Adaptation of The Built Environment to Changing Urban Microclimates

A residential high-rise case study

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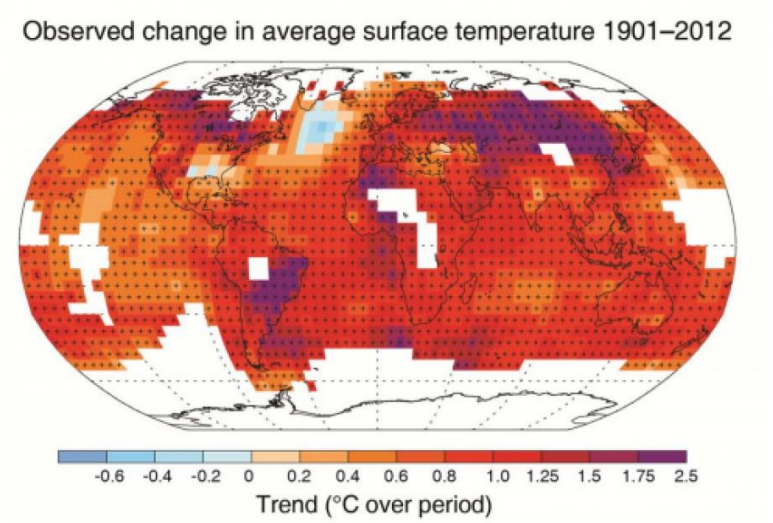
Introduction & Context

Introduction - Context & background

Climate change

Rising temperatures

Extreme weather & frequency heatwaves



Sea level rise by 2085

80 cm

Warmest 3 decades in

1400 years

Average temperature increase

0,5 °C - 2,5 °C

Chance of Elfstedentocht

0,2%

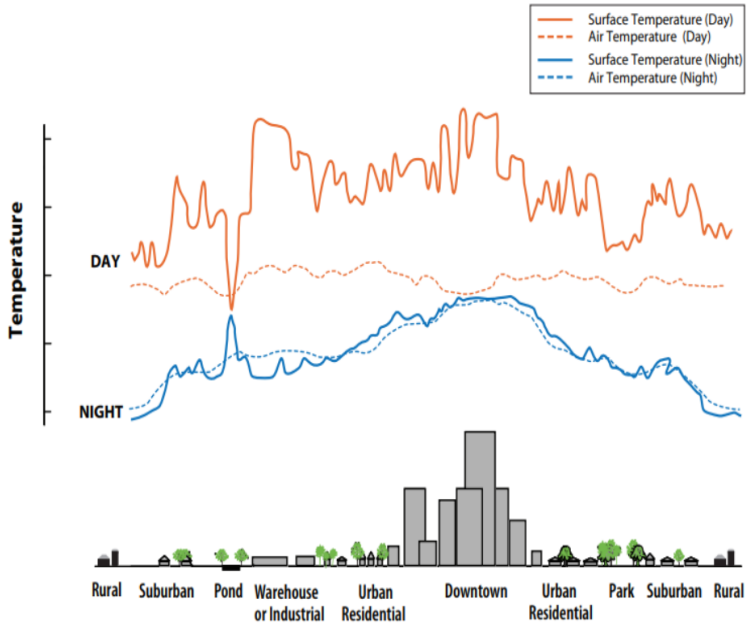
(KNMI 2014)

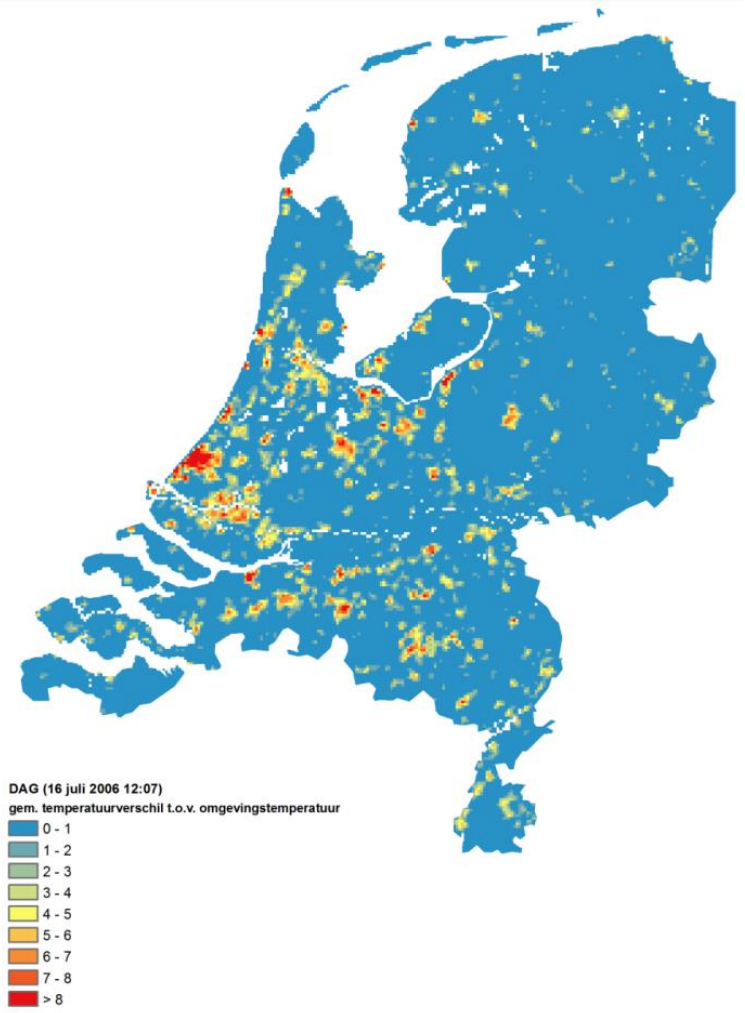
Introduction - Context & background

Temperature difference between urban and rural areas

Urban heat island effect

UHI-effects related to properties of urban areas





Adaptation

Reduce vulnerability to UHI-effect

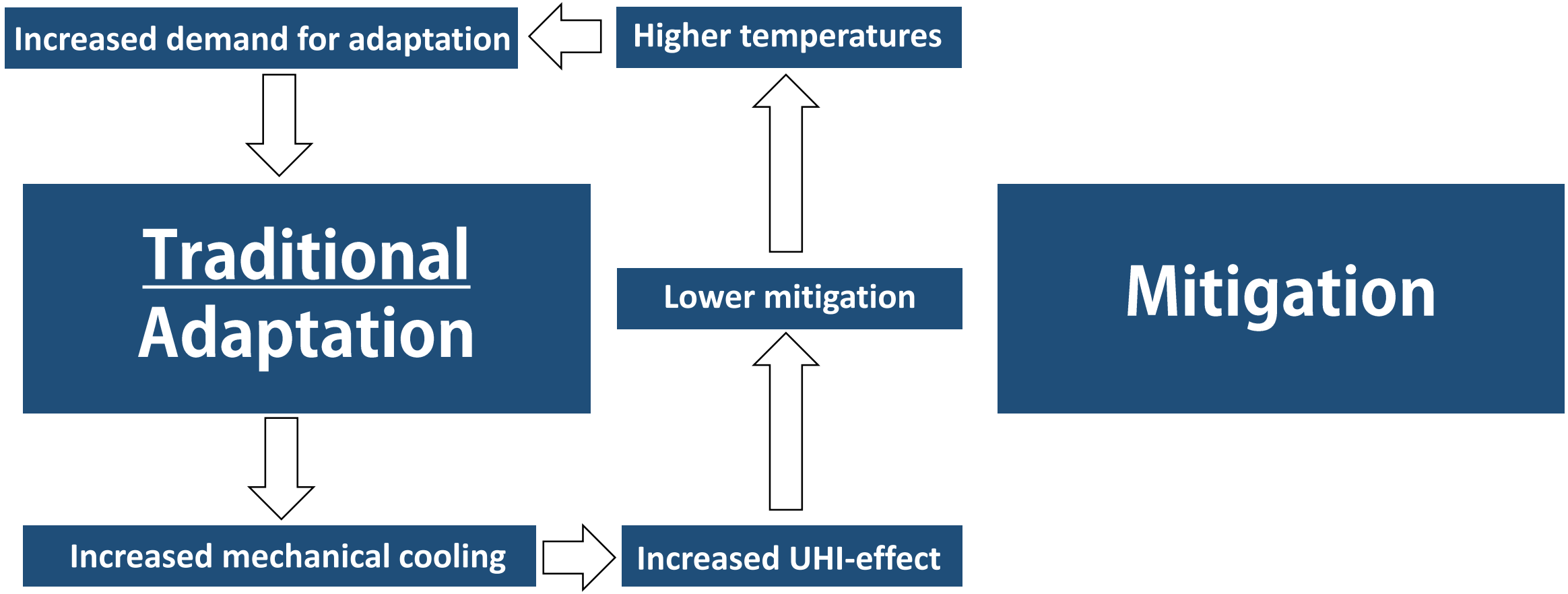
Climate adaptive city/buildings that can adapt to higher temperatures

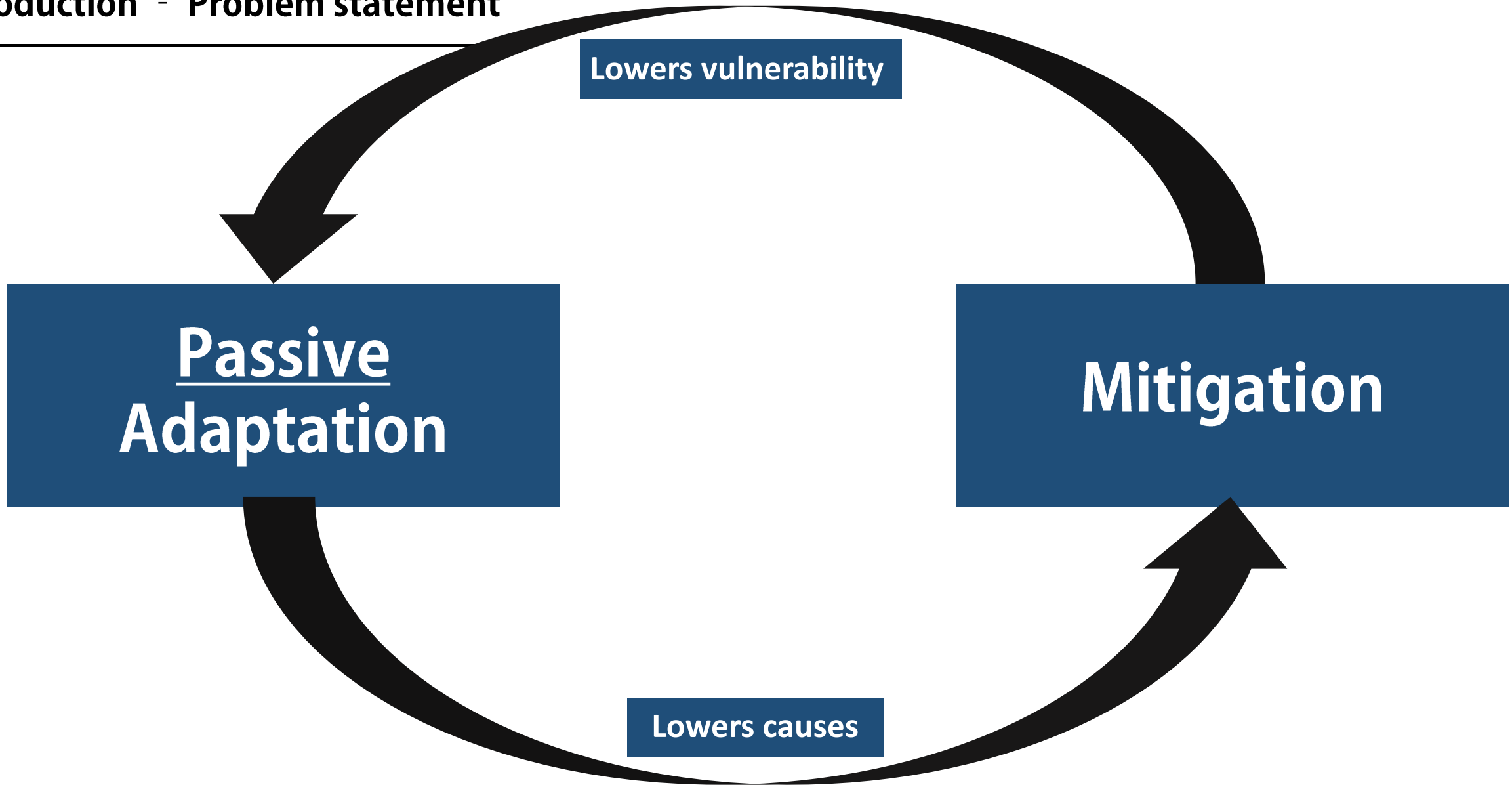
Mitigation

Reduce causes of the UHI-effect

UHI-conscious design of city/buildings to lower the effects of the UHI-effect.

Introduction - Problem statement




Lowers vulnerability
Passive Adaptation
Mitigation
Lowers causes

"Traditional adaptation of buildings to increased temperatures in changing urban microclimates negatively interferes with the mitigation of the cause of these changes."

Introduction - Research questions

How can a residential building in a Dutch urban center integrate passive design measures on a building/urban scale to ensure indoor thermal comfort without negatively impacting the temperature of its microclimate in future climate scenarios?

