Design parameter guidelines for purely passive cooling buildings in tropical area

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Christien Janssen

1. Introduction
2. Methodology
3. Results
4. Conclusions
5. Further research

1 Introduction

2 Methodology

3 Results

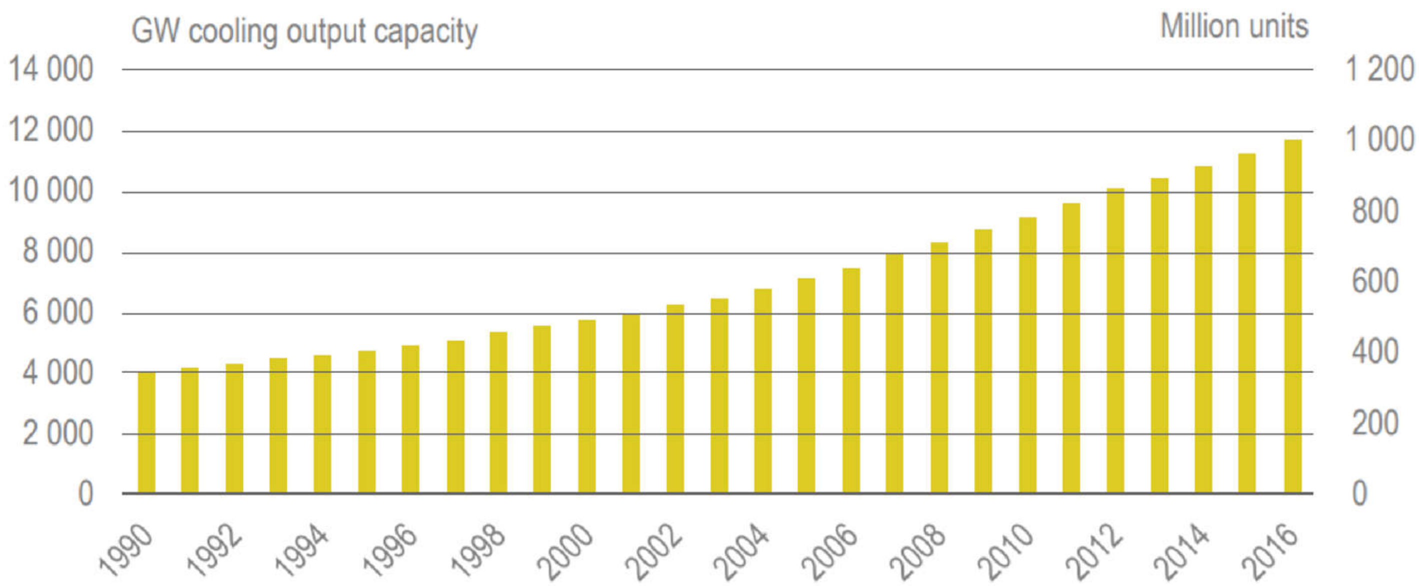
4 Conclusions

5 Further research

Research problem

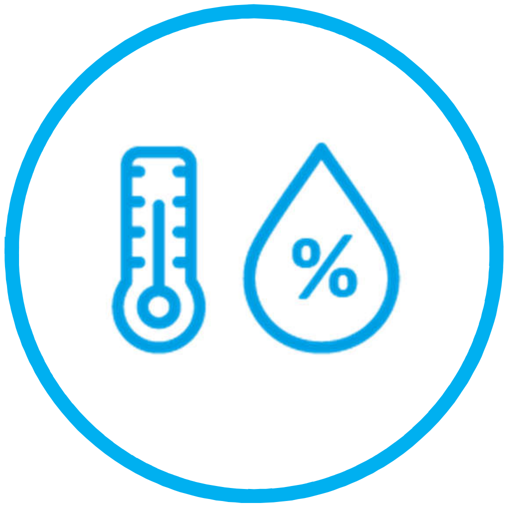
High energy consumption

- The **energy** for space cooling is **tripling** between 1990 and 2016 (IEA, 2018).
- Over **50%** of the building's energy consumption is used for **cooling** purposes. (A. Katili, 2015)

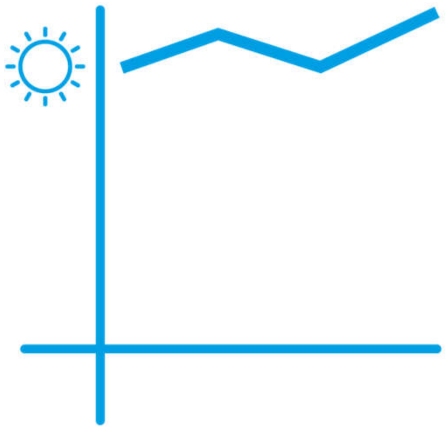


Research problem

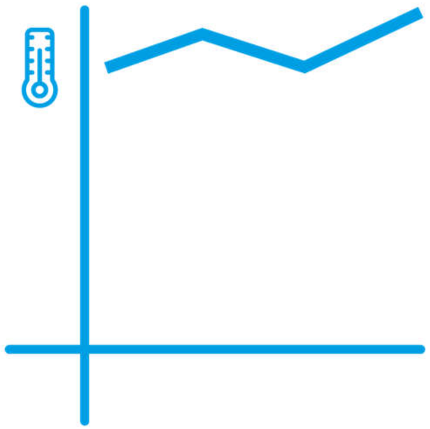
High energy consumption



- Intense radiation
- High air temperature
- High relative humidity

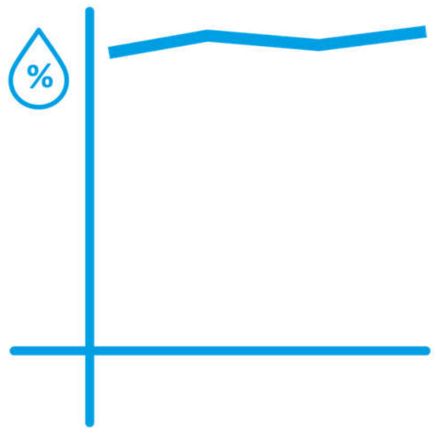


Intense radiation



High air temperature

24-31°C

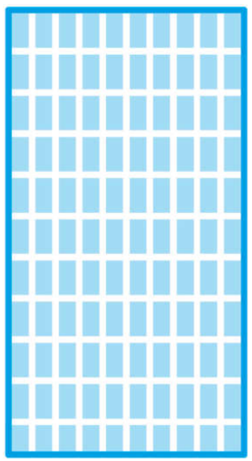


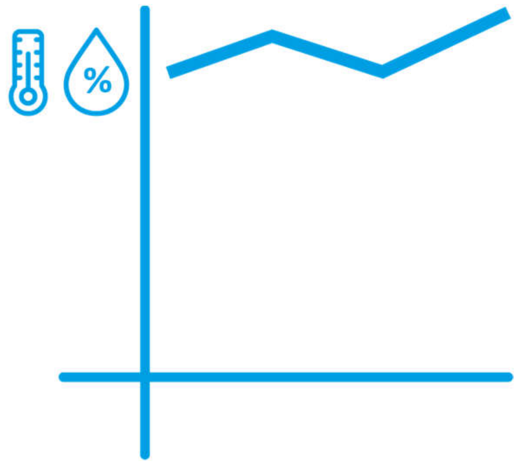
High relative humidity

60-93%

Research problem

High energy consumption → Fully glazed high rises → Tropical climates

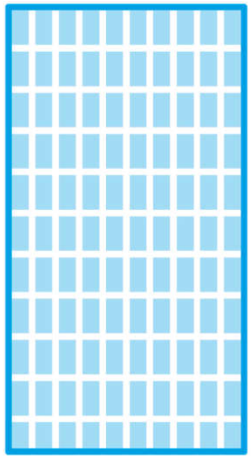


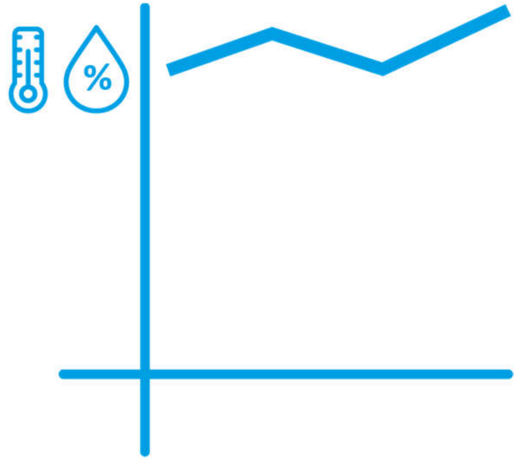


Can a **passive** high rise building be the solution?

Research problem

High energy consumption → Fully glazed high rises → Tropical climates





How can a **purely passive office building** be achieved in a **tropical climate** ensuring the indoor **thermal comfort**?

Research question

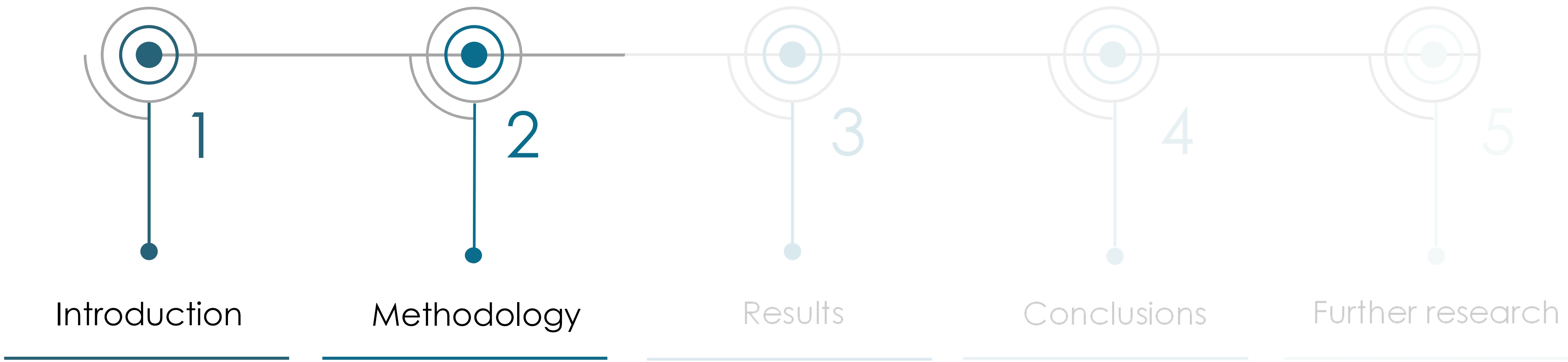
How can a **purely passive office building** be achieved in a **tropical climate** ensuring the indoor **thermal comfort**?

Objectives

- Investigate the possibility of the design of a **purely passive building** in tropical climate
- Investigate to what extent it is possible to achieve a **low energy building**.

Sub-questions

- What have been done in **bioclimatic architecture** to solve hot and humid climate issue in passive way?
- What are the applicable **passive building strategies** in a hot and humid climate?
- What is the most optimized combination of passive envelope strategies in order to reduce the cooling demands?
- What is the effect of the **envelope design parameters** on the cooling consumption?
- What is the effect of the combination of envelope parameters and **indoor comfort parameters** on the cooling consumption?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Further research

Methodology

Question?

How can a **purely passive office building** be achieved in a **tropical climate** ensuring the indoor **thermal comfort**?

1 Research for design

Climate design

- Tropical climate conditions
- Indoor thermal comfort
- Bioclimatic architecture
- Passive cooling strategies
  - Heat dissipation

Facade design

- Passive cooling strategies
  - Heat prevention

Computational design

- Energy performance
- Indoor air quality performance

2 Research through design

Energy simulation

- Computational model → Energy & comfort performance

Optimization

- Optimization (modeFRONTIER)

Methodology

Question?

How can a **purely passive office building** be achieved in a **tropical climate** ensuring the indoor **thermal comfort**?

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→ Heat dissipation

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2 Research through design

Energy simulation

Computational model → Energy & comfort performance →

Optimization

Optimization

modeFRONTIER

Methodology: Research for design

Climate design | **Facade design** | **Computational design**

Zero Energy Buildings in Tropical climates

Bioclimatic architecture

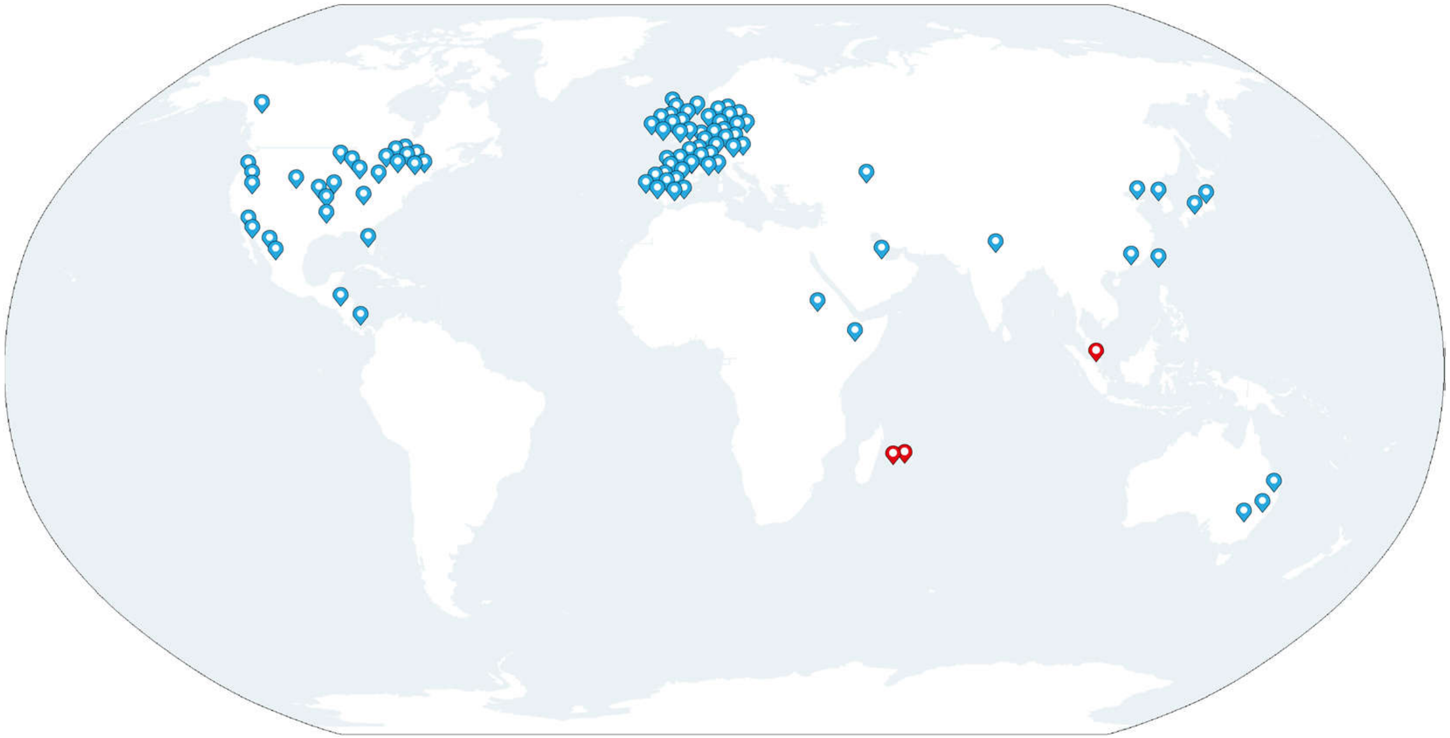
Passive cooling strategies

Adaptive thermal comfort

Building performance simulation

Building performance optimization

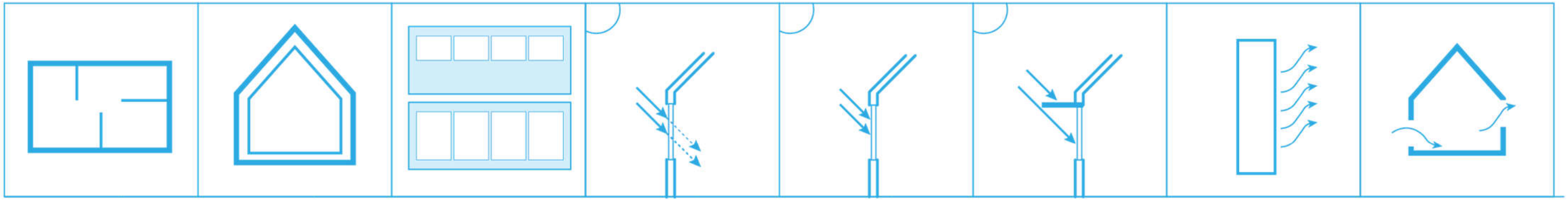
Zero Energy Buildings in Tropical climates



Out of **332 Zero Energy Buildings** (ZEB) globally, **only three** ZEBs are built in the **tropical climate**.
(2016 List of Zero NET Energy Buildings, 2019)

Methodology: Research for design

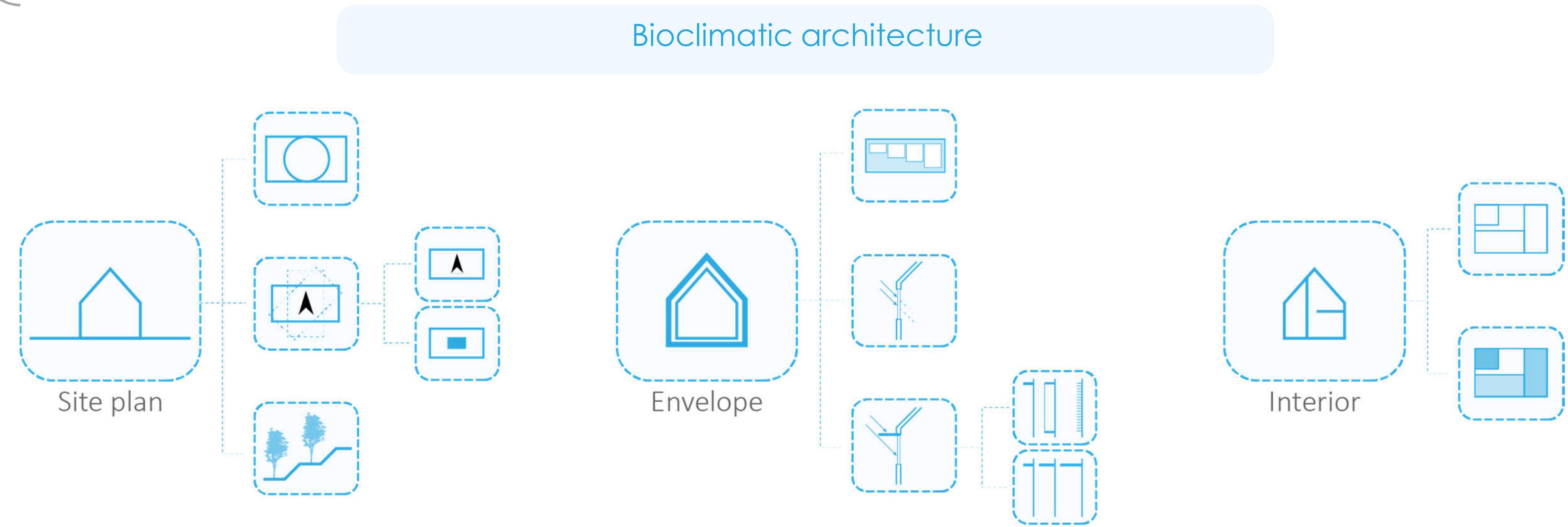
Zero Energy Buildings in Tropical climates



	Advanced floor plan	Advanced envelope	Window to wall ratio	Advanced glazing	Passive solar heat gain	Solar shading	Thermal mass	Natural ventilation
BCA	●	●		●	●	●		
Ilet du Centre	●	●		●		●		●
Enerpos	●	●	●			●	●	●

Strategies applied in the three ZEB buildings in Tropical regions.

Methodology: Research for design



The bioclimatic approach for the design of a multi-story building in the tropics area is composed by three steps:

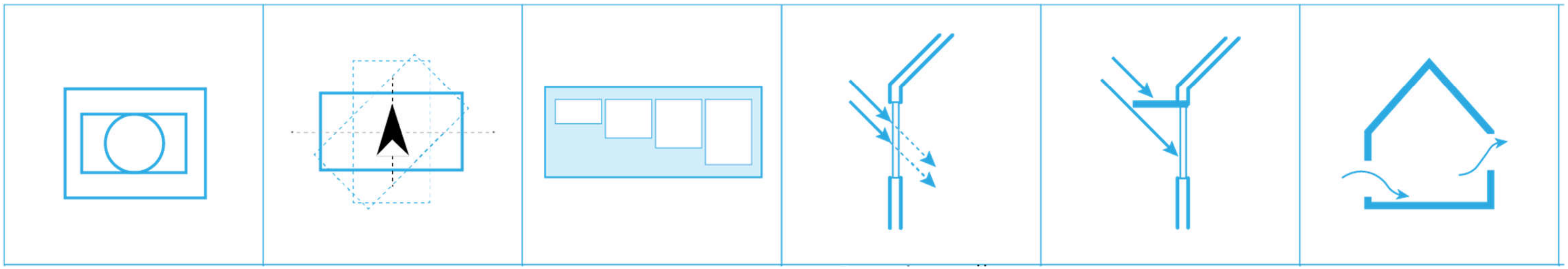
- the analysis and design of the site plan,
- the design of the envelope
- the interior design.

(Dewi Larasati Zr, 2013)

Methodology: Research for design

Passive cooling strategies

Building shape	Building Orientation	Window to wall ratio	Advanced glazing	Solar shading	Natural ventilation



Methodology

Question?

How can a **purely passive office building** be achieved in a **tropical climate** ensuring the indoor **thermal comfort**?

