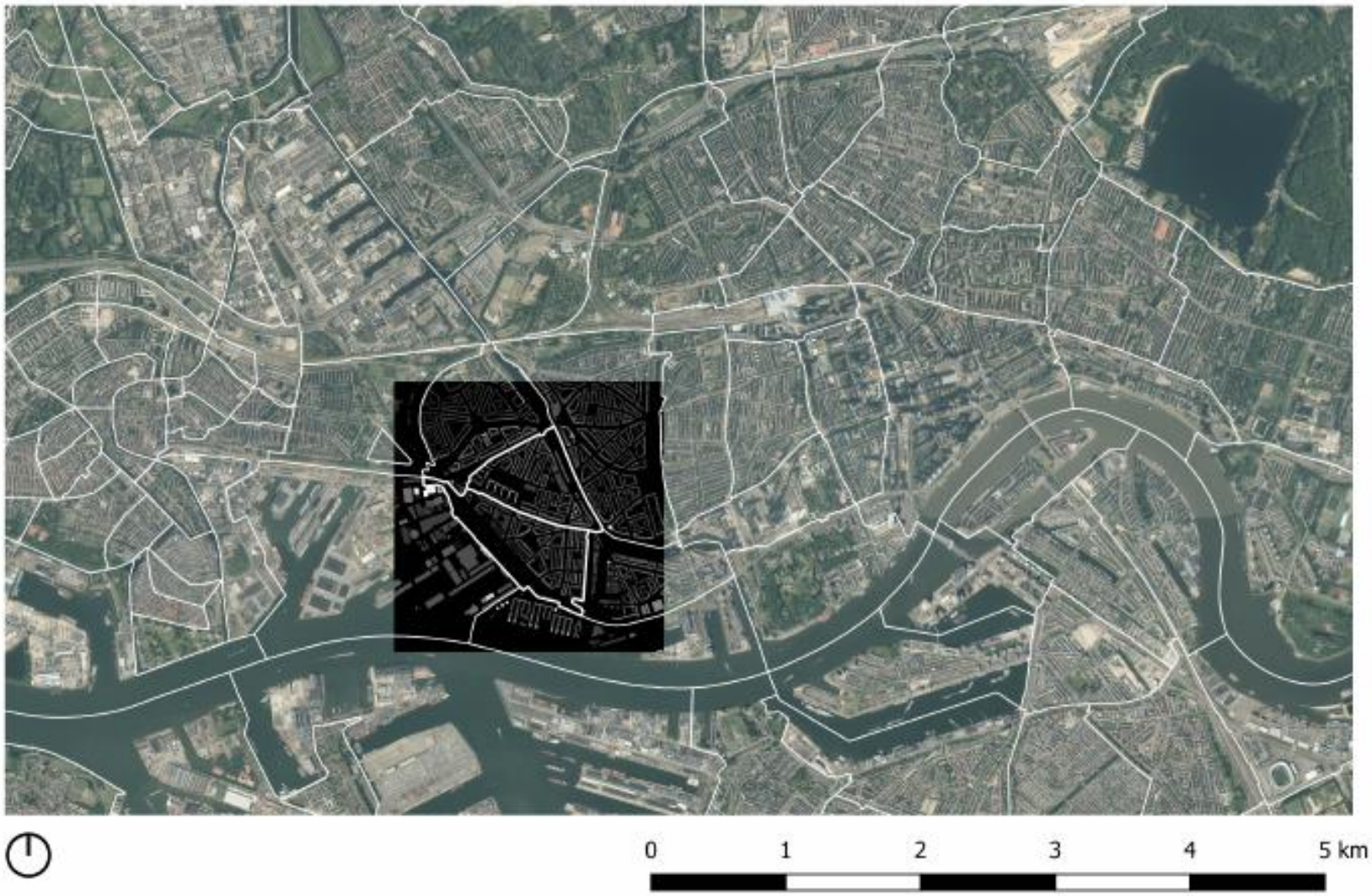
Source: United Nations, 2018

https://www.metlink.org/fieldwork-resource/urban-heat-island-introduction/

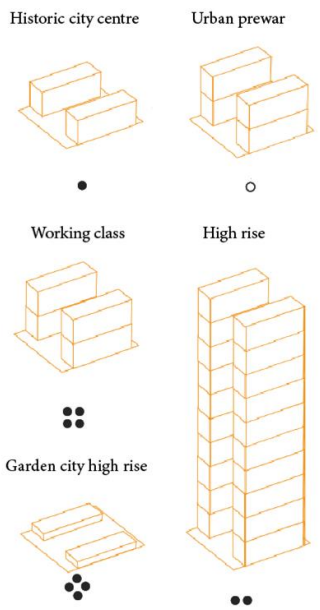
Stakeholders and current heat mitigation

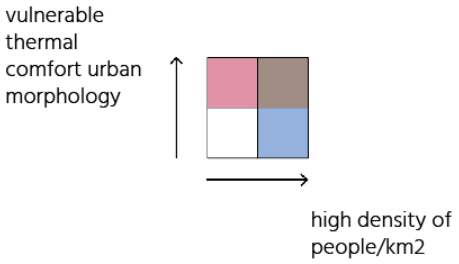


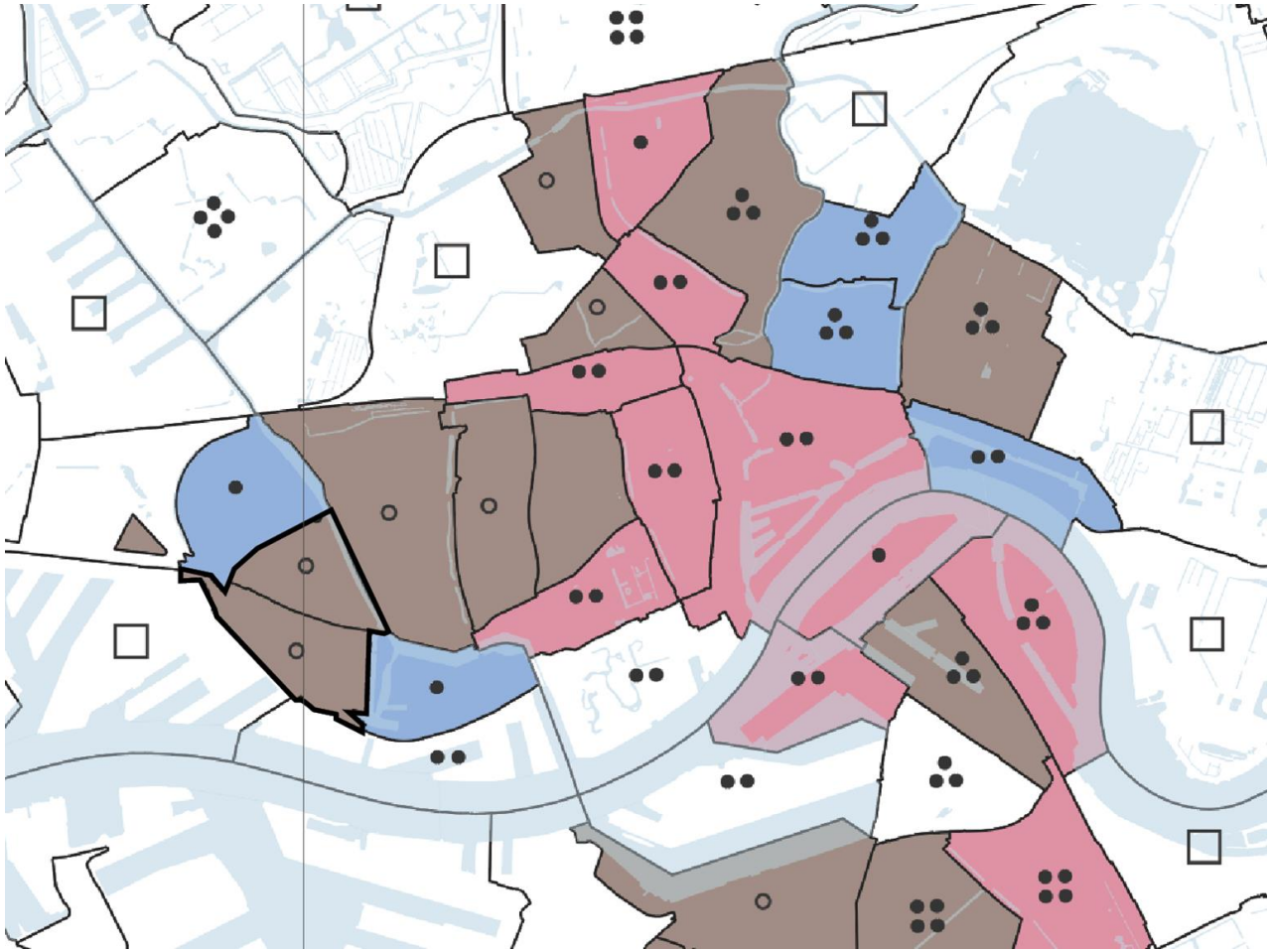
Context Bospolder Tussendijken



Case study: Bospolder Tussendijken







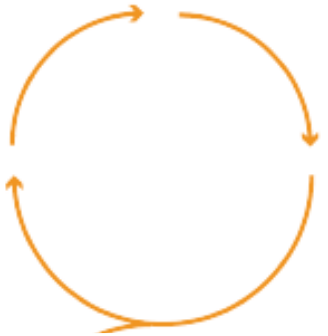
Problem statement

''Rotterdam with its urban morphology is vulnerable to high temperatures and this influences the daily life of its inhabitants, now and increasingly in the future"

Structure

- Introduction
- Research aim
- Methodology
- Analysis & synthesis
- Design
- Conclusion
- Reflection

Geomatics
PART 1:
Thermal comfort



Urbanism
PART 2:
Requirements urban design

Research gap

1) Lack of an open reproducible tool for modelling thermal comfort

2) Strategy missing for intervening in public space in urban areas

Research aim

1) Lack of an open reproducible tool for modelling thermal comfort

2) Strategy Approach missing for intervening in public space in urban areas

1) Creating a reproducible tool for modelling thermal comfort

2) Strategy for intervening in public space for vulnerable target groups

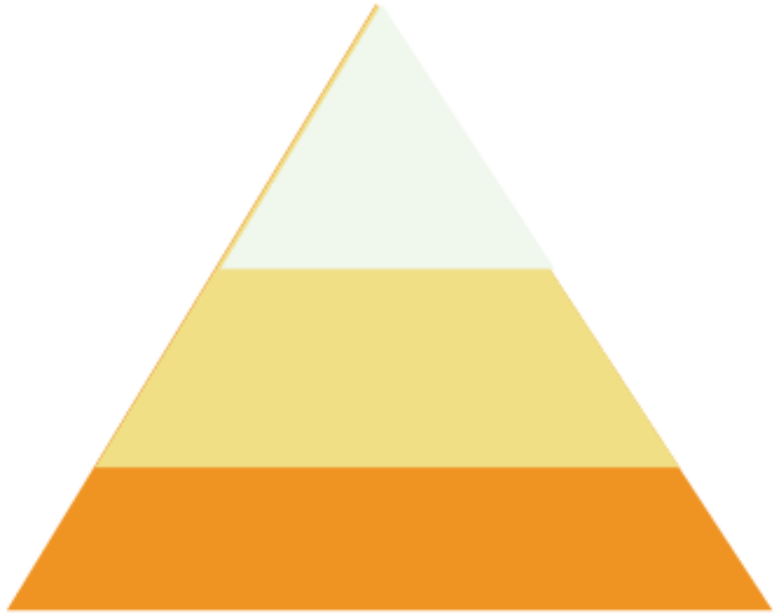
Research question

(a) *""To what extent could a reproducible tool help with identifying spatial-temporality of heat stress through PET in urban environments and test design interventions?"*

(b) *"How can a strategy be developed for mitigating heat stress through Physiological Equivalent Temperature model while ensuring a liveable environment for vulnerable groups in Bospolder Tussendijken, Rotterdam, the Netherlands?""*

Theoretical framework

Maslow pyramid:
universal needs of humans
(Maslow, 1943)



Self-actualisation

Esteem

Social belongness

Safety

Physiological needs

Experience

Comfort

Safety

Temperature rise

Liveability?

- Physical liveability (environment)
- Social liveability (amenities, social structures)
- Safety liveability

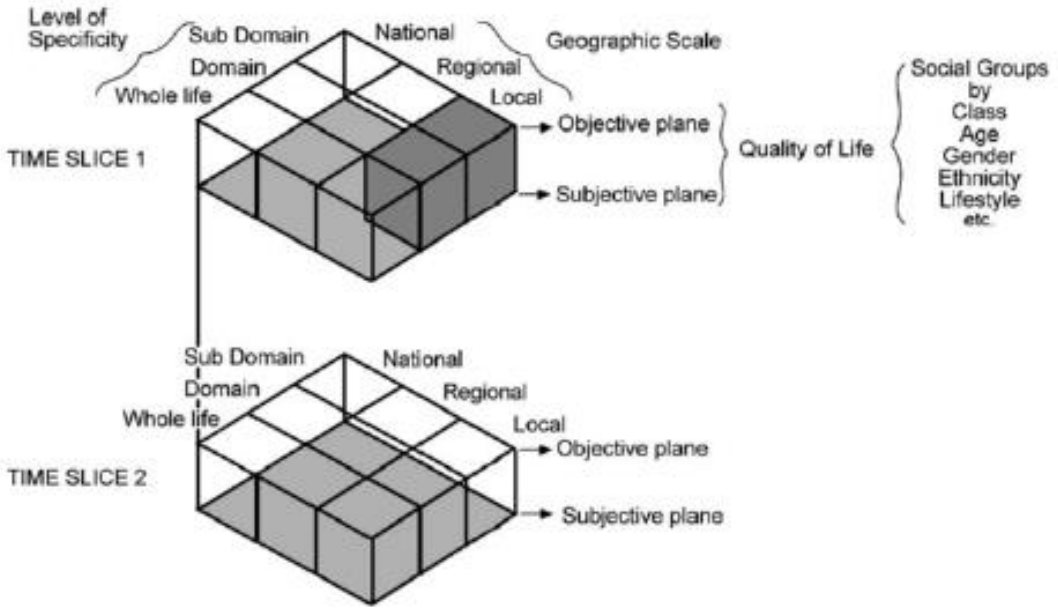


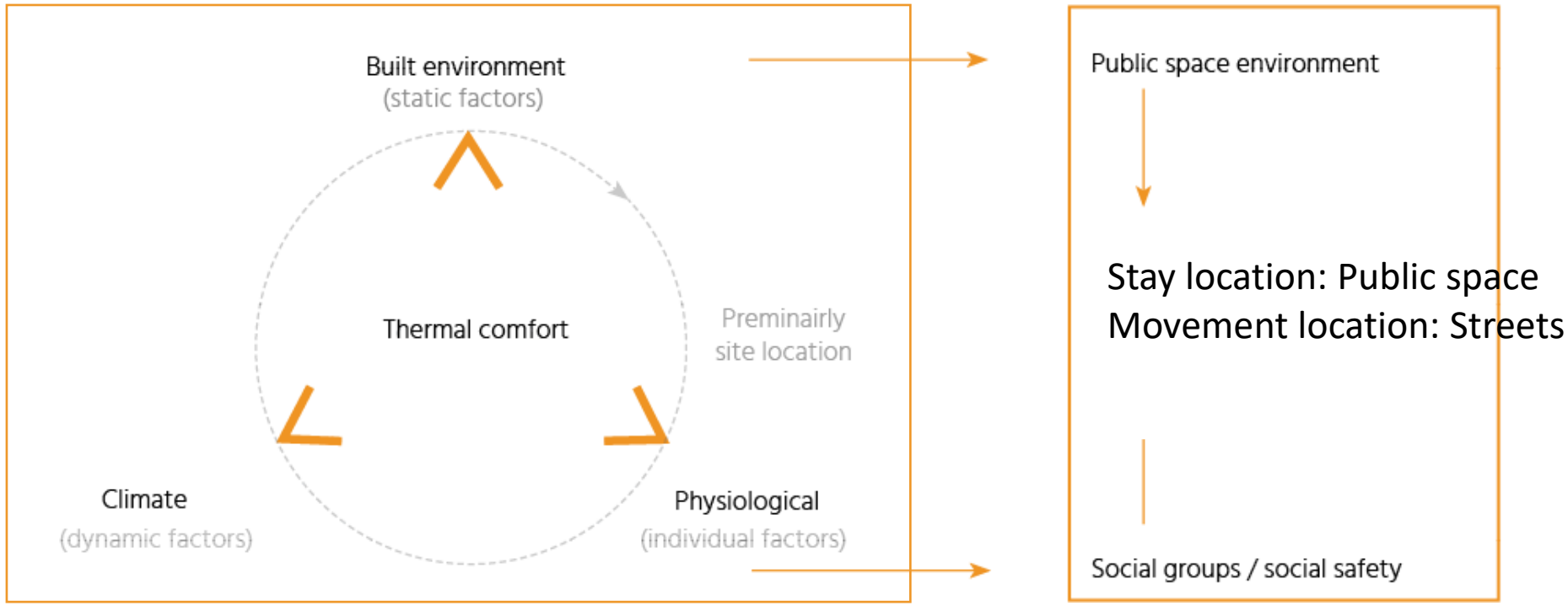
Fig. 2.9 A five-dimensional structure for quality of life research (fig. 1, Pacione, 2013)

Conceptual framework

Liveability =

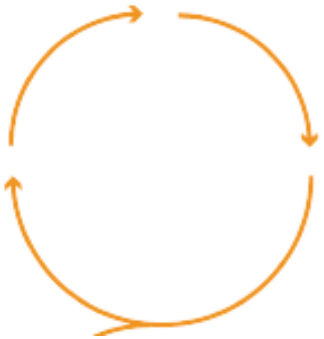
Physical liveability

Social liveability



Methodology

Geomatics
PART 1:
Modelling
thermal comfort



Urbanism
PART 2:
Urban design

Methodology

Geomatics
PART 1:
Modelling
thermal comfort

Urbanism
PART 2:
Urban design

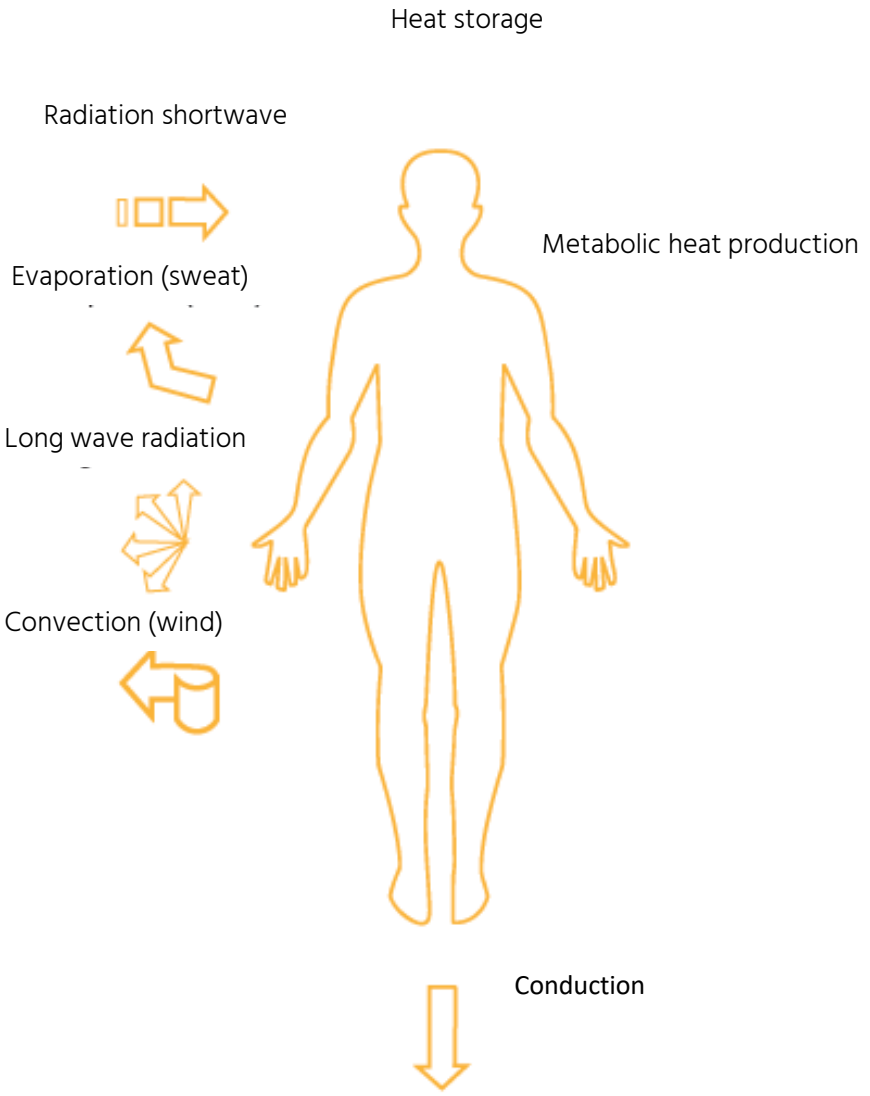
- Heat stress models
- Heat stress software
- Heat stress requirements
- Heat stress application

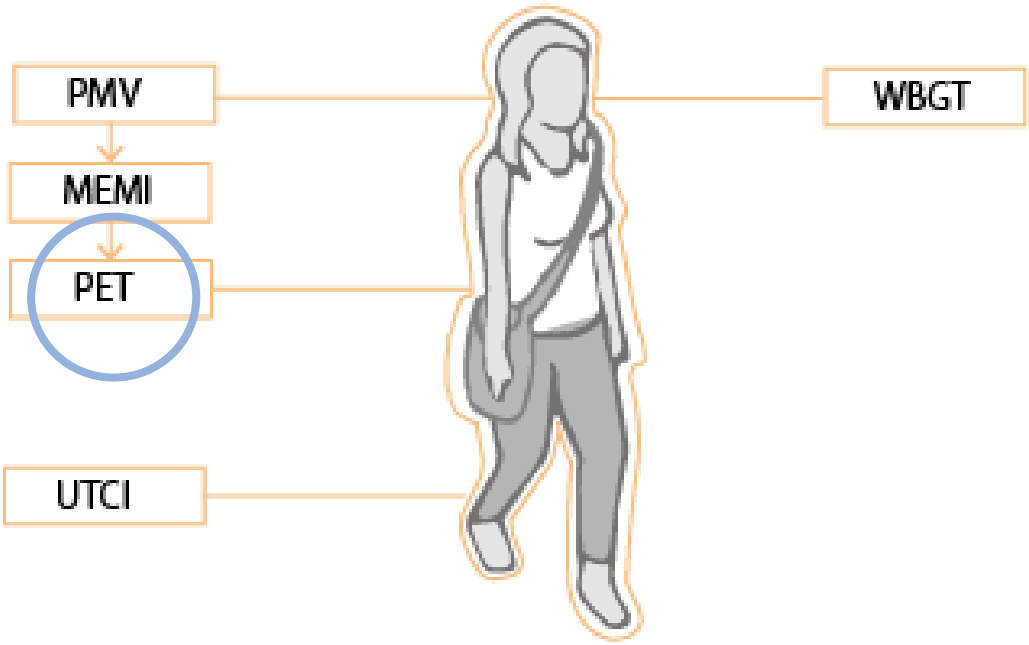
- Liveability conditions
- Analysis liveability
- Strategy & design
- **PART 3:** Assessment design
  Conclusion & future work

PART 1: Geomatics, Analysis & Synthesis

1. What kind of models and software do exist?
2. What is the evaluation of the reproducibility PET model?
3. What is the evaluation of the reproducibility PET simulator?

Modelling Thermal comfort





Modelling Thermal comfort - Physiological Equivalent Temperature (PET)

PET	Thermal perception	Grade of physiological stress
<4	Very cold	Extreme cold stress
4-8	Cold	Strong cold stress
8-13	Cool	Moderate cold stress
13-18	Slightly cool	Slight cold stress
18-23	Thermal comfortable	**No thermal stress**
23-29	Slightly warm	**Slight thermal stress**
29-35	Warm	**Moderate heat stress**
35-41	Hot	**Strong heat stress**
>41	Very hot	**Extreme heat stress**

Physical environment and climate factors

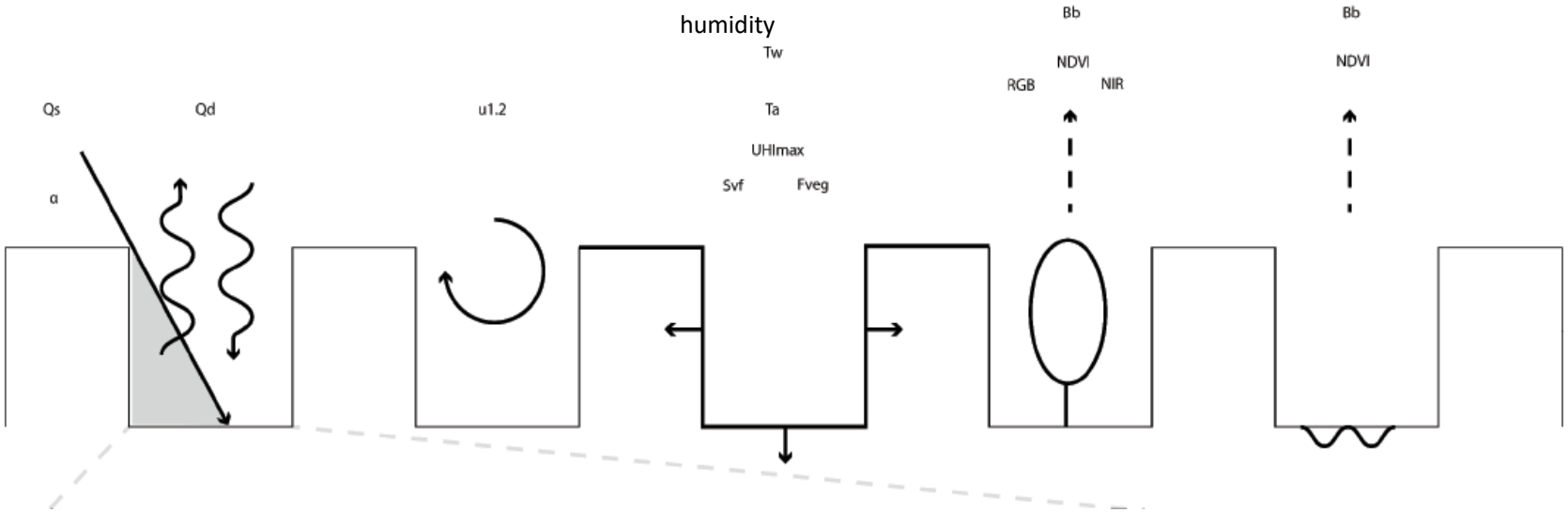
Radiation
Shortwave
Longwave

Wind

Urban
morphology
temperature

humidity

Landscaping elements



PET calculation

$$PET_{sun} = -13.26 + 1.25T_a + 0.011Q_s - 3.37ln(u_{1.2}) + 0.078T_w + 0.005Q_s \ln(u_{1.2})5.56sin(\phi) - 0.0103Q_s \ln(u_1.2)\sin(\phi) + 0.0546B_b + 1.94S_{vf} \quad (1)$$

$$PET_{shade,night} = -12.14 + 1.25T_a - 1.47 \ln(u_{1.2} + 0.060T_w + 0.015S_{vf}Q_d + 0.0060(1 - S_{vf})\sigma(T_a + 273.14)^4 \quad (2)$$

where:

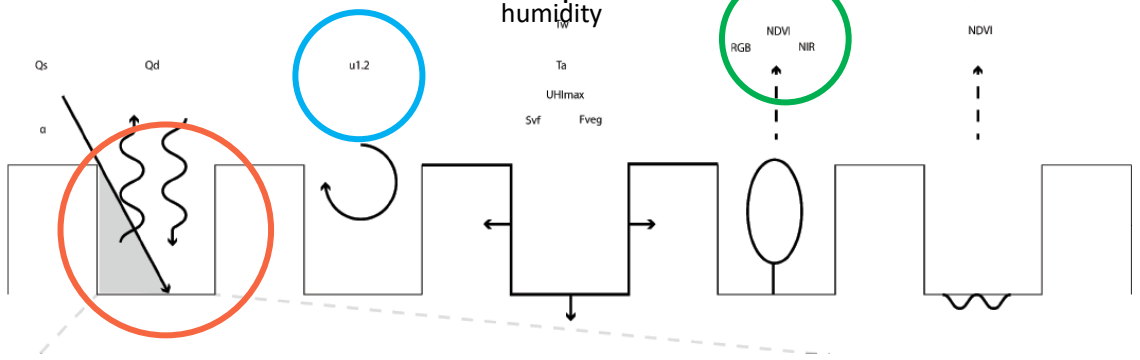
T_a	denotes the 2 m air temperature (°C)
Q_s	solar irradiation (Wm^{-2})
$u_{1.2}$	wind speed at 1.2 m height (ms^{-1})
T_w	wet bulb temperature (°C)
ϕ	solar elevation angle (degrees)
B_b	Bowen ratio (ratio between sensible and latent heat flux)
Q_d	diffuse irradiation (W m^{-2})
σ	Stefan Boltzmann constant ($5.67 \cdot 10^{-8}$ $Wm^{-2}K^{-1}$)
S_{vf}	the sky-view factor

Radiation
Shortwave
Longwave

Wind

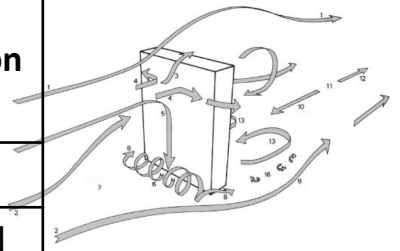
Urban
morphology
temperature
humidity

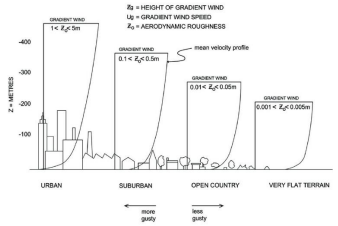
Landscaping
elements



Modelling Thermal comfort software

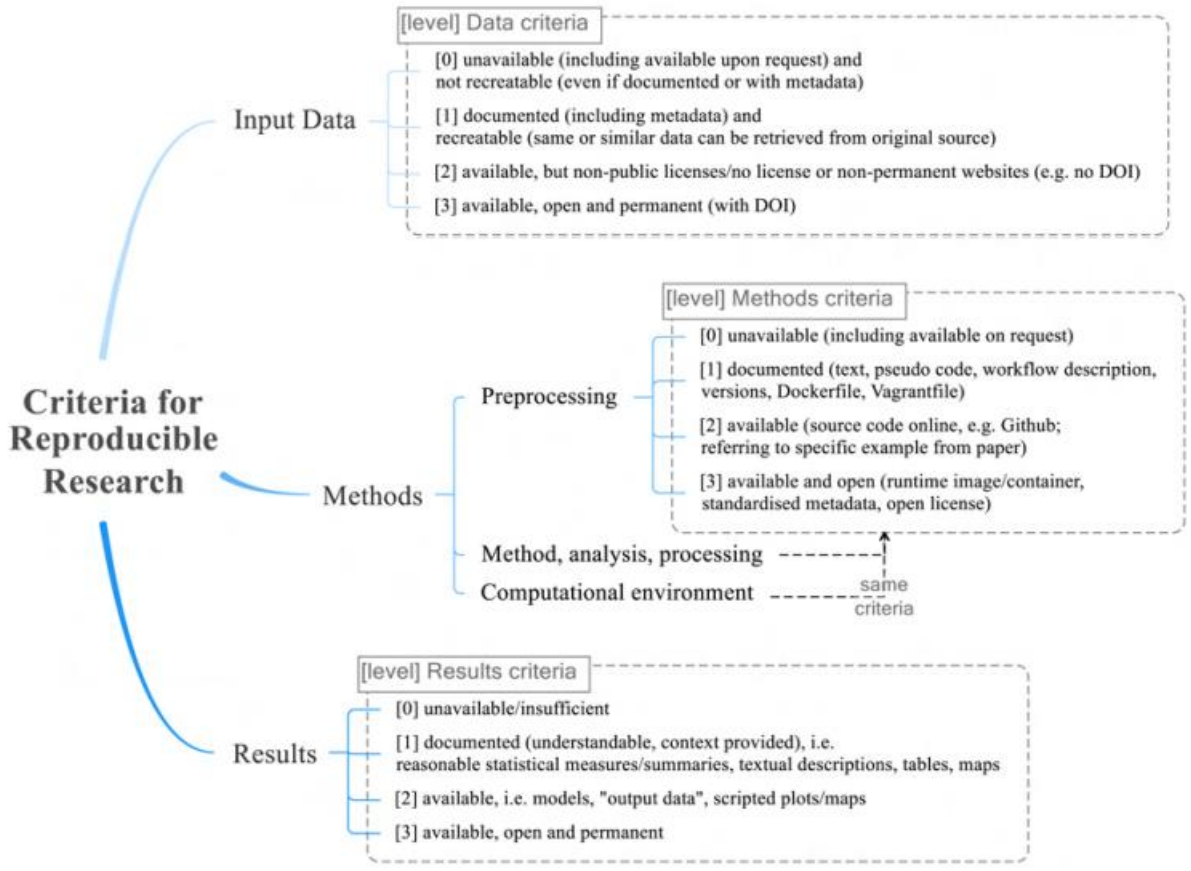
	Owner	Open software	Input environment	Reproducible outcomes	Design options	Computation time 1km2	Wind computation
ENVIMET	GmBH	No	By hand	Yes	Yes	100+ min	CFD
Climate Resilient Cities tool	Deltares	No	From maps	No	Yes	0-10 min	Macdonald method
Urban Microclimate	Grasshopper	Yes	From BAG	Yes	Yes	0-10 min	Macdonald method
PET map	Wageningen University, CAS and Witteveen en Bos	No	From satellite imagery	No	Viewer	-	Macdonald method



