SUMMER COMFORT IN ENERGY-EFFICIENT HIGH-RISE DWELLINGS

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OVERVIEW

1. INTRODUCTION
2. LITERATURE STUDY & GUIDELINES
4. CASE STUDY
5. REDESIGN
6. INNOVATIVE DESIGN EXPLORATION
7. CONCLUSIONS

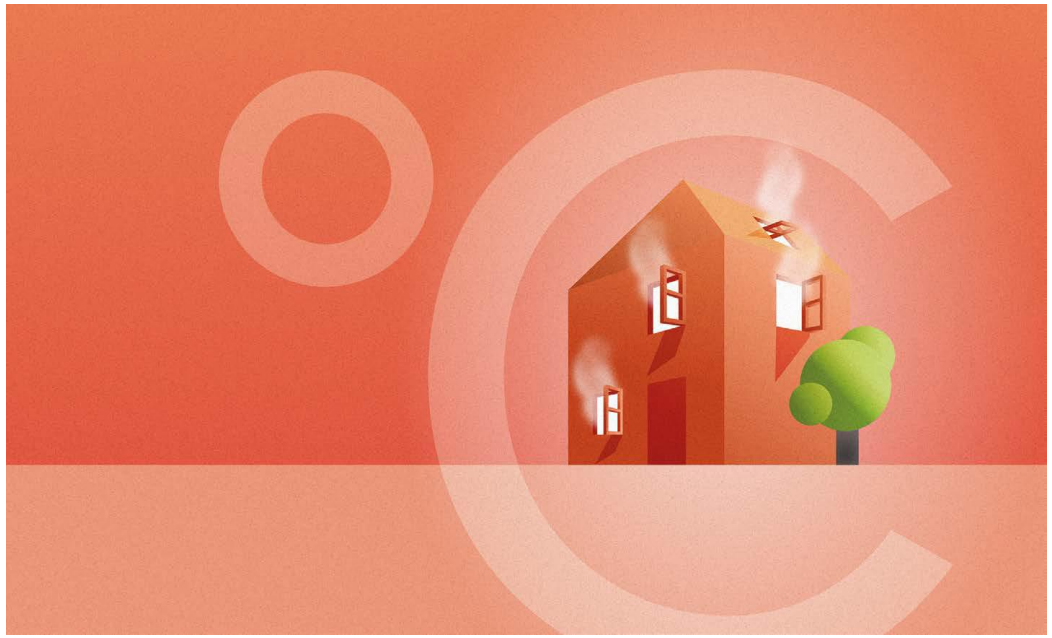
INTRODUCTION

Background

Overheating in energy-efficient dwellings:

I. Insulation

II. Airtightness



Source: Zero Carbon Hub, 2015

Problem Statement

High risk of overheating in high-rise dwellings.

The market preference

Lightweight material

Limited ventilation

Stack effect

Research Questions

How to **prevent overheating** in **energy-efficient high-rise dwellings** of temperate climate with high window to wall ratio **without** using **active cooling?**

Can these measures help to **avoid active cooling** in the **future** as global **temperature rises**?

Design Goal

As the **case study** a high-rise dwelling **in Netherlands** is selected to examine a solution package through facade design. Through this the **effectivity** of these measures in **prevention of overheating** in the apartments is examined.

LITERATURE STUDY & GUIDELINES

Assessment and Definition of Overheating

1. TO_{juli}
2. AGT

Assessment and Definition of Overheating

1. TO_{juli} Predicts the chance of temperature exceedance in a building, in July, the hottest month of the year.

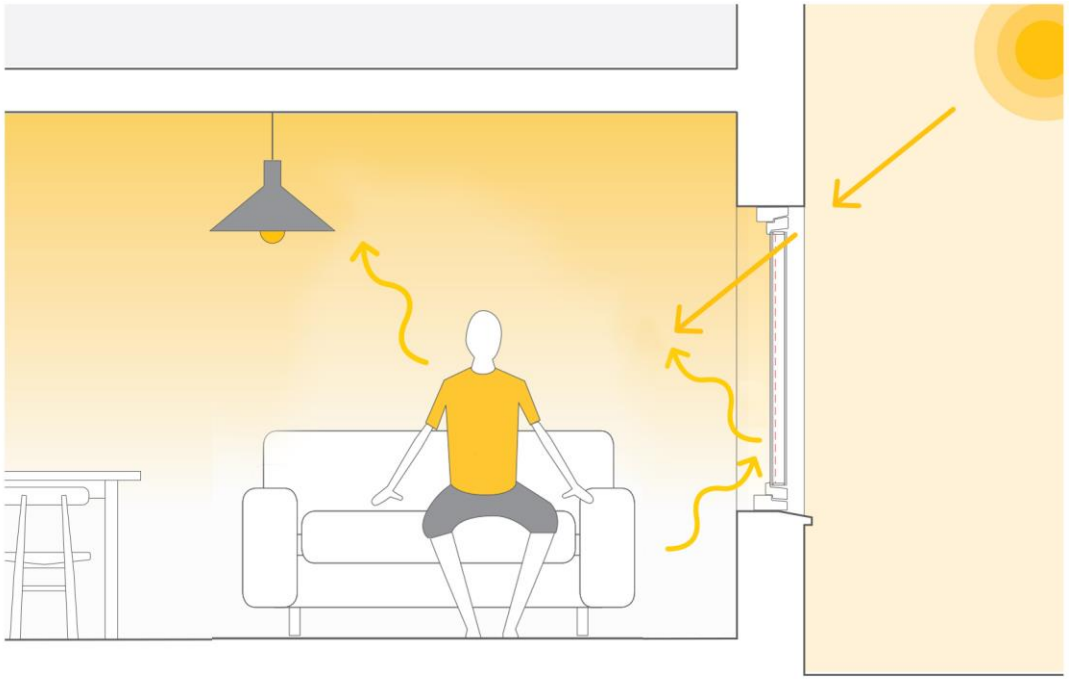
Assessment and Definition of Overheating

2. AGT

A room considered overheated if temperature exceeds adaptive comfort upper threshold for more than 200 occupied hours a year

Sources of Overheating

- External heat gain
- Internal heat gain
- Inadequate ventilation



Overheating risk in the future

Season	Indicator	Scenario change values for the climate around 2050				Scenario change values for the climate around 2085			
Climate scenario		G_L	G_H	W_L	W_H	G_L	G_H	W_L	W_H
Global temperature rise		+1 °C	+1 °C	+2 °C	+2 °C	+1.5 °C	+1.5 °C	+3.5 °C	+3.5 °C
Air circulation pattern change		Low	Low	High	High	Low	Low	High	High
Winter	Average temperature	+0.9°C	+1.1°C	+1.8°C	+2.3°C	+1.8°C	+2.3°C	+3.6°C	+4.6°C
	Coldest winter day of the year	+1.0°C	+1.5°C	+2.1°C	+2.9°C	+2.1°C	+2.9°C	+4.2°C	+5.8°C
Summer	Average temperature	+0.9°C	+1.4°C	+1.7°C	+2.8°C	+1.7°C	+2.8°C	+3.4°C	+5.6°C
	warmest summer day of the year	+1.0°C	+1.9°C	+2.1°C	+3.8°C	+2.1°C	+3.8°C	+4.2°C	+7.6°C

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Exploration of energy efficient solutions

- Urban planning
- Spatial design
- Detailing and materialization
- Feasibility and simulation
- During occupancy

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- Heat protection
- Heat dissipation
- Thermal storage

Design Guidelines

- Urban Level
- Spatial Design Level
- Materialisation & Detailing Level
- During Occupancy

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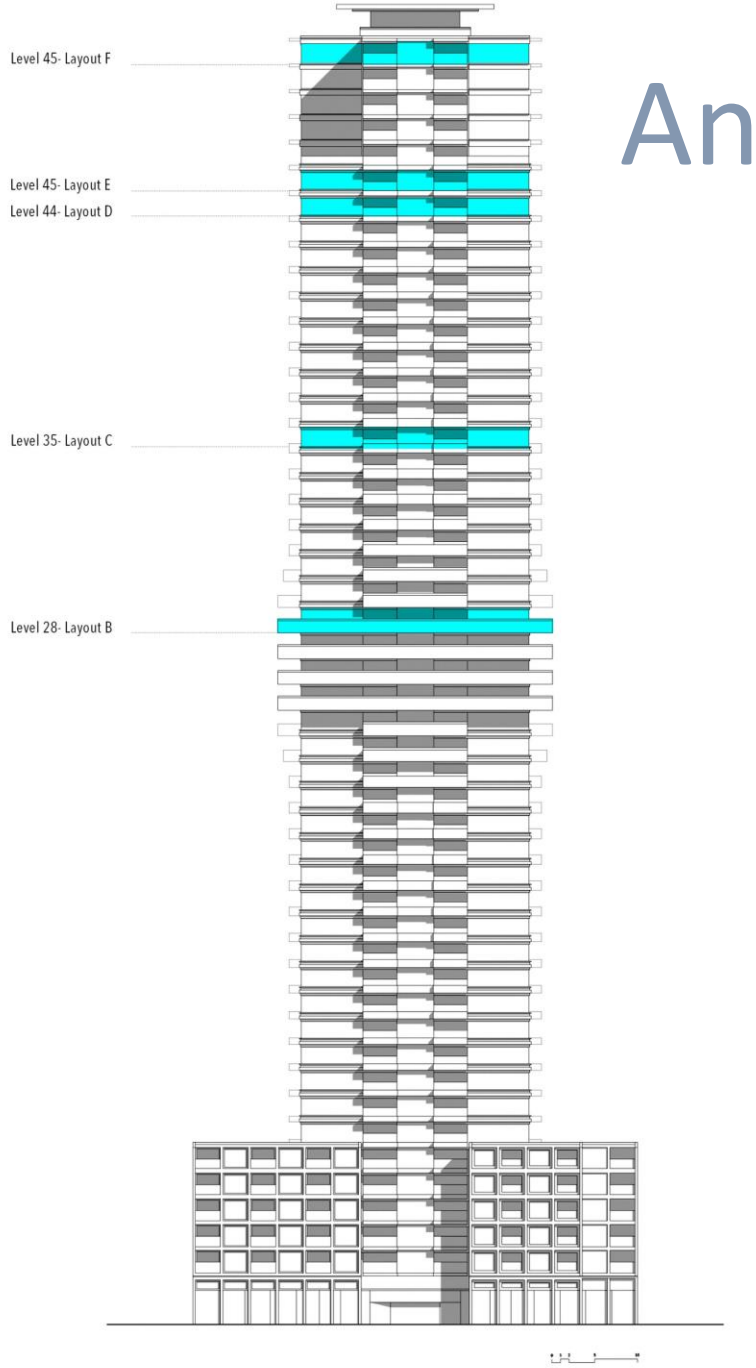
CASE STUDY