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Indoor thermal comfort
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Energy performance
Indoor air quality performance

2 Research through design

Energy simulation

Computational model

Energy & comfort performance

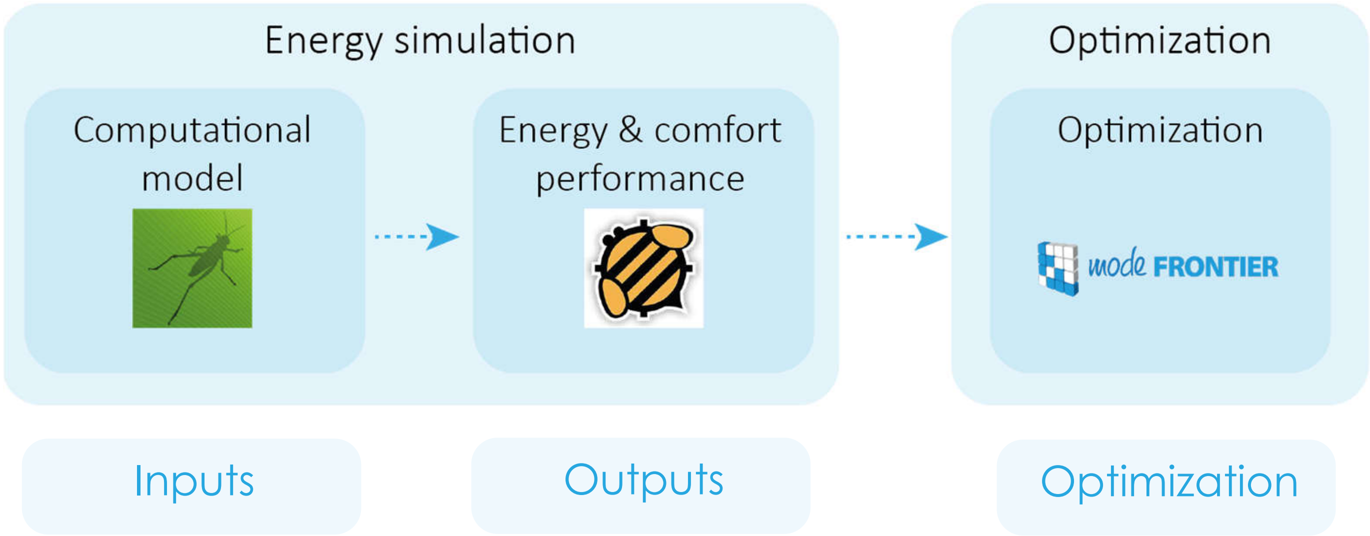
Optimization

Optimization

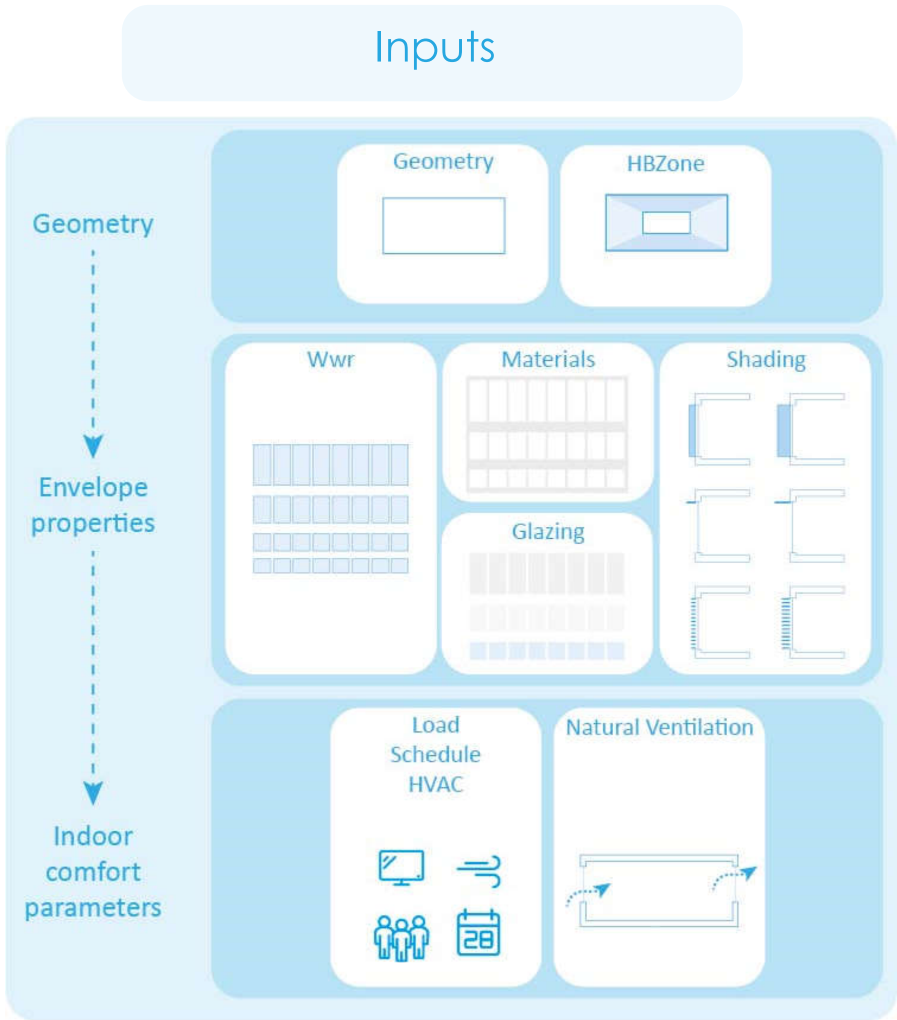
modeFRONTIER

Methodology: Research through design

2 Research through design

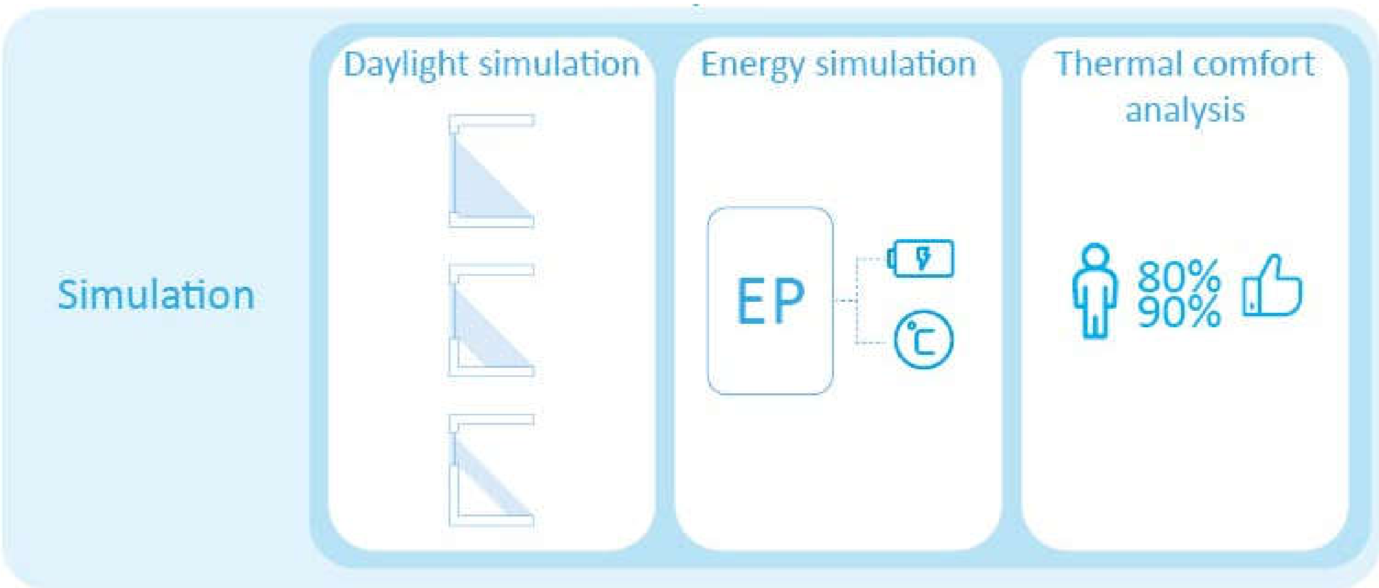


Methodology: Research through design

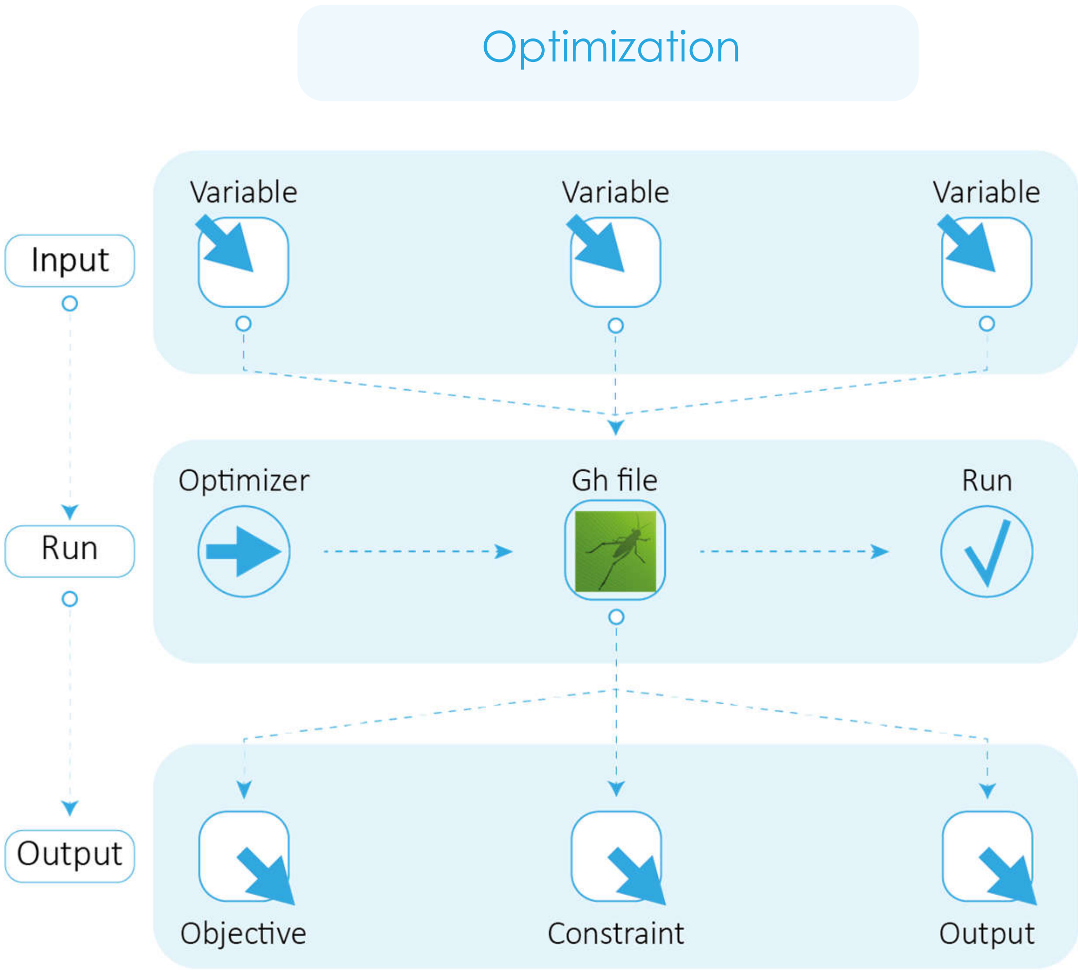


Methodology: Research through design

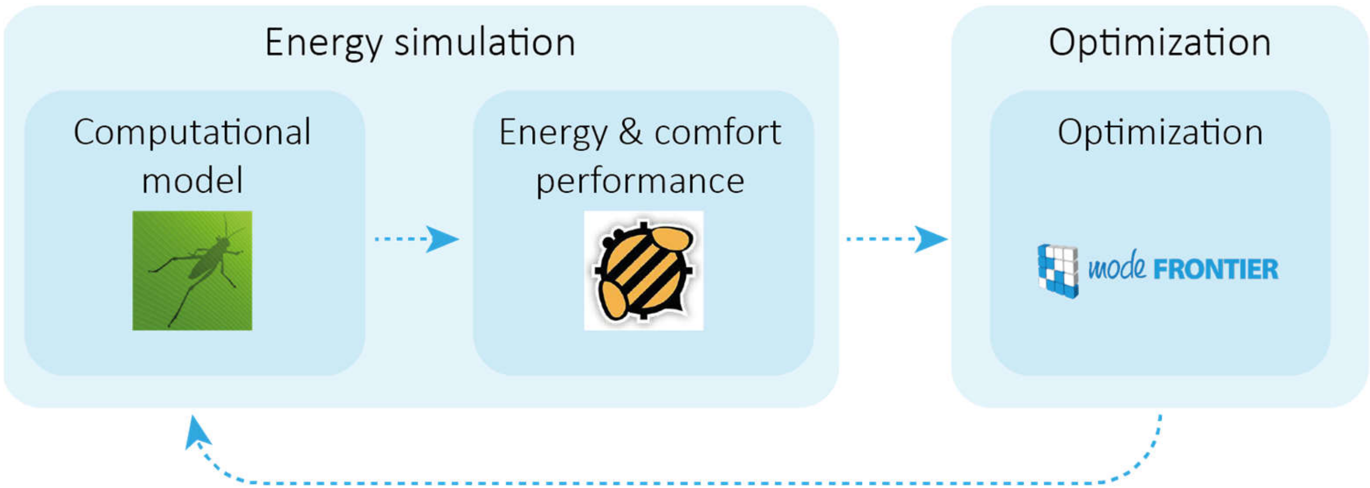
Outputs



Methodology: Research through design



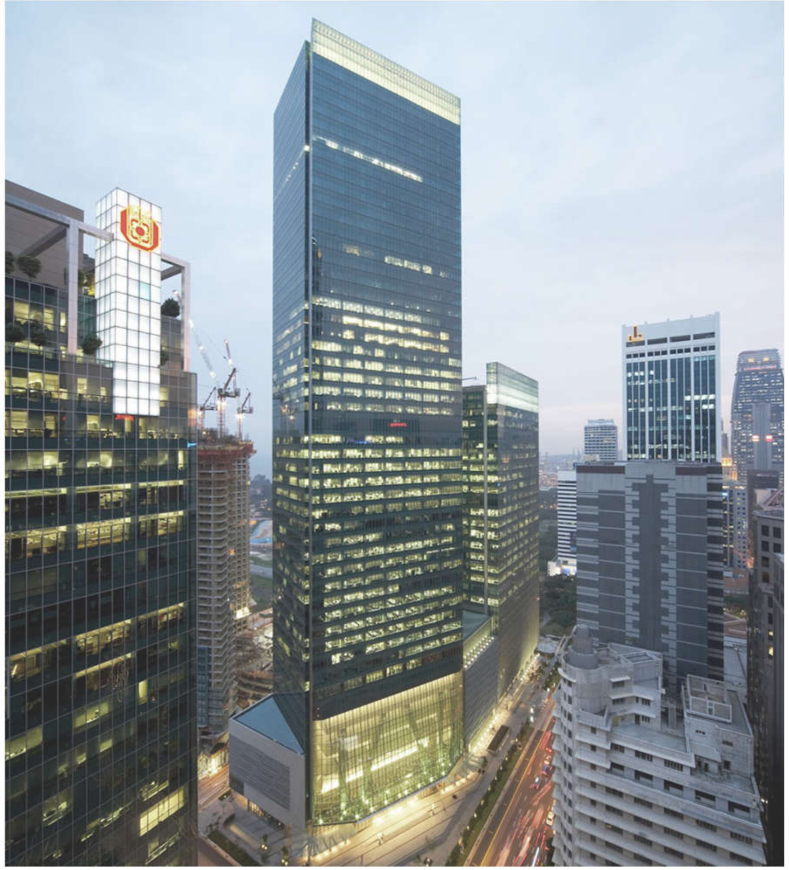
Methodology: Computational workflow



Methodology: Case study

One Raffles Quay

Kohn Pederson Fox Architects
Function: office building
Typical floor area: 1,700 m2

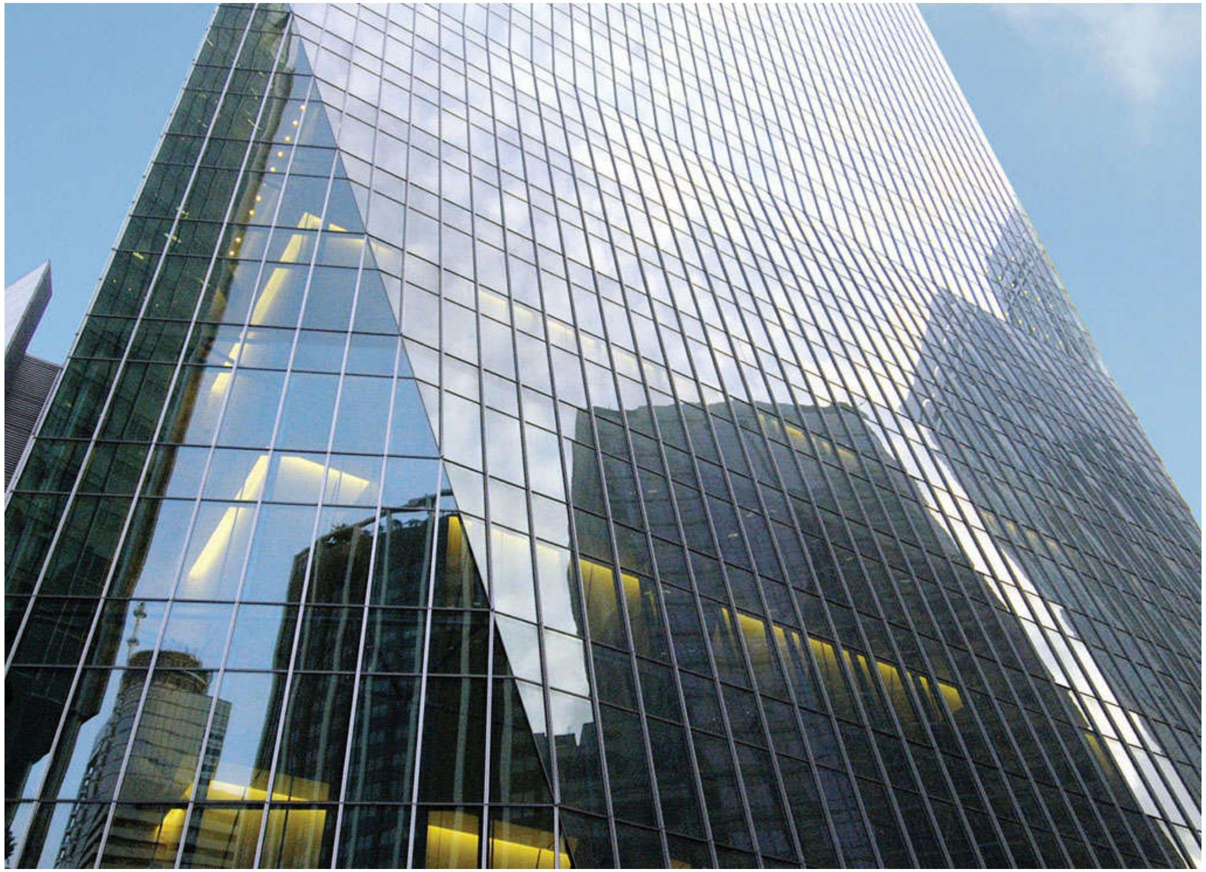


Source: https://www.meinhardt.com.sg/projects/one-raffles-quay

Methodology: Case study

One Raffles Quay

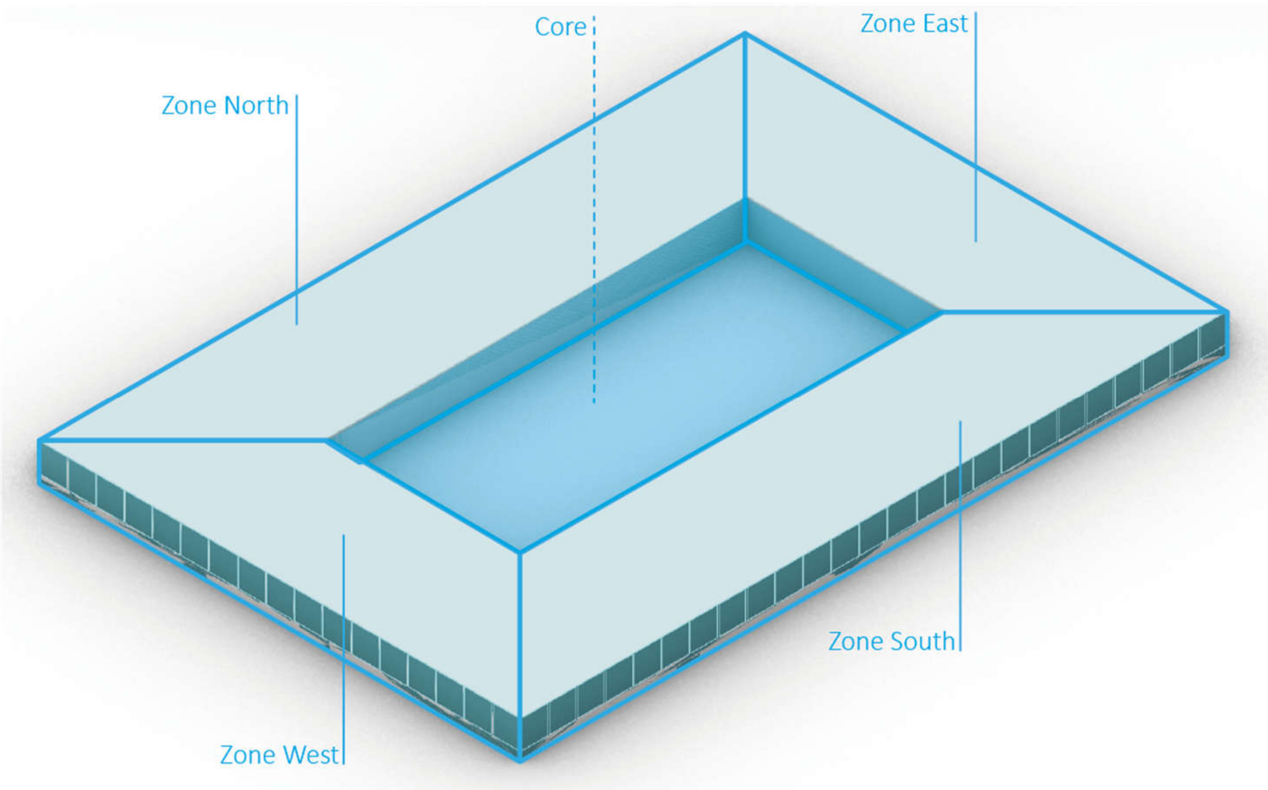
Facade system:
Unitized aluminium system with double glazed low E-solar tinted