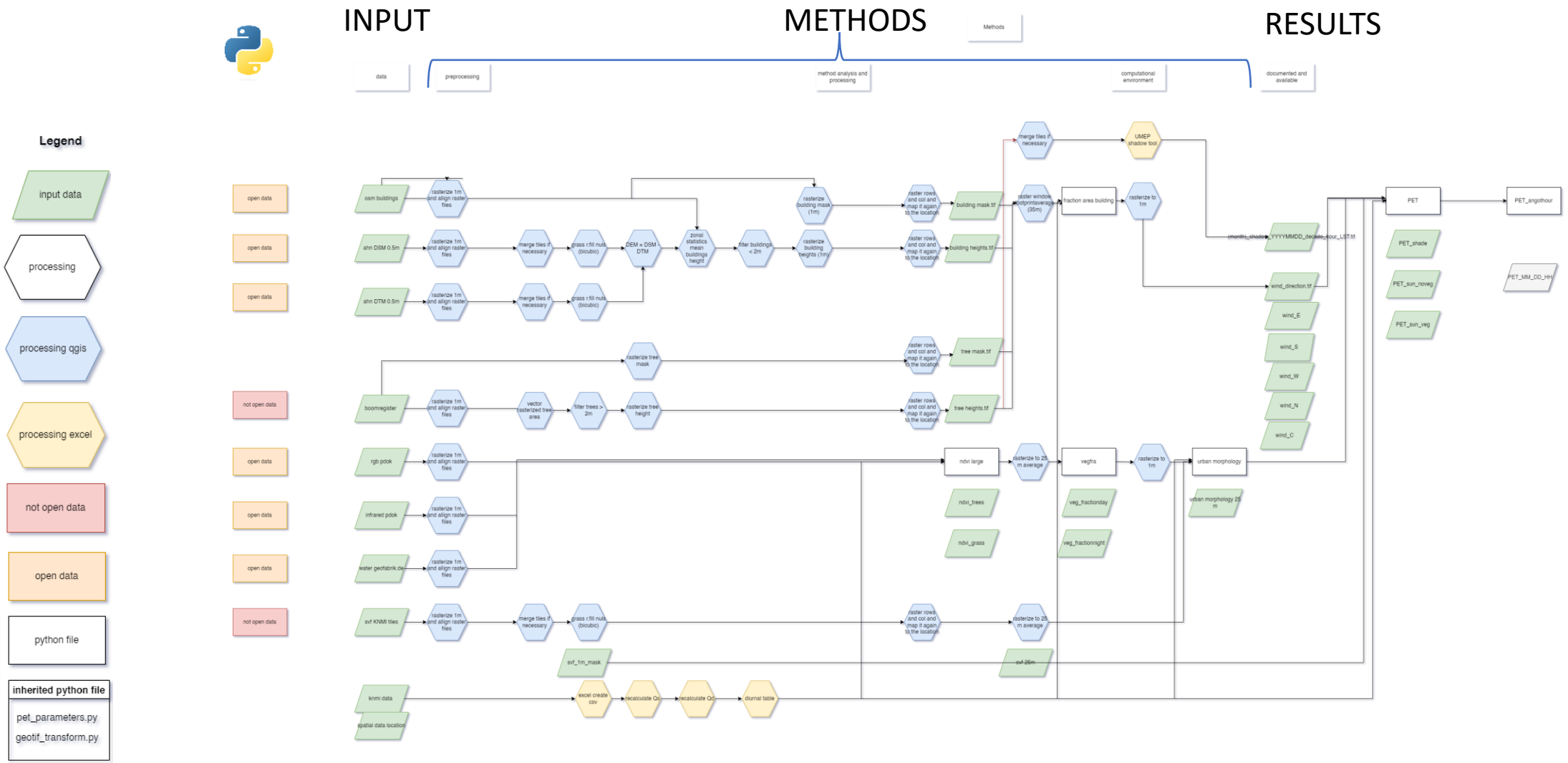


Reproducibility guidelines

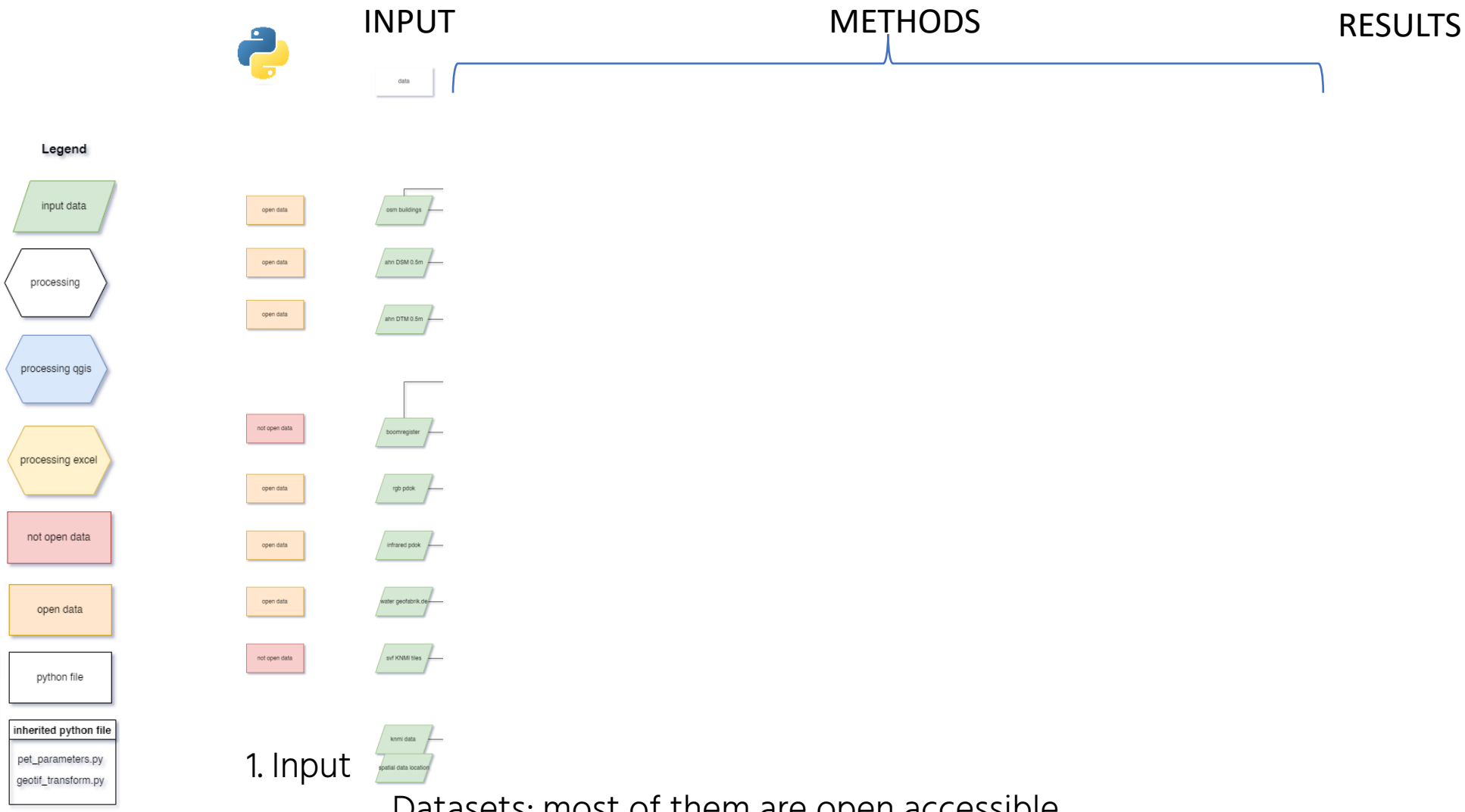
1. INPUT
   - Datasets
2. Methods
   - Software tools/libraries/packages & computational workflow (FAIR)
3. Results
   - Data & software
   - Camera ready paper



Model Koopmans et al. (2020)



Model Koopmans et al. (2020)

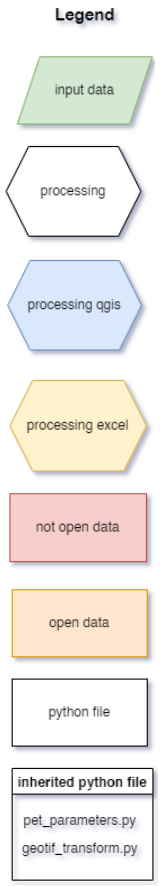


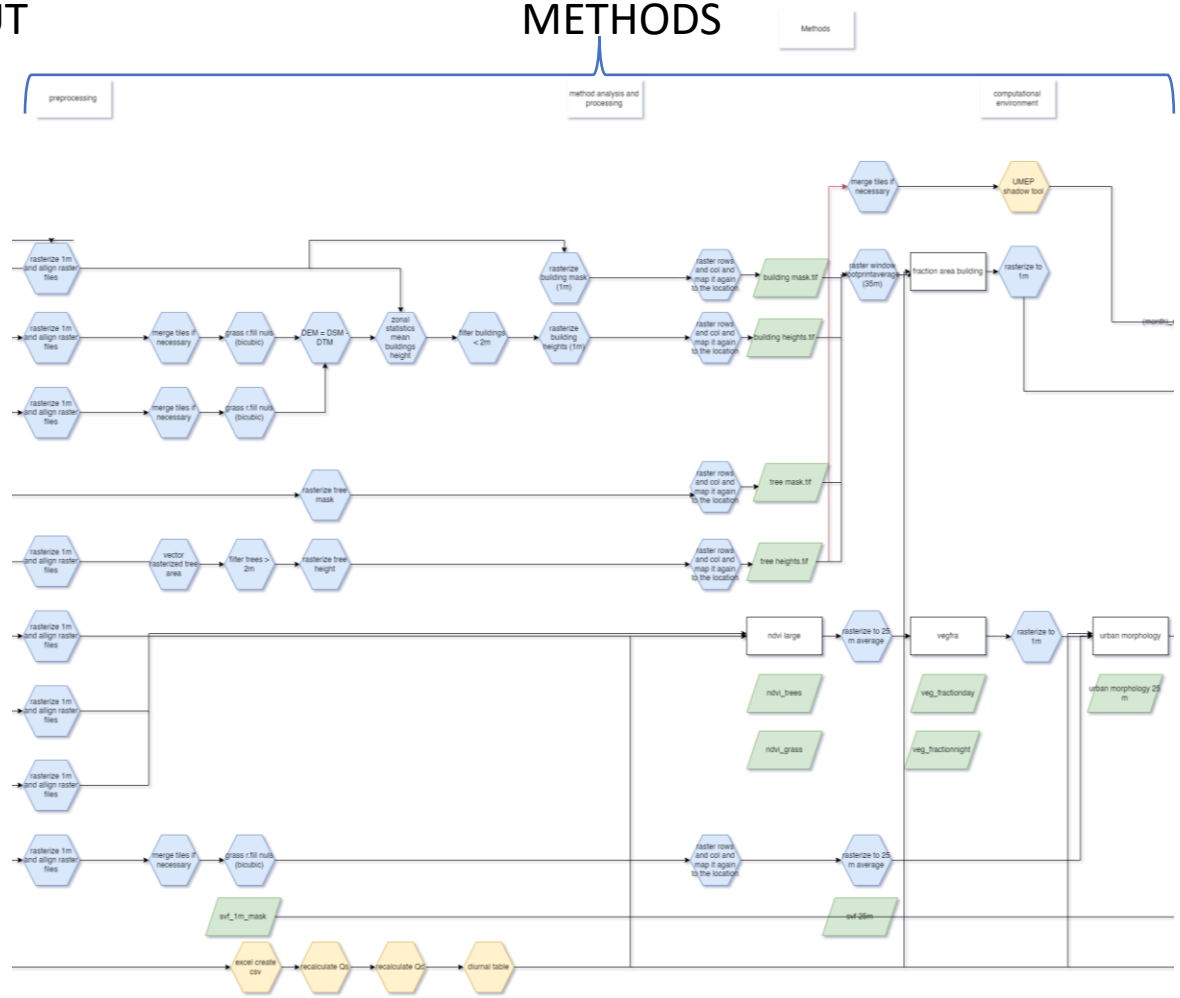
1. Input

Datasets: most of them are open accessible

Model Koopmans et al. (2020)

INPUT METHODS RESULTS





2. Methods

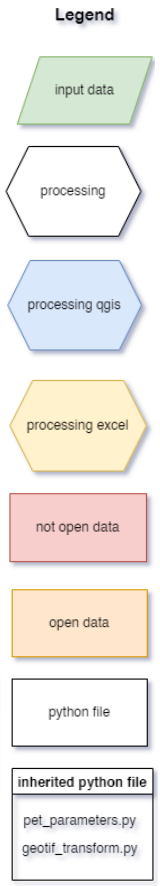
Preprocessing: steps are required
Methods: no inherited parameters
Multiple computational environment: downgrade

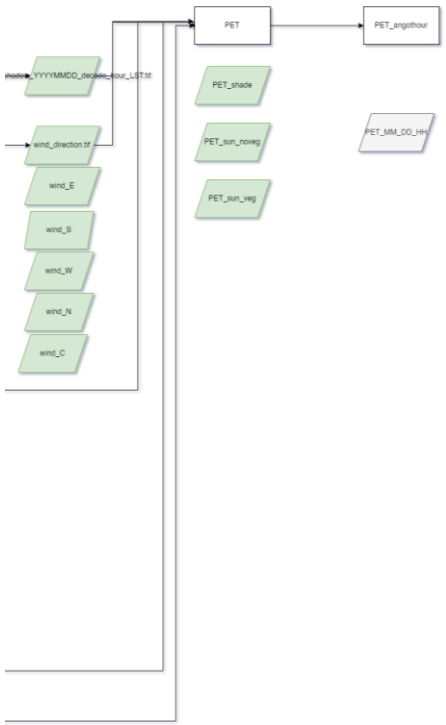
Model Koopmans et al. (2020)

INPUT

METHODS

RESULTS



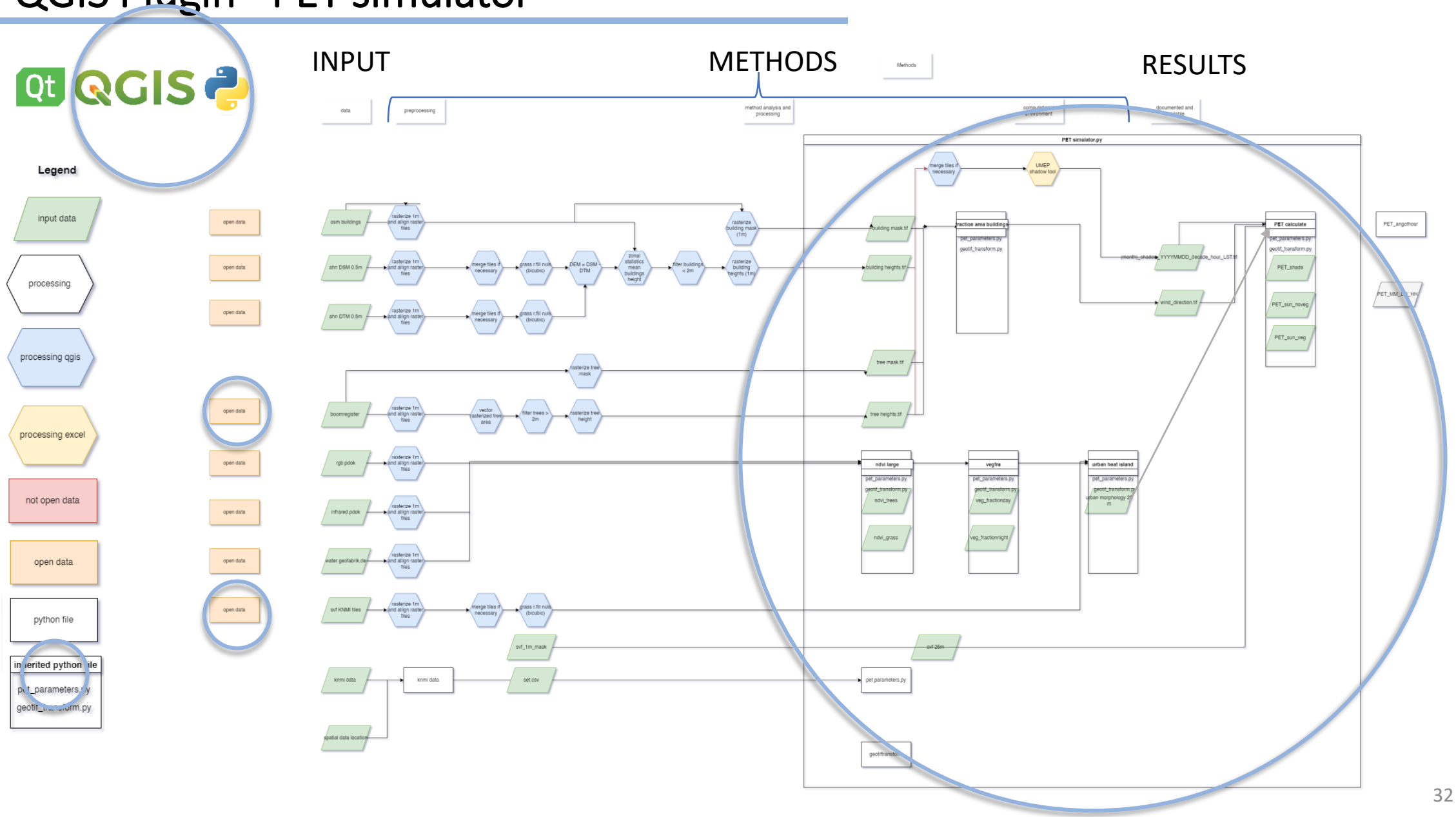


3. Results

Software only on request

Camera ready paper: Appendix describes steps

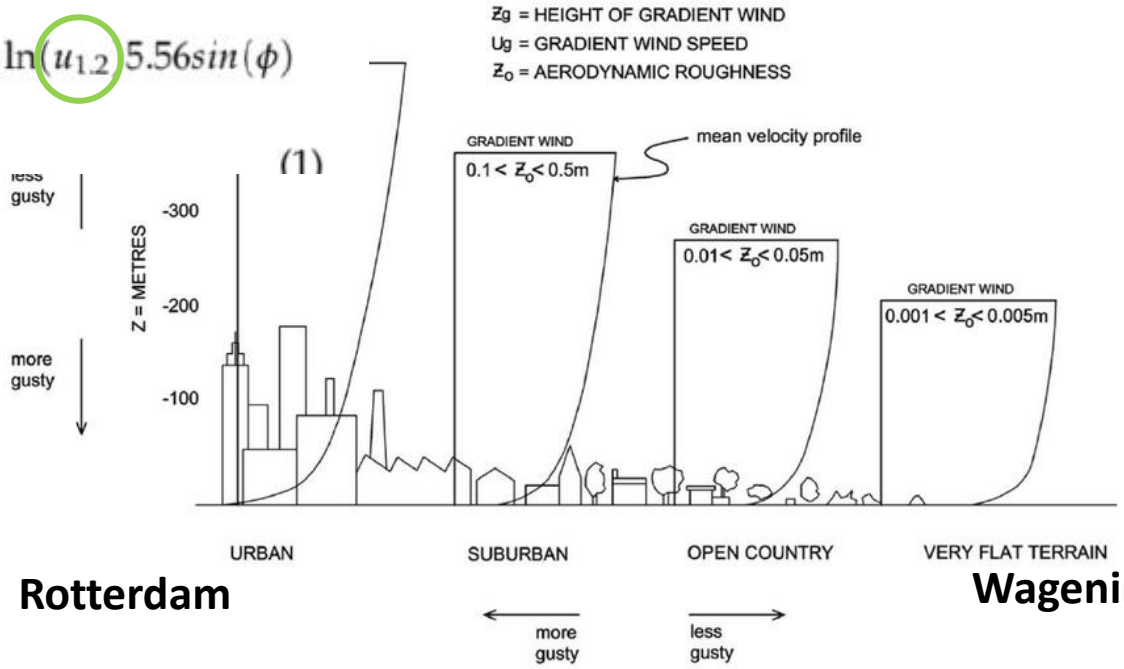
QGIS Plugin - PET simulator



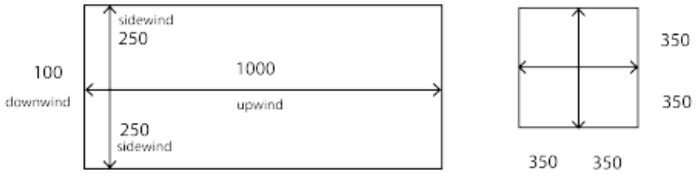
QGIS Plugin - PET simulator - METHODS

$$PET_{sun} = -13.26 + 1.25T_a + 0.011Q_s - 3.37ln(u_{1.2}) + 0.078T_w + 0.005Q_s \ln(u_{1.2}) 5.56sin(\phi)$$
$$- 0.0103Q_s \ln(u_1.2)\sin(\phi) + 0.0546B_b + 1.94S_{vf}$$

Figure 5.3: research area 1000x1000 m white (output), extended research area 1500x2100m black (input) and base map rgb 4000x4000 m(data).



Rotterdam **Wageningen**



Depending on wind direction

No wind

QGIS Plugin - PET simulator - wind

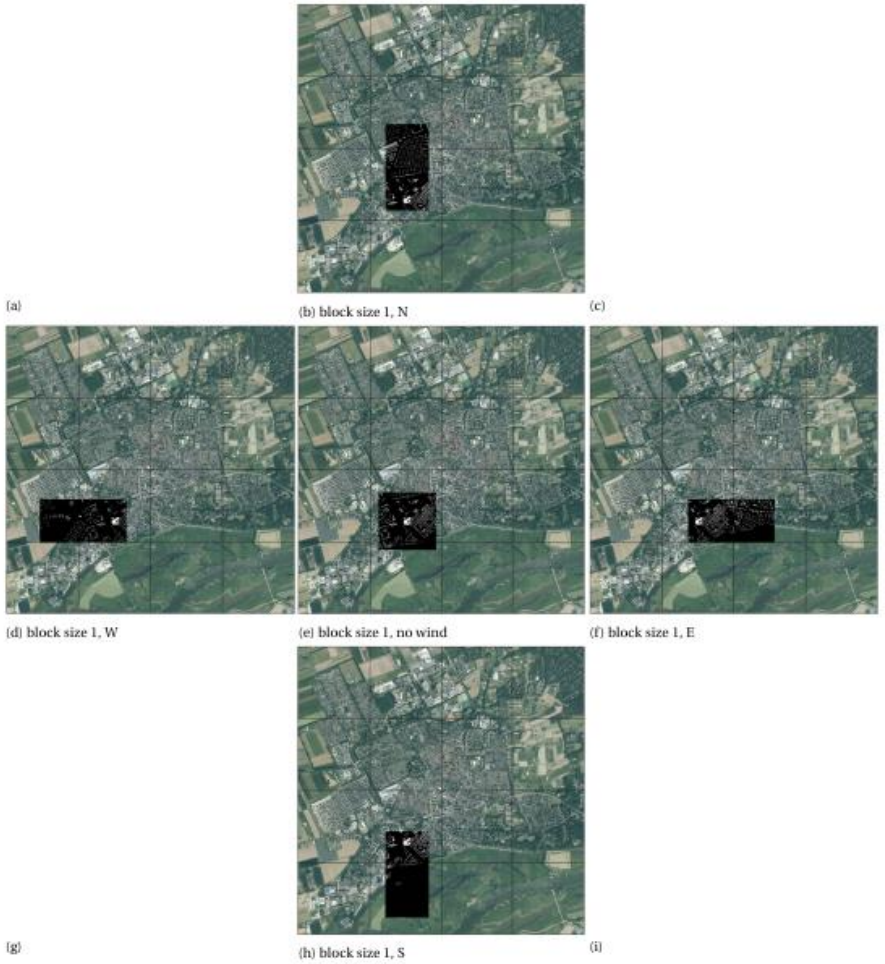
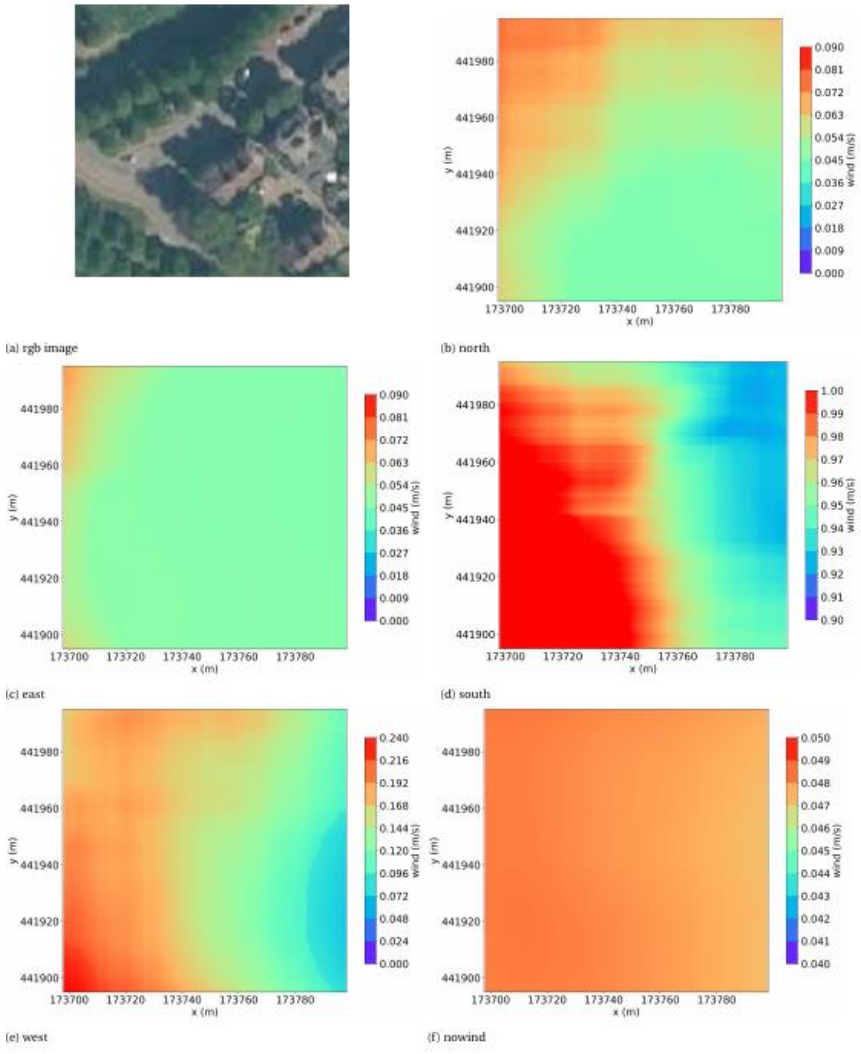


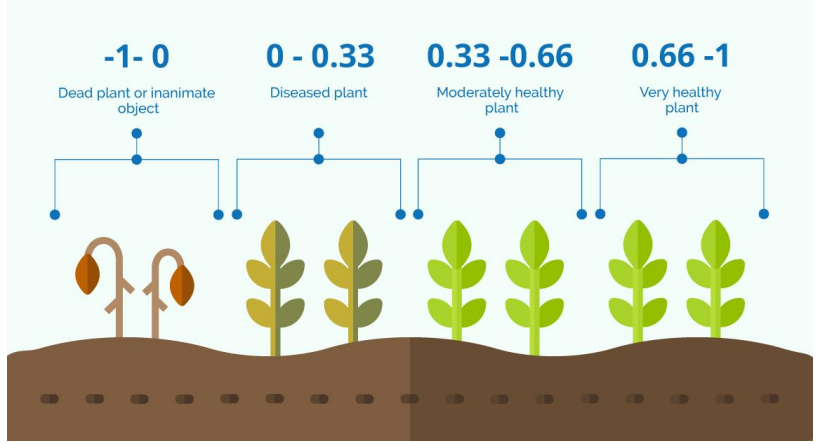
Figure 5.6: Wind direction for the research area of 100x100m.