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Temperature change of the future urban Dutch microclimate due to climate change and the UHI-effect

Determining the indoor thermal quality under changing outdoor temperatures due to climate change & UHI-effect

Design measures to minimize the negative temperature effects of a building on the urban microclimate

Passive design measures to ensure indoor thermal comfort in buildings in the Dutch urban areas

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Research

Research - Future urban climate

UHI-effect

Increases temperature on top of maximum temperature in a city

intensity based on location and population density

0,09 °C - 0,17 °C increase per 1 °C increase in max average temperature

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Climate change

Different KNMI scenarios

Range based on climate change intervention worldwide

0,9 °C - 2,8 °C increase in max average temperature in 2050

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0,9 °C - 2,8 °C increase in max average temperature in 2050

Combined

Climate change and UHI-effect amplify temperatyre effects

Range based on projected population and density growth

0,1 °C - 0,3 °C increase 1 °C per increase in maximum average temperature due to climate change

Research - Future urban climate

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Climate data file containing 2050 scenario for specific urban region

Research - Indoor thermal comfort

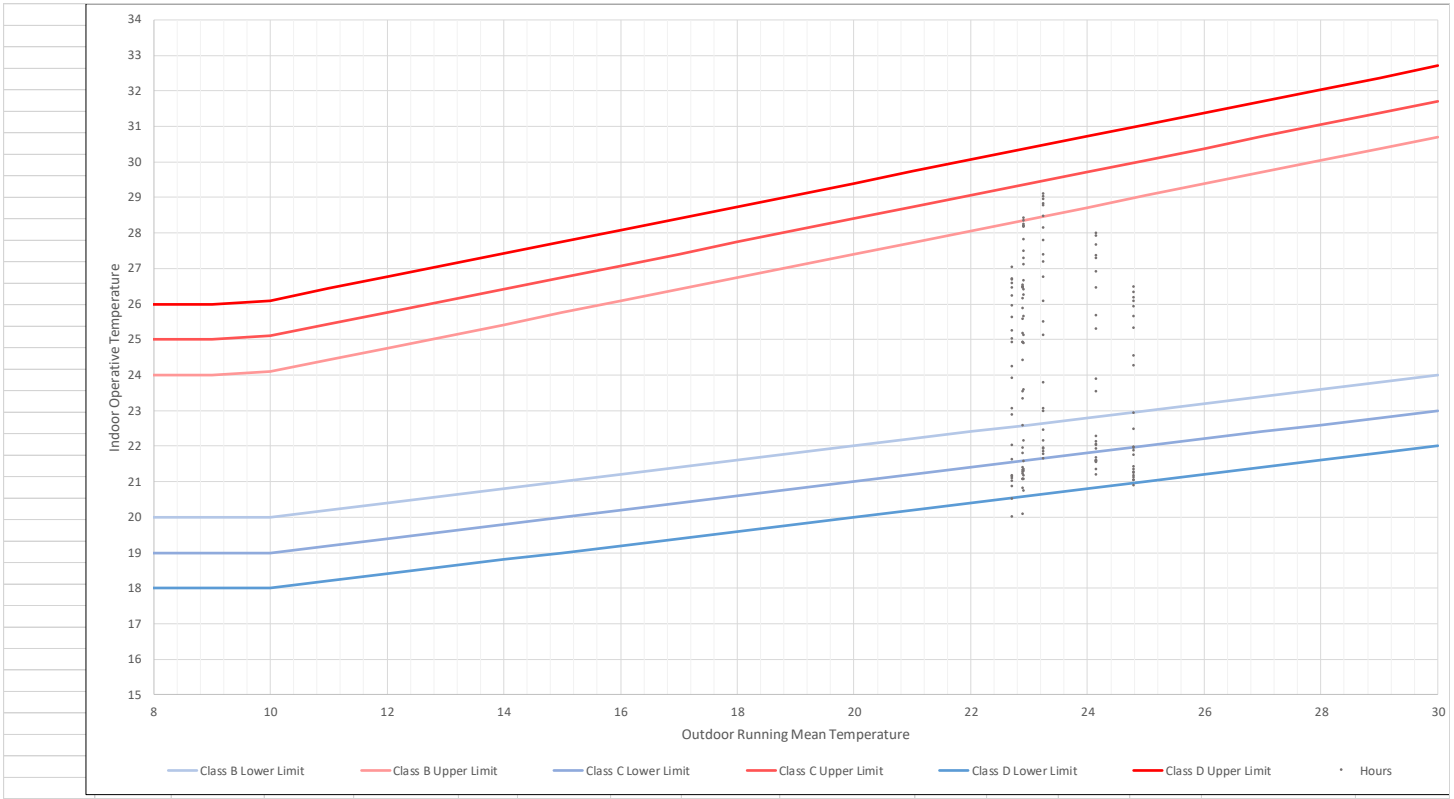
ATG (adaptive temperature limit method)

Runnning mean outdoor temperatures

Thermal comfort classes (A-E)

Good fit for research

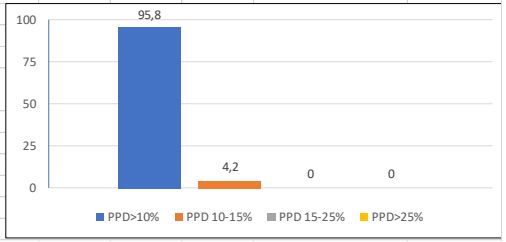
Passive cooling, psychological and behaviour factors



Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Operative Temperature
Analysis Period		3-8 aug	
Occupied Hours		144	

Thermal Performance	Class B	good

Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	138	95,8
Class C	6	4,2
Class D	0	0
Class E	0	0



Research - Passive urban design measures

Vegetation

Evapotranspiration
Transpiration
Shading surroundings

Water

Evaporation
Heat buffer
Heat sink

Urban geometry

Radiation
Shading
Airflow

Materialization

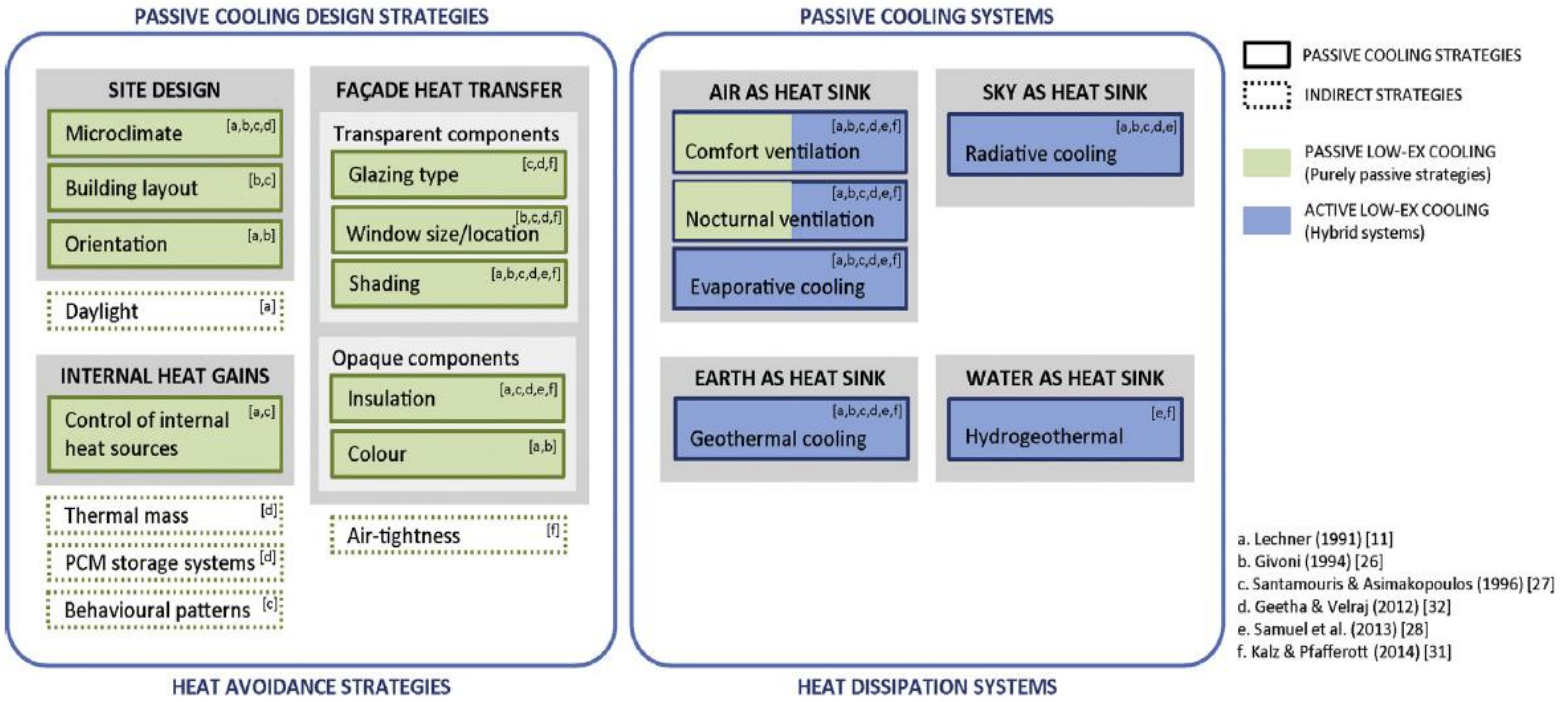
Reflective properties
Thermal admittance
Airflow (via coloring)

Research - Passive building design measures

Integrated passive cooling strategy framework

Every measure has an impact on others

Adapt strategy towards every individual building for optimal performance



Categorization of different design measures of passive cooling (Prieto, Knaack et al. 2018)

Methodology

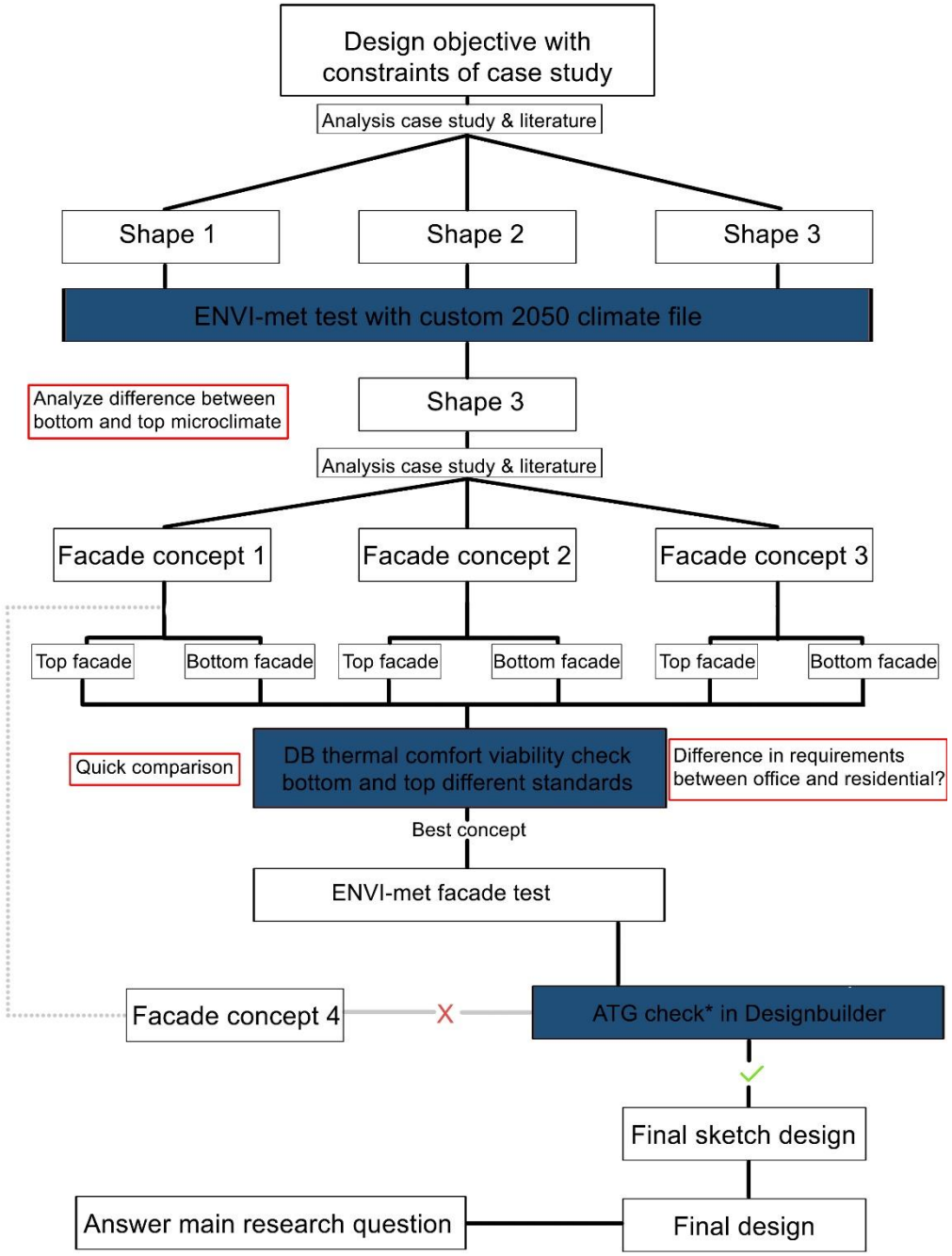
Methodology - Framework

Relevant case study

Variants via literature

Simulations via software

Validation via Indoor thermal comfort (ATG)