Source: https://www.executivecentre.com/office-space/singapore-one-raffles-quay/

Methodology: Case study

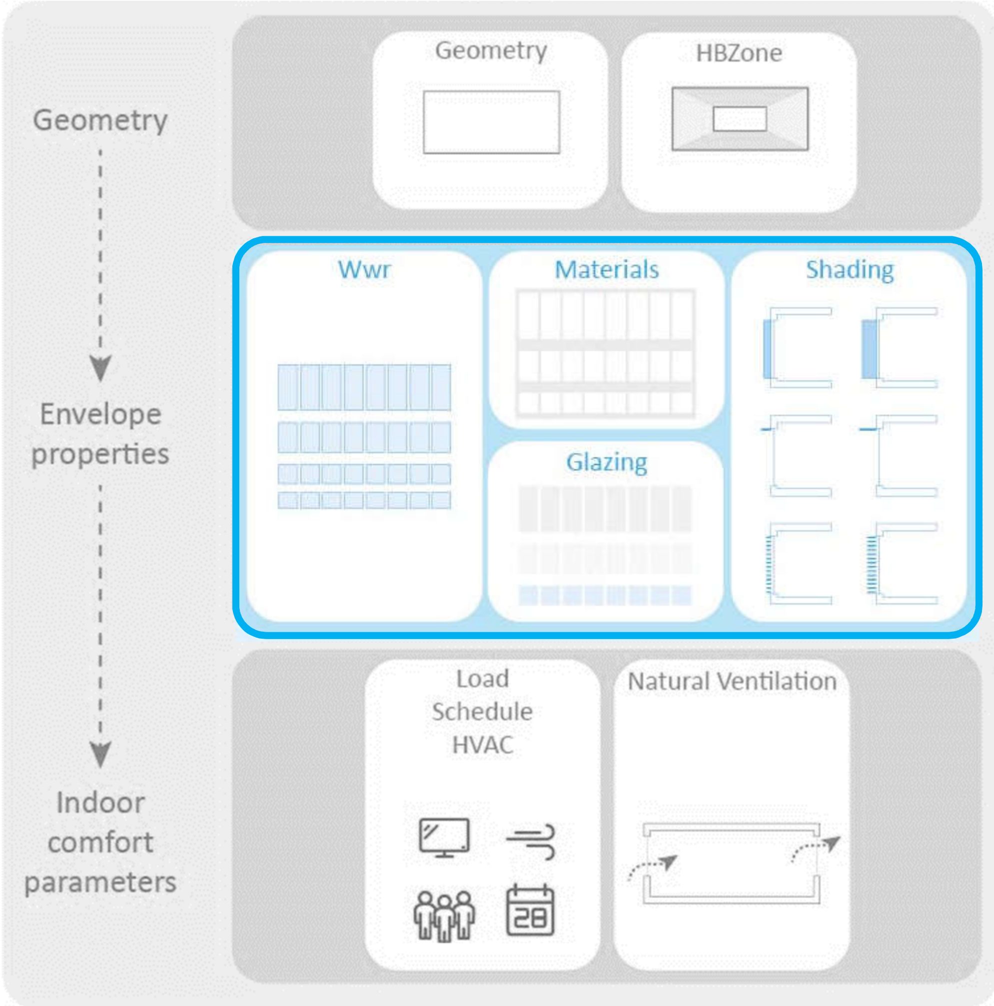
One Raffles Quay



1. Envelope optimization
2. Envelope and indoor comfort optimization

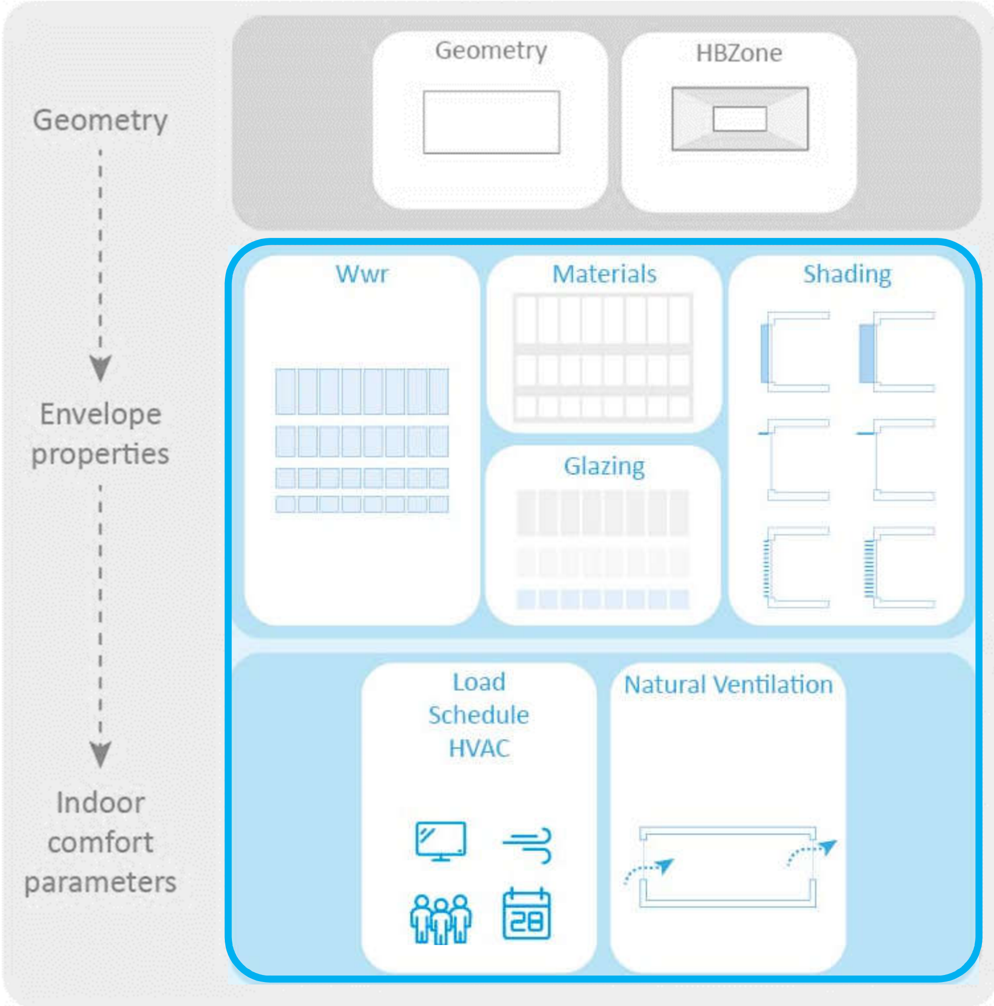
Computational optimization: Envelope parameters optimization

	1st Optimization	
	Variable	Constant
Building shape		✓
Building orientation		✓
Window to wall ratio	✓	
Glazing properties	✓	
Shading system	✓	
Shading properties	✓	
Occupancy density		✓
Lighting density		✓
Cooling set-point		✓
Adaptive comfort acceptance		✓



Computational optimization: Envelope parameters optimization

	2nd Optimization	
	Variable	Constant
Building shape		✓
Building orientation		✓
Window to wall ratio	✓	
Glazing properties	✓	
Shading system	✓	
Shading properties	✓	
Occupancy density	✓	
Lighting density	✓	
Cooling set-point	✓	
Adaptive comfort acceptance	✓	



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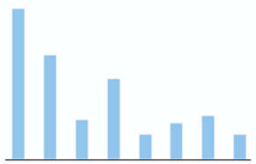
Results

Screening results

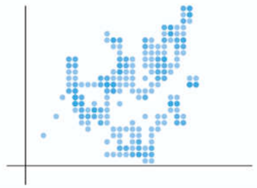
Correlation matrix

Definition of the most impactful variables



Bubble chart

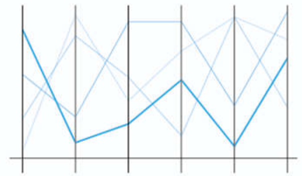
Definition of the most impactful values of the most impactful variables



Design selection

Parallel chart

Selection of the optimal design, after limiting the ranges of the less impactful variables



Results

1. General

	Cooling energy	Lighting energy
cooling set point	-0.65	-0.11
lighting density	0.17	0.88
occupancy density	0.45	0.03
depth of shading	-0.18	-0.04
number of shading	-0.33	0.12
shading type	0.13	0.18
glazing type	-0.67	0.03
wwr west	0.07	-0.27
wwr east	0.17	-0.17
wwr south	0.04	-0.26
wwr north	-0.00	-0.28

2. Envelope

	Cooling energy	Lighting energy
depth of shading	-0.18	-0.04
number of shading	-0.33	0.12
shading type	0.13	0.18
glazing type	-0.67	0.03
wwr west	0.07	-0.27
wwr east	0.17	-0.17
wwr south	0.04	-0.26
wwr north	-0.00	-0.28

3. Indoor comfort

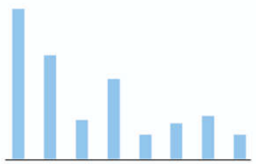
	Cooling energy	Lighting energy
cooling set point	-0.65	-0.11
lighting density	0.17	0.88
occupancy density	0.45	0.03

Results

Screening results

Correlation matrix

Definition of the most impactful variables



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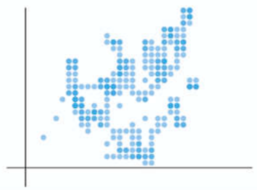

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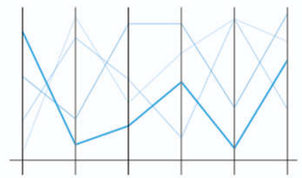
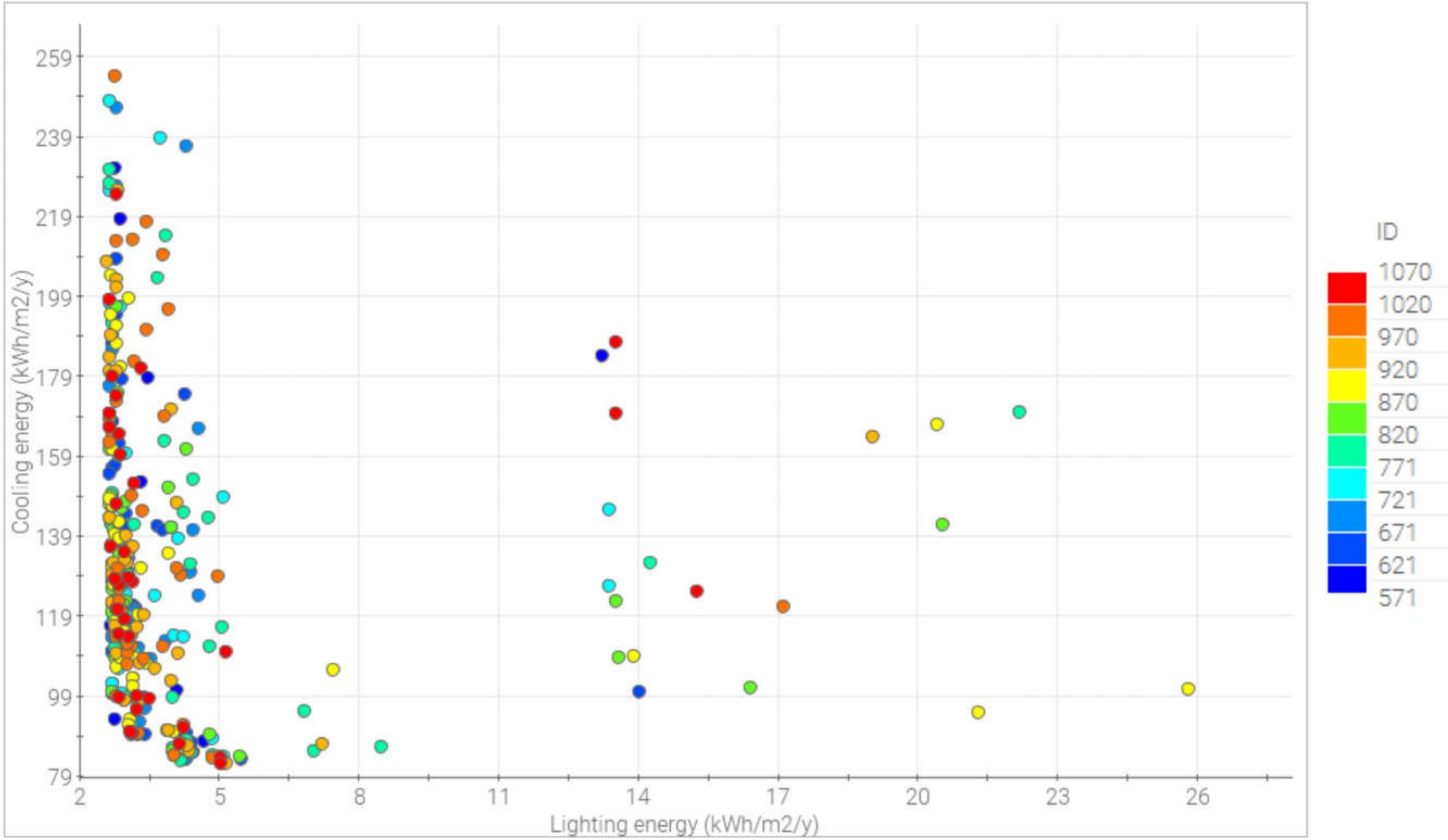
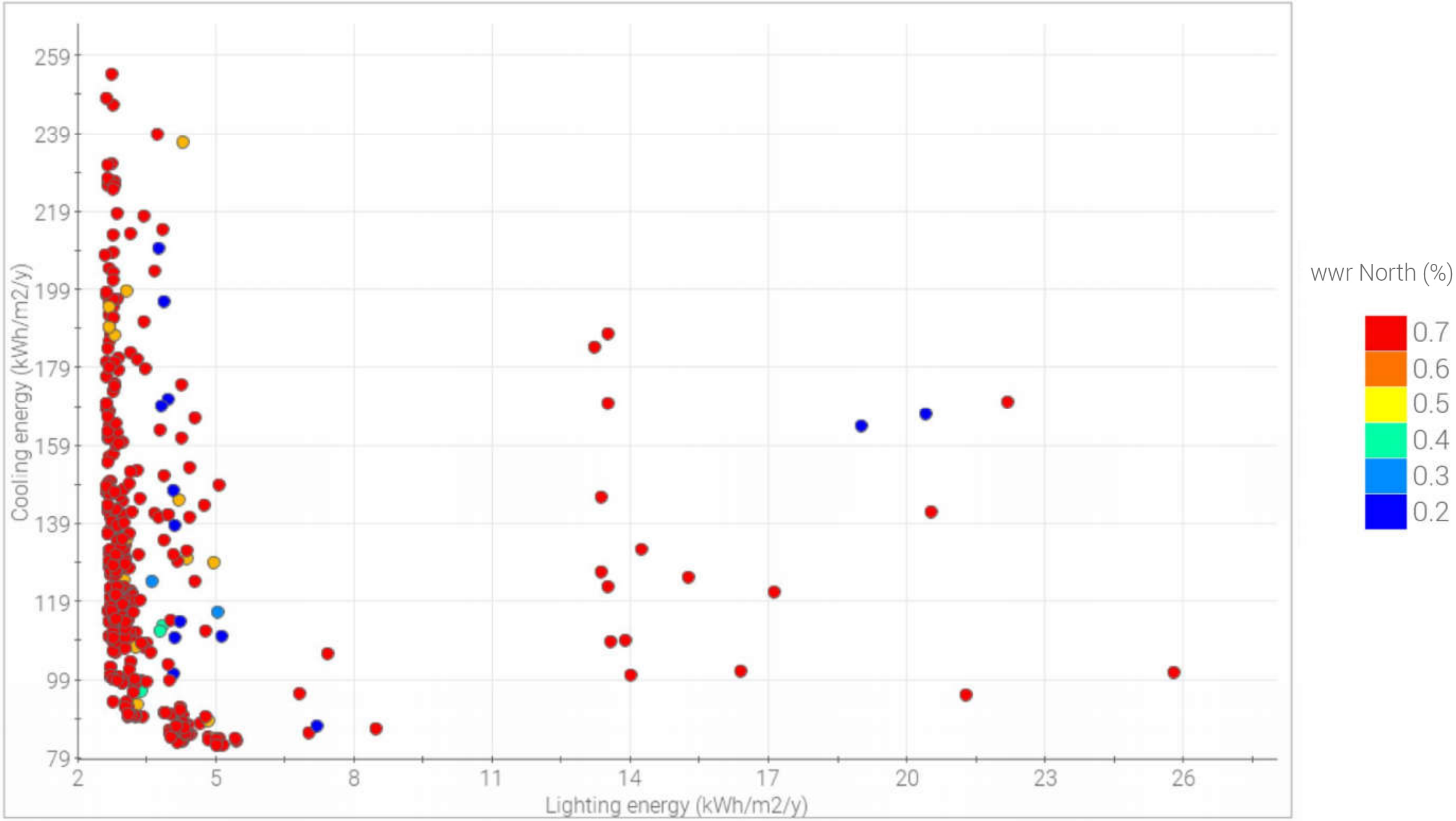


Results

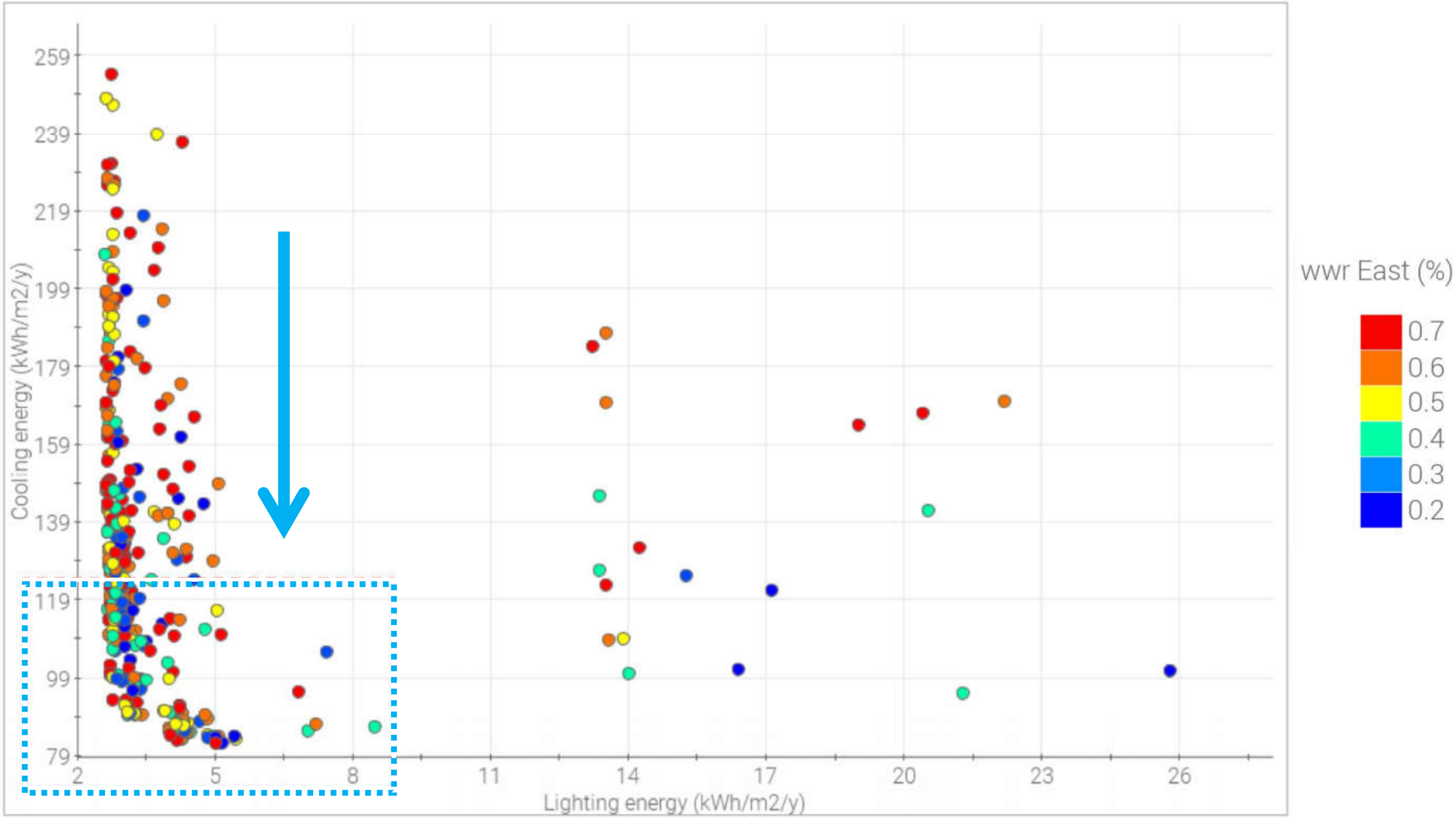


Cooling energy (kWh/m2/y)
259
239
219
199
179
159
139
119
99
79
2
5
8
11
14
17
20
23
26
Lighting energy (kWh/m2/y)
ID
1070
1020
970
920
870
820
771
721
671
621
571