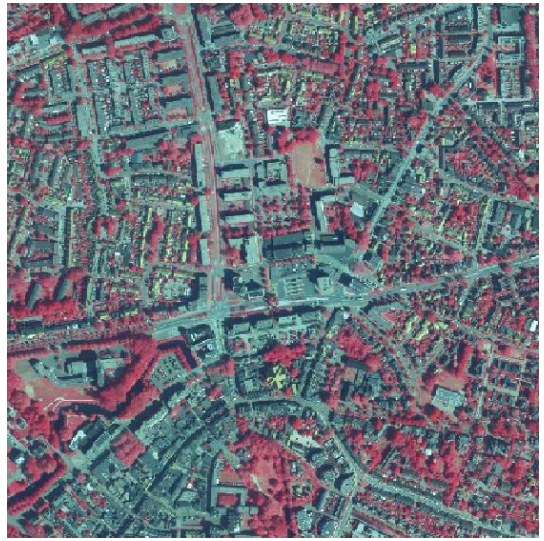
QGIS Plugin - PET simulator – vegetation Normalised Difference vegetation index (NDVI)

$$PET_{sun} = -13.26 + 1.25T_a + 0.011Q_s - 3.37ln(u_{1.2}) + 0.078T_w + 0.005Q_s \ln(u_{1.2})5.56sin(\phi) - 0.0103Q_s \ln(u_1.2)\sin(\phi) + 0.0546B_b + 1.94S_{vf} \quad (1)$$

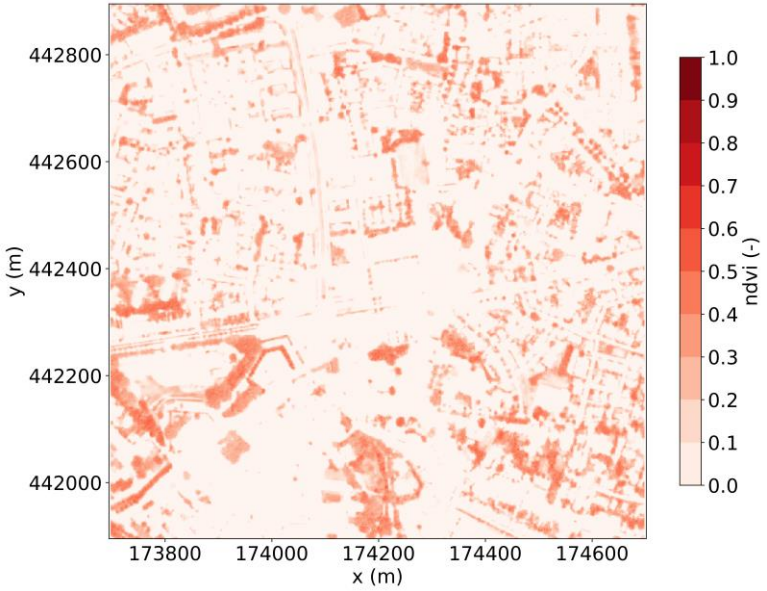
$$NDVI = \frac{NIR - R}{NIR + R}$$



RGB image



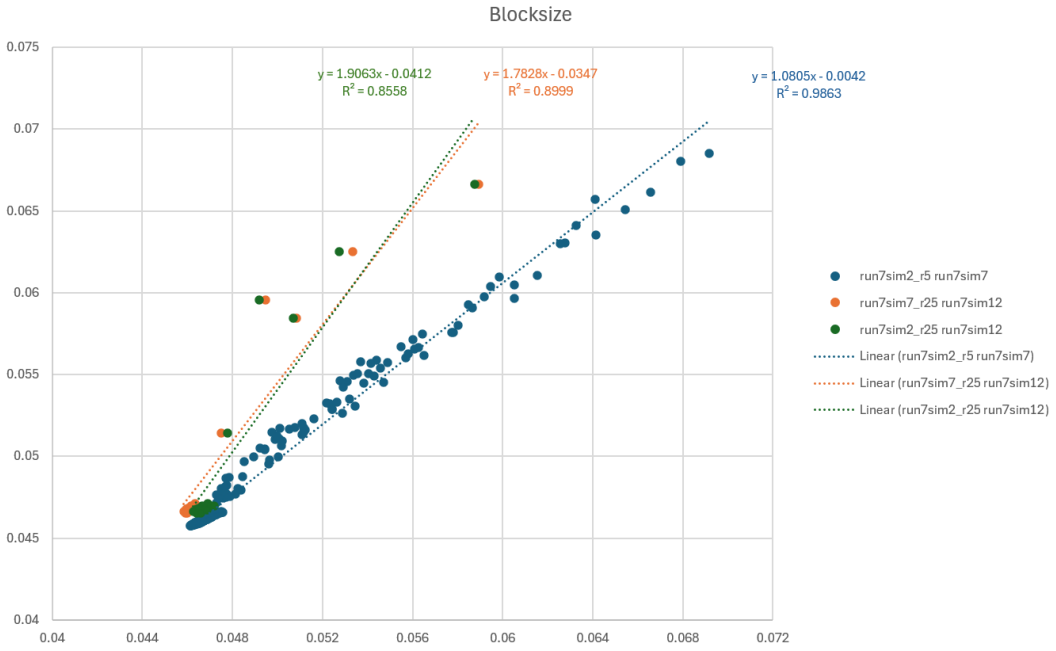
NIR image



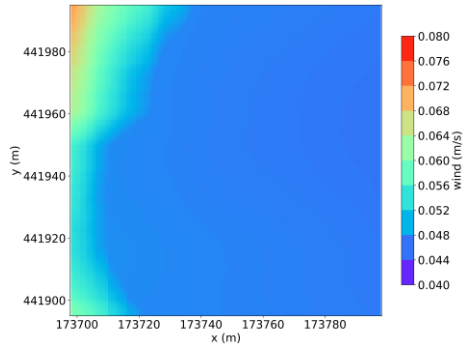
NDVI

PET sensitivity wind block sizes

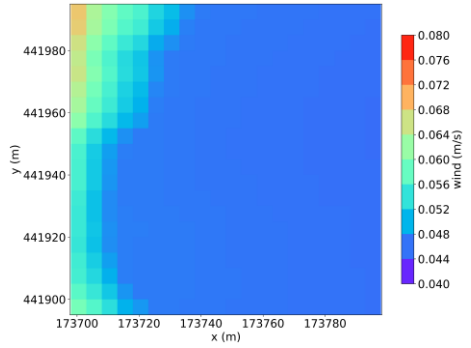
- R2 factor – 0.9 for the use of different block sizes



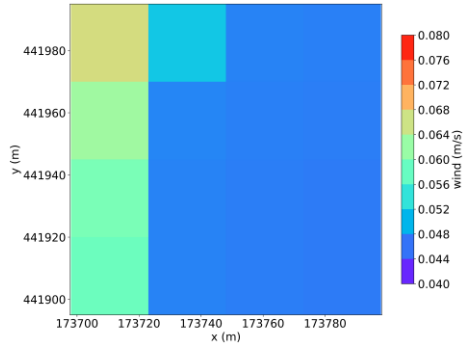
Block size 1m



Block size 5m

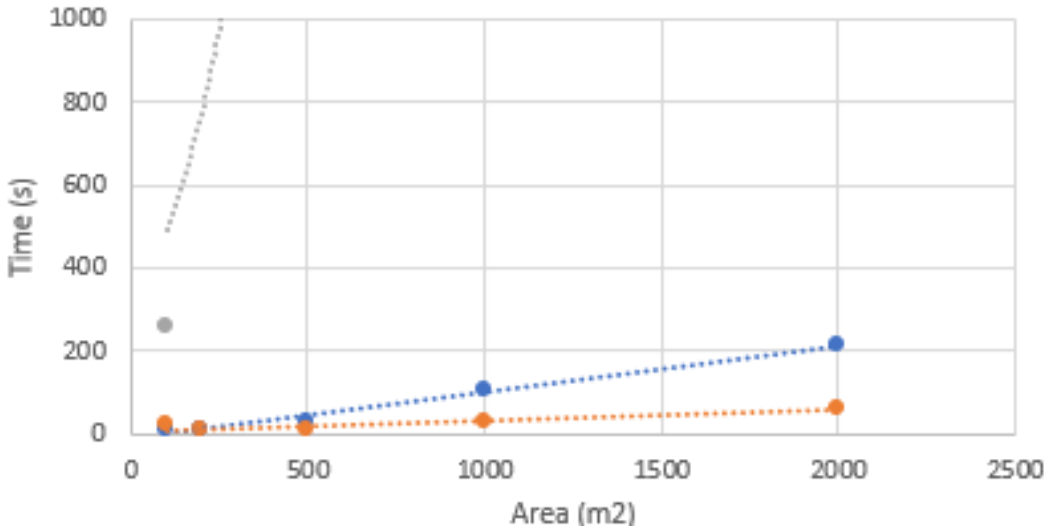


Block size 25m



Computation time

- Scalability area size vs computation time



Blocksize 1m

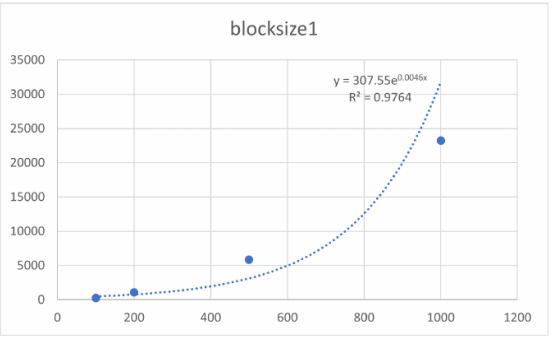


Figure 6.8: Fig. X Qgis plugin PETs window 3 calculation screen

Blocksize 5m

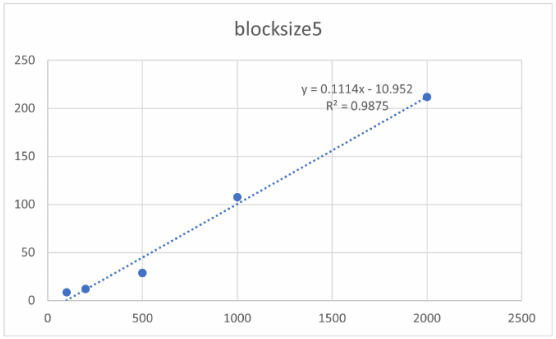


Figure 6.9: Fig. X Qgis plugin PETs window 3 calculation screen

Blocksize 25m

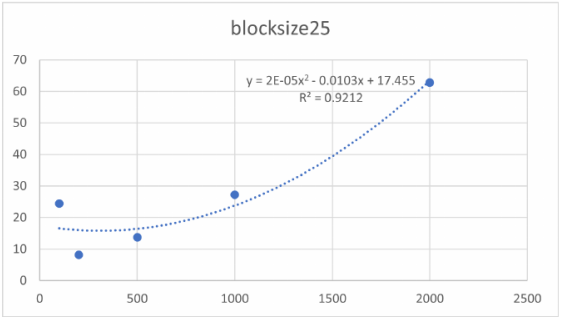


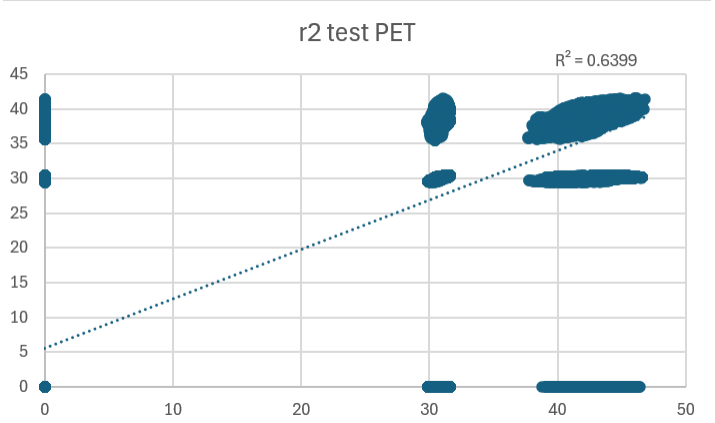
Figure 6.10: Fig. X Qgis plugin PETs window 3 calculation screen

PET after wind calibration

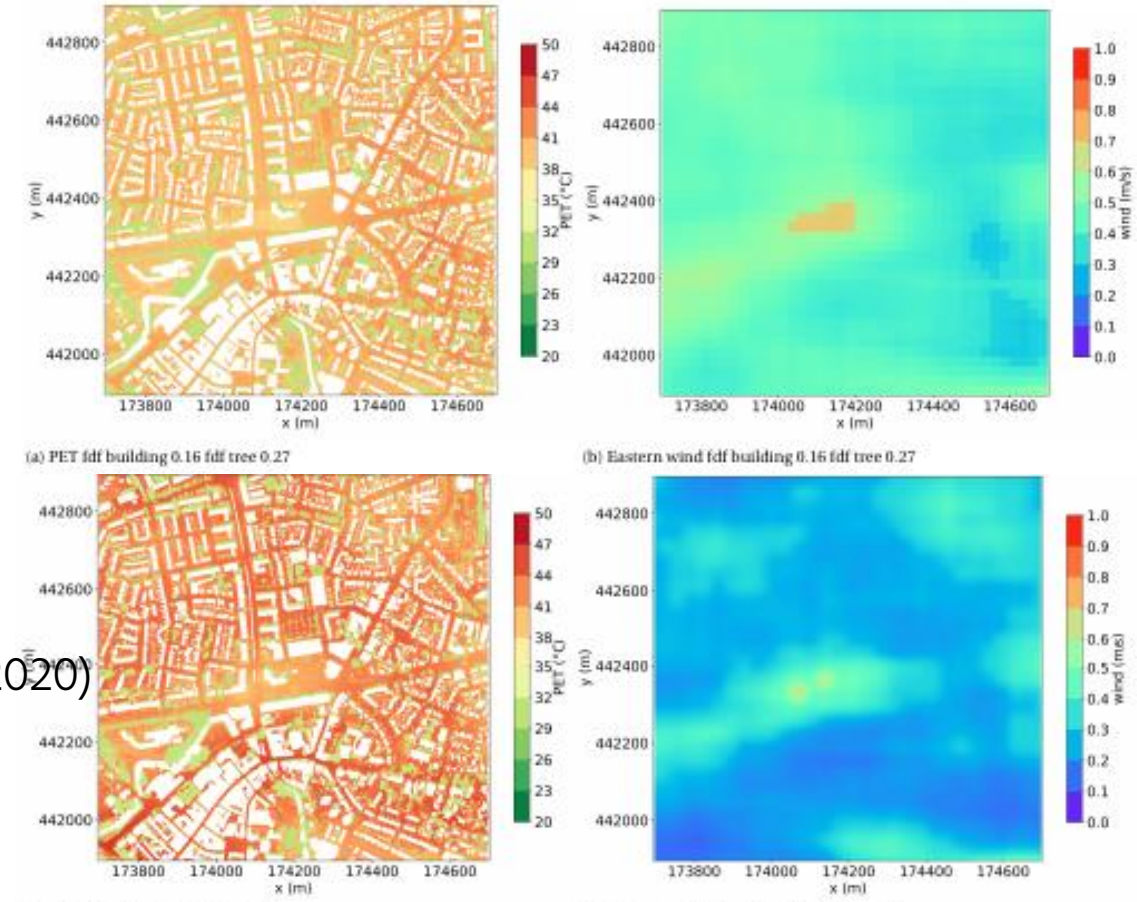
- MSE wind = 0.0774
- R2 factor wind = 0.7803

- MSE of PET = 137.43
- R2 factor PET 0.6399

PET simulator



Koopmans et al. (2020)



(a) PET fdf building 0.16 fdf tree 0.27

(b) Eastern wind fdf building 0.16 fdf tree 0.27

(a) PET fdf building 0.6 fdf tree 0.27

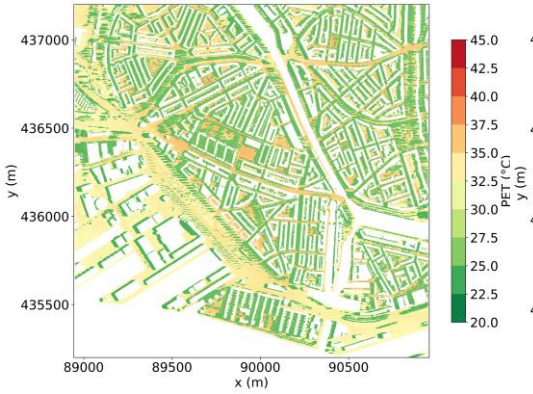
(b) Eastern wind fdf building 0.6 fdf tree 0.27

Figure 6.12: Outcome Sytse Koopmans

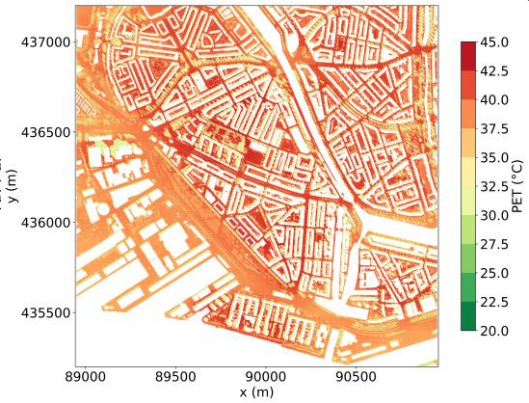
- Still differences due to different input of buildings
- More finetuning with wind footprint window +Fdf

PET simulator application

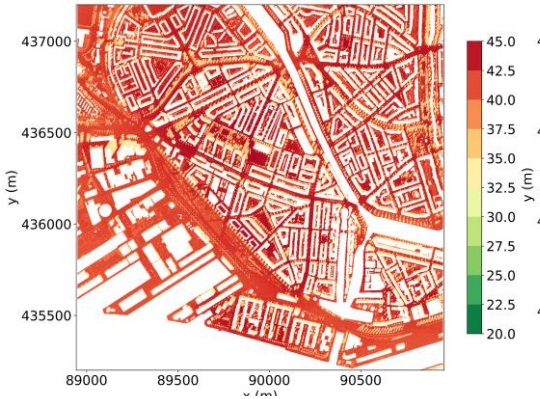
9:00



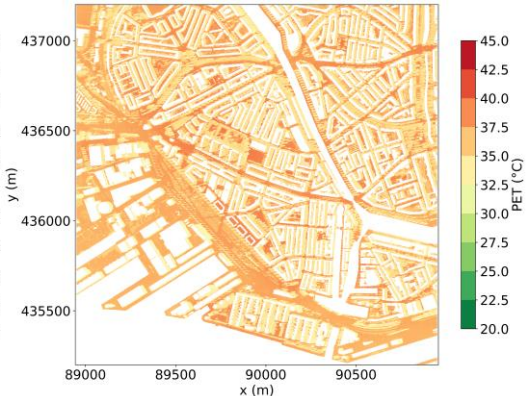
12:00

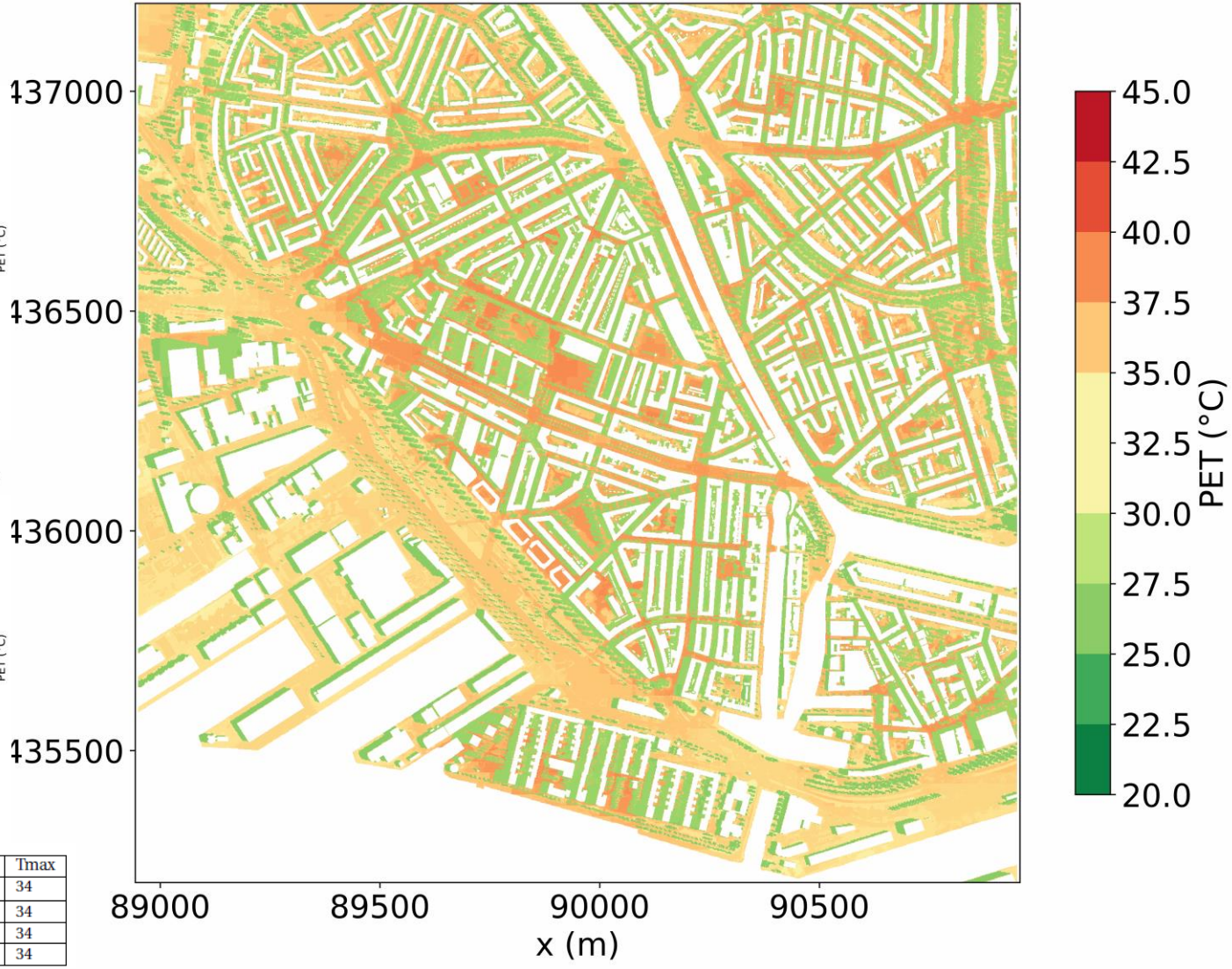


15:00



18:00





hour	TT	FF	dd	Q	Qdif	sunalt	RH	wind	WE	winddir	day	diurnal	Tmin	Tmax
9	27.2	4	100	699.425	155.9823	48	45	TRUE	TRUE	E	day	0.007	23.7	34
12	31.8	6	110	865.625	176.726	60.9	32	TRUE	TRUE	E	day	0.07	23.7	34
15	33.8	5	120	634.33	143.5459	42.5	31	TRUE	TRUE	E	day	0.23	23.7	34
18	32.9	5	110	202.21	95.36945	15.2	36	TRUE	TRUE	E	day	0.56	23.7	34

PET simulator semantic visualisation

Summer day – 25+ C

Legend
PET classification

13-18	slightly cold stress
18-21	no thermal stress
23-29	slight heat stress
29-35	moderate heat stress
35-41	strong heat stress
>41	extreme heat stress

Fig. 5.19 PET on a warm day and a summer day. Createc 's simulator tool

PET application

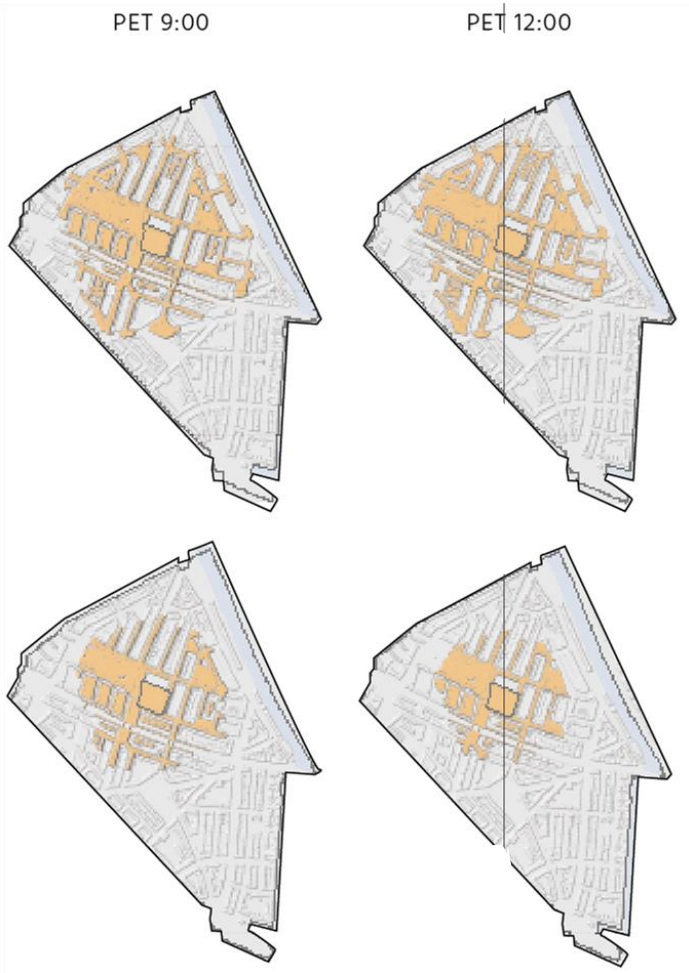
- R.walk as tool in grass

thermal accessibility based on PET resistance
and distance

Legend

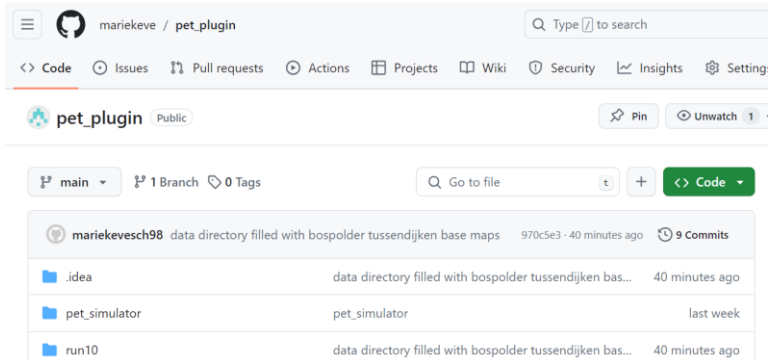
Warm day – 20+ C

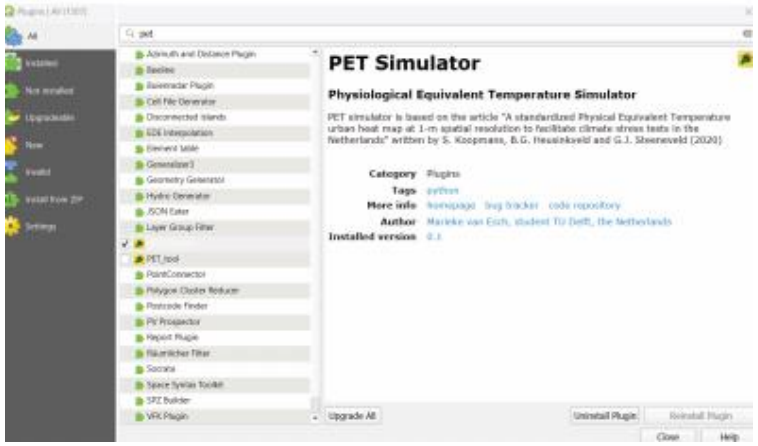
Summer day – 25+ C

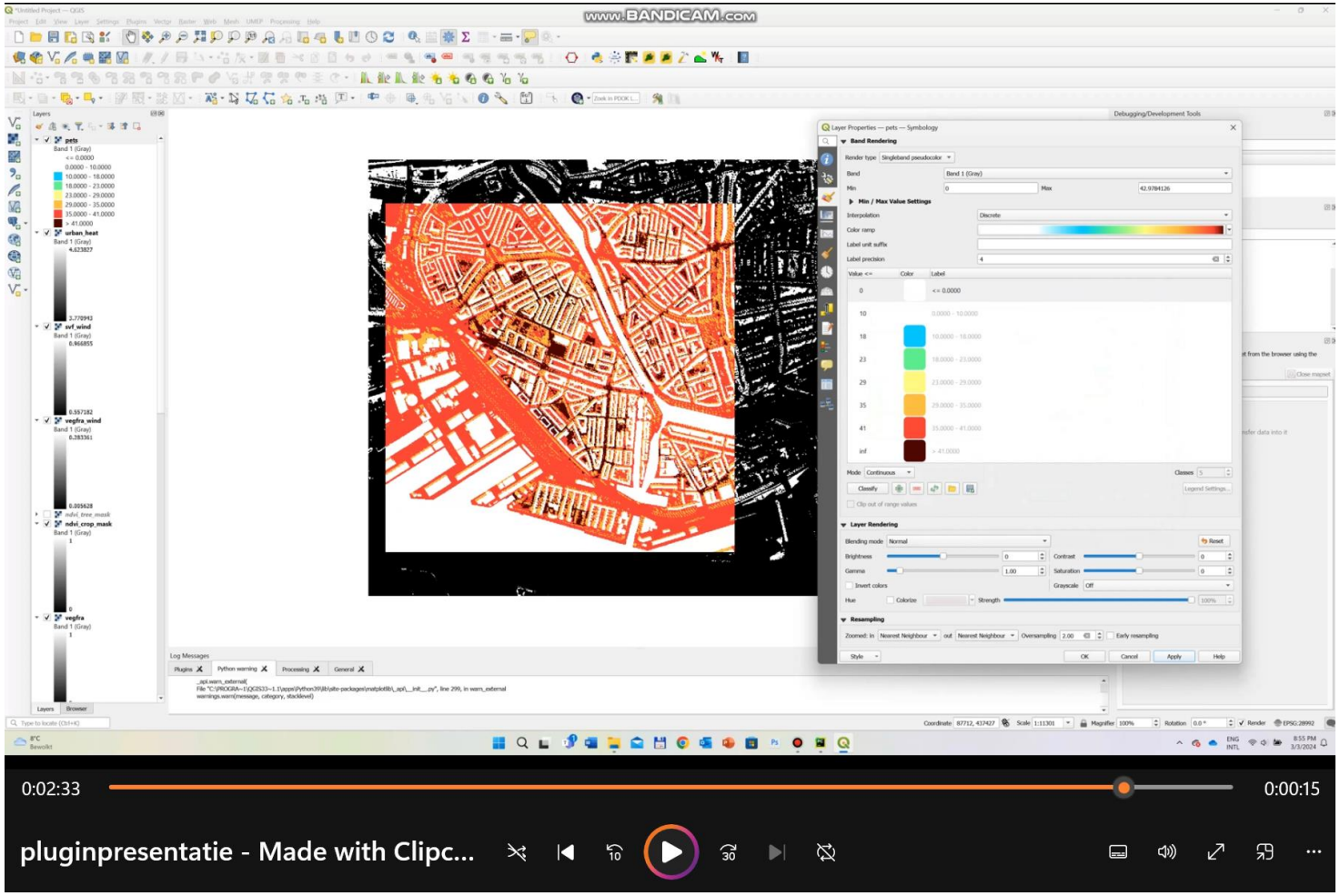


PET simulator - results

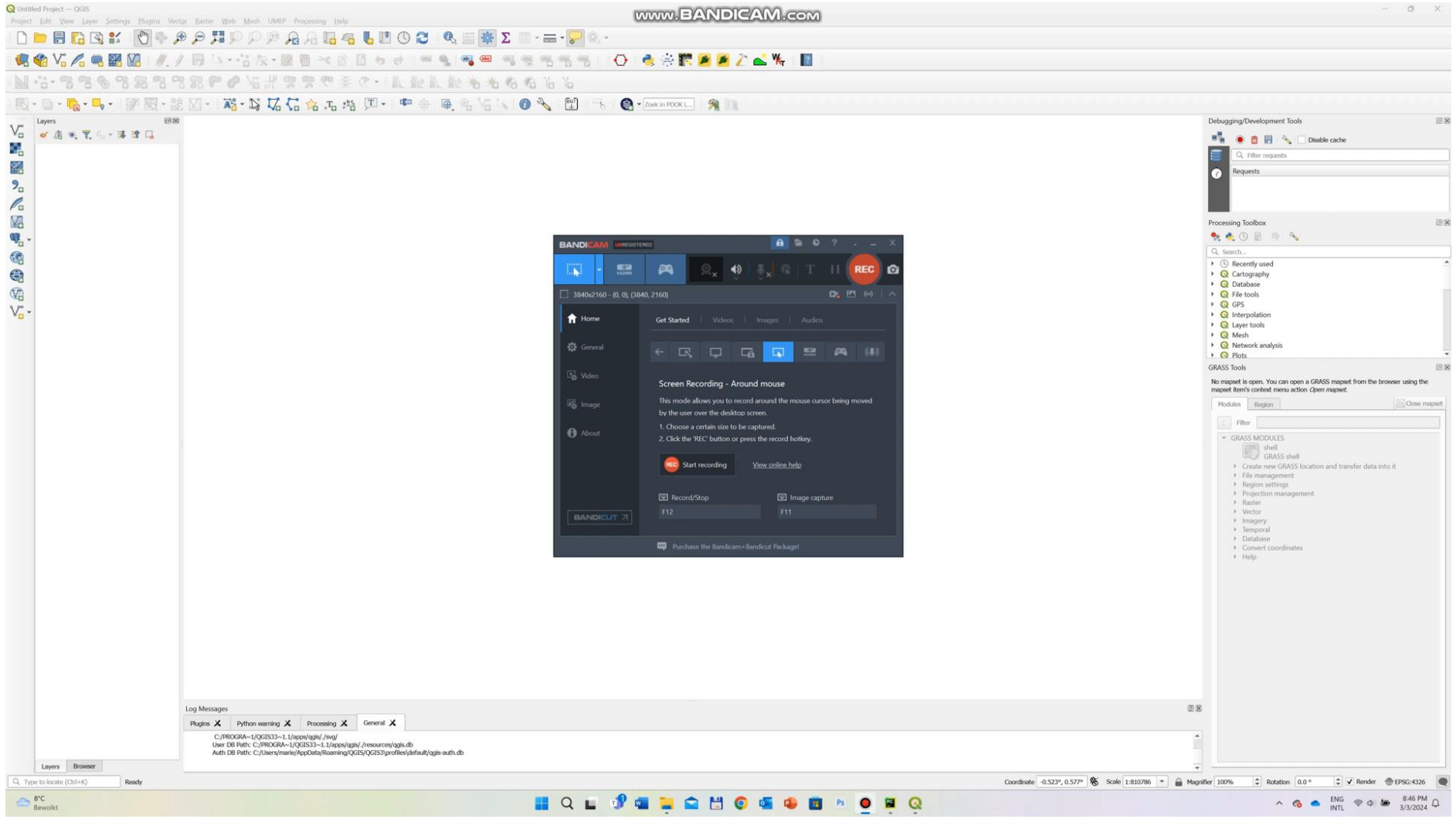
Available via Github!







PET simulator plugin



Reproducibility conclusion

		Model Koopmans et al. (2020)	PET simulator
Input data		2	2
Methods	Pre-processing	1	1
	Method, analysis and processing	1	**2**
	Computational environment	1	**3**
	Visualisation	2	**2**
Results		1	**3**

Limitations

- Accuracy of open available tree data
- Calibration with Wageningen model, no validation real measurements Rotterdam

Conclusions

(a) To what extent could a reproducible tool heat stress tool through PET identify heat stress in urban environments and test design interventions?

