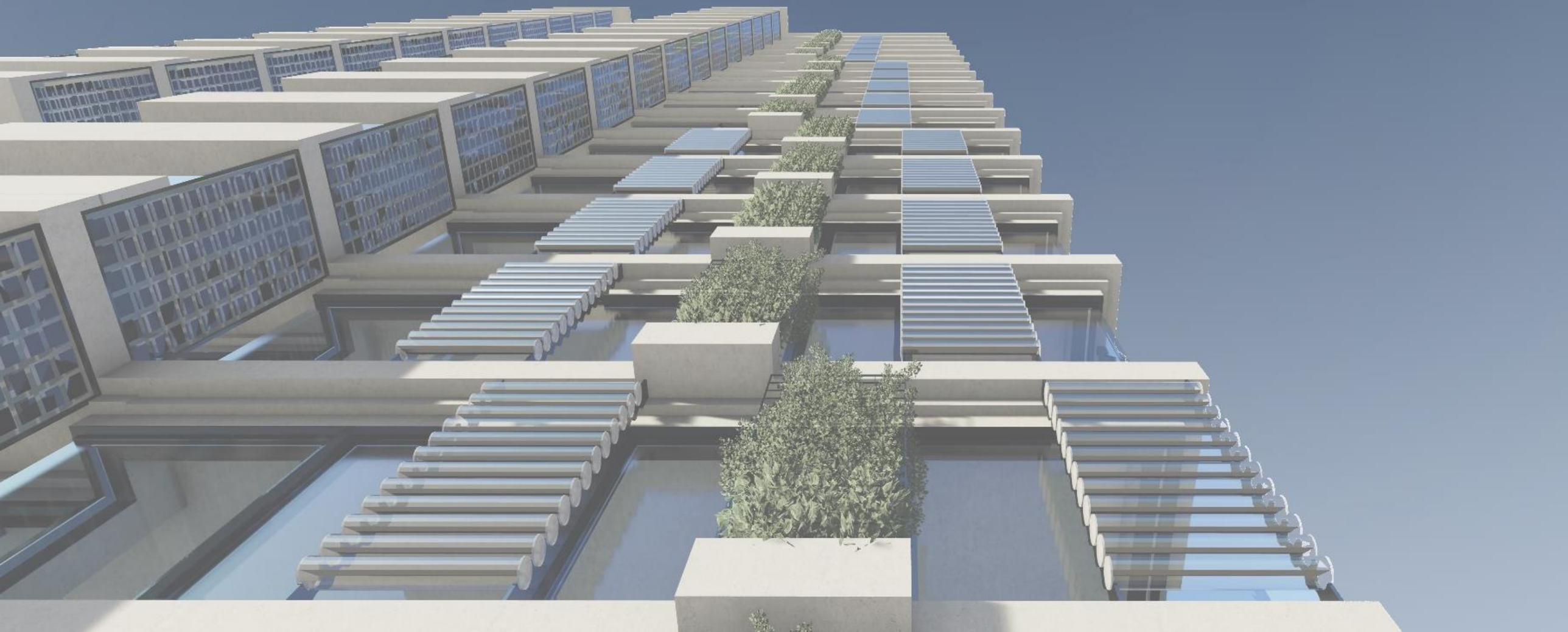
Optimized Façade Design towards Nearly Zero-Energy Residential High-Rises

Facade Design Assessment Criteria for Residential High-Rise Buildings in the Netherlands

2018/2019

Cristina Maria Mărginean

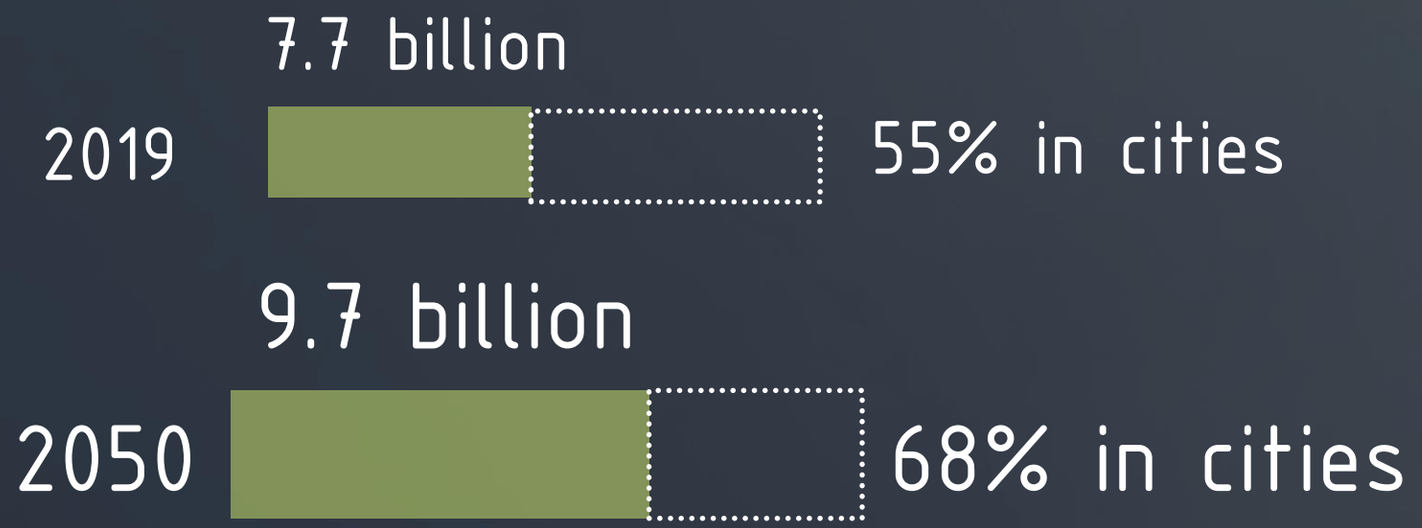


1 Framework

2 3 4 5 6

BACKGROUND

Human overpopulation gives rise to environmental problems...



35% of the global resources

40% of the total energy

12% of the world's drinkable water

40% of global carbon emissions

80-90%

Operational Energy

10-20%

Embodied Energy

2020

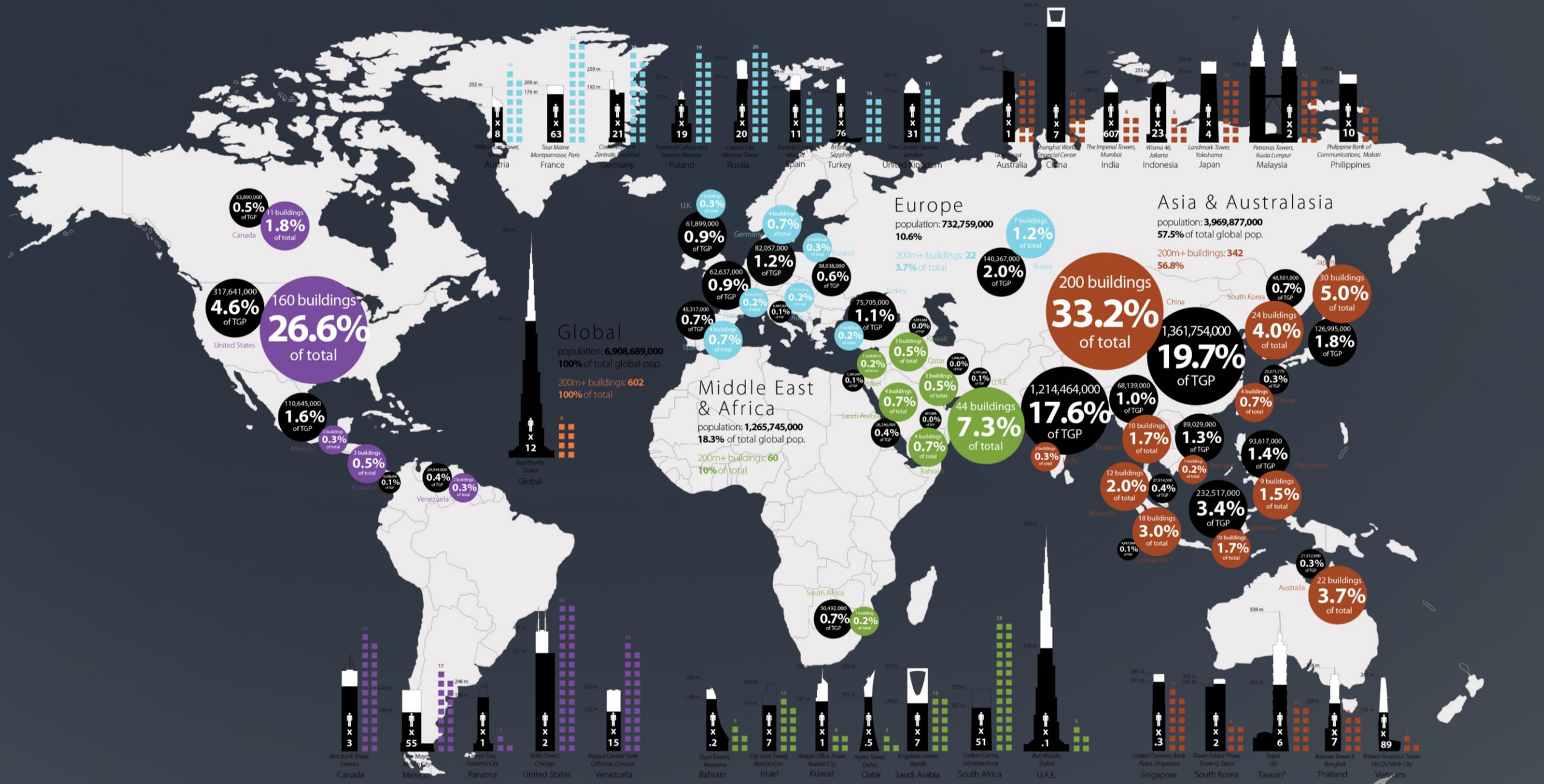
New energy regulations: BENG

Bijna Energie Neutrale Gebouwen

		RESIDENTIAL	OFFICE	HEALTHCARE	EDUCATION
BENG 1 Energy Need kWh/m²		< 70	70	180	100
BENG 2 Primary Fossil Energy Use kWh/m²		< 50	30	80	60
BENG 3 Share or Renewable Energy %		> 40	50	40	40

Concentrating people on smaller plots by building vertically...

...more sustainable?



Source: CTBUH, 2019 April 13

RESEARCH PROBLEM

UCL's Energy Institute:

high-rise buildings >20 stories are $2^{1/2}$ times more energy-intensive than low rise buildings

Godoy-Shimizu et al. , 2018

orientation, shape & facade the main influential parameters that determine the energy performance of a high-rise

Raji, Tenpierik, Dobbelsteen, 2017

orientation & shape usually limited by urban conditions

↓

facade design crucial!

RESEARCH QUESTION

'What is the impact of facade design on energy, daylight and thermal comfort to achieve a nearly zero-energy residential high-rise building in a temperate climate?'

- Which are the most influential facade parameters?
- Which is the best combination of parameters in terms of energy demand, energy production, daylight and thermal comfort?
- How much can the BENG requirements for residential buildings be met in high-rises through an optimized façade?
- Does a variation in façade with respect to height lead to better performance?

2 Case Study

1 3 4 5 6

TU Delft
Cristina Maria Mărginean

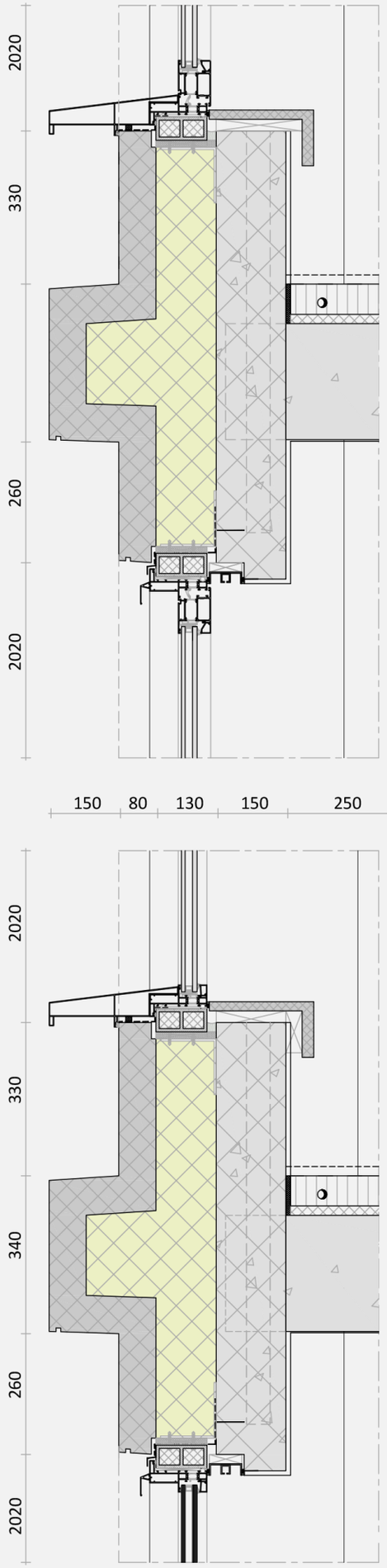
COOLTOREN
V8 Architects

2016-2020
Residential

150m high
50 levels
282 apartments

V8 Architects

TU Delft
Cristina Maria Mărginean



Current Facade

V8 Architects

Active Systems

Mech.Vent.

Heat Recovery 95%

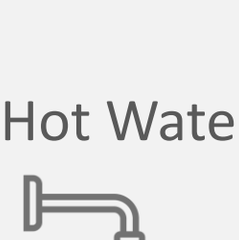
Hot Water

COP 3.95

Radiant Cooling

COP 15

Radiant Heating



COP 3.95

WKO (groundwater)