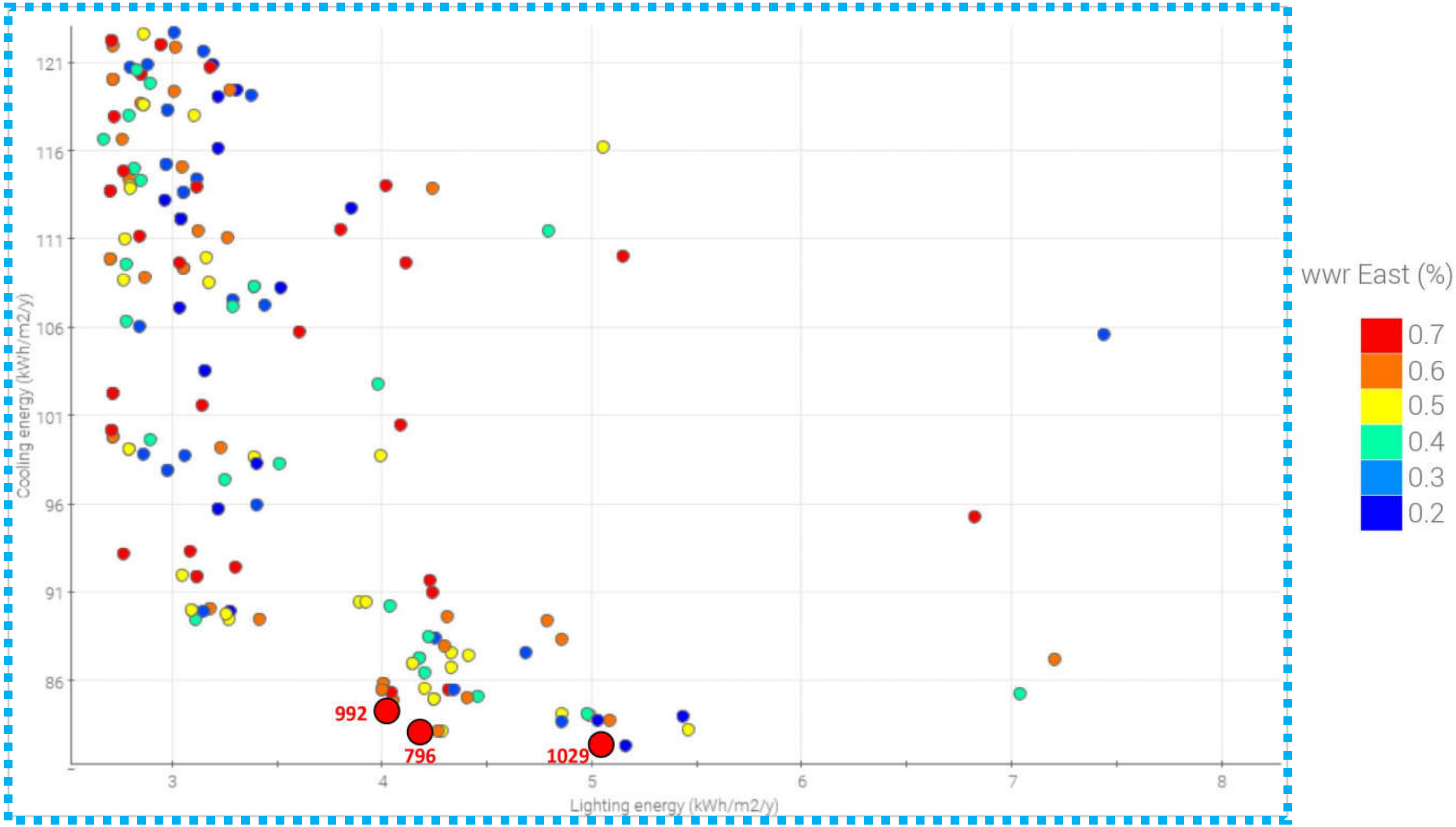
Results: North facade



Results: East facade



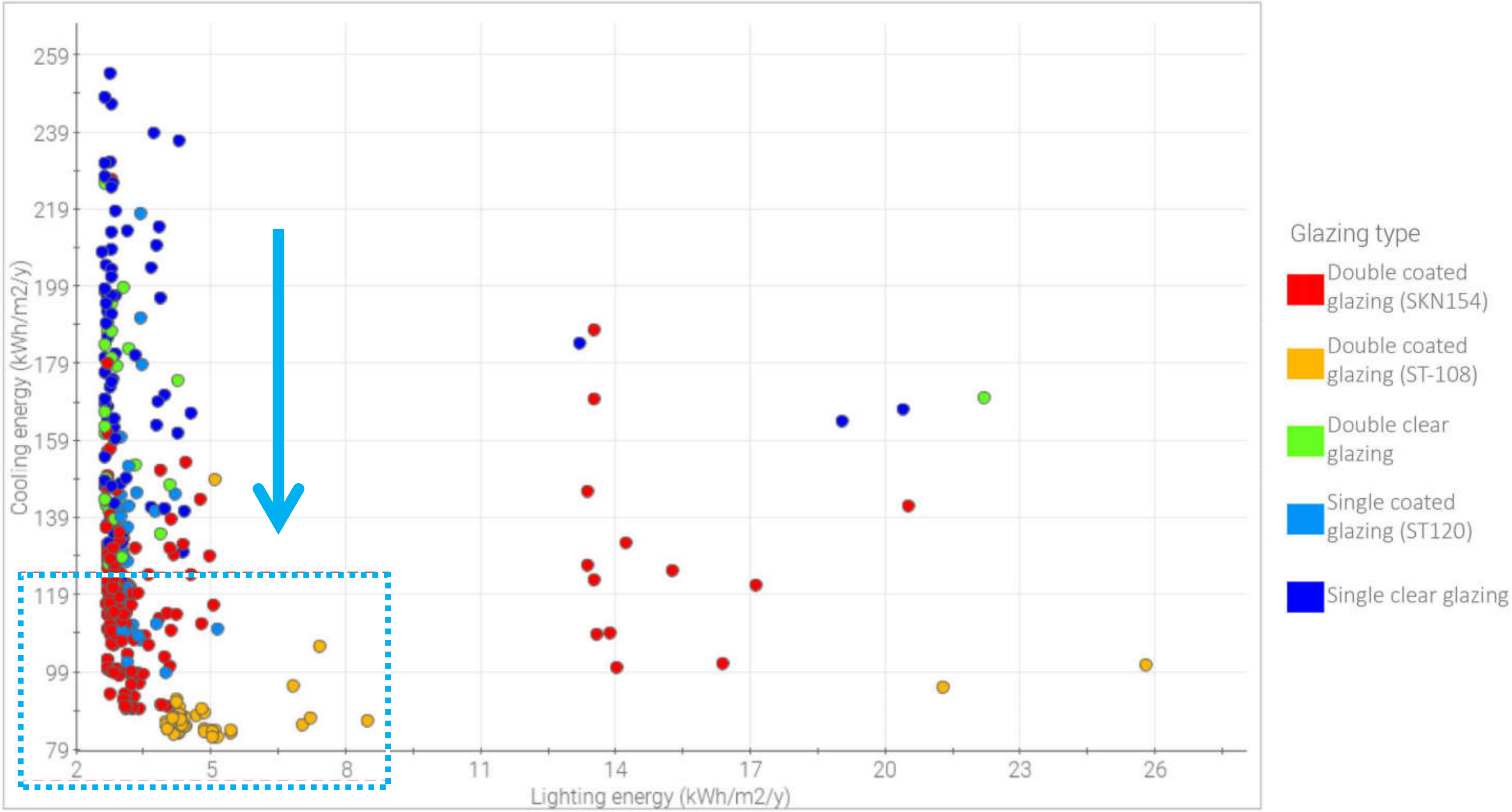
Results: East facade



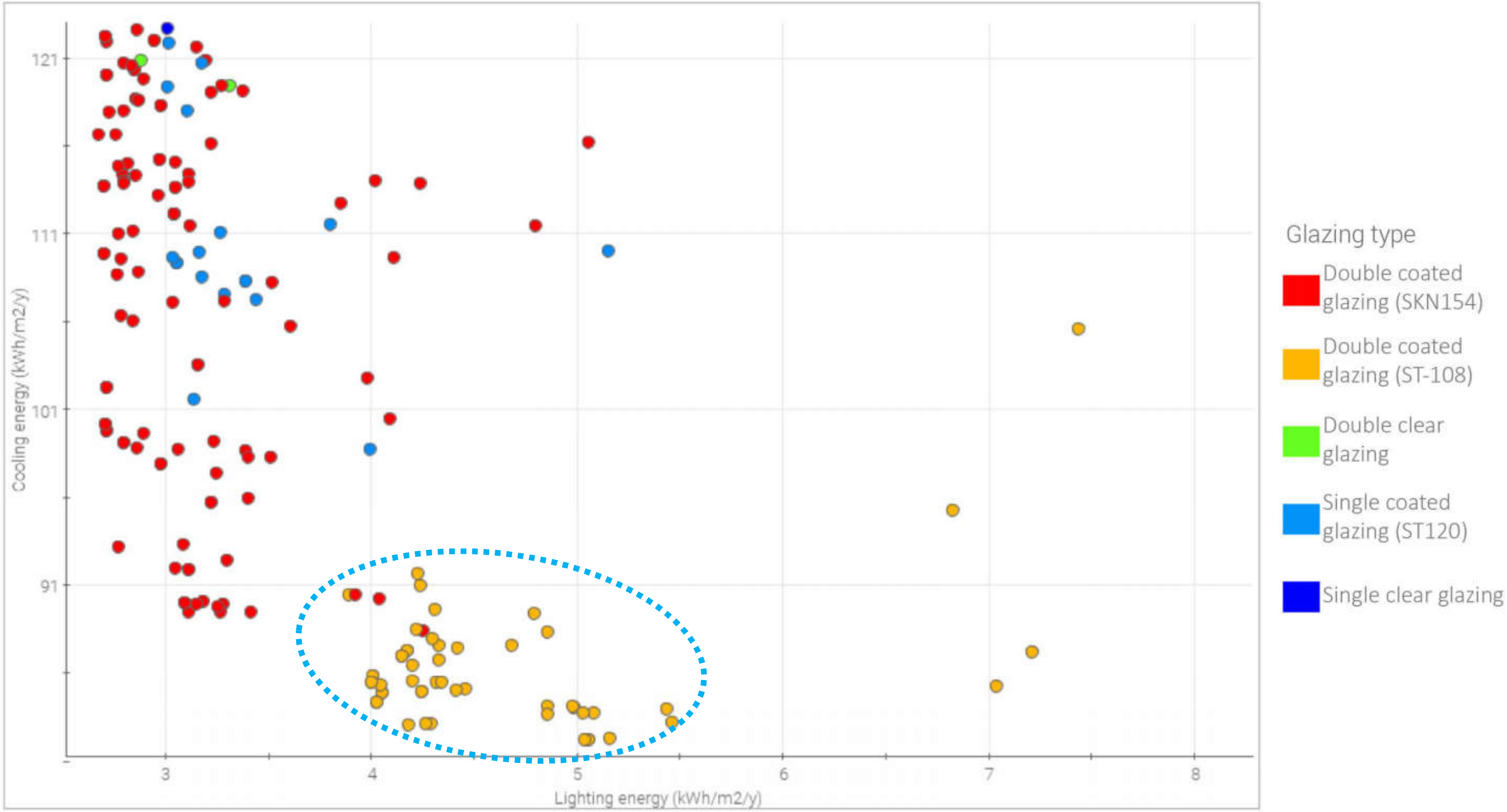
Results: high wwr on east facade

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
170	70%	70%	70%	70%	4	horizontal	2	0.9	0.15	15	24	204
178	70%	70%	70%	70%	3	vertical	2	0.5	0.15	15	24	202
220	70%	40%	70%	40%	4	horizontal	4	0.5	0.15	15	24	199
67	70%	70%	70%	70%	3	vertical	1	0.9	0.15	15	24	197
1029	70%	70%	70%	70%	3	horizontal	3	0.9	0.1	3	30	82
796	70%	70%	70%	70%	3	horizontal	4	0.5	0.1	3	30	83
992	70%	70%	70%	70%	3	horizontal	2	0.9	0.1	3	30	84

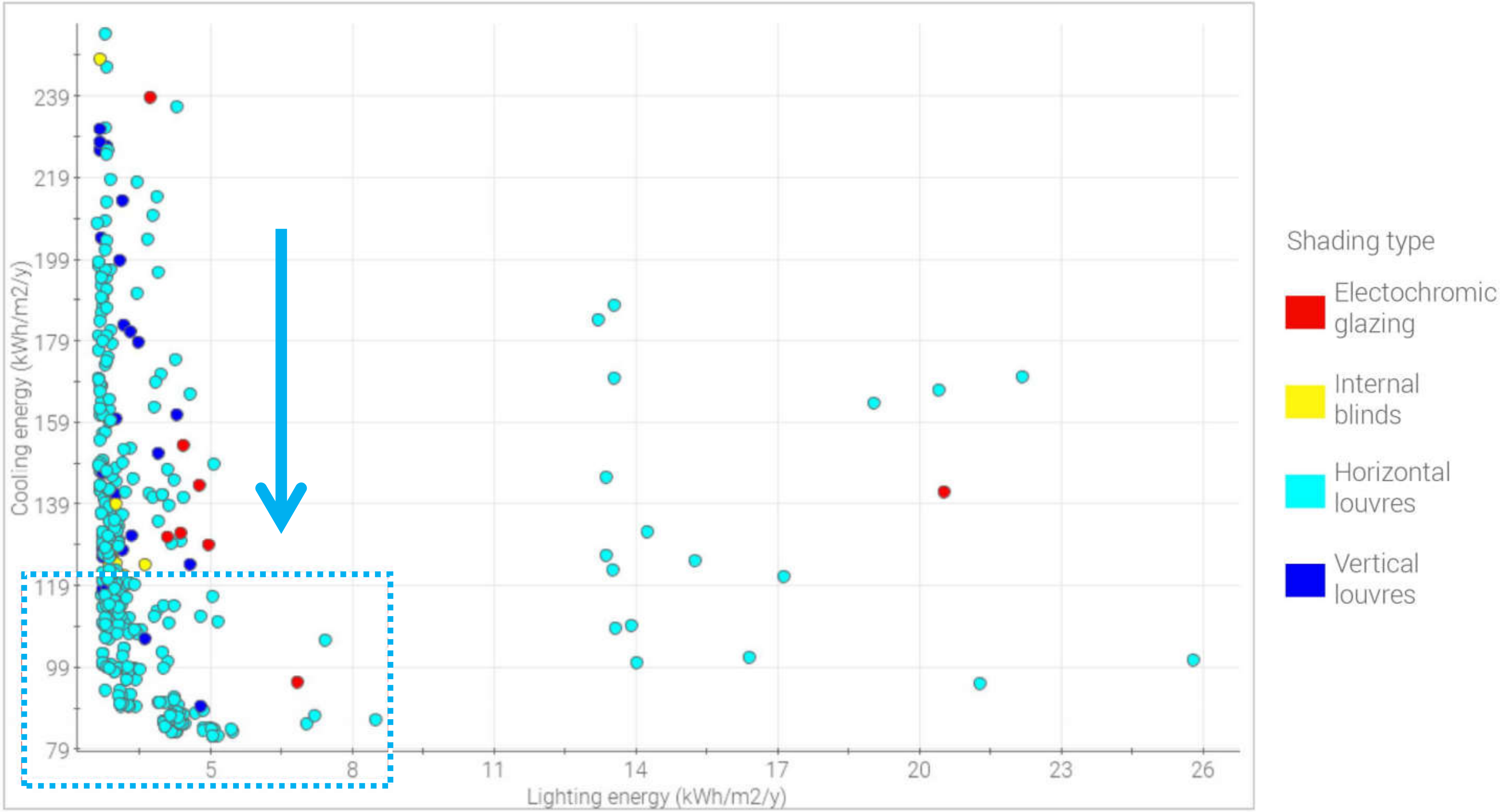
Results: Glazing type



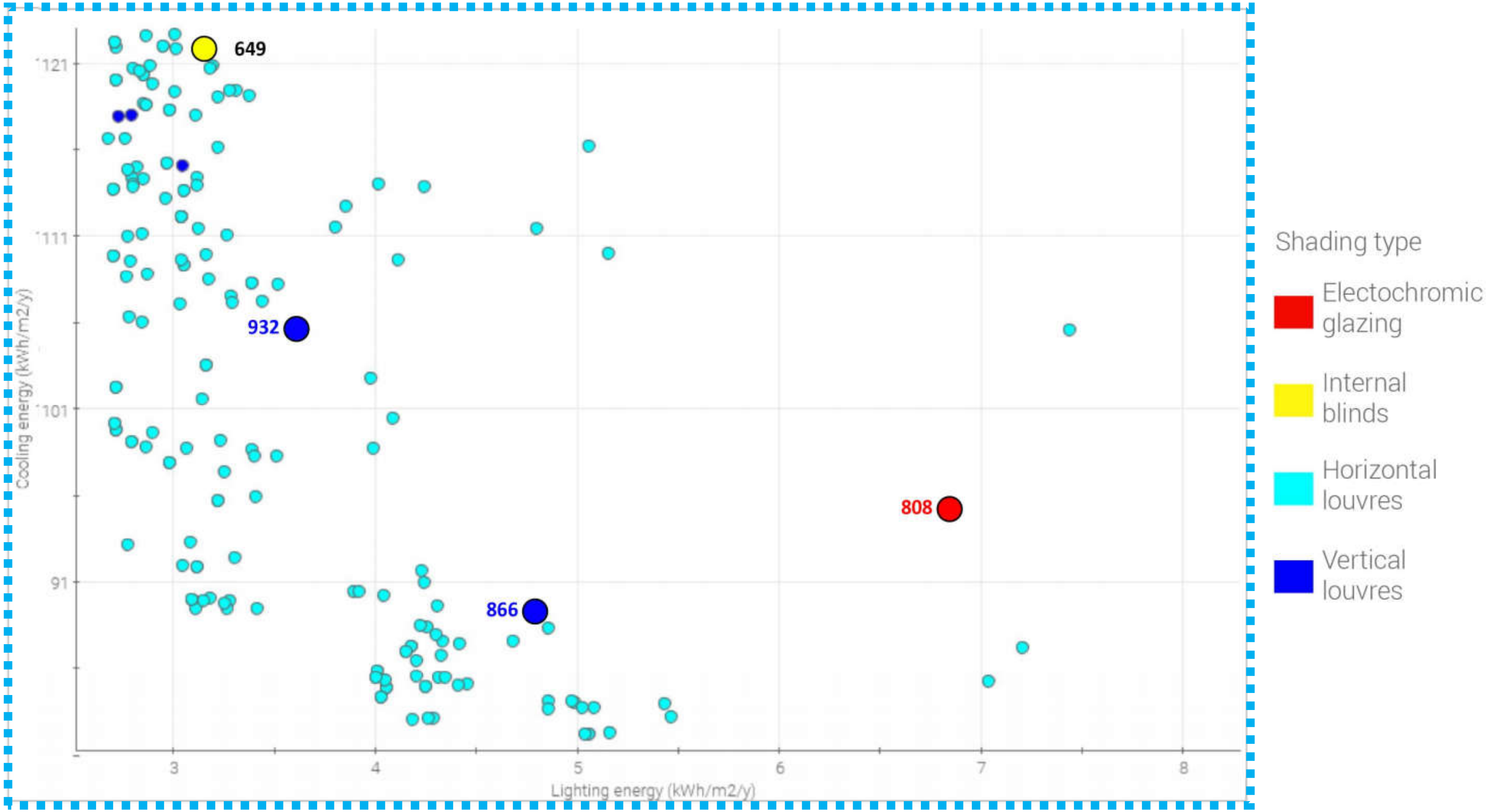
Results: Glazing type



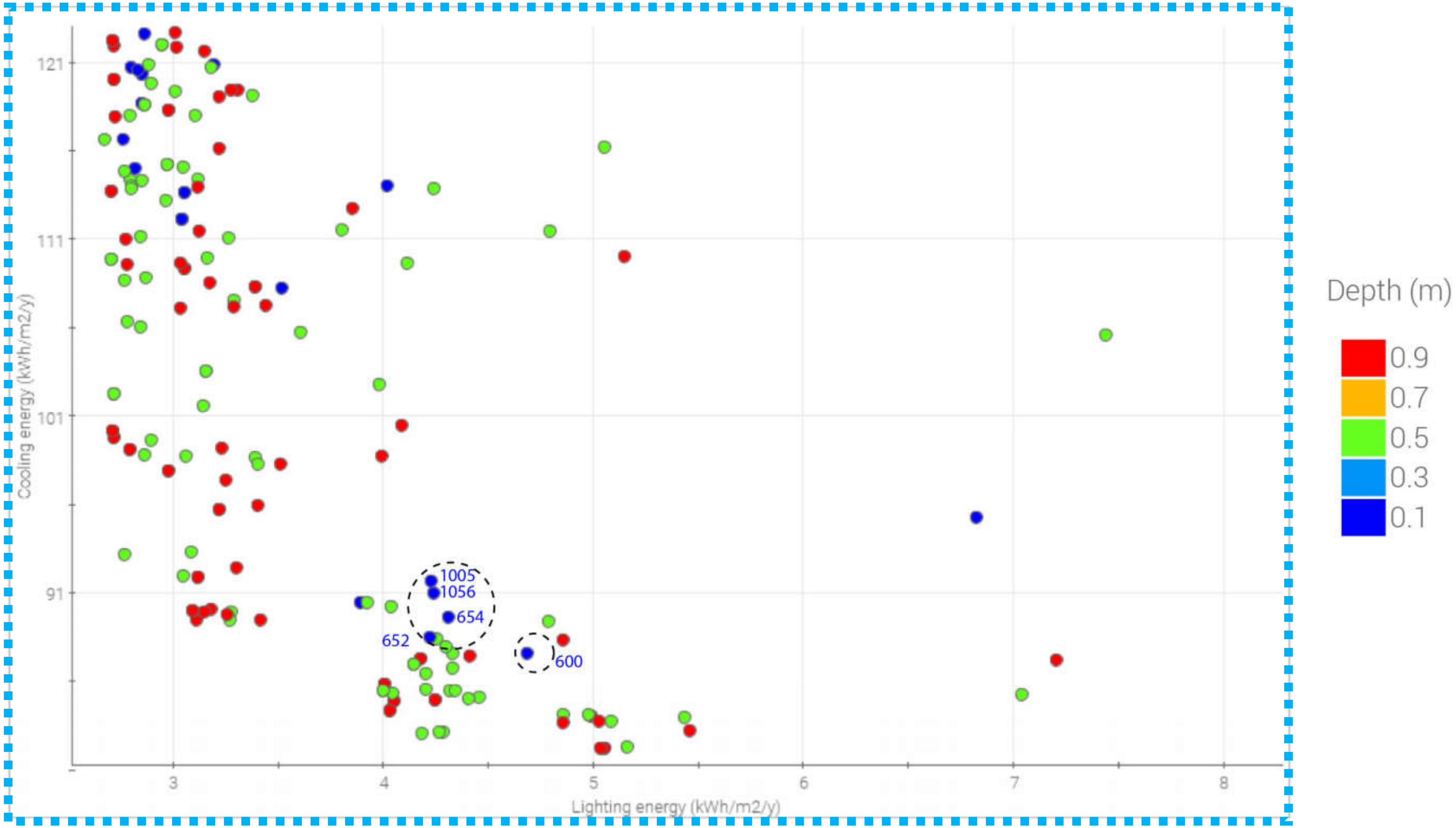
Results: shading system



Results: shading system



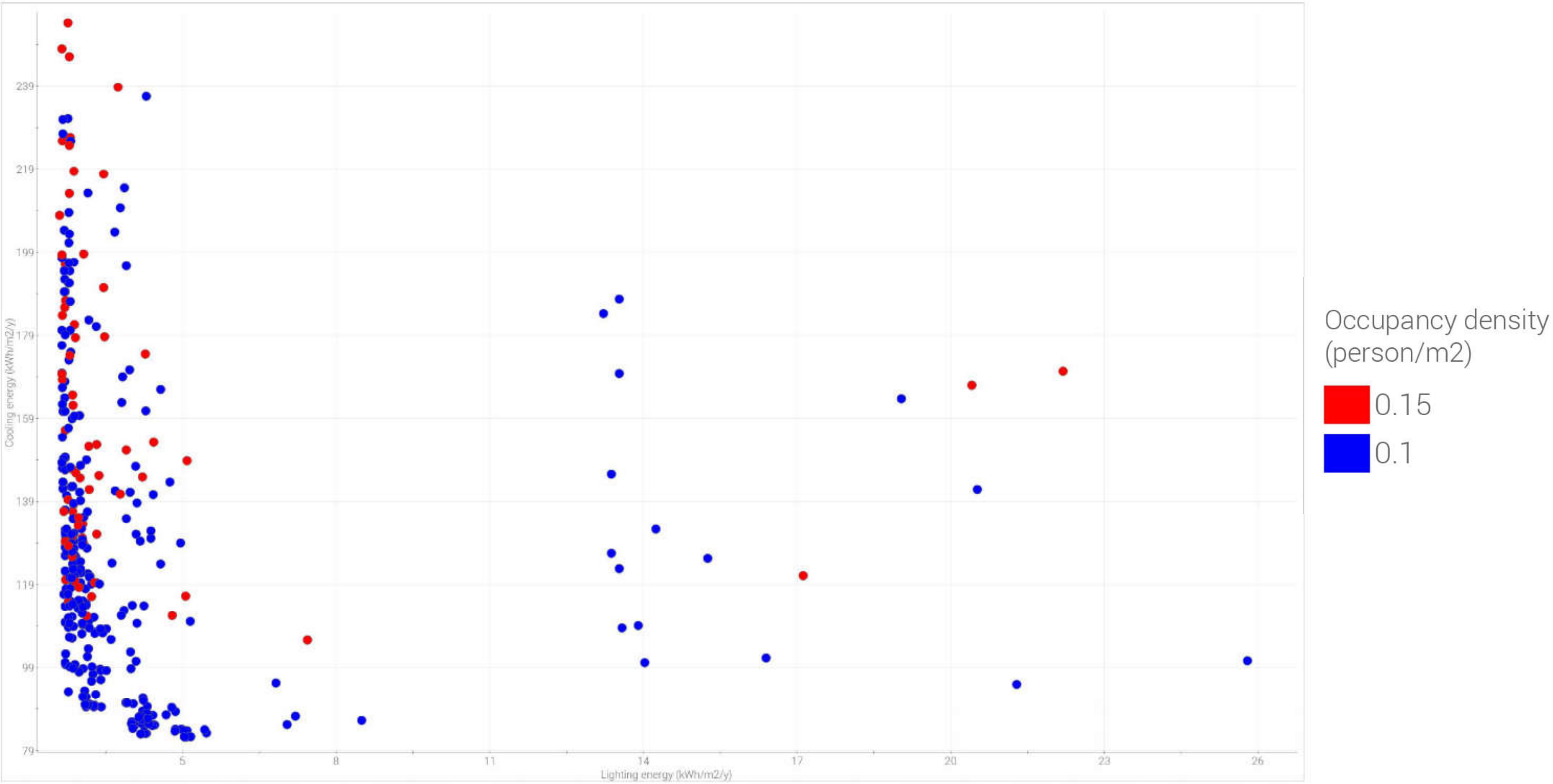
Results: shading depth



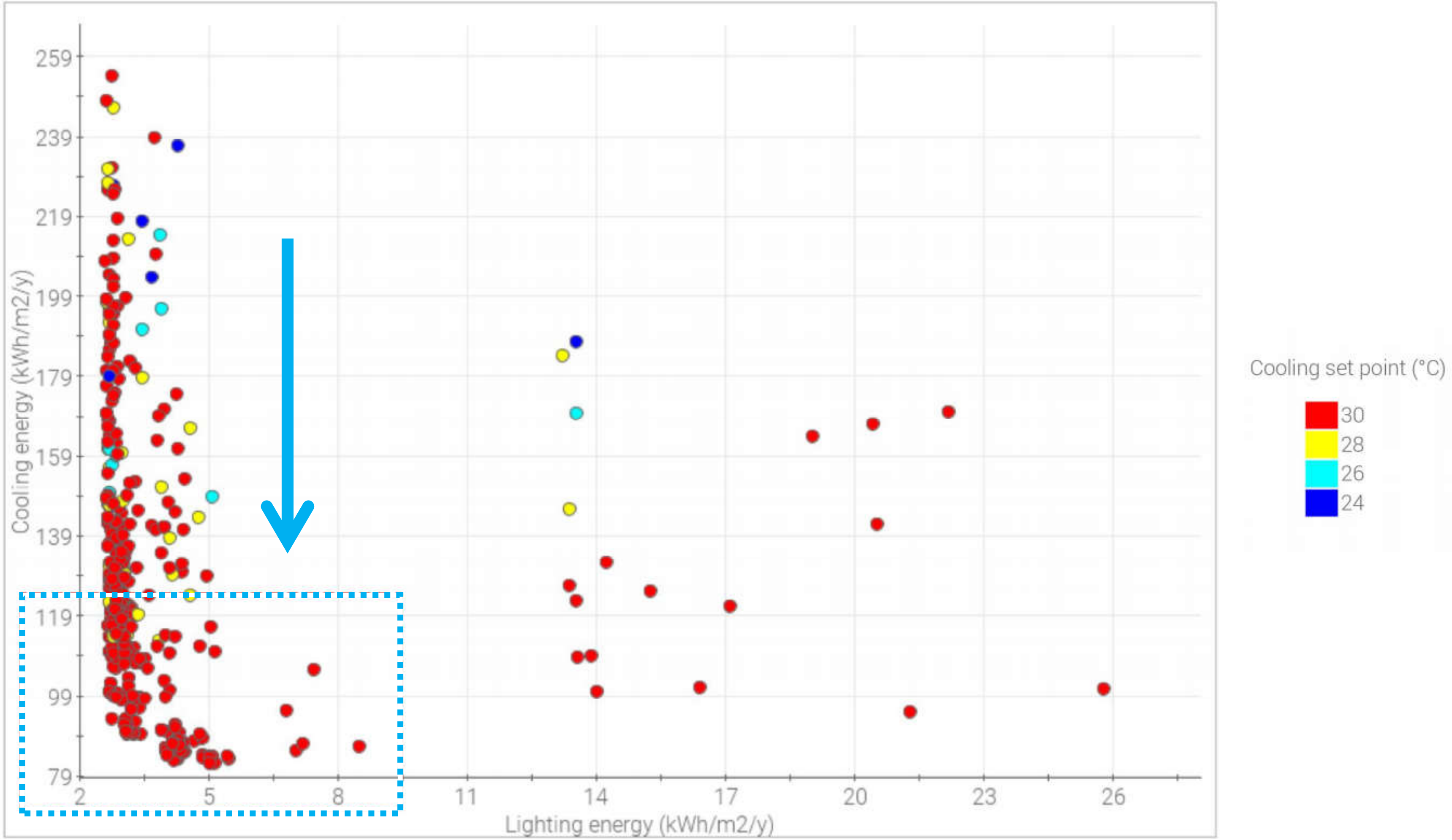
Results: minimum shading depth

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
1005	70%	70%	70%	70%	3	horizontal	2	0.1	0.1	3	30	92
1056	70%	70%	70%	70%	3	horizontal	3	0.1	0.1	3	30	91
654	70%	70%	60%	70%	3	horizontal	4	0.1	0.1	3	30	90
652	70%	70%	40%	70%	3	horizontal	4	0.1	0.1	3	30	88
600	70%	70%	30%	70%	3	horizontal	4	0.1	0.1	3	30	88