*For current and future climate

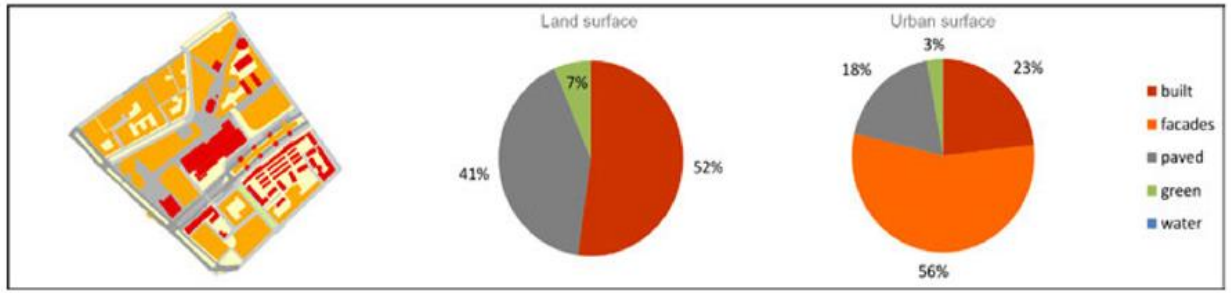
Methodology - Case study

-Hooghe Rijn located in The Hague

-Neighborhood suffering from UHI-effect

-Early stage of design phase

-Complex urban environment



Methodology - Weather files

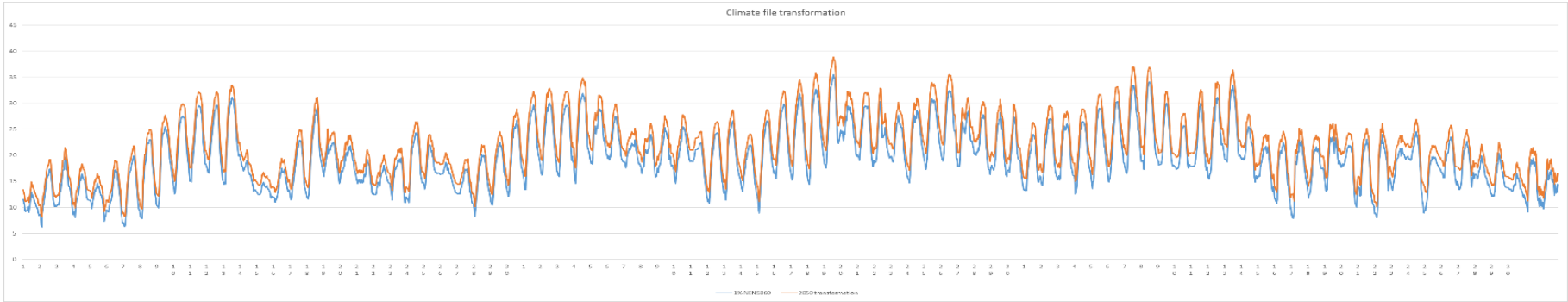
-Creating a 2050 heatwave scenario

-1% climate year of NEN5060

-Local weather data combined with future KNMI scenarios temperature data

-End product: hourly weather data of June, July, august 2050 during a heatwave

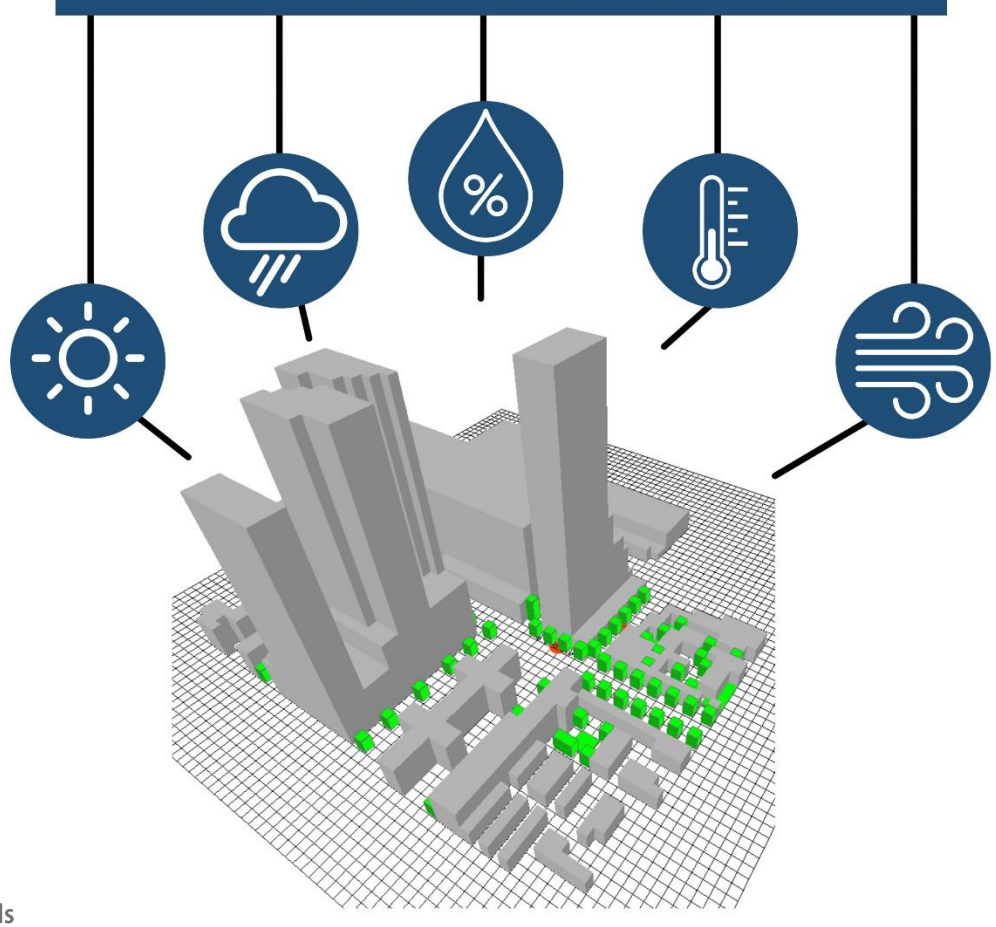
Overschrijdingskans	5 %	1 %
Maand		
Januari	2013	1997
Februari	1996	2012
Maart	2013	2005
April	1996	2007
Mei	2006	1998
Juni	2011	2006
Juli	2013	2006
Augustus	1997	2003
September	1999	2005
Oktober	2001	2011
November	1999	2010
December	2009	2010



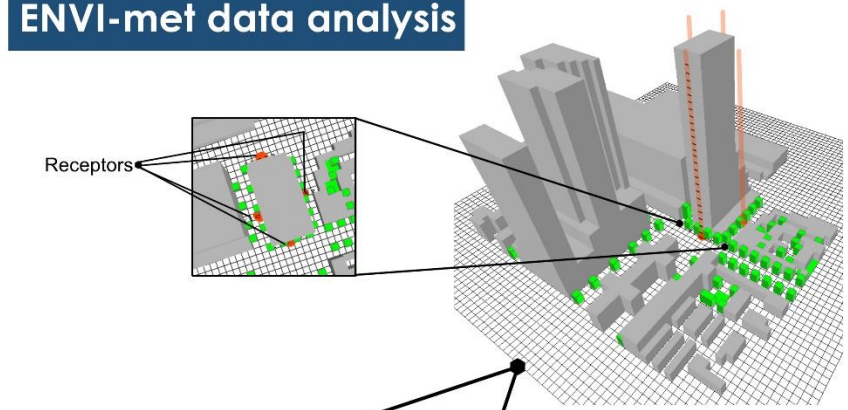
Methodology - ENVI-met

ENVI-met CFD Simulation

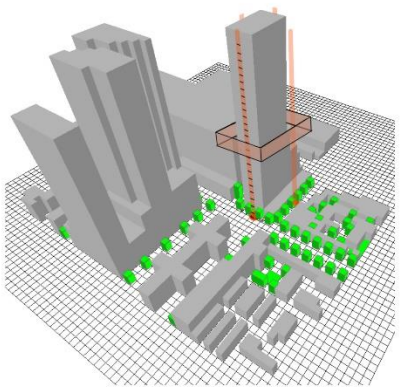
Climate data file 2050 heatwave scenario

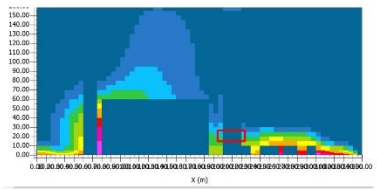


ENVI-met data analysis



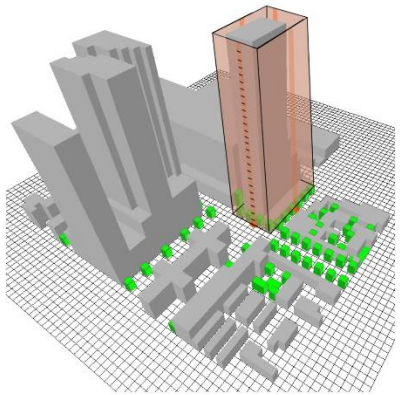
Option 1

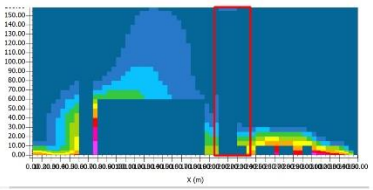




Range of microclimate

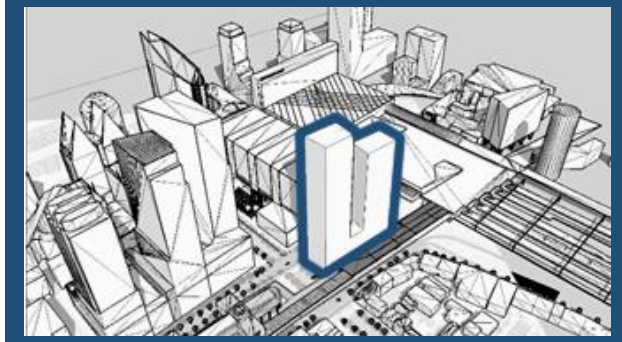
Option 2





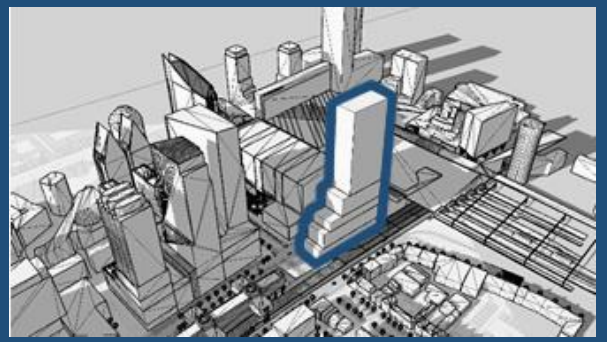
Range of microclimate

Methodology - Shape design



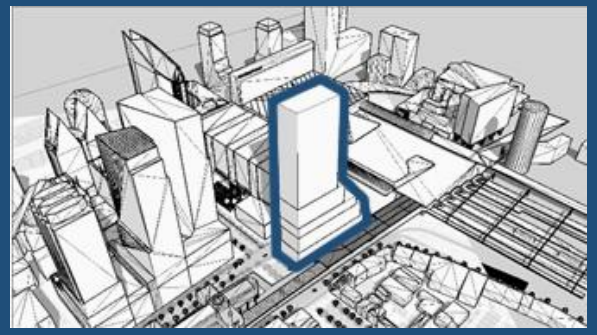
HR11

Skyview factor
Low profile
Compact shape



HR12

Wind profile
Shading environment
Facade wind exposure

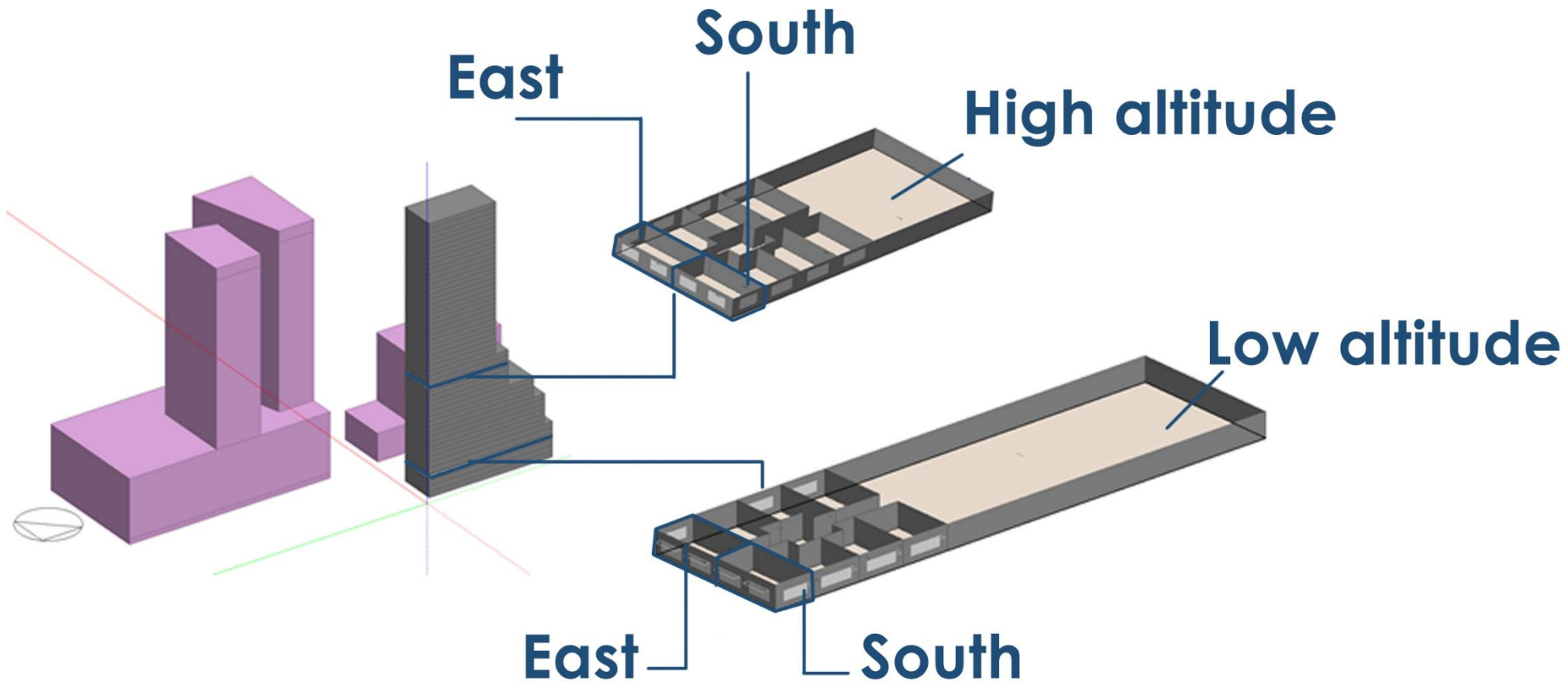


HR13

Downdraught
Shading facade
Minimizing solar
exposure facade

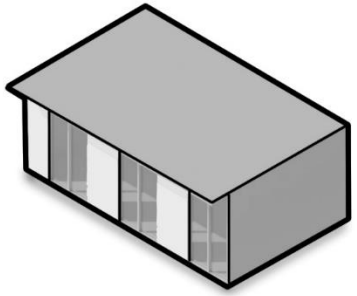
Methodology - Designbuilder

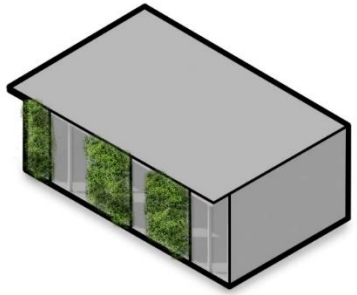
Climate file from previous step as input



Methodology - Facades

Facade 1 High alt.
W/W ratio: 60%
0,5m overhang
White metal cladding
Low g-value glazing
Basic insulation

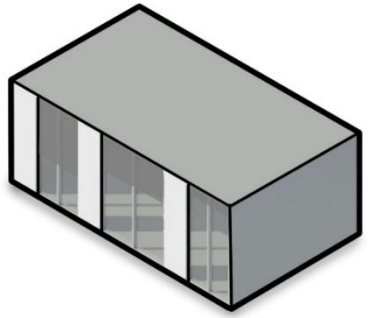


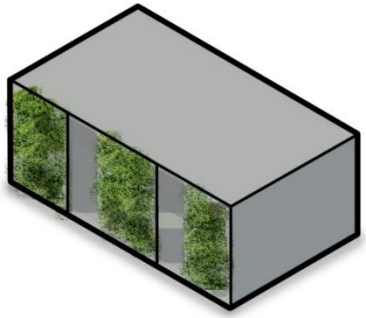


W/W ratio: 50%
0,5m overhang
Green facade
Low g-value glazing
Basic insulation

Facade 1 Low alt.

Facade 2 High alt.
W/W ratio: 70%
External sunscreen
White metal cladding
Low g-value glazing
High insulation

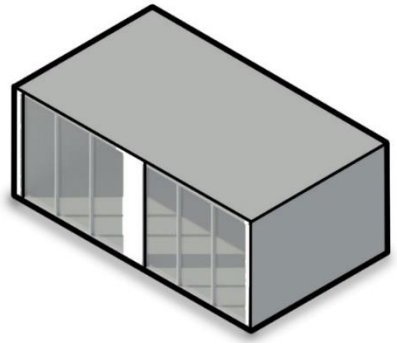


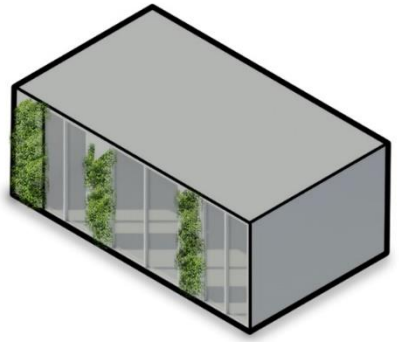


W/W ratio: 30%
External sunscreen
Green facade
Low g-value glazing
High insulation

Facade 2 Low alt.