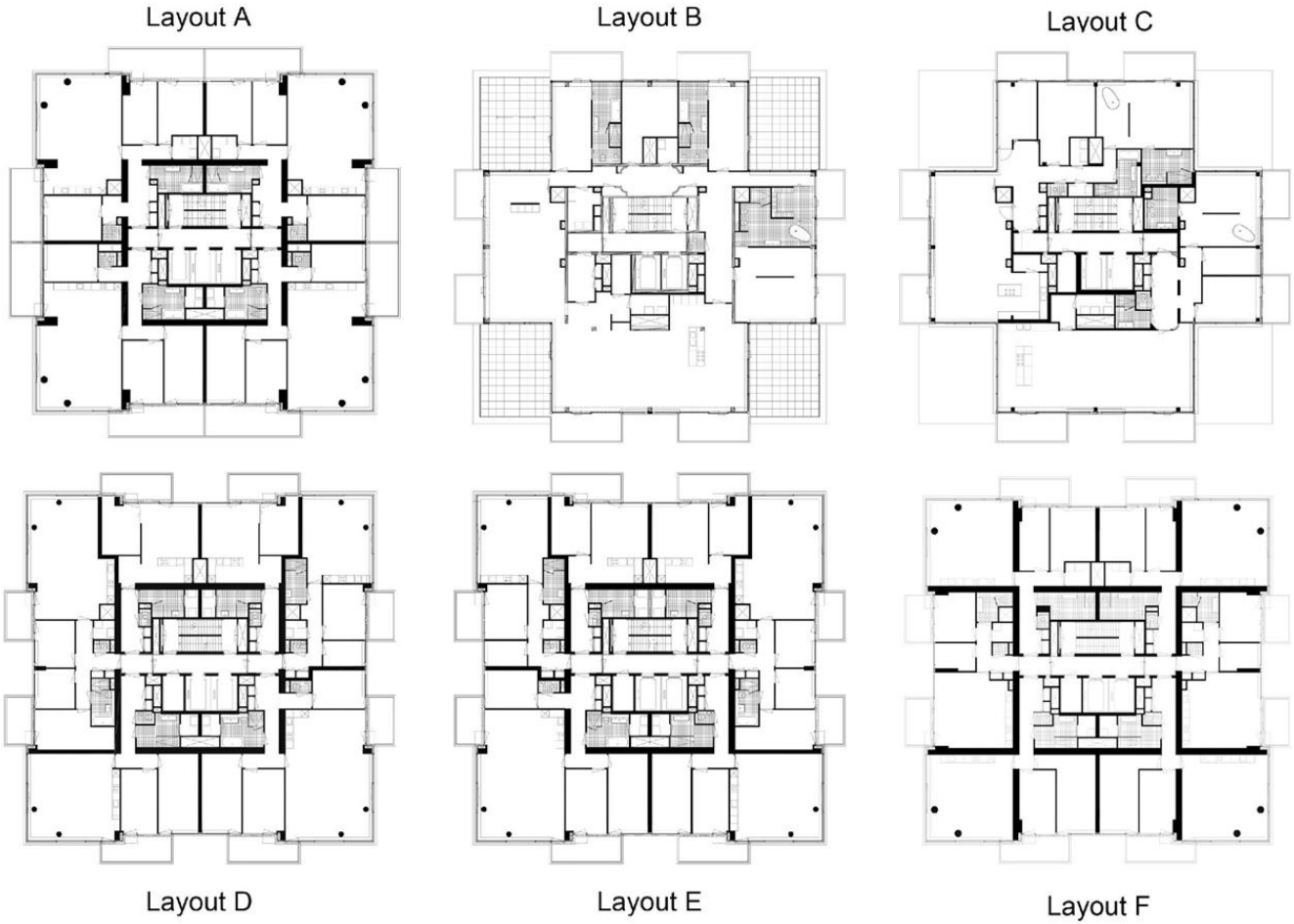
COOLTOREN

- Location: Rotterdam
- Architects: V8 architect
- 50 floors & 154 m height

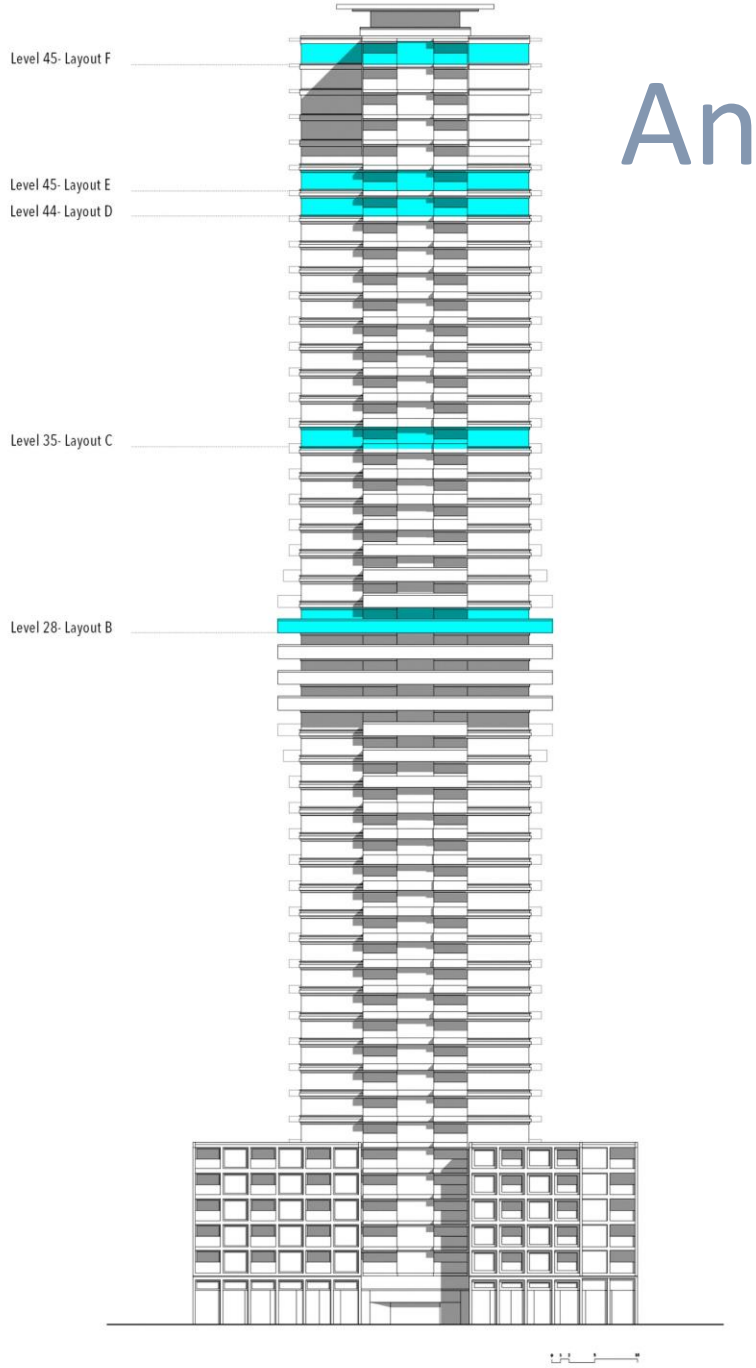
Source: V8 architects

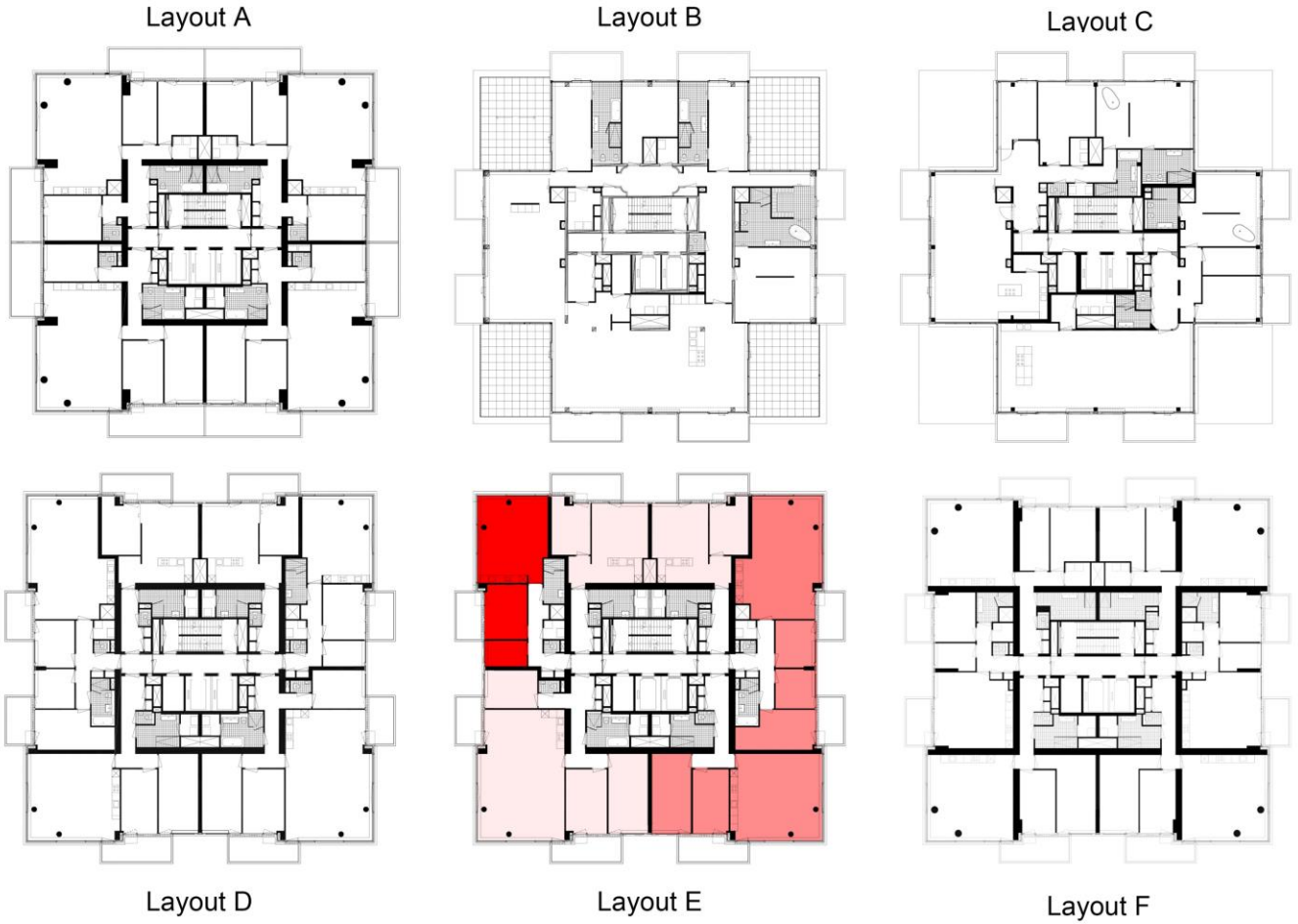
Analytical Analysis



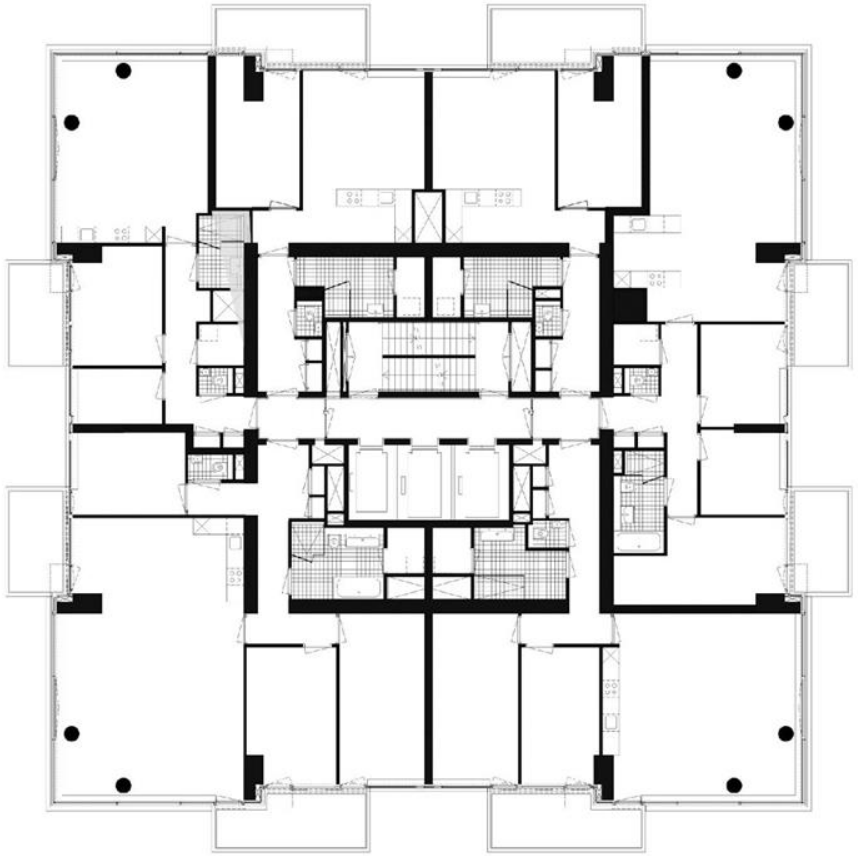


Analytical Analysis

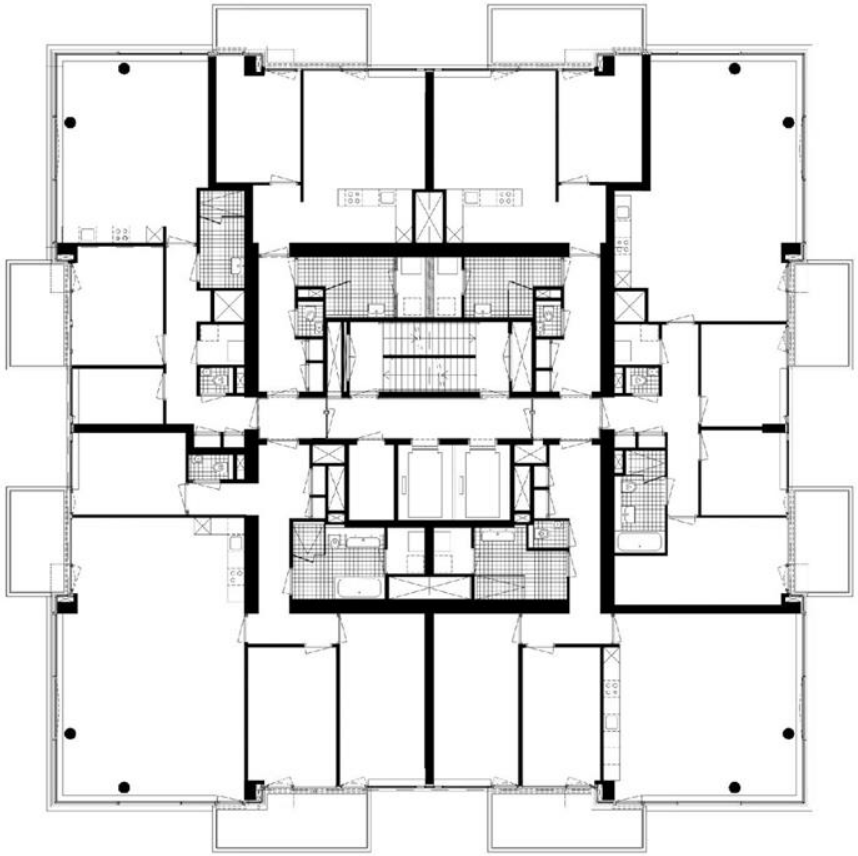




Numerical Analysis for Layout E



Level 9 (28 m)



Level 45 (132 m)

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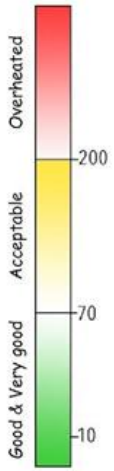

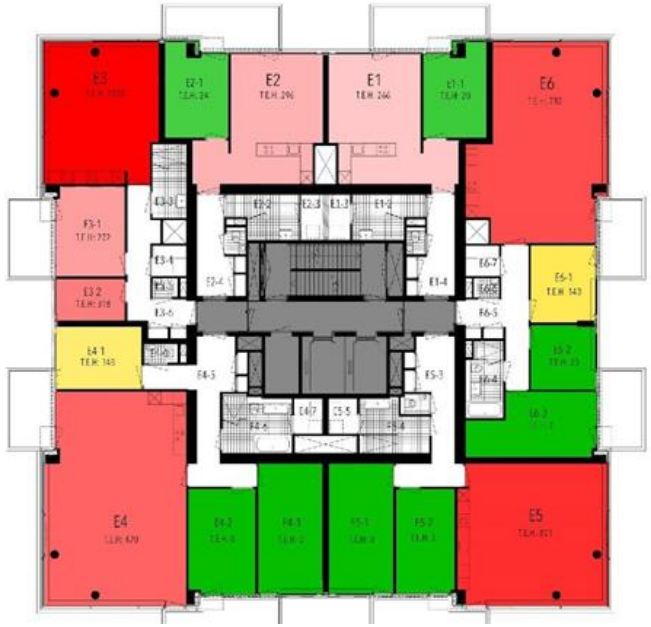

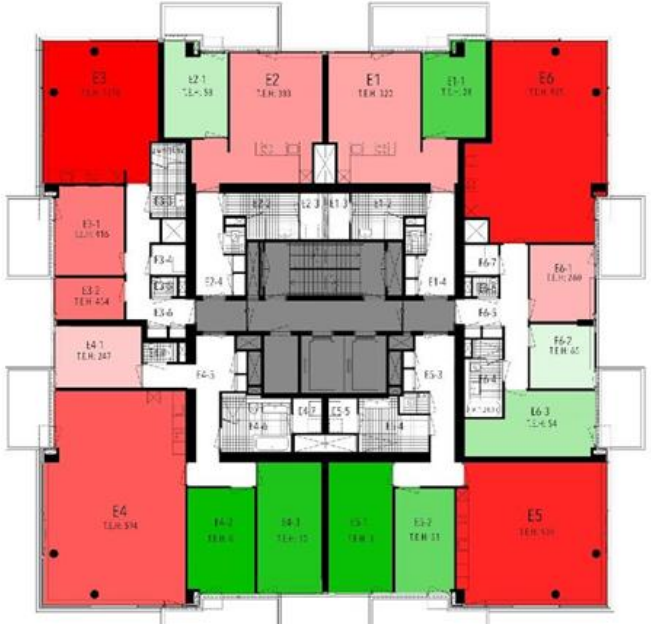

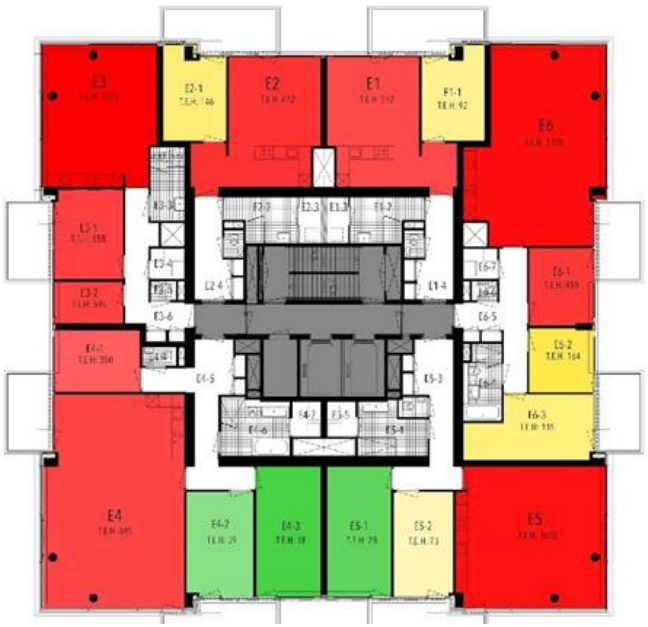

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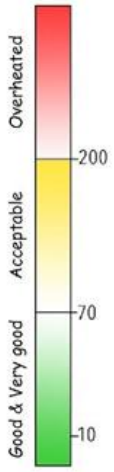
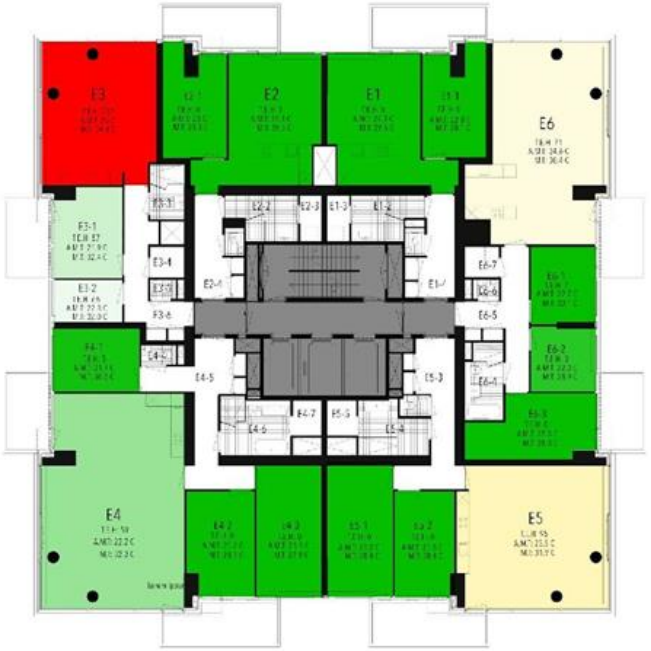
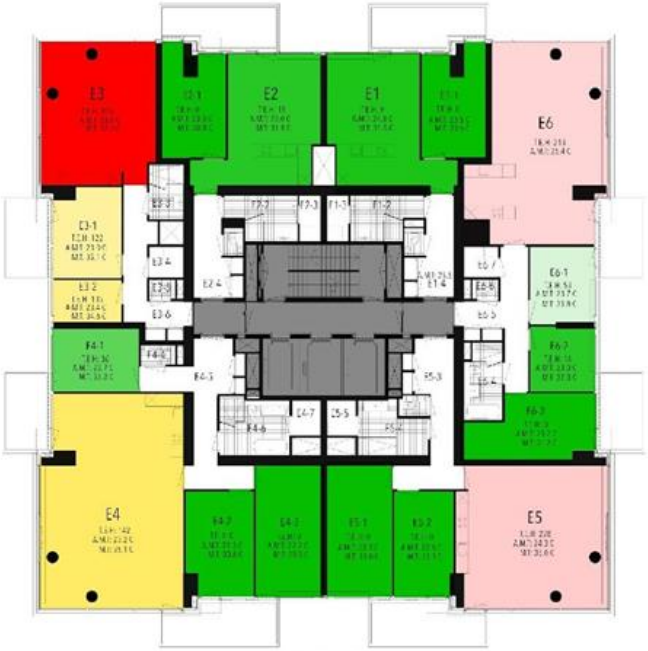






Present

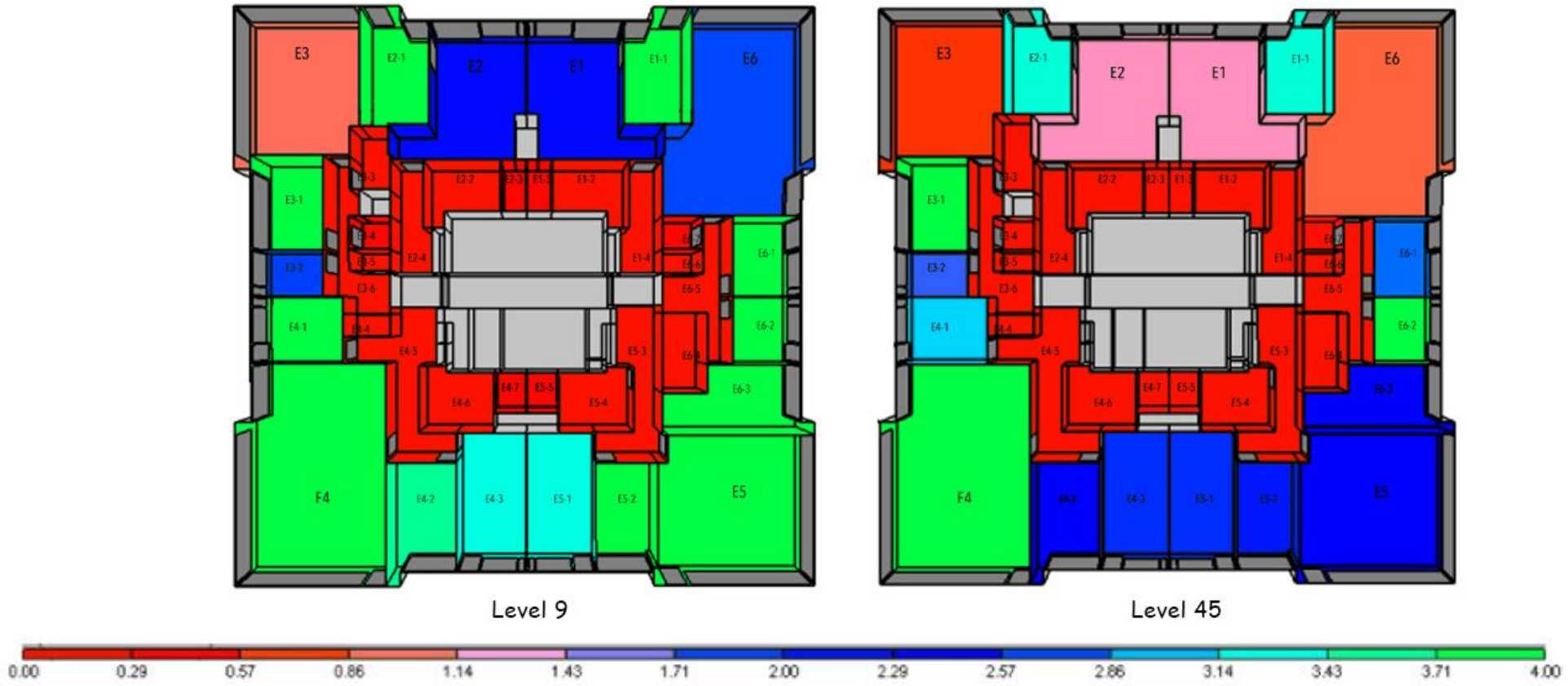
2050

2085

External Gains

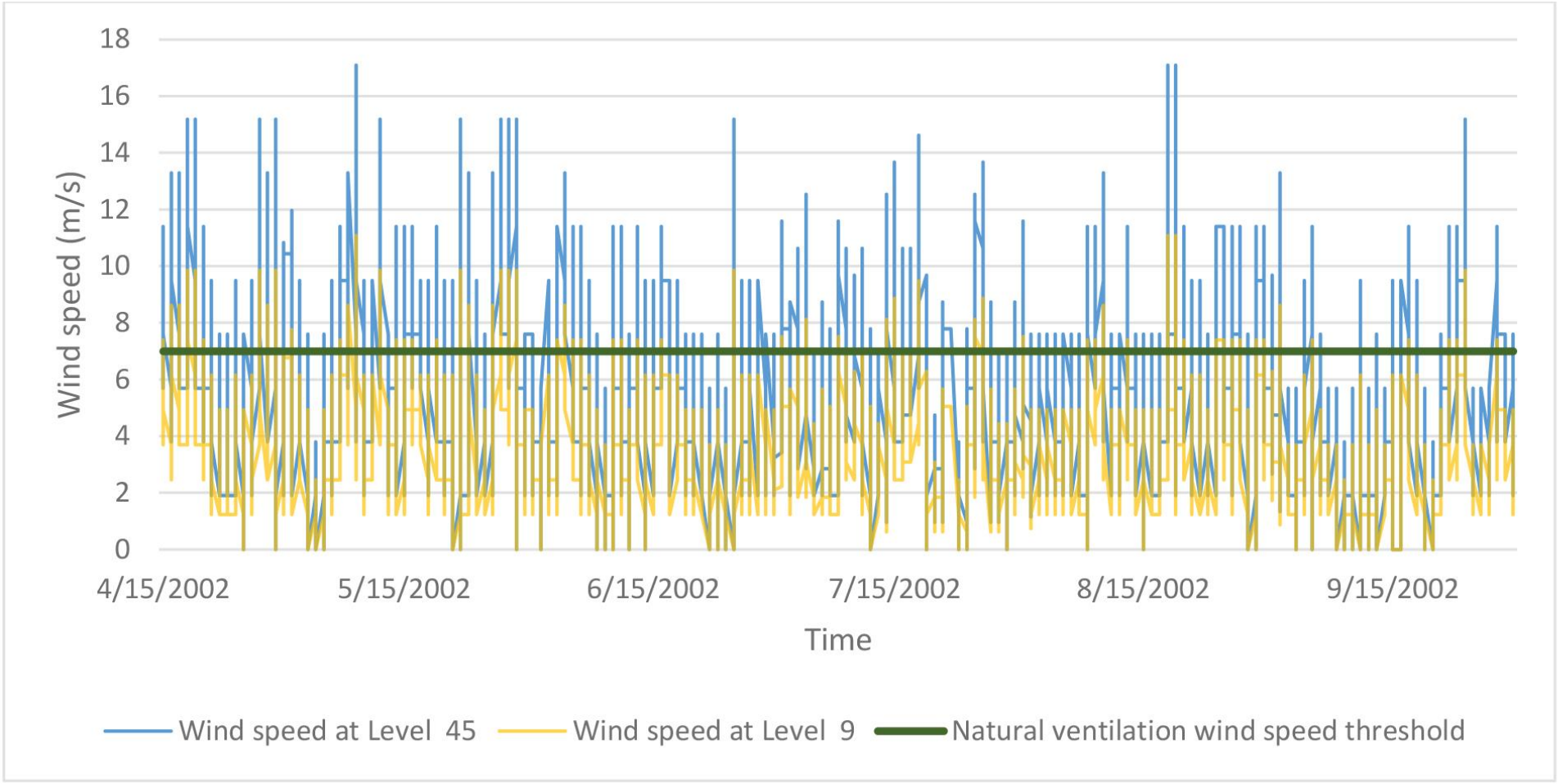
Solar gains of the double sided zones during the summer