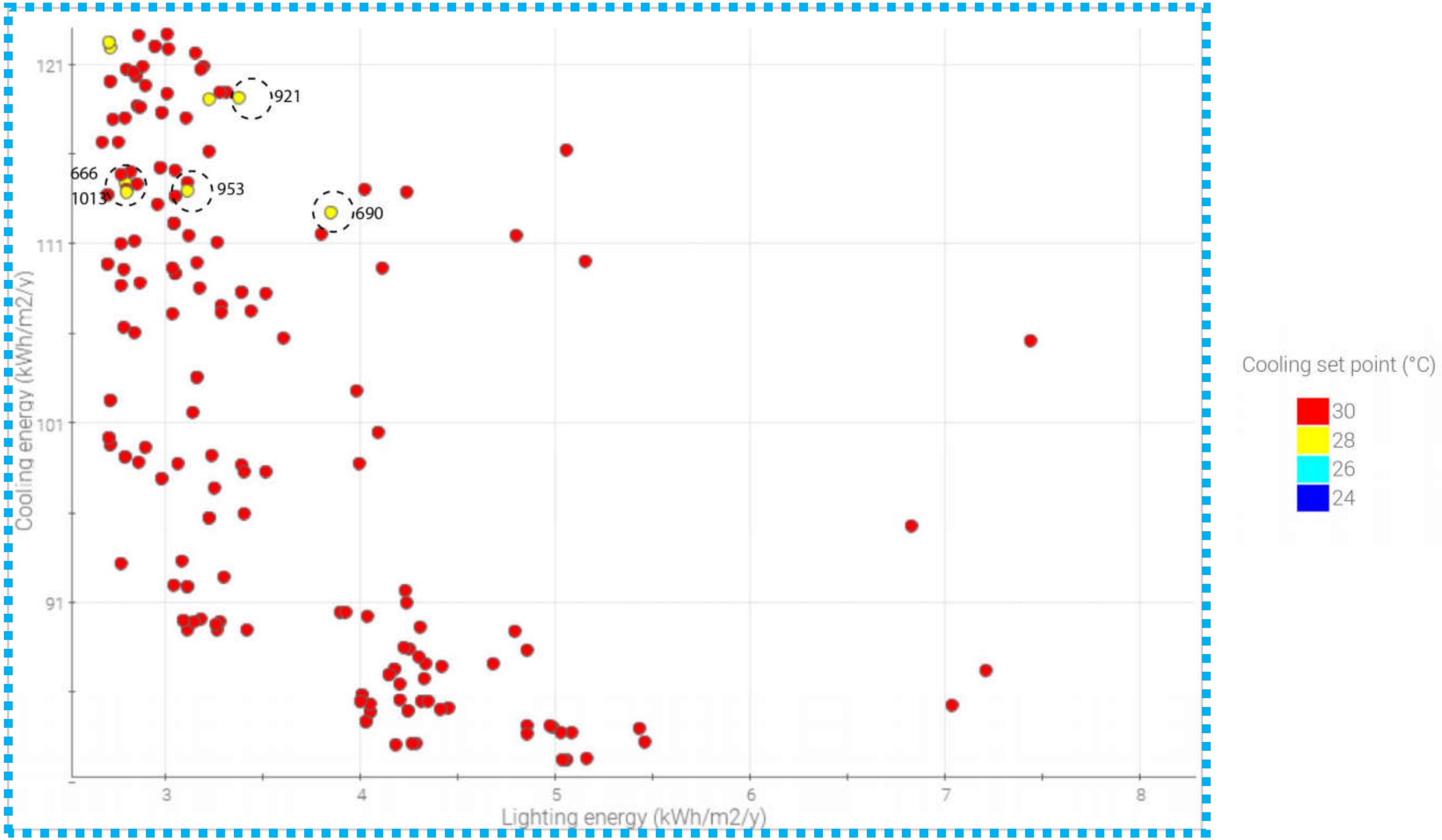
Results: occupancy density



Results: cooling set point temperature



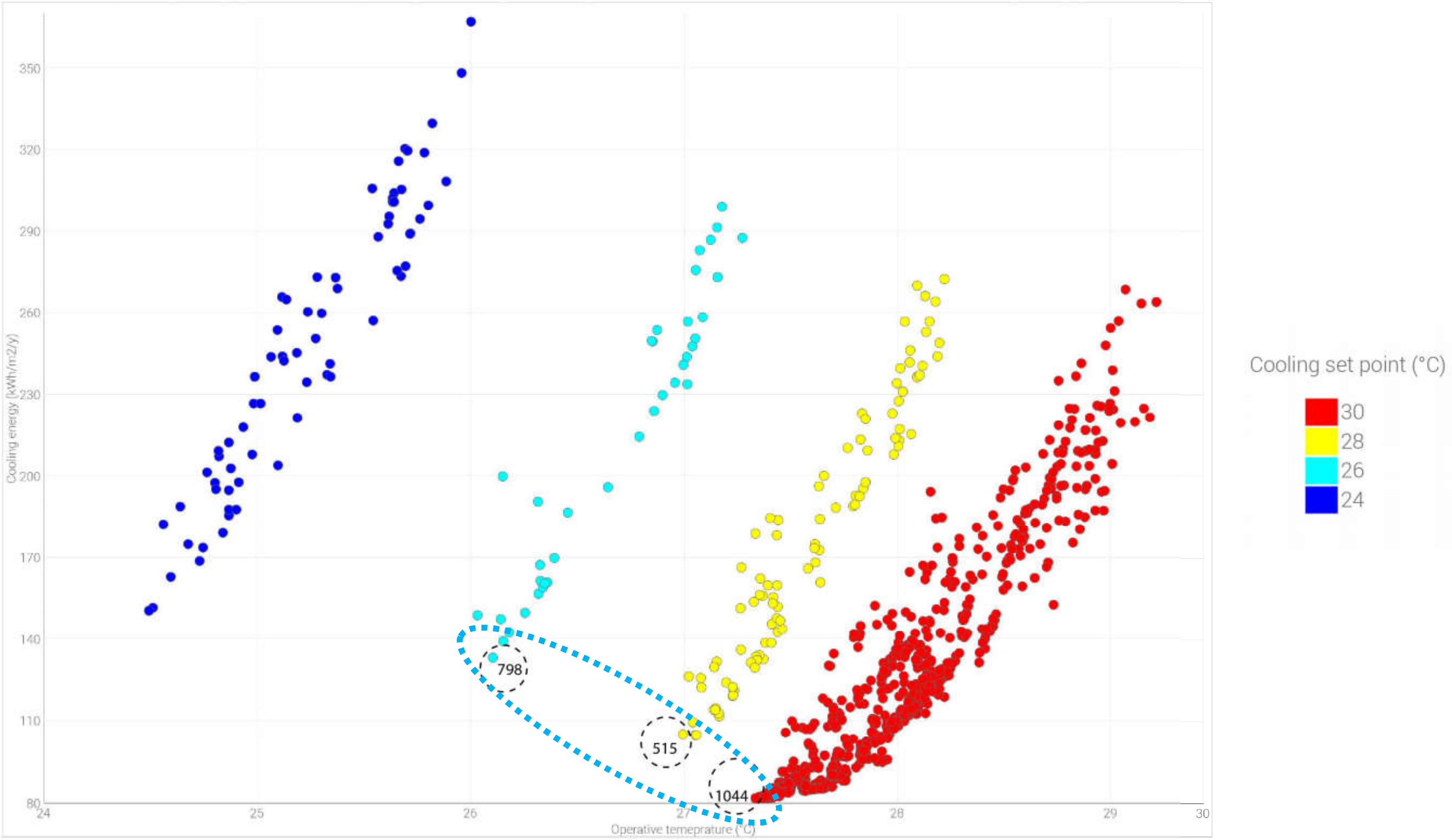
Results: cooling set point temperature



Results: 28°C cooling set point

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
921	70%	50%	30%	70%	4	horizontal	3	0.5	0.1	3	28	119
666	70%	70%	60%	70%	4	horizontal	4	0.5	0.1	3	28	114
1013	70%	70%	50%	70%	4	horizontal	4	0.5	0.1	3	28	114
953	70%	70%	70%	70%	4	horizontal	3	0.9	0.1	3	28	114
690	50%	70%	20%	70%	4	horizontal	3	0.9	0.1	3	28	113

Results: cooling set point temperature



Results:

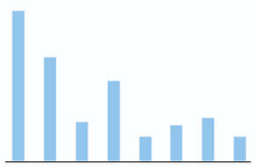
Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
1044	70%	70%	70%	70%	3	horizontal	4	0.9	0.1	3	30	82
515	70%	70%	40%	70%	3	horizontal	2	0.5	0.1	3	28	105
798	60%	70%	70%	60%	4	horizontal	4	0.9	0.1	3	26	133

Results

Screening results

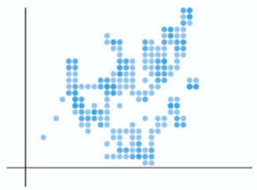
Correlation matrix

Definition of the most impactful variables



Bubble chart

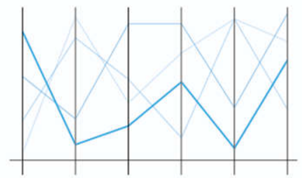
Definition of the most impactful values of the most impactful variables



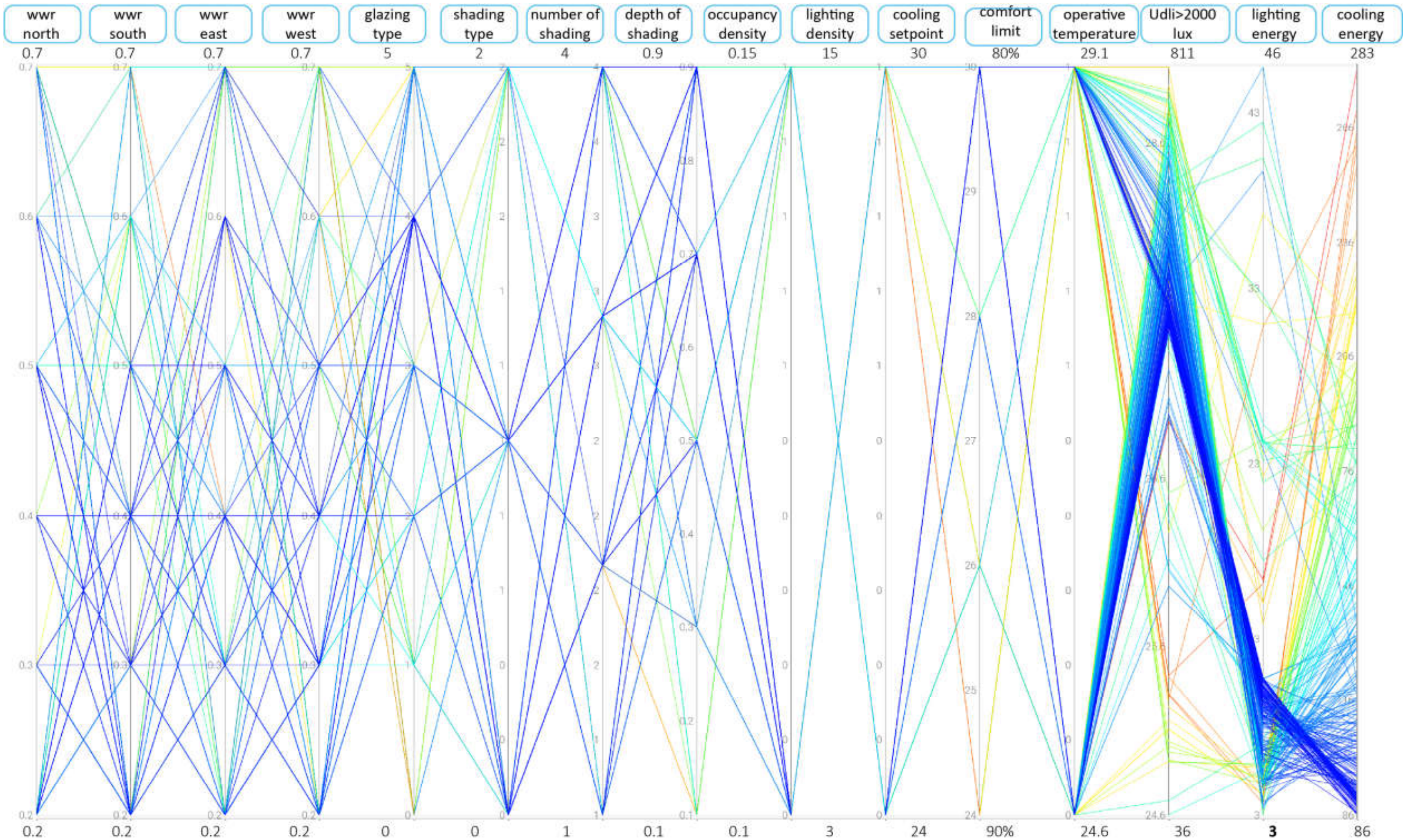
Design selection

Parallel chart

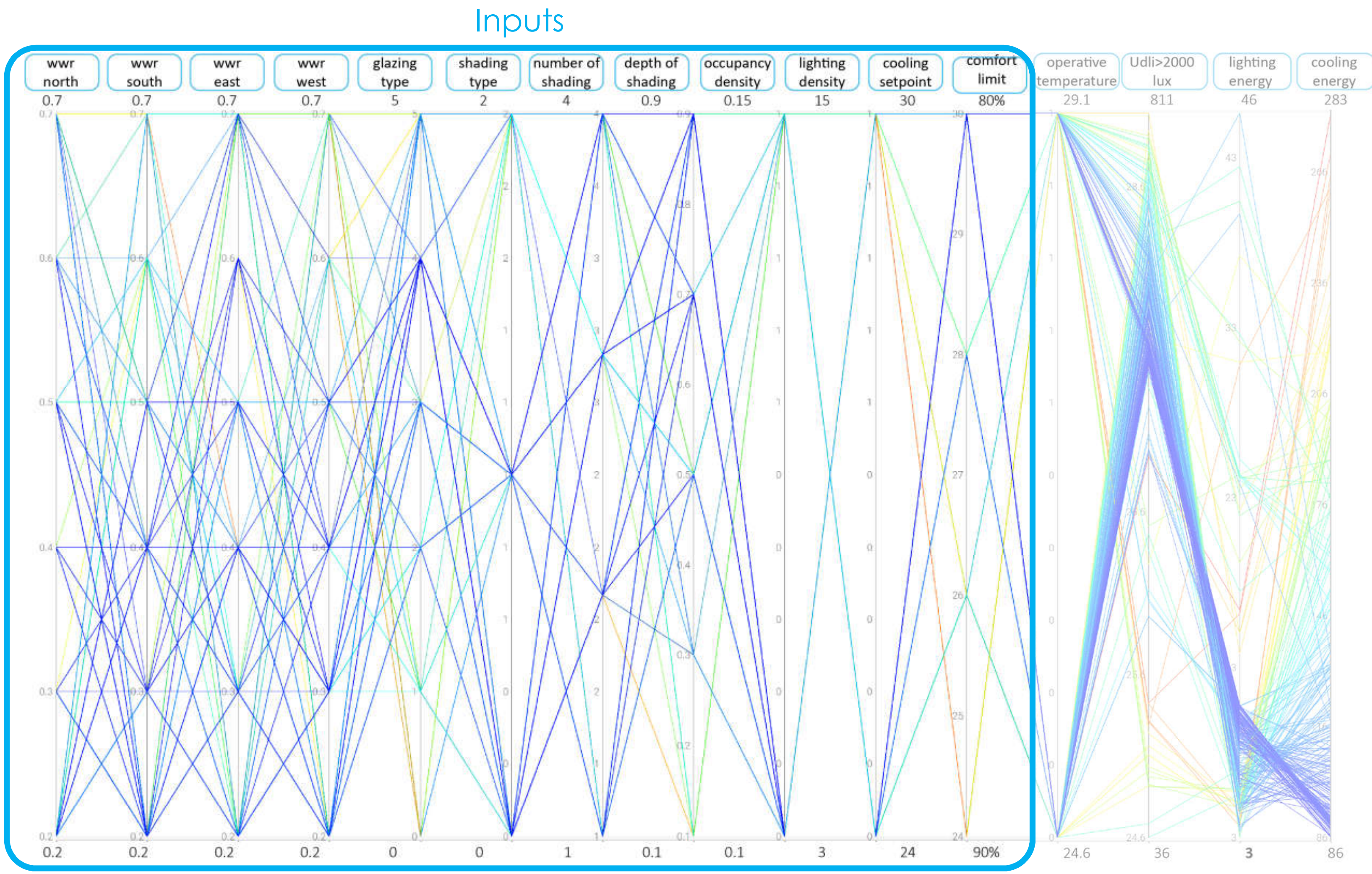
Selection of the optimal design, after limiting the ranges of the less impactful variables



Results

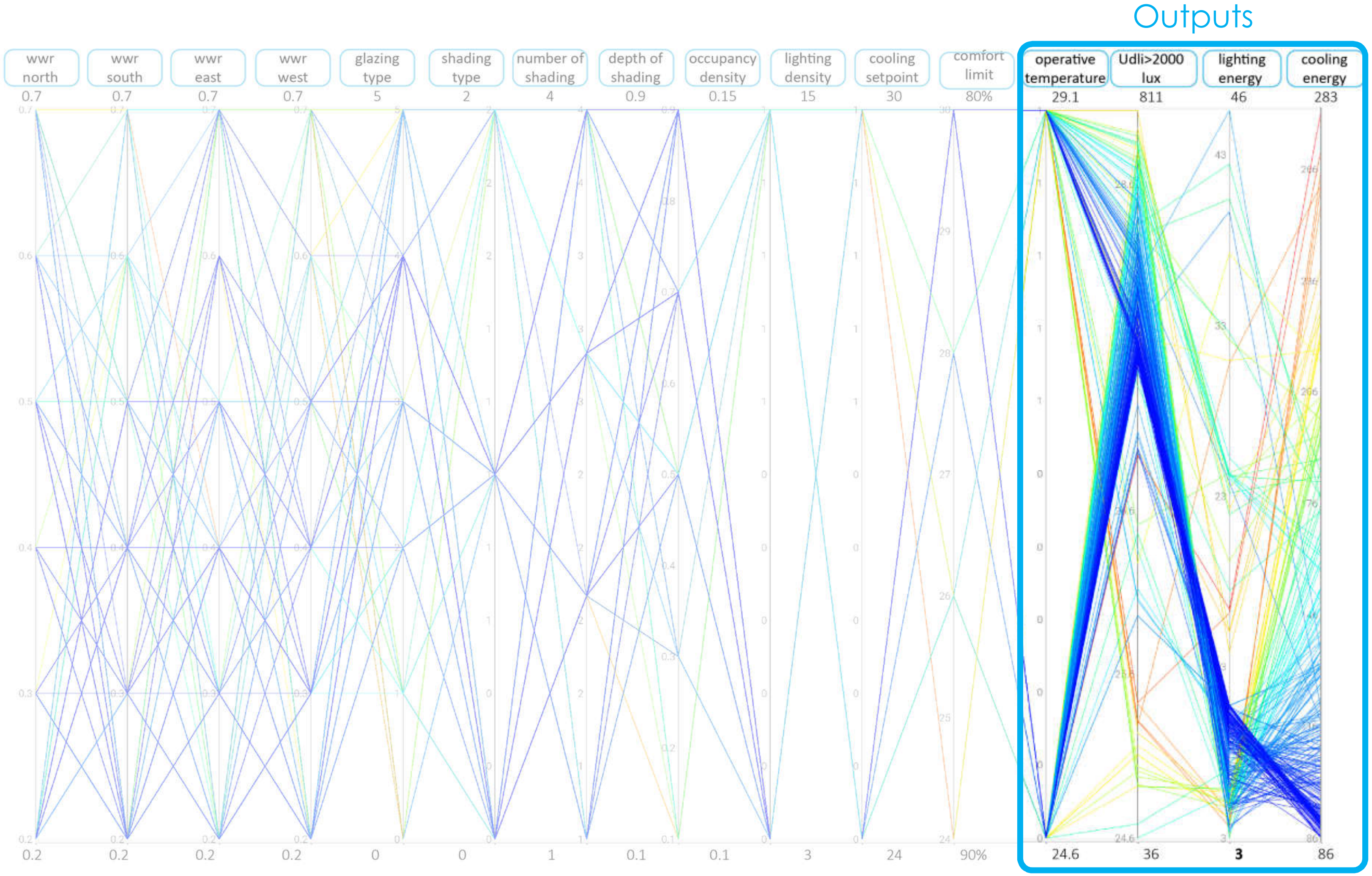

wwr north
0.7
0.2
wwr south
0.7
0.2
wwr east
0.7
0.2
wwr west
0.7
0.2
glazing type
5
0
shading type
2
0
number of shading
4
1
depth of shading
0.9
0.1
occupancy density
0.15
0.1
lighting density
15
3
cooling setpoint
30
24
comfort limit
80%
90%
operative temperature
29.1
24.6
Udli>2000 lux
811
36
lighting energy
46
3
cooling energy
283
86

Results



Inputs
wwr north
0.7
0.2
wwr south
0.7
0.2
wwr east
0.7
0.2
wwr west
0.7
0.2
glazing type
5
0
shading type
2
0
number of shading
4
1
depth of shading
0.9
0.1
occupancy density
0.15
0.1
lighting density
15
3
cooling setpoint
30
24
comfort limit
80%
90%
operative temperature
29.1
24.6
Udli>2000 lux
811
36
lighting energy
46
3
cooling energy
283
86