V8 Architects

1 2 3 4 5 6

3 Simulation Workflow

GEOMETRY

Rhinoceros

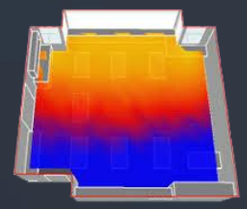
INPUT DATA

Honeybee

Ladybug

SIMULATIONS

DAYLIGHT



Daysim

Evalglare

ENERGY

Open Studio

THERMAL COMFORT

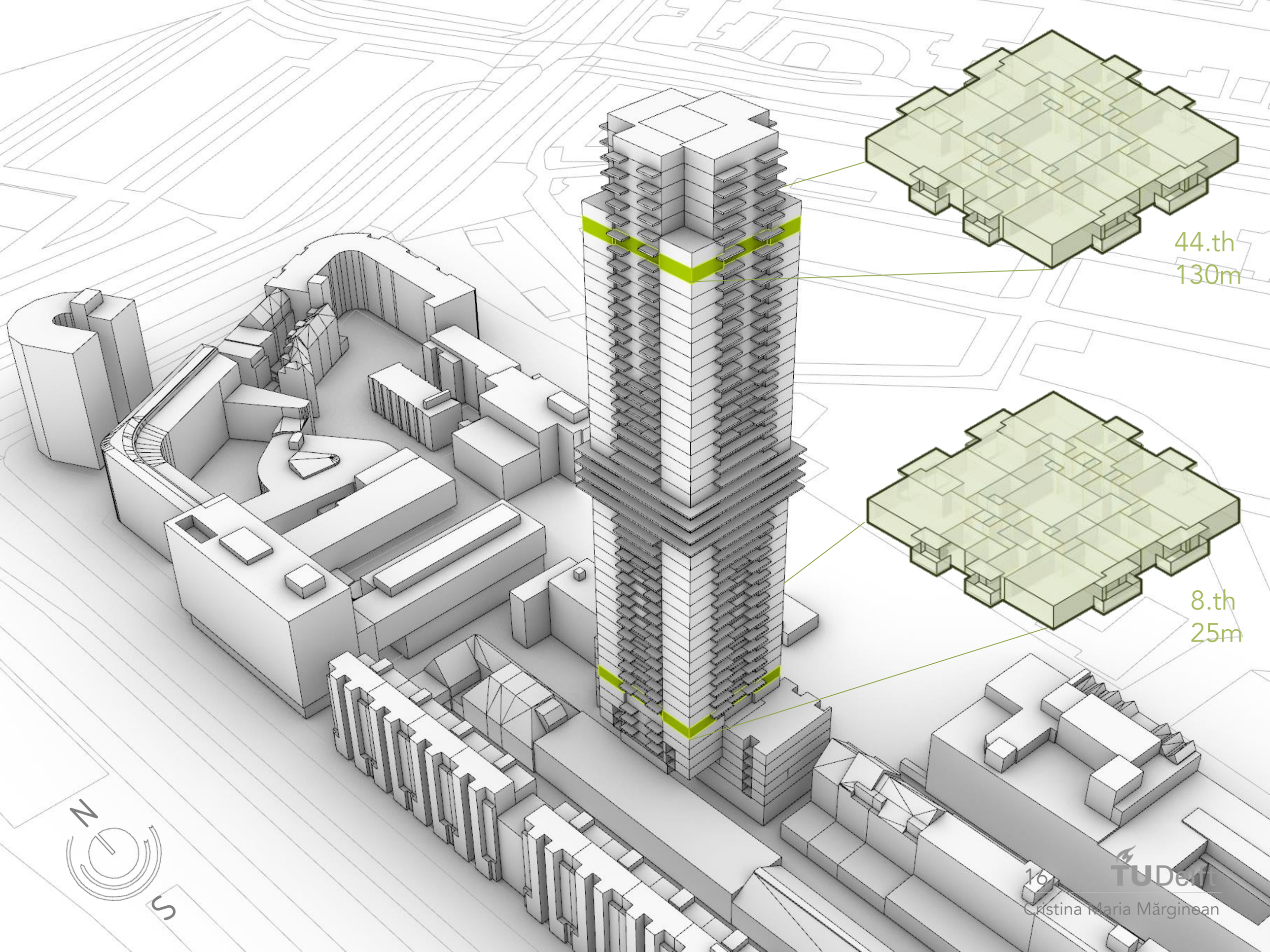
Ladybug

DESIGN ITERATIONS

Colibri

RESULTS

Design Explorer


44.th
130m
8.th
25m
N
S

W

HIGH WIND SPEEDS

DIRECT SUN

°C

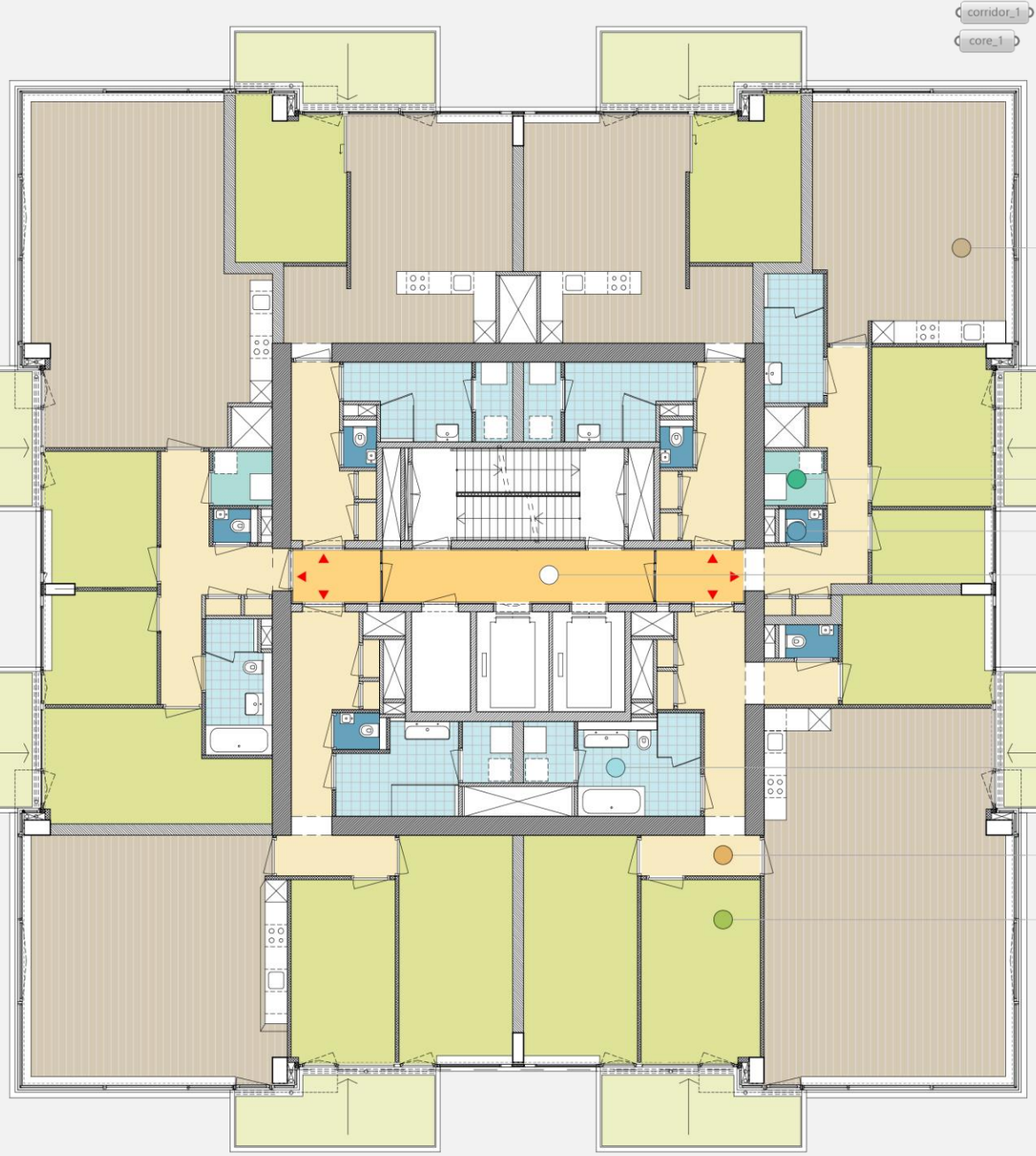
LOW AIR TEMPERATURES

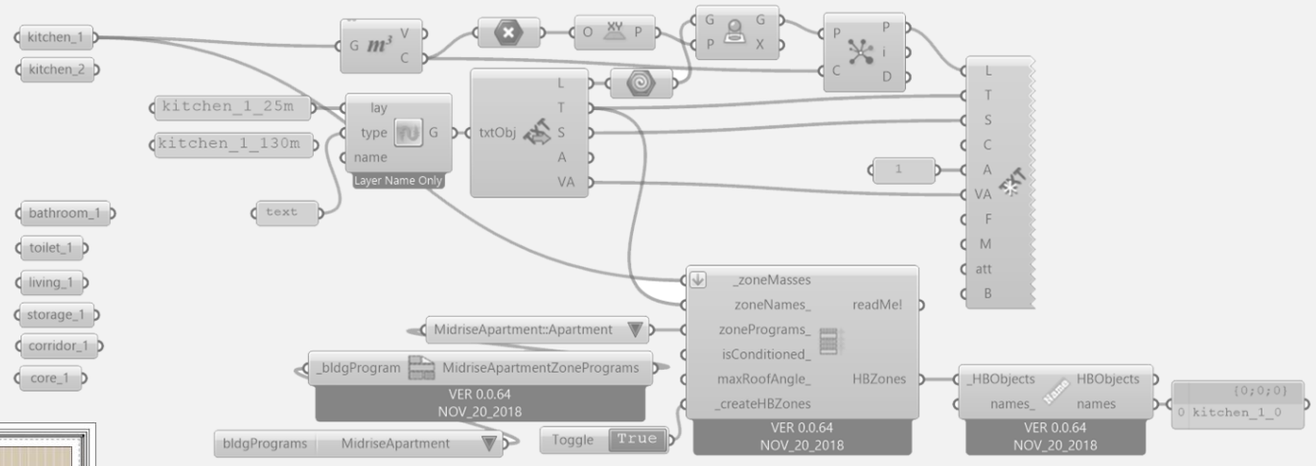
N

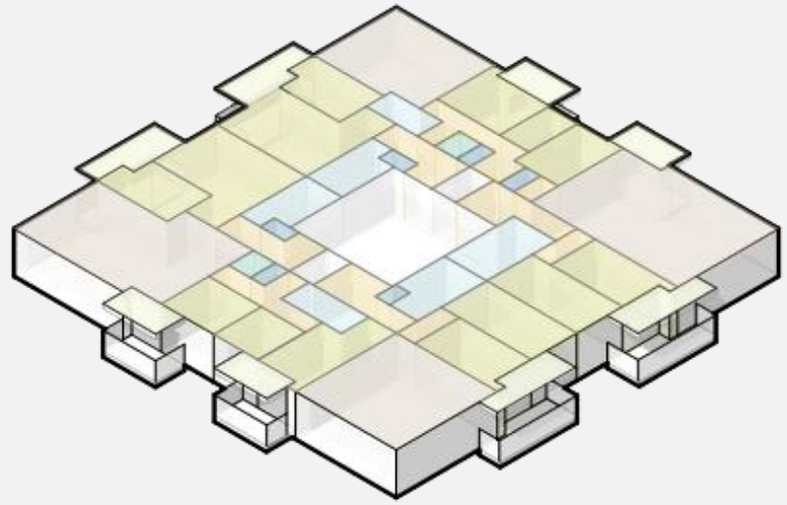
S

ROOM

FUNCTIONS



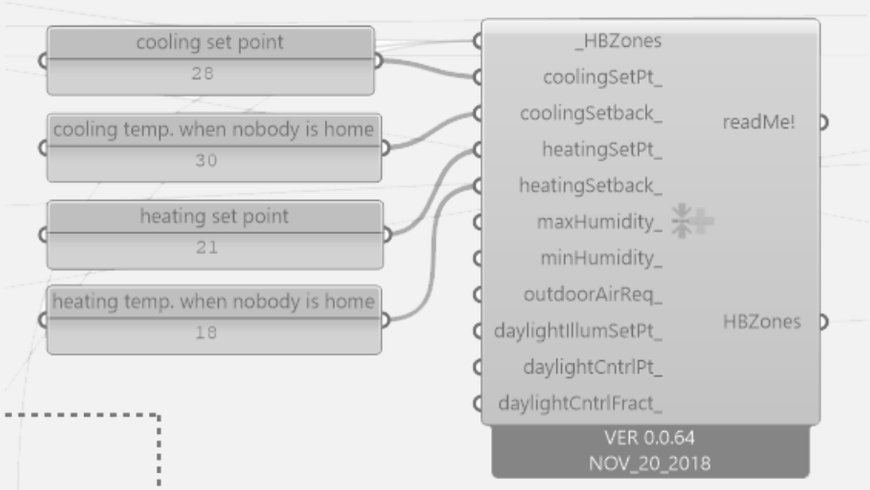


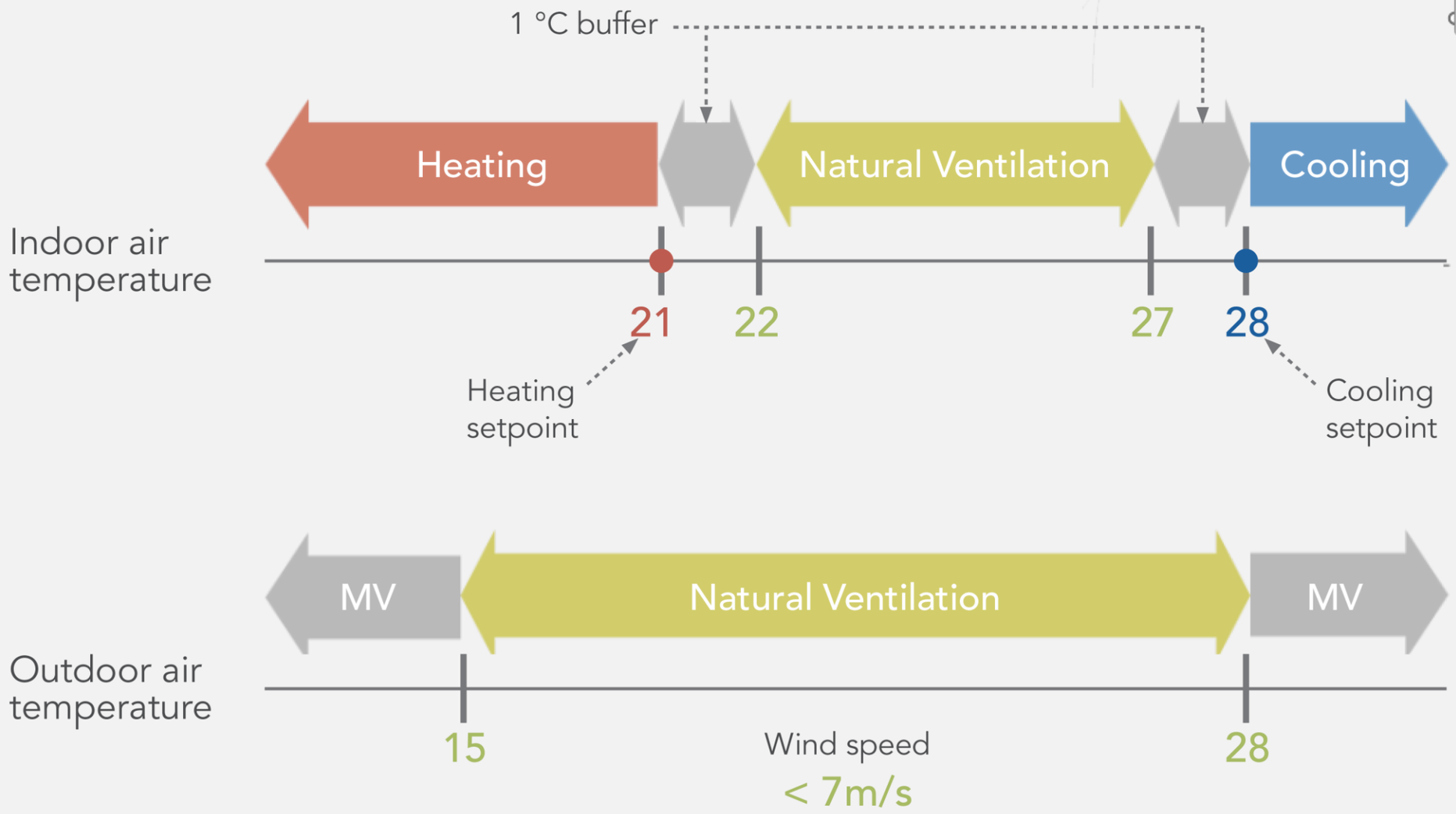


kitchen
storage
toilet
core
bathroom
corridor
bedroom

Cristina Maria Mărginean

SETPOINTS



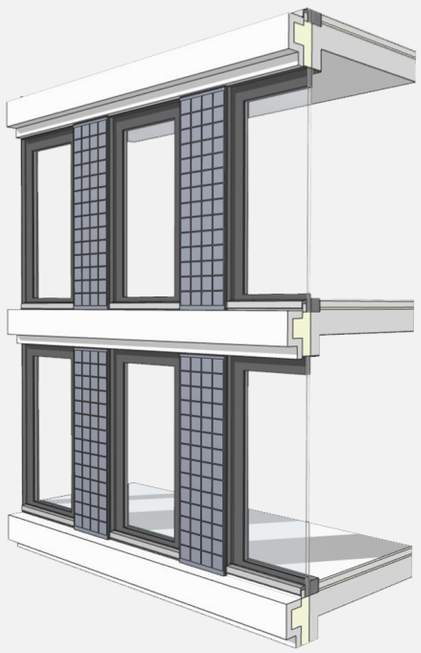


DYNAMIC SHADING

$20 W/m^2 \approx 2500$ lux

TUDelft
Cristina Maria Mărginean

VARIABLES



4 x Window Ratio and Energy

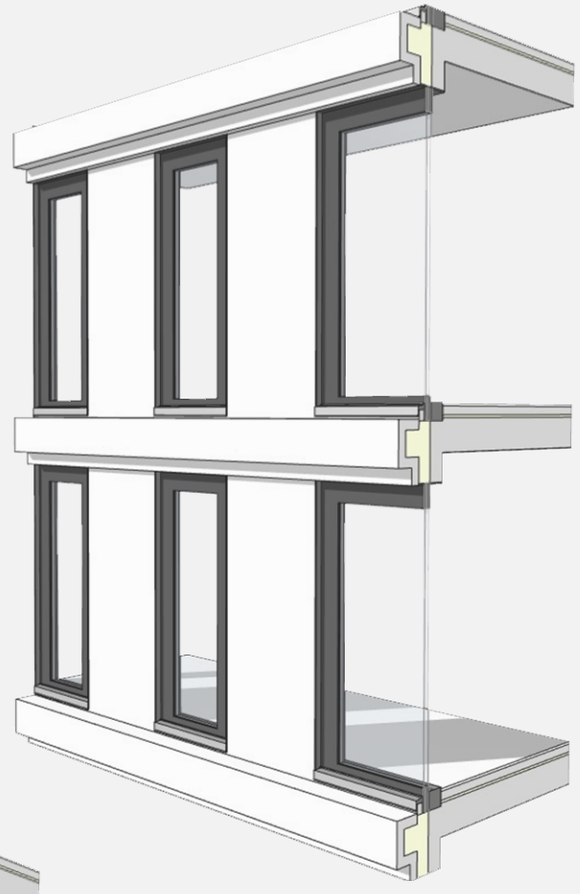
5 x Glazing Type

4 x Shading System

3 x Natural Ventilation

2 x Thermal Insulation

35% WWR



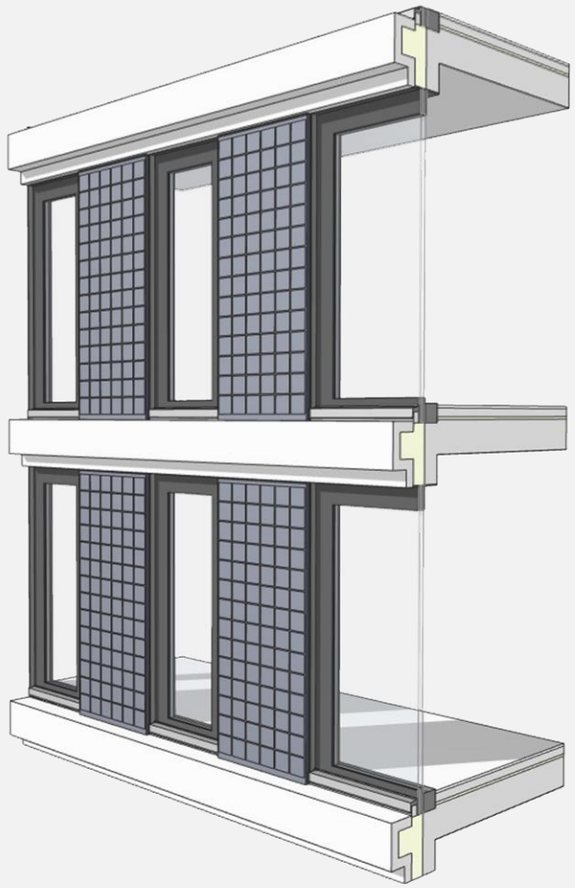
65% WWR

50% WWR