Inadequate Ventilation



Average air change rate (ac/h) of the simulated zones

Inadequate Ventilation

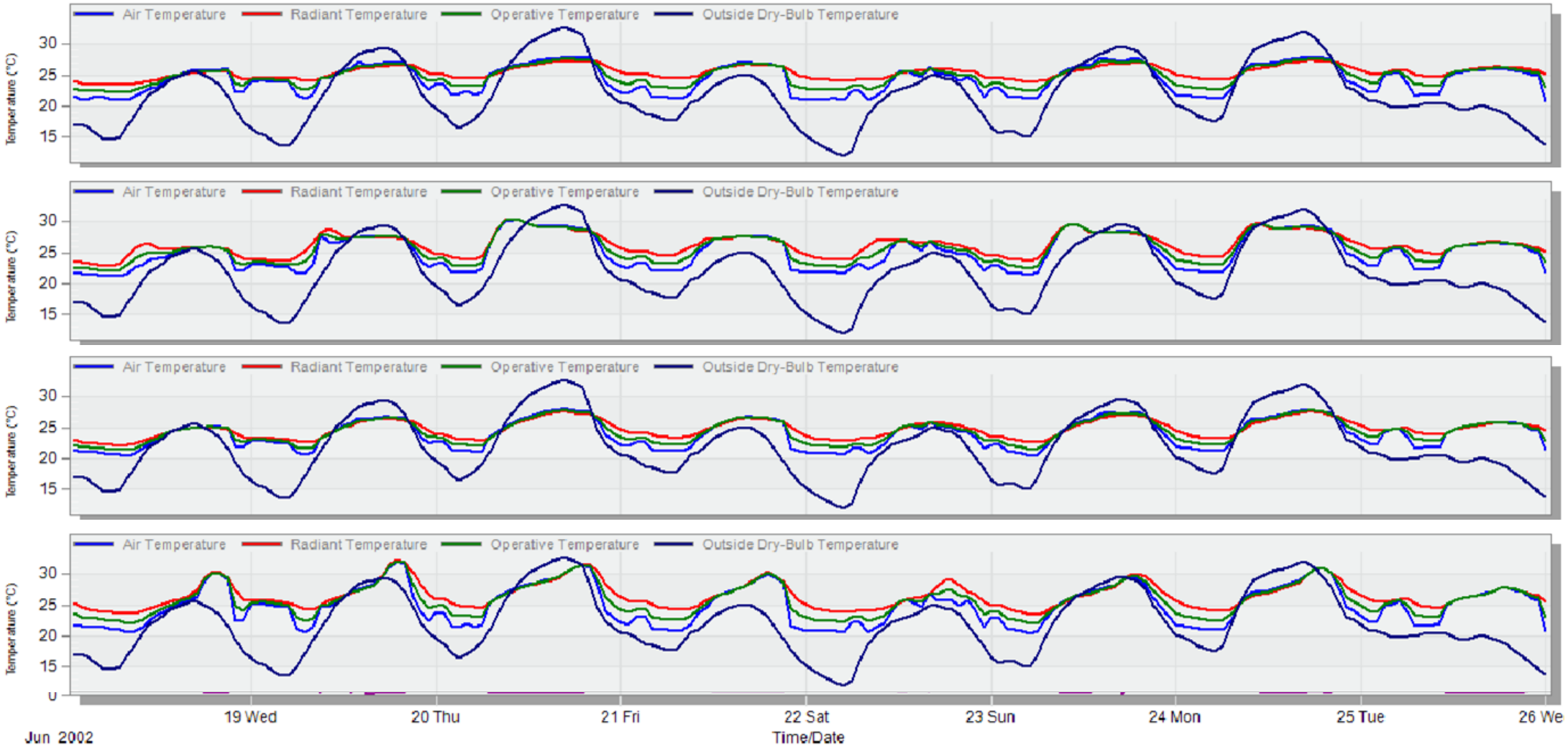


North

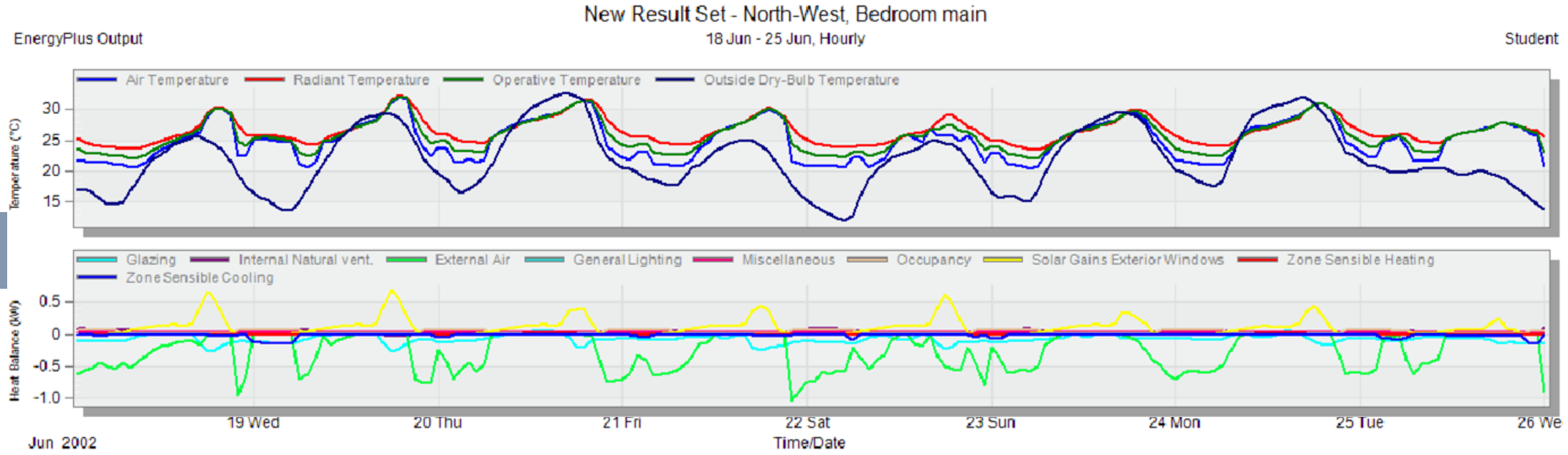
East

South

West



West


New Result Set - North-West, Bedroom main
EnergyPlus Output
18 Jun - 25 Jun, Hourly
Student
Air Temperature
Radiant Temperature
Operative Temperature
Outside Dry-Bulb Temperature
Temperature (°C)
30
25
20
15
Glazing
Internal Natural vent.
External Air
General Lighting
Miscellaneous
Occupancy
Solar Gains Exterior Windows
Zone Sensible Heating
Zone Sensible Cooling
Heat Balance (kW)
0.5
0
-0.5
-1.0
19 Wed
20 Thu
21 Fri
22 Sat
23 Sun
24 Mon
25 Tue
26 We
Jun 2002
Time/Date

Cooltoren overheating in summary

	Positive characteristics	Negative characteristics
Heat gains	+ Balconies shade main bedrooms + Low solar transmittance value of the South, East and West facing glazing reduces solar gains	– Unshaded bedroom facing east and west – High solar gains from Northern windows – Spreading of overheated areas
Heat dissipation	+ Cross-ventilation is possible + Free cooling possible	– Inadequate ventilation in apartments facing North and thermal mass cannot be recharged during the night – Openings are not protected from rain and high wind speed, making natural ventilation impossible – Internal partitions hinder airflow – Zones with lower thermal mass are at greater risk of overheating in the future
Thermal storage	+ East- North and South: Stable indoor environment with small temperature swings + Big bedrooms: Stable toward diurnal temperature swings	

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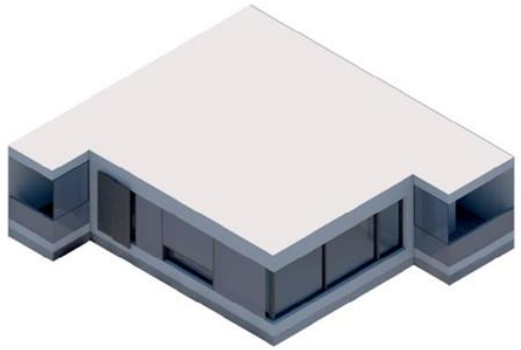
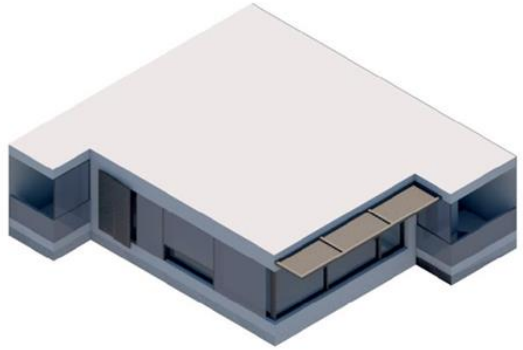
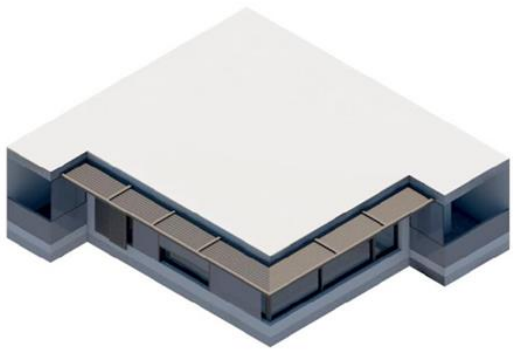
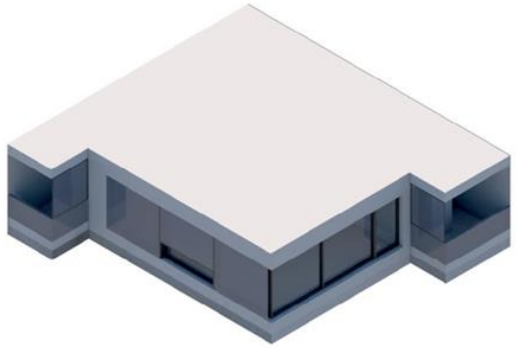
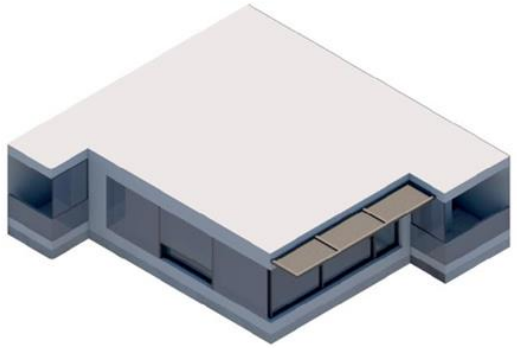
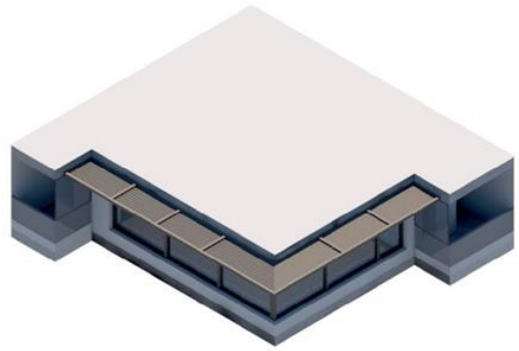
REDESIGN

Design Requirements

- Visual field: Should not restrict the visual field
- Acoustic comfort: Should not harm indoor acoustical quality
- Construction impact: Not taking valuable space
- Cost: 45000 Euro for each floor

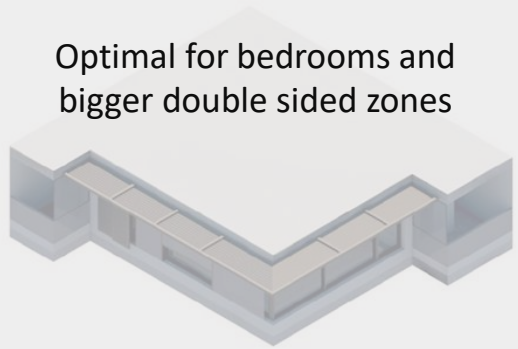
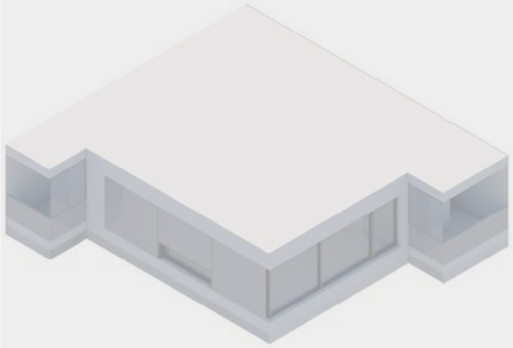
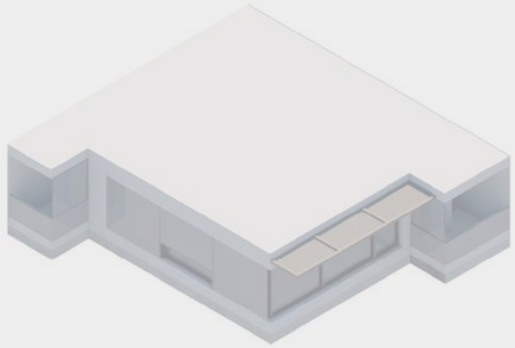
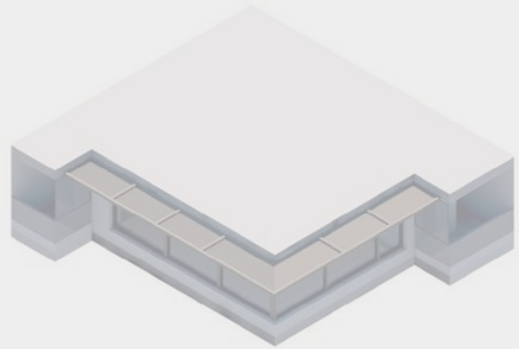
Design variations

	Minimizing architectural impact	Minimizing solar radiation	Minimizing solar maintenance
Increasing natural ventilation			
Rescheduling mechanical ventilation			

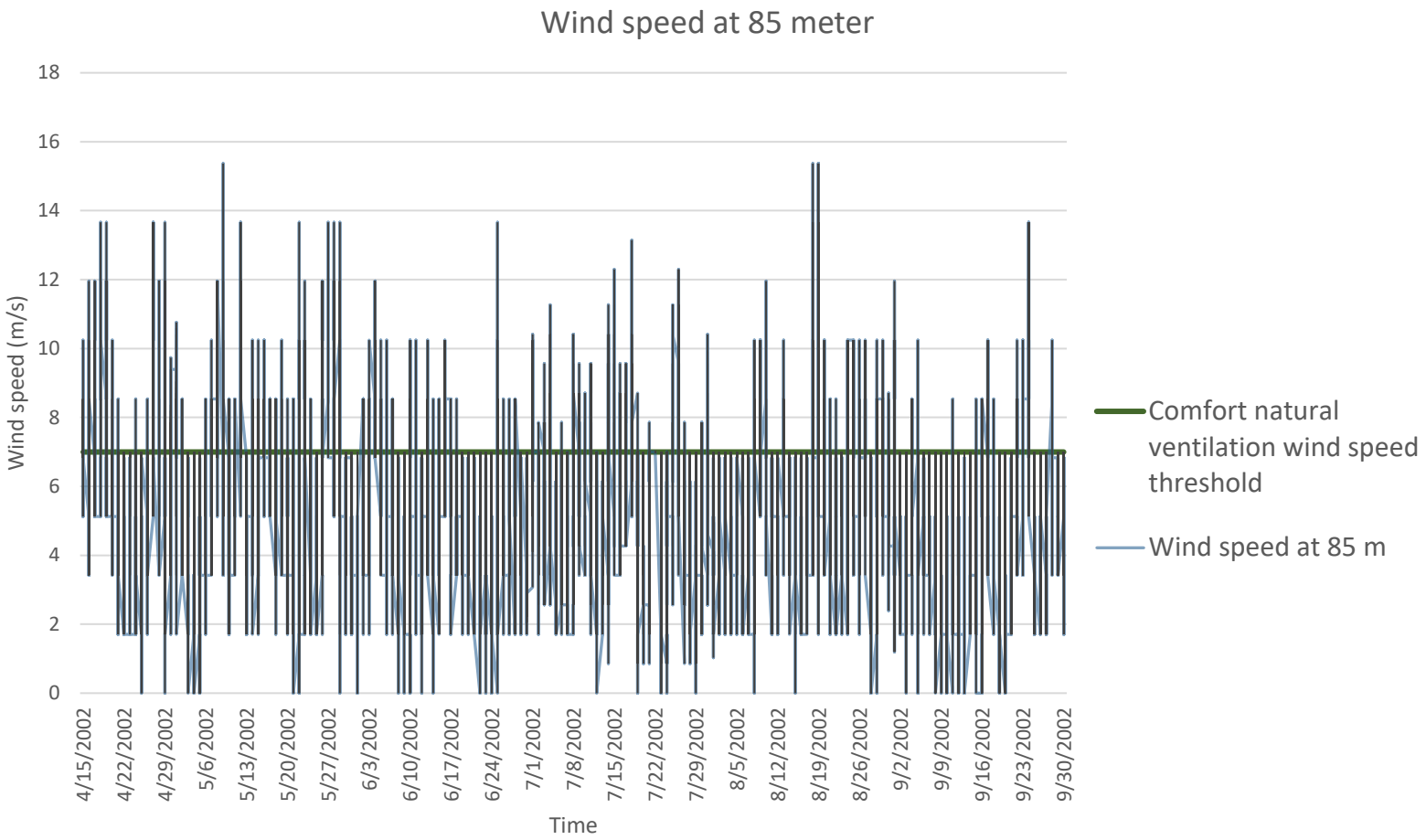
Design Evaluation

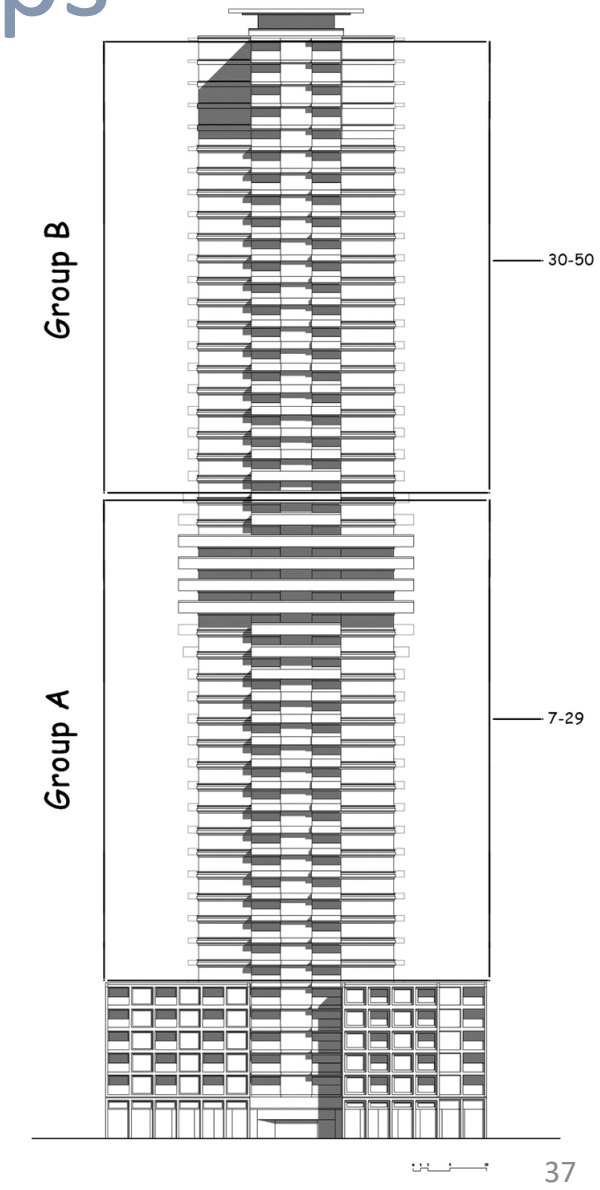
	Minimizing architectural impact	Minimizing solar radiation	Minimizing solar maintenance
• Overheating Increasing natural ventilation • Visual field			
• Cost Rescheduling mechanical ventilation			