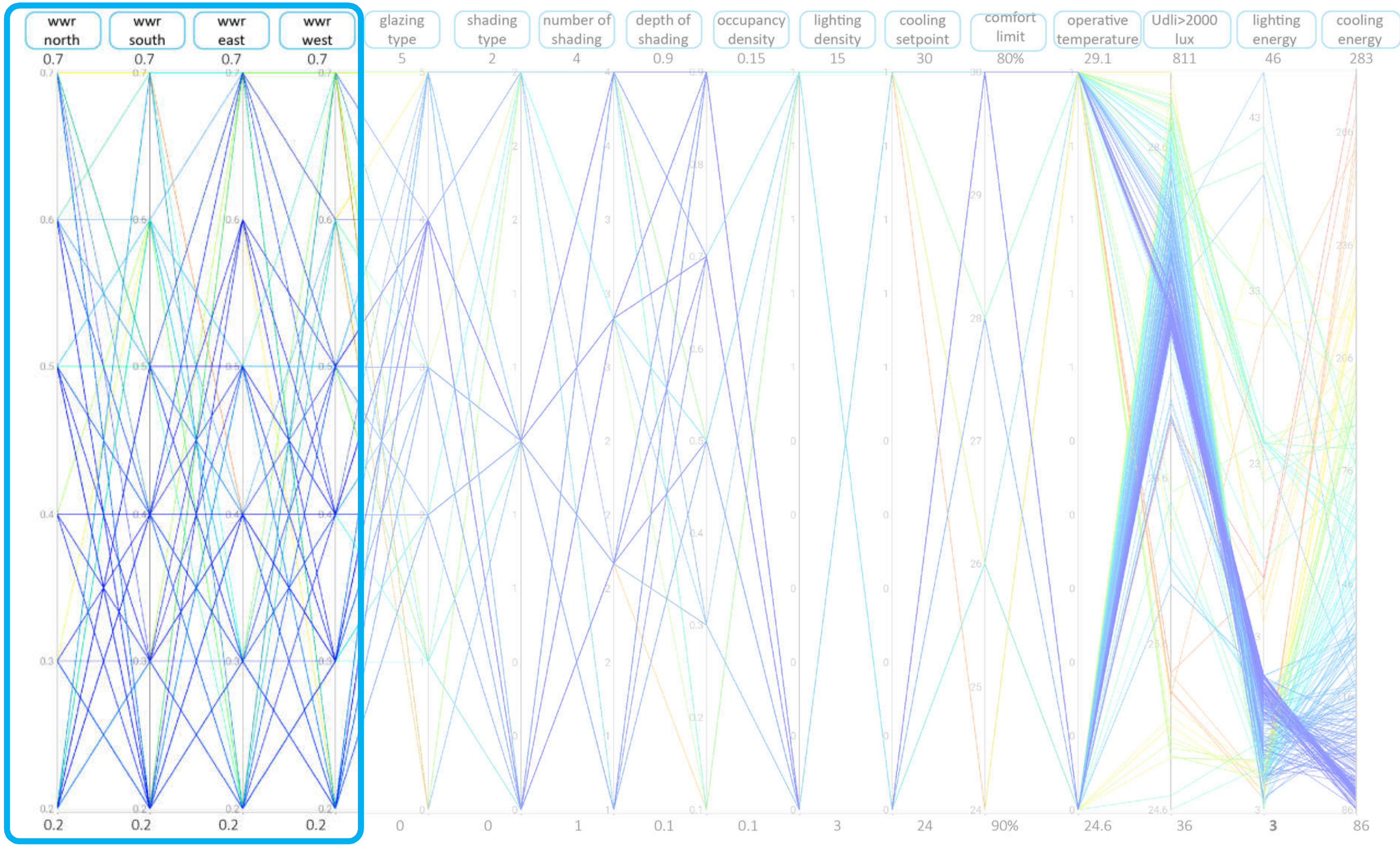
Results



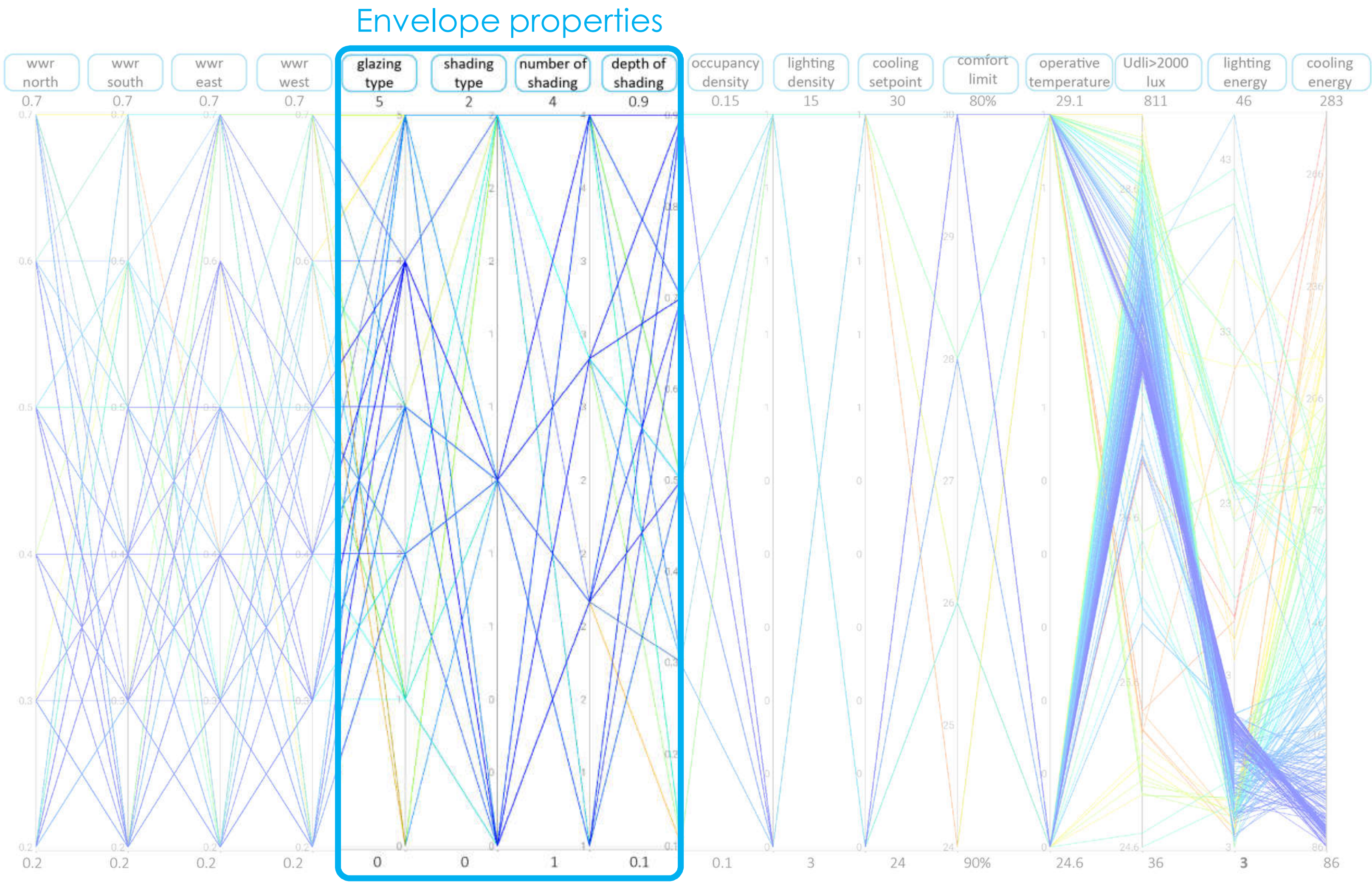
Outputs
wwr north
0.7
0.2
wwr south
0.7
0.2
wwr east
0.7
0.2
wwr west
0.7
0.2
glazing type
5
0
shading type
2
0
number of shading
4
1
depth of shading
0.9
0.1
occupancy density
0.15
0.1
lighting density
15
3
cooling setpoint
30
24
comfort limit
80%
90%
operative temperature
29.1
24.6
Udli>2000 lux
811
36
lighting energy
46
3
cooling energy
283
86

Results

Window-to-wall ratio



Results


Envelope properties
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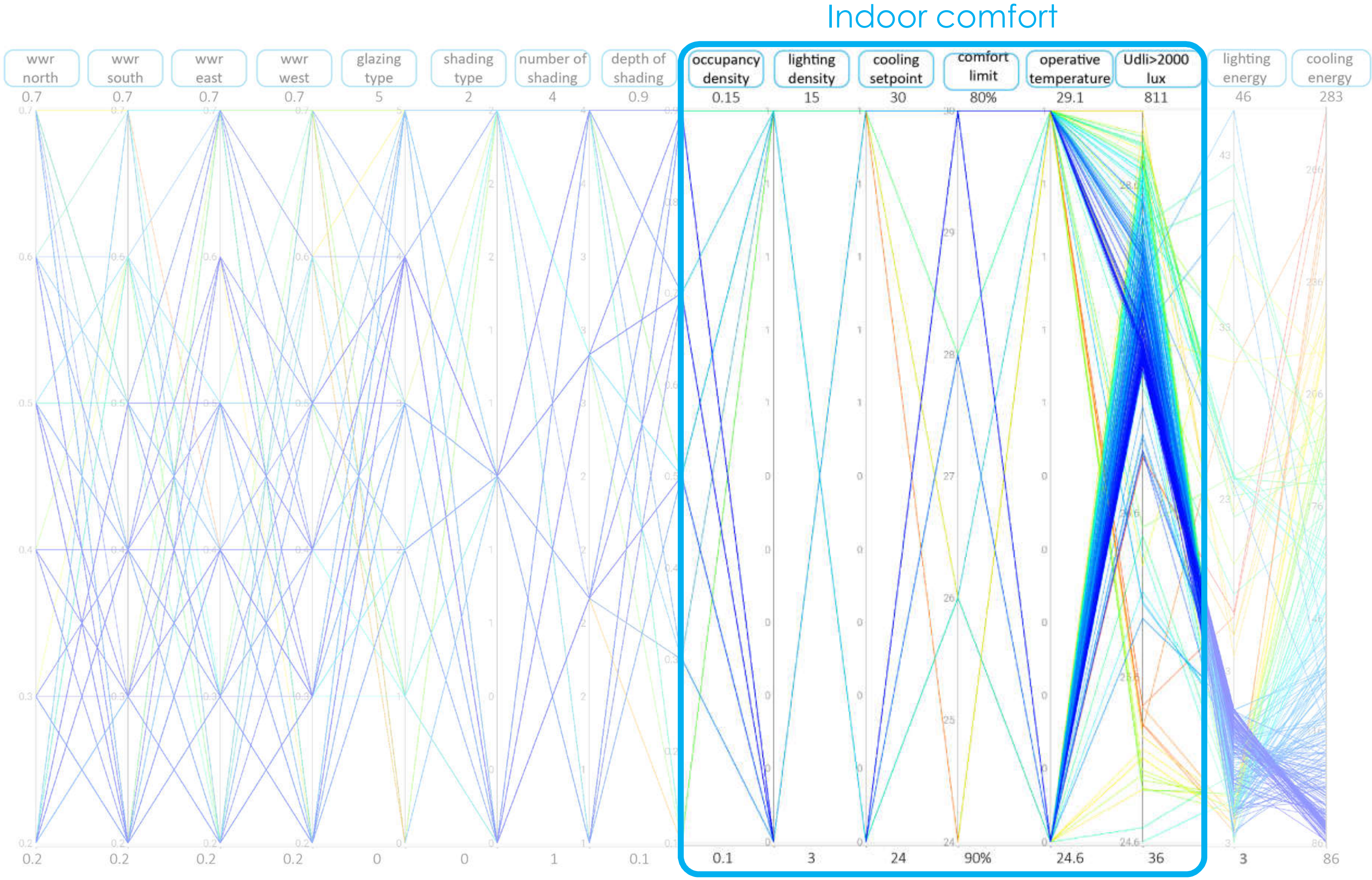
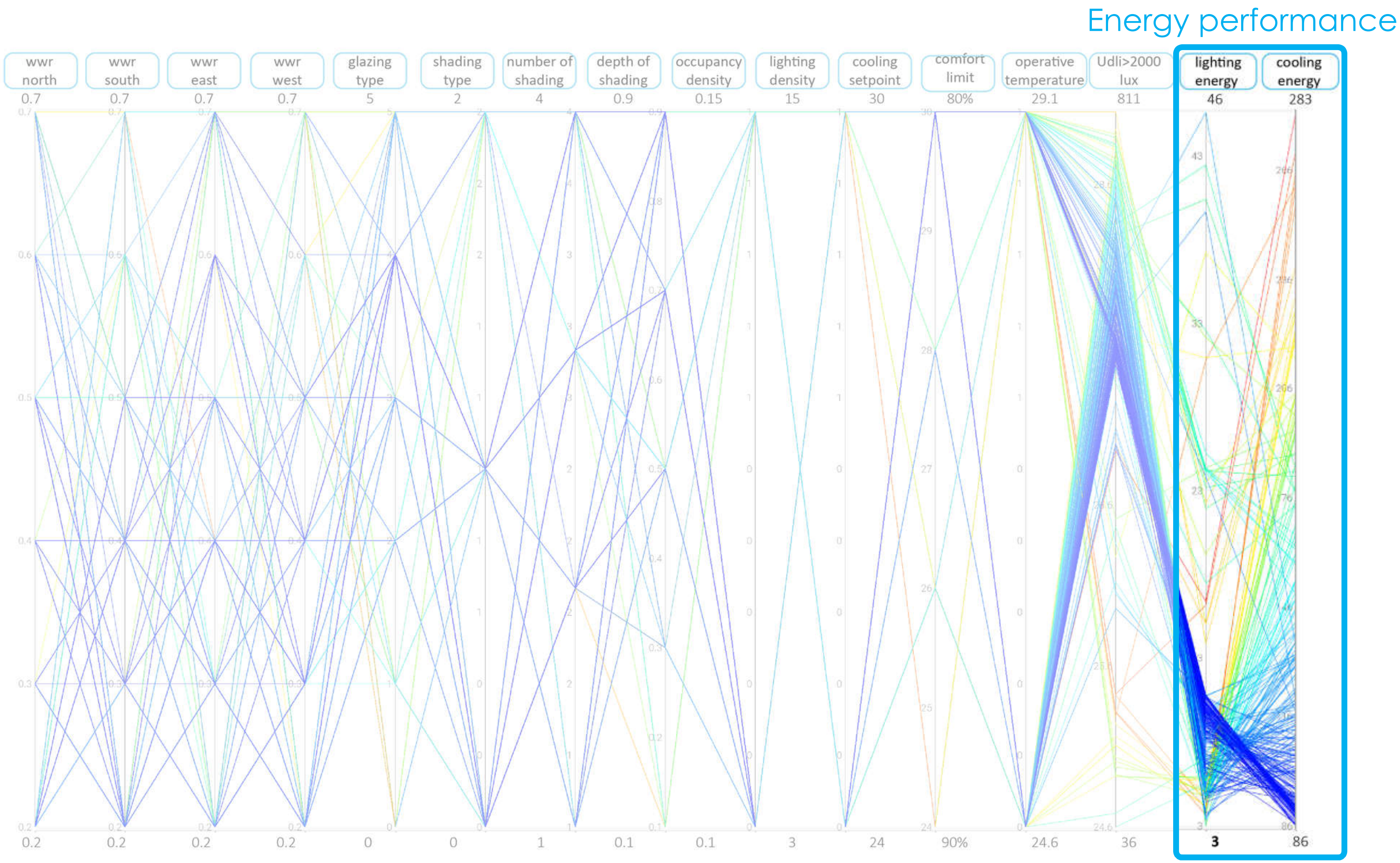
wwr south 0.7
wwr east 0.7
wwr west 0.7
glazing type 5
shading type 2
number of shading 4
depth of shading 0.9
occupancy density 0.15
lighting density 15
cooling setpoint 30
comfort limit 80%
operative temperature 29.1
Udli>2000 lux 811
lighting energy 46
cooling energy 283
0.2
0.2
0.2
0.2
0
0
1
0.1
0.1
3
24
90%
24.6
36
3
86

Results



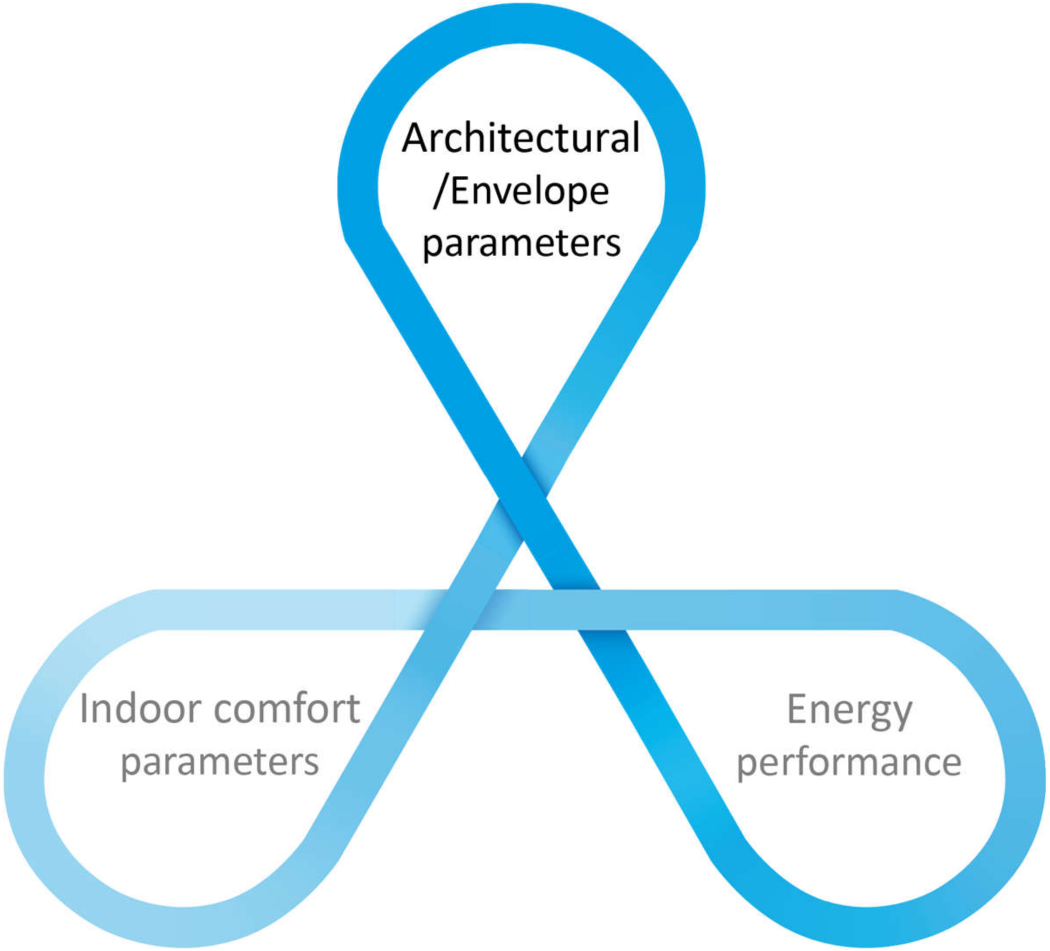
Indoor comfort
wwr north
0.7
0.2
wwr south
0.7
0.2
wwr east
0.7
0.2
wwr west
0.7
0.2
glazing type
5
0
shading type
2
0
number of shading
4
1
depth of shading
0.9
0.1
occupancy density
0.15
0.1
lighting density
15
3
cooling setpoint
30
24
comfort limit
80%
90%
operative temperature
29.1
24.6
Udli>2000 lux
811
36
lighting energy
46
3
cooling energy
283
86

Results

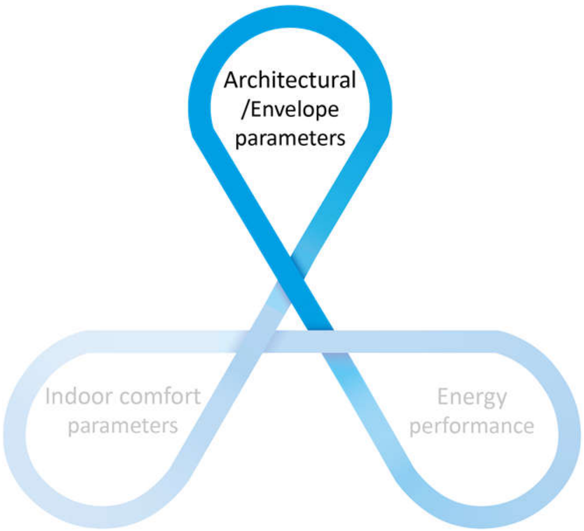


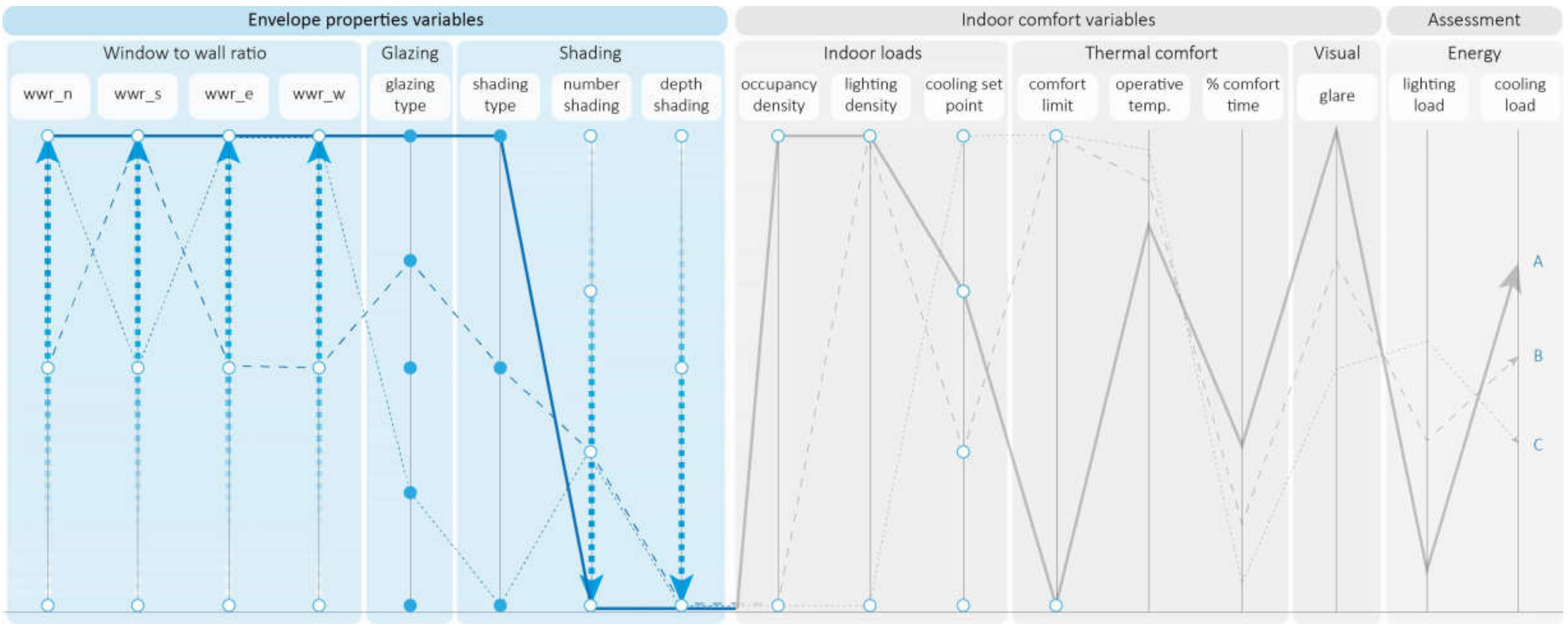
Energy performance
wwr north
0.7
0.2
wwr south
0.7
0.2
wwr east
0.7
0.2
wwr west
0.7
0.2
glazing type
5
0
shading type
2
0
number of shading
4
1
depth of shading
0.9
0.1
occupancy density
0.15
0.1
lighting density
15
3
cooling setpoint
30
24
comfort limit
80%
90%
operative temperature
29.1
24.6
Udli>2000 lux
811
36
lighting energy
46
3
cooling energy
283
86