80% WWR

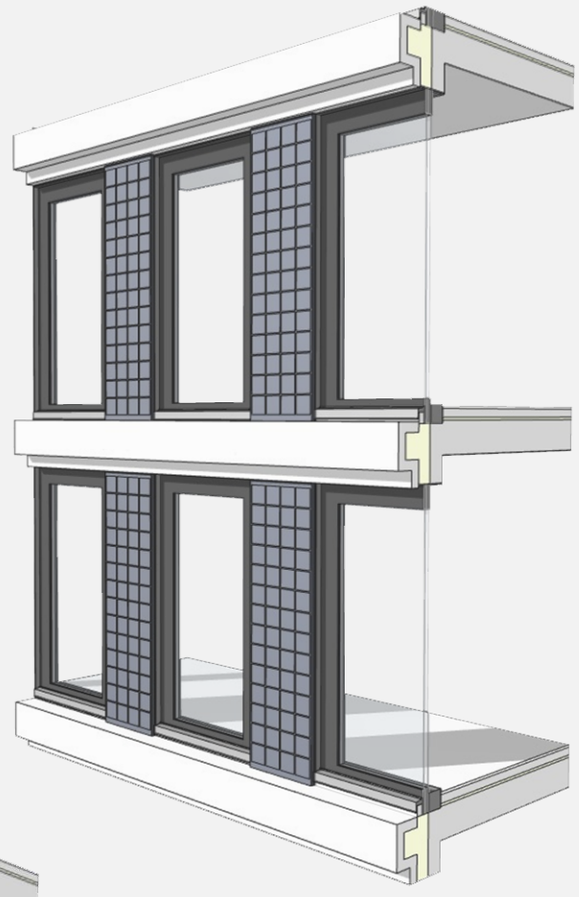
35% WWR

BIPVT



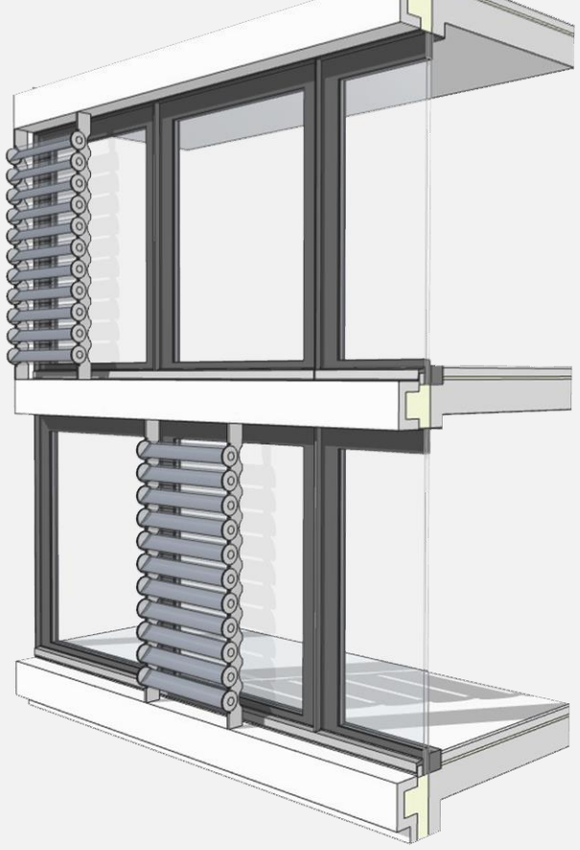
50% WWR

BIPVT

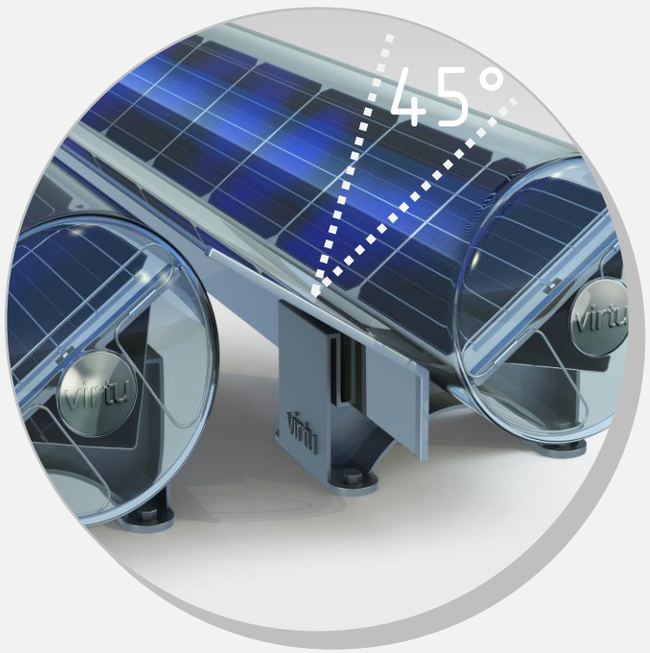


65% 80% WWR

PVT Shading

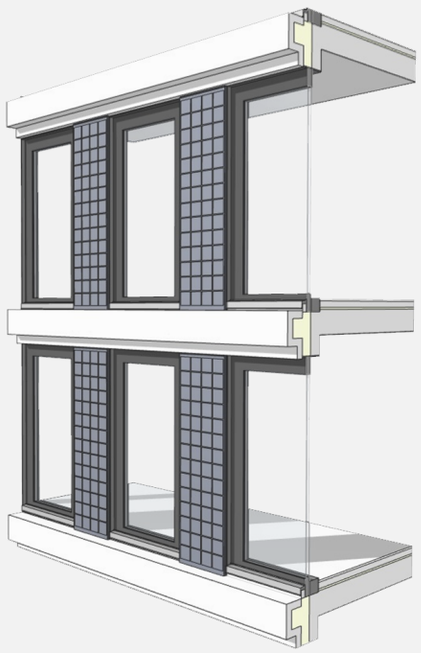


25% more energy

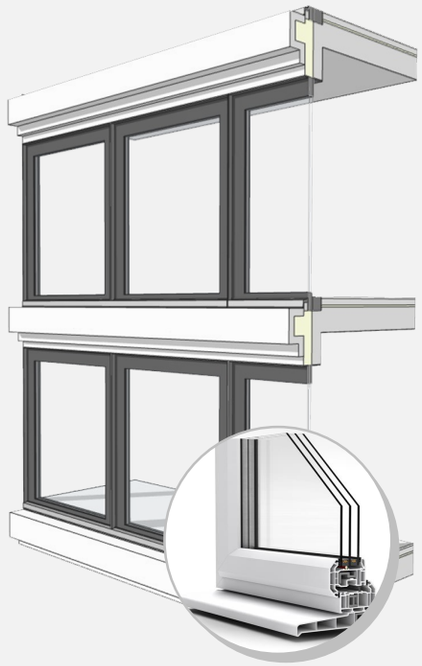


FACADE

VARIABLES



4 x Window Ratio and Energy



5 x Glazing Type

4 x Shading System

3 x Natural Ventilation

2 x Thermal Insulation

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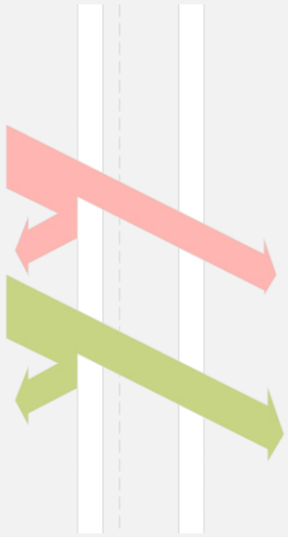


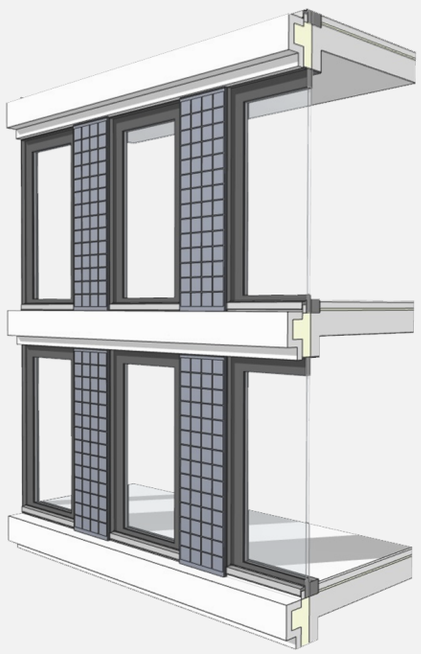
Double Glazing

	1	2	3
U-value	1.21 W/m²K	1.16 W/m²K	1.16 W/m²K
SHGC	60 %	60 %	30 %
VLT	60 %	80 %	60 %

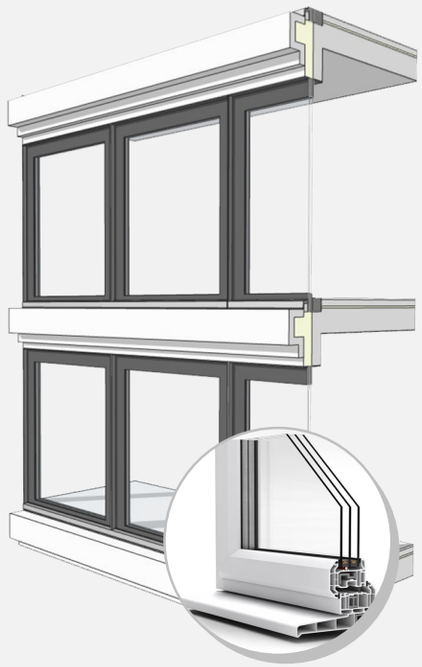
Triple Glazing

	1	2
U-value	0.9 W/m²K	0.9 W/m²K
SHGC	60 %	30 %
VLT	80 %	60 %

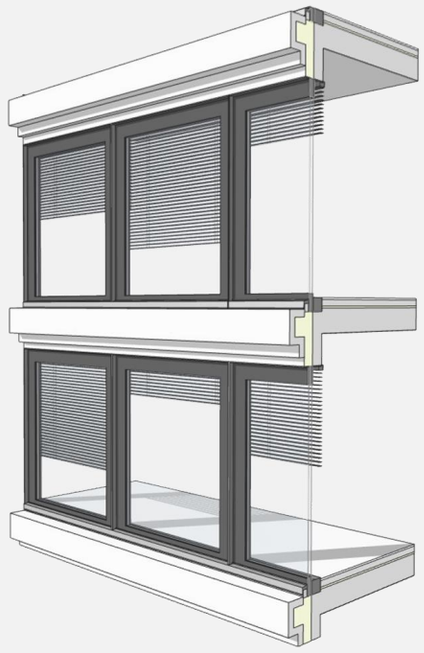
VARIABLES



4 x Window Ratio and Energy



5 x Glazing Type



4 x Shading System

3 x Natural Ventilation

2 x Thermal Insulation

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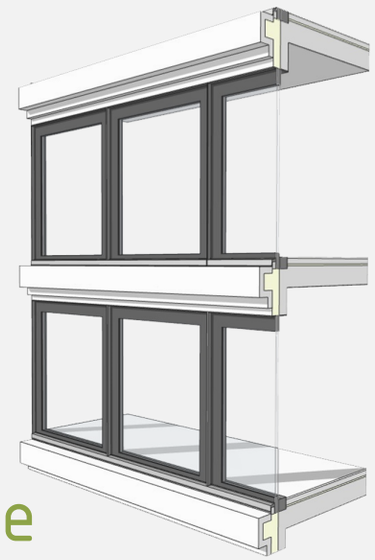
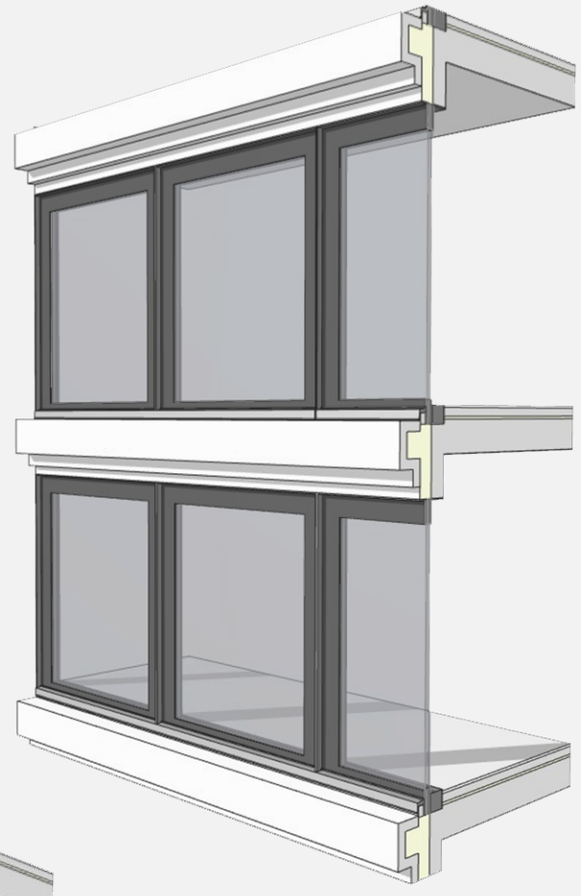
None