Evaluation Results

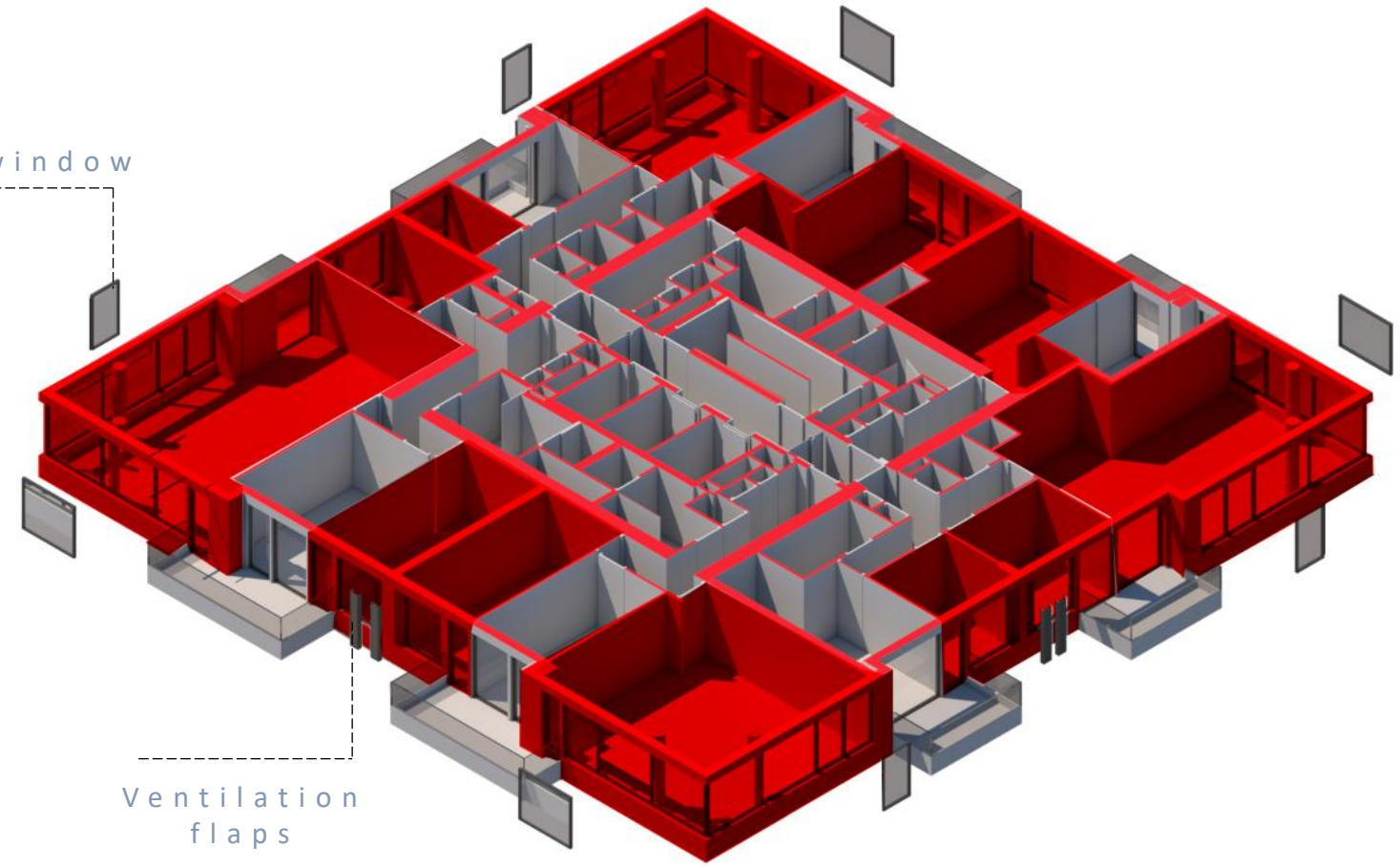
	Minimizing architectural impact	Minimizing solar radiation	Minimizing solar maintenance
Increasing natural ventilation Optimal for apartments at Higher levels	Optimal for small double sided zones facing North 	Optimal for small double sided zones facing south 	Optimal for bedrooms and bigger double sided zones 
Rescheduling mechanical ventilation Optimal for apartments at Lower levels			