Facade 3 High alt.
W/W ratio: 90%
External sunscreen
White metal cladding
High g-value glazing
High insulation



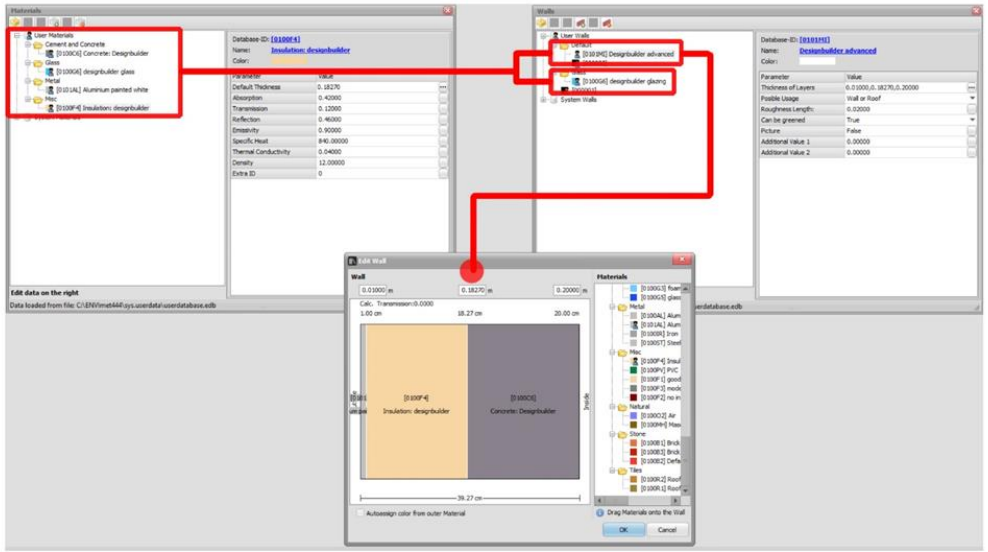


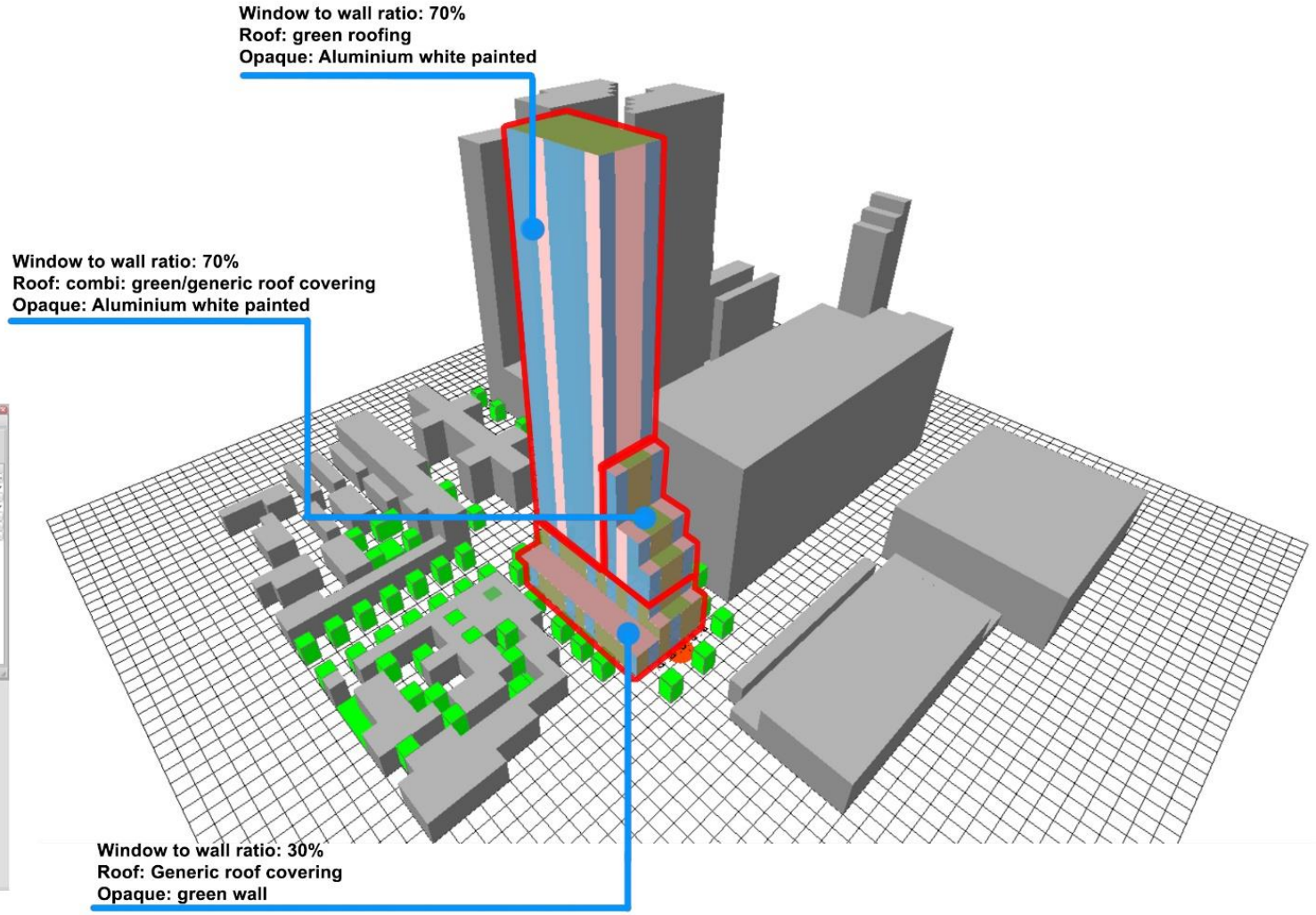
W/W ratio: 70%
External sunscreen
Green facade
High g-value glazing
High insulation

Facade 3 Low alt.

Methodology - New microclimate

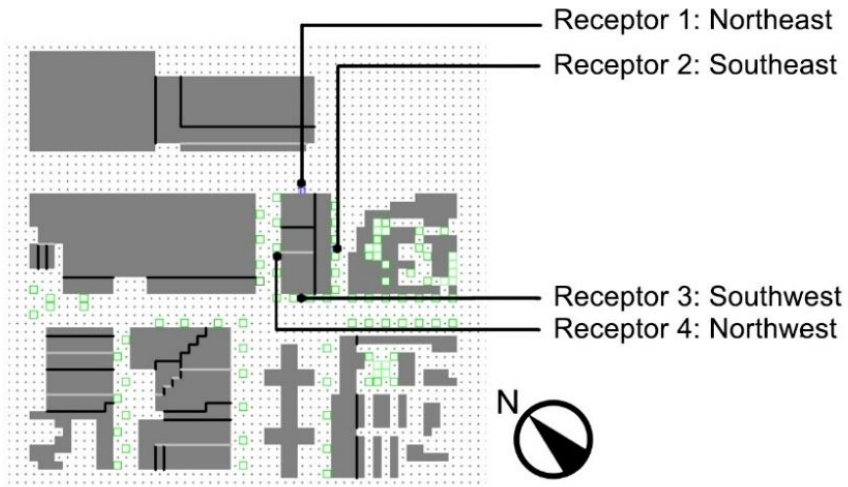
Model chosen facade in ENVI-met simulation

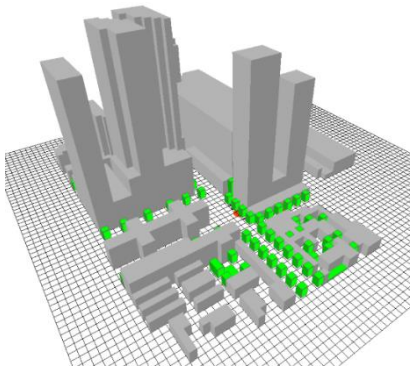




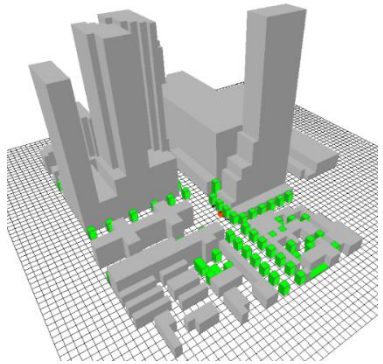
Results

Results - Shape

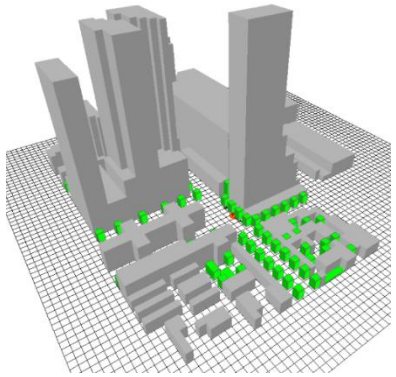




HR 11



HR 12



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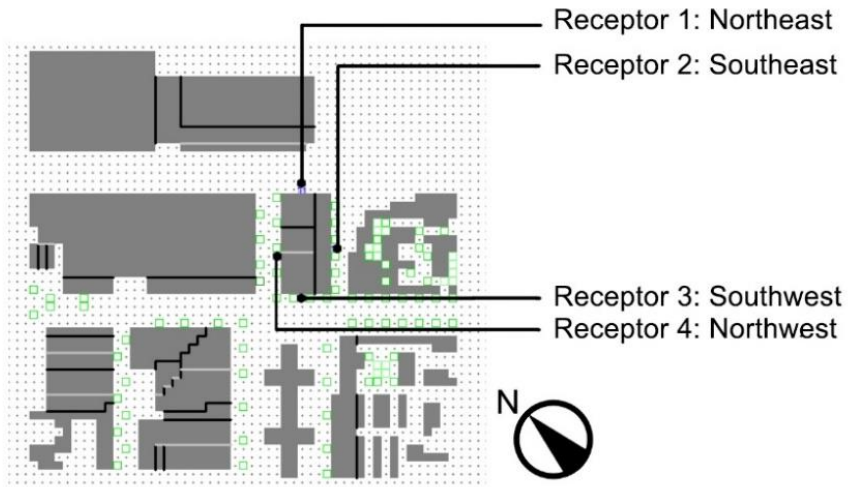

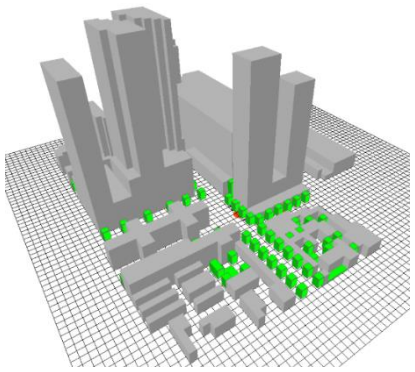

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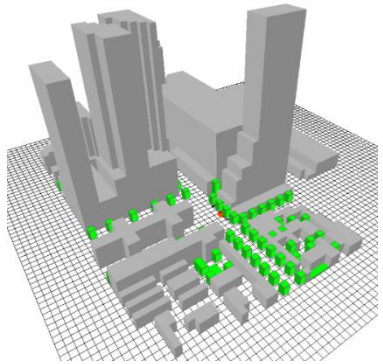

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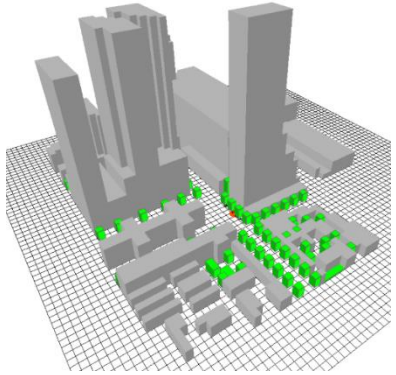
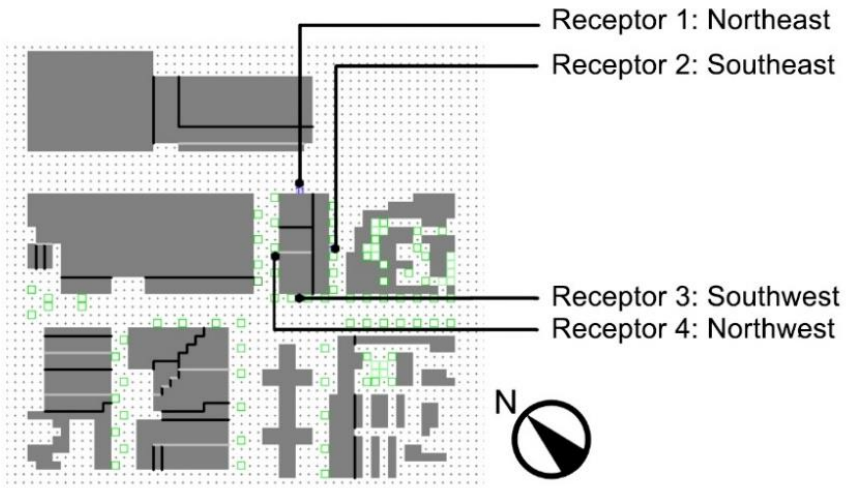
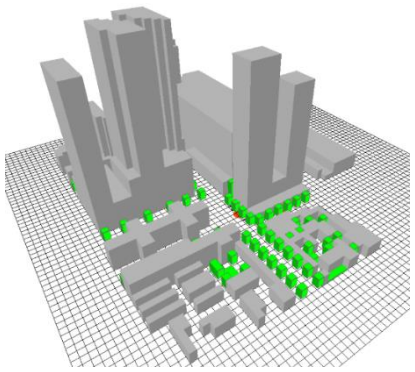


HR 13

Avg ^{0}C under 22,5m					
		R1	R2	R3	R4
	HR13	24,75	24,74	24,60	24,63
	HR12	24,79	24,78	24,69	24,68
	HR11	24,78	24,75	24,61	24,64
Avg ^{0}C total					
		R1	R2	R3	R4
	HR13	24,44	24,41	24,40	24,41
	HR12	24,46	24,42	24,40	24,41
	HR11	24,45	24,41	24,40	24,41
Avg ^{0}C 52,5-77,5m					
		R1	R2	R3	R4
	HR13	24,43	24,37	24,38	24,39
	HR12	24,48	24,37	24,38	24,39
	HR11	24,48	24,37	24,38	24,39

Results - Shape





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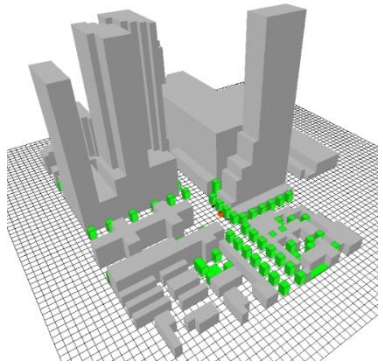

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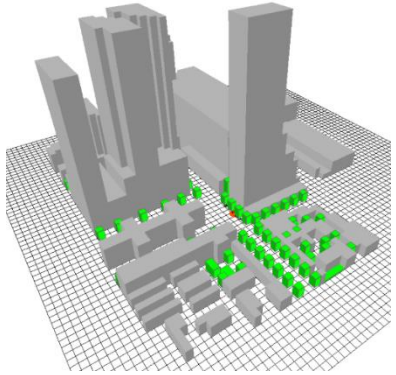