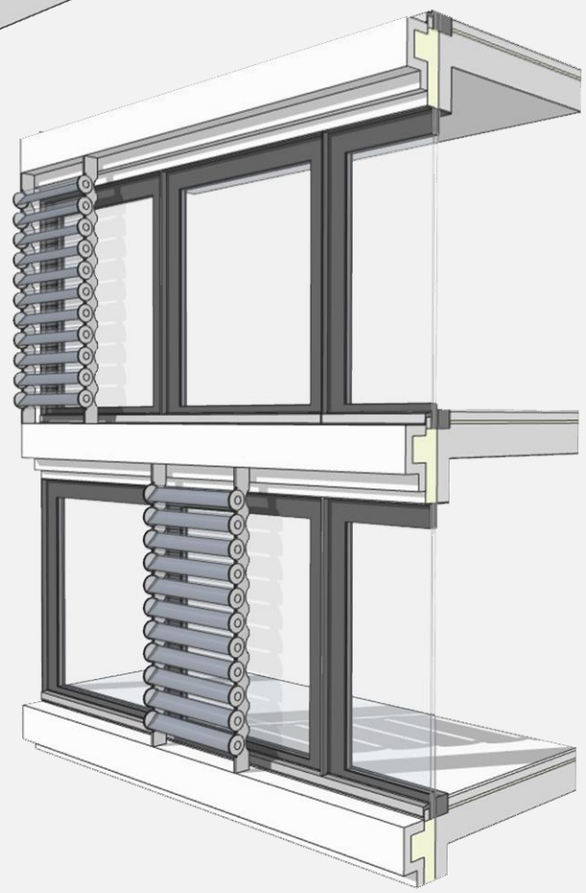


Interior
Blinds

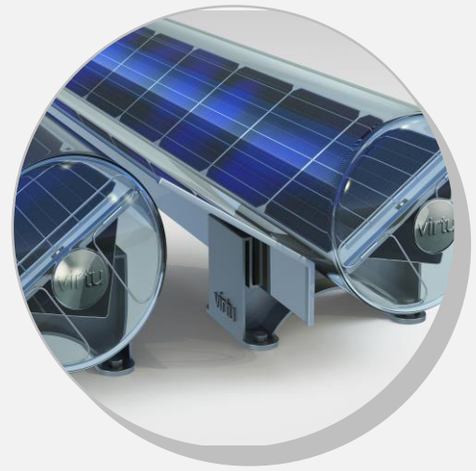
El.chrom.
Glazing



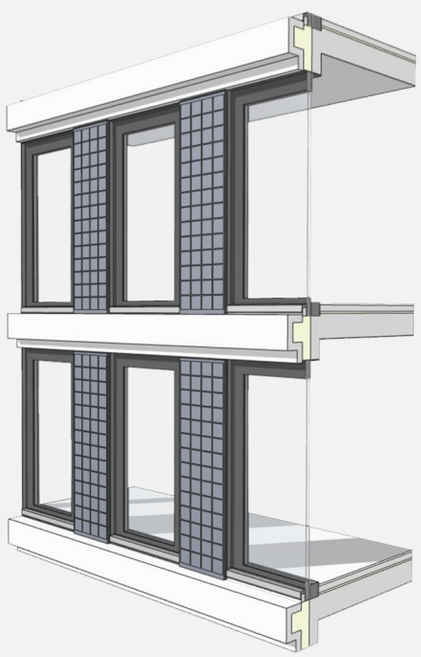
35% 50% WWR
Exterior
Louvres



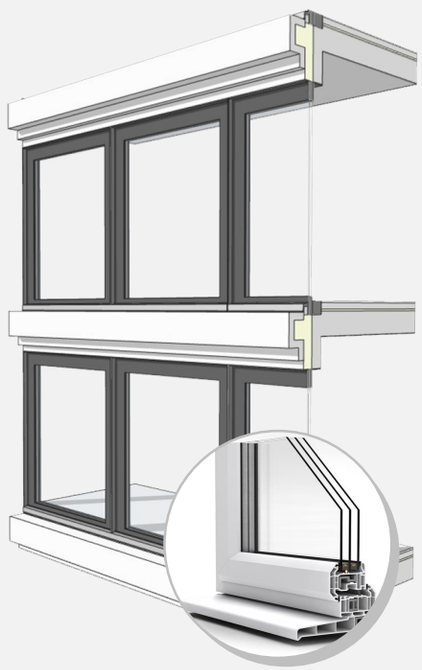
65% 80% WWR
PVT Shading



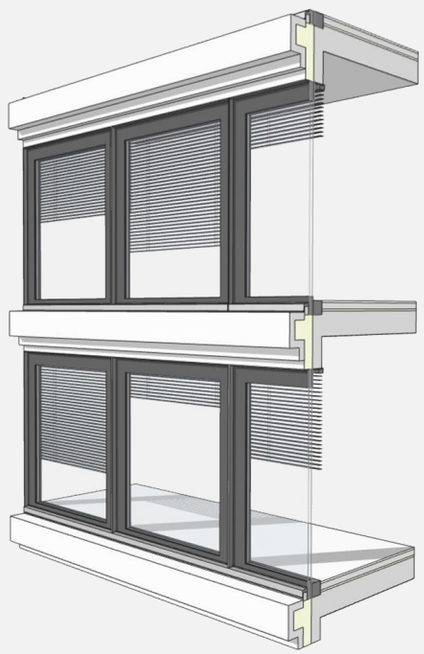
VARIABLES



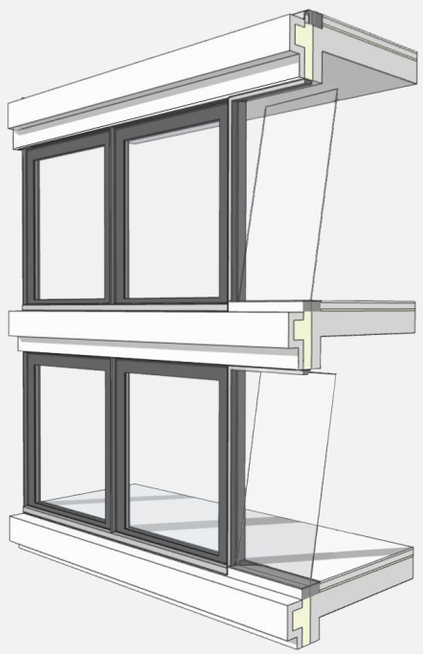
4 x Window Ratio and Energy



5 x Glazing Type

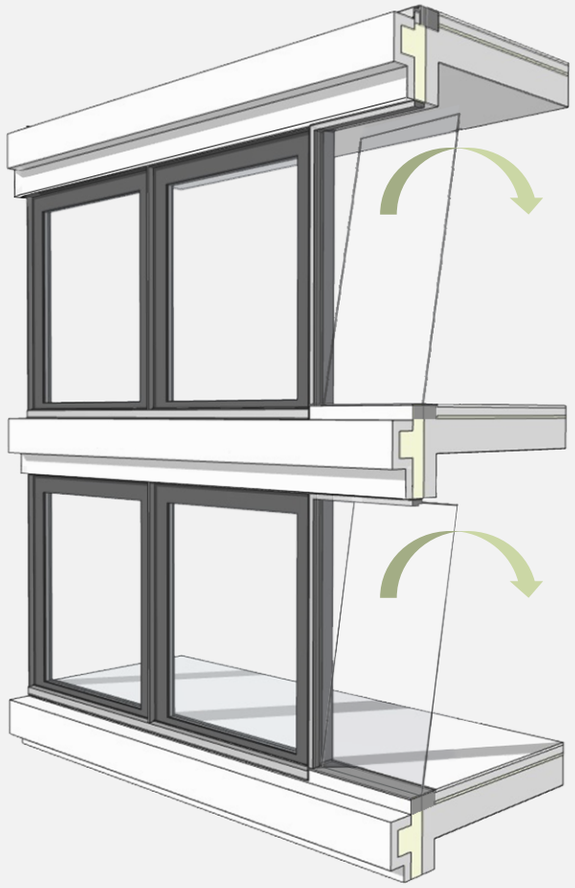


4 x Shading System

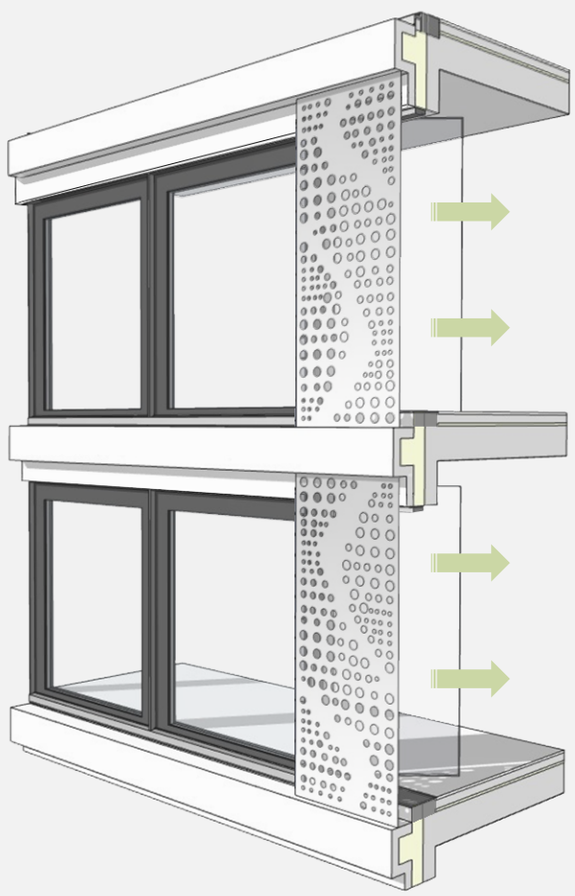


3 x Natural Ventilation

2 x Thermal Insulation

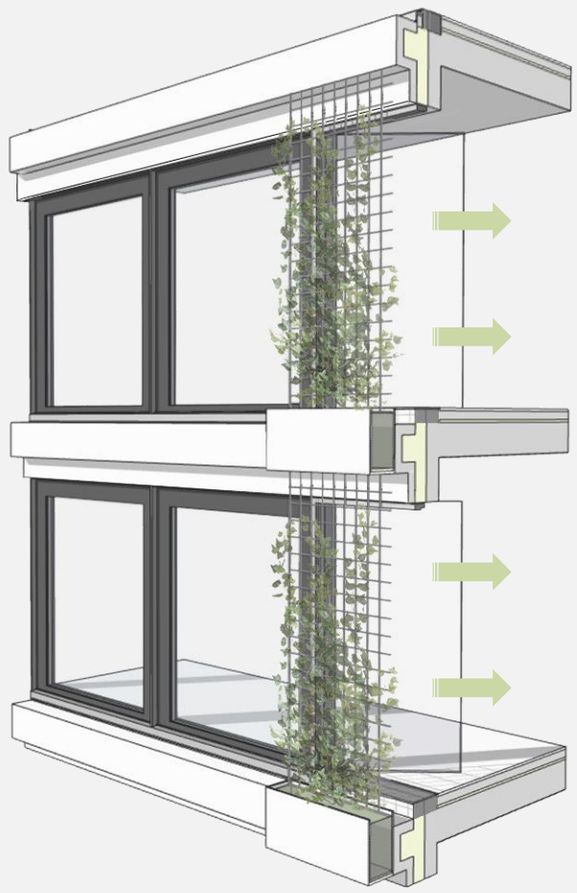


Tilting
Windows



Openable Windows
+Perf. Screen

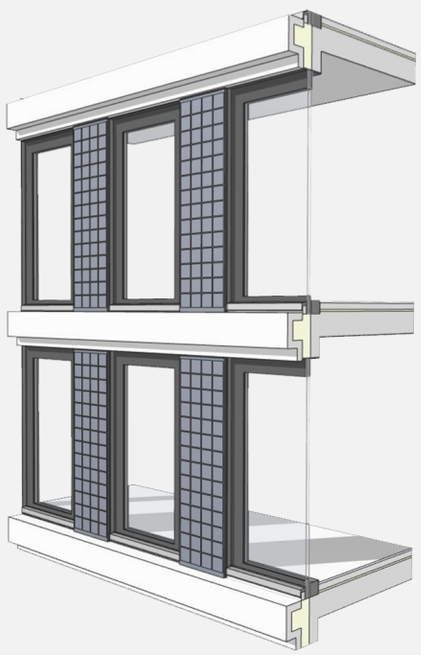
-25% wind speed



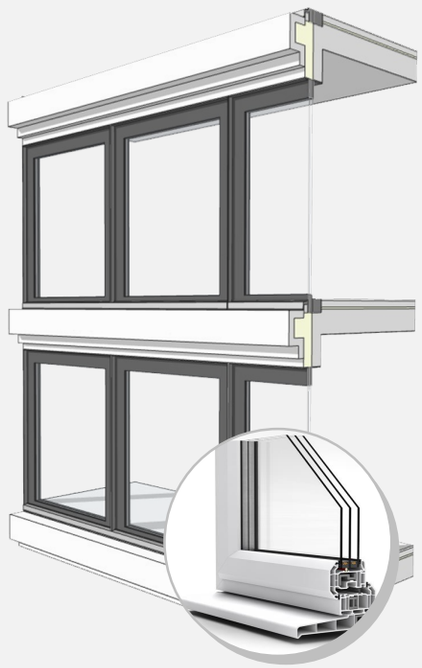
Openable Windows
+Vegetation

-50% wind speed

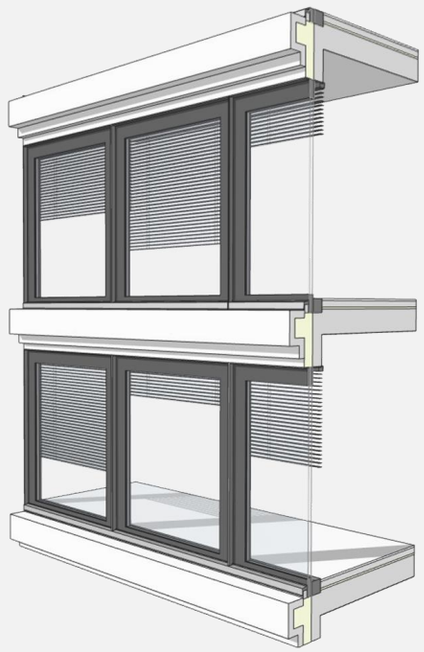
VARIABLES



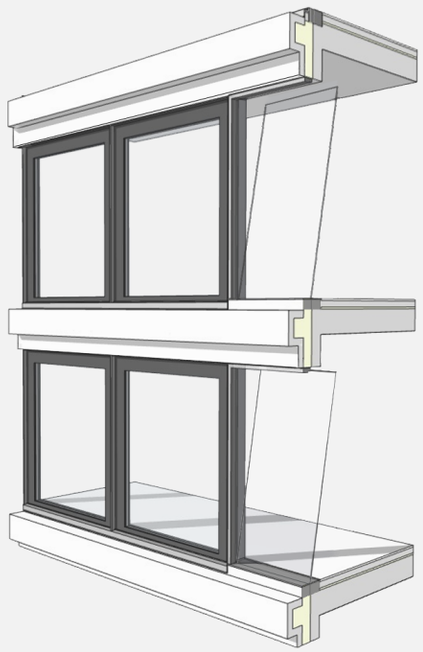
4 x Window Ratio and Energy



5 x Glazing Type



4 x Shading System



3 x Natural Ventilation

2 x Thermal Insulation

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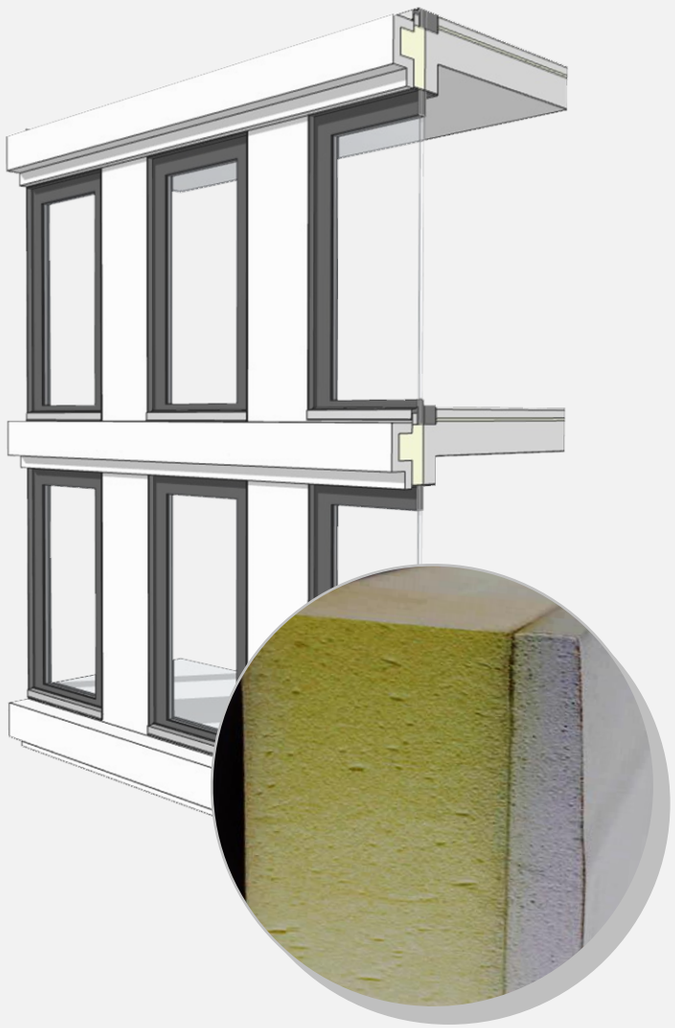
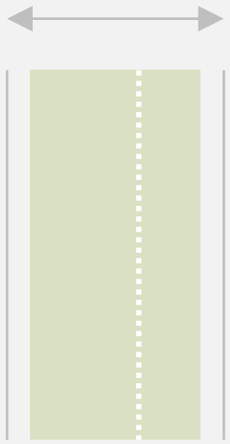
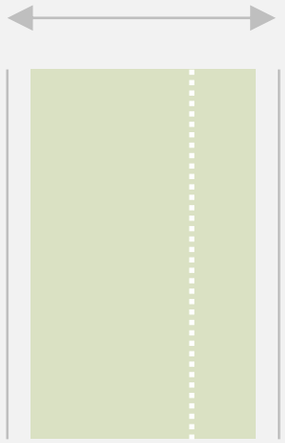


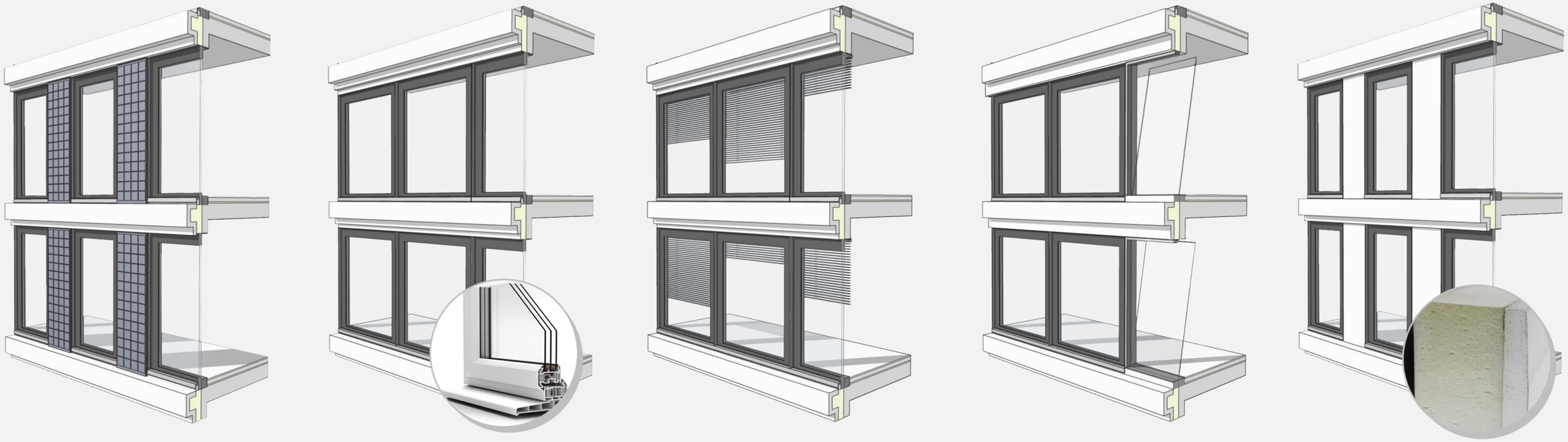


R = 4.5 m^2K/W



R = 6.0 m^2K/W

VARIABLES



4 x Window Ratio and Energy

5 x Glazing Type

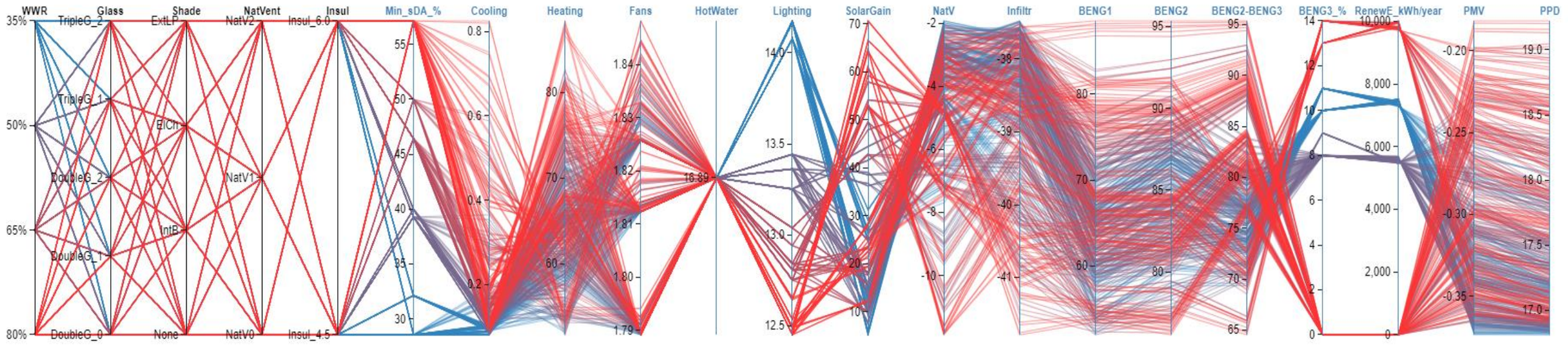
4 x Shading System

3 x Natural Ventilation

2 x Thermal Insulation

480 DESIGN COMBINATIONS

METHOD


WWR
Glass
Shade
NatVent
Insul
Min_sDA_%
Cooling
Heating
Fans
HotWater
Lighting
SolarGain
NatV
Infiltr
BENG1
BENG2
BENG2-BENG3
BENG3_%
RenewE_kWh/year
PMV
PPD
35%
50%
65%
80%
TripleG_2
TripleG_1
DoubleG_2
DoubleG_1
DoubleG_0
ExtLP
ElCh
IntB
None
NatV2
NatV1
NatV0
Insul_6.0
Insul_4.5
16.89