Design selection

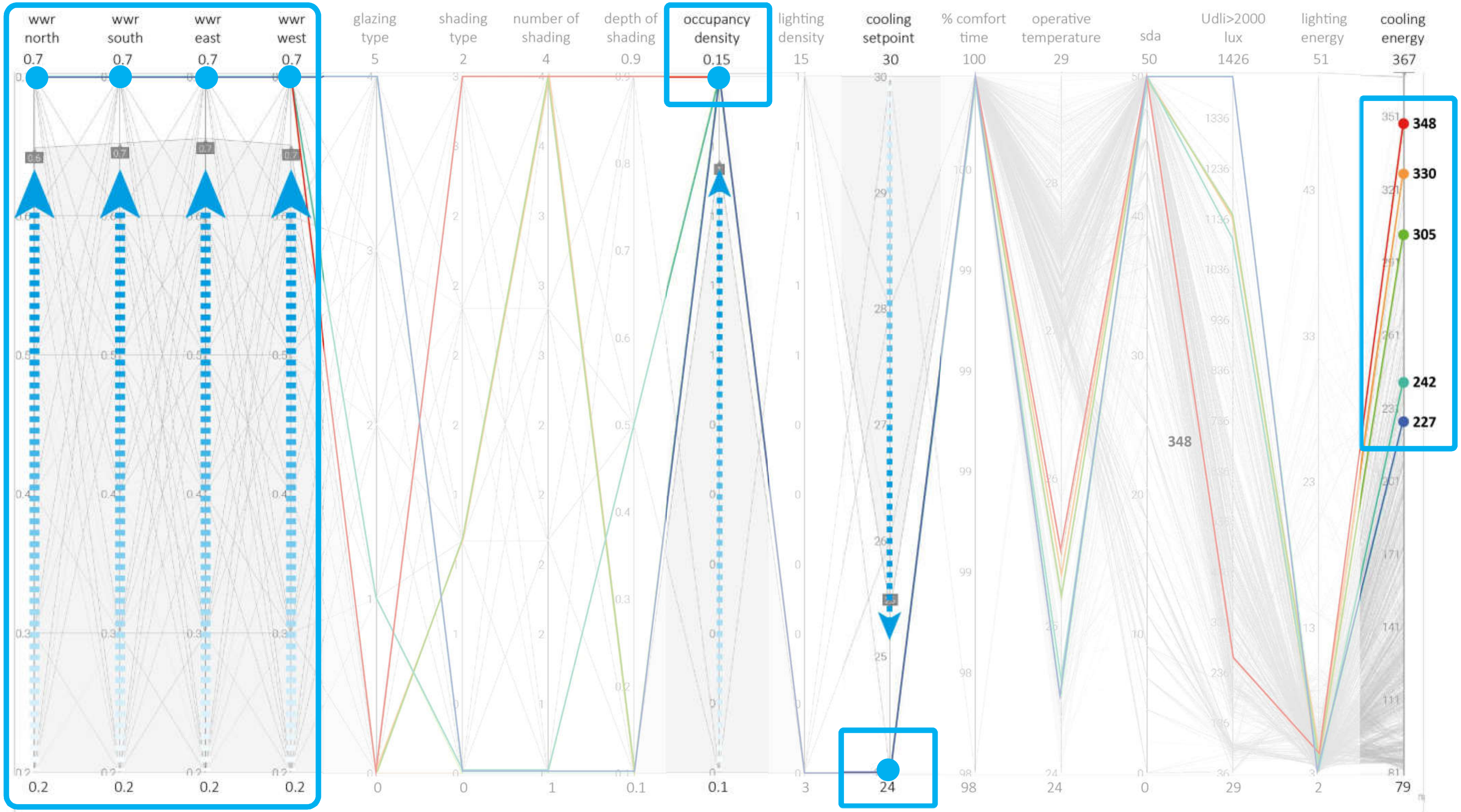


Design selection: fully high glazed facade

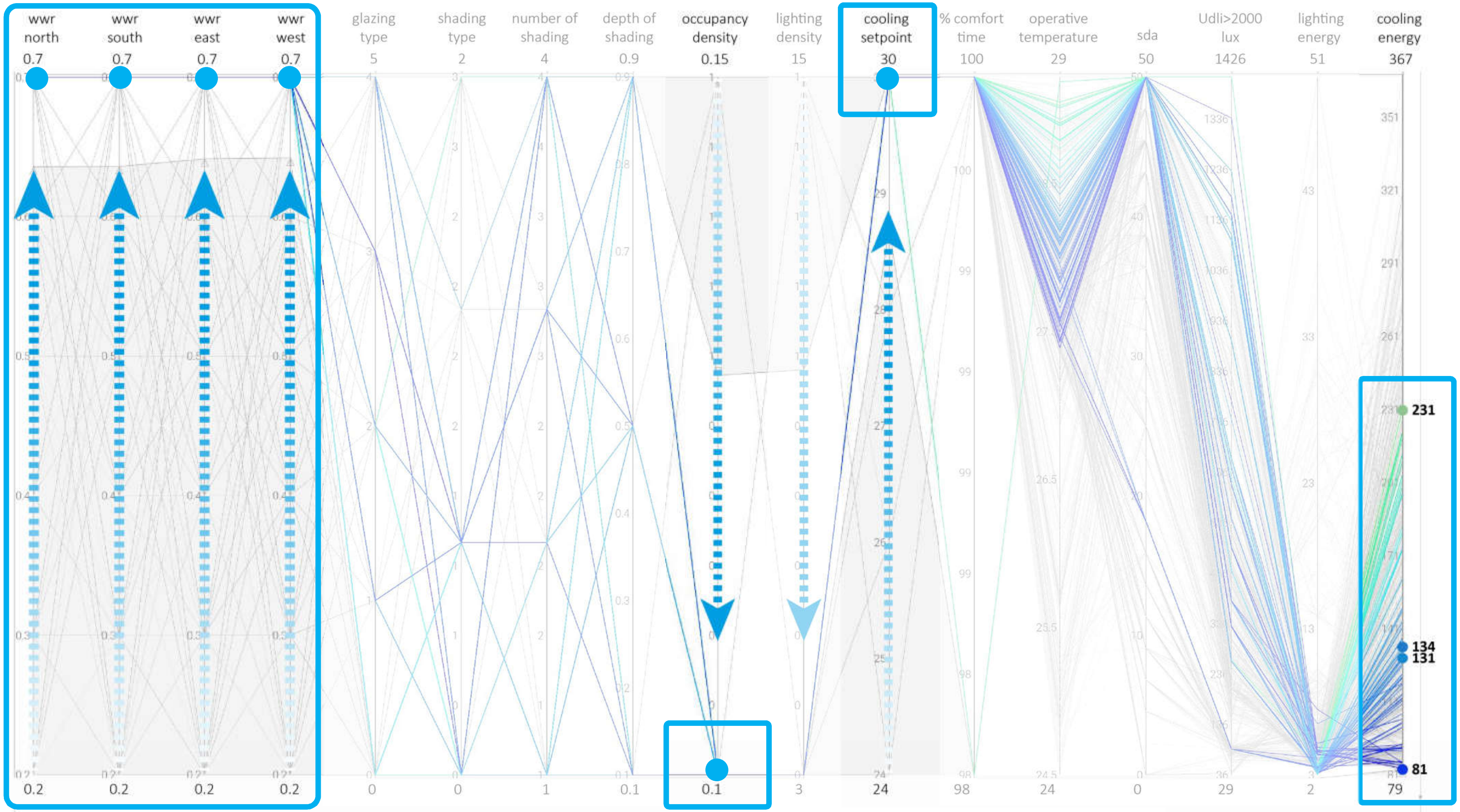




Design selection: fully high glazed facade

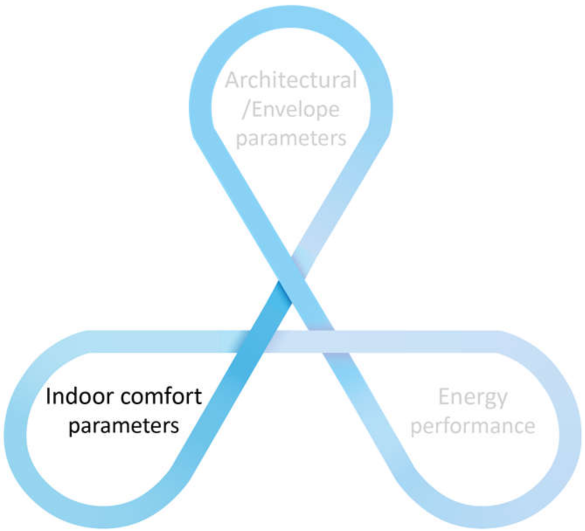


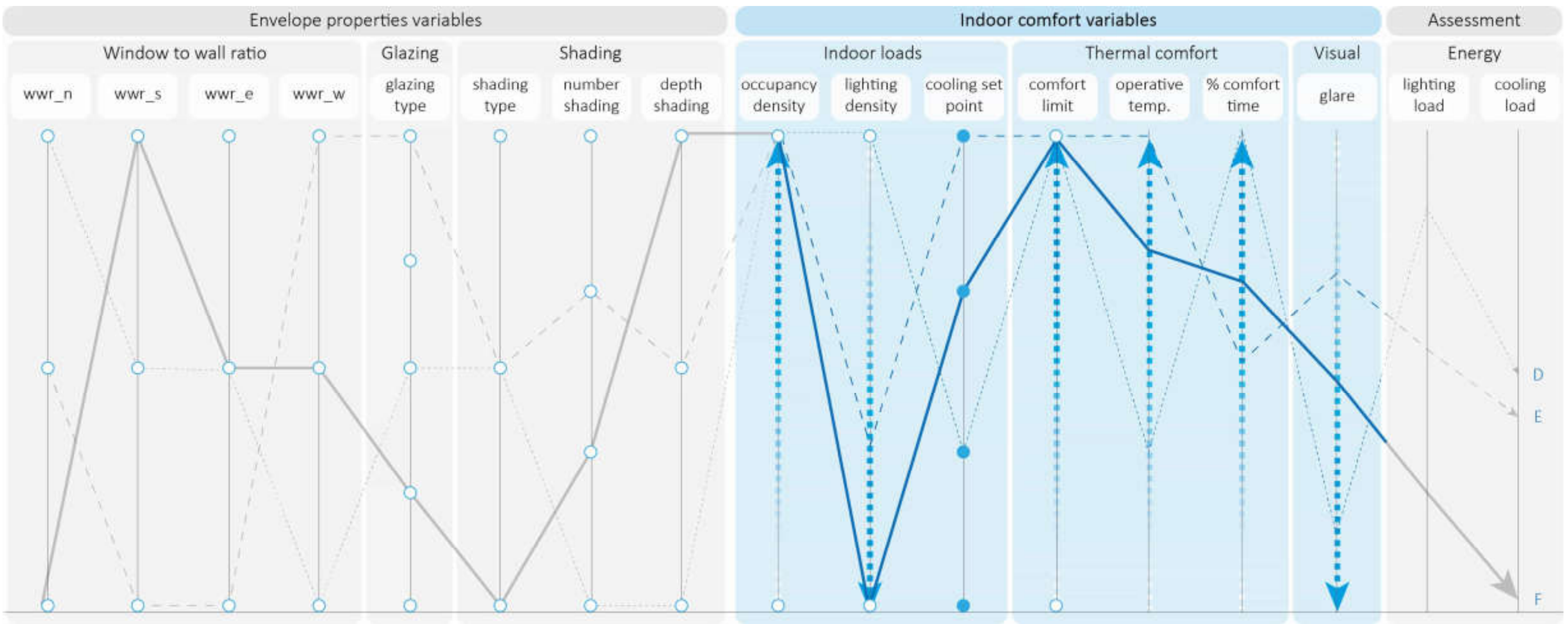
Design selection: fully high glazed facade



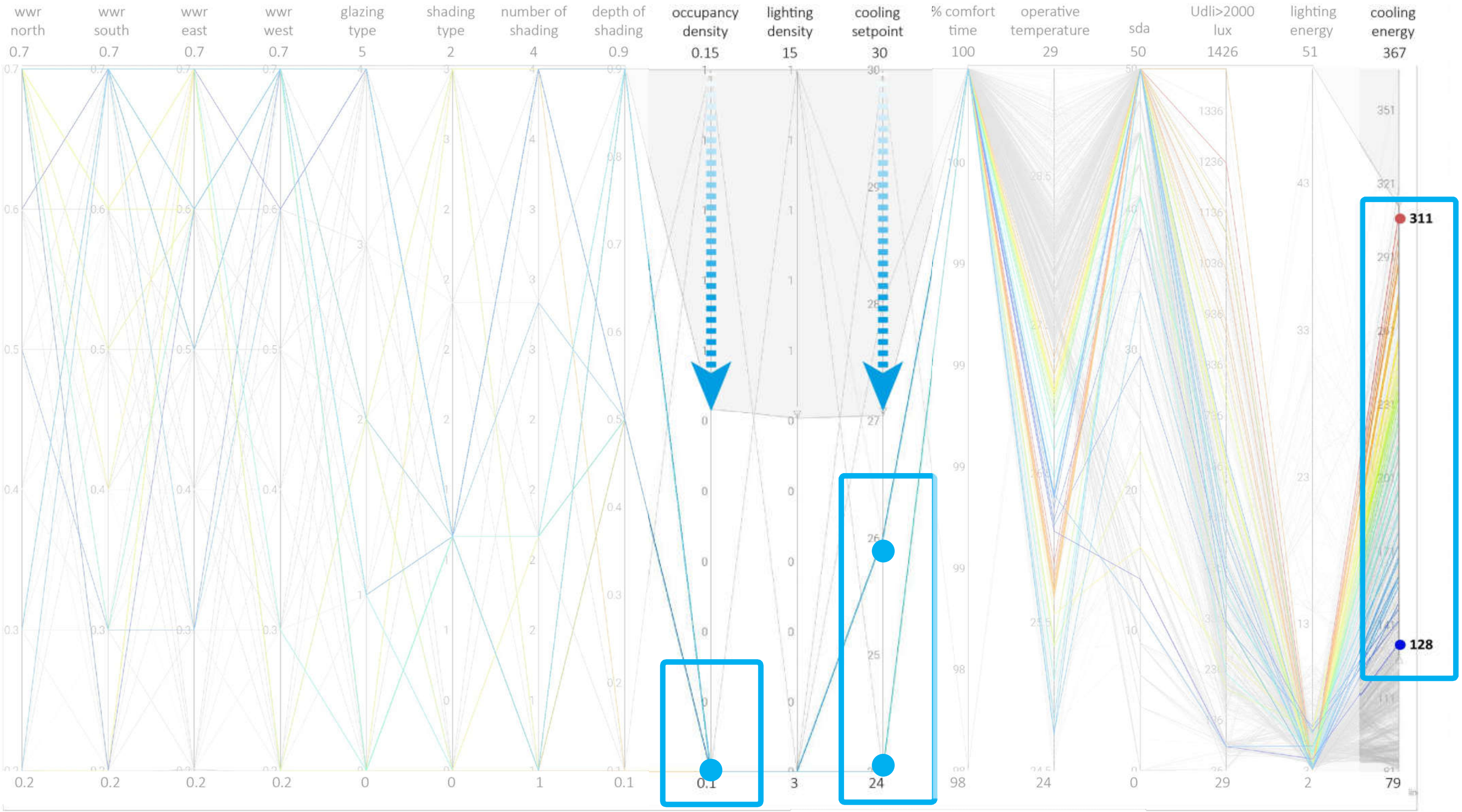
Design selection: fully high glazed facade

Design selection: Indoor comfort parameters

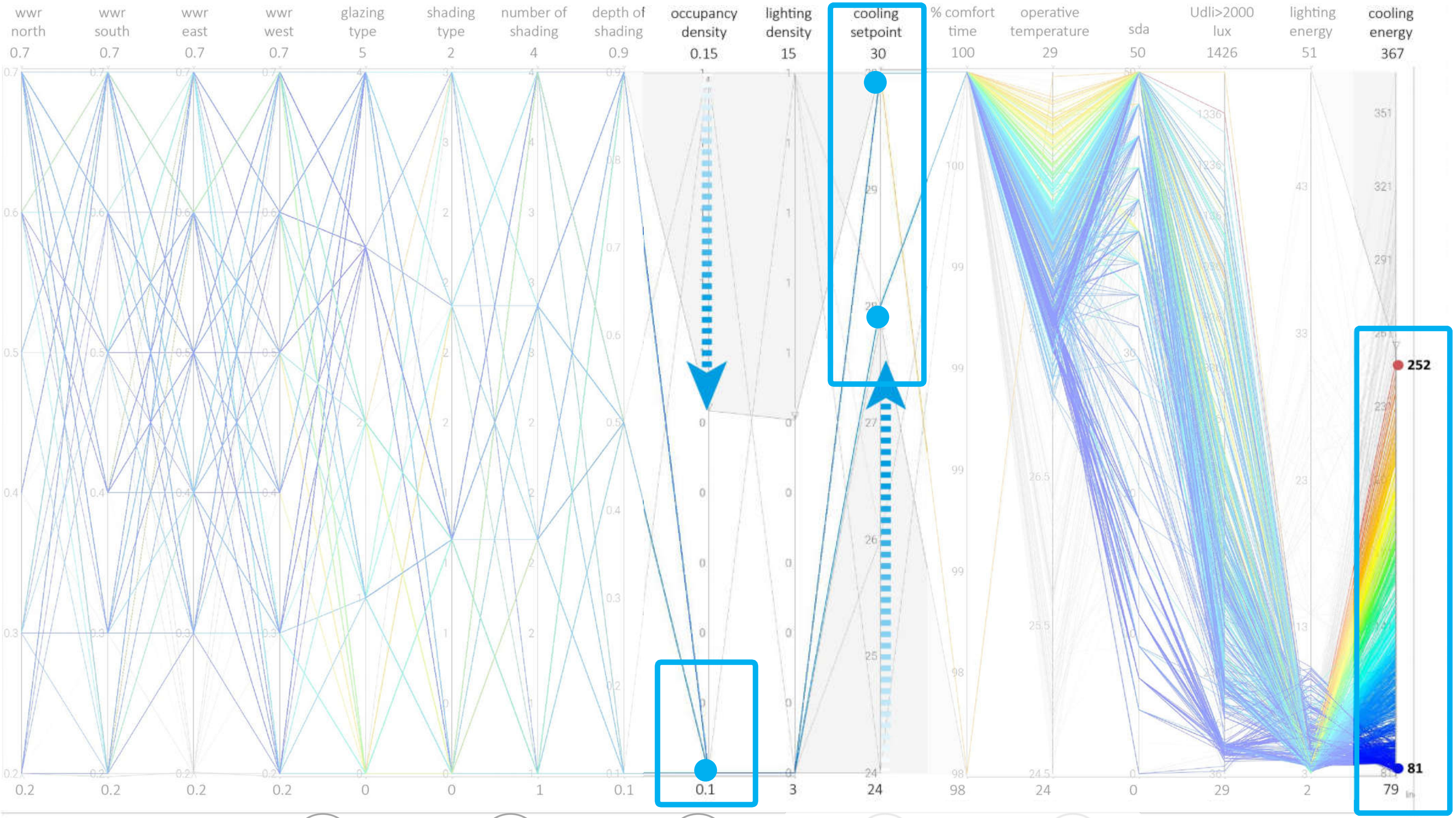




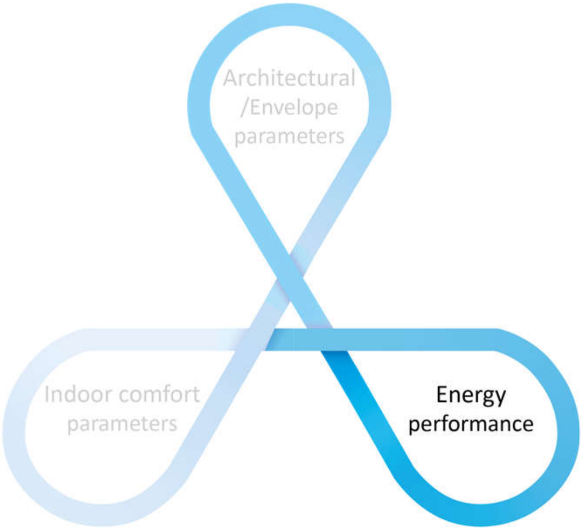
Design selection: Indoor comfort parameters