- The reproducibility is improved through PET simulator software for third parties to use
- Robustness of result does depend on wind computation, more calibration is needed
- More calibration with the same input results are required

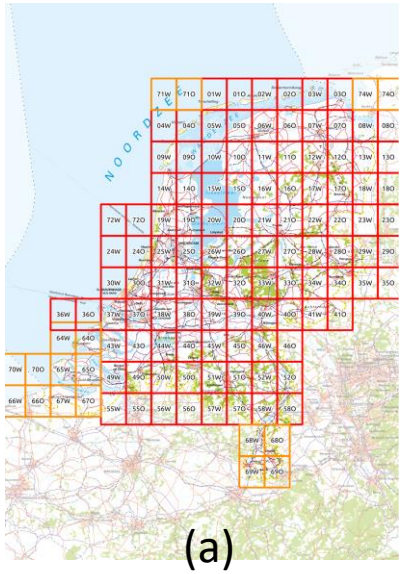
Future work

(a) Geodatabase integration in code connection to PostGIS for file handling

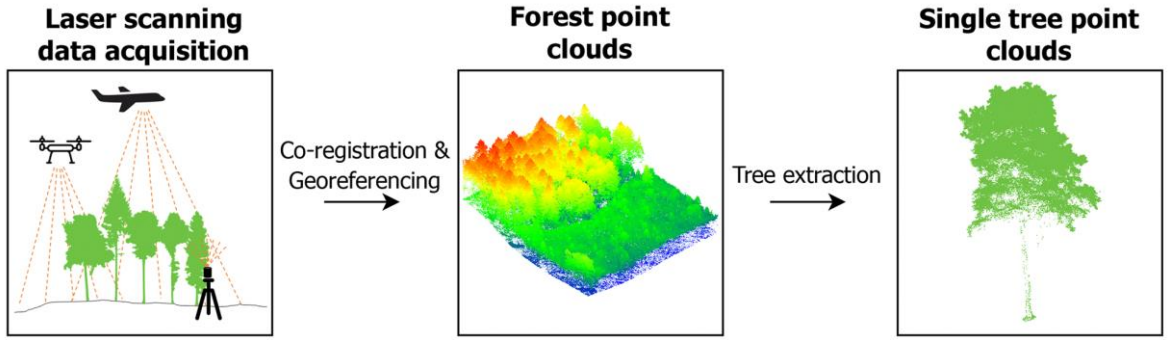
(a) Usage of C++ for larger areas simultaneously modelling

(b) Better modelling of the trees, point cloud segmentation and NDVI combination

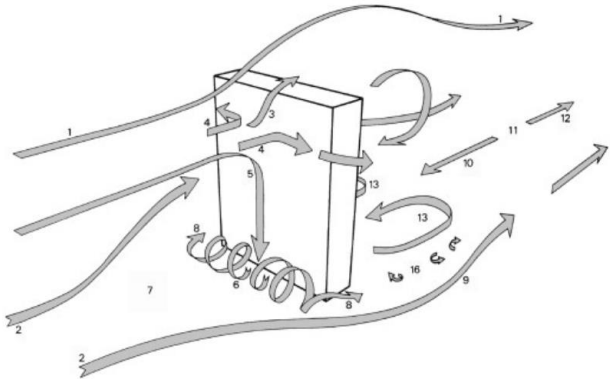
(c) Better wind modelling Computational Fluid Dynamics method, see de Jongh thesis (2021)



(a)



(b)



(c)

PART 2: Urbanism Analysis & Synthesis

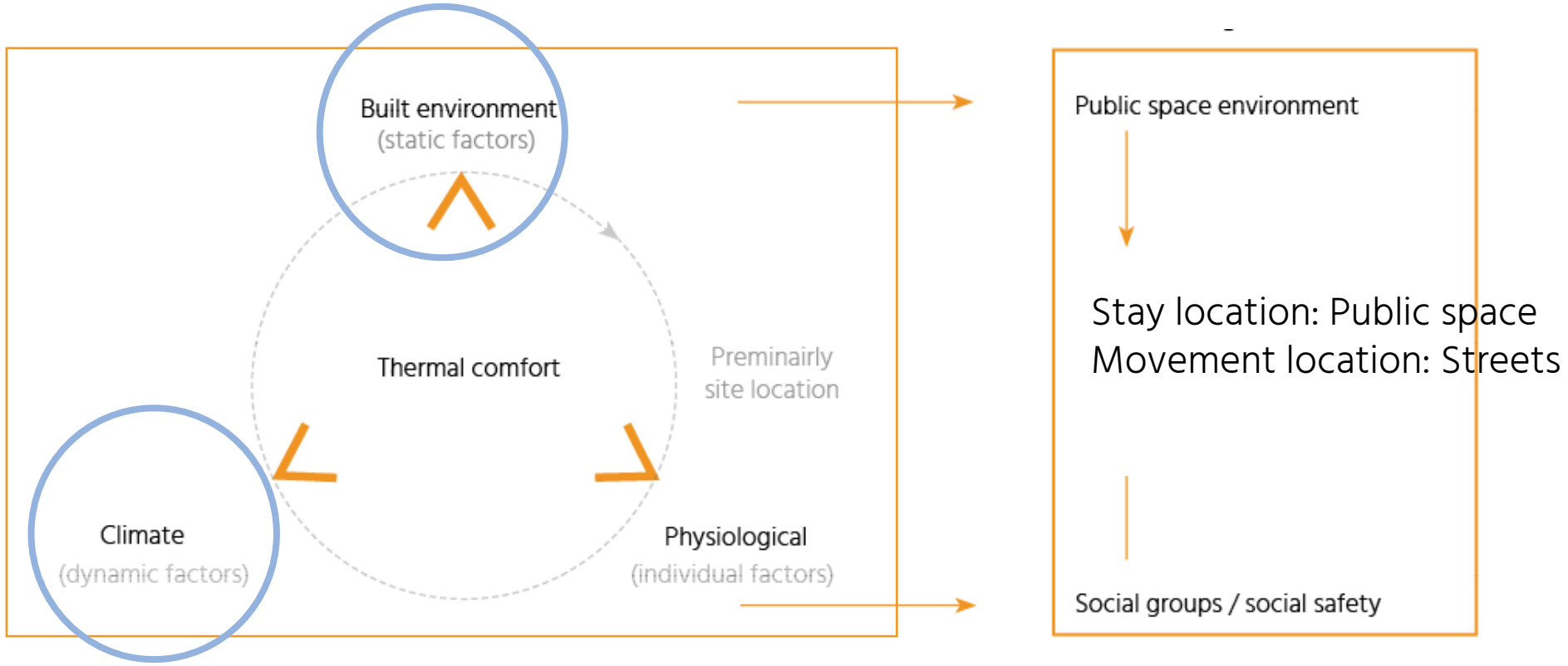
1. What are the liveability conditions?

2. What is the current liveability in Bospolder Tussendijken?

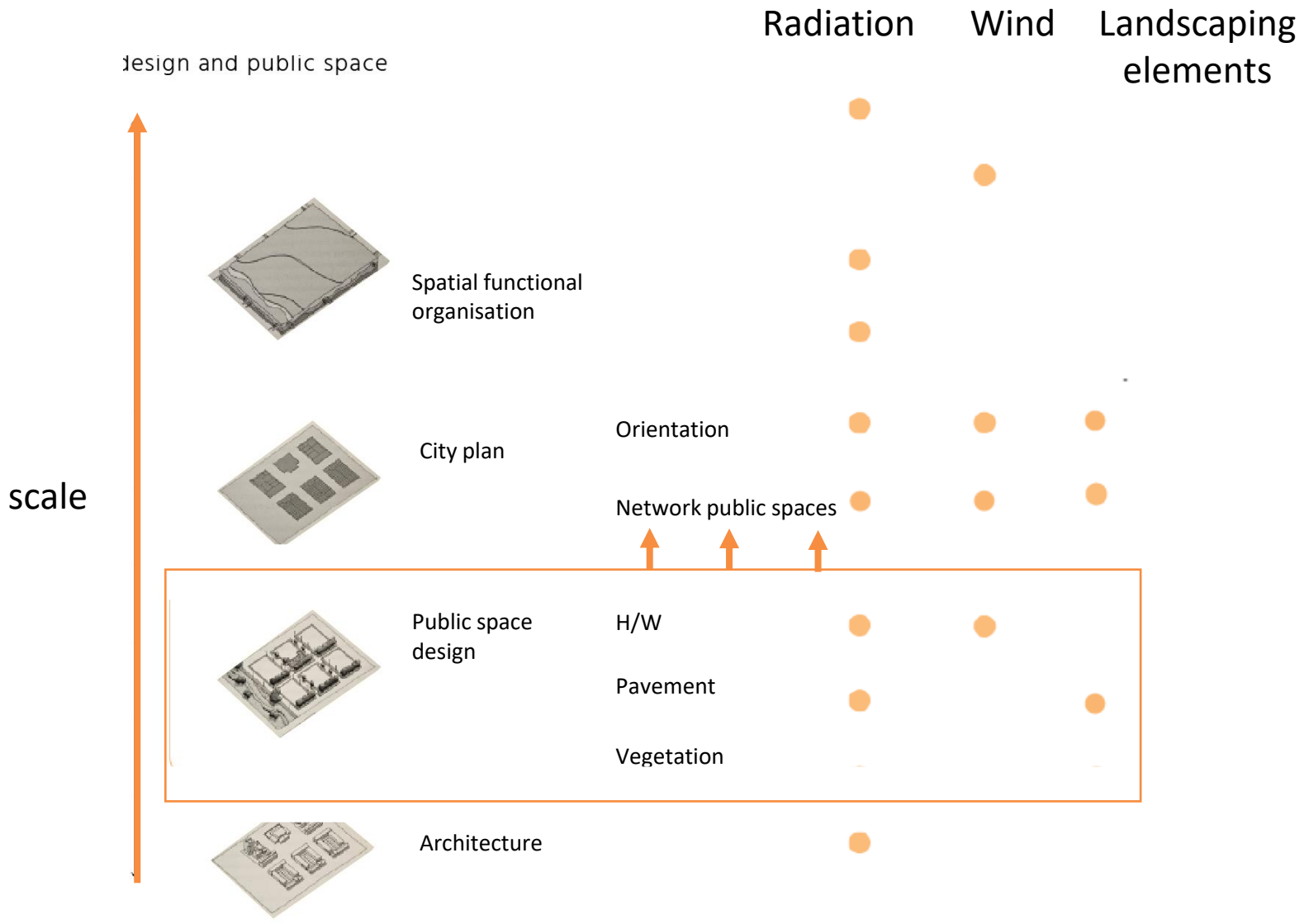
Conceptual framework

Physical liveability

Social liveability



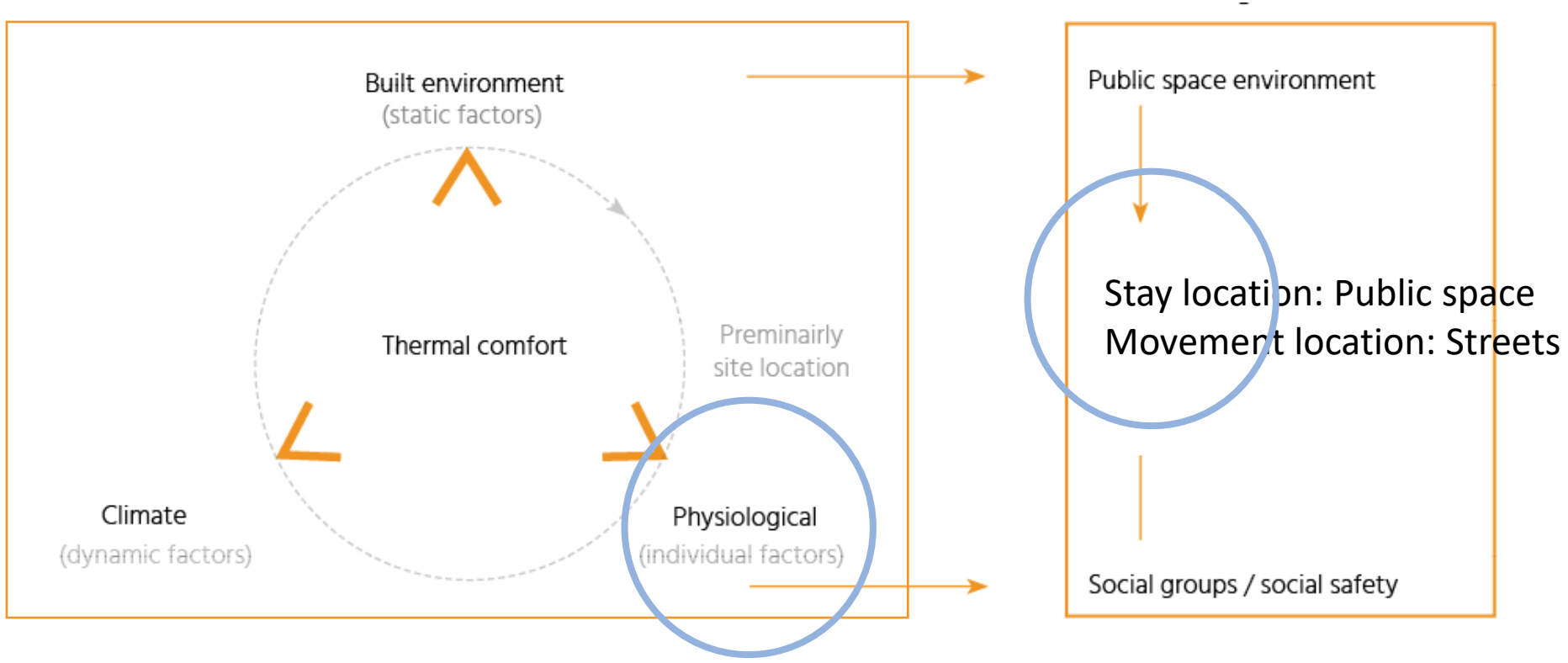
Scale dependent interventions



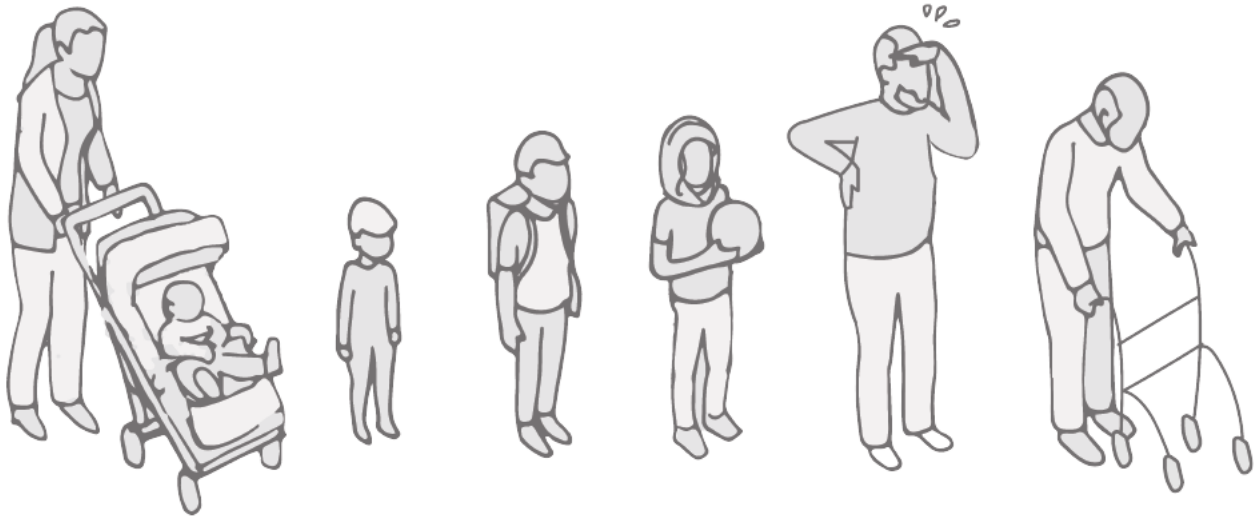
Conceptual framework

Physical liveability

Social liveability



Inclusive approach: thermal vulnerable target groups



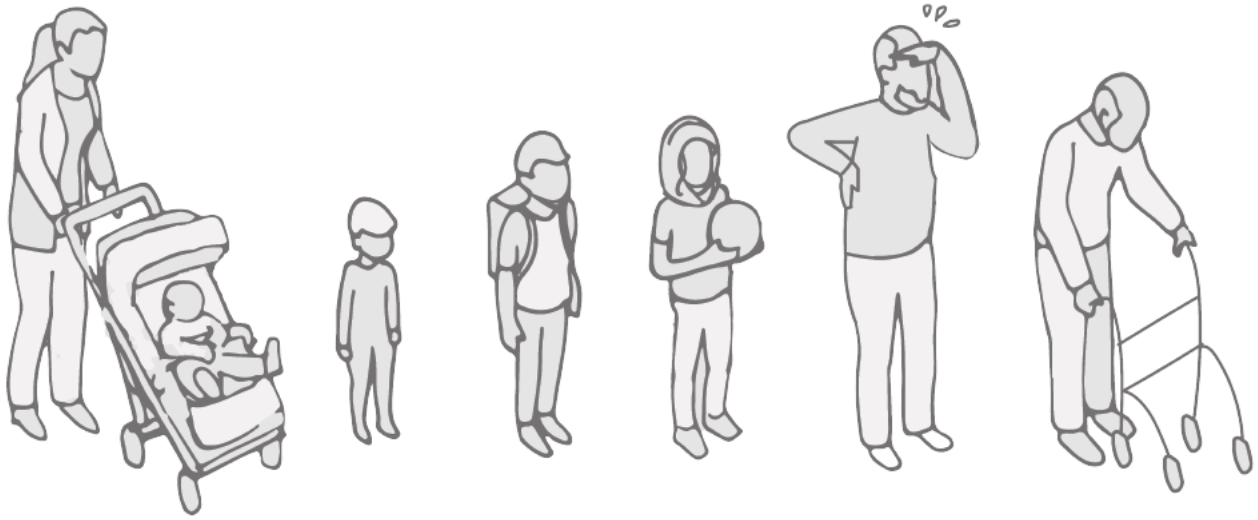
1. Young children (0-7 years)
- Growth
- Metabolic rate

2. Elderly (65+)
- Degraded performance body
- Less thirst response

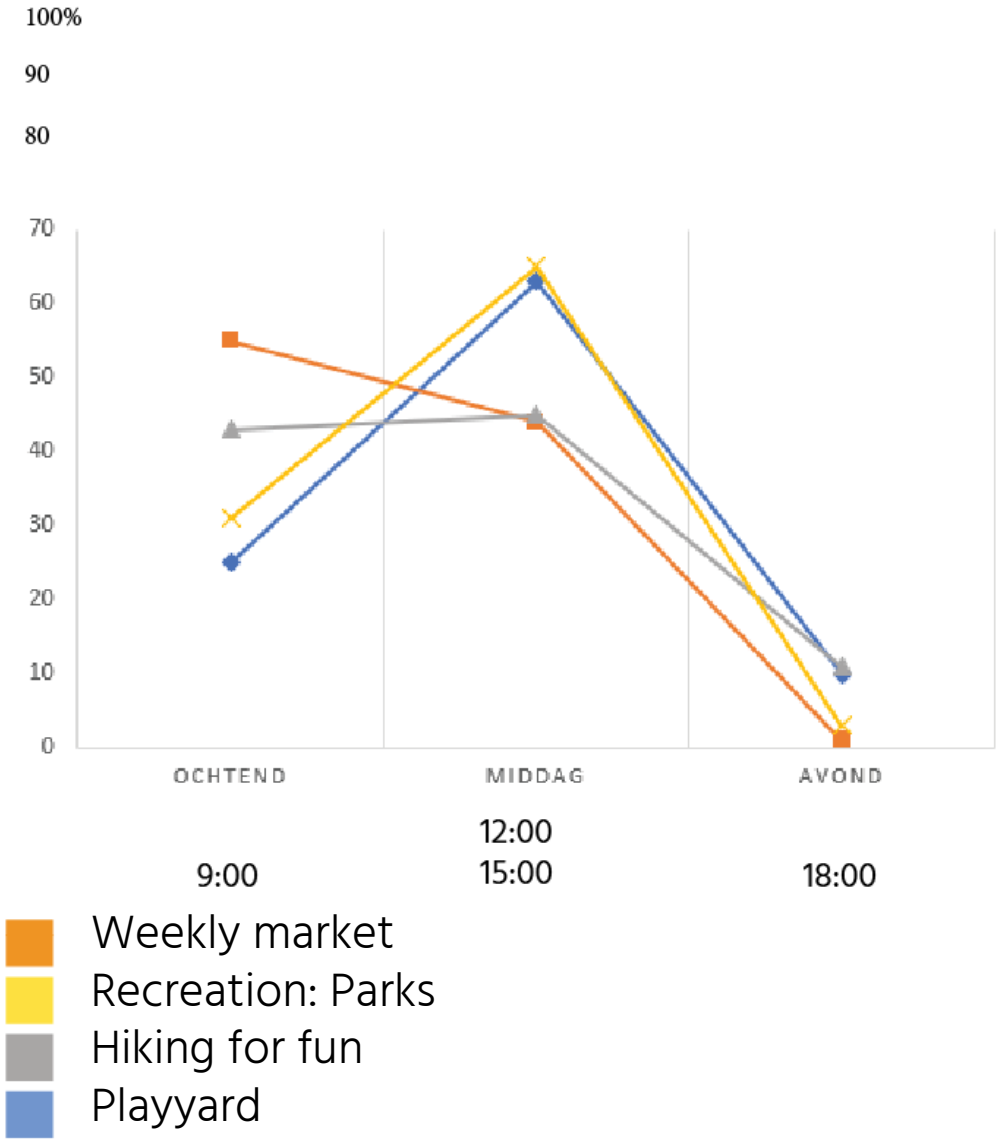
3. Obese

4. Vascular diseases

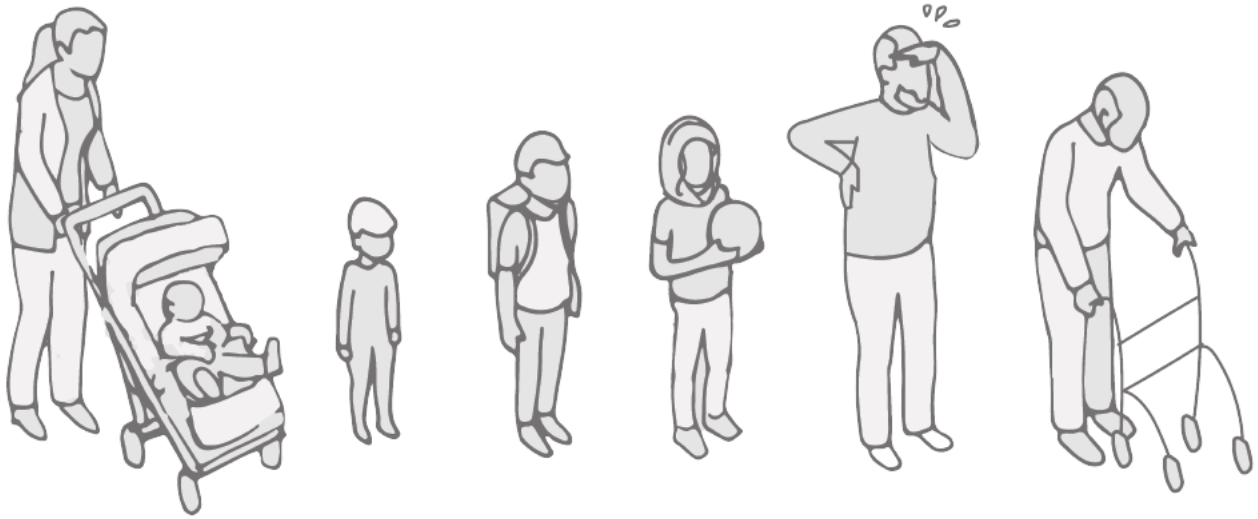
Social liveability: social places mobility



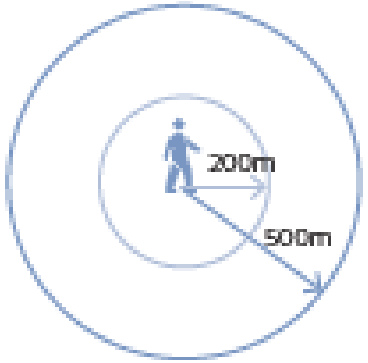
Places of interest during the day



Social liveability: spatial mobility



15 min city: the neighbourhood as unit



Liveability conditions

Physical liveability

Thermal accessibility elderly

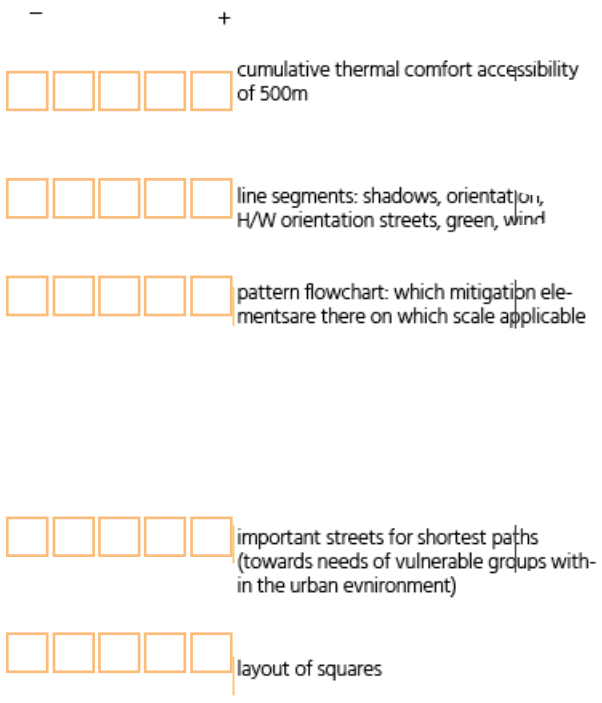
Continuity mitigation measures: for higher scale effectiveness

Durable mitigation measures

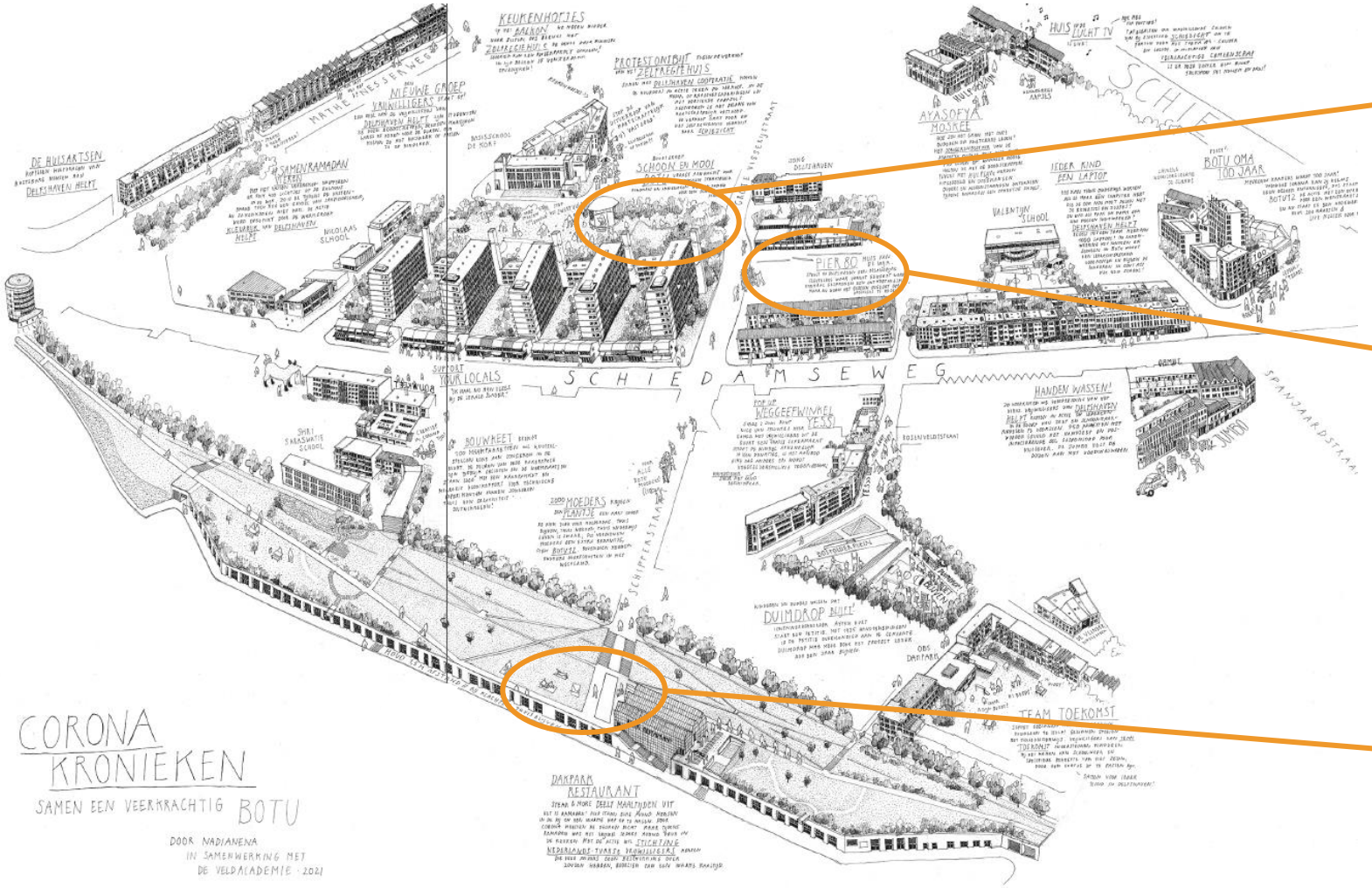
Social liveability

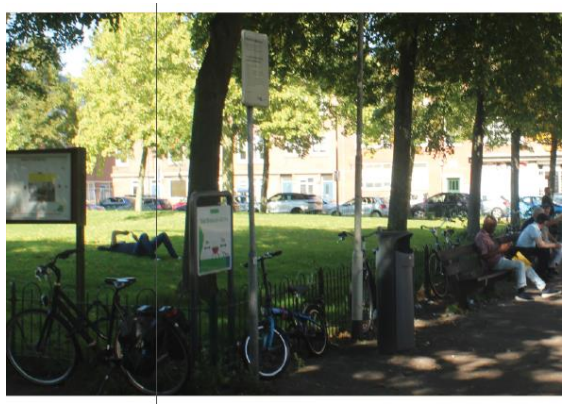
Walkable environment

Social places which are inviting to vulnerable groups



Context Bospolder Tussendijken





Physical liveability – climate condition warm day vs summer day

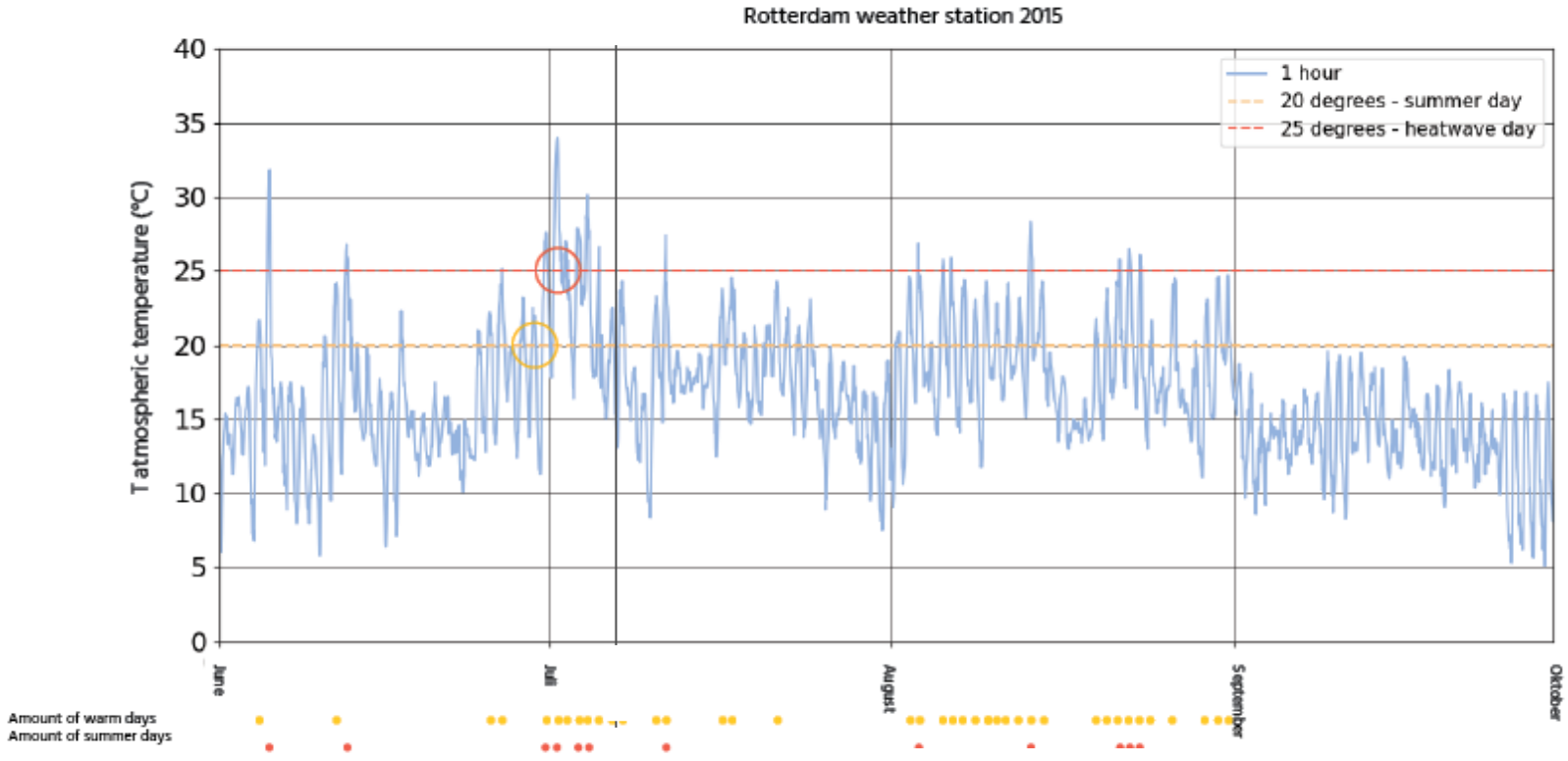


Fig. 4.6 from KNMI hourly data. Adapted by Author

Physical liveability– PET 20 C and PET 25 C

Warm day – 20+ C
(29-6-2015)

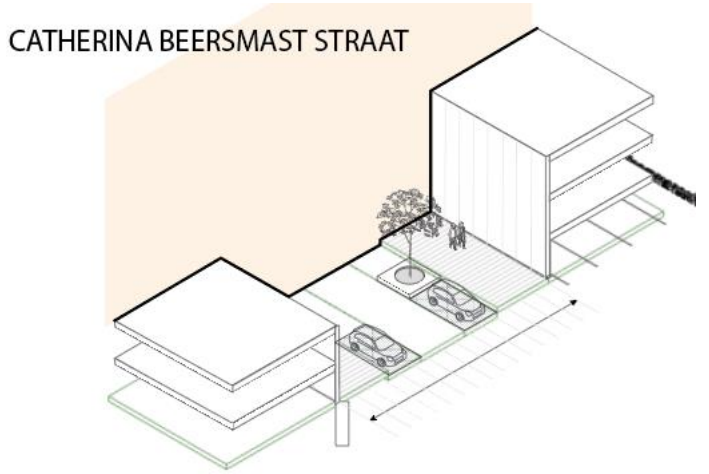
Summer day – 25+ C
(1-7-2015)