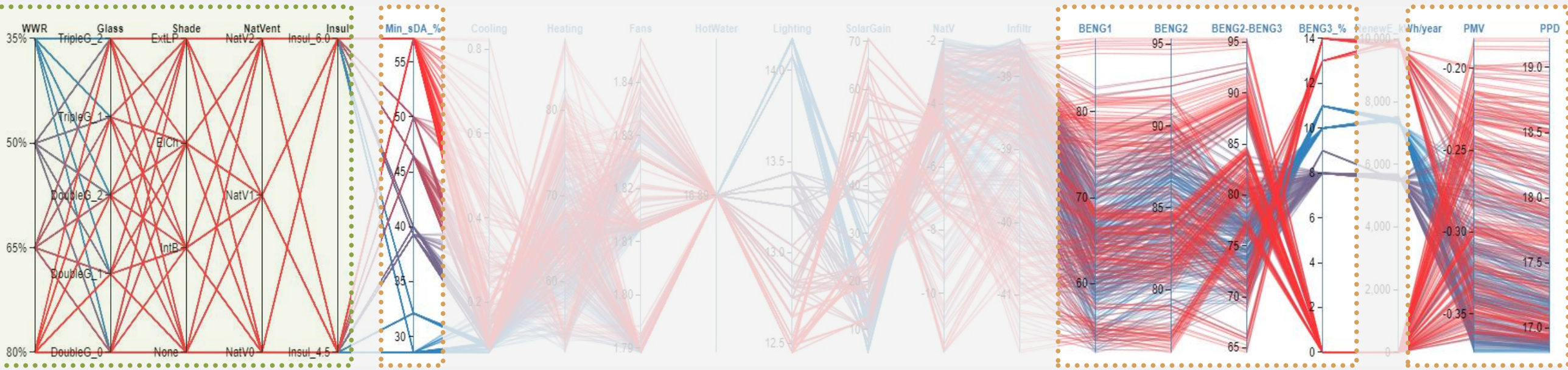
METHOD

FAÇADE VARIABLES

IMPACT DAYLIGHT

IMPACT ENERGY (BENG)

IMPACT THERMAL COMFORT

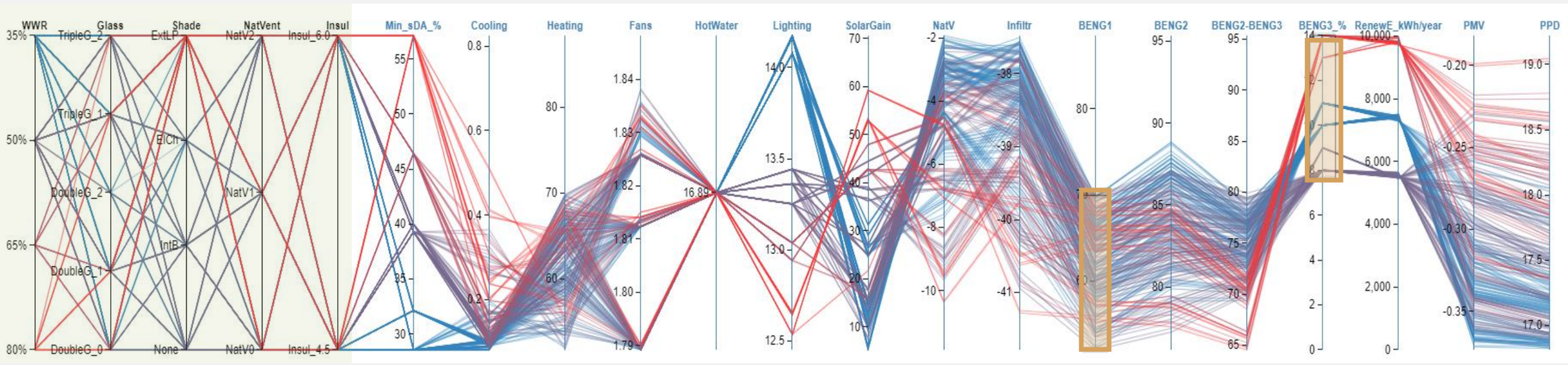


TUDelft

METHOD

FAÇADE VARIABLES

IMPACT ENERGY (BENG)



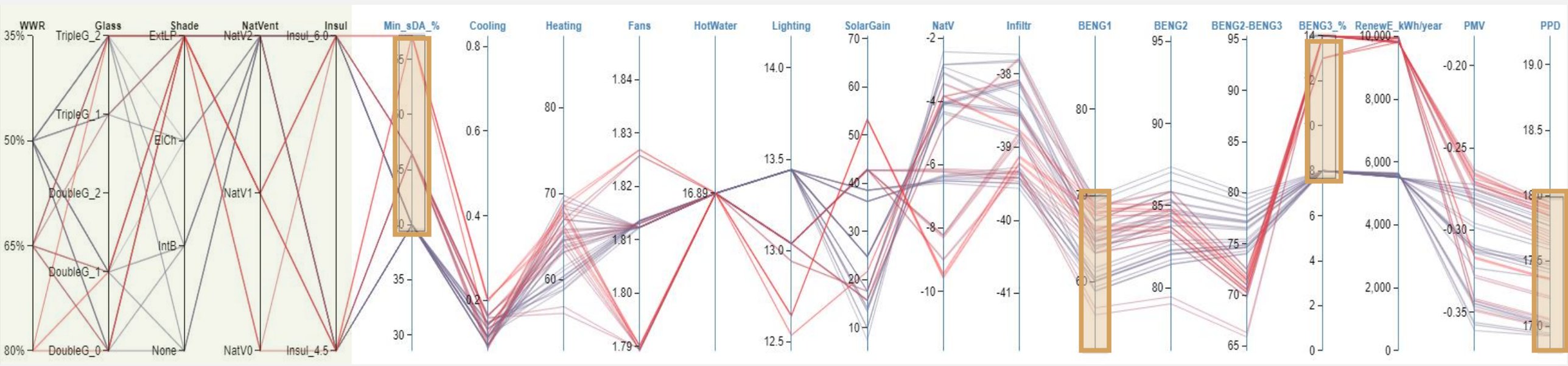
METHOD

FAÇADE VARIABLES

IMPACT DAYLIGHT

IMPACT ENERGY (BENG)

IMPACT THERMAL COMFORT



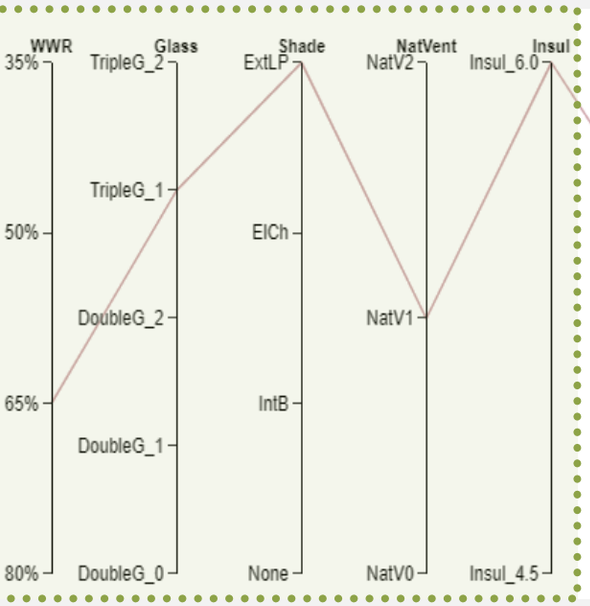
METHOD

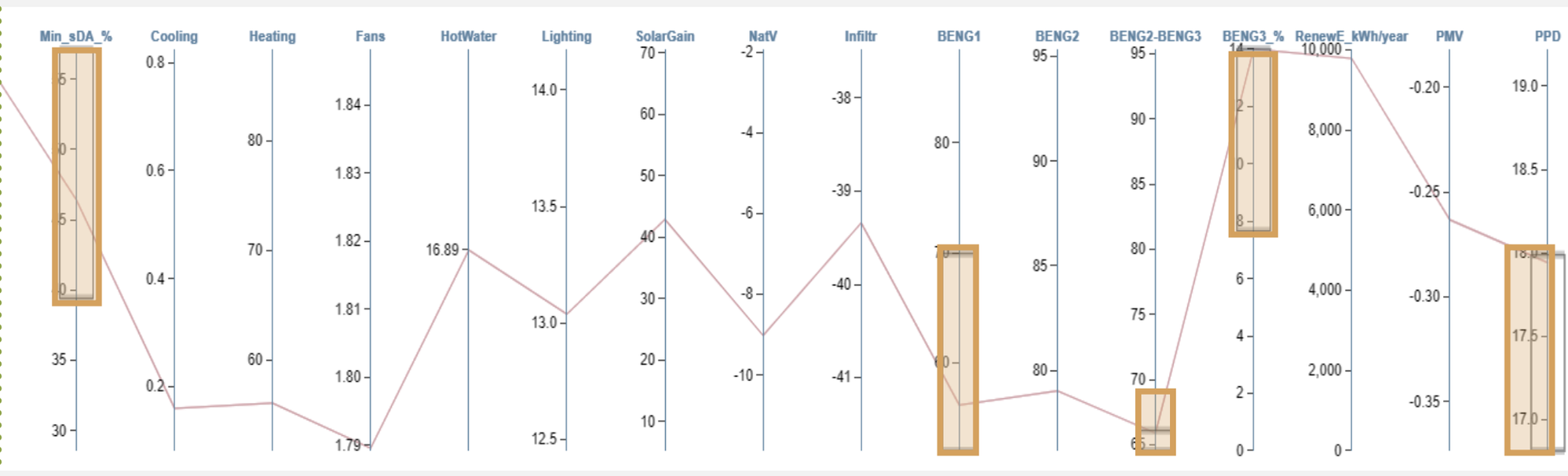
FAÇADE VARIABLES

IMPACT DAYLIGHT

IMPACT ENERGY (BENG)

IMPACT THERMAL COMFORT





TUDelft

Cristina Maria Mărginean

1 2 3

4 Results

5 6

METHOD

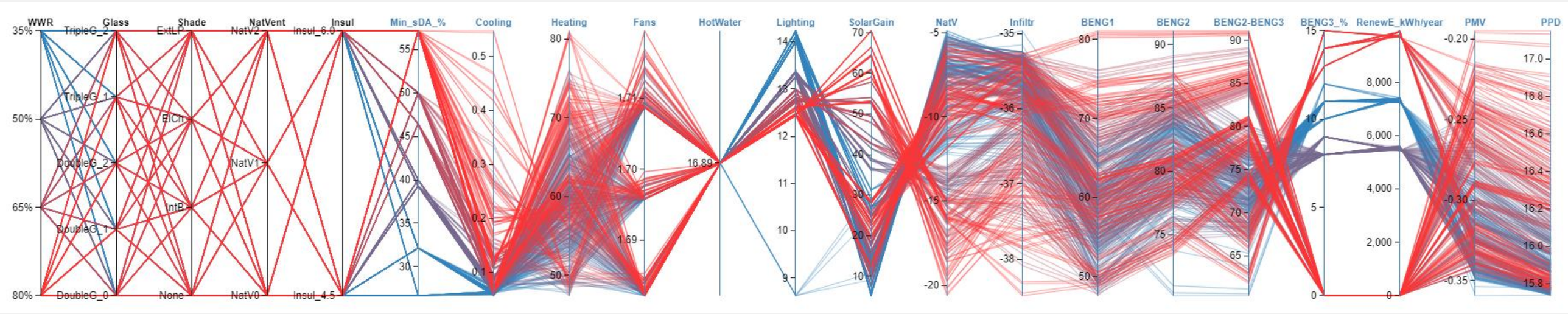
How much can the BENG requirements for residential buildings be met in high-rises through an optimized façade?

BENG 1 Energy Need kWh/m²		< 70	✓	70% of analyzed Façade Designs
BENG 2 Primary Fossil Energy Use kWh/m²		< 50	✗	Only with Facade
BENG 3 Share or Renewable Energy %		> 40	✗	Only with Facade

FACADE

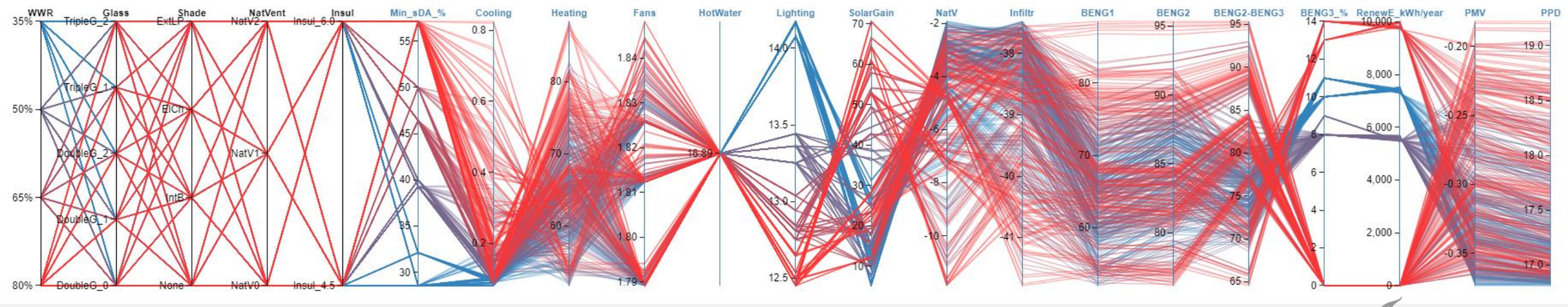
VARIABLES

25m



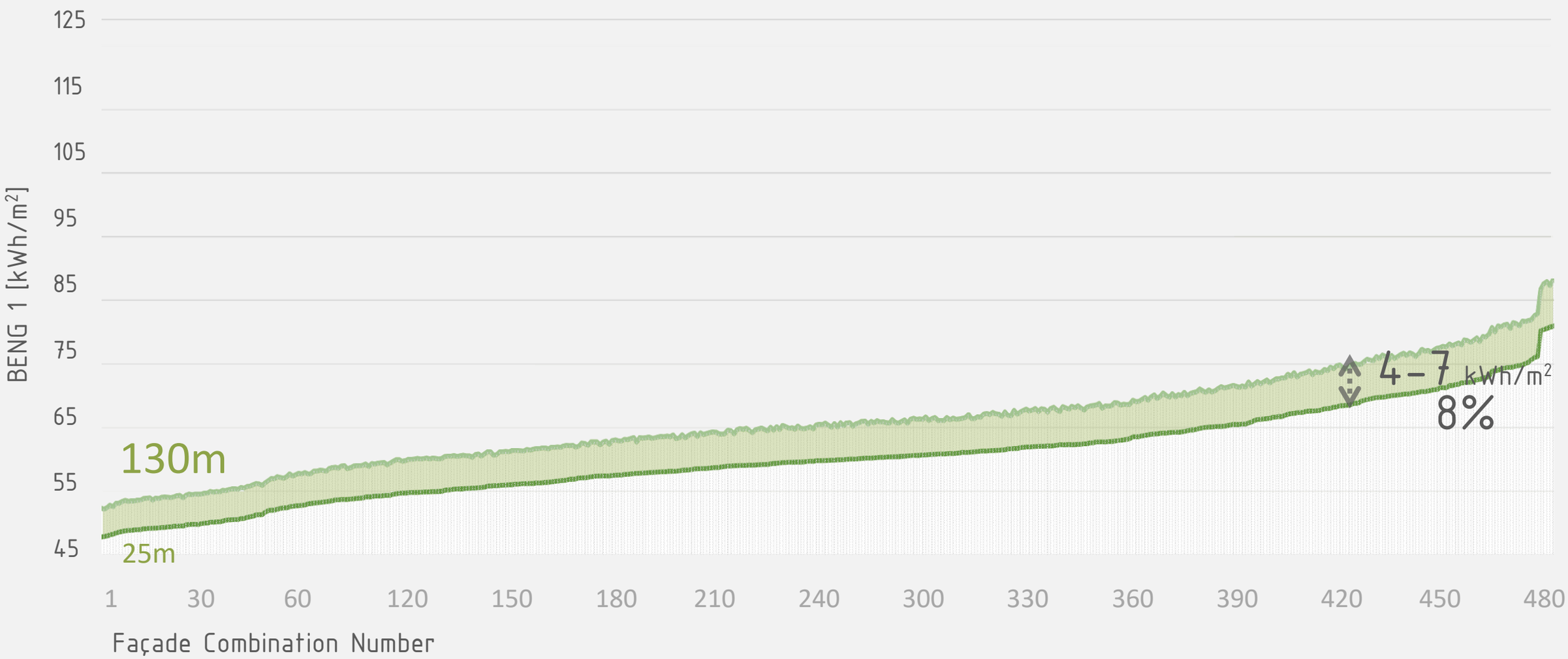
Does a variation in facade with respect to height lead to better performance?