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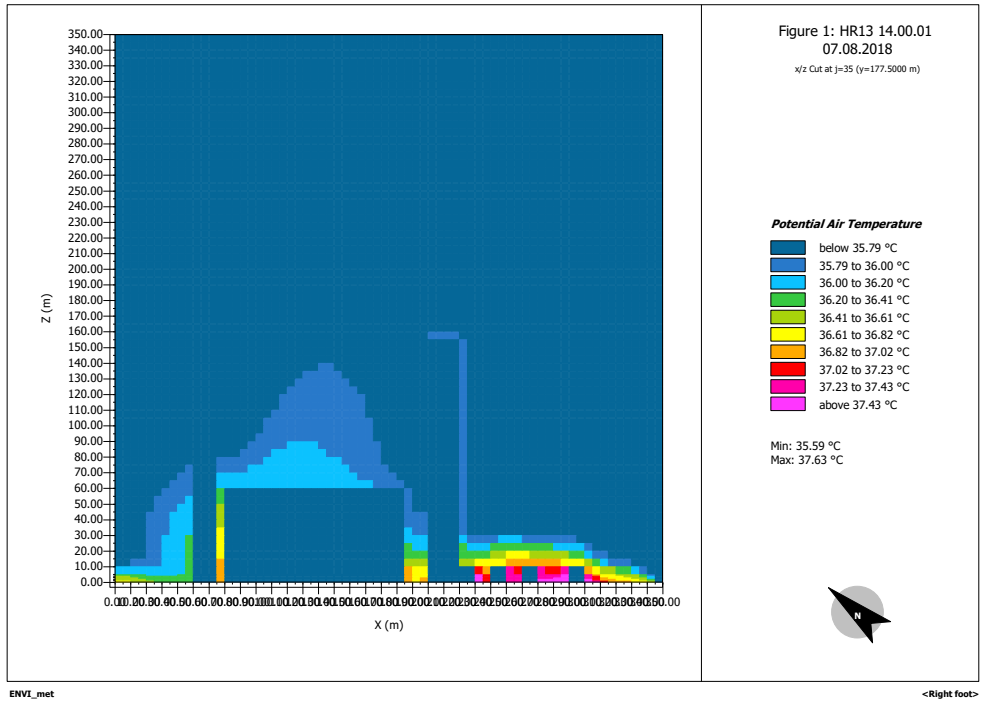
	HR12	24,48	24,37	24,38	24,39
	HR11	24,48	24,37	24,38	24,39

Average is non conclusive and too broad

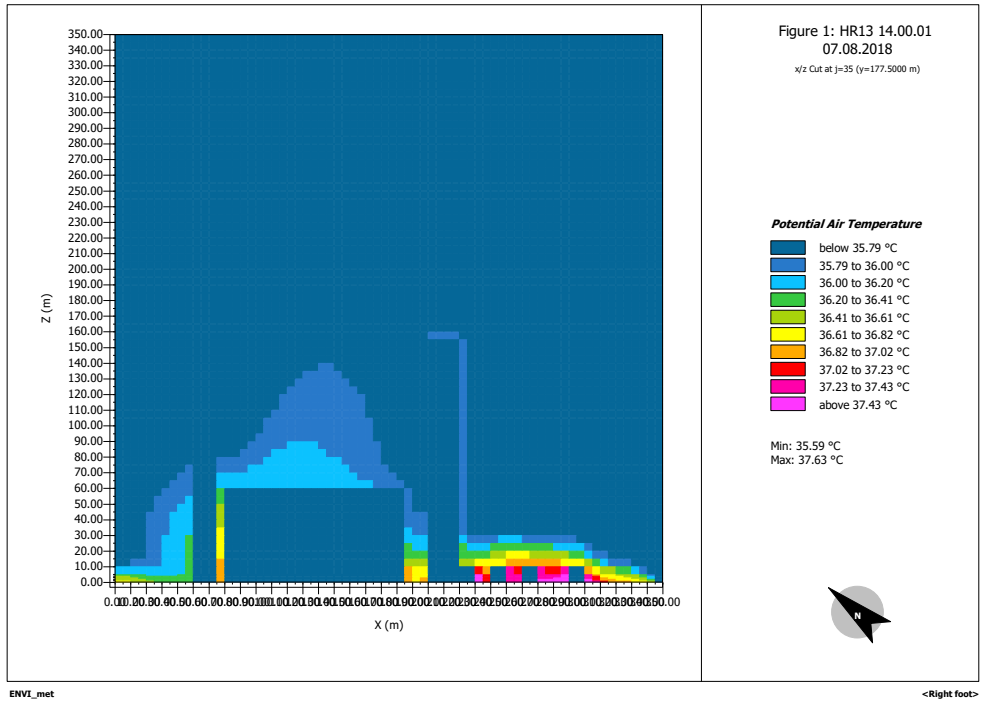
Results - Shape

Maximum °C under 22,5m					
		R1	R2	R3	R4
	HR13	36,76	37,07	36,49	36,70
	HR12	36,78	37,06	36,68	36,77
	HR11	36,74	36,99	36,49	36,65
Maximum °C 52,5-77,5m					
		R1	R2	R3	R4
	HR13	35,91	35,72	35,77	35,82
	HR12	36,04	35,71	35,70	35,82
	HR11	36,00	35,72	35,77	35,82



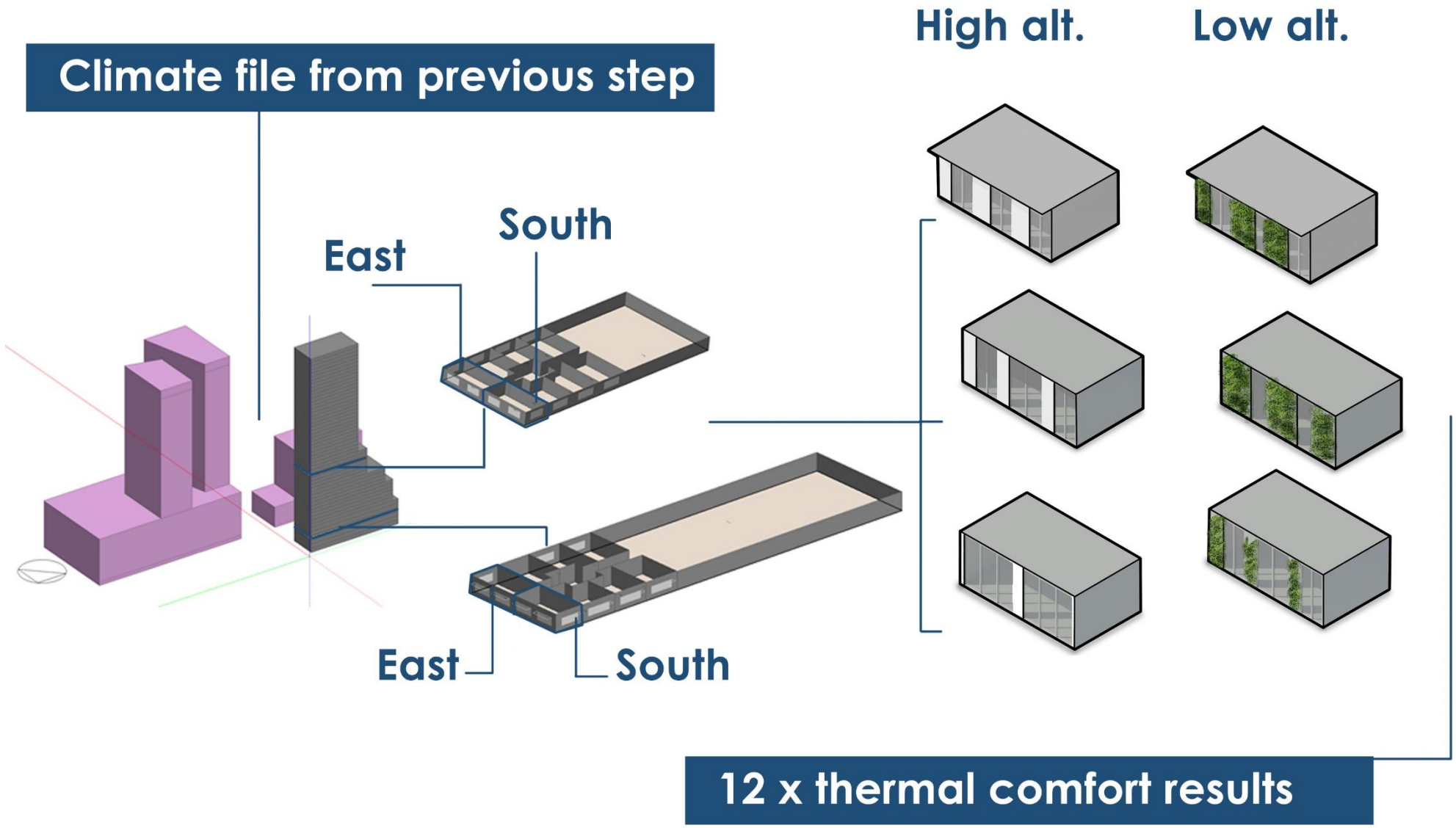
Results - Shape

Maximum °C under 22,5m					
		R1	R2	R3	R4
	HR13	36,76	37,07	36,49	36,70
	HR12	36,78	37,06	36,68	36,77
	HR11	36,74	36,99	36,49	36,65
Maximum °C 52,5-77,5m					
		R1	R2	R3	R4
	HR13	35,91	35,72	35,77	35,82
	HR12	36,04	35,71	35,70	35,82
	HR11	36,00	35,72	35,77	35,82



Maximum is precise enough but not conclusive

Results - Facade



Results - Facade

East facade - 144 hours simulated

Facade type	Class B		Class C		Class D		Class E	
	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time
Facade 1 low alt	132,0	91,7	9,1	6,3	3,0	2,1		
Facade 1 high alt	130,0	90,3	9,9	6,9	4,0	2,8		
Facade 2 low alt	132,0	91,7	8,1	5,6	4,0	2,8		
Facade 2 high alt	138,0	95,8	6,0	4,2	0,0			
Facade 3 low alt	134,1	93,1	9,1	6,3	1,0	0,7		
Facade 3 high alt	130,0	90,3	9,9	6,9	4,0	2,8		

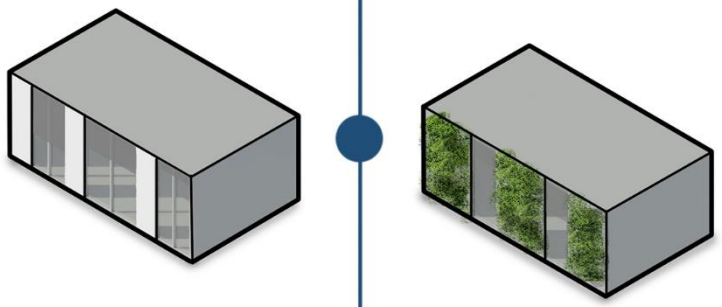
Results - Facade

South facade - 144 hours simulated

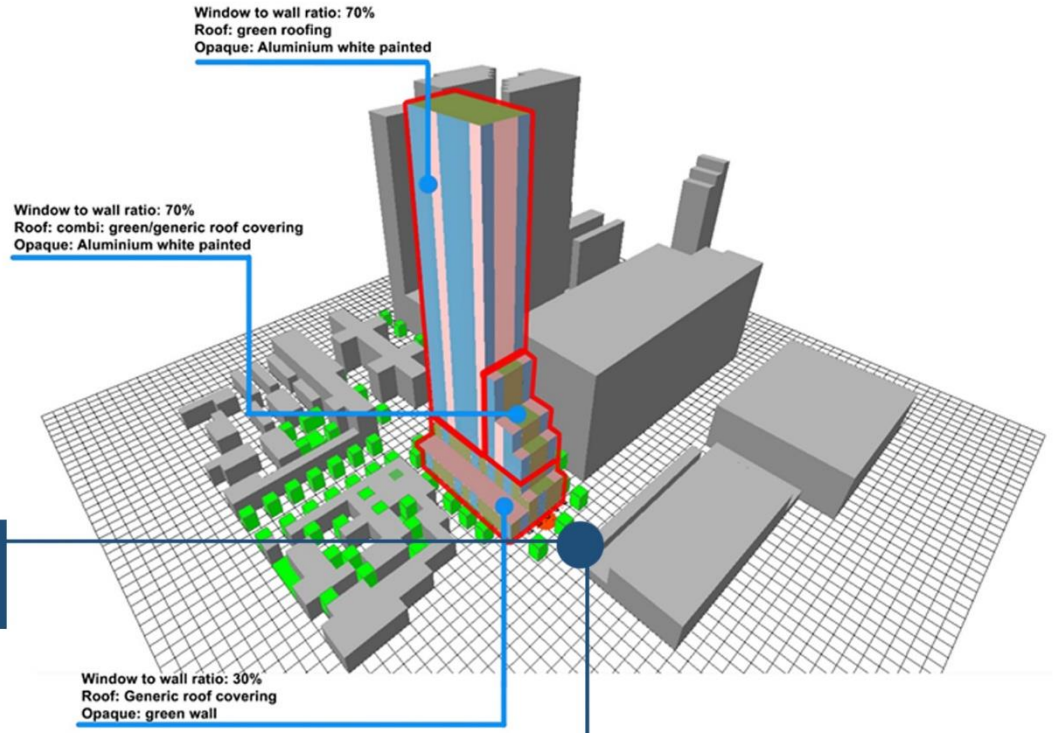
Facade type	Class B		Class C		Class D		Class E	
	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time
Facade 1 low alt	121,0	84,0	10,9	7,6	9,1	6,3	3,0	2,1
Facade 1 high alt	122,0	84,7	9,9	6,9	9,1	6,3	3,0	2,1
Facade 2 low alt	136,0	94,4	8,1	5,6	0,0	0,0	0,0	
Facade 2 high alt	136,9	95,1	7,1	4,9	0,0	0,0	0,0	
Facade 3 low alt	130,0	90,3	10,9	7,6	3,0	2,1	0,0	
Facade 3 high alt	129,0	89,6	10,9	7,6	4,0	2,8	0,0	

Results - New microclimate

Facade 2 from previous step



Detailed ENVI-met model



New Microclimate data file

Results - changed microclimate

Average hourly temperature difference

0m-25m	R1	R2	R3	R4
Passive measures	24,64	24,67	24,54	24,54
No passive measures	24,75	24,74	24,60	24,63
ΔT in °C	-0,11	-0,07	-0,06	-0,09

52,5m-77,5m	R1	R2	R3	R4
Passive measures	24,48	24,37	24,38	24,39
No passive measures	24,43	24,37	24,38	24,39
ΔT in °C	0,04	0,00	0,00	0,00

Maximum hourly temperature difference

0m-25m	R1	R2	R3	R4
Passive measures	36,55	36,77	36,34	36,50
No passive measures	36,76	37,07	36,49	36,70
ΔT in °C	-0,20	-0,30	-0,16	-0,19

52,5m-77,5m	R1	R2	R3	R4
Passive measures	35,74	35,69	35,71	35,74
No passive measures	35,91	35,72	35,77	35,82
ΔT in °C	-0,17	-0,03	-0,06	-0,08

Results - changed microclimate

Average hourly temperature difference

0m-25m	R1	R2	R3	R4
Passive measures	24,64	24,67	24,54	24,54
No passive measures	24,75	24,74	24,60	24,63
ΔT in °C	-0,11	-0,07	-0,06	-0,09

52,5m-77,5m	R1	R2	R3	R4
Passive measures	24,48	24,37	24,38	24,39
No passive measures	24,43	24,37	24,38	24,39
ΔT in °C	0,04	0,00	0,00	0,00