Fig. 5.19 PET on a warm day and a summer day. Created by simulator tool

Social liveability – percentage cars and greenery

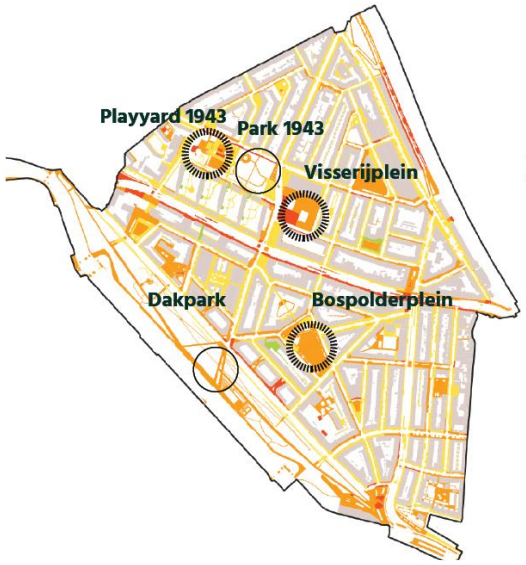
- Car occupation and pavement
- Low quality walkable environment

Fig. 5.7 percentage car occupation on streetlevel (parking+road)



Social liveability– public spaces

Summer day – 25+ C



Legend
PET classification

13-18	slightly cold stress
18-21	no thermal stress
23-29	slight heat stress
29-35	moderate heat stress
35-41	strong heat stress
>41	extreme heat stress

9:00

Market
Playgrounds

12:00

Market
Playgrounds
Parks

15:00

Market
Playgrounds
Parks

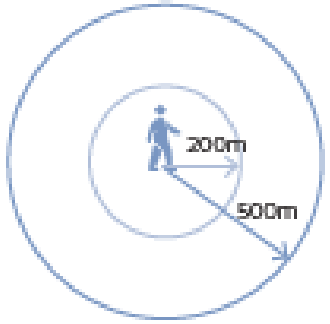
18:00

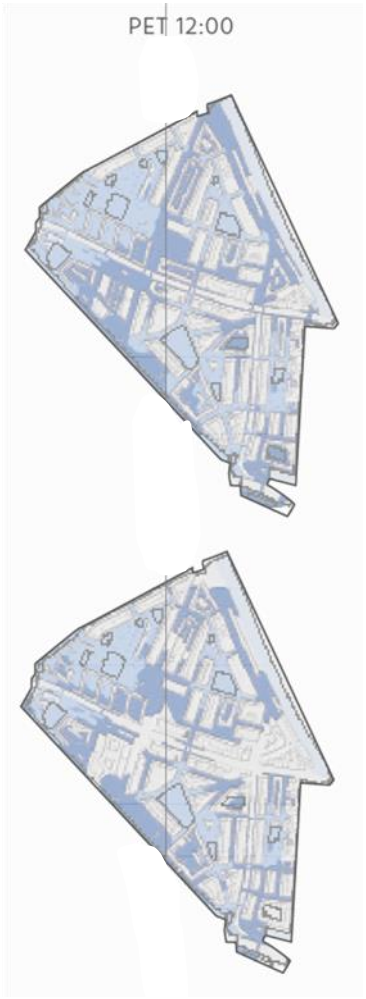
Playgrounds

Physical liveability : thermal accessibility

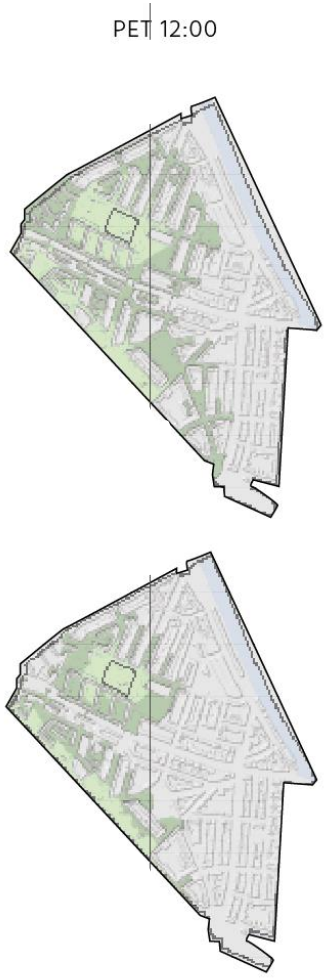
- Schoolyards service area covered everywhere
- Parks and market square are degraded in accessibility

Legend

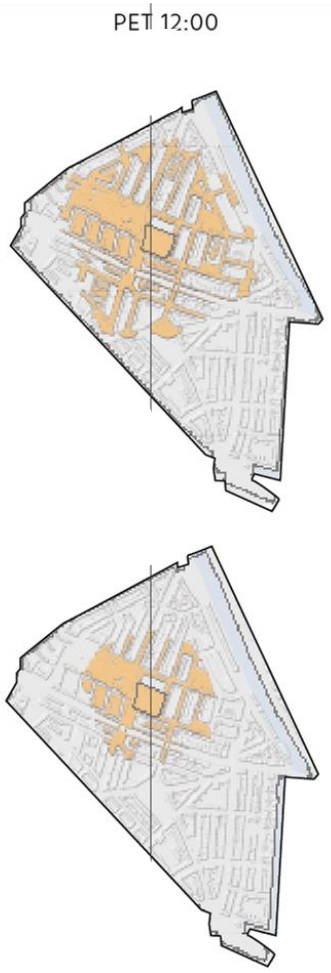




Playgrounds



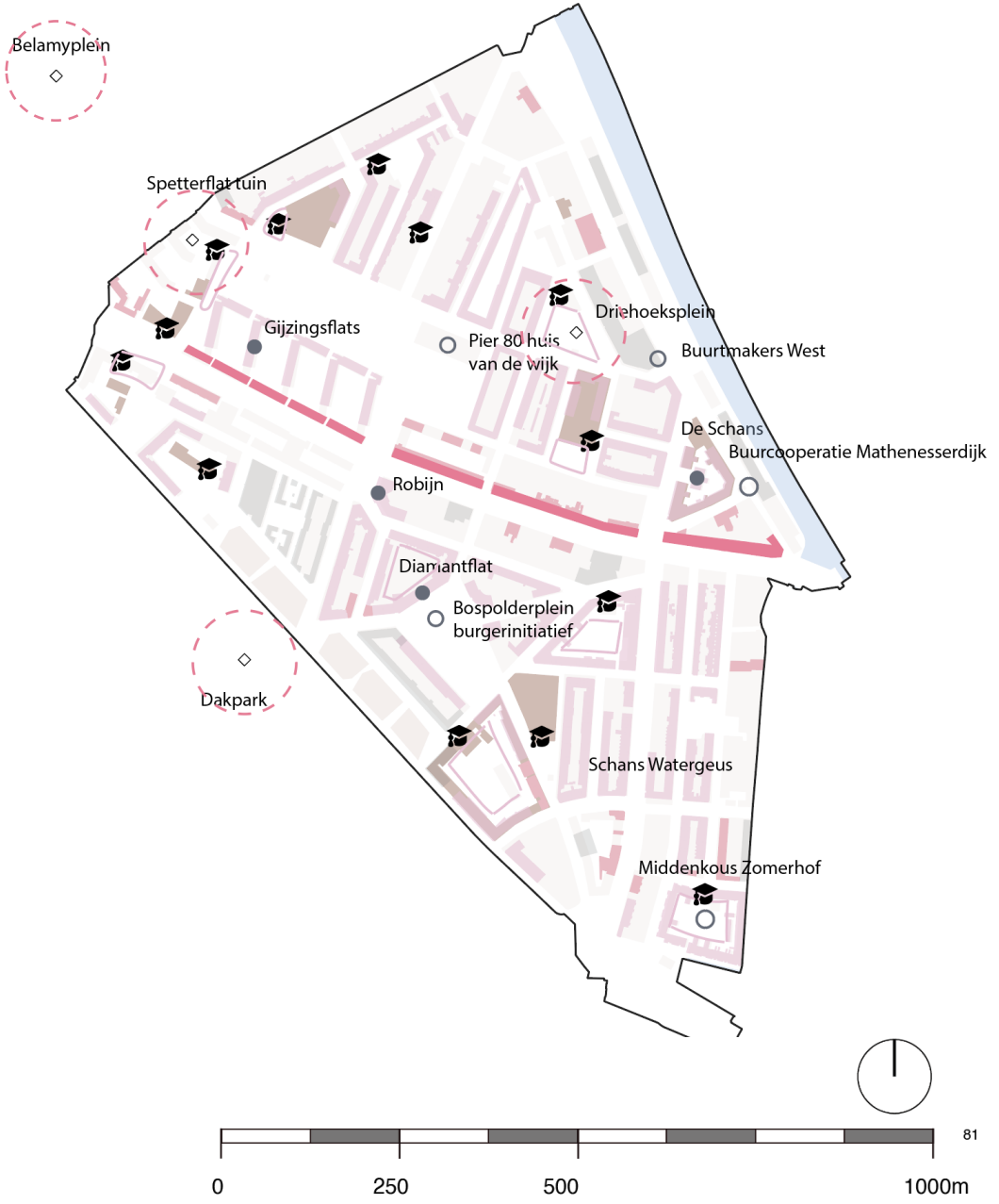
Parks



Market

Policies

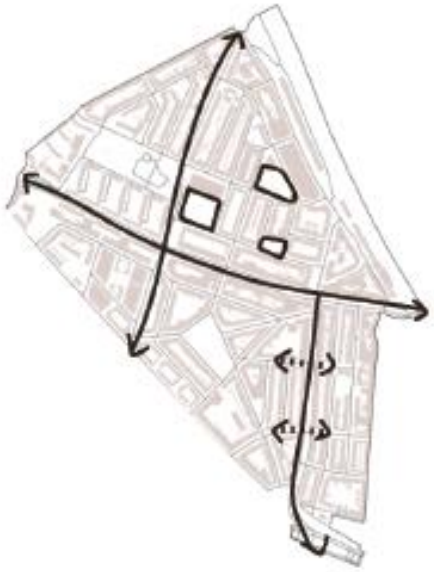
- Subsidies for greening schoolyards
- Rotterdam Omgevingsvisie for climate action
- Co-operation in the neighbourhood



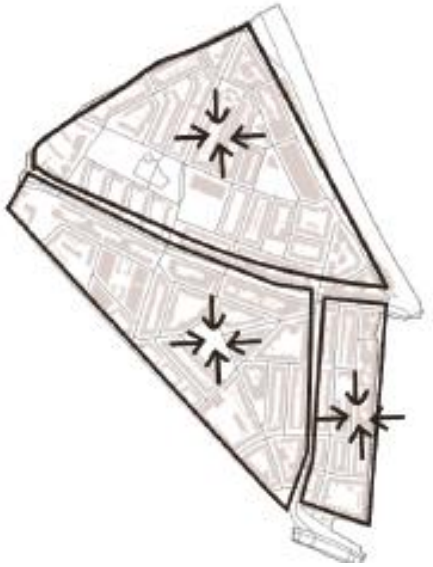
Conclusion current liveability (SWOT)

Strengths

Opportunities



Weaknesses



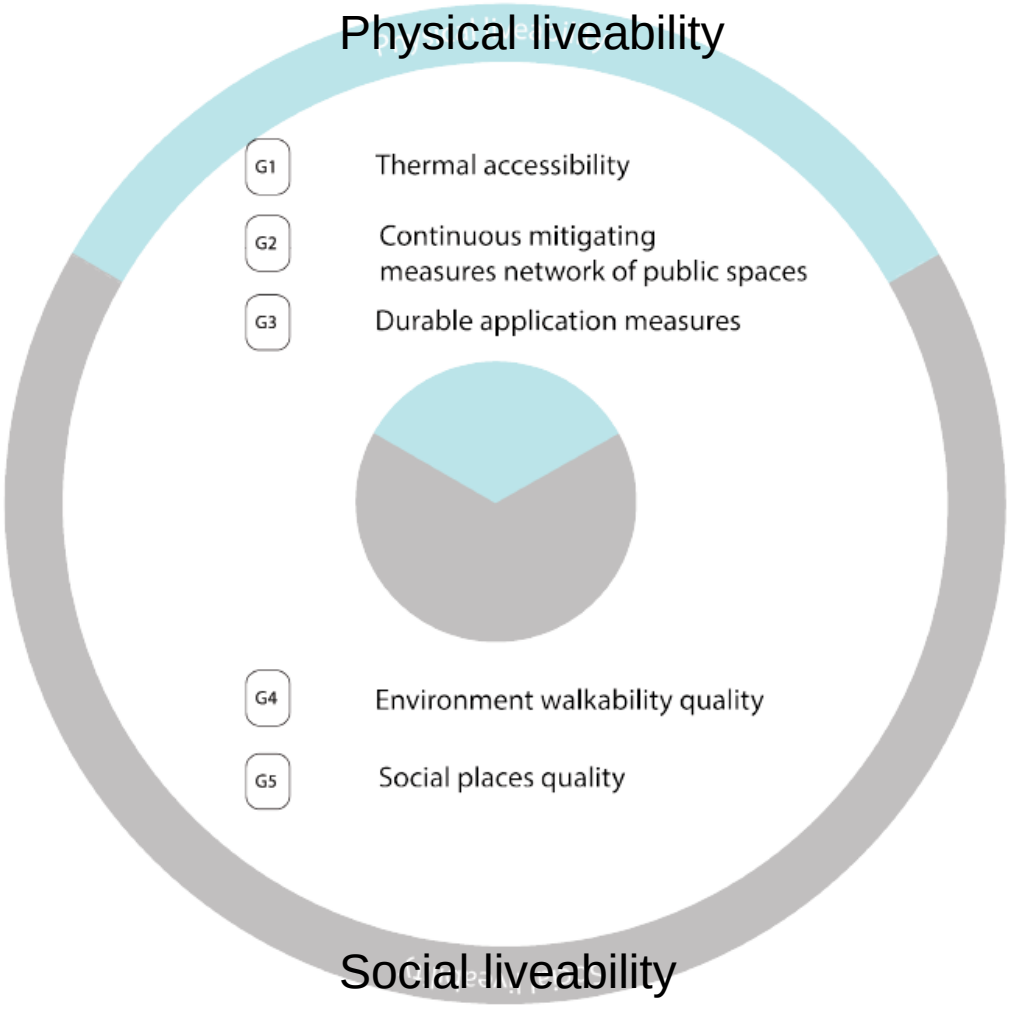
Threats

Vision

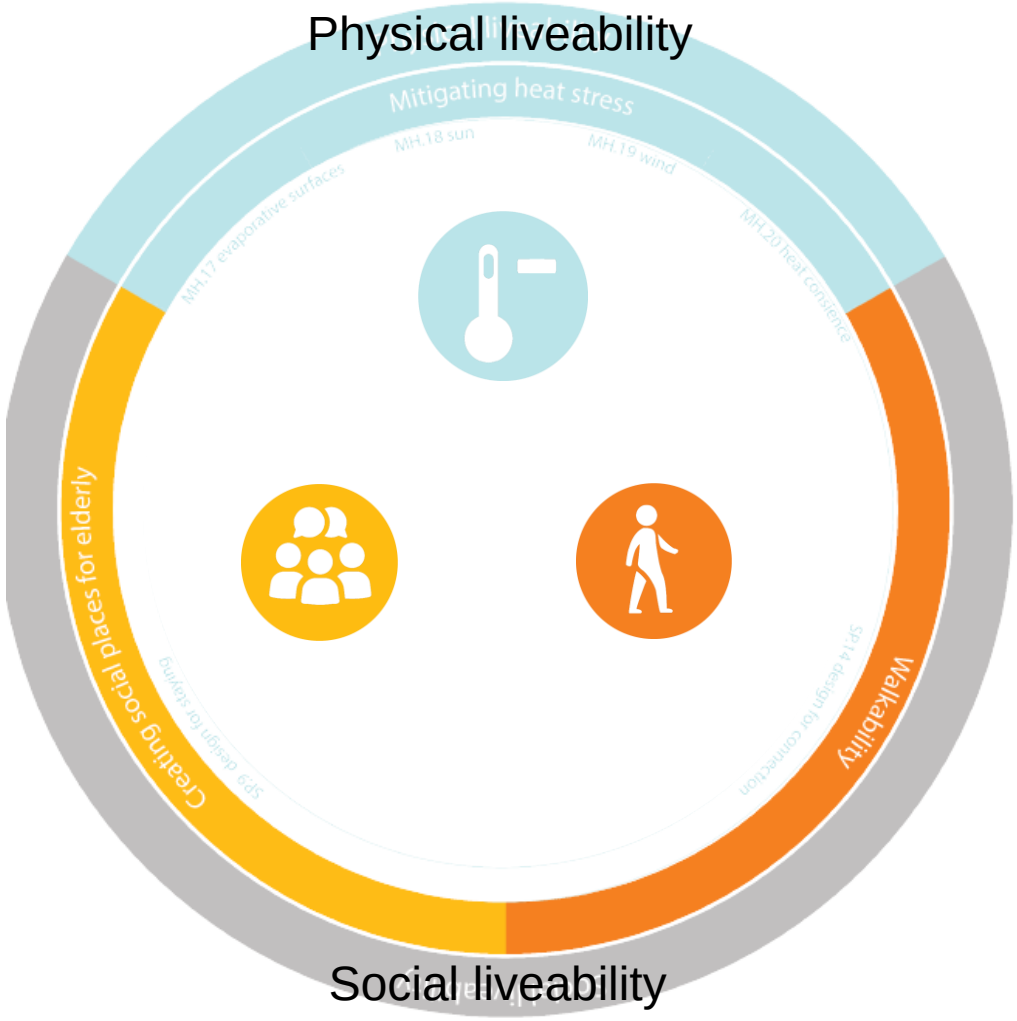
"By combining liveability urban design from the connection of neighbourhood-scale climate adaptation with citizen centric public design.

Importance of not only reducing temperatures but also cater for social structures for vulnerable groups. By the prioritisation of the network of public spaces, a liveable neighbourhood can be created."

Design principles



Design principles

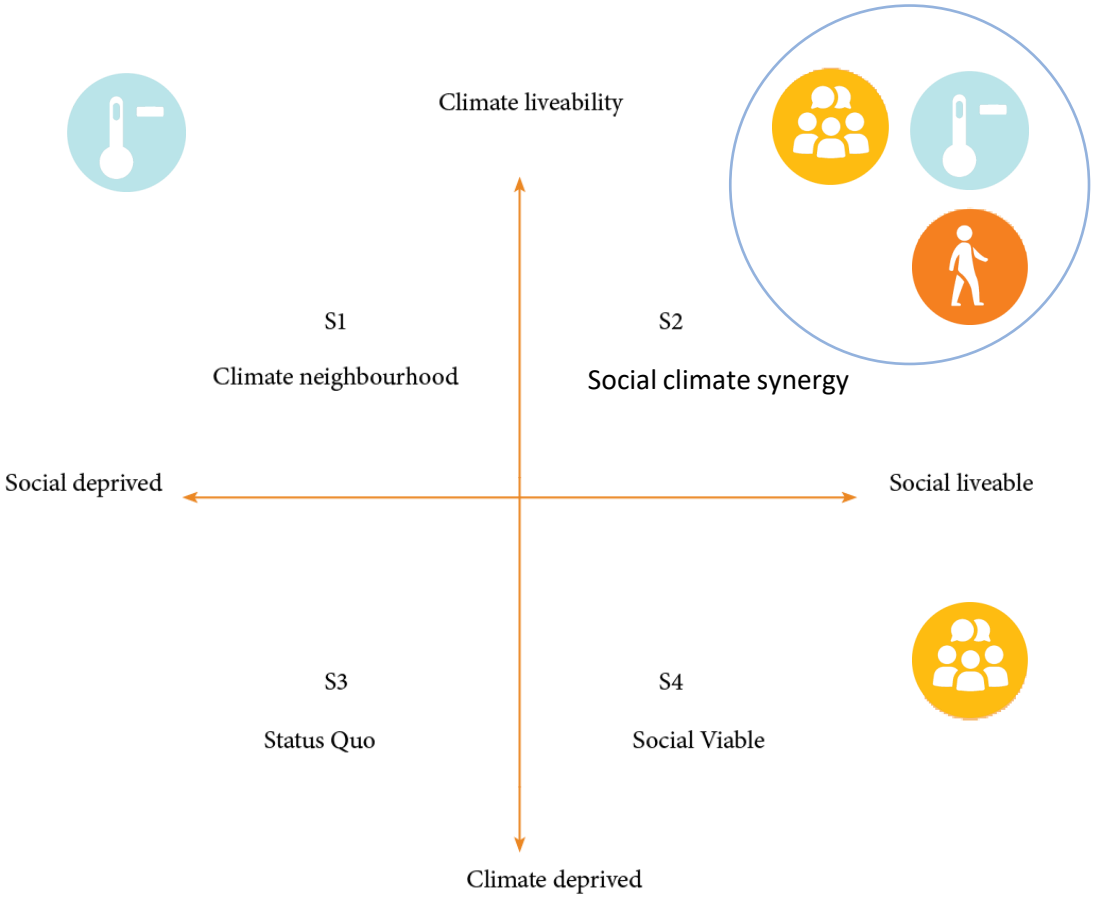


Mitigating heat stress

Improving walkability

Creating social
Spaces for vulnerable groups

Design scenario

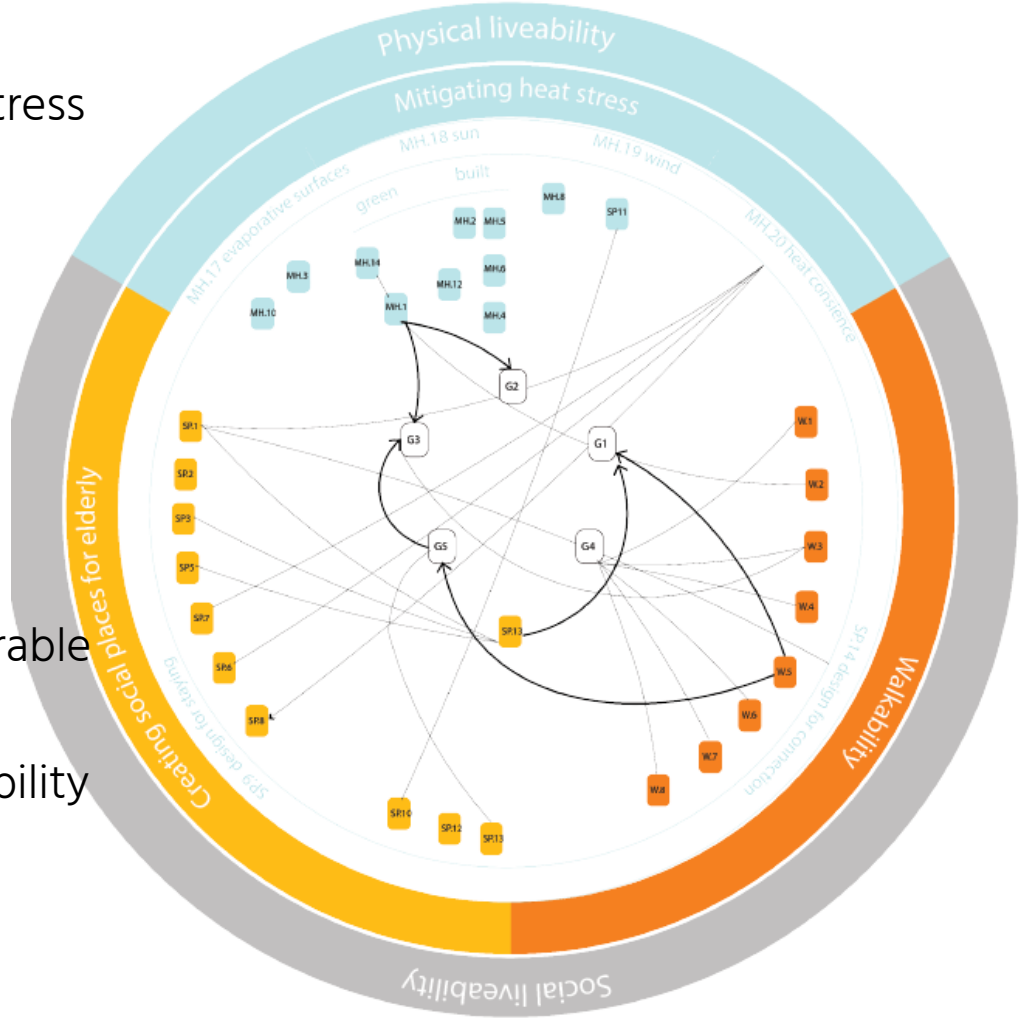


Design toolkit field

Mitigating heat stress

Creating social Spaces for vulnerable groups

Improving walkability



MH.5 toolkit

Toolkit

Code: Title

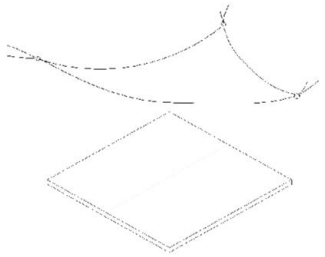
MH.5

Hypothesis

Design principle(s) related

MH.5 Sun screens

Mitigating effects



Hypothesis: shading element as flexible option

Design principle related

Context: The shade screen's projection can result in the formation of a shadow, thereby limiting the amount of shortwave radiation reaching the area. If the projection is placed at a higher level to avoid traffic, there is a possibility that the sun's rays may come from below decreasing their functionality. It does require special attention, could be placed on a eficient manner, is more common victim of vandalism.

Practical implication:

cost
multifunctional
implementation speed
ownership

Literature: Lenzholzer (2018)

IMAGE FROM: Taken by Author Portimao, Portugal

Reference picture

Context

Practical implementation (context relevant!)

Literature

Toolkit

Abstract idea

MH.20 Designing for evaporative surfaces

Mitigating effects

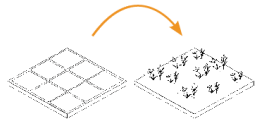
Hypothesis: evaporative materials will mitigate heat

Design principle related

Implementation

MH.10 Evaporative pavement

Mitigating effects



Hypothesis: improving the evaporative surfaces will mitigate the temperature

Design principle related

Context: Depaving causes a difference in the ratio between two types of heat transfer - sensible heat and latent heat. The ratio is inversely proportional to the wetness of the surface, implying that the wetter the surface, the lower the Bowen ratio. Next to a tree this has a higher potential of full grown canopies of trees. Therefore it is very important to give more room to a tree.

Practical implication:
cost
multifunctional
Implementation speed
ownership

Literature: Potz (2016) van Loon et al. (2016)
Relations:

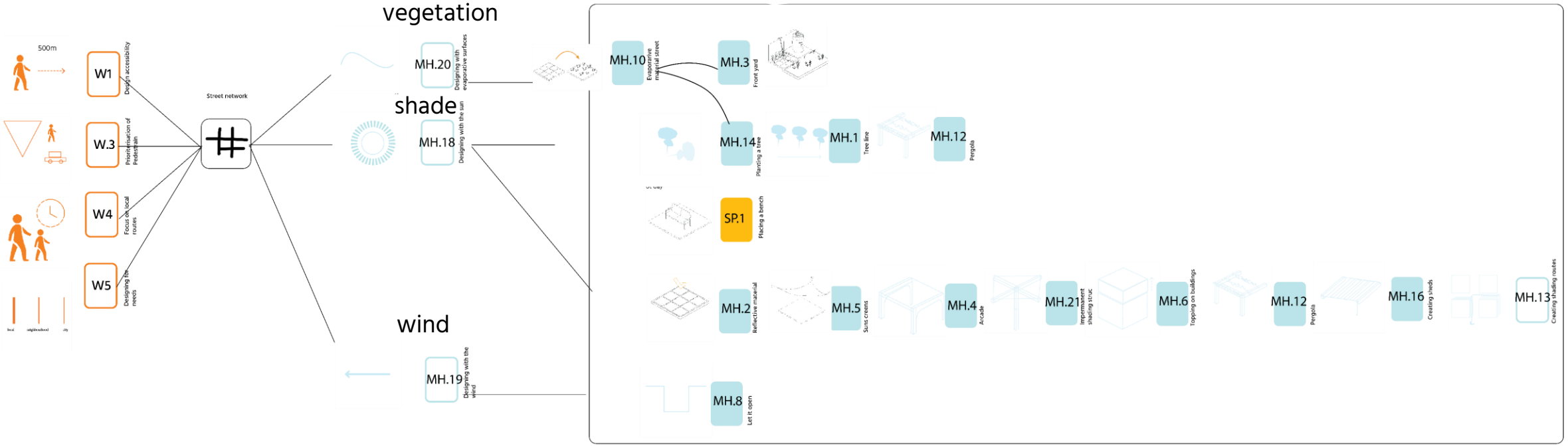
IMAGE FROM: https://earthbound.report/2015/06/02/10-reasons-to-depave-your-city/

Design flowchart streets

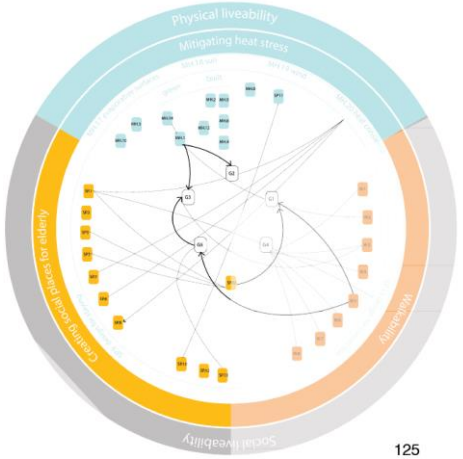
Streets

Mitigating strategy

Implementations



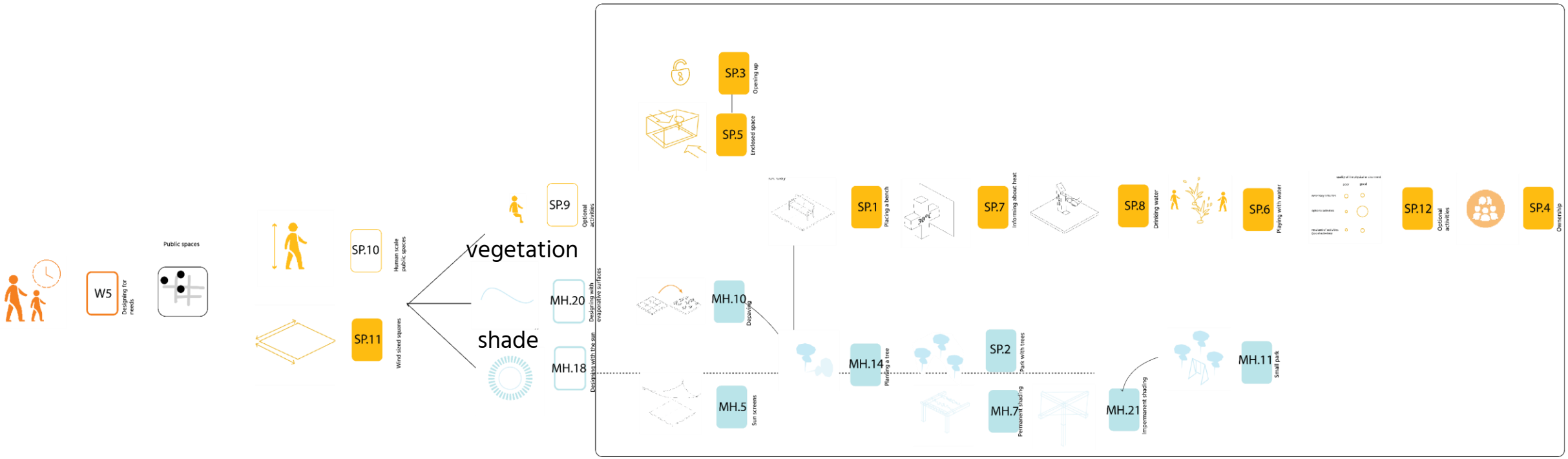
Design flowchart public spaces



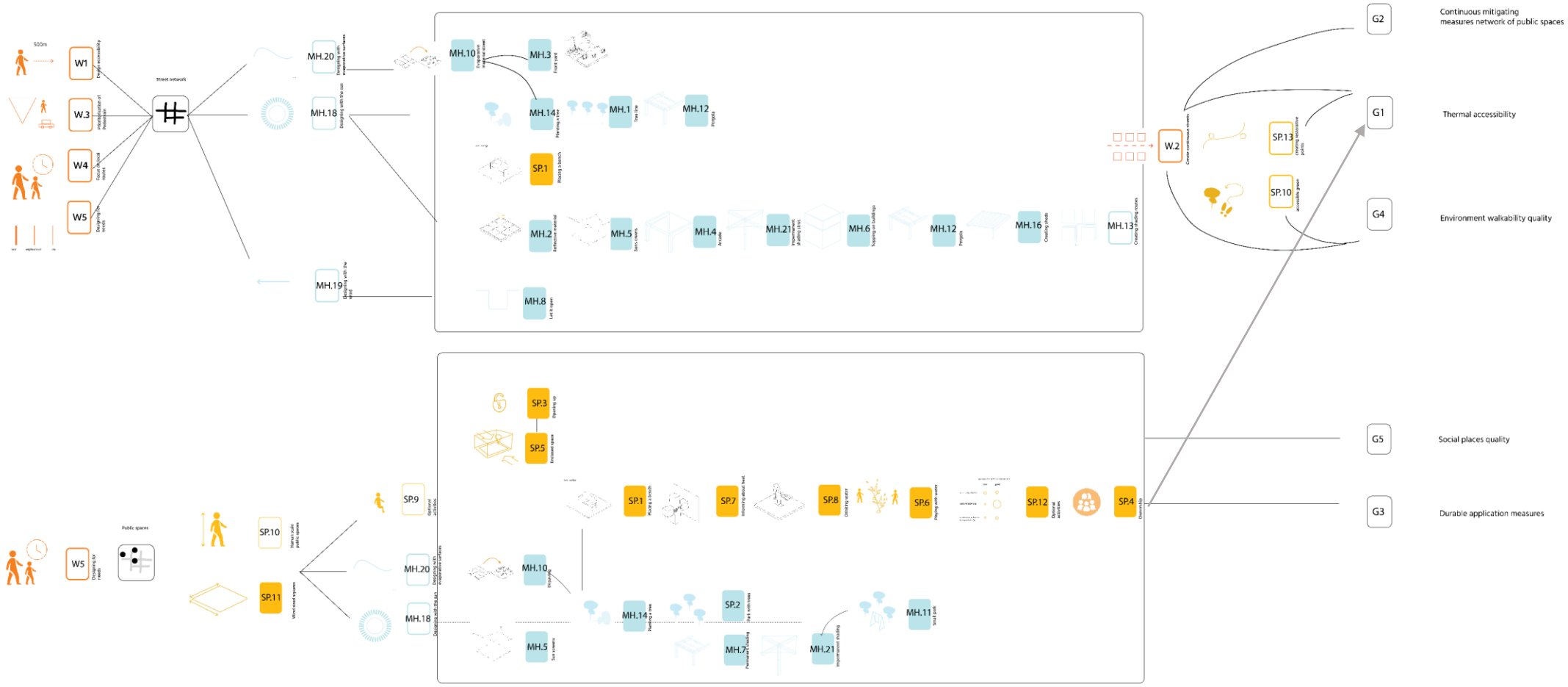
Public spaces

Mitigating strategy

Implementations



Design flowchart public spaces



Design flowchart combined

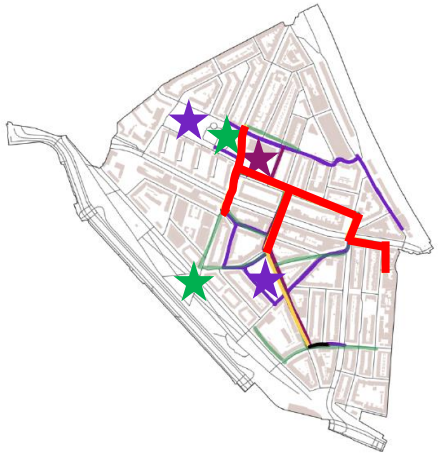
W.5 Designing for needs

Mitigating effects

Hypothesis: taking into account the usability of the place can reveal the need for heat mitigation