130m



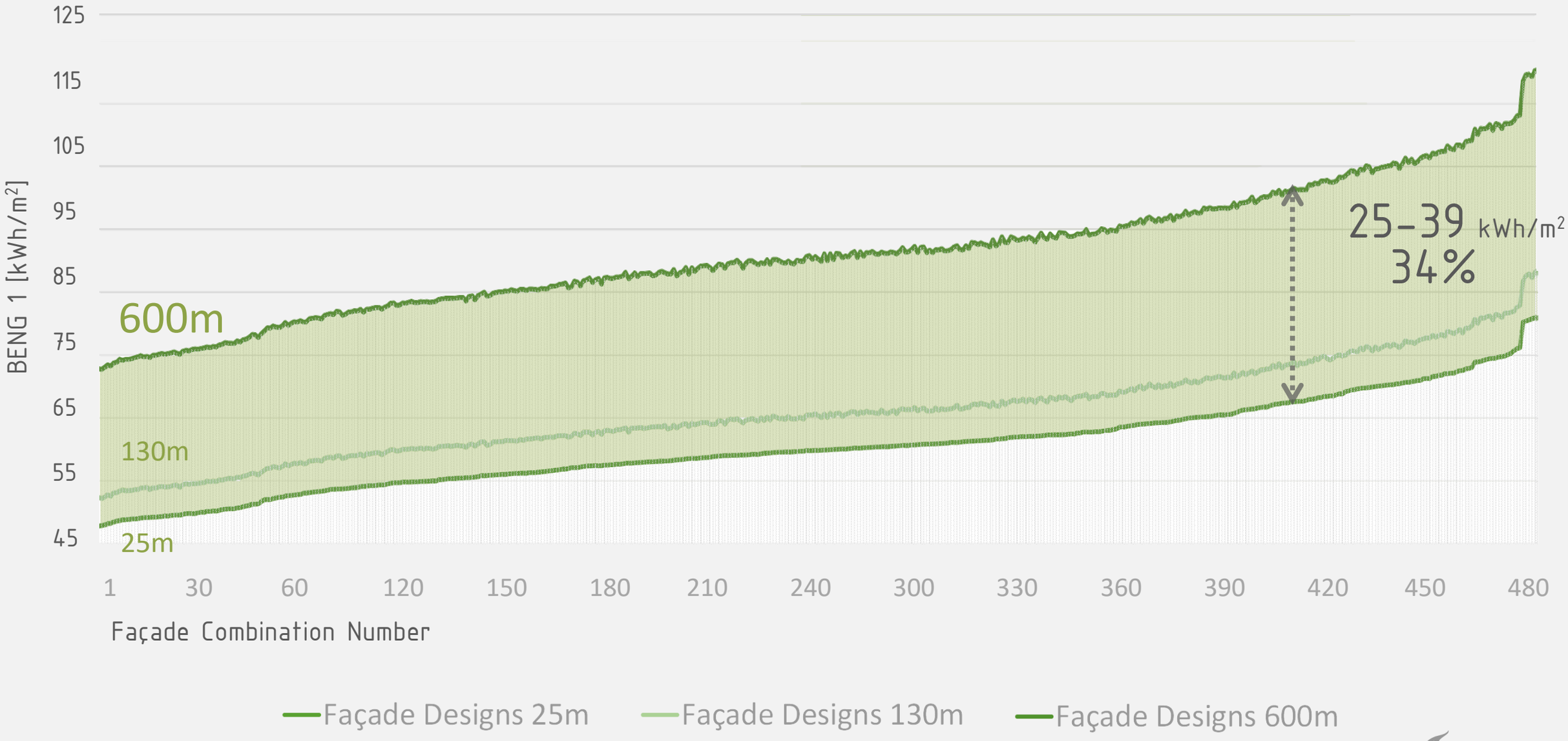
TUDelft

VARIABLES


BENG 1 [kWh/m²]
125
115
105
95
85
75
65
55
45
130m
25m
4-7 kWh/m²
8%
1
30
60
120
150
180
210
240
300
330
360
390
420
450
480
Façade Combination Number
Façade Designs 25m
Façade Designs 130m

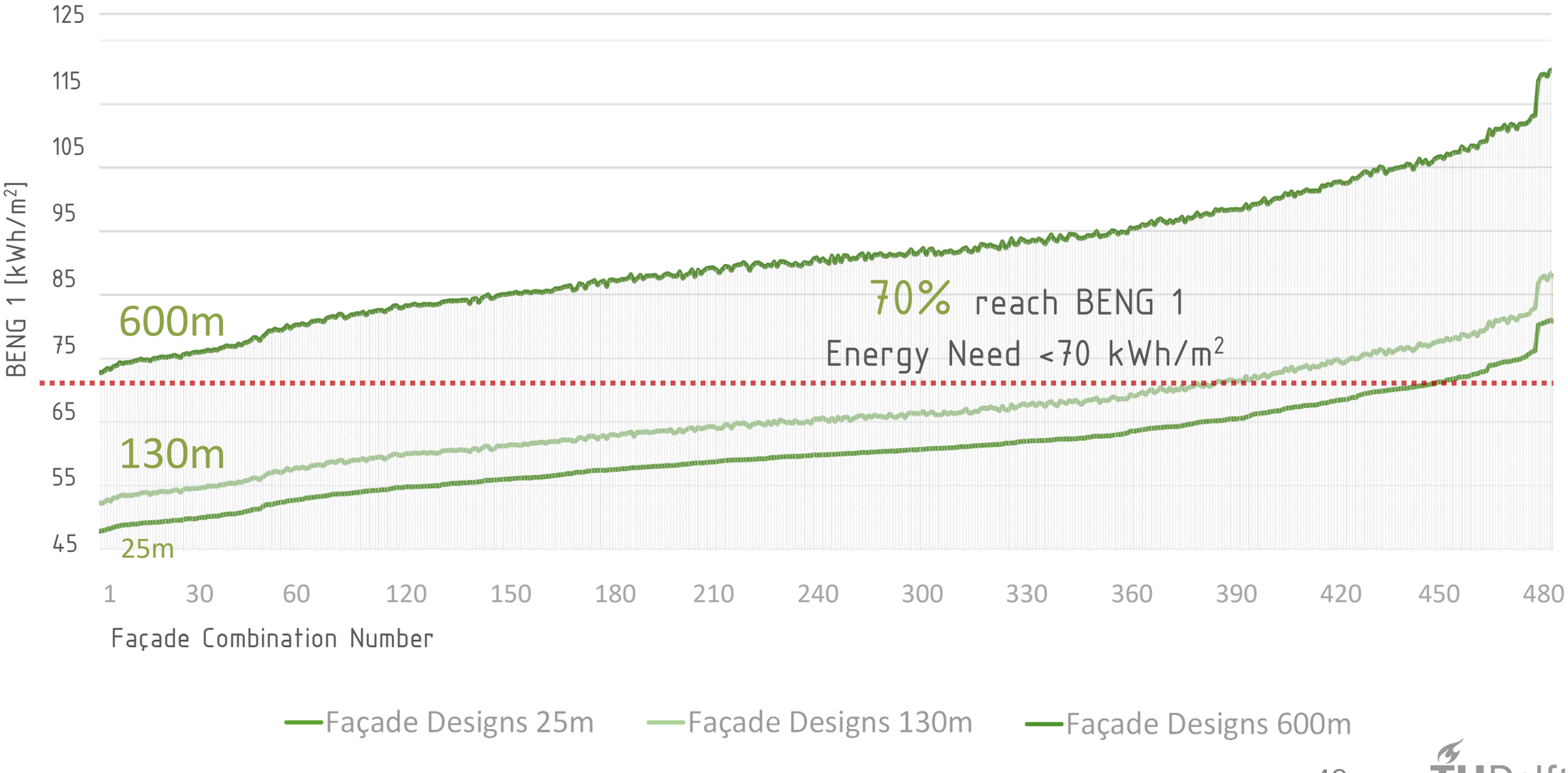
VARIABLES

+6% more energy consumption
with every 100m



Cristina Maria Mărginean

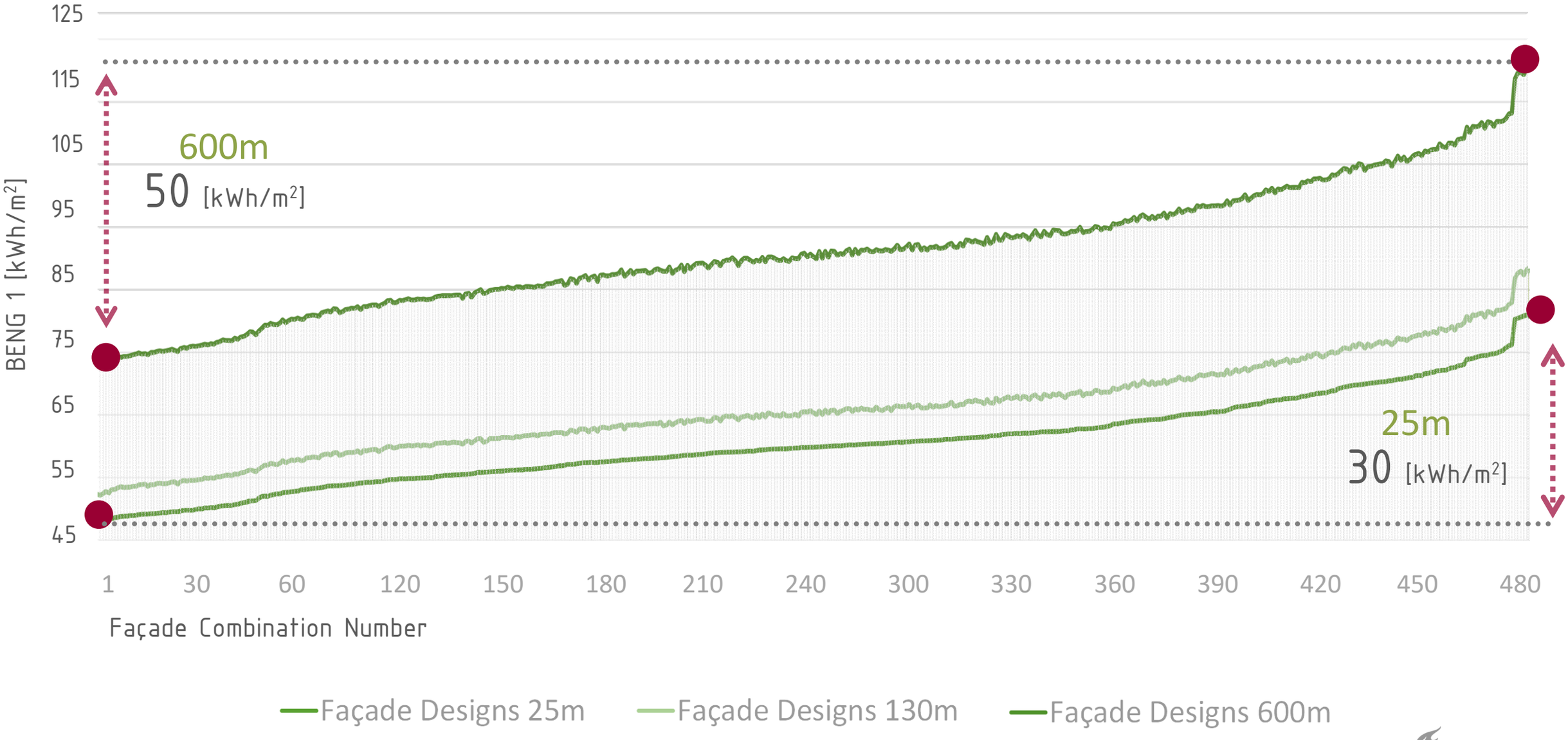
VARIABLES


125
115
105
95
85
75
65
55
45
BENG 1 [kWh/m²]
600m
130m
25m
70% reach BENG 1
Energy Need <70 kWh/m²
1
30
60
120
150
180
210
240
300
330
360
390
420
450
480
Façade Combination Number
Façade Designs 25m
Façade Designs 130m
Façade Designs 600m

VARIABLES

ANSWER: *A façade design variation with height would not lead to better performance*

BUT *the impact of the façade design on the energy performance is greater with height*



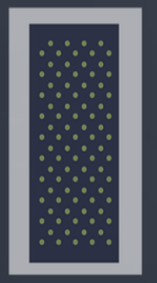
TU Delft
Cristina Maria Mărginean

IMPACT FAÇADE PARAMETERS

DAYLIGHT | ENERGY | THERMAL COMFORT

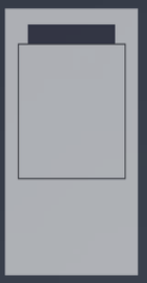
WWR
35%
50%
65%
80%

Energy
35%: PV/T Facade
50%: PV/T Facade
65%: PV/T Louvres
80%: PV/T Louvres



Glazing
DoubleG 1.21,0.6,60
DoubleG 1.16,0.6,80
DoubleG 1.16,0.3,60
TripleG 0.9,0.6,80
TripleG 0.9,0.3,60

Shading
None
Interior Blinds
Electrochrom. Glz
Exterior Louvres (PV/T)



Nat. Ventilation
Tilting Windows
Open W. + Vegetation
Open W. + Perf. Panel

Insulation
R = 4.5 m^2K/W
R = 6.0 m^2K/W

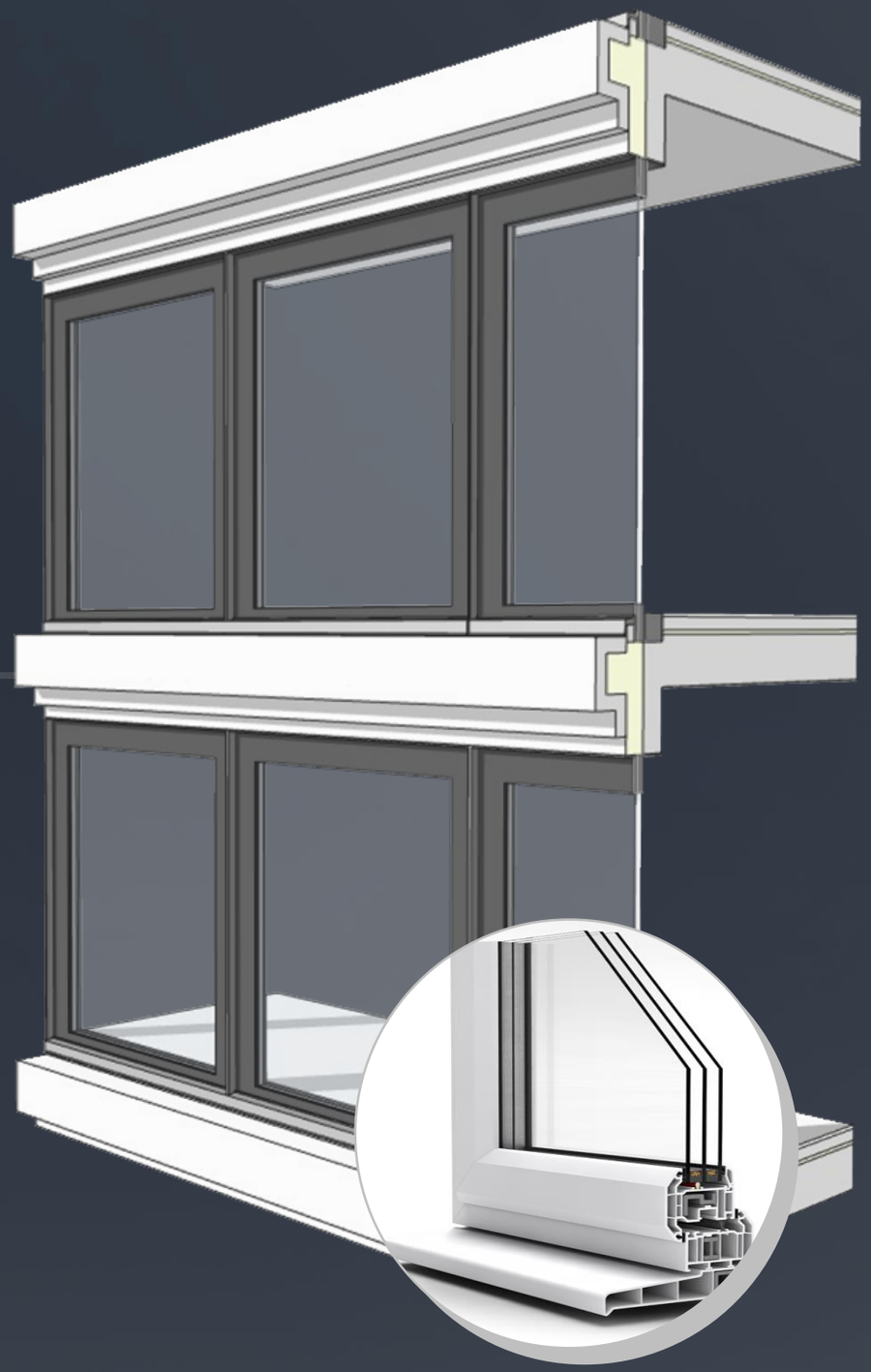
TUDelft

Cristina Maria Mărginean

IMPACT

GLAZING TYPE

DAYLIGHT | ENERGY | THERMAL COMFORT



WWR
35%
50%
65%
80%

Energy
35%: PV/T Facade
50%: PV/T Facade
65%: PV/T Louvres
80%: PV/T Louvres

Glazing
DoubleG 1.21,0.6,60
DoubleG 1.16,0.6,80
DoubleG 1.16,0.3,60
TripleG 0.9,0.6,80
TripleG 0.9,0.3,60