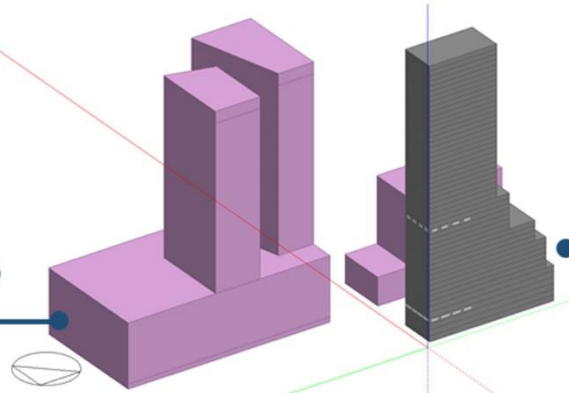
Maximum hourly temperature difference

0m-25m	R1	R2	R3	R4
Passive measures	36,55	36,77	36,34	36,50
No passive measures	36,76	37,07	36,49	36,70
ΔT in °C	-0,20	-0,30	-0,16	-0,19

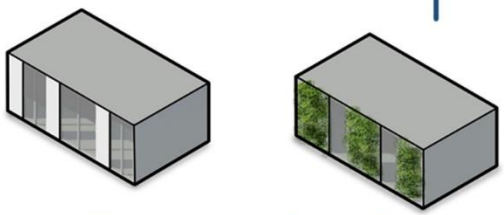
52,5m-77,5m	R1	R2	R3	R4
Passive measures	35,74	35,69	35,71	35,74
No passive measures	35,91	35,72	35,77	35,82
ΔT in °C	-0,17	-0,03	-0,06	-0,08

Results - Thermal indoor comfort new microclimate

Microclimate data file from previous step



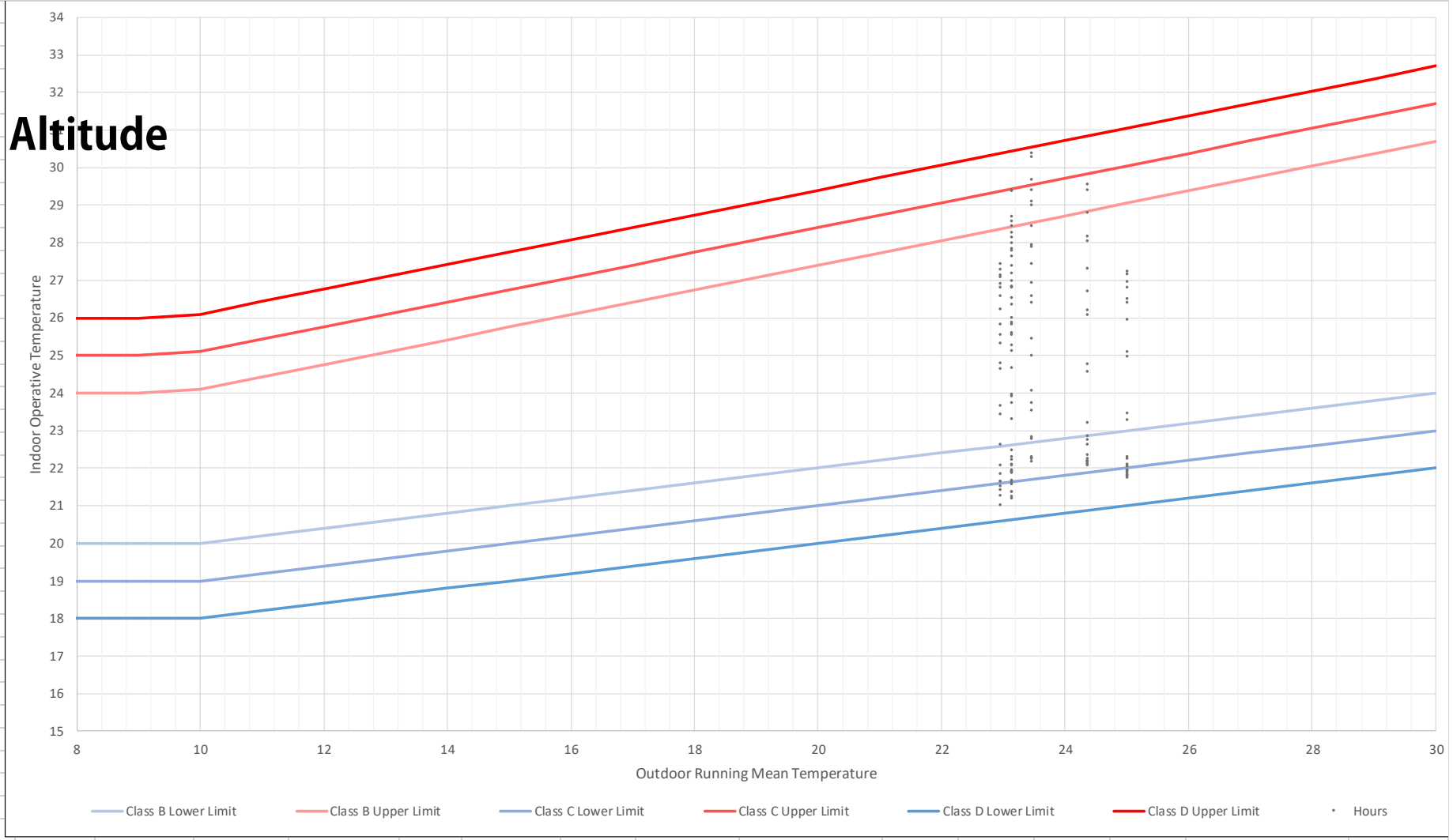
Designbuilder simulation



Facade 2

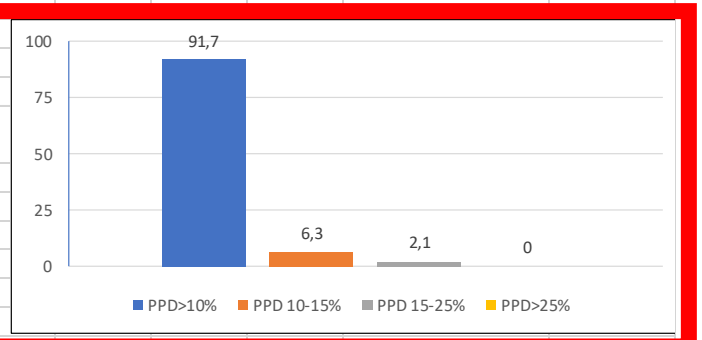
Final Thermal comfort results

Results - Low Altitude

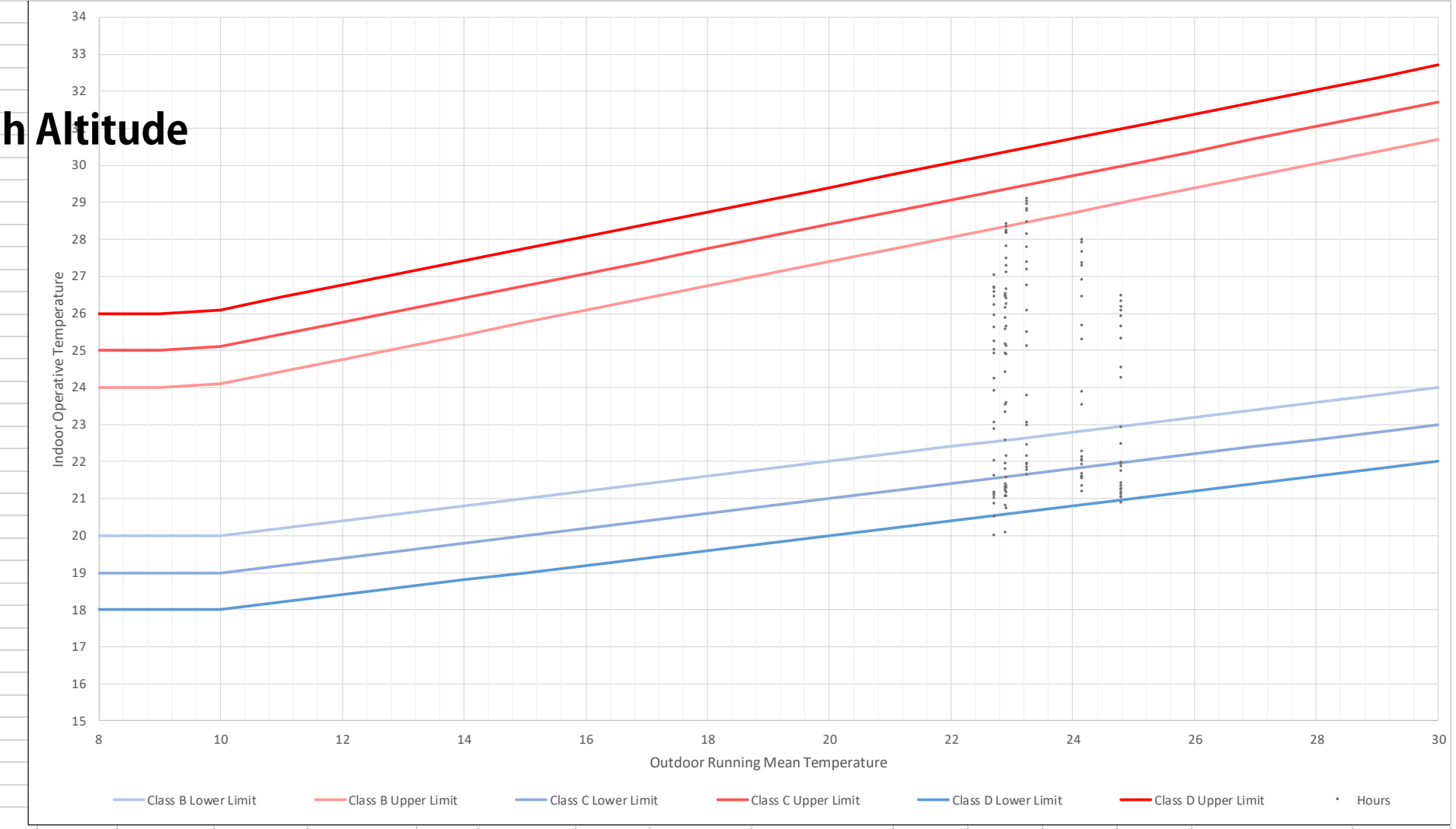


Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Operative Temperature
Analysis Period		summer months Only Working Hours	
Occupied Hours		**144**	

Thermal Performance	Class B	good
Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	132	91,7
Class C	9	6,3
Class D	3	2,1
Class E	0	0



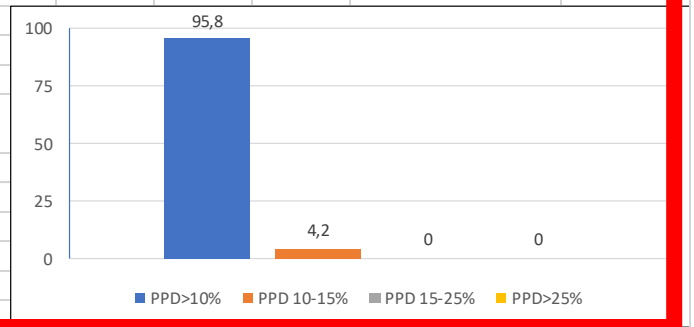
Results - High Altitude



Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Operative Temperature
Analysis Period		3-8 aug	
Occupied Hours		**144**	

Thermal Performance	Class B	good

Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	138	95,8
Class C	6	4,2
Class D	0	0
Class E	0	0



Results - Differences

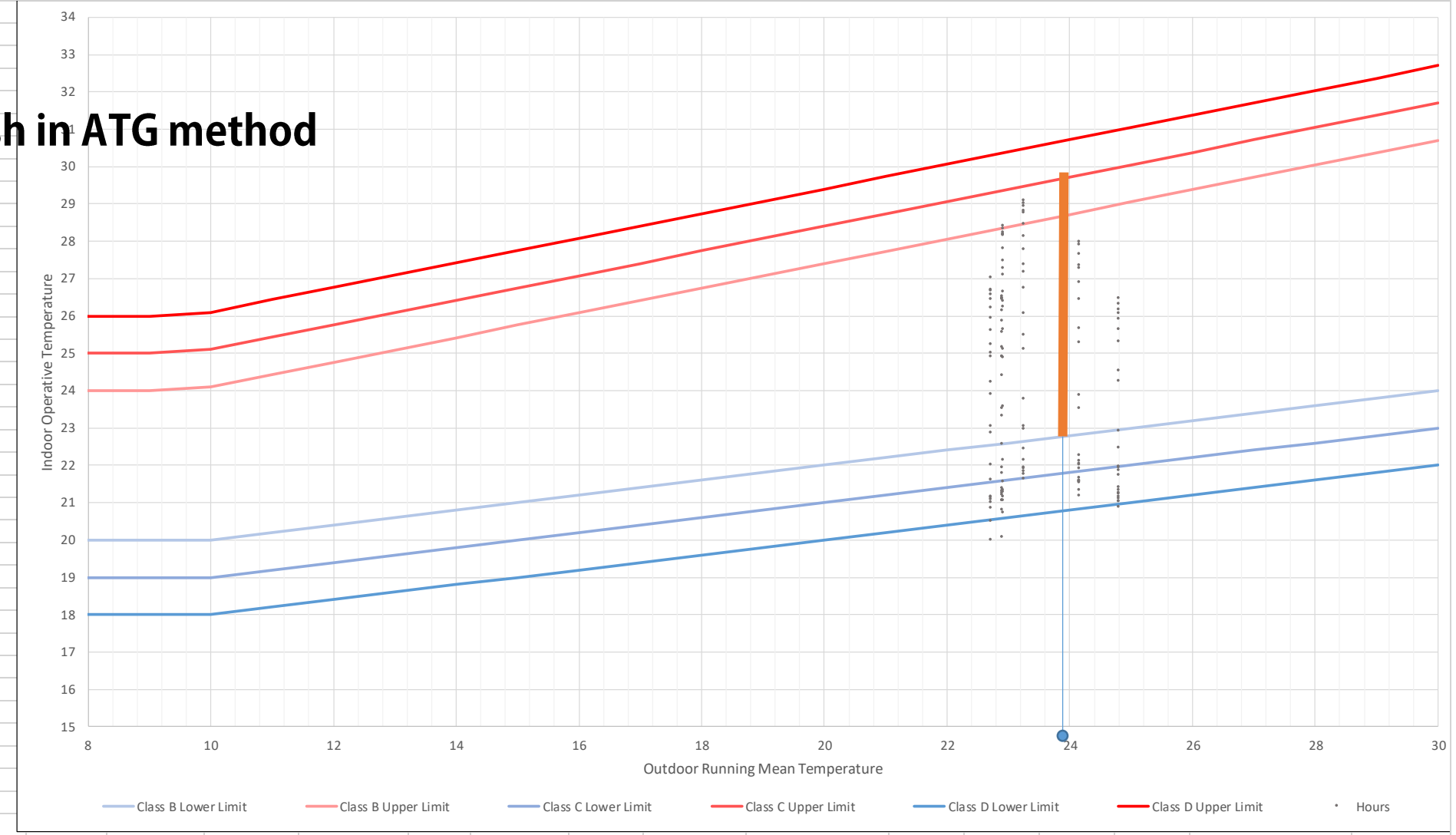
Substantial difference in climate

Minimal result with ATG method

Low Altitude	Class B		Class C		Class D		Class E	
	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time
Old climate low	132,0	91,7	8,1	5,6	4,0	2,8		
New climate low	132,0	91,7	9,1	6,3	3,0	2,1		