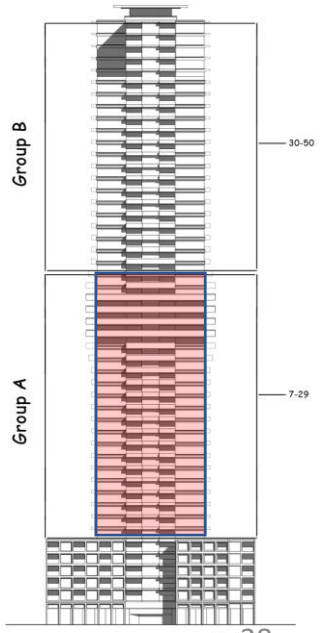
Heat dissipation Groups



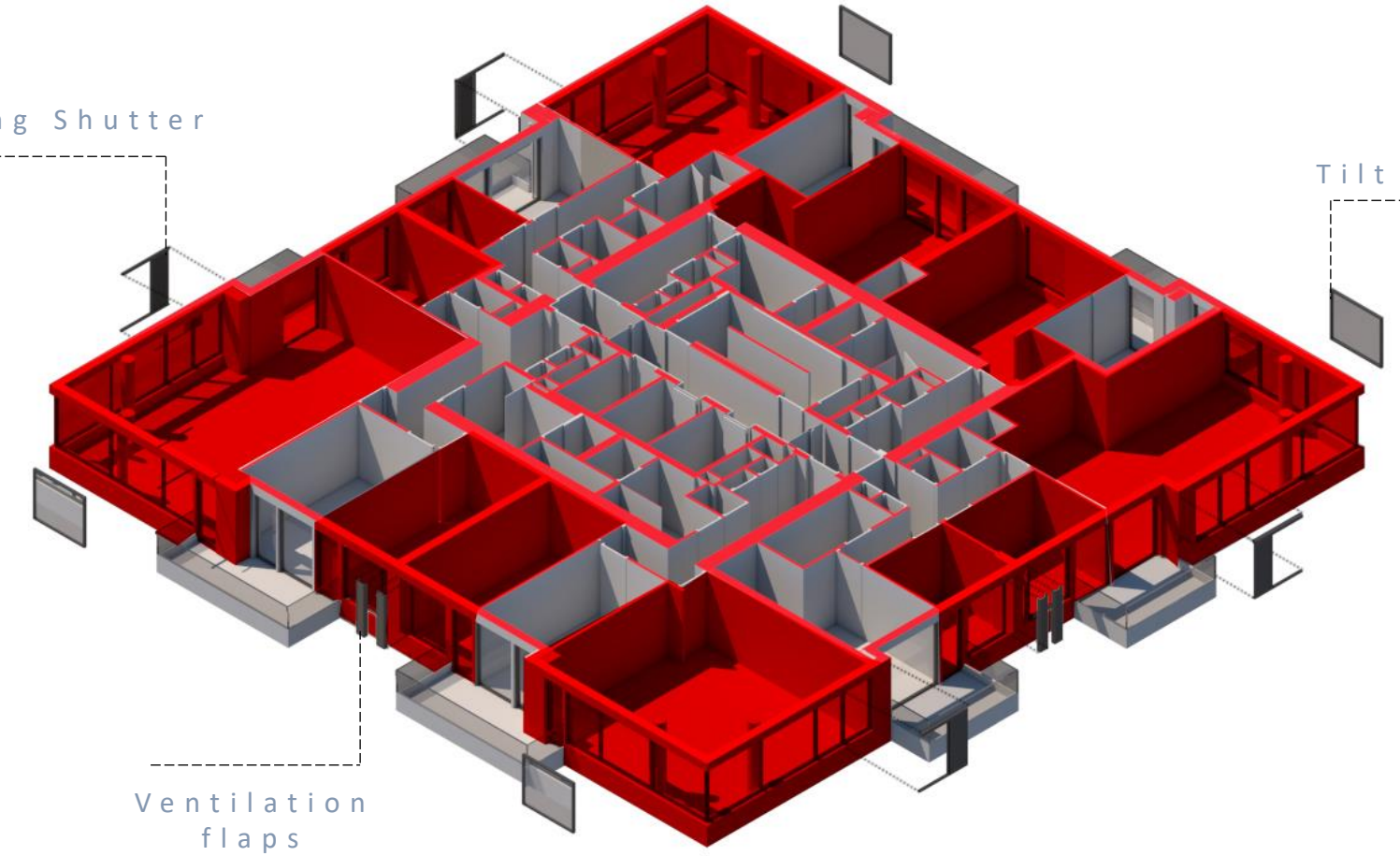


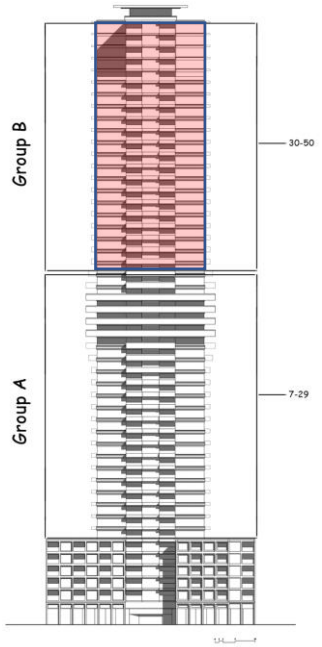
Heat dissipation Groups





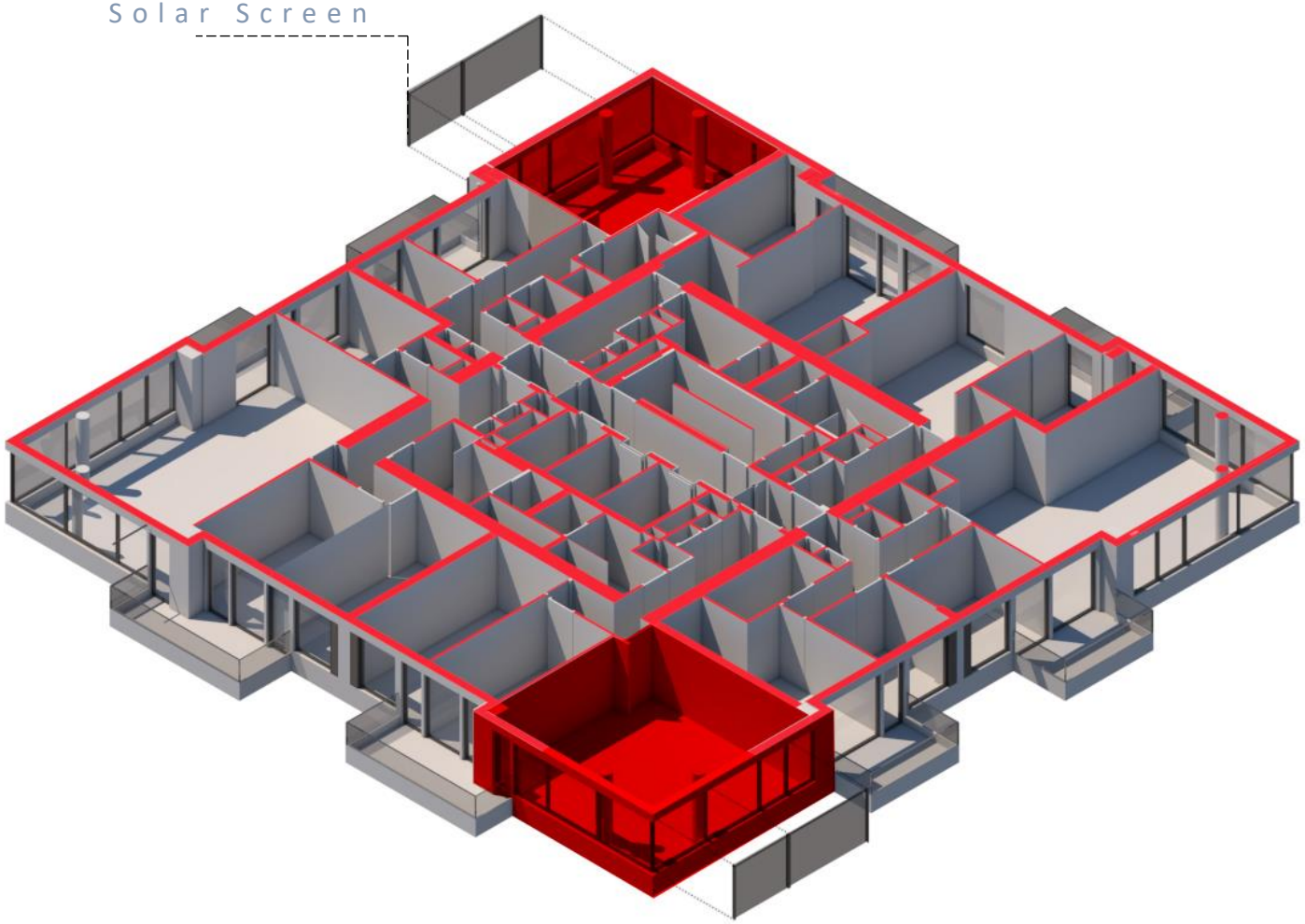
Heat dissipation Groups





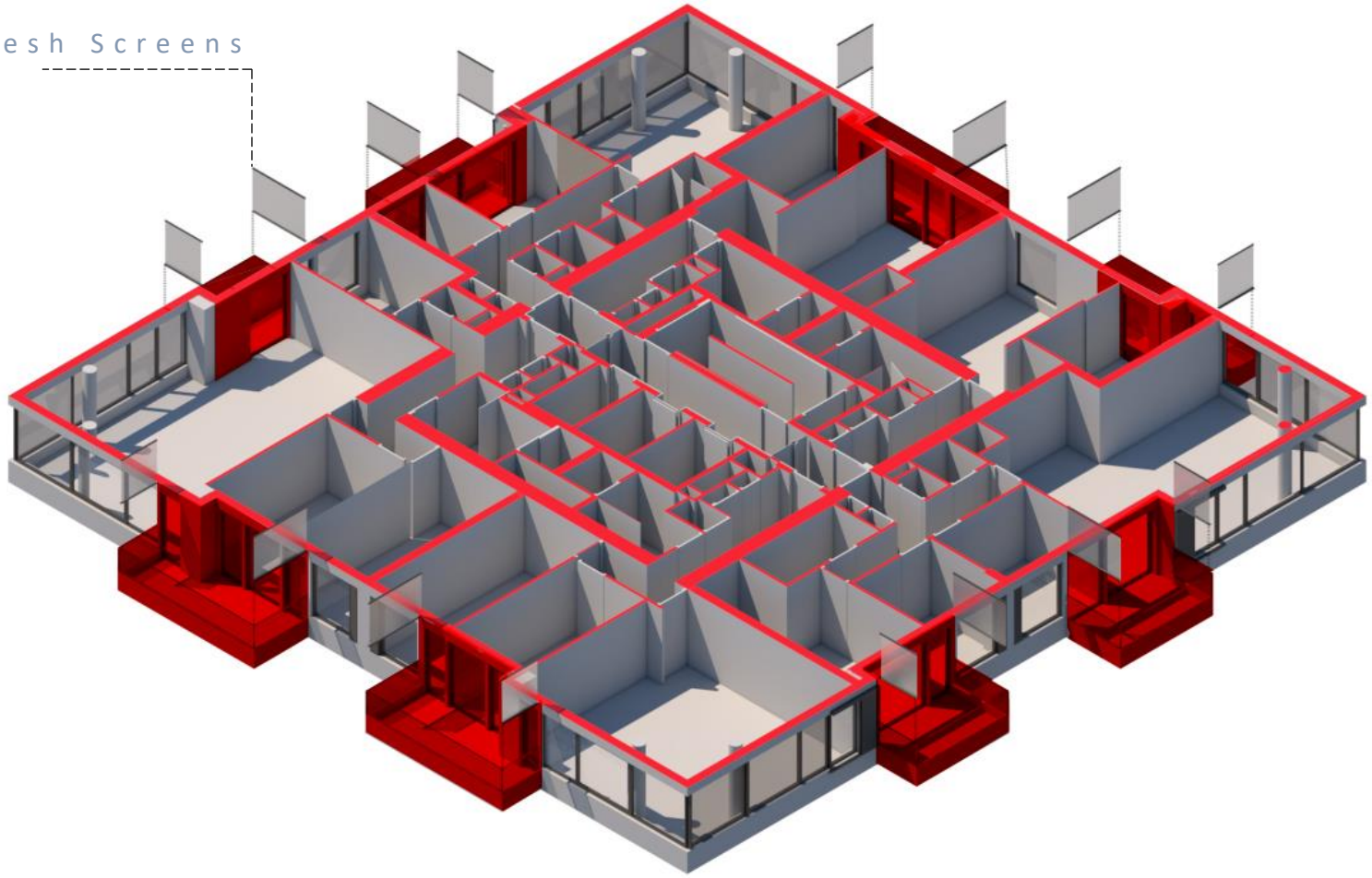
REDESIGN

Heat Protection



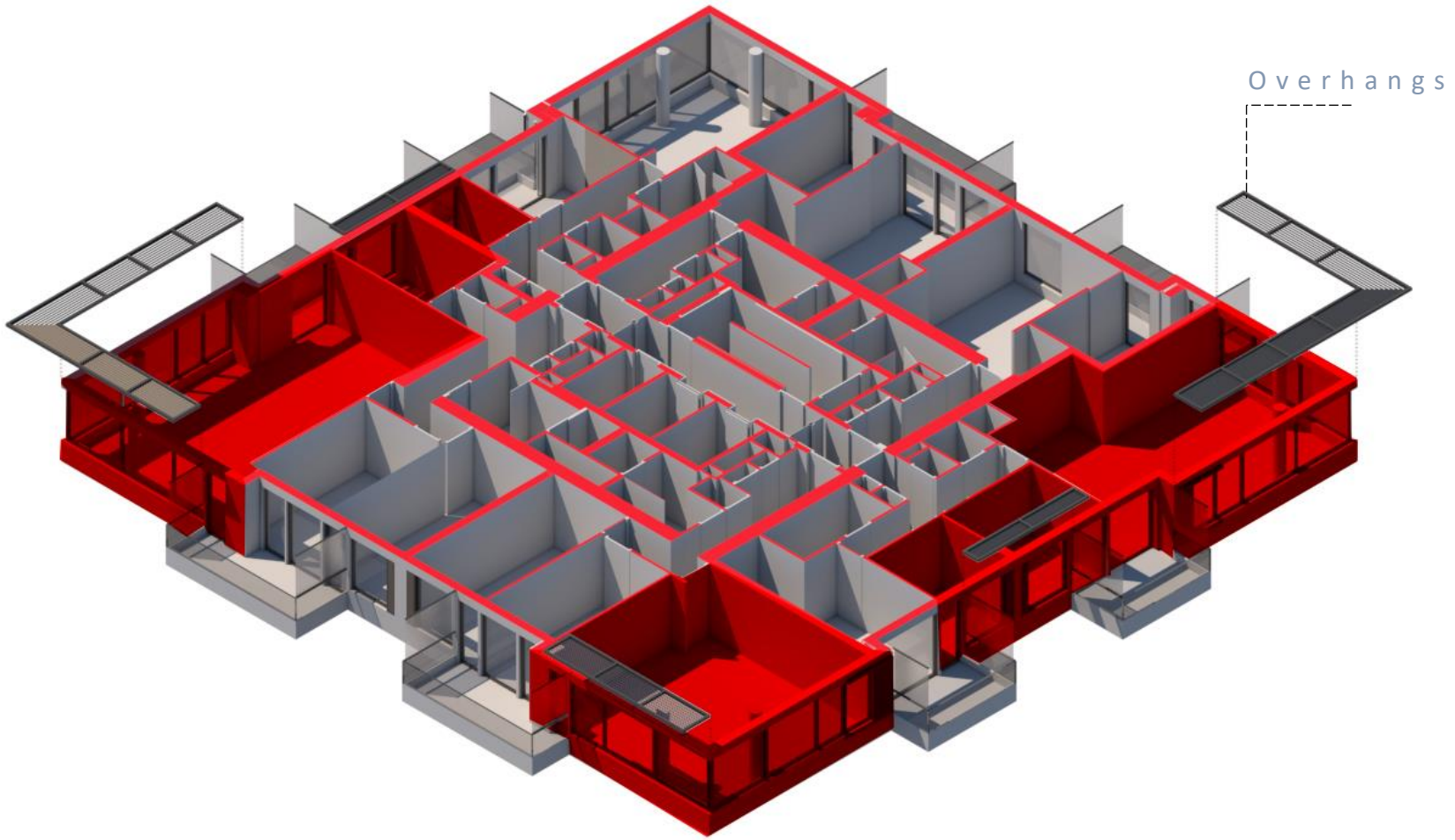
REDESIGN

Heat Protection



REDESIGN

Heat Protection



REDESIGN

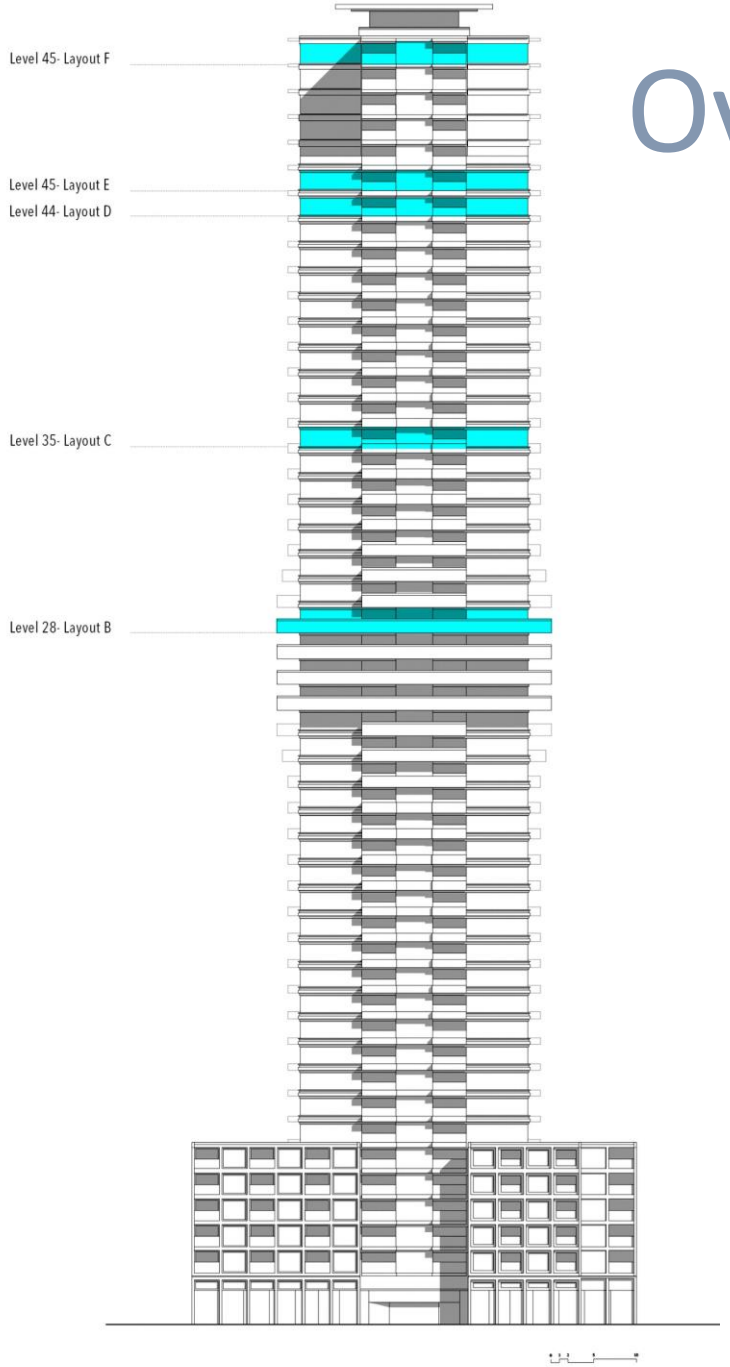
BEFORE

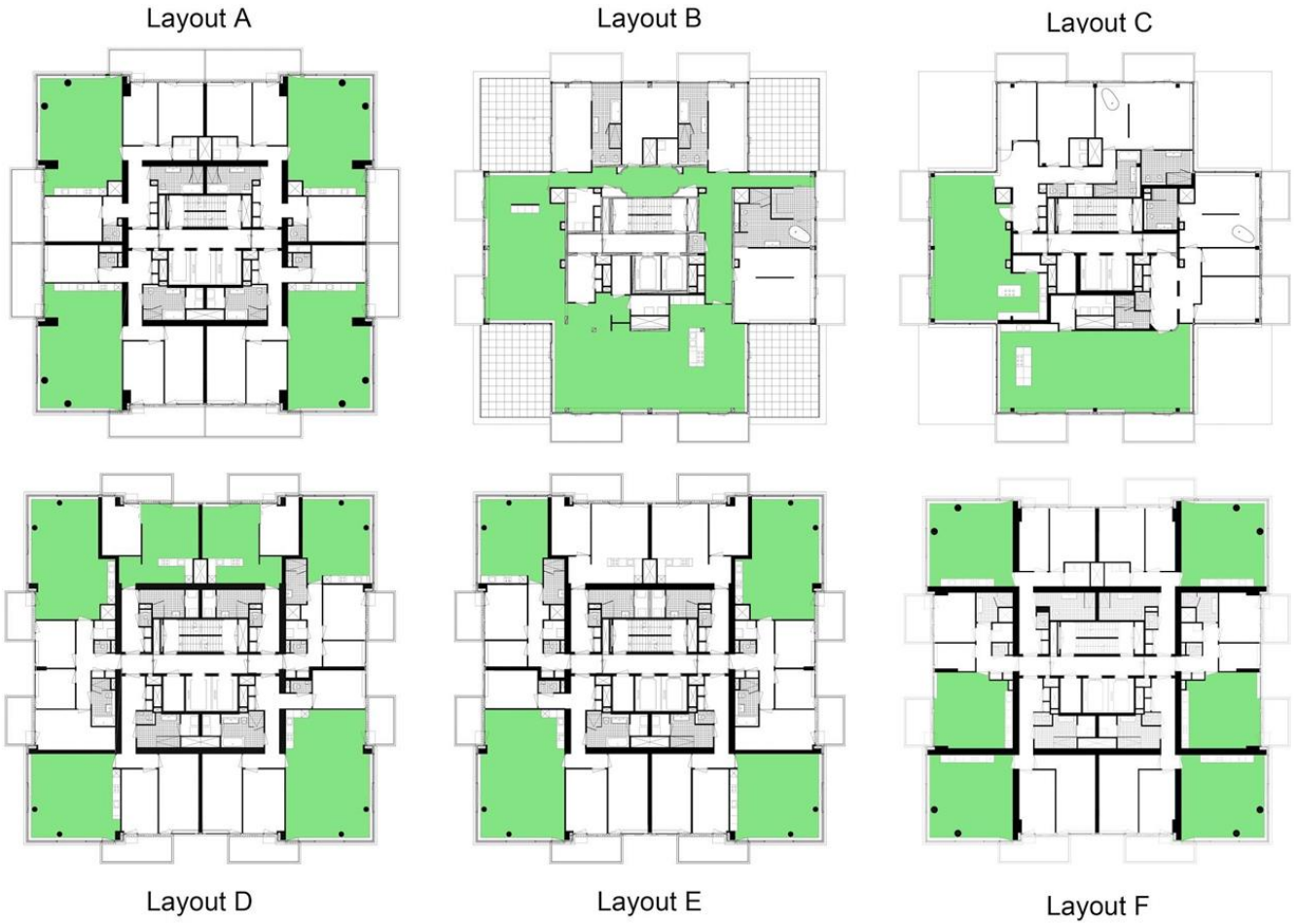
AFTER

REDESIGN

Redesign from source: V8 Architects

Overheating Analysis





Numerical Results for 2085

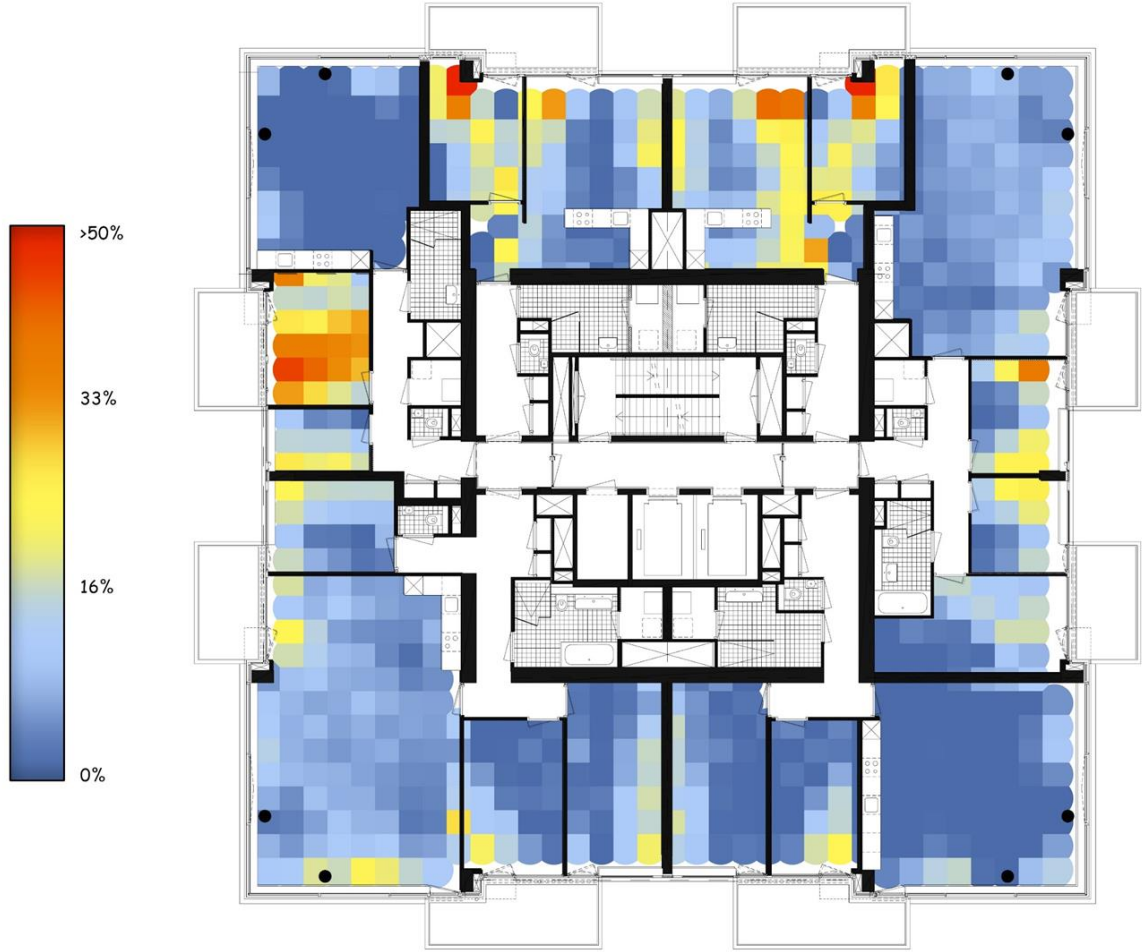
Level 45 (132m)

Level 9 (28m)

REDESIGN

Visual Field Analysis

Visual access reduction compared to the original design



Different plan layouts in different level result in the rotation of the overhangs limiting its effect on the visual field.

Level 45 at 132 m

Item	quantity	Unit	Price per unit (Euro)	Overall cost (Euro)
Dexone horizontal sun louvre	47.2	m^2	70	3234
Solozip Screen (220*200)	2	-	984	1968
Solozip Screen (330*200)	2	-	1437	2874
HAVER Architectural Mesh	42.6	m^2	150	6390
Wicona ventilation Flaps	3.6	m^2	500	1800
Additonal cost for sliding window	9.6	m^2	150	1440
Baier sliding shutter	10.6	m^2	800	8480
Open woven vinyl mesh	10.6	m^2	50	530
Motorizing windows -Soonkst actuator	44.7	m^2	80	3476
SELVE Home Server	6	-	350	2100
Total Cost (Euro)	32292 €			

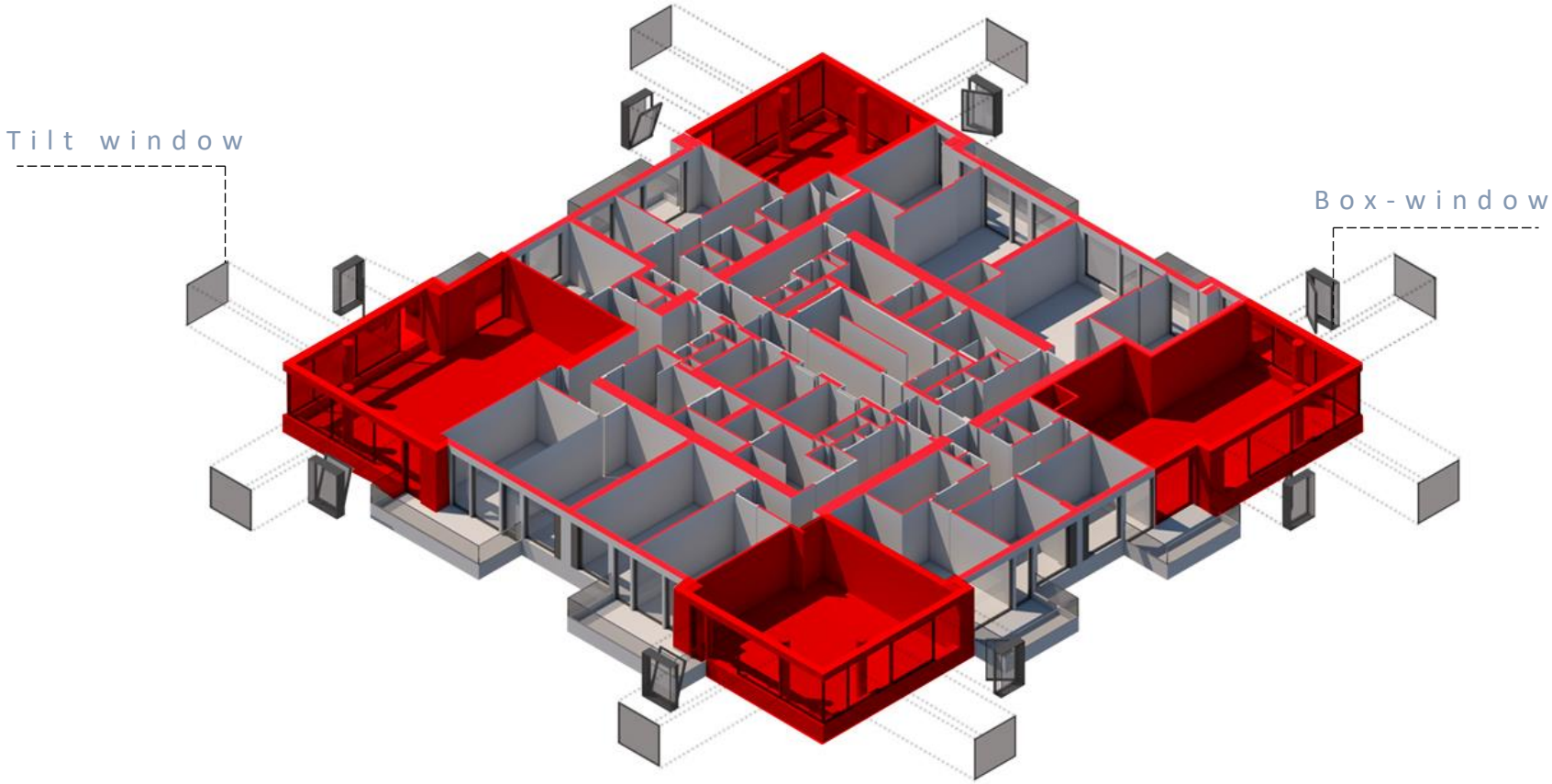
Level 9 at 28 m

Item	quantity	Unit	Price per unit (Euro)	Overall cost (Euro)
Dexone horizontal sun louvre	47.2	m^2	70	3234
Sigara Screen (220*200)	6	-	689	4134
HAVER Architectural Mesh	42.6	m^2	150	6390
Wicona ventilation Flaps	3.6	m^2	500	1800
Additional cost for hinged window	27.2	m^2	60	1632
Motorizing windows -Soonkst actuator	44.7	m^2	80	3476
SELVE Home Server	6	-	350	2100
Total Cost (Euro)	22766 €			