Design principle related

9:00



12:00

15:00

18:00

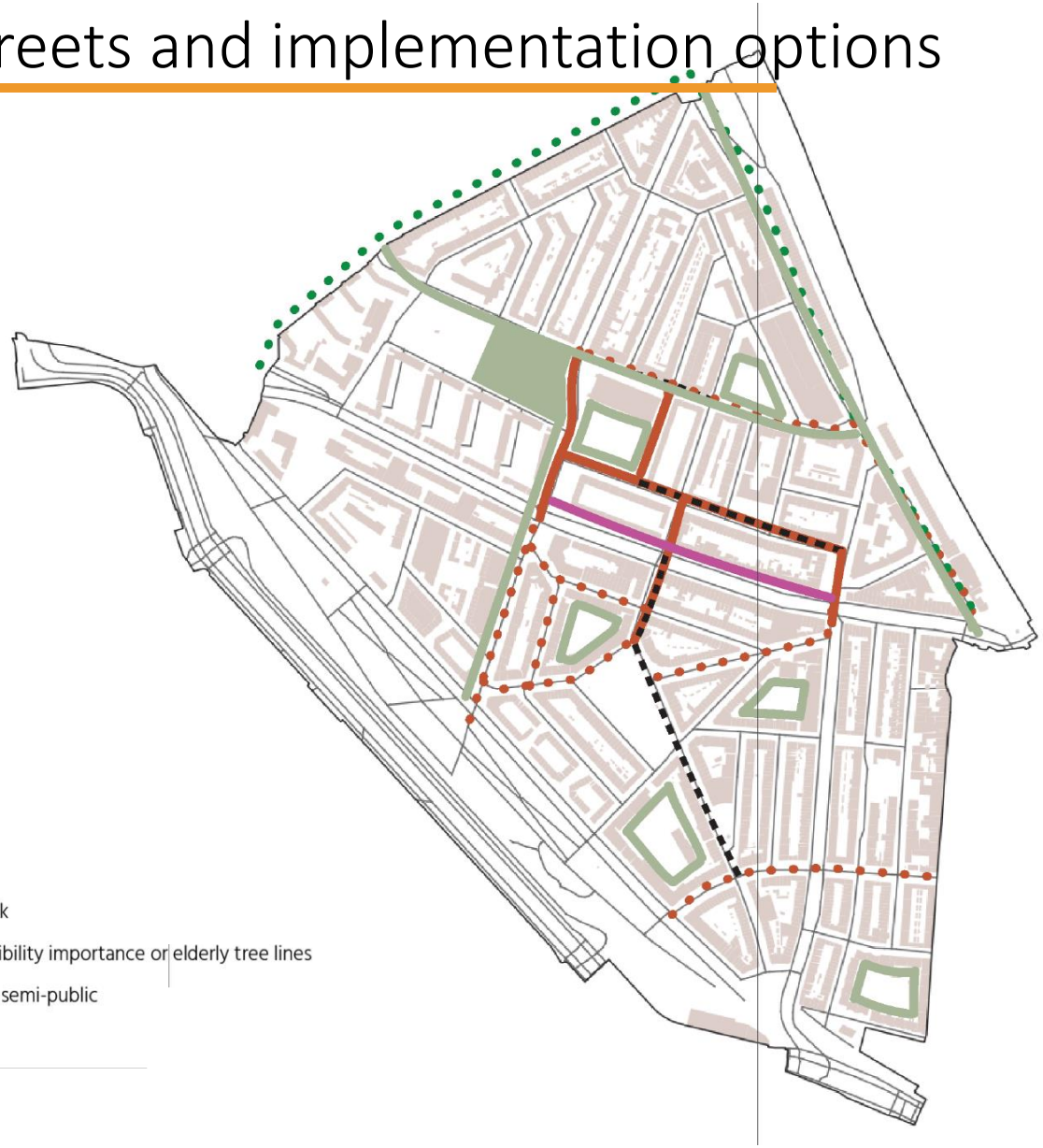
Market

Playgrounds

Parks

Overlapping streets

Prioritisation streets and implementation options



Overlapping streets

High ownership

Social retail street

2nd grade: Solely street destination

Switch in shadow demand 12 and 15 o'clock

Connection to green spaces, green accessibility importance or elderly tree lines

(Potential) Green (inner) spaces which are semi-public

Elderly tree lines

Vision

retail shading and public space option

restorative square for elderly as well

refurbished adapted to climate and social preferences Visserijplein

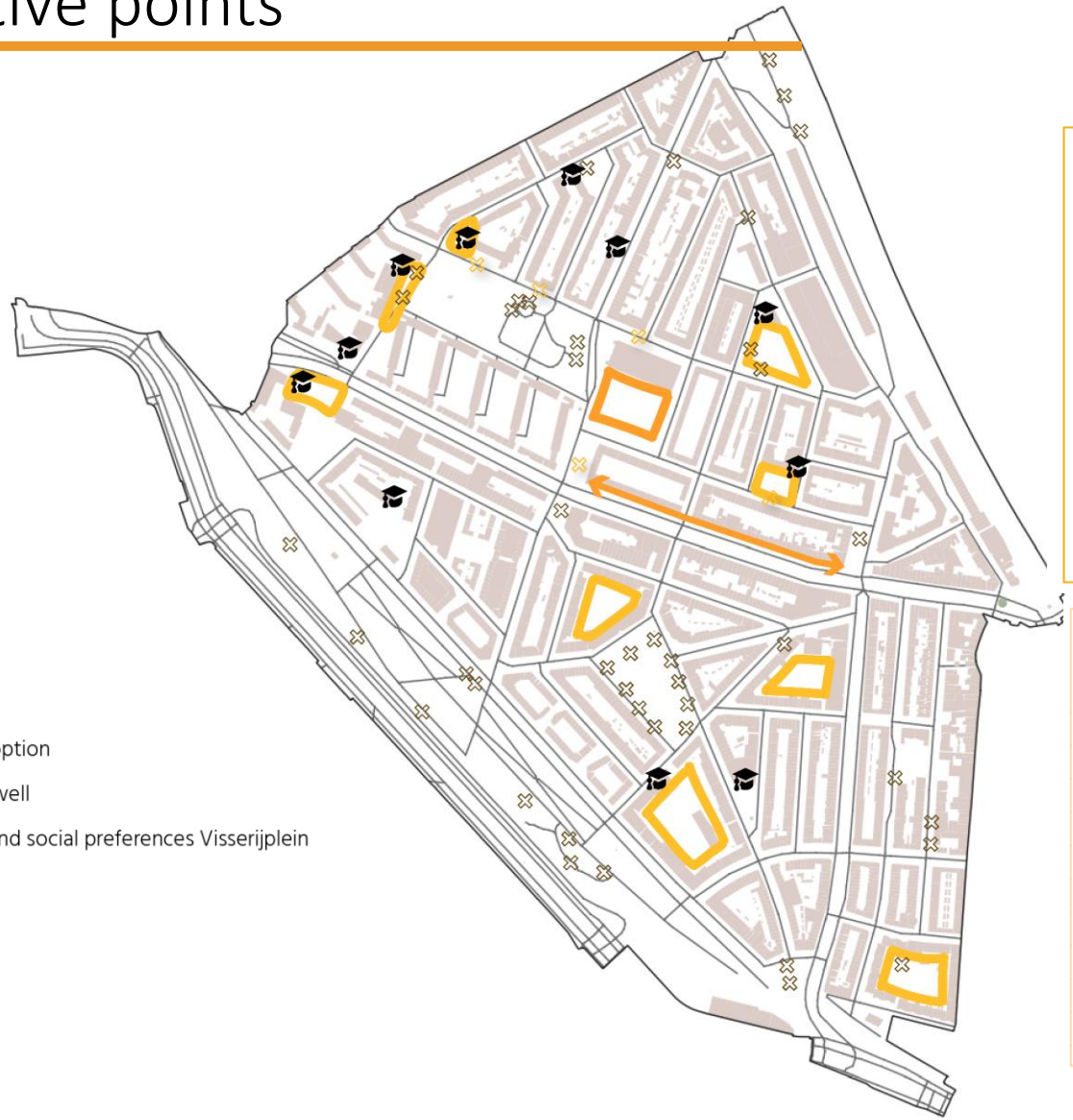
residential street

accessible green connection

small green connection

current tree line

Vision: Restorative points



retail shading and public space option

restorative square for elderly as well

refurbished adapted to climate and social preferences Visserijplein

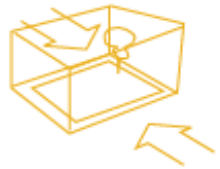
SP.9 Restorative points

Hypothesis: creating resorative points along the way

Design principle related

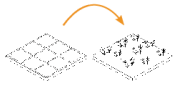
SP5. Enclosed gardens

HYPOTHESIS: lots of green and shadow formed in enclosed places can provide shelter place



MH.10 Evaporative pavement

Mitigating effects



Hypothesis: improving the evaporative surfaces will mitigate the temperature

Design principle related

SP.3 Opening up public spaces

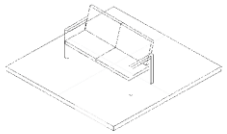
Mitigating effects

Hypothesis: opening up public spaces can enlarge the service areas of certain public spaces accessibility

Design principle related

SP.1 A bench in the shade

Mitigating effects



Hypothesis: creating resting spots for elderly during a hot day

Design principle related

Vision: Social places

SP.4 Ownership

Mitigating effects

Hypothesis: creating resting spots for elderly during a hot day

Design principle related

retail shading and public space option

restorative square for elderly as well

refurbished adapted to climate and social preferences Visserijplein

residential street

Vision: Greenery

W7. Accessible green

Mitigating effects

Hypothesis: making sure that greenery is accessible to everyone

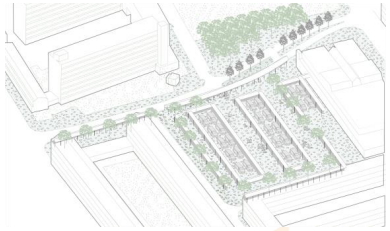
Design principle related

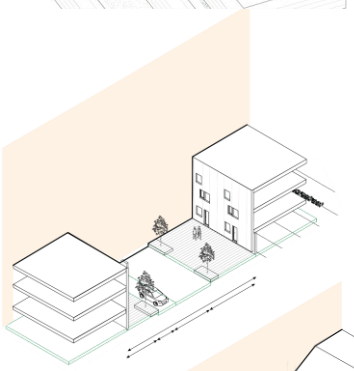
accessible green connection

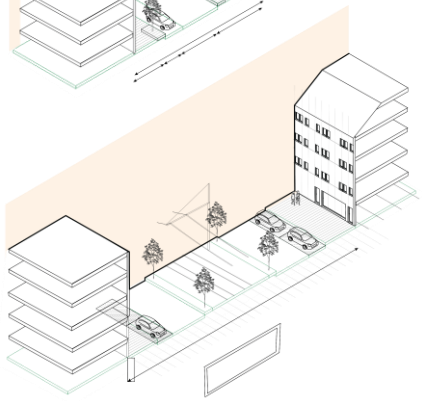
small green connection

current tree line

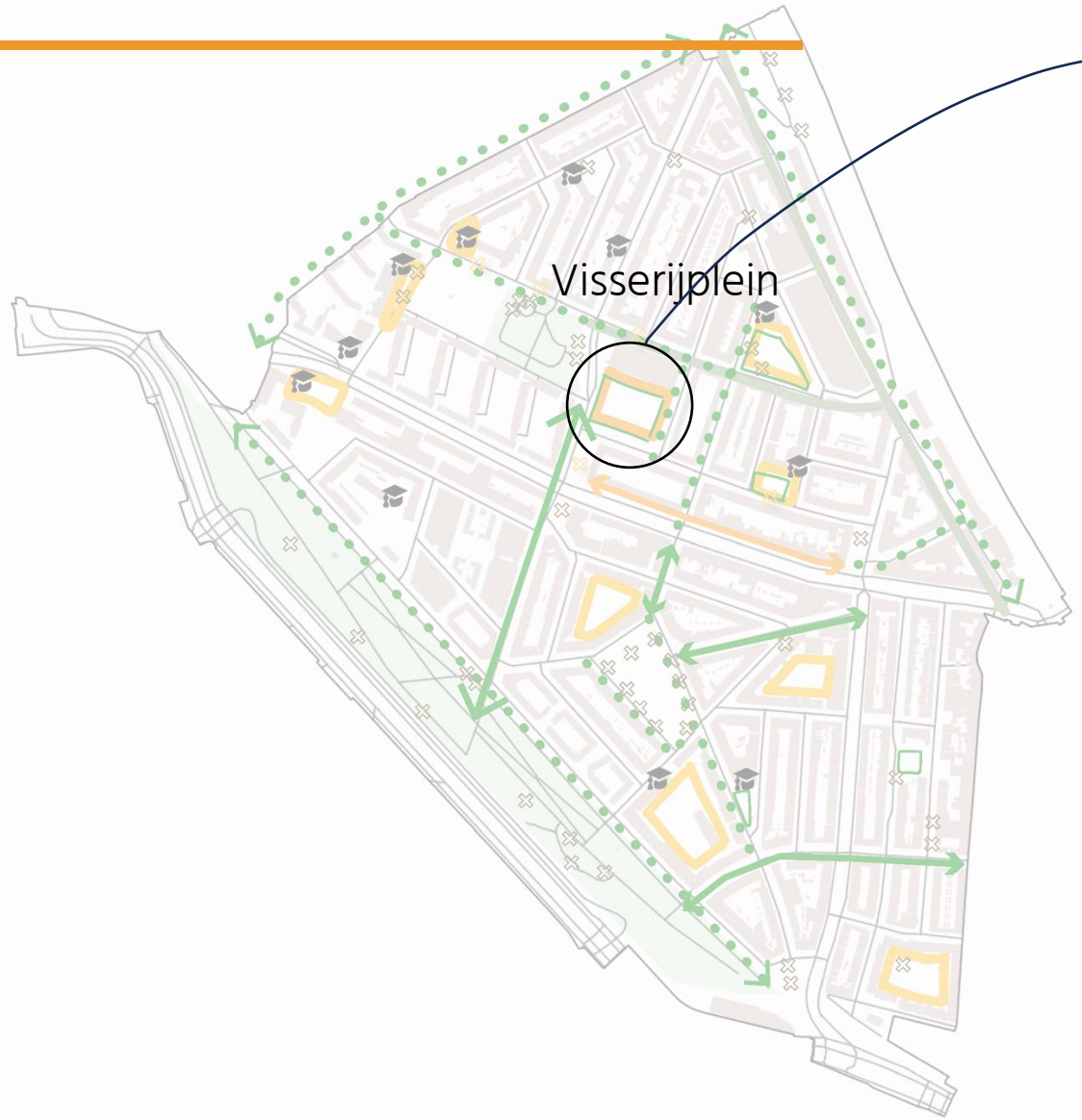
Zoom ins

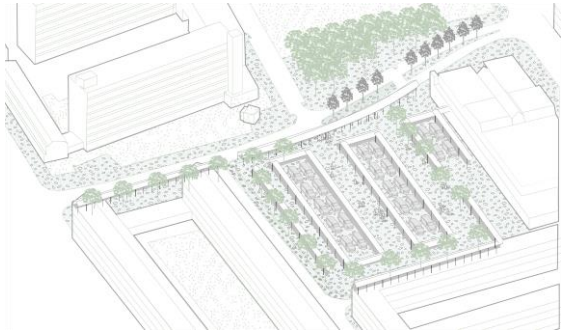




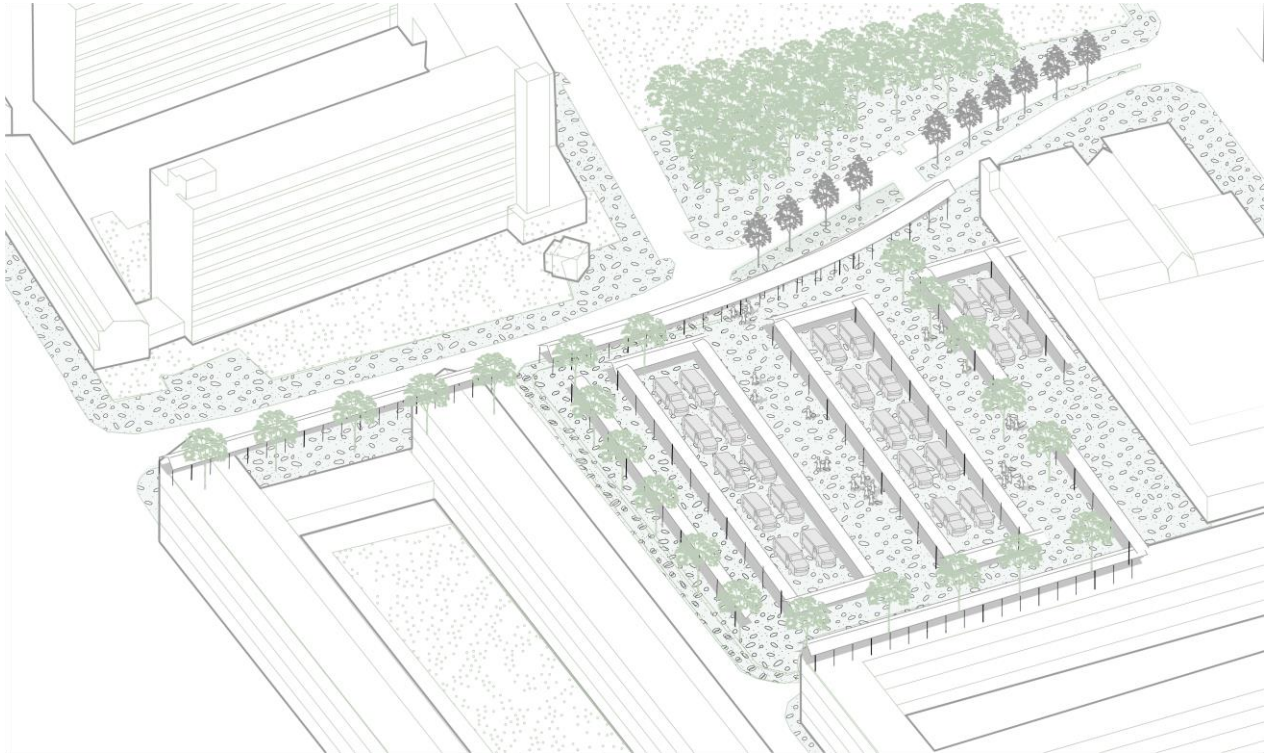


Zoom ins





Visserijplein



Visserijplein: social green option

SP.10 Human scale public spaces

Mitigating effects

Hypothesis: public spaces with 20-25 metres distances are perceived as social spaces

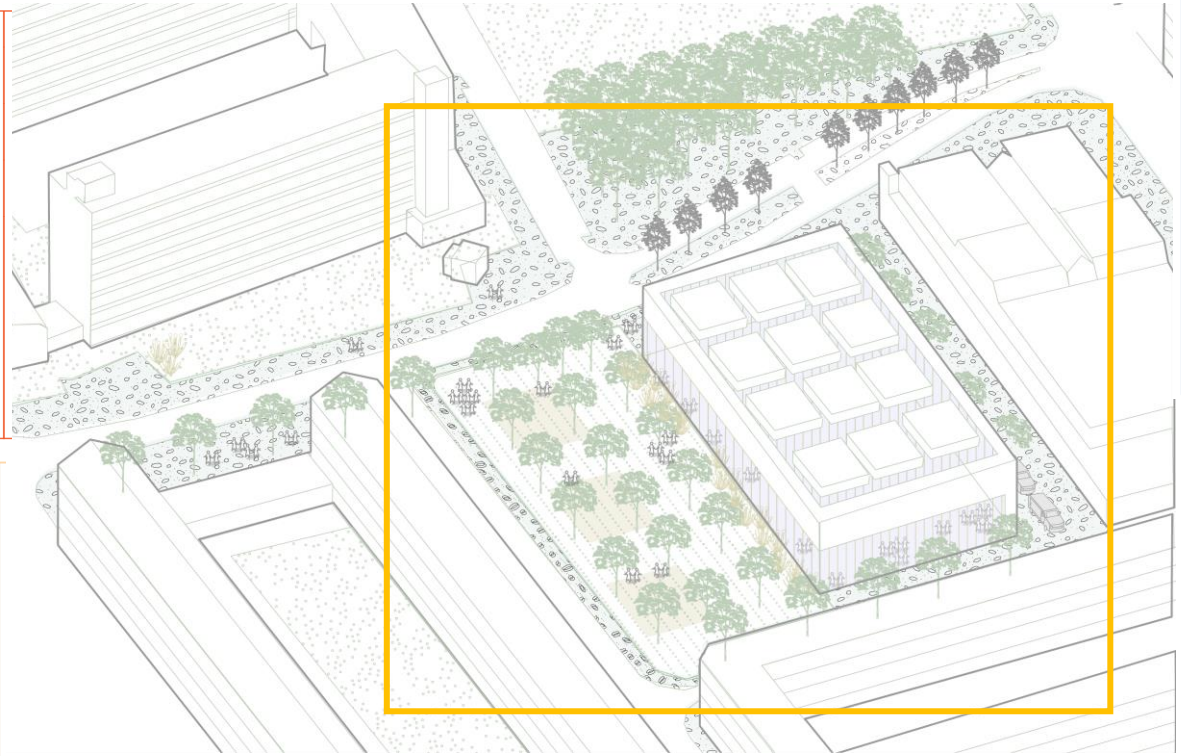
Design principle related

W.5 Designing for needs

Mitigating effects

Hypothesis: taking into account the usability of the place can reveal the need for heat mitigation

Design principle related



MH.12 Pergola

Mitigating effects

Hypothesis: creating a natural shading improves the shading as evaporative areas

Design principle related

MH.14 Planting a tree

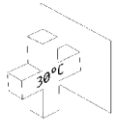
Mitigating effects

Hypothesis: creating evaporative srfaces for mitigating heat

Design principle related

SP.7 Informing about heat

Mitigating effects

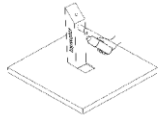


Hypothesis: informing people of the heat causing behaviour conscience

Design principle related

SP.8 Drinking water

Mitigating effects



Hypothesis: facilitating hydratation spots causes behaviour conscience

Design principle related

SP.12 Optional activities

Mitigating effects

Hypothesis: A place which offers optional activities has a residual better public space

Design principle related

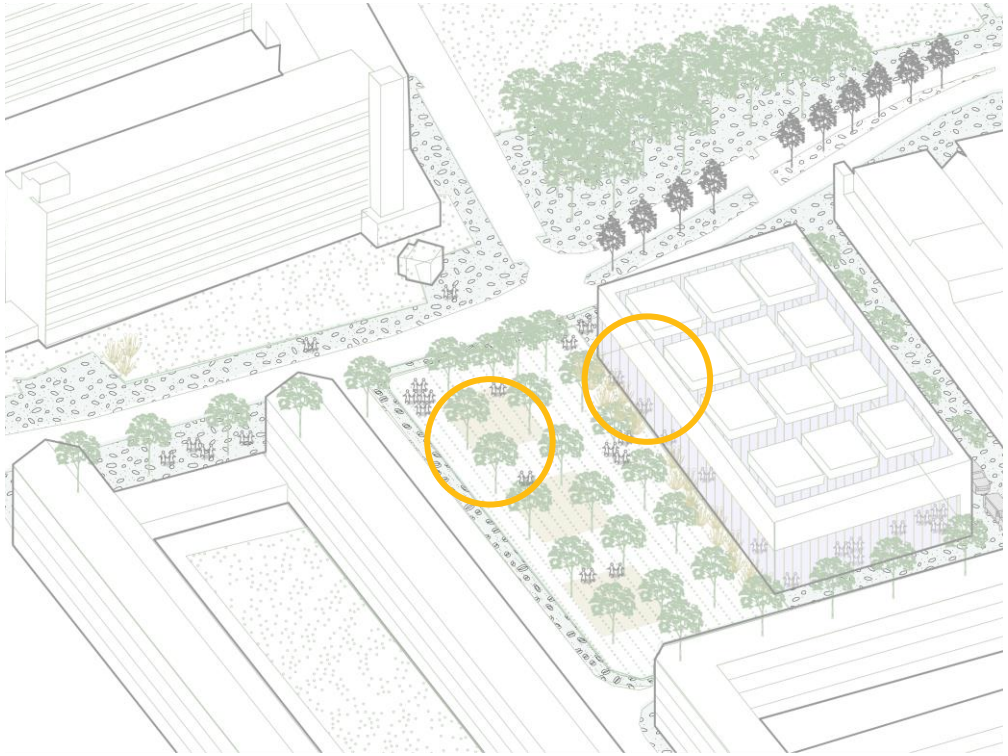
MH.11 Small park

Mitigating effects

Hypothesis: little spot for evaporative area as well as a little communal space

Design principle related

Visserijplein: social green option

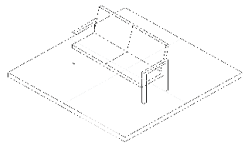


Zoom ins

Schipperstraat: Green connection

SP.1 A bench in the shade

Mitigating effects



Hypothesis: creating resting spots for elderly during a hot day

Design principle related

MH.11 Small park

Mitigating effects

Hypothesis: little spot for evaporative area as well as a little communal space

Design principle related

W7. Accessible green

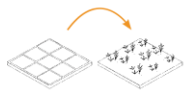
Mitigating effects

Hypothesis: making sure that greenery is accessible to everyone

Design principle related

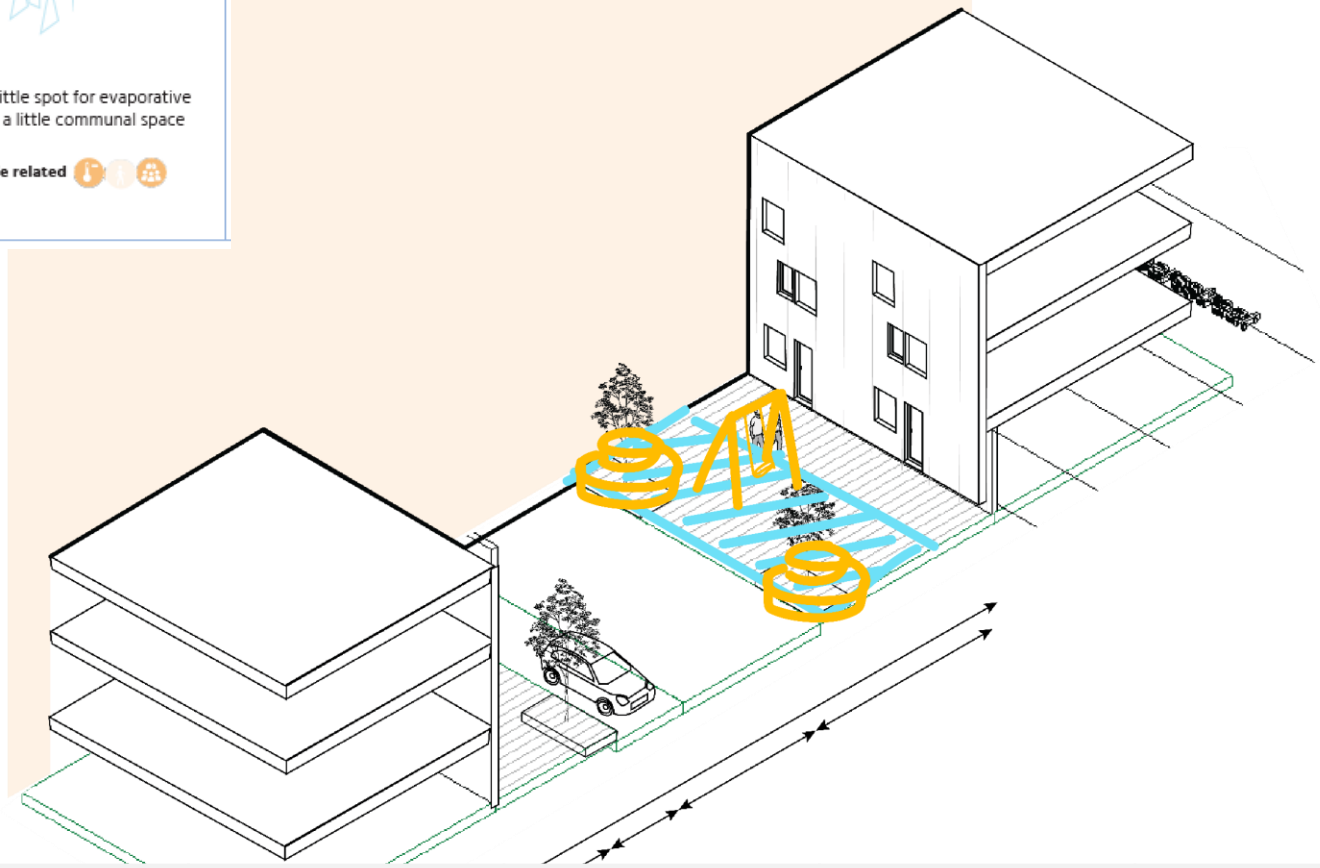
MH.10 Evaporative pavement

Mitigating effects

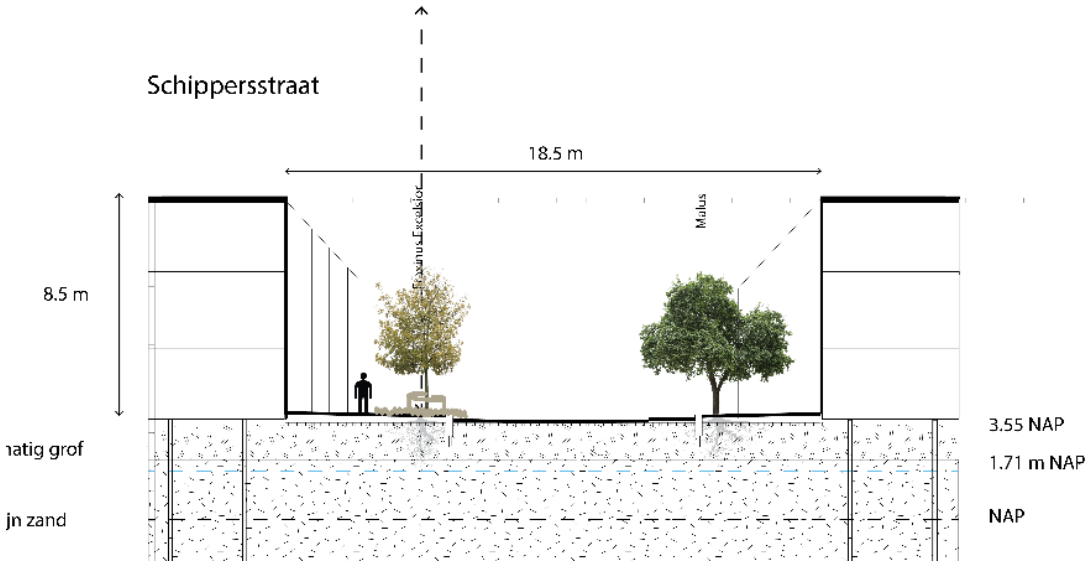


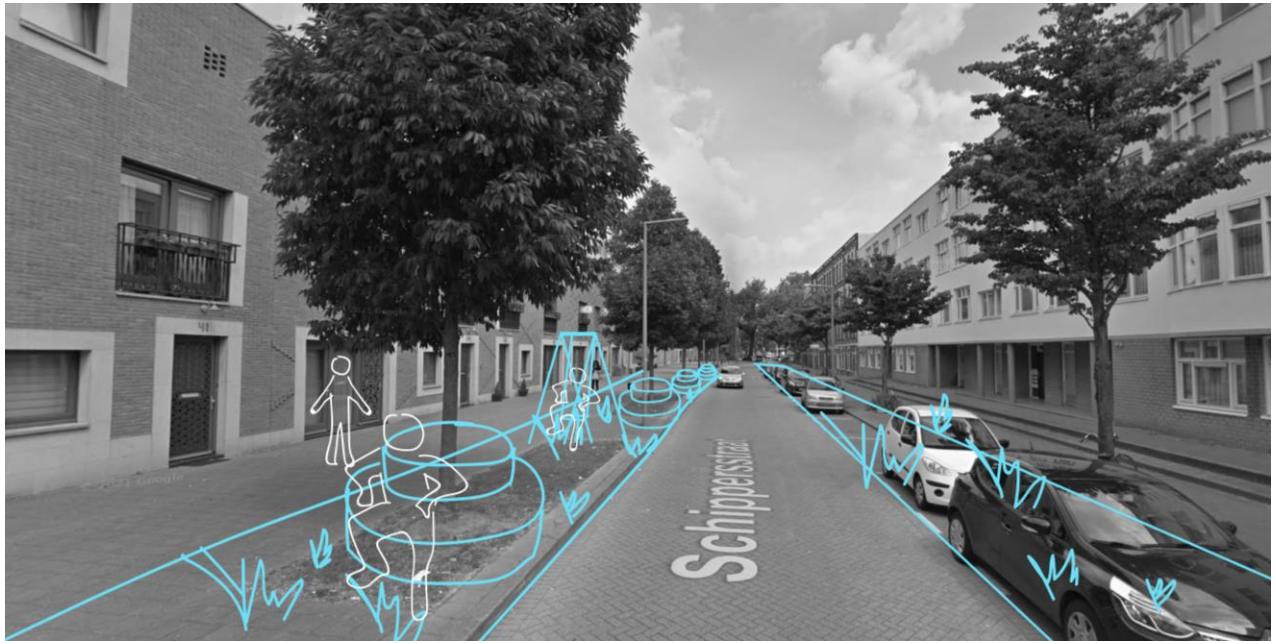
Hypothesis: improving the evaporative surfaces will mitigate the temperature