High Altitude	Class B		Class C		Class D		Class E	
	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time
Old climate low	138,0	95,8	6,0	4,2	0,0			
New climate low	138,0	95,8	6,0	4,2	0,0			

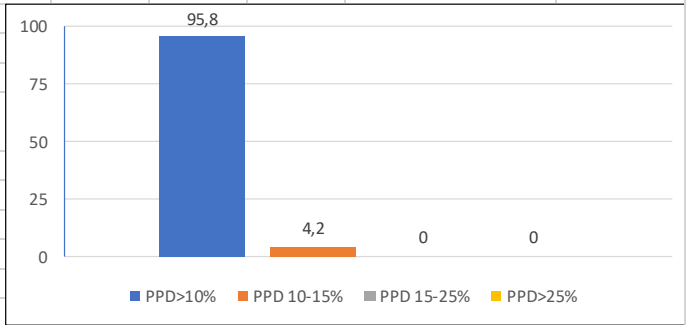
Results - Clash in ATG method



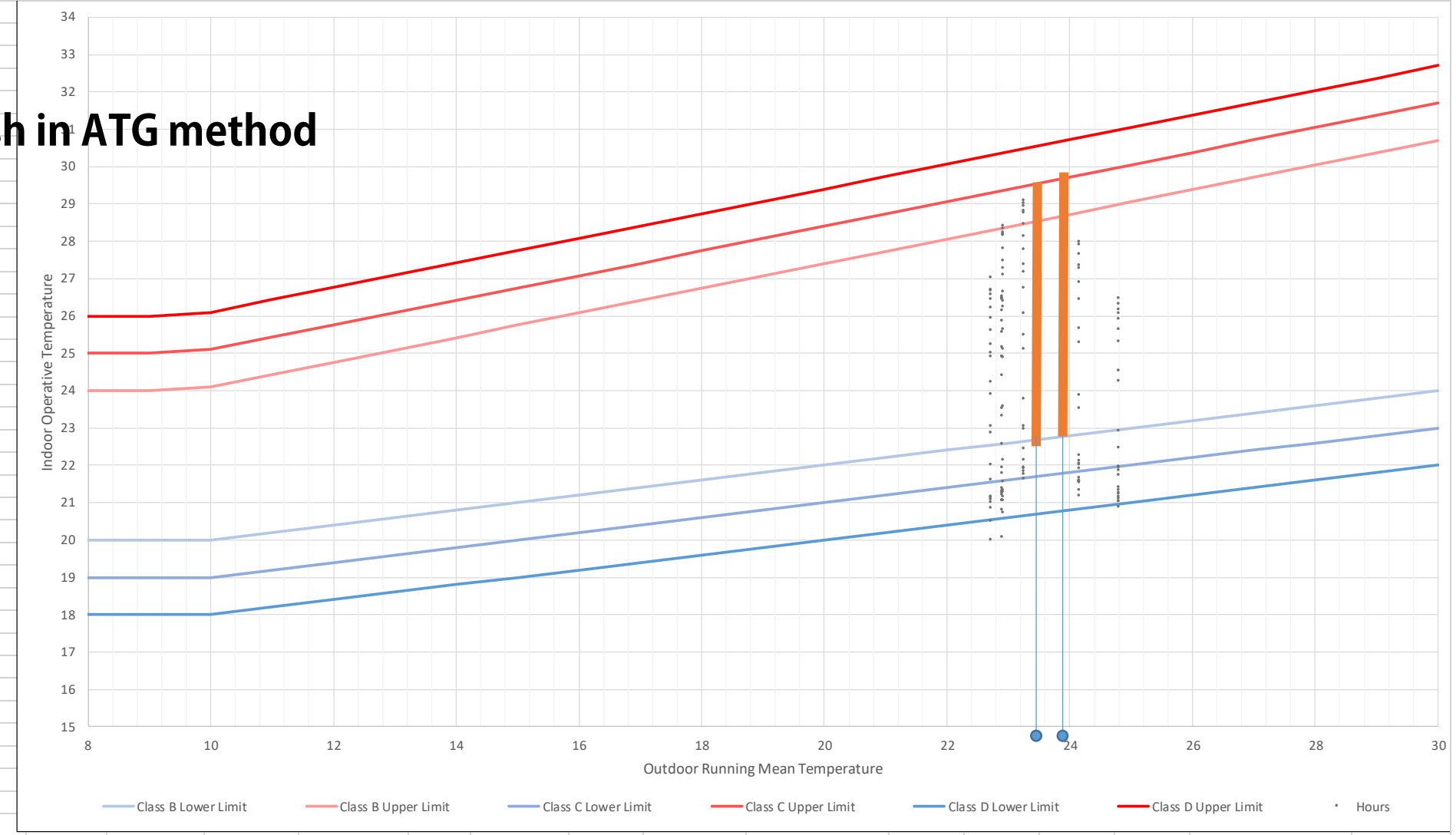
Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Operative Temperature
Analysis Period		3-8 aug	
Occupied Hours		**144**	

Thermal Performance	Class B	good

Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	138	95,8
Class C	6	4,2
Class D	0	0
Class E	0	0



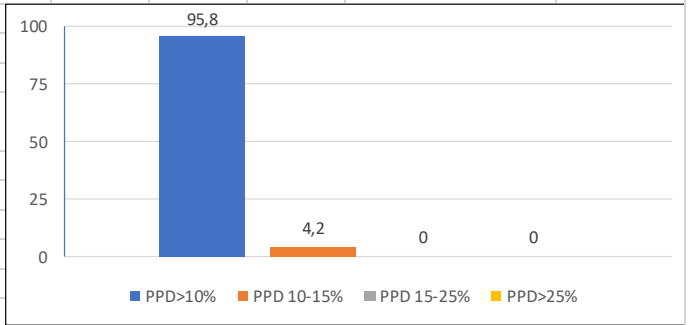
Results - Clash in ATG method



Building :	Hooghe Rijn	**Room No.**	Dwelling
Room Type :	Alpha	**Temp. Type**	Operative Temperature
Analysis Period		3-8 aug	
Occupied Hours		**144**	

Thermal Performance	Class B	good

Comfort Bandwidth	**No.of Hours**	**% of time**
Class B	138	95,8
Class C	6	4,2
Class D	0	0
Class E	0	0

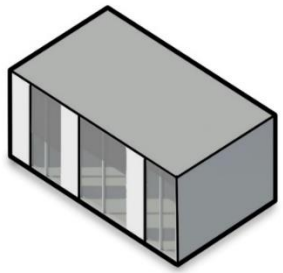


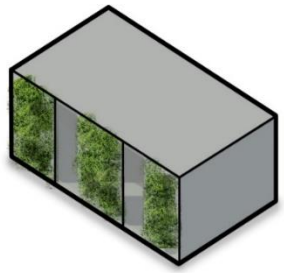
Final Design

Final design - Shading

Sunscreens not desirable at high altitudes

Alternatives to sunscreen

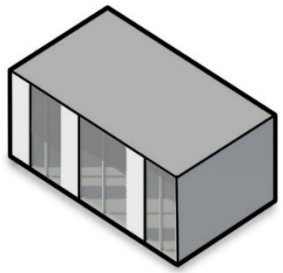


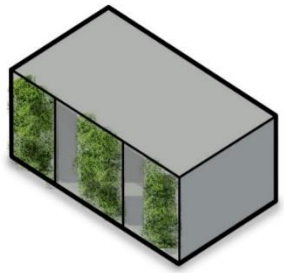


Final design - Shading

Sunscreens not desirable at high altitudes

Alternatives to sunscreen





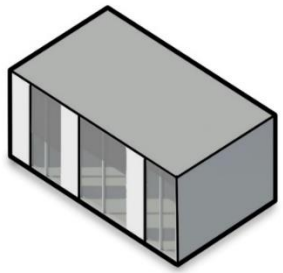
South	Class B		Class C		Class D		Class E	
	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time
No sunshading	87,0	60,4	10,9	7,6	6,0	4,2	40,0	27,8
Balconies 2m	104,0	72,2	13,0	9,0	12,0	8,3	15,0	10,4
Low g-value	108,7	75,5	15,0	10,4	9,1	6,3	10,9	7,6
Sidefins 1m	99,1	68,8	14,0	9,7	10,9	7,6	20,0	13,9
balconies/g-value	131,0	91,0	9,9	6,9	3,0	2,1	0,0	0
sidefines/g-value	127,0	88,2	11,0	7,6	6,0	4,2	0,0	0

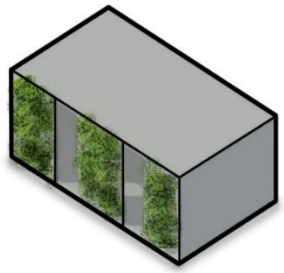
East	Class B		Class C		Class D		Class E	
	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time
No sunshading	108,0	75,0	9,9	6,9	8,1	5,6	18,0	12,5
Balconies 2m	128,0	88,9	6,0	4,2	7,1	4,9	3,0	2,1
Low g-value	131,0	91,0	9,1	6,3	3,0	2,1	1,0	0,7
Sidefins 1m	120,0	83,3	8,1	5,6	8,1	5,6	8,1	5,6
balconies/g-value	144,0	100,0	0,0	0,0	0,0	0,0	0,0	0
sidefines/g-value	141,0	97,9	11,0	2,1	0,0	0,0	0,0	0

Final design - Shading

Sunscreens not desirable at high altitudes

Alternatives to sunscreen



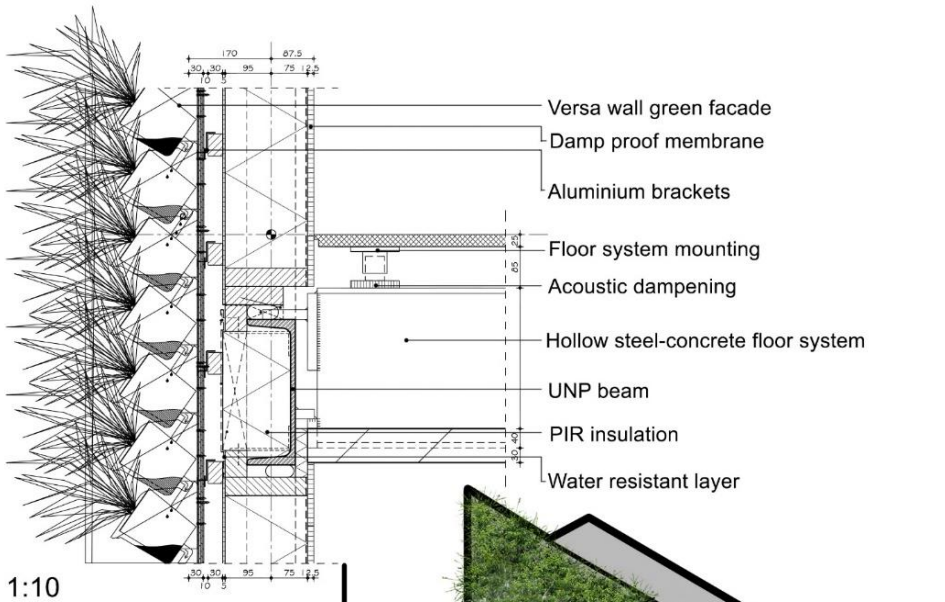


South	Class B		Class C		Class D		Class E	
	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time
No sunshading	87,0	60,4	10,9	7,6	6,0	4,2	40,0	27,8
Balconies 2m	104,0	72,2	13,0	9,0	12,0	8,3	15,0	10,4
Low g-value	108,7	75,5	15,0	10,4	9,1	6,3	10,9	7,6
Sidefins 1m	99,1	68,8	14,0	9,7	10,9	7,6	20,0	13,9
balconies/g-value	131,0	91,0	9,9	6,9	3,0	2,1	0,0	0
sidefines/g-value	127,0	88,2	11,0	7,6	6,0	4,2	0,0	0

East	Class B		Class C		Class D		Class E	
	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time	No.of Hours	% of time
No sunshading	108,0	75,0	9,9	6,9	8,1	5,6	18,0	12,5
Balconies 2m	128,0	88,9	6,0	4,2	7,1	4,9	3,0	2,1
Low g-value	131,0	91,0	9,1	6,3	3,0	2,1	1,0	0,7
Sidefins 1m	120,0	83,3	8,1	5,6	8,1	5,6	8,1	5,6
balconies/g-value	144,0	100,0	0,0	0,0	0,0	0,0	0,0	0
sidefines/g-value	141,0	97,9	11,0	2,1	0,0	0,0	0,0	0

Final design -

Vertical floor-facade detail



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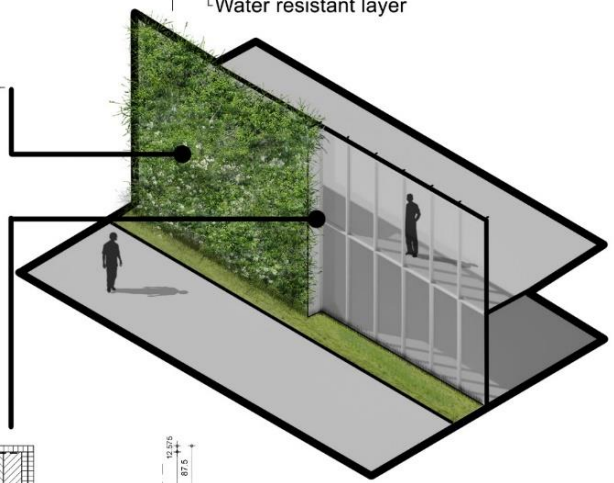
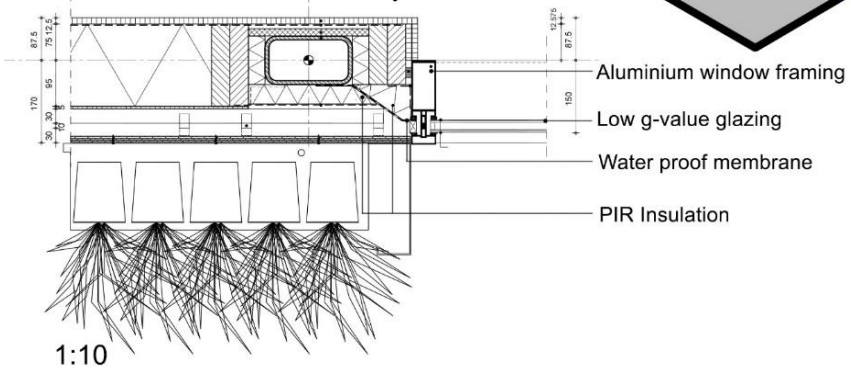