INNOVATIVE DESIGN EXPLORATION

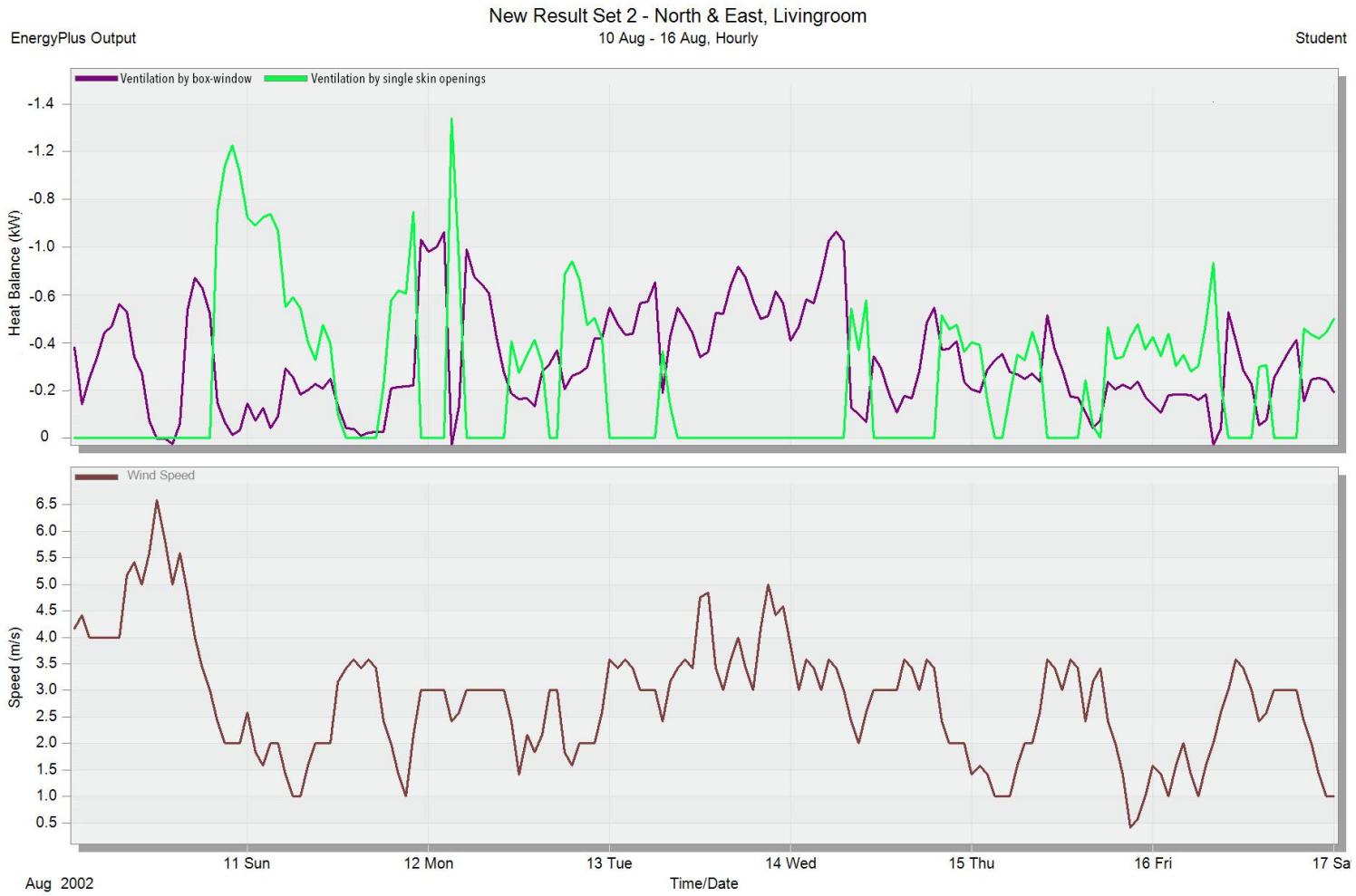
Design configuration

Ventilation & heat dissipation



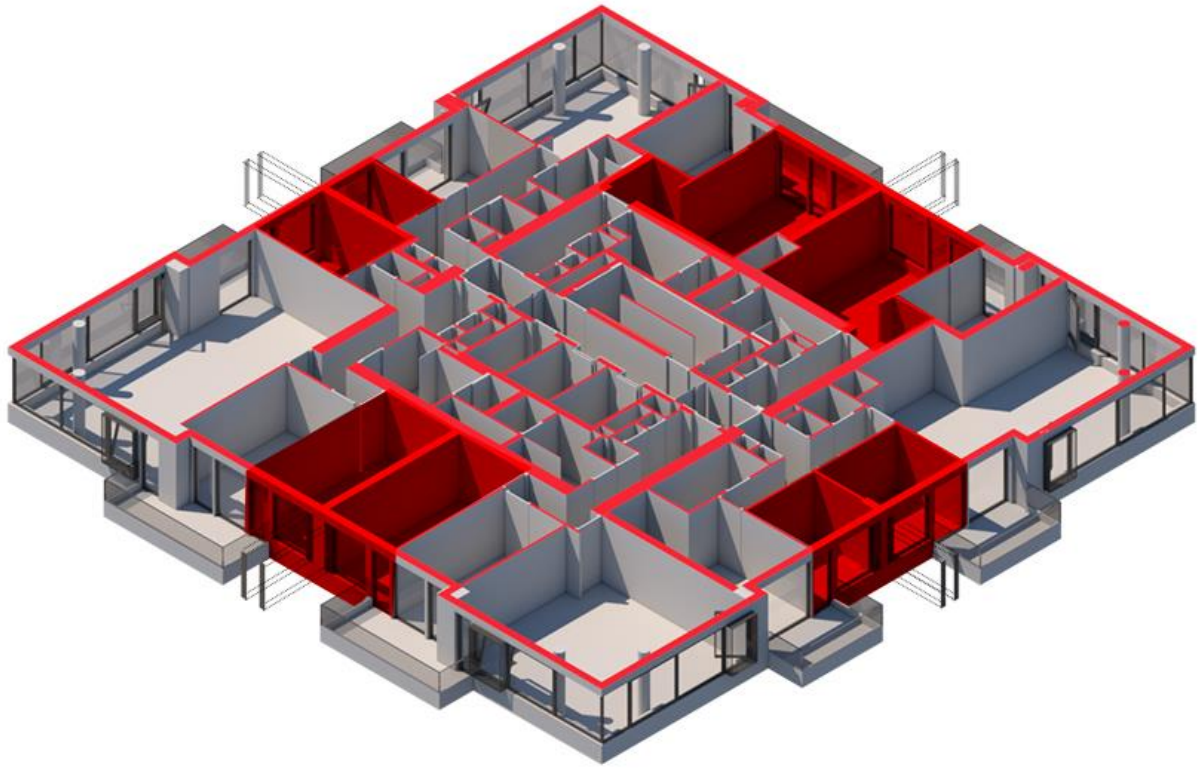
Design configuration

Ventilation & heat dissipation



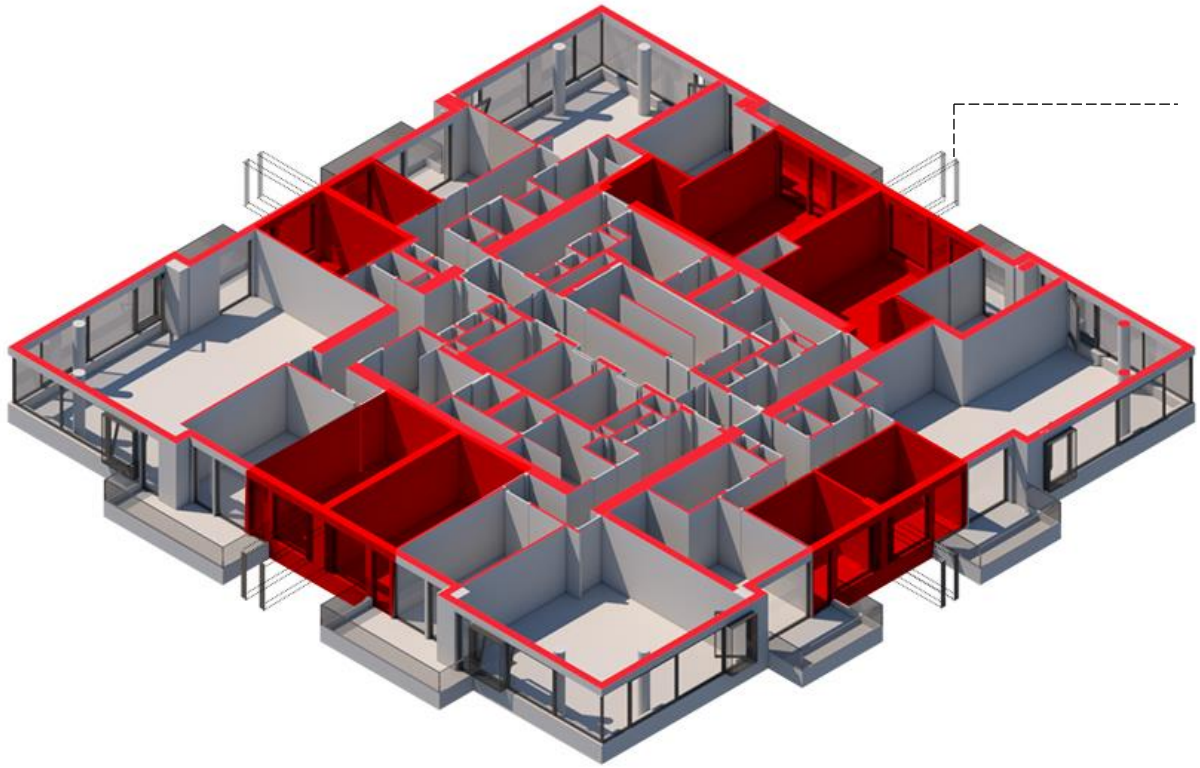
Design configuration

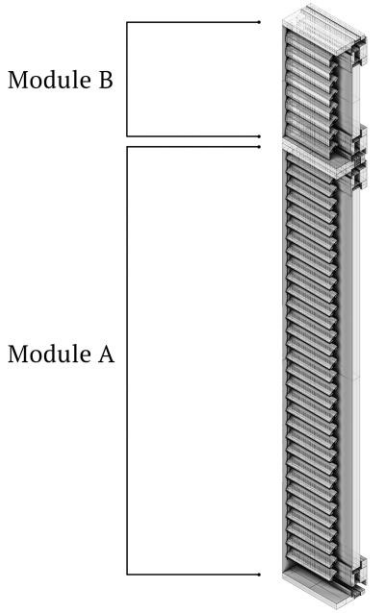
Ventilation & heat dissipation



Design configuration

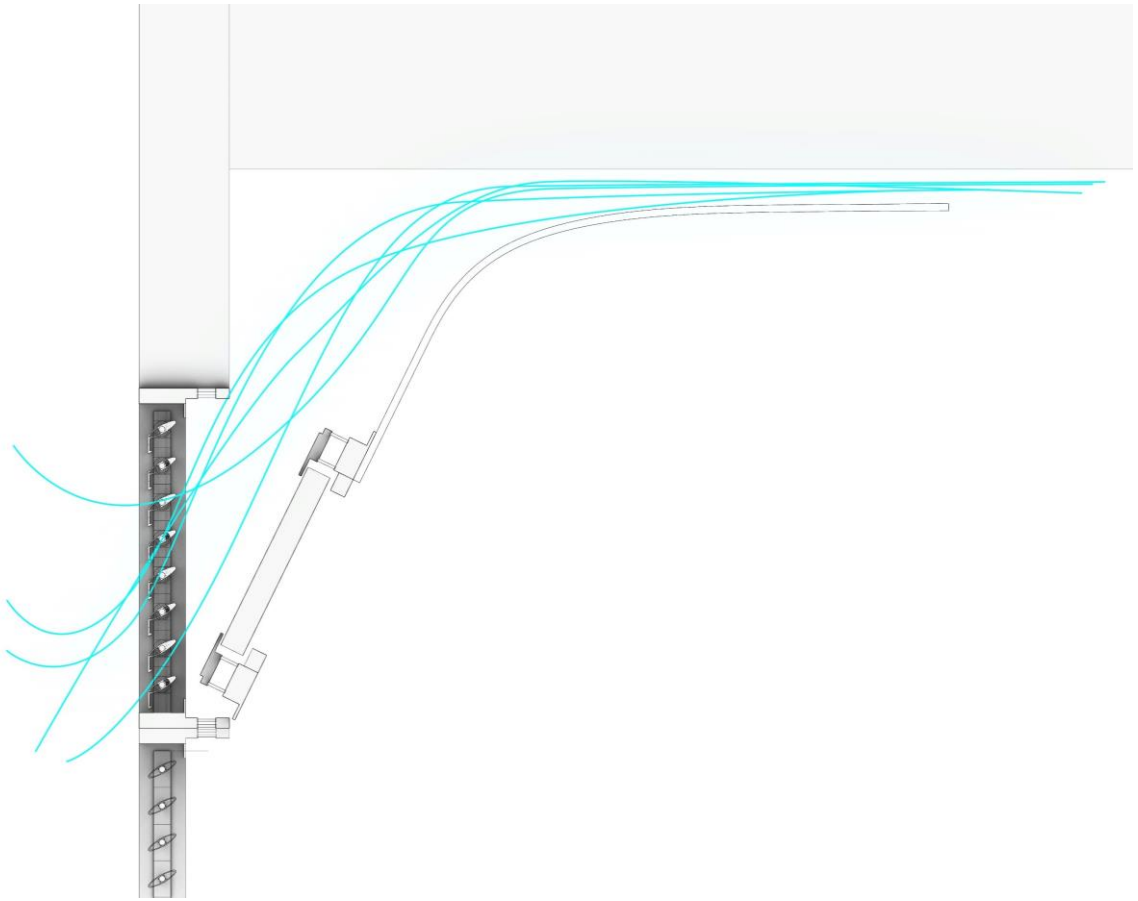
Ventilation & heat dissipation

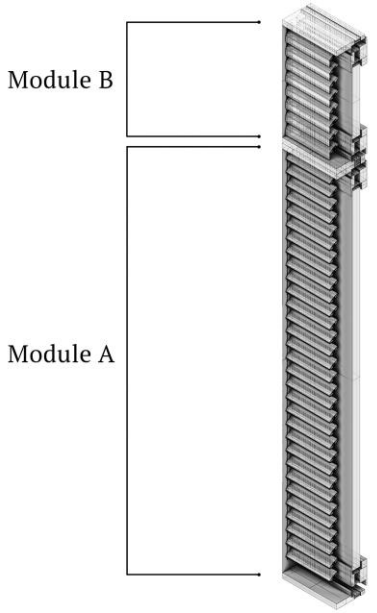




Design configuration

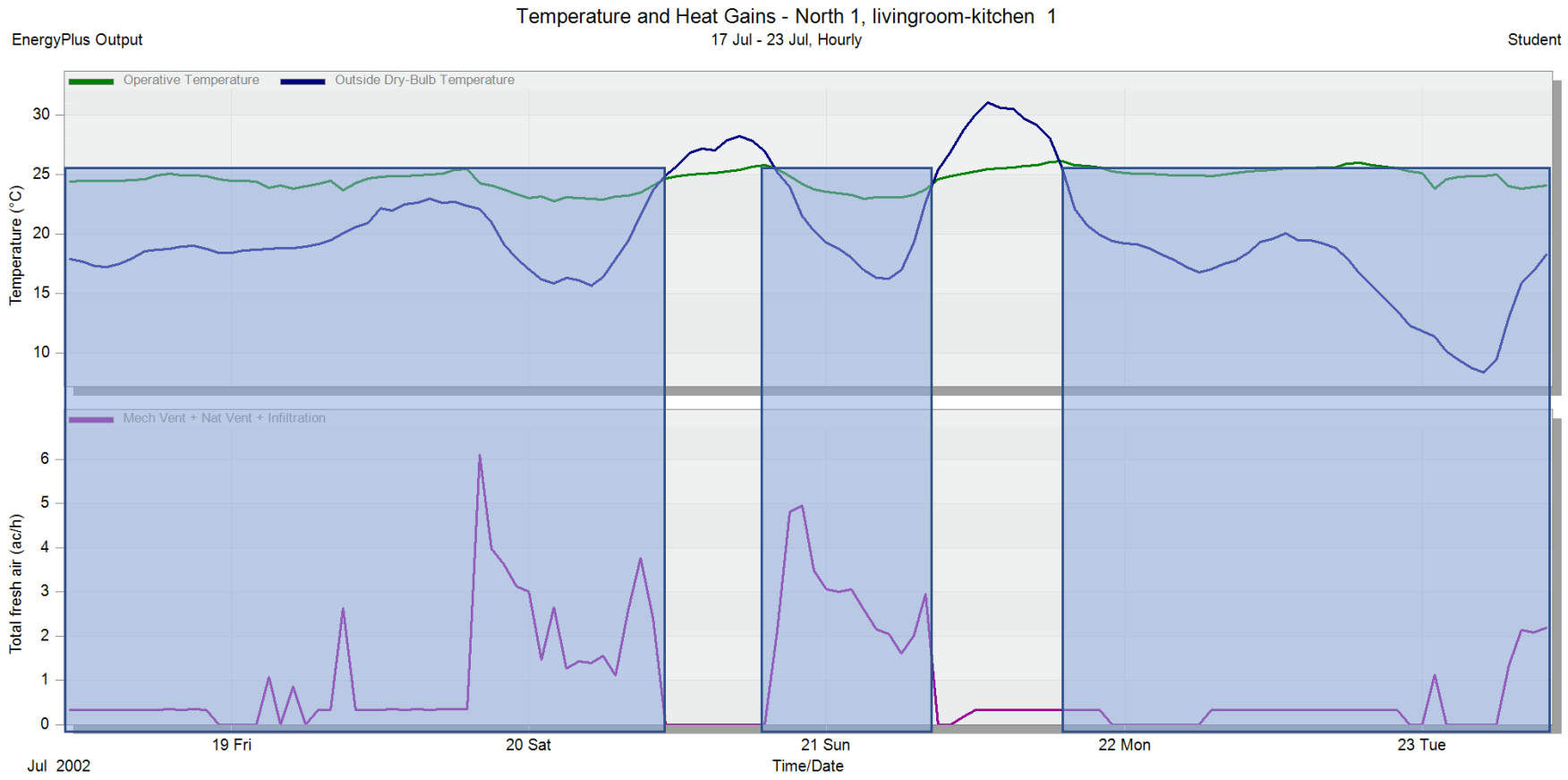
Ventilation & heat dissipation





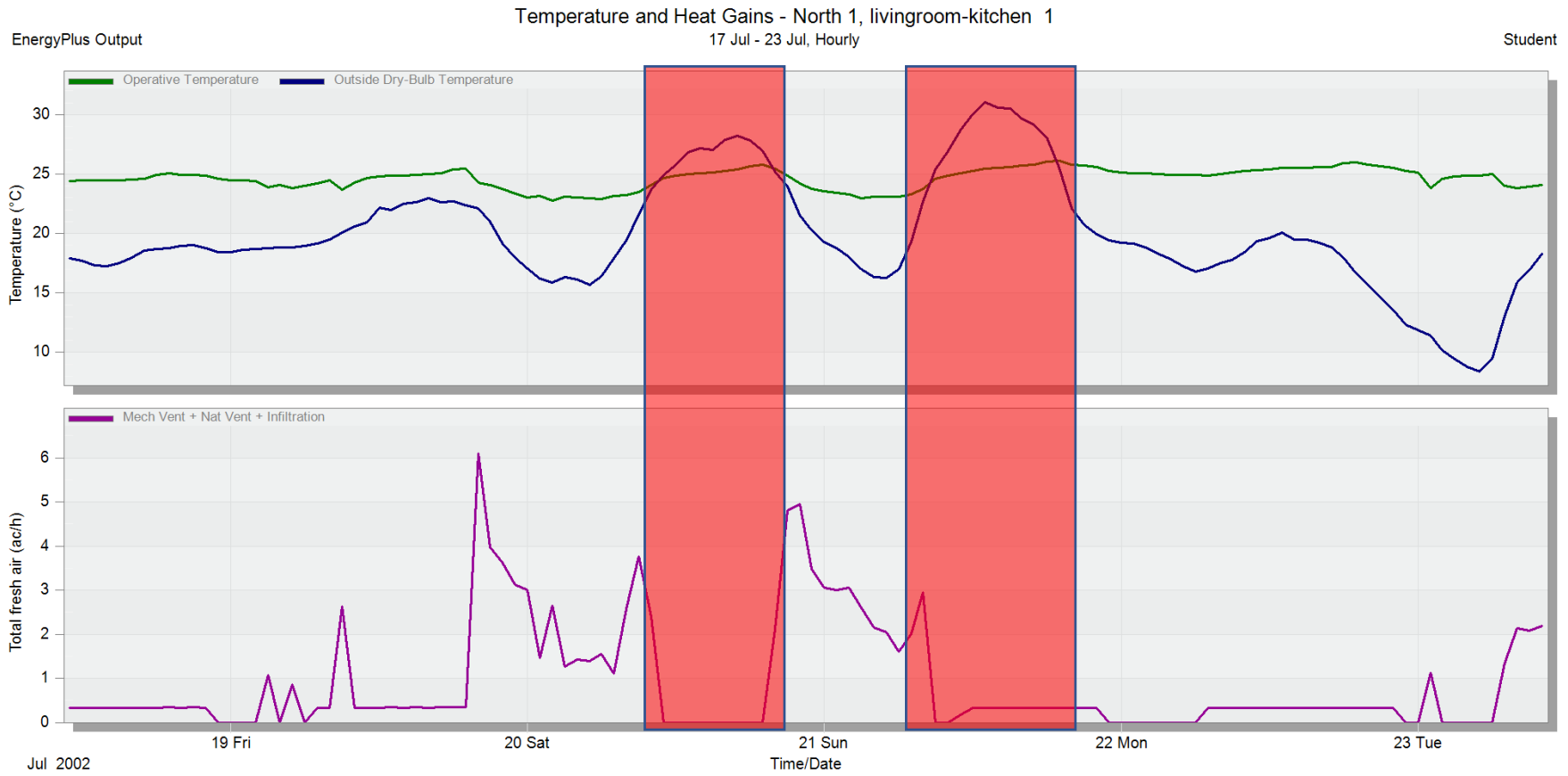
Design configuration