Design principle related



Schipperstraat





Zoom ins

Schiedamseweg: Retailstreet

SP.9 Restorative points

Hypothesis: creating resorative points along the way

Design principle related

W.3 Prioterisation of the pedestrain

Mitigating effects

Hypothesis: less car dominant will lead to an pedestrain friendly environment

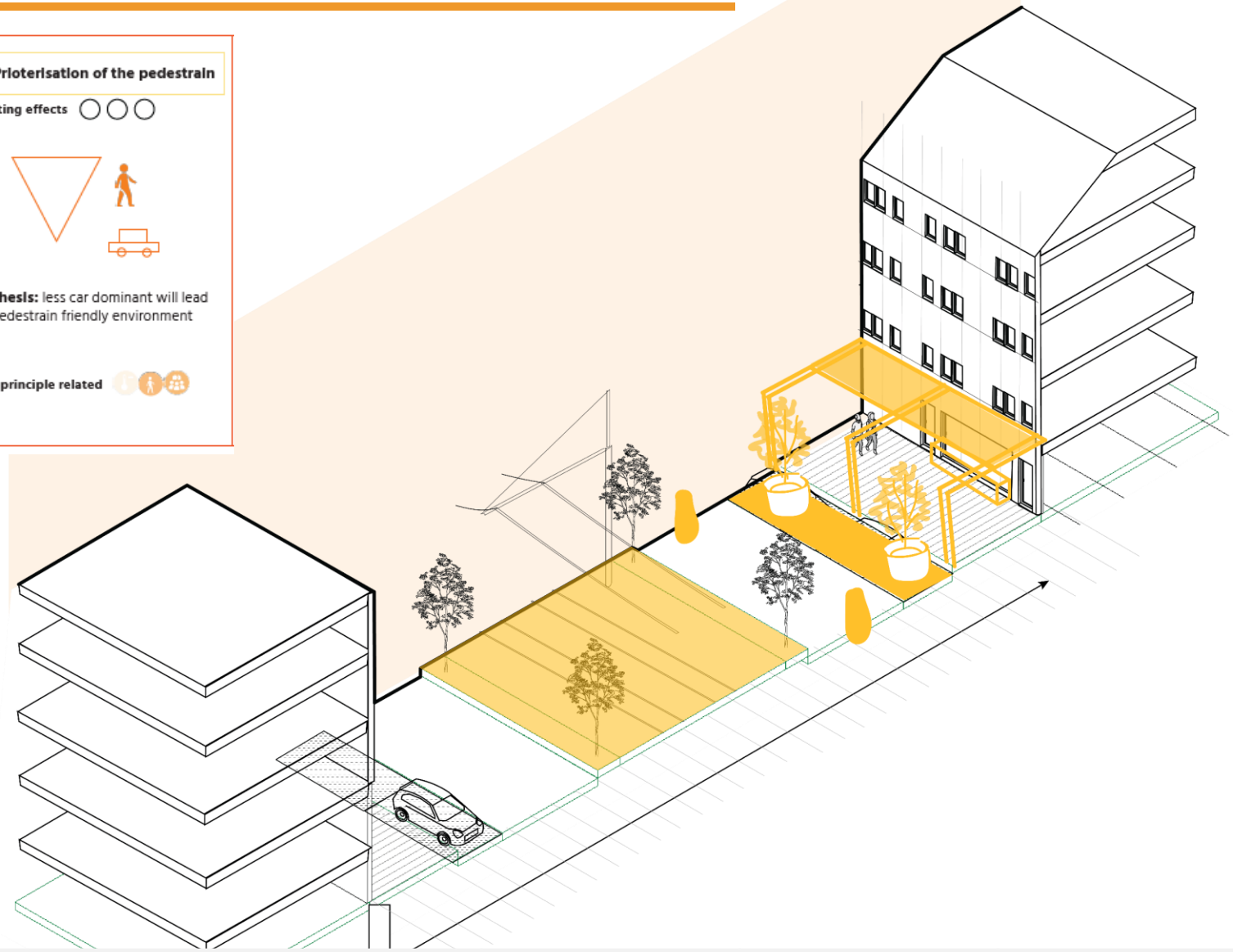
Design principle related

SP.4 Ownership

Mitigating effects

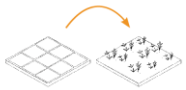
Hypothesis: keeping responsibility towards places increases durability of mitigating effects

Design principle related



MH.10 Evaporative pavement

Mitigating effects



Hypothesis: improving the evaporative surfaces will mitigate the temperature

Design principle related

Schiedamseweg: Retail street

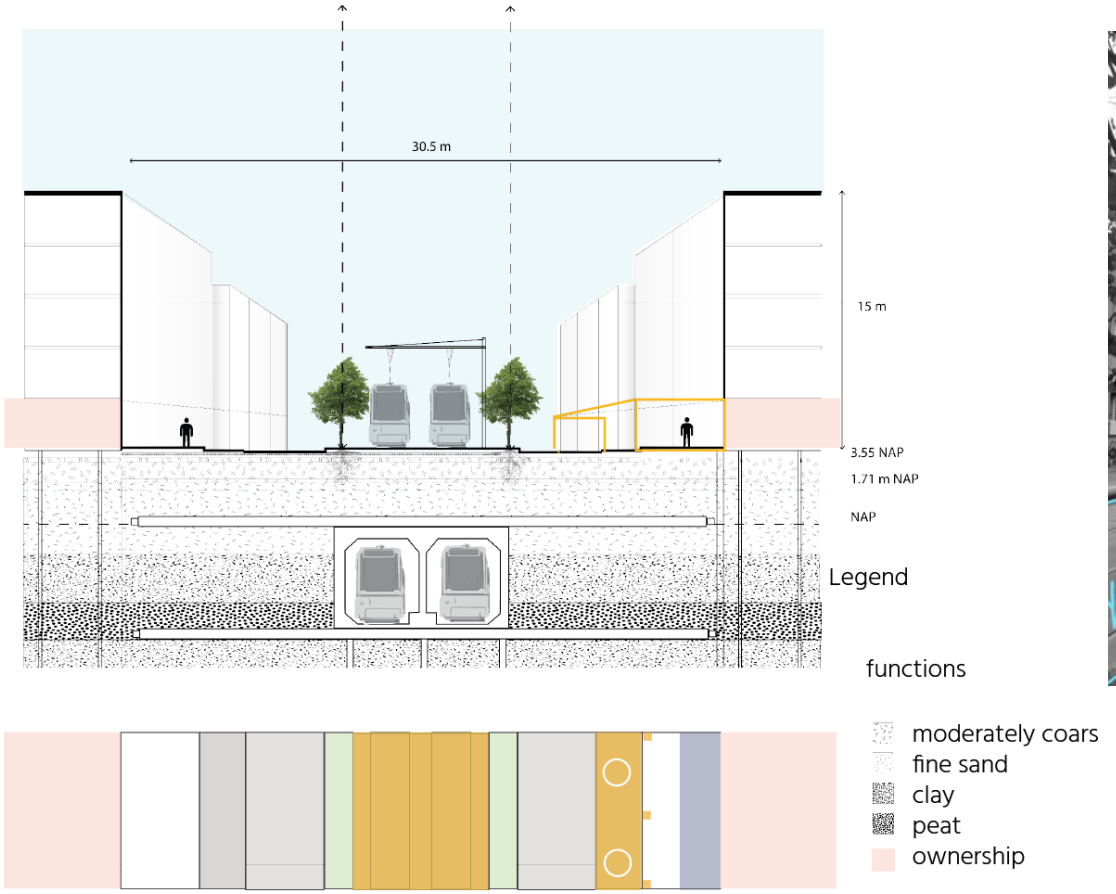


Fig. 6.25 Technical section drawing. Created by Author

Vision

Driehoeksplein by Urbanism firm Urban Synergy

https://duurzaam010.nl/nieuws/driehoeksplein-wordt-veel-groener-net-als-de-rest-van-rotterdam/

Conclusion

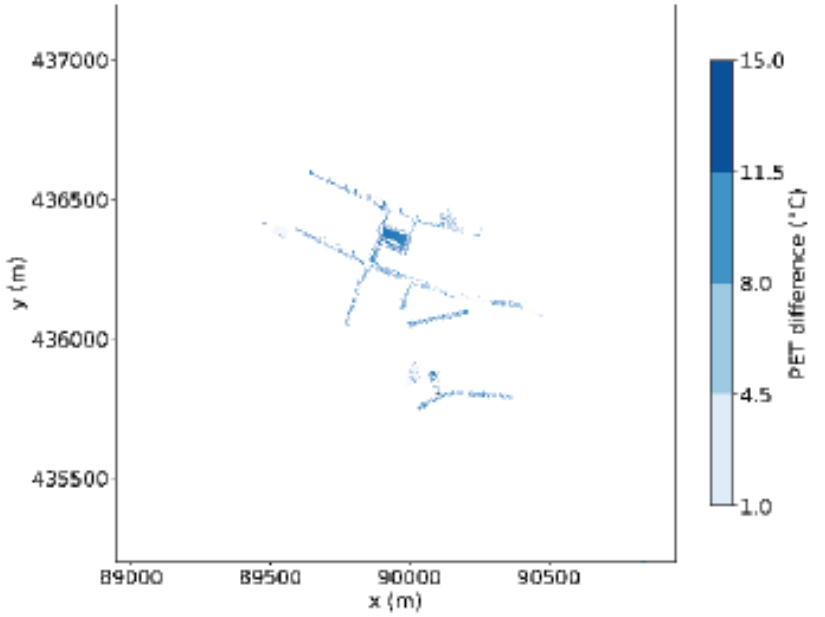
1. How could a reproducible tool help to simulate mitigating heat?

2. Is the liveability improved?

Assessment intervention – green effect

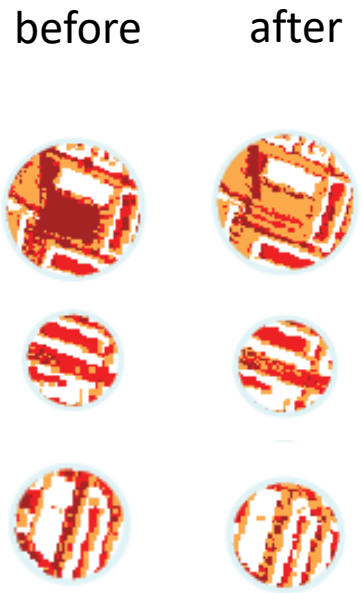
7.2 Trees addition or update of crownsize

7.3 Intervention adding green in the streetscape



12:00 PET C design intervention tested
PET mitigating effect

Assessment intervention – green and shadow effect 12:00



Legend
PET classification

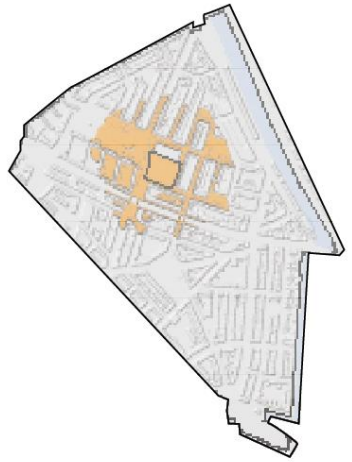
13-18	slightly cold stress
18-21	no thermal stress
23-29	slight heat stress
29-35	moderate heat stress
35-41	strong heat stress
>41	extreme heat stress

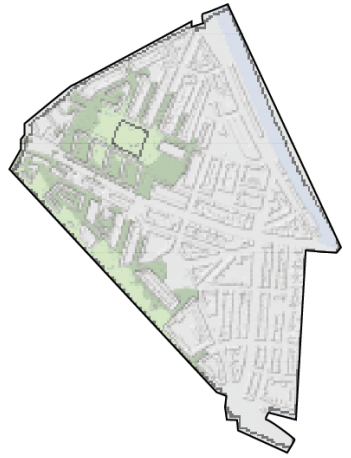
Assessment intervention

12:00: market

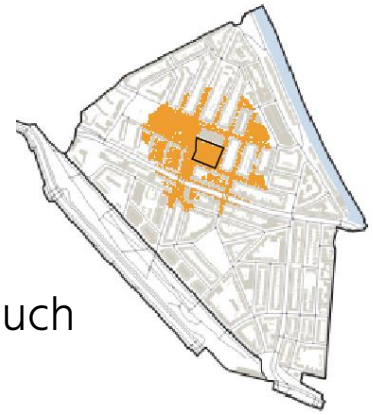
12:00: parks

Thermal accessibility 500m without intervention





Thermal accessibility 500m with intervention



Not much of a difference
Resistance differences not too much

Assessment

Climate liveability

Thermal accessibility elderly summer day

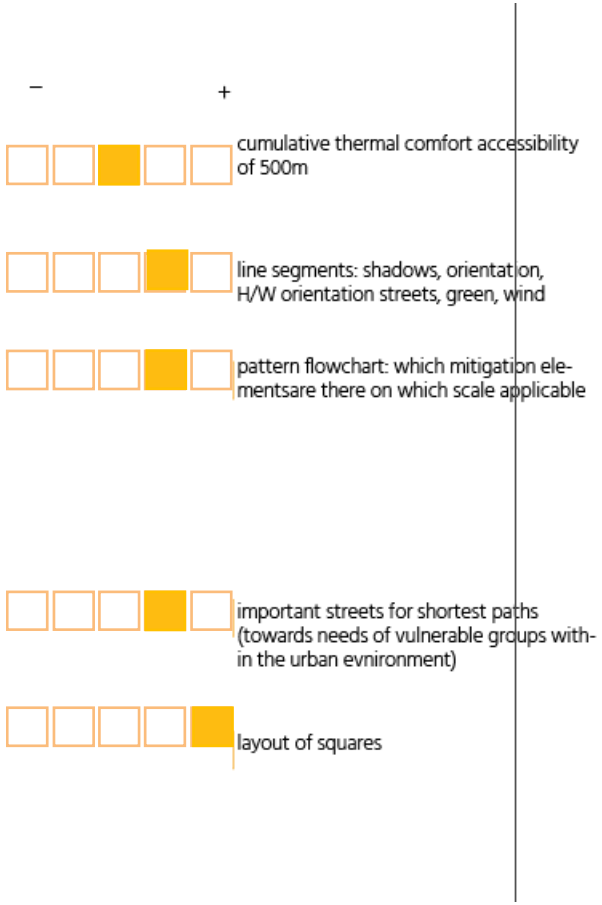
Continuous mitigation measures

Durable mitigation measures

Social liveability

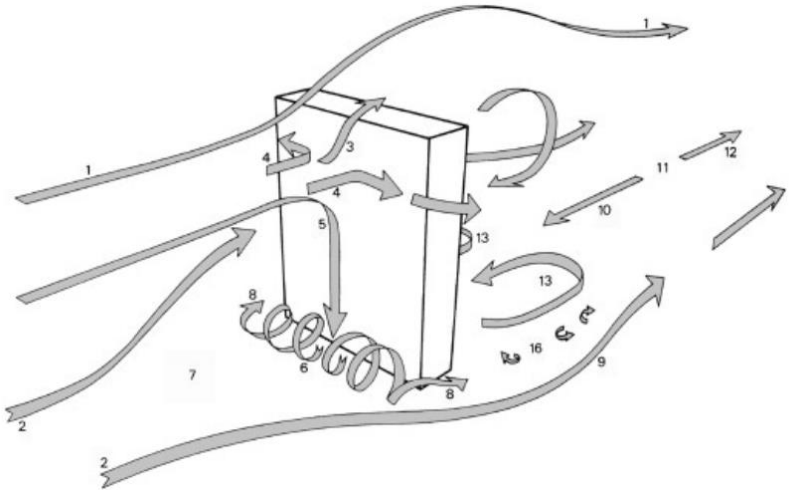
Continuous walkable routes towards destinations

Social places which are inviting to vulnerable groups



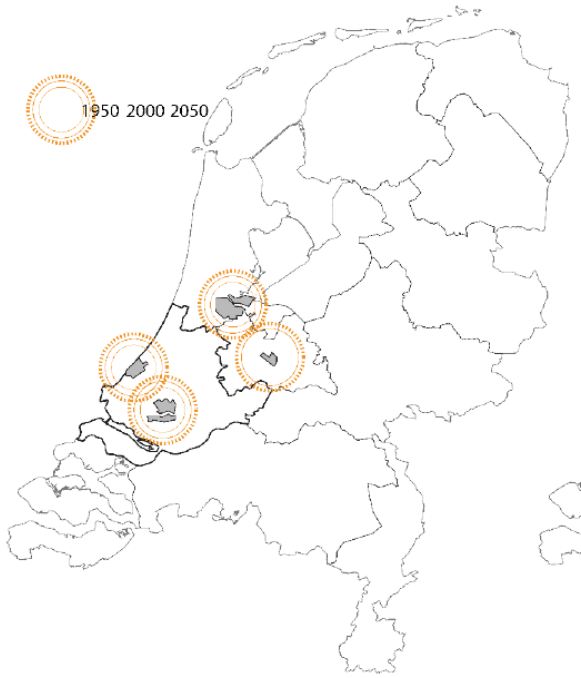
Limitations

- Wind modelling should be improved to be able to design with it
- Not too extreme design decisions were made



Transferability

- Directly transferable to the same neighbourhood typology
- Other neighbourhood typologies do need another rearrangement in the toolkit approach
- Other target groups are possible



Big population growth in Dutch cities

Same demographic and building type

Conclusions

"How can a strategy be developed for mitigating heat stress through Physiological Equivalent Temperature model while ensuring a liveable environment for vulnerable groups in Bospolder Tussendijken, Rotterdam, the Netherlands?"

- Different methods are required: heat stress model to indicate and assess interventions and toolkit
- With a combination of social liveability and physical liveability, citizen-centric is combined with neighbourhood performances of the neighbourhood a synergy is established
- By improving several streets with different design concepts like greenery, creating restorative places and acting on social ownership on public spaces and streets a heat mitigation network for vulnerable groups is developed

Future work

- Health experts' consultation
- Health is more affected during the night (Urban Heat Island)
- Implementation of more heat mitigation measures within the PET model

Reflection

- **Academic relevance:** integrating knowledge for more application options
- **Social relevance:** more heat action for health improvements
- **Ethical considerations:** short term shortages vs long term improvements for health

- Different methods do have different functions in developing a holistic heat mitigation strategy
- Due to climate change an integrated strategy is needed by multiple parties to act for climate change

➢ By integrating a more walkable and greener environment: less emissions

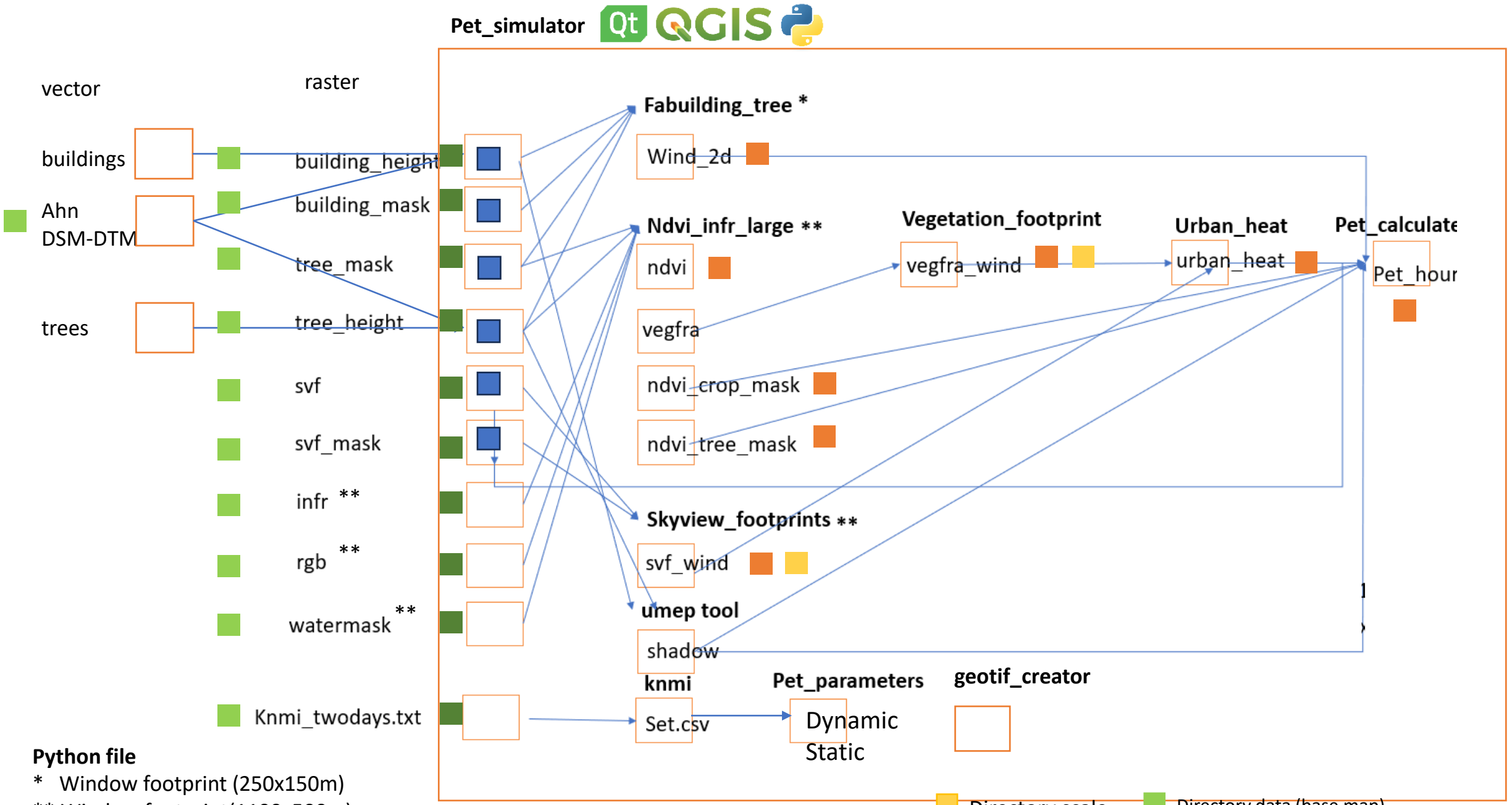
➢ Better life quality for all!

From thermal comfort to heat mitigation action

MSc Thesis Urbanism and Geomatics
Marieke van Esch

TU Delft

Appendix


Pet_simulator
QGIS
vector
raster
buildings
Ahn
DSM-DTM
trees
building_height
building_mask
tree_mask
tree_height
svf
svf_mask
infr **
rgb **
watermask **
Knmi_twodays.txt
Fabuilding_tree *
Wind_2d
Ndvi_infr_large **
ndvi
vegfra
ndvi_crop_mask
ndvi_tree_mask
Vegetation_footprint
vegfra_wind
Urban_heat
urban_heat
Pet_calculate
Pet_hour
Skyview_footprints **
svf_wind
umep tool
shadow
knmi
Set.csv
Pet_parameters
Dynamic
Static
geotif_creator
Python file
* Window footprint (250x150m)
** Window footprint(1100x500m)
Block size averaging incorporated (1m, 5m,25m)
.gtif file also as .jpg in directory tif
Directory scale
Directory output
Directory data (base map)
Directory input (extended research area)

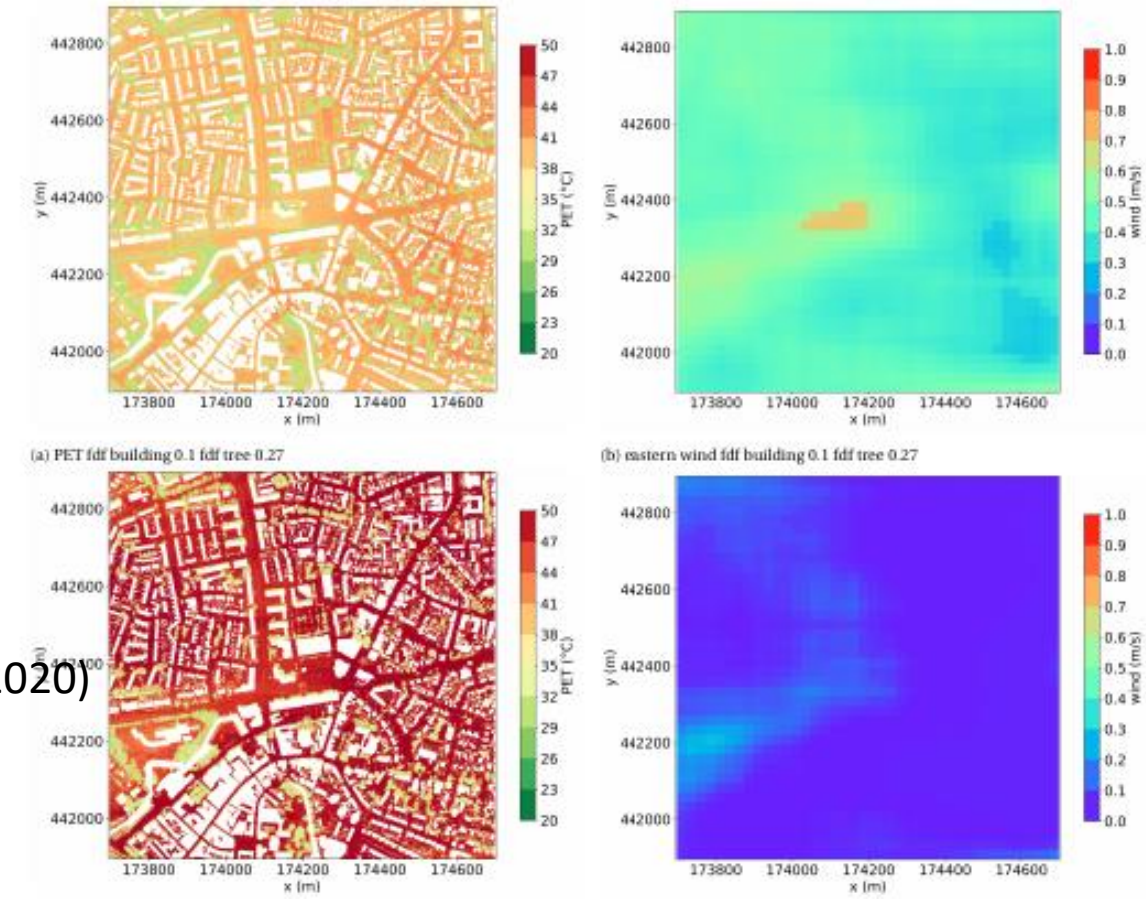
PET sensitivity wind frontal density factor (fdf)

Different footprint window for wind calibration necessary

PETs simulator

Fdf building 0.16 fdf tree 0.27
Fdf building 0.6 fdf tree 0.27

Koopmans et al. (2020)