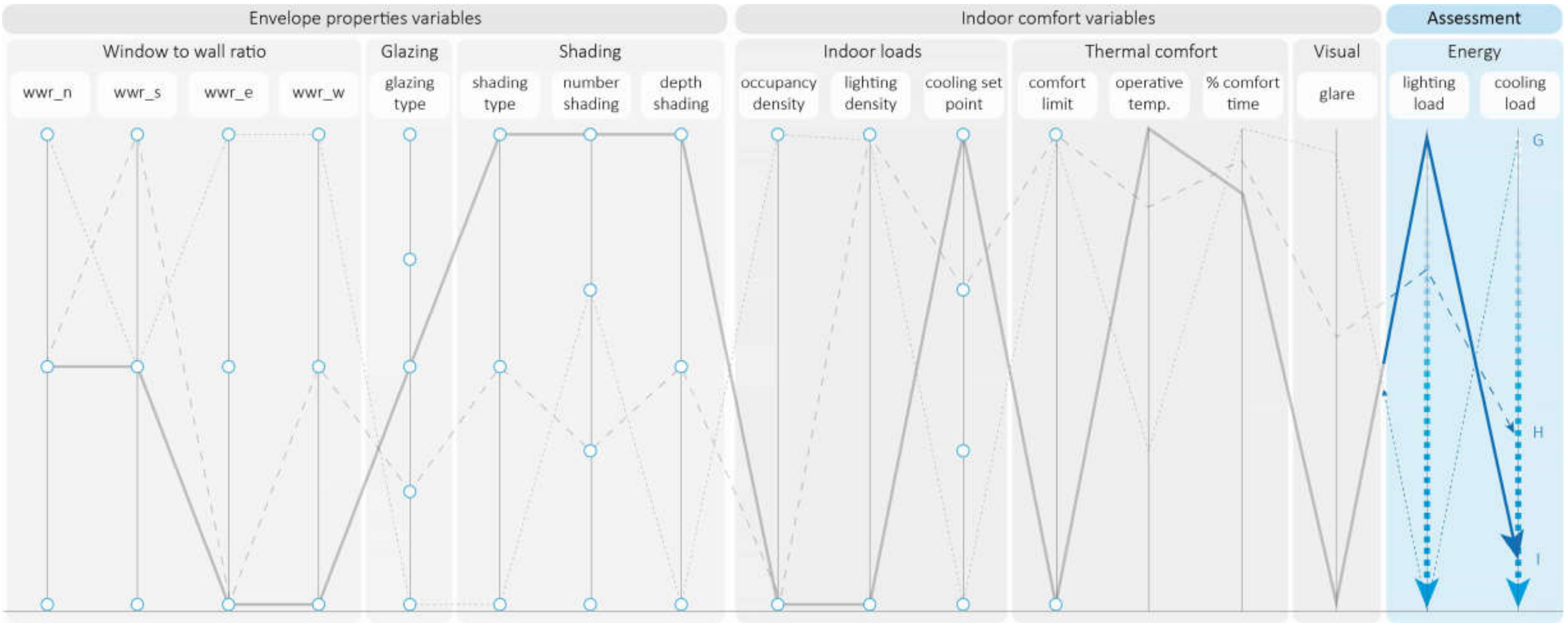


Design selection: Indoor comfort parameters

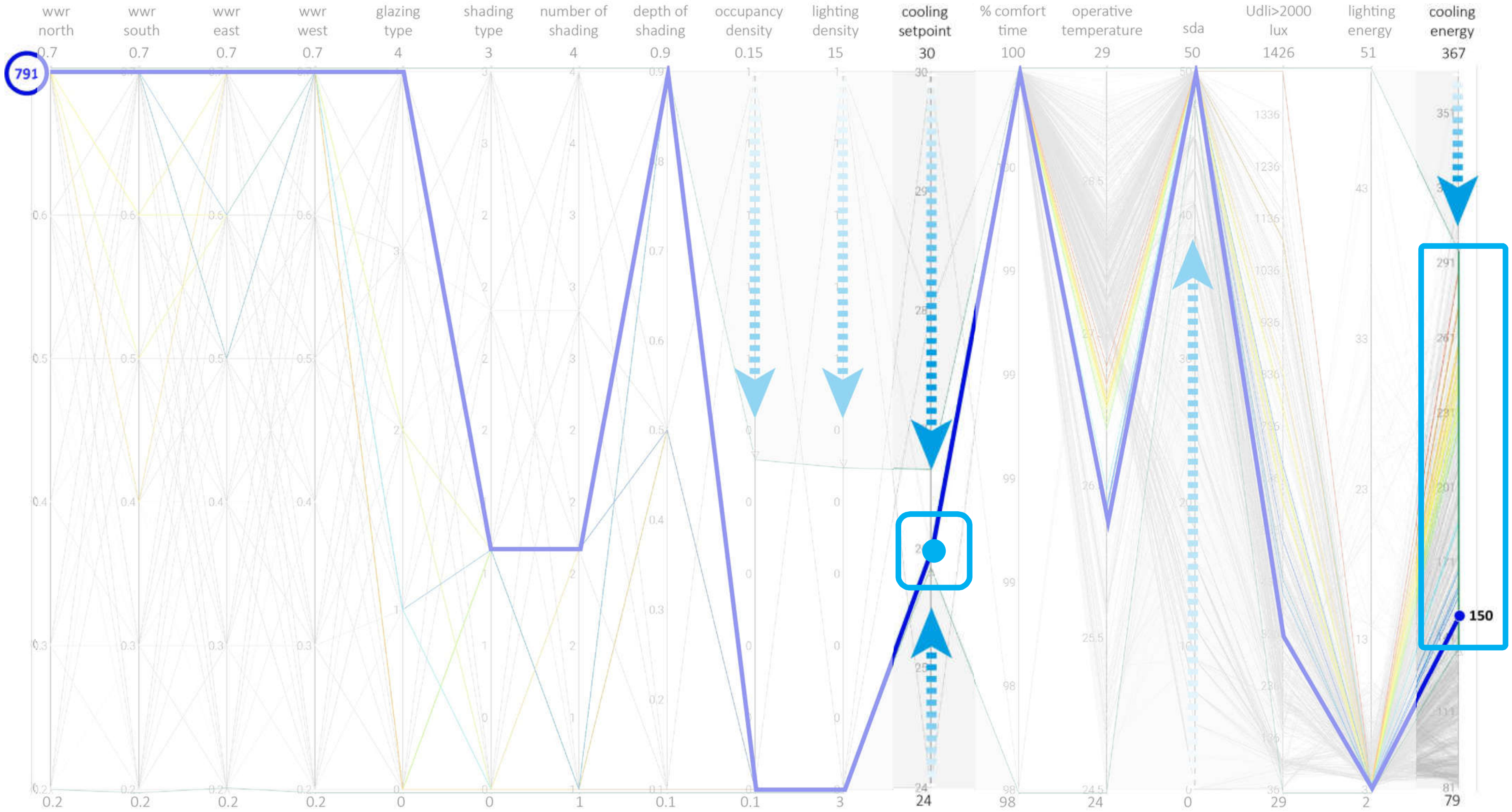


Design selection: Energy performance driven design

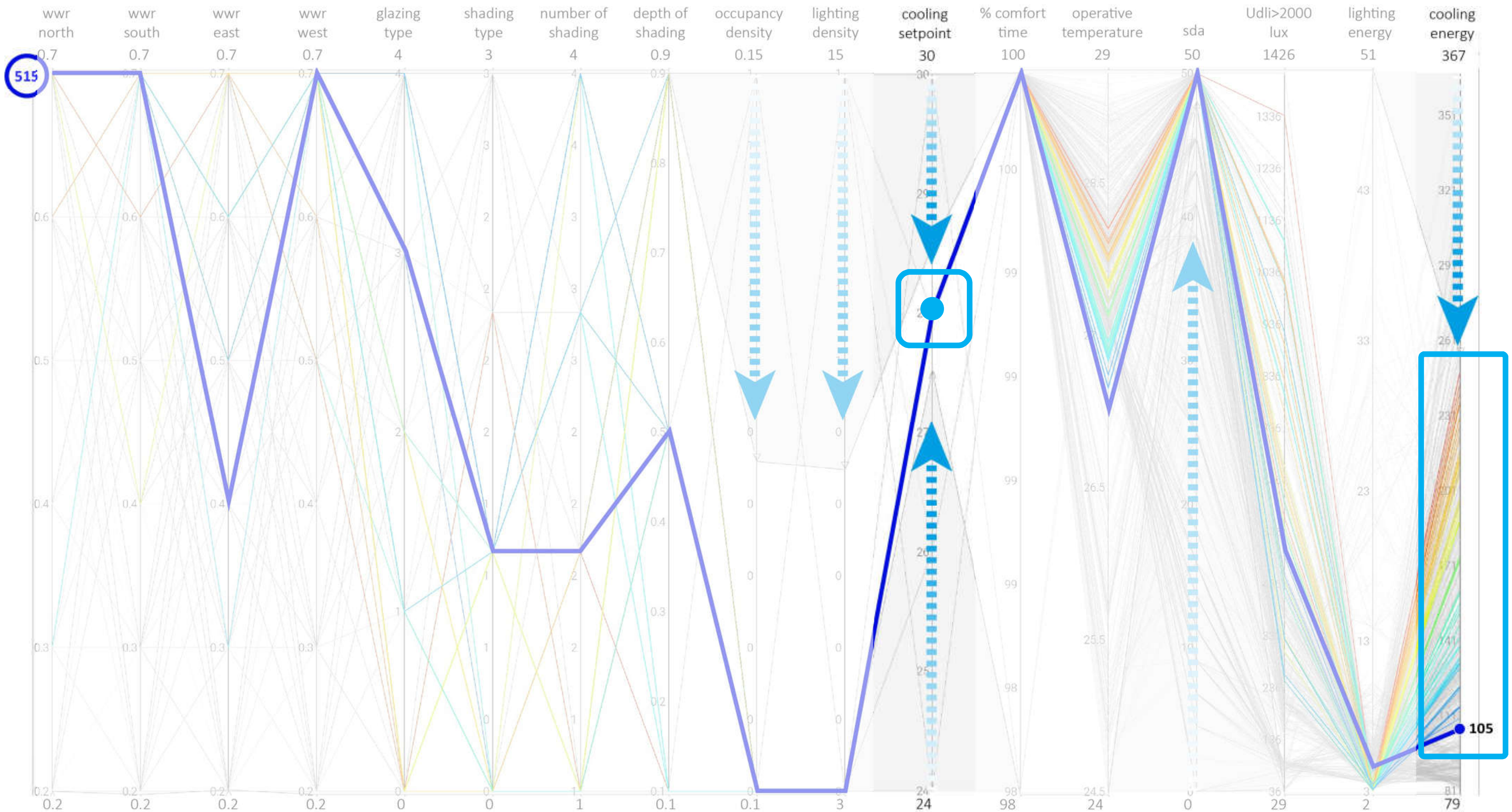




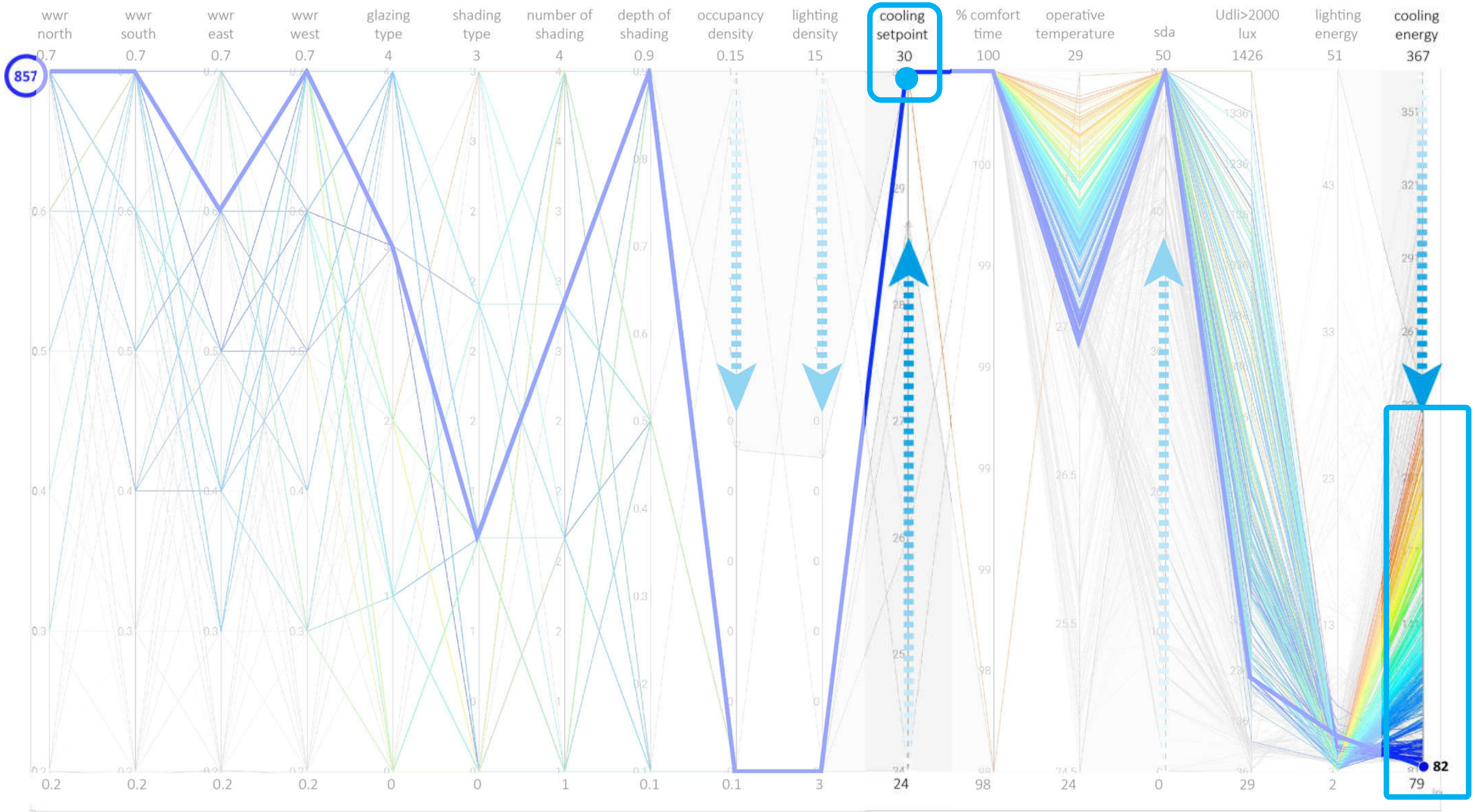
Design selection: Energy performance driven design



Design selection: Energy performance driven design



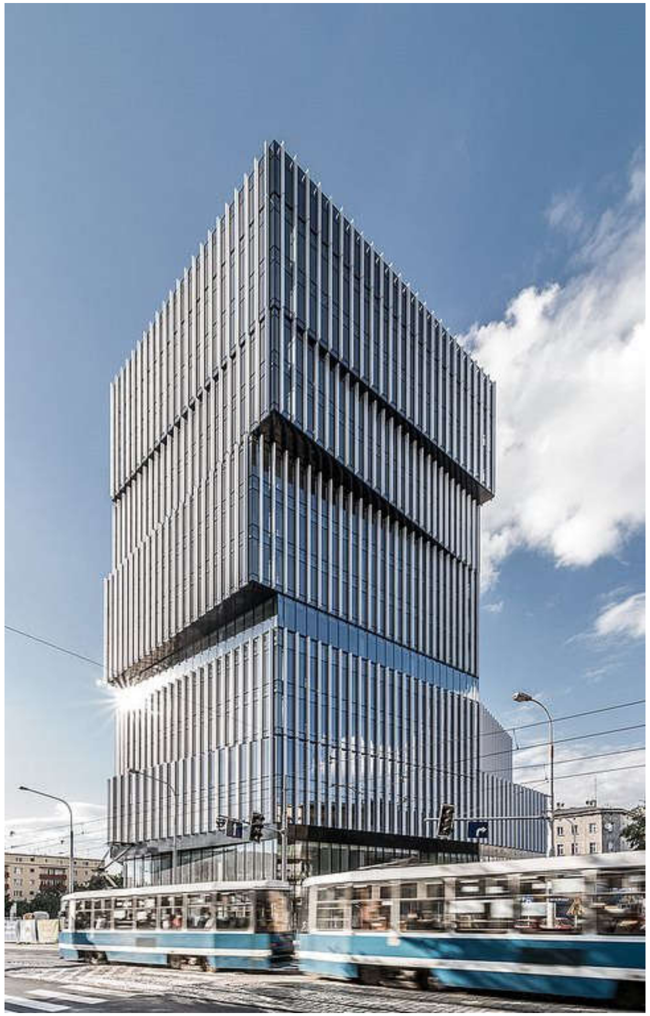
Design selection: Energy performance driven design

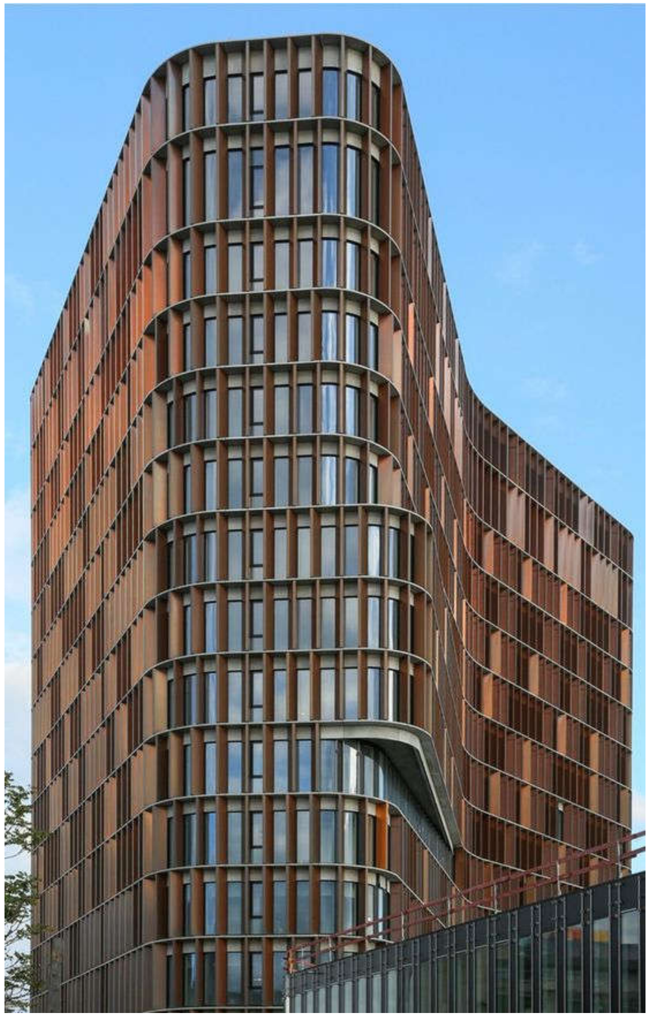


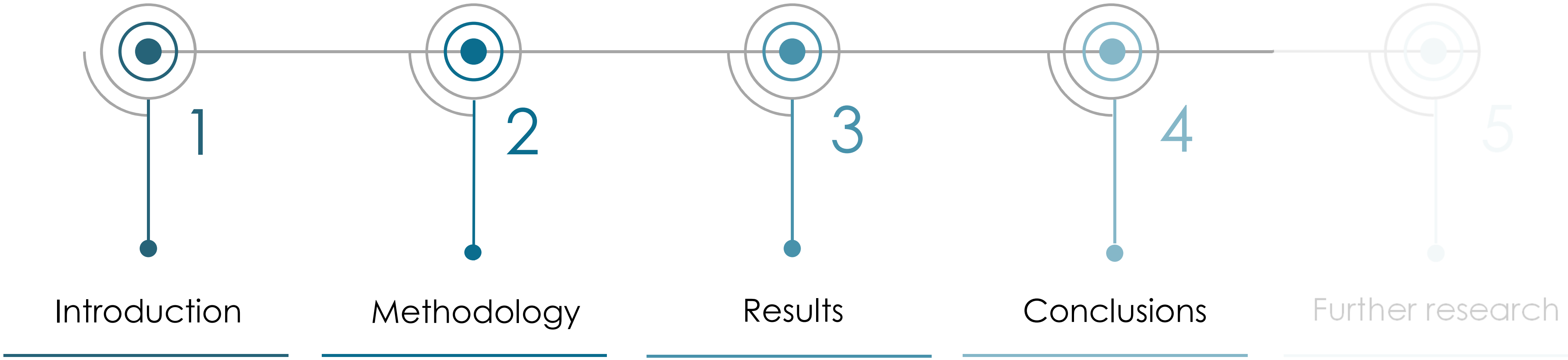
Design selection: Energy performance driven design

Design	wwr north	wwr south	wwr east	wwr west	glazing type	shading type	n° louvres	depth	occupancy density	lighting density	cooling set point	cooling energy
791	70%	70%	70%	70%	4	horizontal	2	0.9	0.1	3	26	150
515	70%	70%	40%	70%	3	horizontal	2	0.5	0.1	3	28	105
857	70%	70%	60%	70%	3	horizontal	3	0.9	0.1	3	30	82

Reference projects: Energy performance driven design



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Introduction
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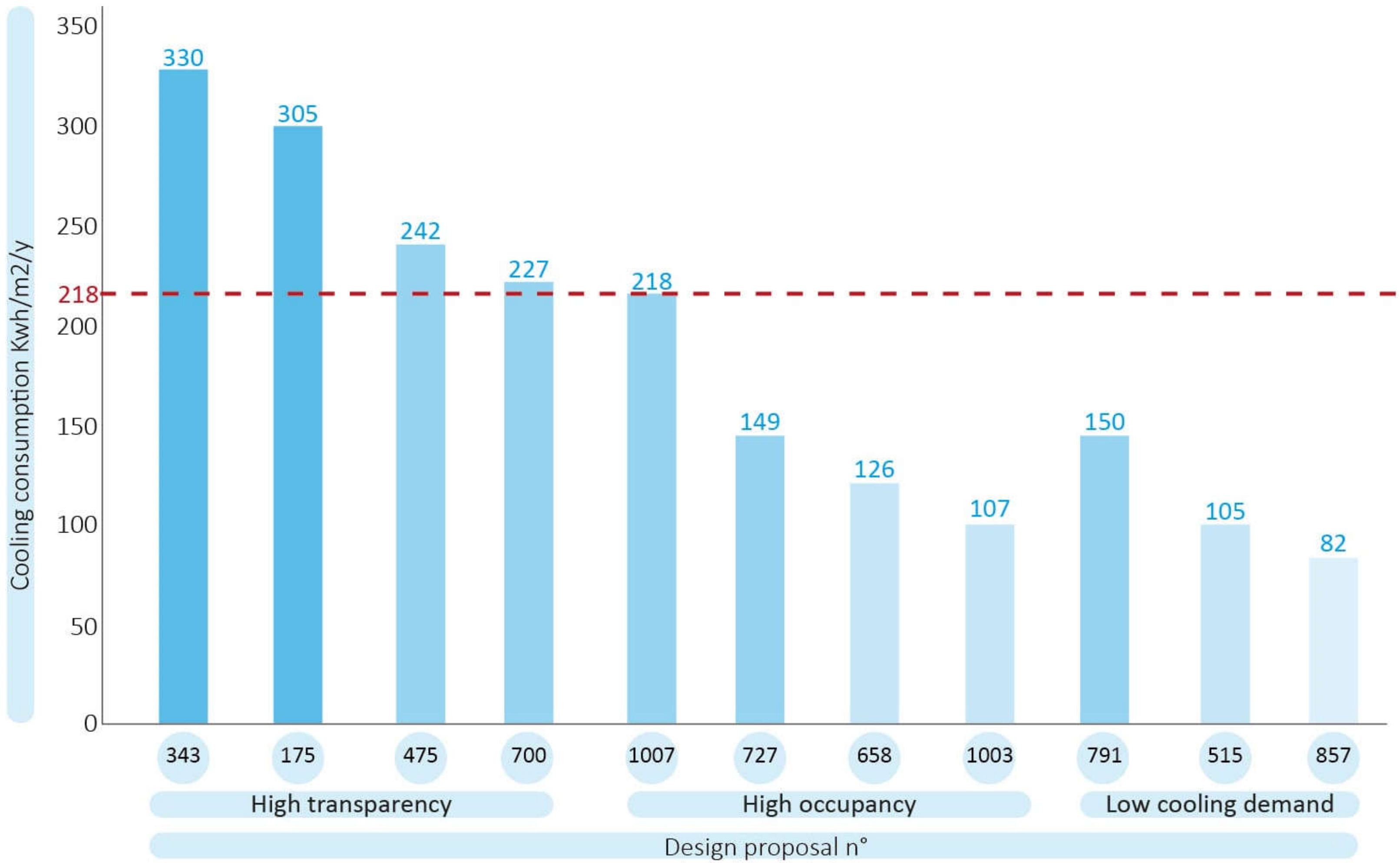
Conclusions

Design goal	Constants	Design n°	Cooling energy (kWh/m2/y)	Energy reduction/increase (%)
High transparency	High wwr High occupancy density Low lighting density Low cooling set point	343	330	+57
		175	305	+45
		475	242	+15
		700	227	+8
High occupancy density	High occupancy density Low lighting density	1007	218	+4
		727	149	-29
		658	126	-40
		1003	107	-49
Low cooling demand	Low occupancy density Low lighting density	791	150	-29
		515	105	-50
		857	82	-61

Conclusions



Conclusions

Can a **passive** high rise building be the solution?

No. It is **not possible** to achieve a purely passive building.

But, it is possible to reduce the cooling demands up to **61%** with respect to the average EUI of an office building in Singapore

Conclusions

How can a **purely passive office building** be achieved in a **tropical climate** ensuring the indoor **thermal comfort**?

The window to wall ratio of **east** and **west facade** have an impact on the cooling demands.

The implementation of a **lower occupancy** and **lighting density** lead to lower cooling consumption.

The implementation of an **external shading** device **is needed**.
Also, the implementation of **cross ventilation** contributed to heat loss.

Finally, the application of **adaptive comfort** models can definitely help in the reduction of cooling demands. The percentage of acceptable time reached the total percentage even if the indoor operative temperature reached up to 28°C.

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Future recommendations

Further development can be done by adding other variables in the optimization phase, such as:

- Dynamic shading system
- Implementation of active system, such as solar panels
- Optimization of the setting of the HVAC system
- Take into account the relative humidity

Thank you!