Shading
None
Interior Blinds
Electrochrom. Glz
Exterior Louvres (PV/T)

Nat. Ventilation
Tilting Windows
Open W. + Vegetation
Open W. + Perf. Panel

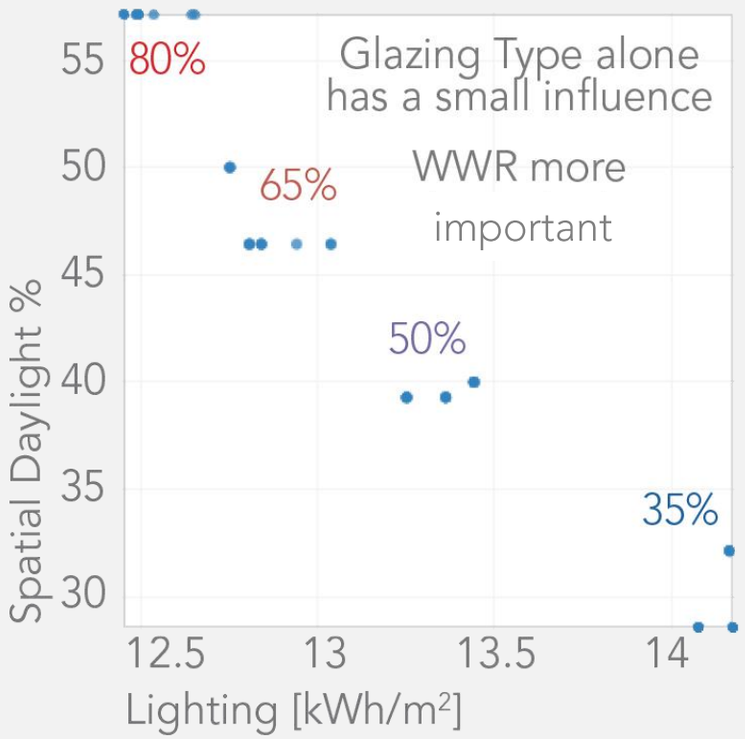
Insulation
R = 4.5 m^2K/W
R = 6.0 m^2K/W

TUDelft

Cristina Maria Mărginean

IMPACT

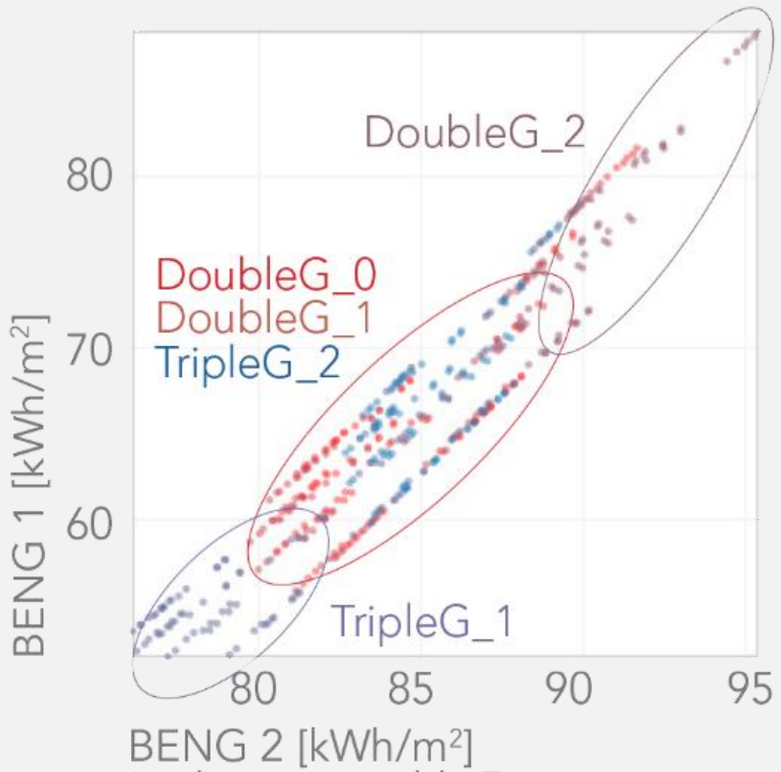
DAYLIGHT



Small impact on DAYLIGHT

IMPACT

ENERGY



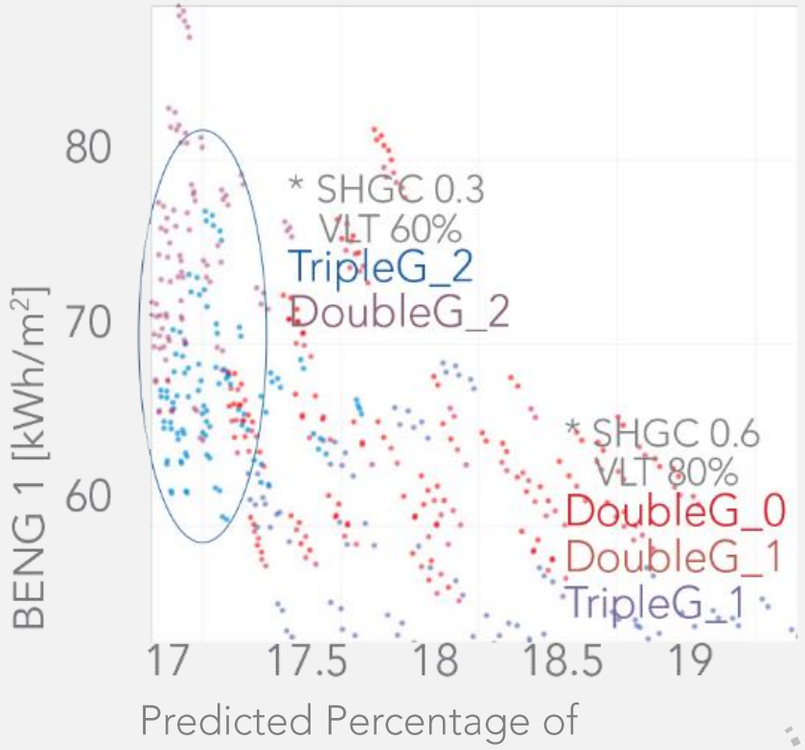
U-vale
SHGC
VLT

Triple Glz

0.9 W/m²K
60 % ↑ SHGC
80 % ↑ VLT

IMPACT

THERMAL COMFORT



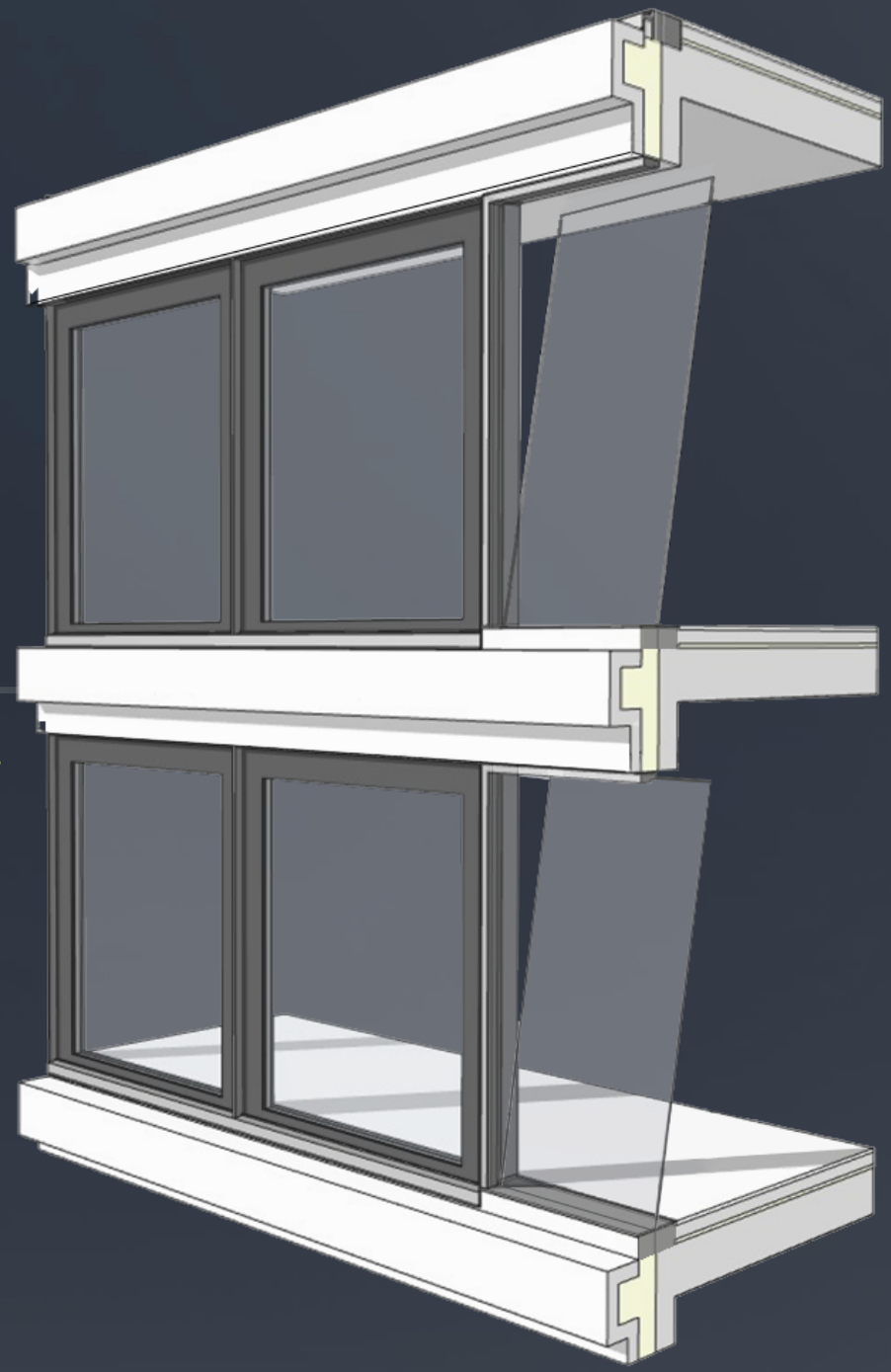
Double Glz
Triple Glz

0.9 W/m²K
30 % ↓ SHGC
60 % ↑ VLT

IMPACT

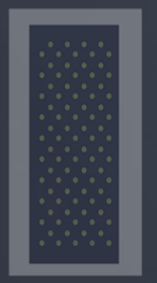
NATURAL VENTILATION

DAYLIGHT | ENERGY | THERMAL COMFORT



WWR
35%
50%
65%
80%

Energy
35%: PV/T Facade
50%: PV/T Facade
65%: PV/T Louvres
80%: PV/T Louvres



Glazing
DoubleG 1.21,0.6,60
DoubleG 1.16,0.6,80
DoubleG 1.16,0.3,60
TripleG 0.9,0.6,80
TripleG 0.9,0.3,60

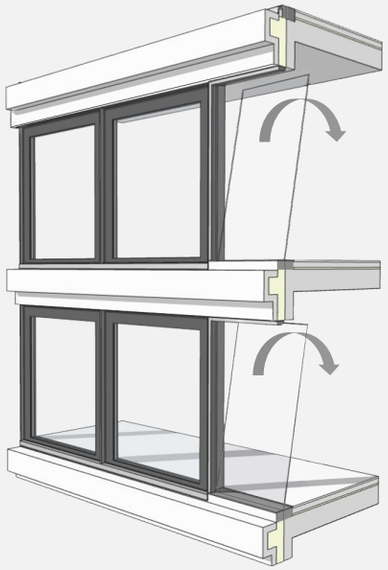
Shading
None
Interior Blinds
Electrochrom. Glz
Exterior Louvres (PV/T)