Horizontal facade detail



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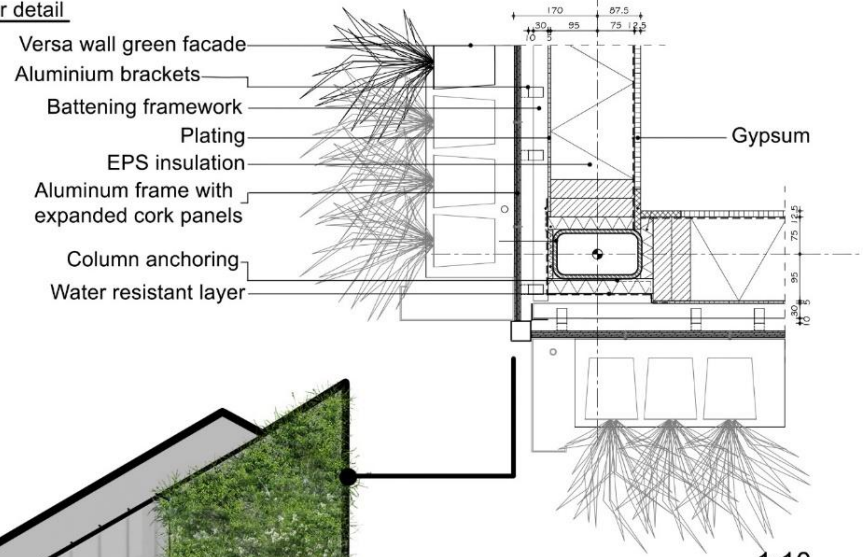
Horizontal corner detail



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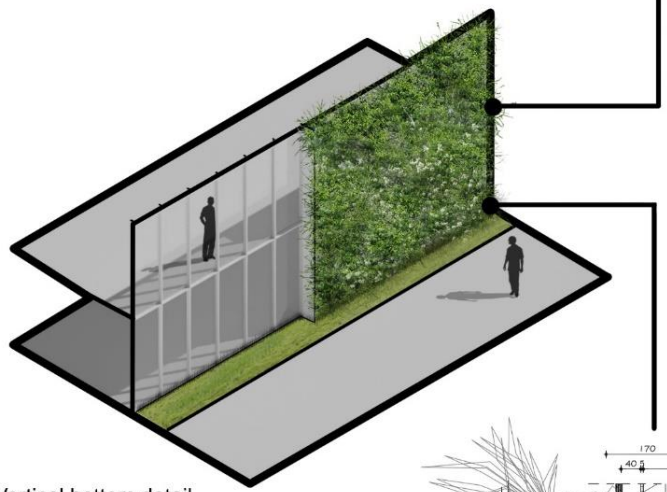
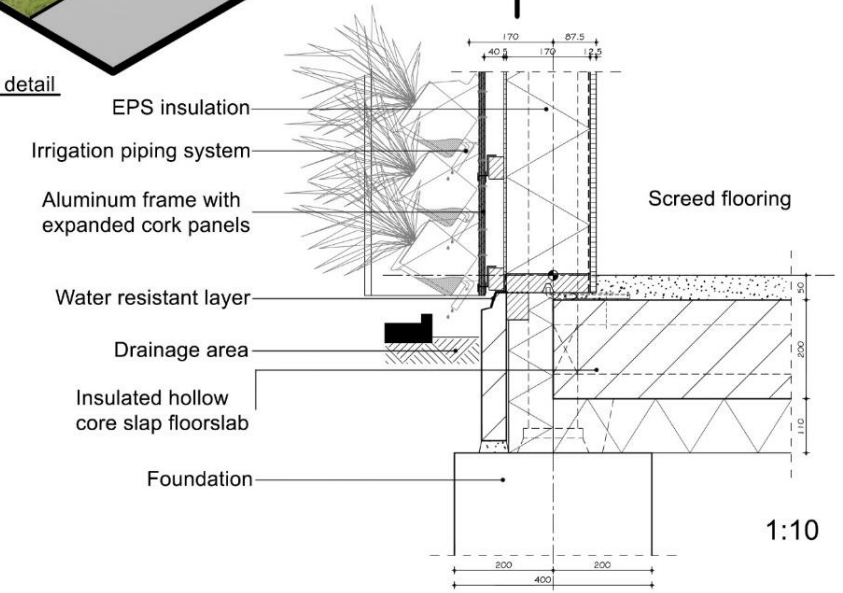


Vertical bottom detail



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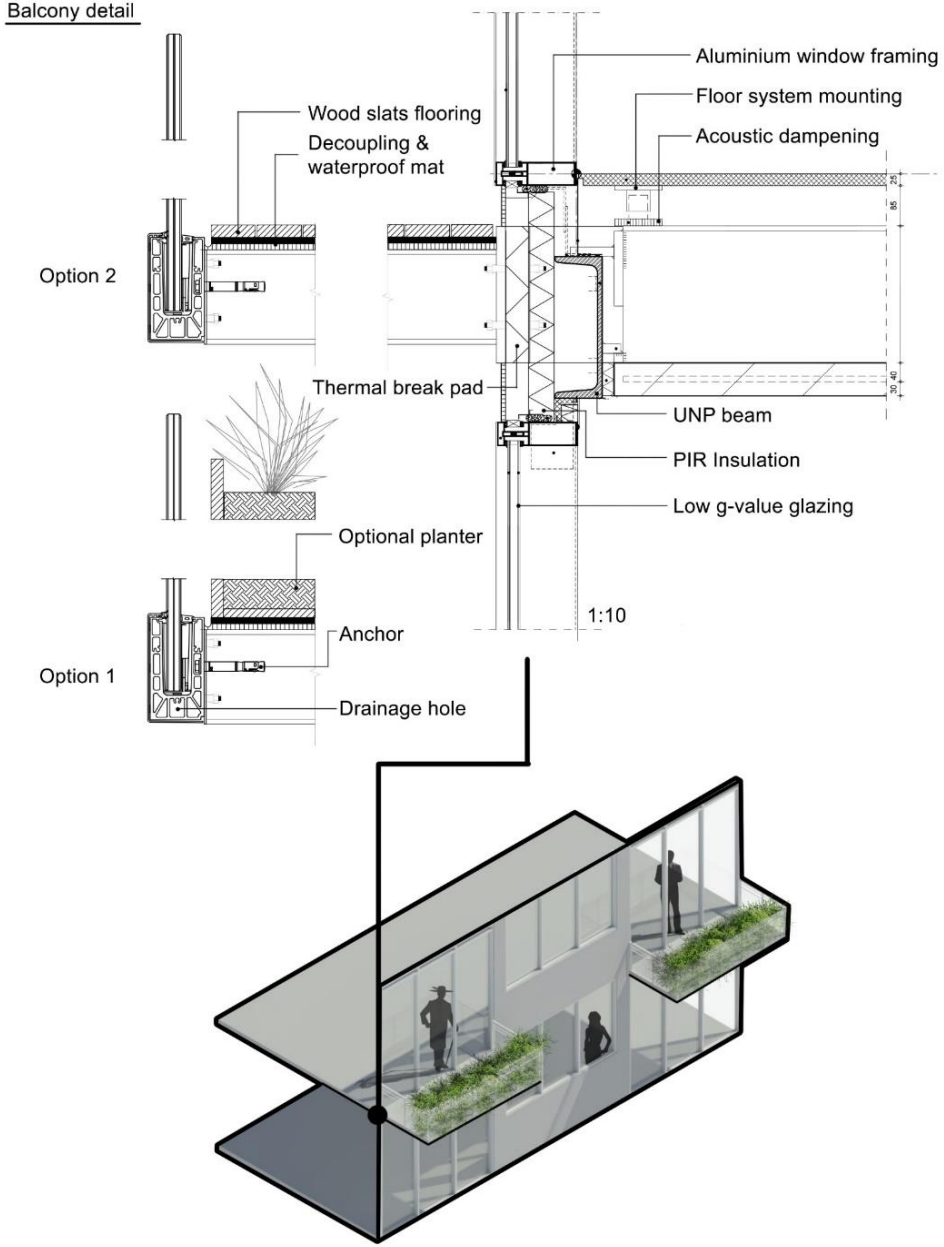
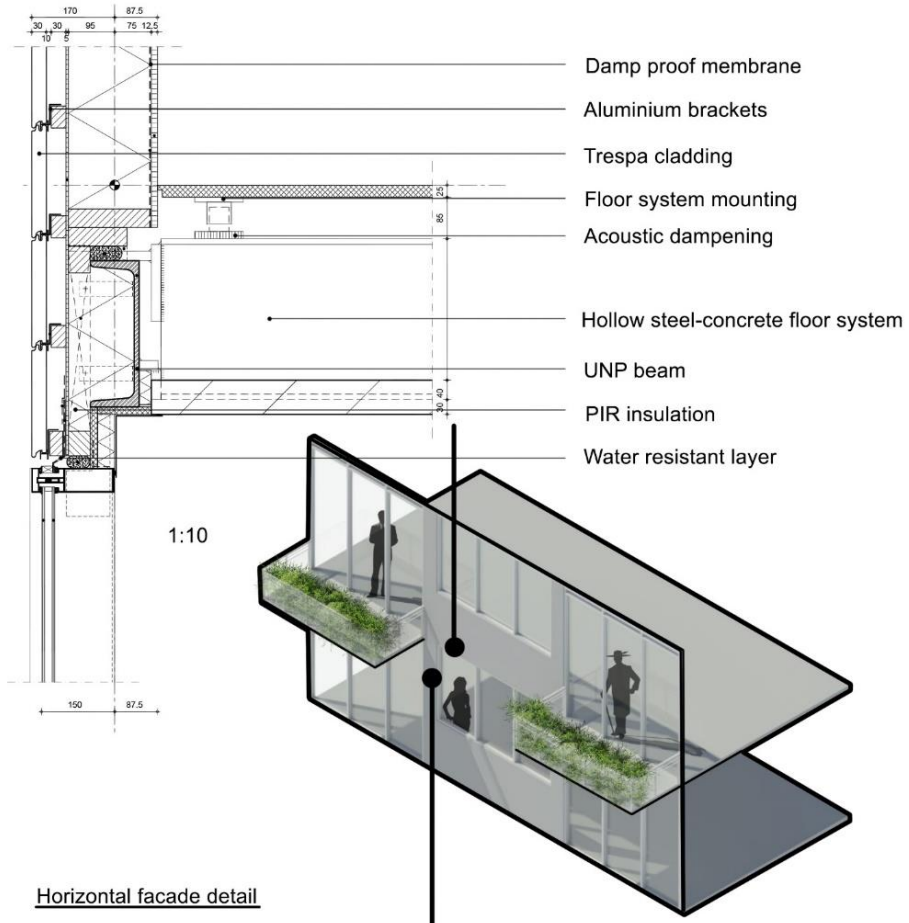
Final design -

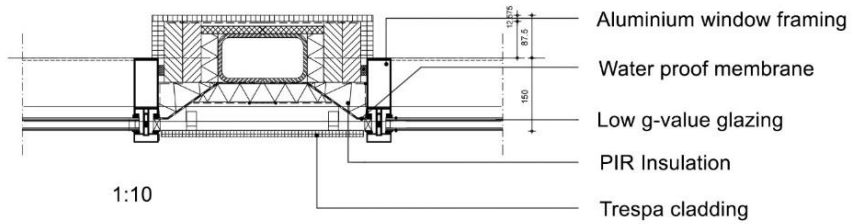
Balcony detail



Vertical floor-facade detail



Horizontal facade detail

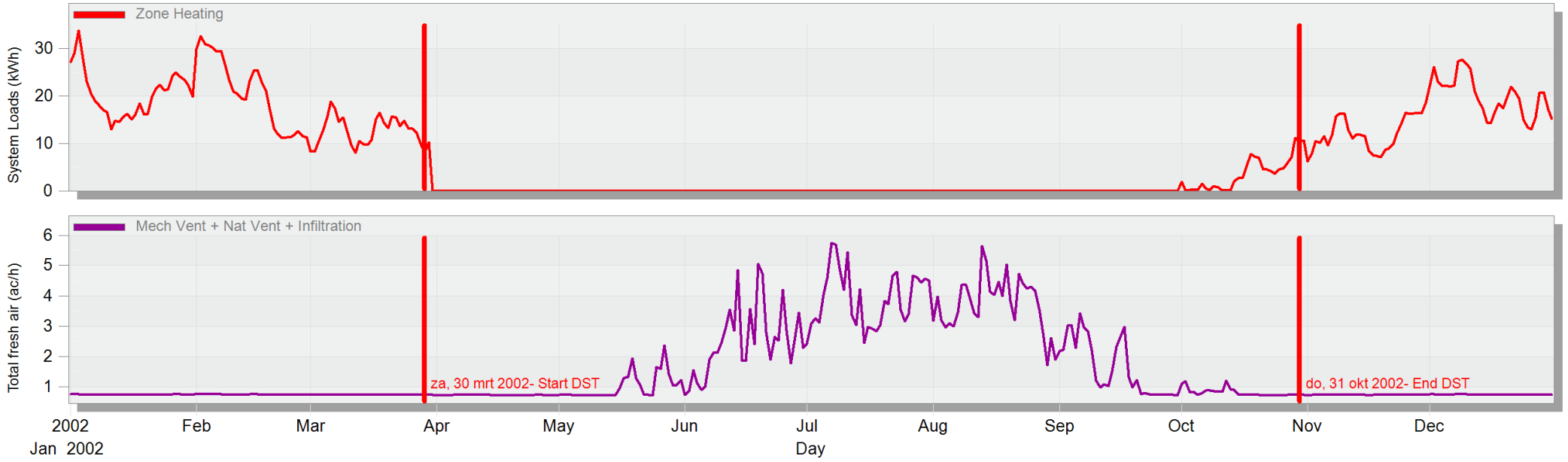


Final Design - Thermal

Lower facade Layer	Width [m]	λ [W/m x K]	R_C [m2 x K/W]
Cork	0,02	0,04	0,5
Cavity	0,04	0,22	0,1818182
Plywood	0,005	0,18	0,0277778
EPS Insulation	0,17	0,031	5,483871
Gypsum	0,0125	0,13	0,0961538
Total			6,2896208

Lower facade thermal bridge Layer	Width [m]	λ [W/m x K]	R_C [m2 x K/W]
Cork	0,02	0,04	0,5
cavity	0,04	0,22	0,18181818
plywood	0,005	0,18	0,02777778
Wood block	0,17	0,13	1,30769231
Gypsum	0,0125	0,13	0,09615385
Total			2,11344211

Upper facade Layer	Width [m]	λ [W/m x K]	R_C [m2 x K/W]
Trespa	0,02	0,3	0,0666667
Cavity	0,04	0,22	0,1818182
Plywood	0,005	0,18	0,0277778
PIR Insulation	0,17	0,029	5,862069
Gypsum	0,0125	0,13	0,0961538
Total			6,2344854



Discussion & Conclusion

Discussion

ATG method vs changing urban microclimates

Passive measures in a single building

Short simulation period

Real estate development and financial aspects

Reaction from SENS (developers of the case study)

Legislative role in this topic

Conclusion

“How can a high-rise residential building in a Dutch urban center integrate passive design measures to ensure indoor thermal comfort without negatively impacting the temperature of its surrounding microclimate in future climate scenarios?”

Combining, testing and optimizing different compositions of measures.

Microclimate impact can be minimized and lower UHI-effect, creating another passive measure

Combining adaptation and mitigation allow for symbiosis creating a virtuous cycle for livable cities


THANK YOU!
QUESTIONS?