Ventilation & heat dissipation



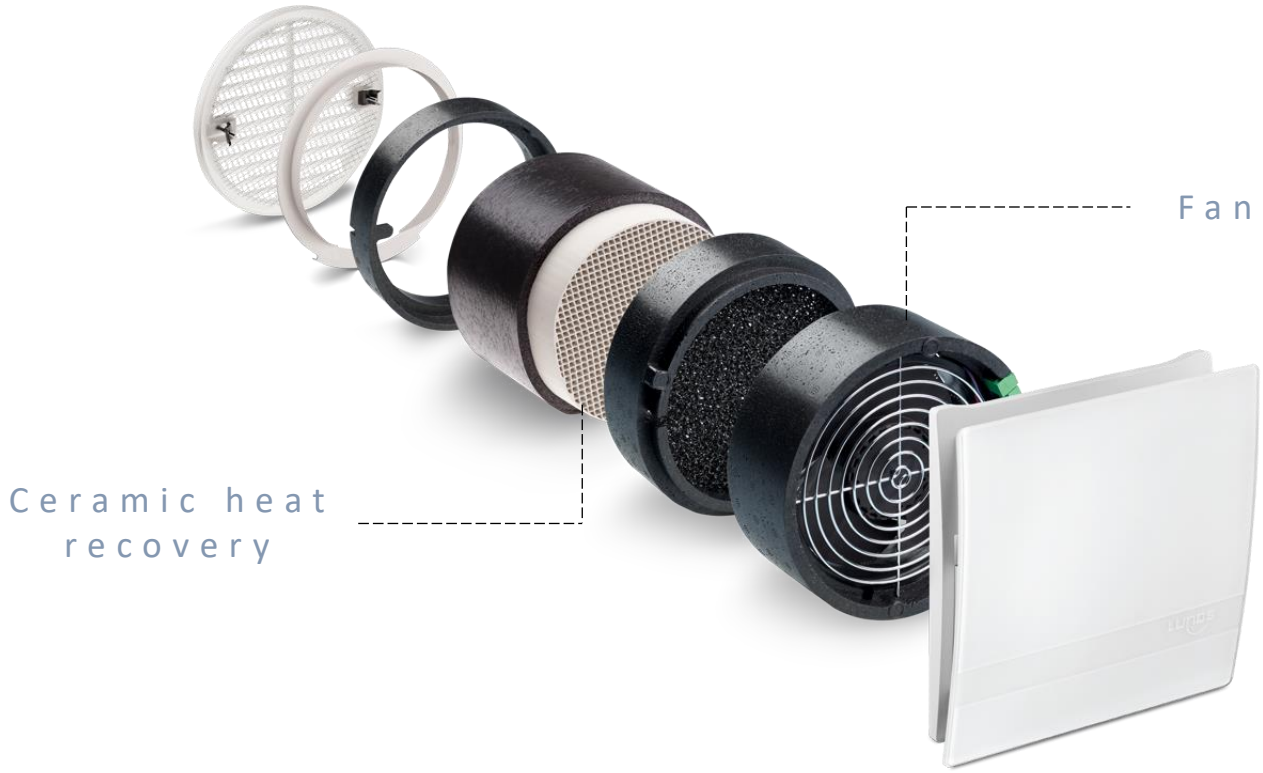
Design configuration

Ventilation & heat dissipation



Design configuration

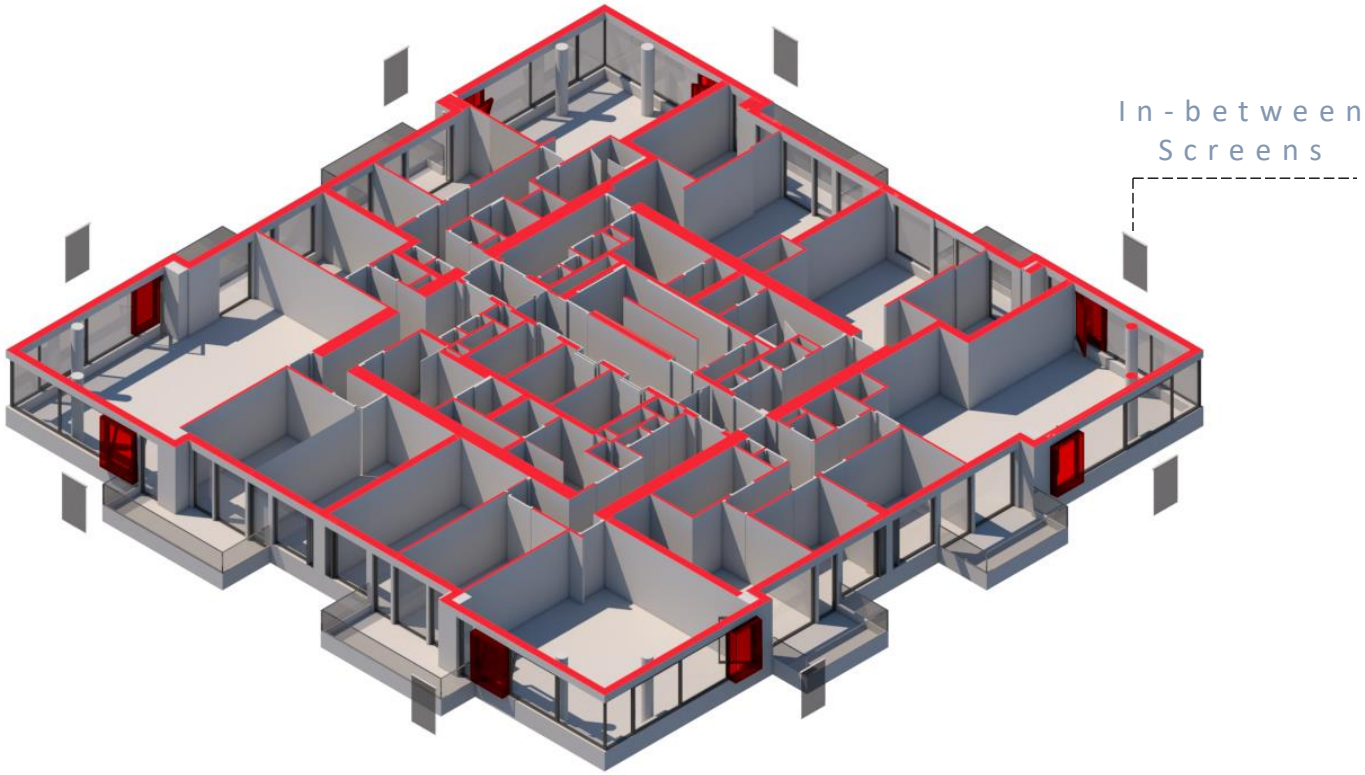
Ventilation & heat dissipation



Source: https://www.lunos.de/en/product/

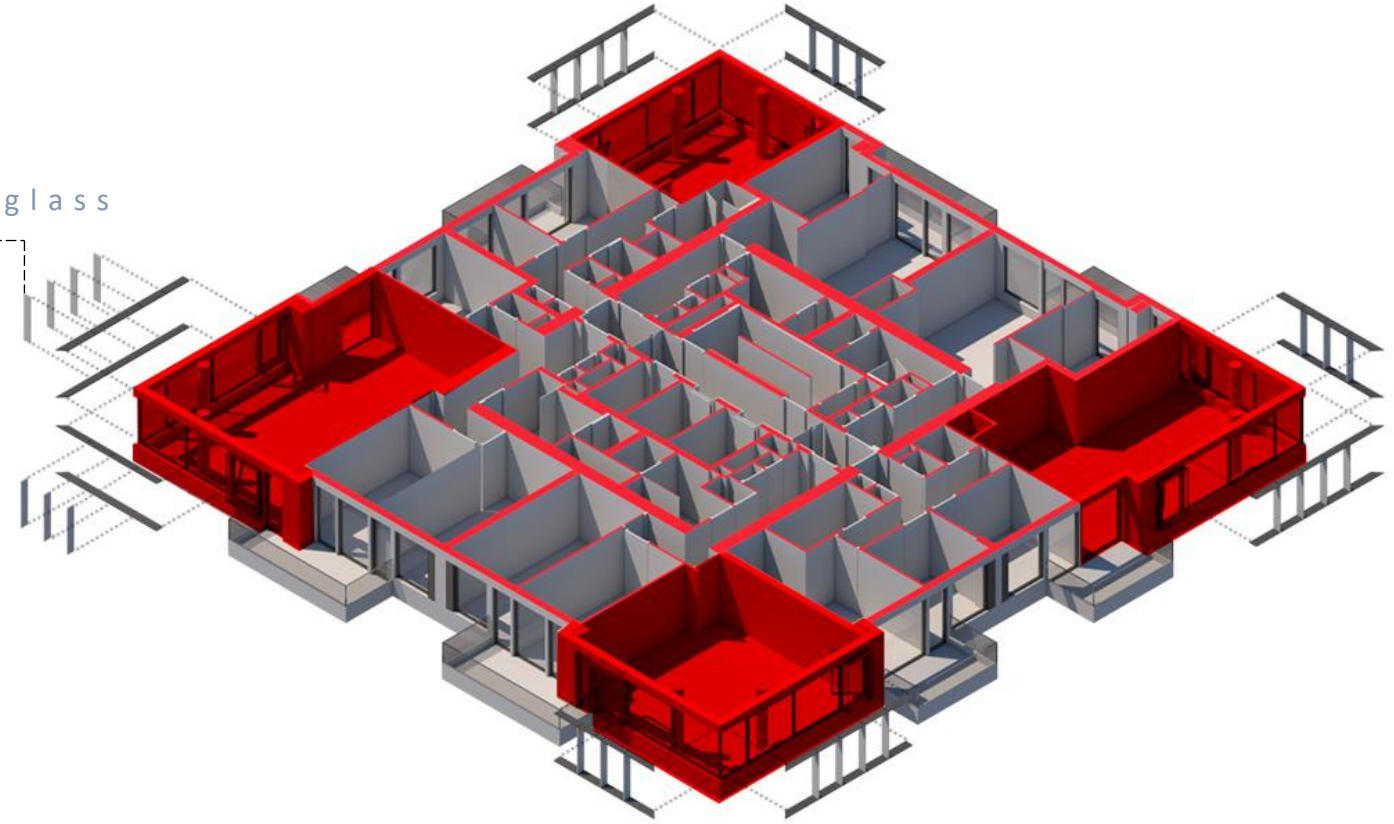
Design configuration

Heat prevention



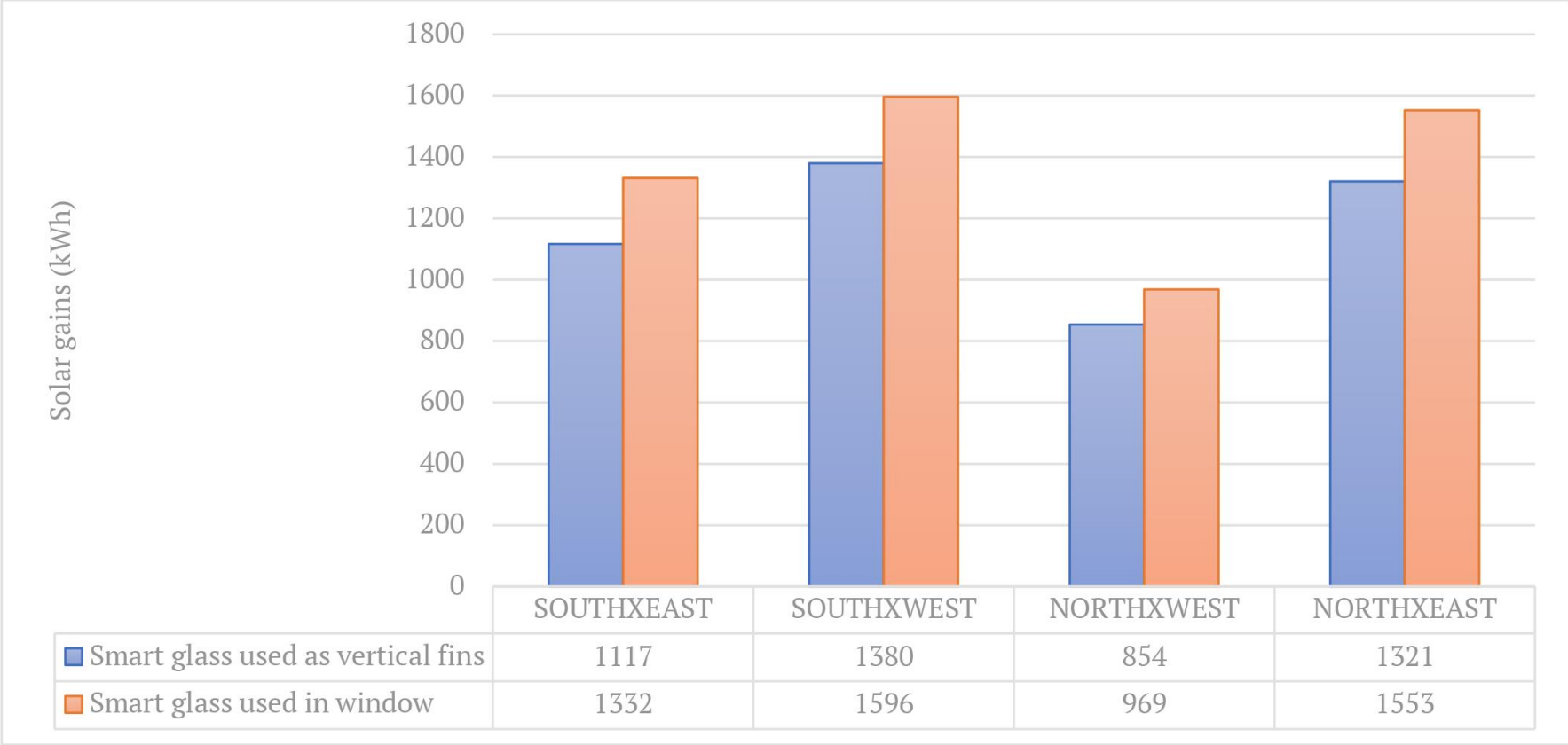
Design configuration

Heat prevention



Design configuration

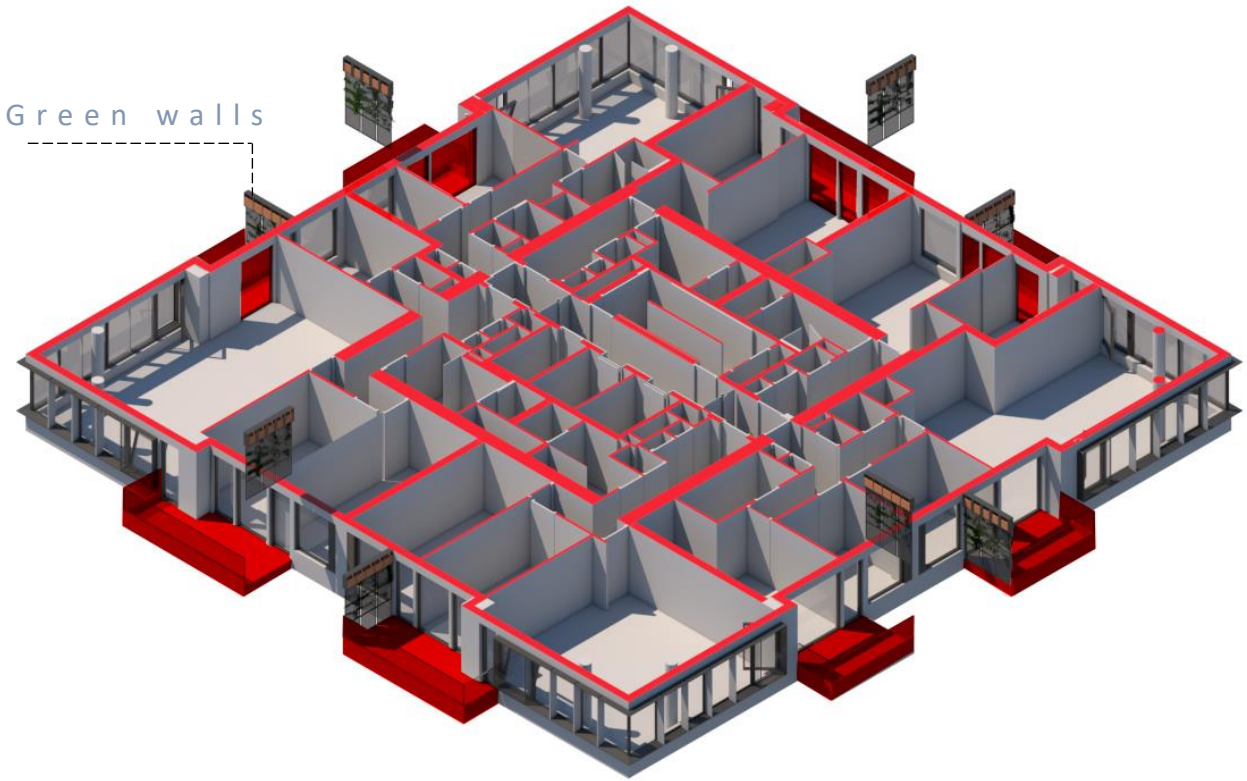
Heat prevention



	SOUTHXEAST	SOUTHXWEST	NORTHXWEST	NORTHXEAST
Smart glass used as vertical fins	1117	1380	854	1321
Smart glass used in window	1332	1596	969	1553