Wind calculation

Building_height_fine

10	0
0	5

Building_mask_fine

1	0
0	1

Building_area

(1+1+0+0) / 4 = 0.5

Building_height

7.5

(10+0+0+5)/4 / building area = 7.5

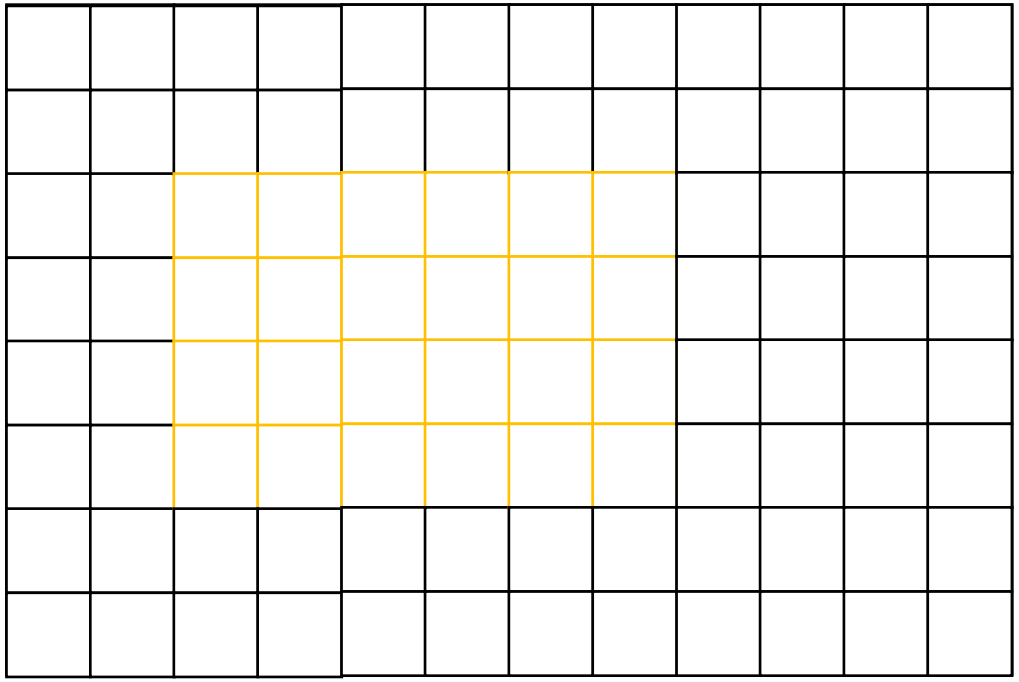
Building_weight

7.5

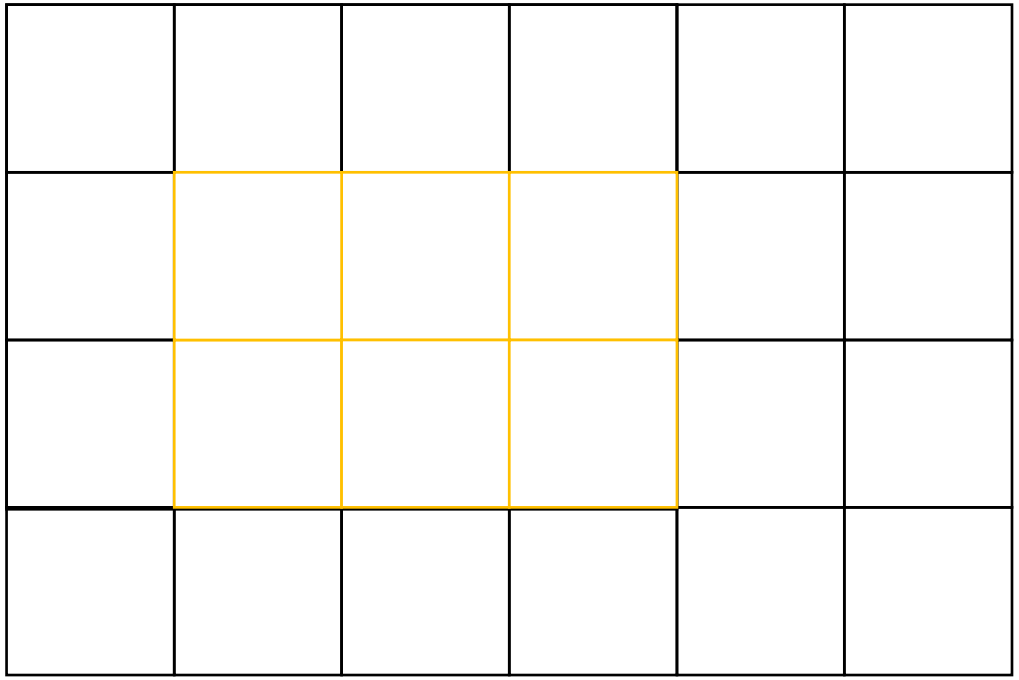
|10-0|/2 + |0-5| /2 = 7.5

Wind calculation

Building_height_fine

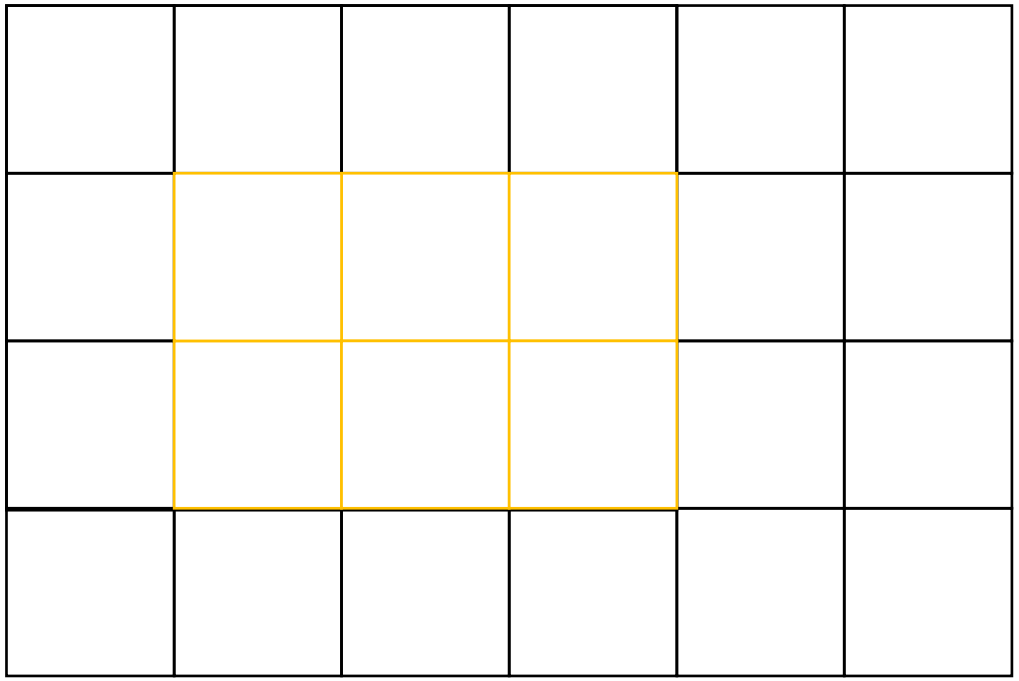


Building_height

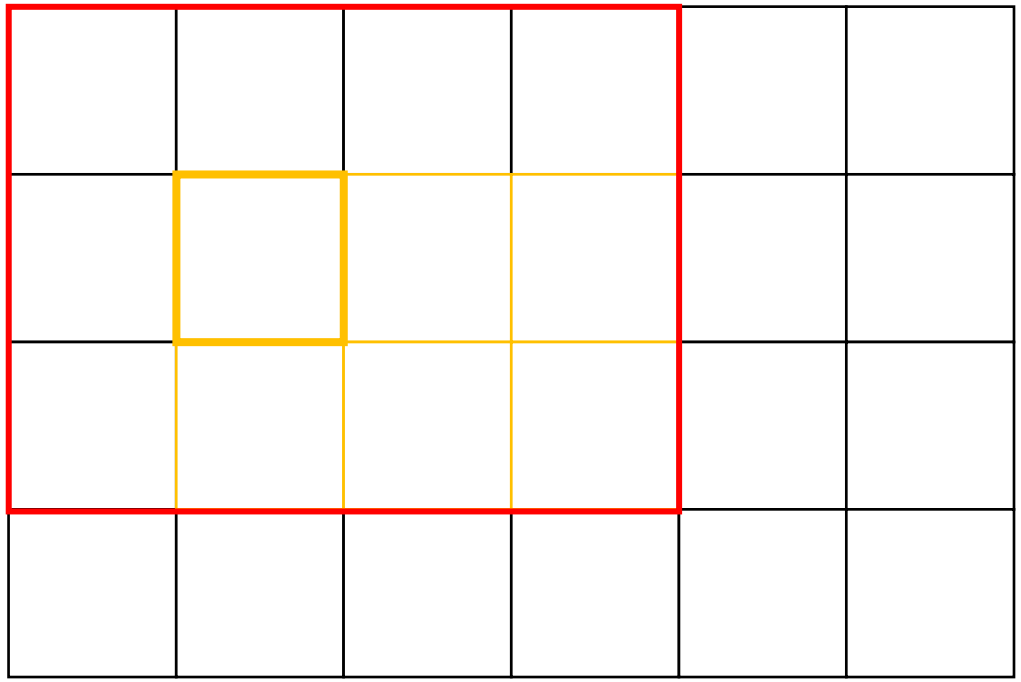


Wind calculation

Building_height

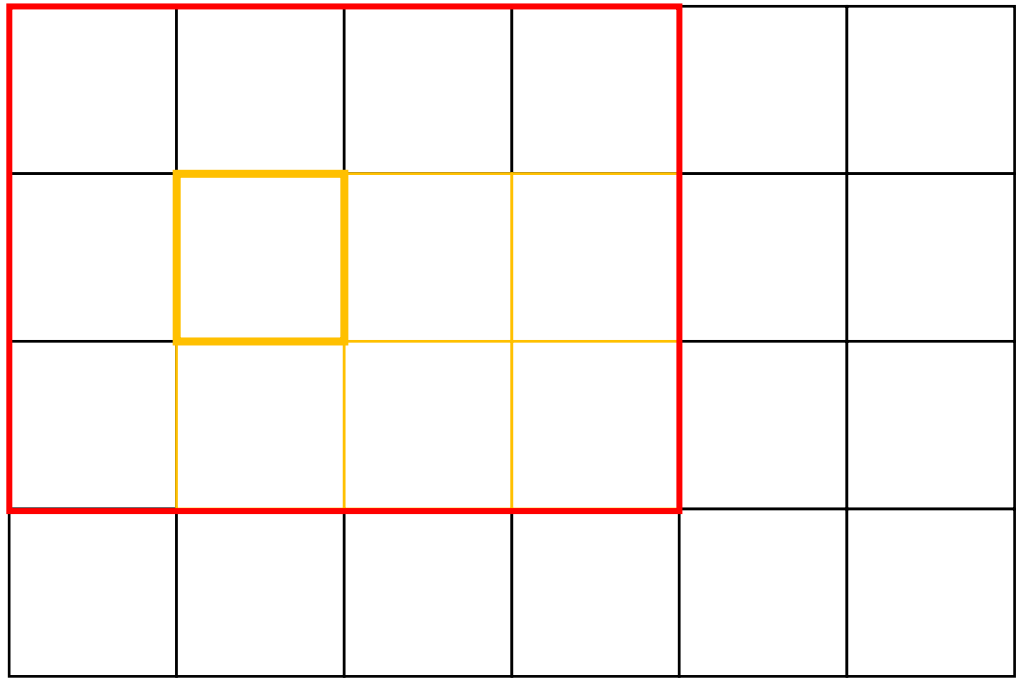


Building_height_mean

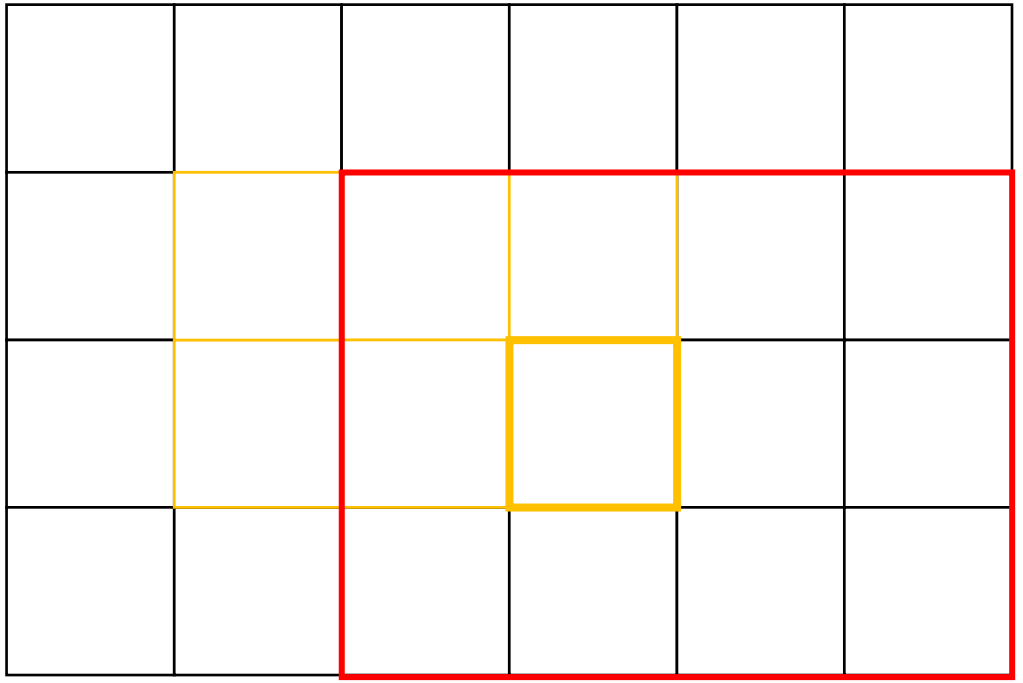


Wind calculation

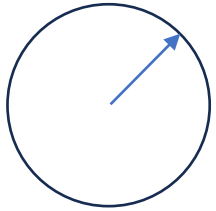
Building_height_mean

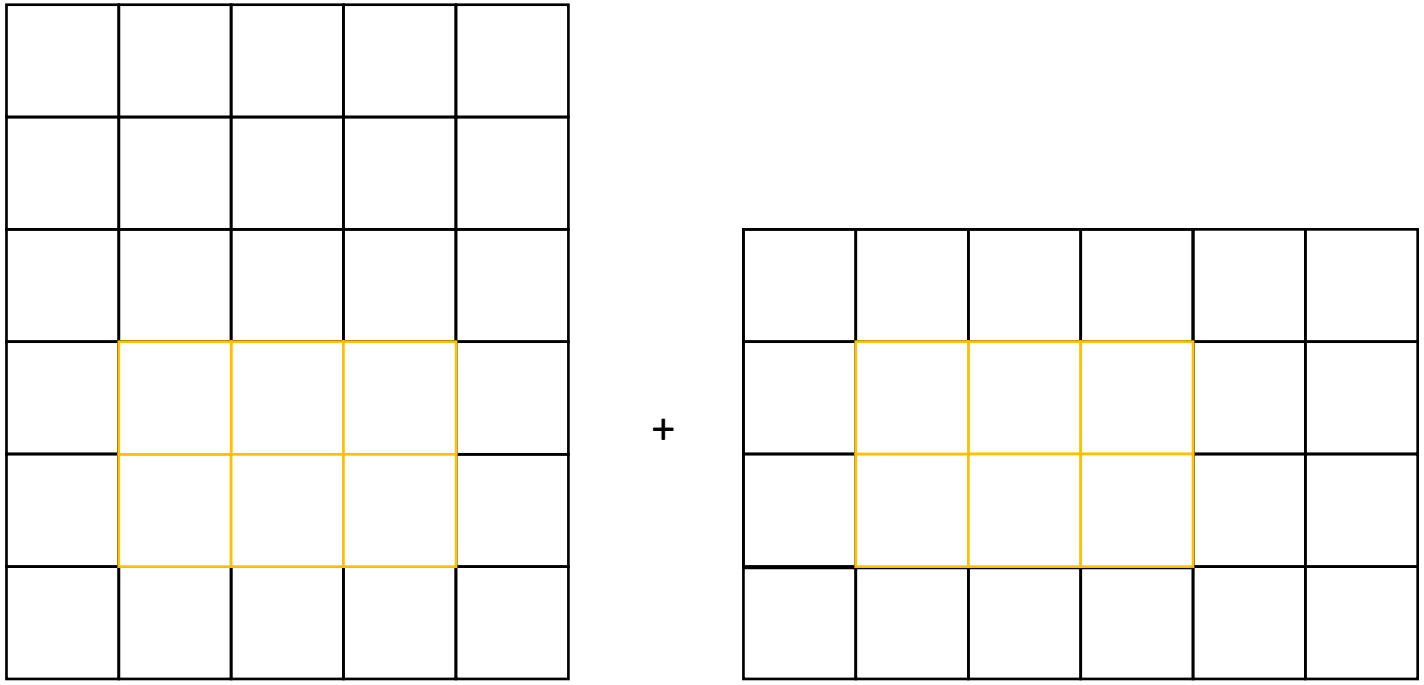


Building_height_mean



Wind calculation suggestion angle



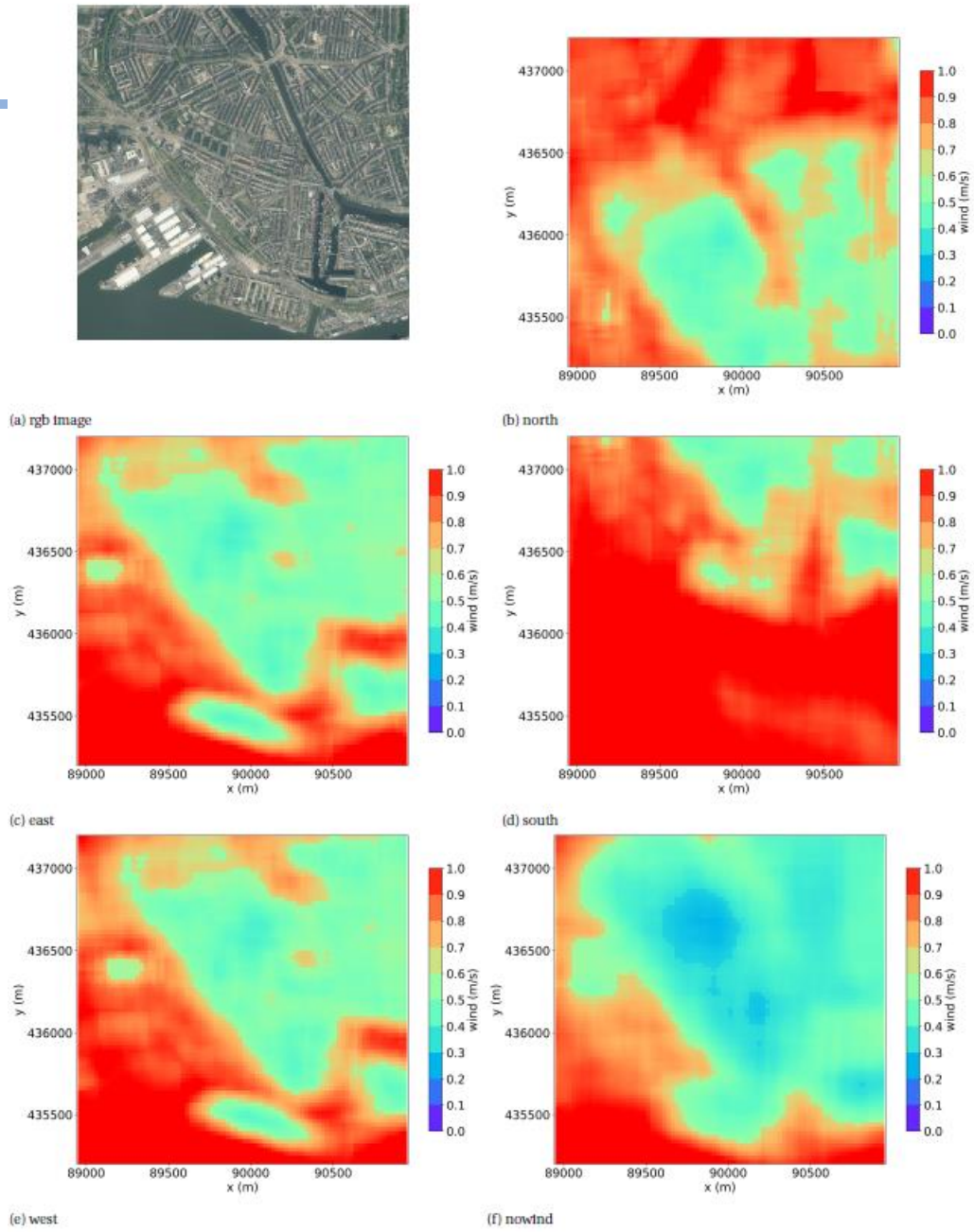


* √2

Phasing

Fig. 6.28 Phasing design decisions. Created by author

Wind directions Rotterdam



Data for 2015 1st of Juli

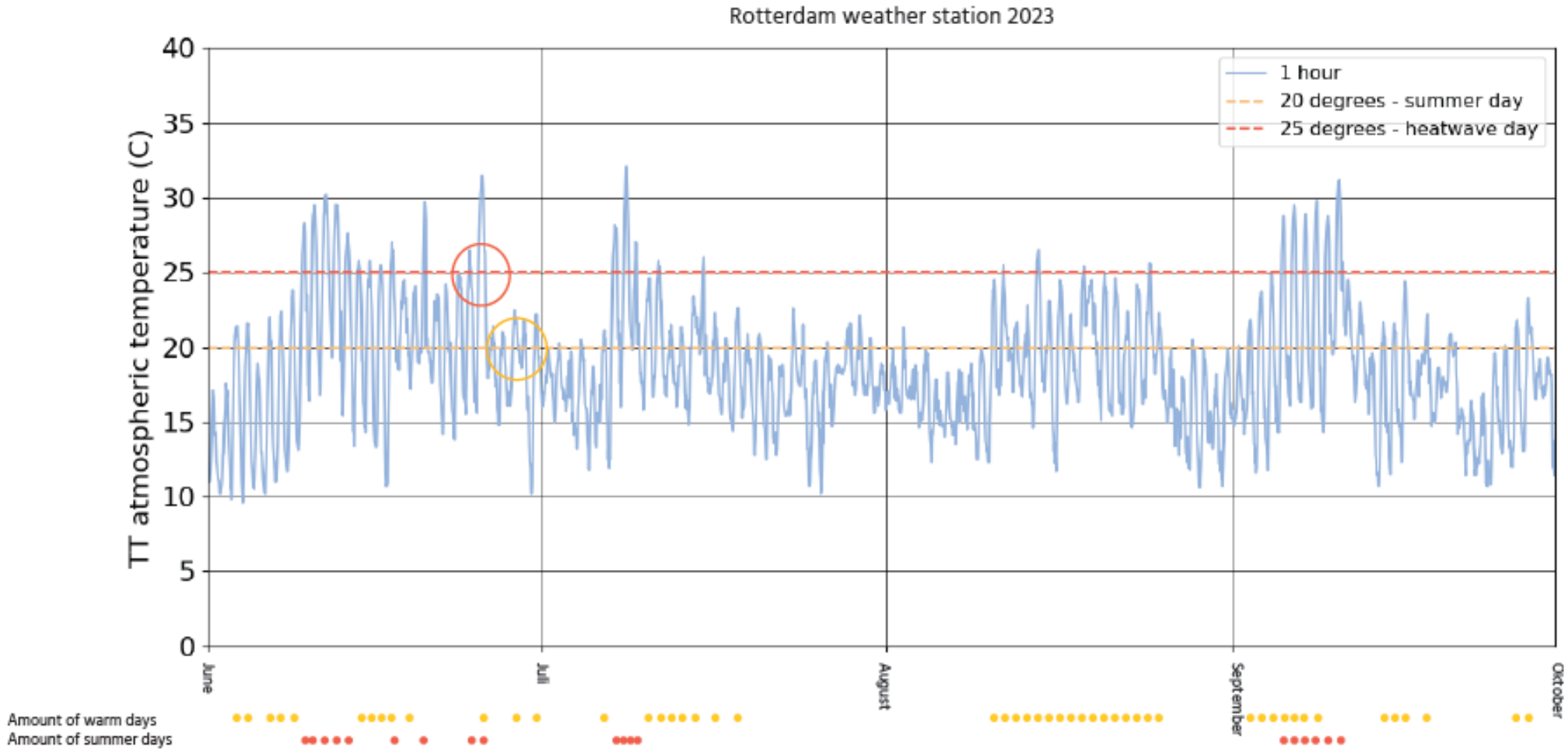
Table 7.1: Table dynamic data Rotterdam 1 juli 2015

hour	TT	FF	dd	Q	Qdif	sunalt	RH	wind	WE	winddir	day	diurnal	Tmin	Tmax
9	27.2	4	100	699.425	155.9823	48	45	TRUE	TRUE	E	day	0.007	23.7	34
10	29	5	100	808.84	154.012	55.3	43	TRUE	TRUE	E	day	0.03	23.7	34
11	30.3	7	90	865.625	169.524	60.1	39	TRUE	TRUE	E	day	0.05	23.7	34
12	31.8	6	110	865.625	176.726	60.9	32	TRUE	TRUE	E	day	0.07	23.7	34
13	32.5	5	110	821.305	169.524	57.4	29	TRUE	TRUE	E	day	0.11	23.7	34
14	33	5	120	745.13	158.998	50.8	30	TRUE	TRUE	E	day	0.16	23.7	34
15	33.8	5	120	634.33	143.5459	42.5	31	TRUE	TRUE	E	day	0.23	23.7	34
16	34	5	130	501.37	134.1004	33.4	29	TRUE	TRUE	E	day	0.31	23.7	34
17	33.8	5	130	351.79	121.1653	24.2	33	TRUE	TRUE	E	day	0.42	23.7	34
18	32.9	5	110	202.21	95.36945	15.2	36	TRUE	TRUE	E	day	0.56	23.7	34

Table 7.2: Table dynamic data Rotterdam 29 june 2015

hour	TT	FF	dd	Q	Qdif	sunalt	RH	wind	WE	winddir	day	diurnal	Tmin	Tmax
9	20.5	4	270	559.54	278.8815	48	65	TRUE	TRUE	W	day	0.007	11.3	23.1
10	21.5	4	250	704.965	243.5441	55.3	57	TRUE	TRUE	W	day	0.03	11.3	23.1
11	22.5	4	270	738.205	261.424	60.1	58	TRUE	TRUE	W	day	0.05	11.3	23.1
12	21.3	4	270	735.435	271.0638	60.9	64	TRUE	TRUE	W	day	0.07	11.3	23.1
13	22	4	290	742.36	230.7026	57.4	64	TRUE	TRUE	W	day	0.11	11.3	23.1
14	21.7	3	270	646.795	245.0592	50.8	58	TRUE	TRUE	W	day	0.16	11.3	23.1
15	22	3	320	533.225	237.4175	42.5	53	TRUE	TRUE	N	day	0.23	11.3	23.1
16	21.2	3	350	368.41	228.7261	33.4	56	TRUE	TRUE	N	day	0.31	11.3	23.1
17	20.4	3	350	271.46	171.3269	24.2	57	TRUE	TRUE	N	day	0.42	11.3	23.1
18	19.9	2	350	210.52	89.52669	15.2	55	FALSE	TRUE	C	day	0.56	11.3	23.1

2023 dates


Rotterdam weather station 2023
1 hour
20 degrees - summer day
25 degrees - heatwave day
TT atmospheric temperature (C)
0
5
10
15
20
25
30
35
40
June
Juli
August
September
Oktober
Amount of warm days
Amount of summer days

Data for 2023- 25th of June and 28th of June

Table 7.3: Table dynamic data Rotterdam 25 june 2023 - warm day, average temperature of 25 c degrees

H	T	FF	DD	Q	Qdif	sunalt	RH	wind	WE	winddir	nightday	diurnal	Tmin	Tmax	U
9	21.4	3	50	234	144.4555	47.73691	61	TRUE	TRUE	E	day	0.007	16.4	28.3	4.652174
10	22.8	4	50	274	159.4444	54.95392	58	TRUE	TRUE	E	day	0.029	16.4	28.3	4.652174
11	24.9	5	60	300	169.7222	59.60827	54	TRUE	TRUE	E	day	0.05	16.4	28.3	4.652174
12	26.3	4	70	311	171.1111	60.31511	48	TRUE	TRUE	E	day	0.074	16.4	28.3	4.652174
13	26.9	5	60	305	163.6111	56.80377	46	TRUE	TRUE	E	day	0.108	16.4	28.3	4.652174
14	28.1	6	60	284	147.7778	50.25408	36	TRUE	TRUE	E	day	0.161	16.4	28.3	4.652174
15	28.1	6	80	248	141.6311	42.04118	37	TRUE	TRUE	E	day	0.228	16.4	28.3	4.652174
16	28.3	7	80	205	138.4943	33.08733	32	TRUE	TRUE	E	day	0.312	16.4	28.3	4.652174
17	27.9	5	110	149	130.3254	23.96173	35	TRUE	TRUE	E	day	0.424	16.4	28.3	4.652174
18	27.5	5	80	93	101.4513	15.06734	36	TRUE	TRUE	E	day	0.556	16.4	28.3	4.652174

Table 7.4: Table dynamic data Rotterdam 28 june 2023 - warm day, average temperature of 20 c degrees

H	T	FF	DD	Q	Qdif	sunalt	RH	wind	WE	winddir	nightday	diurnal	Tmin	Tmax	U
9	19.9	4	230	89	273.6111	47.48214	80	TRUE	TRUE	W	day	0.007	18.6	22.5	3.652174
10	20.8	4	230	108	276.3889	54.84529	74	TRUE	TRUE	W	day	0.029	18.6	22.5	3.652174
11	21.5	4	250	91	320.8333	59.74484	72	TRUE	TRUE	W	day	0.05	18.6	22.5	3.652174
12	22.4	5	240	140	379.533	60.74826	68	TRUE	TRUE	W	day	0.074	18.6	22.5	3.652174
13	22.5	5	260	178	355.946	57.46653	68	TRUE	TRUE	W	day	0.108	18.6	22.5	3.652174
14	21.6	3	260	92	229.1667	51.03978	74	TRUE	TRUE	W	day	0.161	18.6	22.5	3.652174
15	22	5	270	73	238.8889	42.88002	69	TRUE	TRUE	W	day	0.228	18.6	22.5	3.652174
16	22	5	260	99	218.0556	33.94235	64	TRUE	TRUE	W	day	0.312	18.6	22.5	3.652174
17	21.9	4	240	58	127.7778	24.81072	65	TRUE	TRUE	W	day	0.424	18.6	22.5	3.652174
18	21.5	3	260	34	73.61111	15.89229	66	TRUE	TRUE	W	day	0.556	18.6	22.5	3.652174

2023 dates

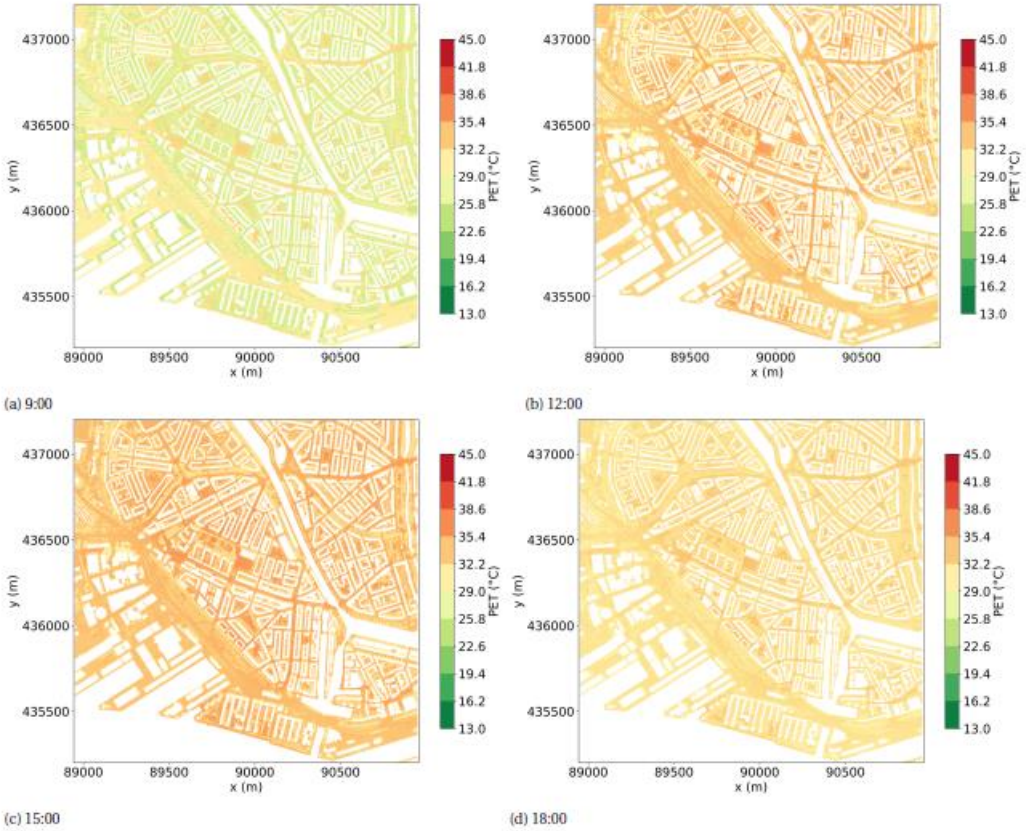


Figure J.3: Output files on research area 25th of Junest 2023.

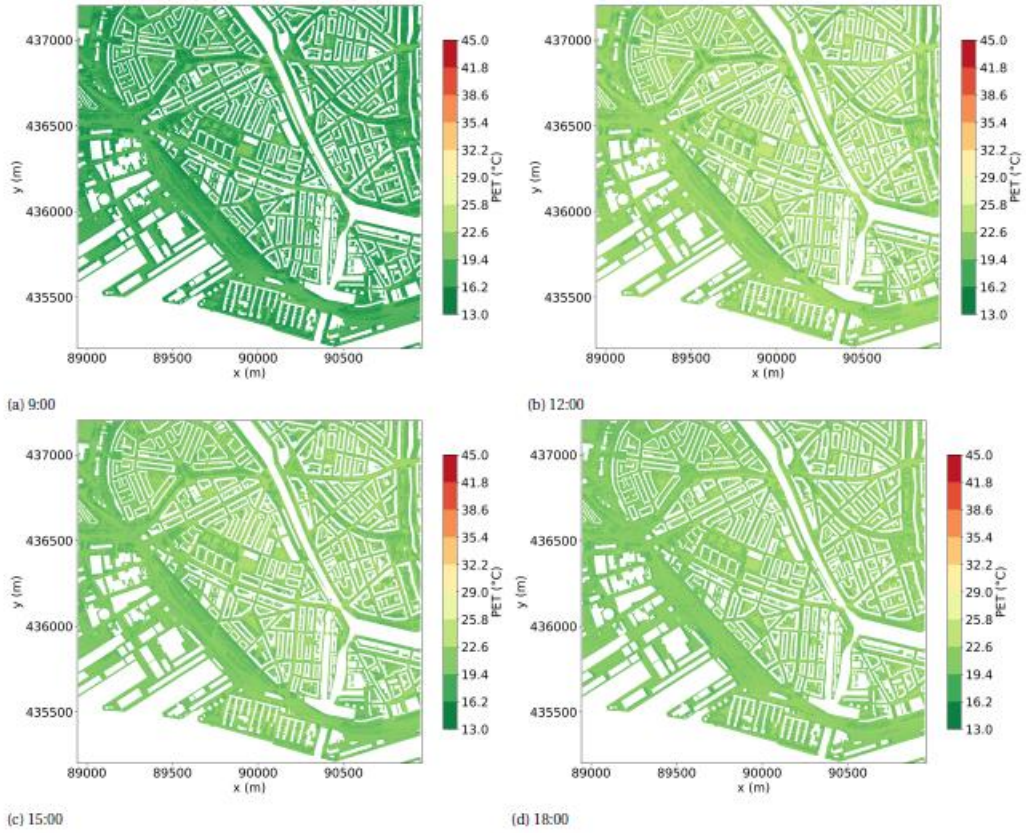


Figure J.4: Output files on research area 28th of Junest 2023.

28th of June 2023

25th of June 2023