Design configuration

Heat prevention

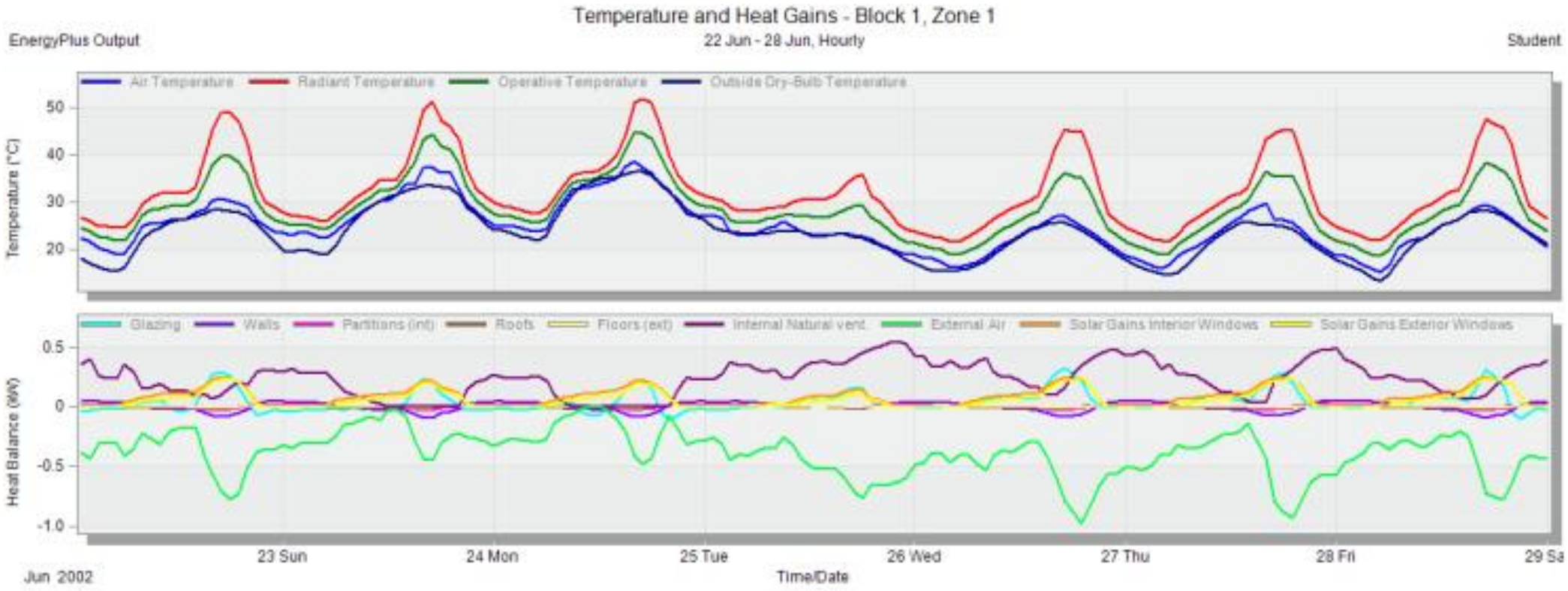


INNOVATIVE DESIGN EXPLORATION

Overheating results

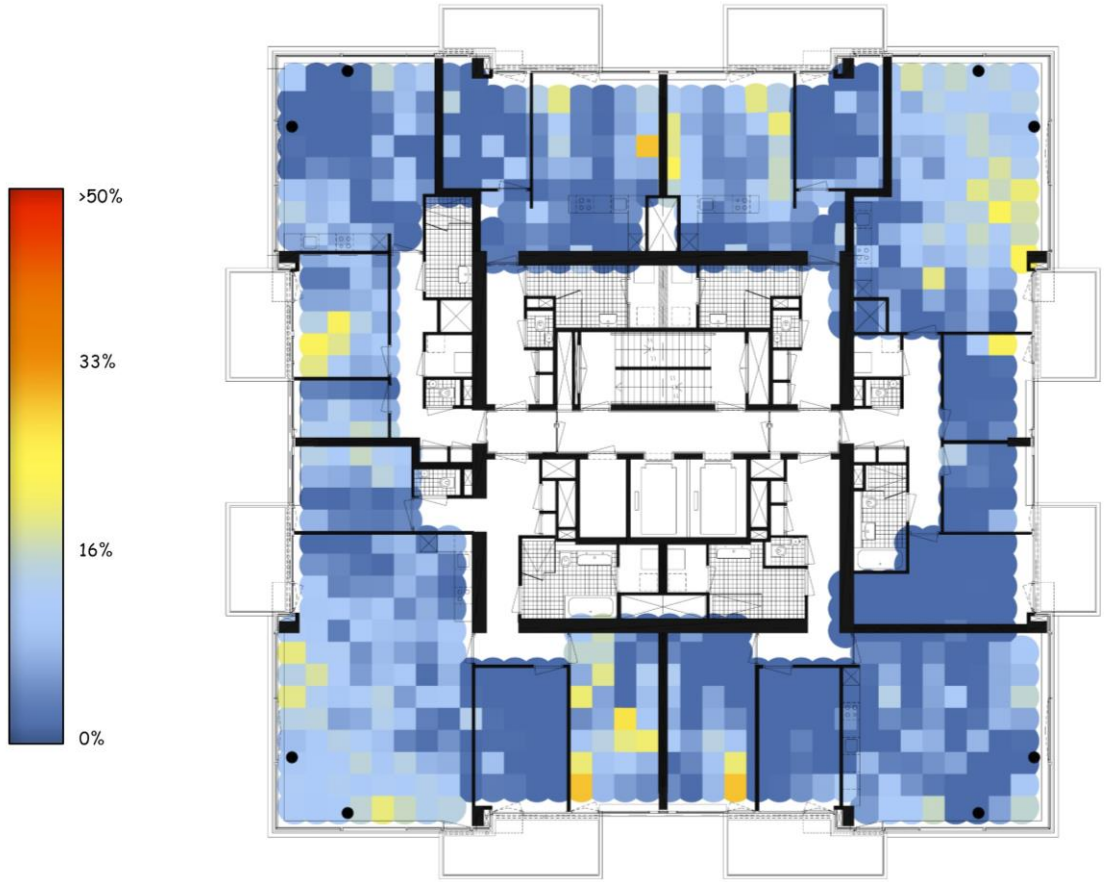
Overheating results

Overheating considerations



Visual Field Analysis

Visual access reduction compared to the original design



CONCLUSION

Summary

- Design Guidelines derived from Literature
- Specific Design Variations and Concepts created for Case Study
- An extensive numerical Simulation Environment was implemented, teseted and used to analyze the Designs

Answering research questions

- Overheating can be prevented by providing shading and heat dissipation in the present time
- In the future overheating by passive means can only be prevented through a proper combination of Heat dissipation, Heat protection and thermal mass.

Further Research

- Research on the temperature and health effect
- Validating the results using monitored dwellings
- Further research on the energy-saving potential
- Effect on bigger sustainability picture should be reviewed

THANK YOU!

Appendix

Positive and Negative characteristics of Cooltoren

	Positive characteristics	Negative characteristics
Heat gains	+ Balconies shade main bedrooms + Low solar transmittance value of the South, East and West facing glazing reduces solar gains	– Unshaded bedroom facing east and west – High solar gains from Northern windows – Spreading of overheated areas
Heat dissipation	+ Cross-ventilation is possible + Free cooling possible	– Inadequate ventilation in apartments facing North and thermal mass cannot be recharged during the night – Openings are not protected from rain and high wind speed, making natural ventilation impossible – Internal partitions hinder airflow – Zones with lower thermal mass are at greater risk of overheating in the future
Thermal storage	+ East- North and South: Stable indoor environment with small temperature swings + Big bedrooms: Stable toward diurnal temperature swings	

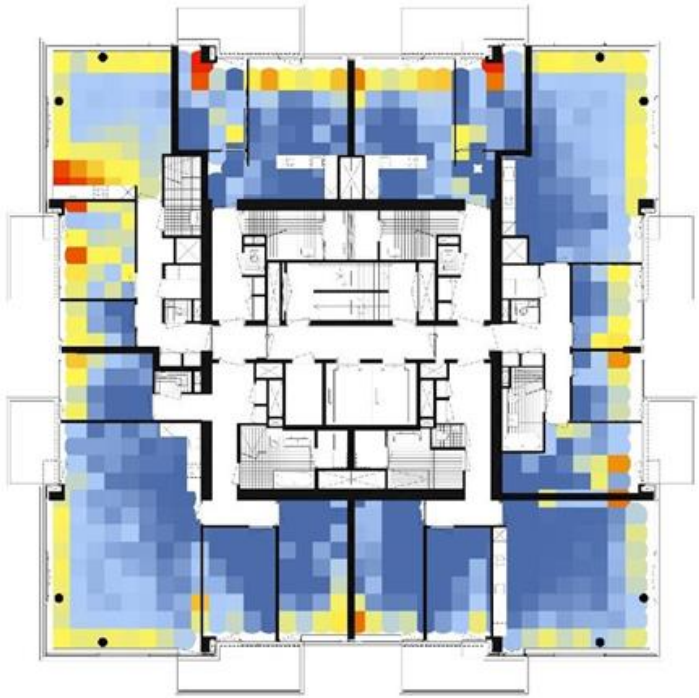
	Positive characteristics	Negative characteristics
Heat gains	+ Balconies shade main bedrooms + Low solar transmittance value of the South, East and West facing glazing reduces solar gains	– Tiny single aspect unshaded bedroom facing east and west – High solar gains from Northern windows because of the high solar transmittance value of the North facing glazing – OOverheated zones or zones with high internal load causes adjacent zones to get overheated or get uncomfortable
Heat dissipation	+ Openable windows and doors on the double-sided apartments facing south make cross-ventilation possible + Mechanical ventilation with summer bypass makes free cooling possible	– Inadequate ventilation in apartments facing North because of single-sided ventilation and small openings – Due to the inadequate ventilation thermal mass cannot be recharged during the night – Openings are not protected from rain and high wind speed making natural ventilation impossible for a great amount of time on upper floors – Internal partitions hinder airflow – Zones with lower thermal mass are at greater risk of overheating in the future
Thermal storage	+ High thermal mass provides a stable indoor environment with small temperature swings + Big bedrooms with structural walls have additional thermal mass which makes them quite stable toward diurnal temperature swings	

	Overheating					
	Present		2050		2085	
	Acceptable	Overheated	Acceptable	Overheated	Acceptable	Overheated
1: M.M & R.M.V	E3-Livingroom (T.E.H: 110)	None	E5-Livingroom (T.E.H: 77)	E3-Livingroom (T.E.H: 259)	E5-Livingroom (T.E.H: 189) E6-Livingroom (T.E.H: 140) E4-Livingroom (T.E.H: 137) E3-2-Bedroom (T.E.H: 82)	E3-Livingroom (T.E.H: 422)
2: M.M & I.N.V	E3-Livingroom (T.E.H: 72)	None	E3-Livingroom (T.H.E: 146)	None	E5-Livingroom (T.E.H: 146) E4-Livingroom (T.E.H: 110)	E3-Livingroom (T.E.H: 207)
3: M.A.I & R.M.V	None	None	E5-Livingroom (T.H.E: 163) E3-Livingroom (T.H.E: 100)	None	E3-Livingroom (T.H.E: 199) E4-Livingroom (T.H.E: 155)	E5-Livingroom (T.H.E: 290)
4: M.A.I & I.N.V	None	None	E5-Livingroom (T.H.E: 152)	None	E4-Livingroom (T.H.E: 124) E3-Livingroom (T.H.E: 105)	E5-Livingroom (T.H.E: 255)
5: M.S.G & R.M.V	None	None	E3-Livingroom (T.H.E: 81)	None	E3-Livingroom (T.H.E: 171)	None
6: M.S.G & I.N.V	None	None	None	None	E3-Livingroom (T.H.E: 101)	None

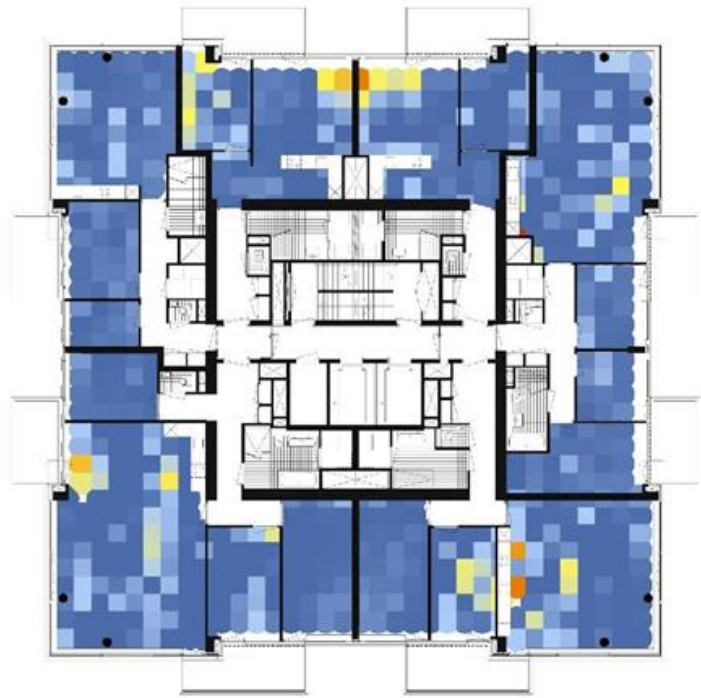
T.H.E: Temperature exceedance hours of ATG
M.M: Minimising maintenace
M.A.I: Minimising architectural impact
M.S.G: Minimising solar gains
R.M.V: Rescheduling mechanical ventilation
I.N.V: Increasing natural ventilation

	Thermal comfort		Visual field		Cost	
	Advantage	Disadvantage	Advantage	Disadvantage	Advantage	Disadvantage
M.M & R.M.V	+ All bedrooms in the comfort range by 2085 + No overheated zone in the present condition simulation	- Small double sided Living room start to overheat by 2050. - All double sided zones become regularly warm by 2085. By this time the small overheated zone will overheat severally	+ Good visual filed on the larger double sided zones. + Unobstructed view with a 2m distance from the window in the larger rooms	- Obstructed view in the bedrooms in between balconies - obstructed view on the corners of the smaller living rooms	+ Most economical solution.	- Additional energy bills
M.M & I.N.V	+ All bedrooms in the good comfort range by 2085 + No overheated zone by 2050	- Small double sided Living room start to overheat marginally by 2085			+ Economical shading solution + Savings in energy bills by reducing the mechanical ventilation energy consumption	
M.A.I & R.M.V	+ All bedrooms in the good comfort range by 2085 + Vertical shadings are very effective in providing good thermal condition for North and South single sided rooms	- Smaller double sided zones facing south will overheat by 2085	+ Very good visual field in all zones despite marginal obstruction on the corners.		- Additional energy bills	
M.A.I & I.N.V					+ Savings in energy bills by reducing the mechanical ventilation energy consumption	- Most expensive combination
M.S.G & R.M.V	+ No Overheating problem + All bedrooms in the good comfort range by 2085		+ Good visual filed on the larger double sided zones, having overhang only on one side the visual field is less obstructed near the immediate adjacency.	- Obstructed view in the bedrooms in between balconies	+ Economical variation	- Additional energy bills
M.S.G & I.N.V	+ No Overheating problem + All zone in good comfort range by 2050				+ Savings in energy bills by reducing the mechanical ventilation energy consumption	- Costly

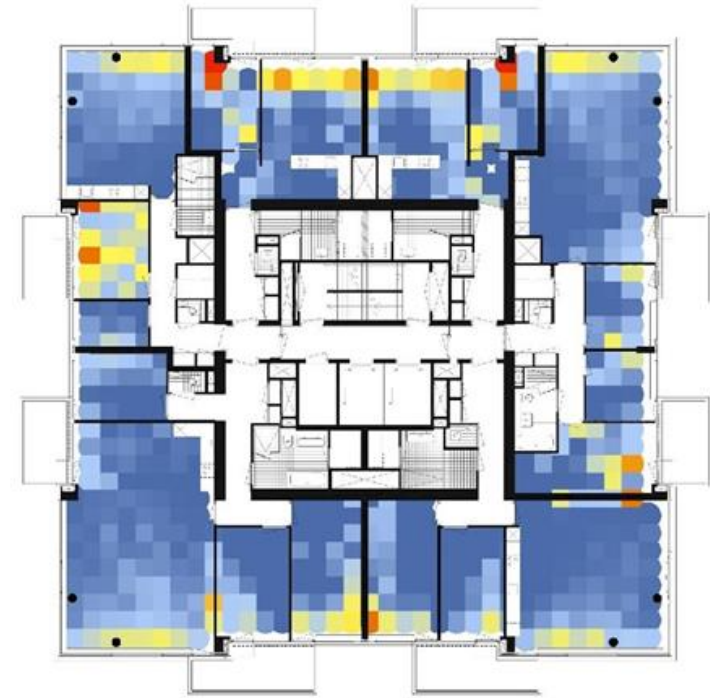
M.M: Minimizing maintenace

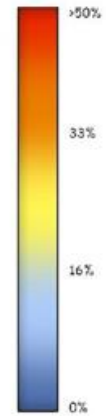


M.A.I: Minimizing architectural impact



M.S.G: Minimizing solar gains





M.A.I & R.M.V	Item	quantity (m2)	Price per unit (Euro)	Overall cost (Euro)
	Zip Screen	68.8	220-280	15136-19263
	Metal mesh	42.6	70-150	2982-6390
	Total Cost (Euro)	18118-25653		
	Electricity Usage	296 Kwh additional energy usage per year 296 kwh * 23 cents: 68.1 Euro		

M.A.I & I.N.V	Item	quantity (m2)	Price per unit (Euro)	Overall cost (Euro)
	Zip Screen	68.8	220-280	15136-19263
	Metal mesh	42.6	70-150	2982-6390
	Ventilation Flaps	3.6	350-500	1260-1800
	Sliding Shutters	10.6	600-850	6360-9010
	Total Cost (Euro)	25738-36463		
	Energy saving	238 Kwh energy saving per year 238 kwh * 23 cents: 54.7 Euro		

M.M & R.M.V	Item	quantity (m2)	Price per unit (Euro)	Overall cost (Euro)
	Overhang	72.2	70-120	5054-8664
	Metal mesh	42.6	70-150	2982-6390
	Total Cost (Euro)	8036-15054		
	Electricity Usage	296 Kwh additional energy usage per year 296 kwh * 23 cents: 68.1 Euro		

M.M & I.N.V	Item	quantity (m2)	Price per unit (Euro)	Overall cost (Euro)
	Overhang	72.2	70-120	5054-8664
	Metal mesh	42.6	70-150	2982-6390
	Ventilation Flaps	3.6	350-500	1260-1800
	Sliding Shutters	10.6	600-850	6360-9010
	Total Cost (Euro)	15656-25864		
	Energy saving	238 Kwh energy saving per year 238 kwh * 23 cents: 54.7 Euro		

M.S.G & R.M.V	Item	quantity (m2)	Price per unit (Euro)	Overall cost (Euro)
	Overhang	48	70-120	3360-5760
	Zip Screen	44	220-280	9680-12320
	Metal mesh	42.6	70-150	2982-6390
	Total Cost (Euro)	16022-24470		
	Electricity Usage	296 Kwh additional energy usage per year per floor 296 kwh * 23 cents: 68.1 Euro		

M.S.G & I.N.V	Item	quantity (m2)	Price per unit (Euro)	Overall cost (Euro)
	Overhang	48	70-120	3360-5760
	Zip Screen	44	220-280	9680-12320
	Metal mesh	42.6	70-150	2982-6390
	Ventilation Flaps	3.6	350-500	1260-1800
	Sliding Shutter	10.6	600-850	6360-9010
	Total Cost (Euro)	23642-35280		
	Energy saving	238 Kwh energy saving per year 238 kwh * 23 cents: 54.7 Euro		