Nat. Ventilation
Tilting Windows
Open W. + Vegetation
Open W. + Perf. Panel

Insulation
R = 4.5 m^2K/W
R = 6.0 m^2K/W

TUDelft

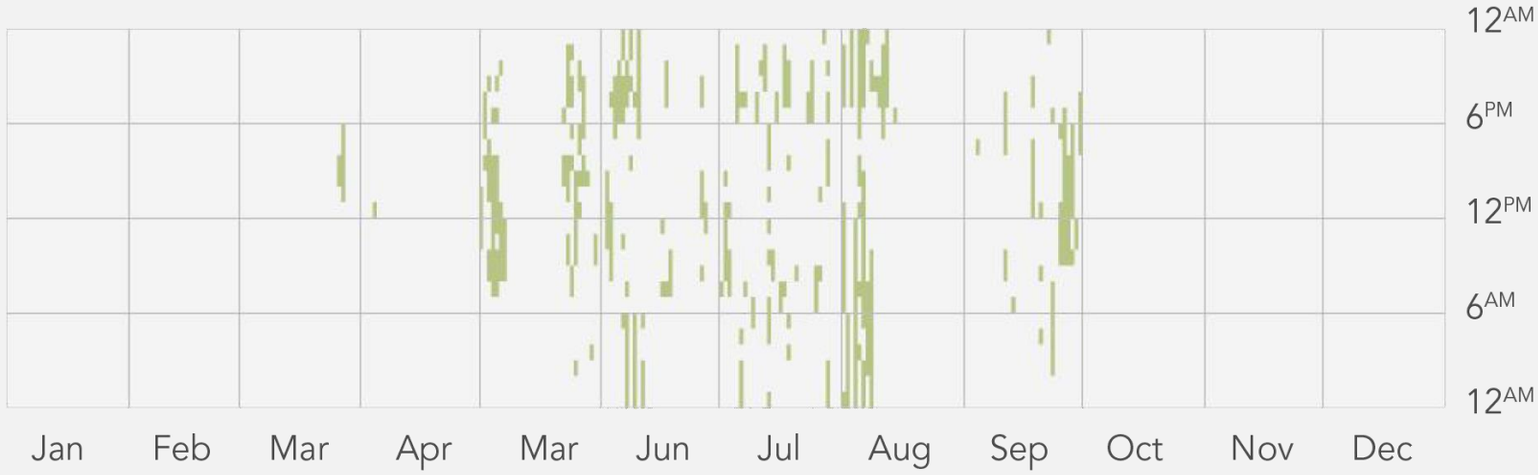
Cristina Maria Mărginean

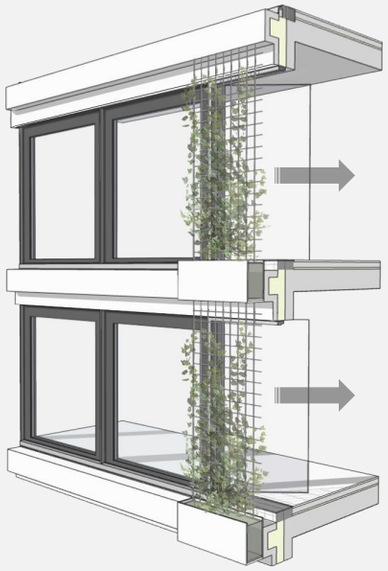


Tilting Windows

130m

410 hours

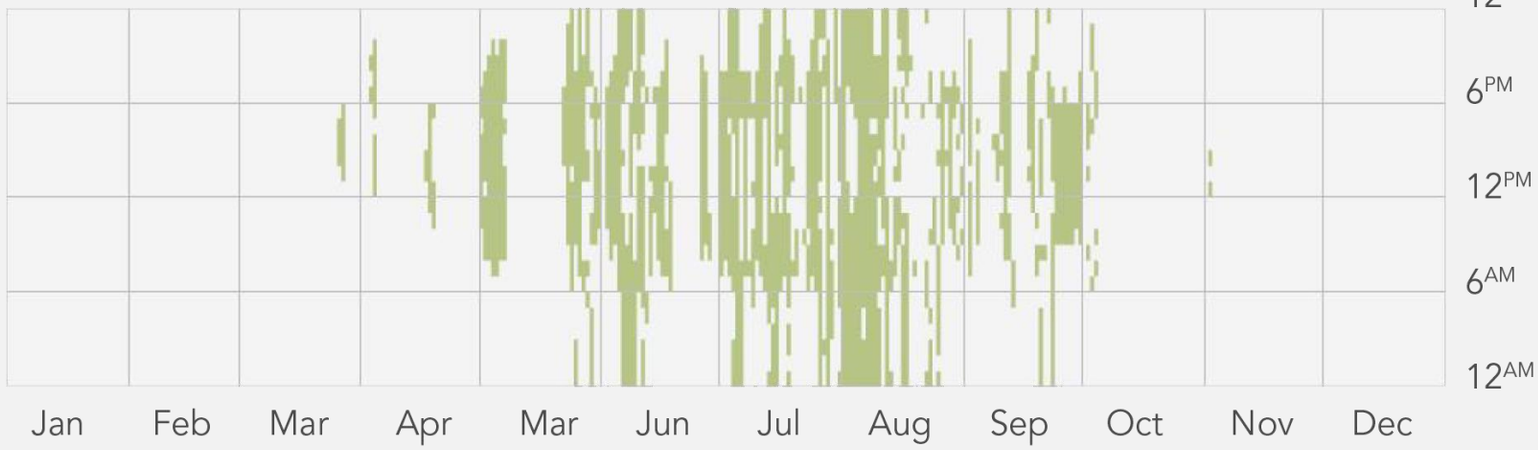


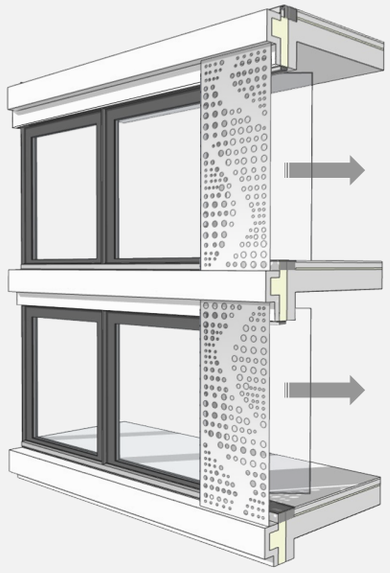


Openable W. +Vegetation

130m

1397 hours

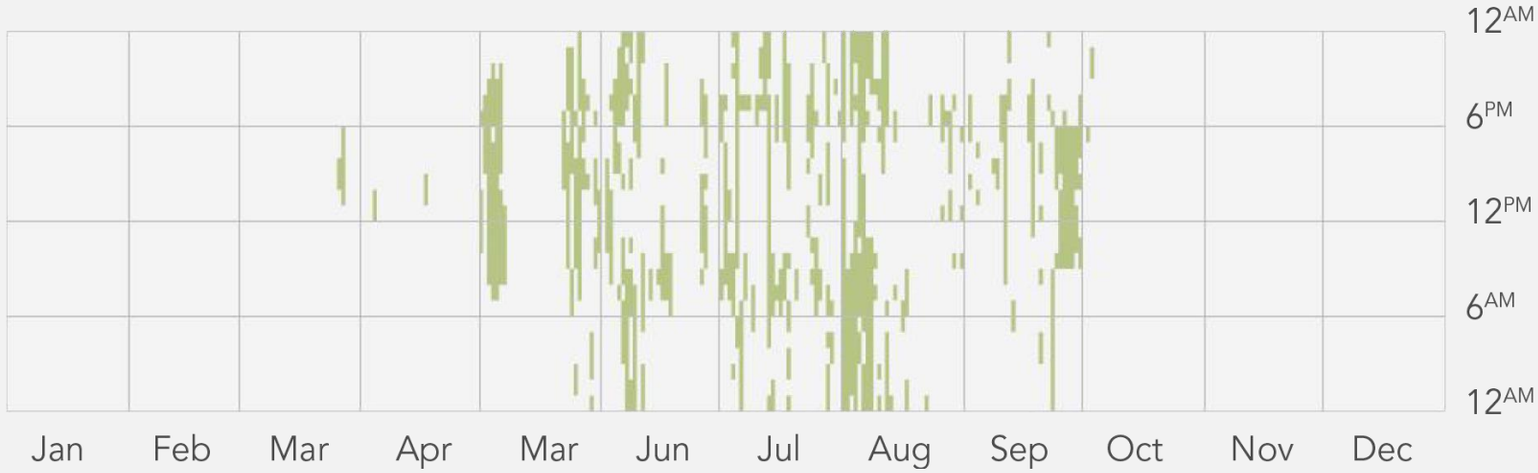




Openable W. +Perf.Screen

130m

772 hours

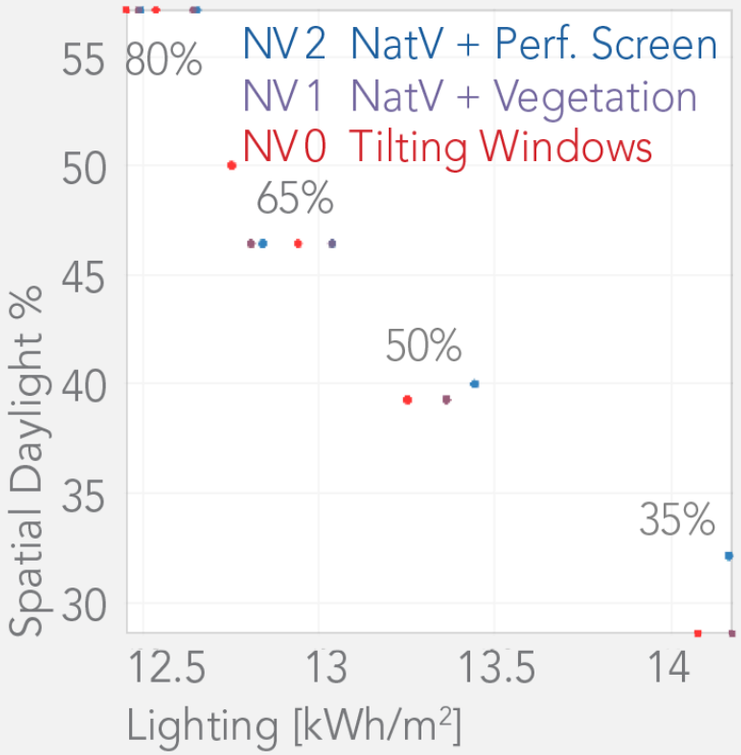


TUDelft

Cristina Maria Mărginean

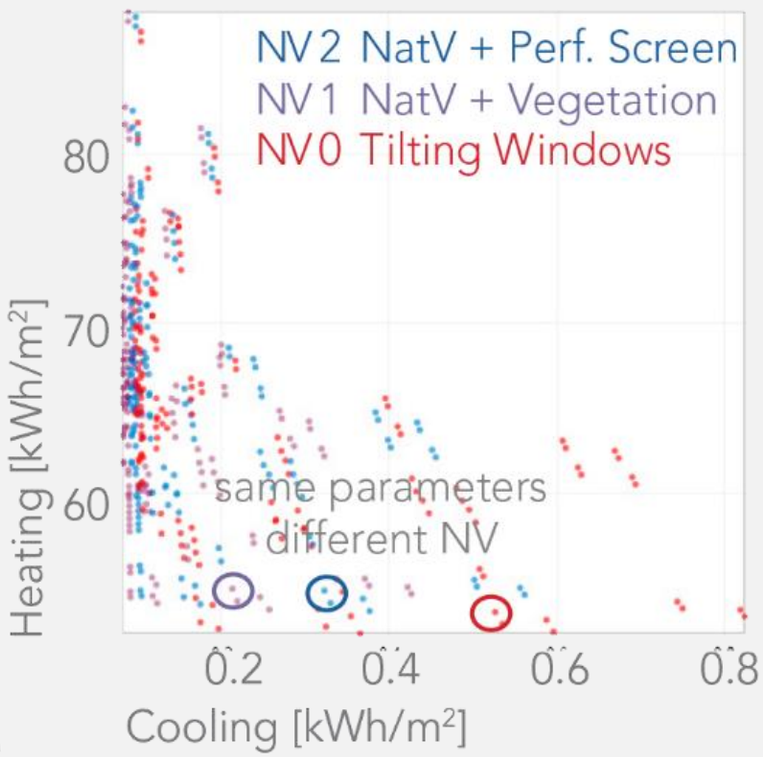
IMPACT

DAYLIGHT



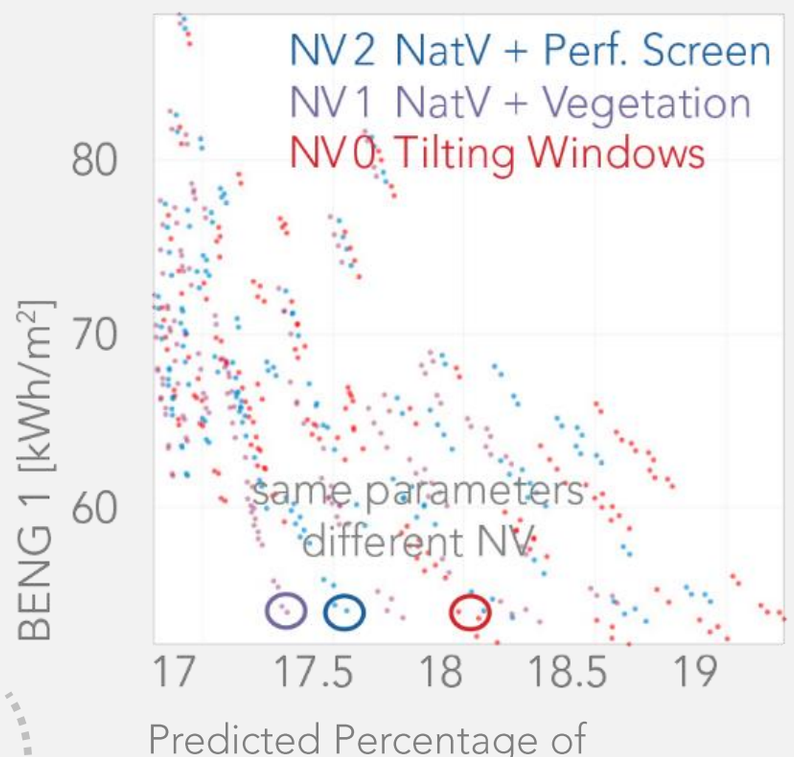
IMPACT

ENERGY



IMPACT

THERMAL COMFORT

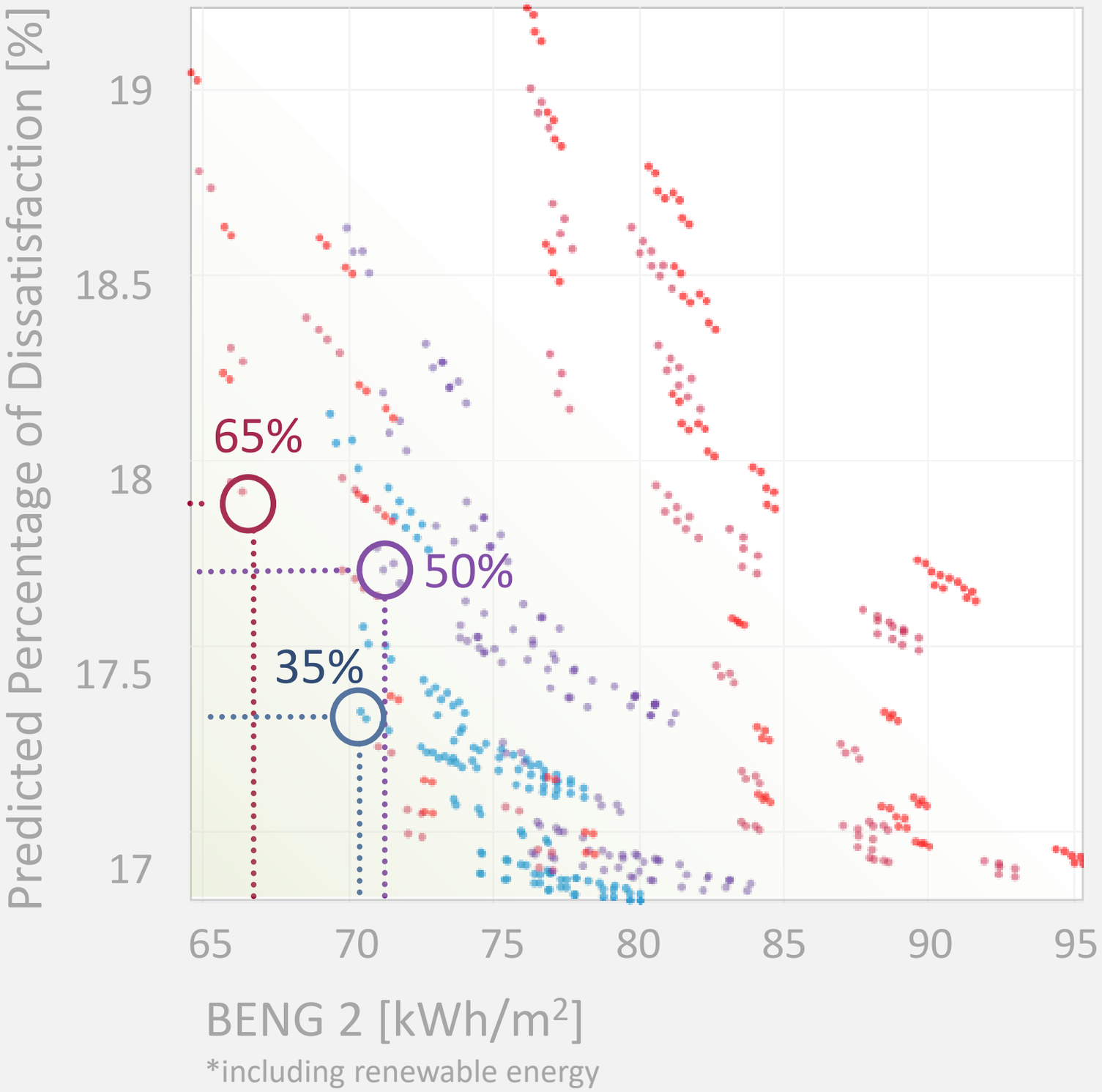


Small impact on
DAYLIGHT

0-4%

PARAMETER

COMBINATIONS



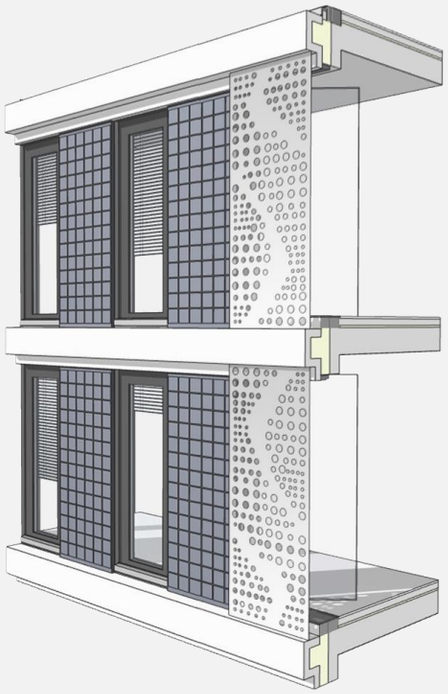
TU Delft

PARAMETER

COMBINATIONS

35%

BIPVT Façade
Triple Glz 0.9, 0.6, 80
No Shading/Interior Blinds
Open.W. + Perf. Screen/ Vegetation
6.0 m^2K/W



50%

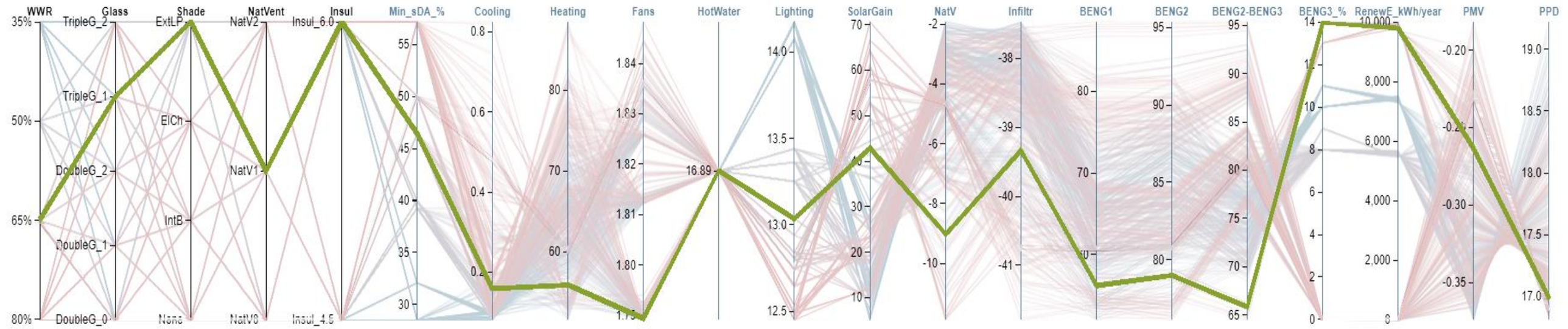
BIPVT Façade
Triple Glz 0.9, 0.6, 80
No Shading/Interior Blinds
Open.W. + Perf. Screen/ Vegetation
4.5 / 6.0 m^2K/W

65%

PVT Shading
Triple Glz 0.9, 0.6, 80
Exterior PVT Shading
Open.W. + Perf Screen/ Vegetation
4.5 / 6.0 m^2K/W

	35%	50%	65%
Daylight [%]	28.6	39.3	46.4
Heating [kWh/m²]	54.2	53.9	56.1
Cooling [kWh/m²]	0.10	0.12	0.16
Renewable Energy [%]	11	9	14
PPD [%]	17.5	17.7	17.9

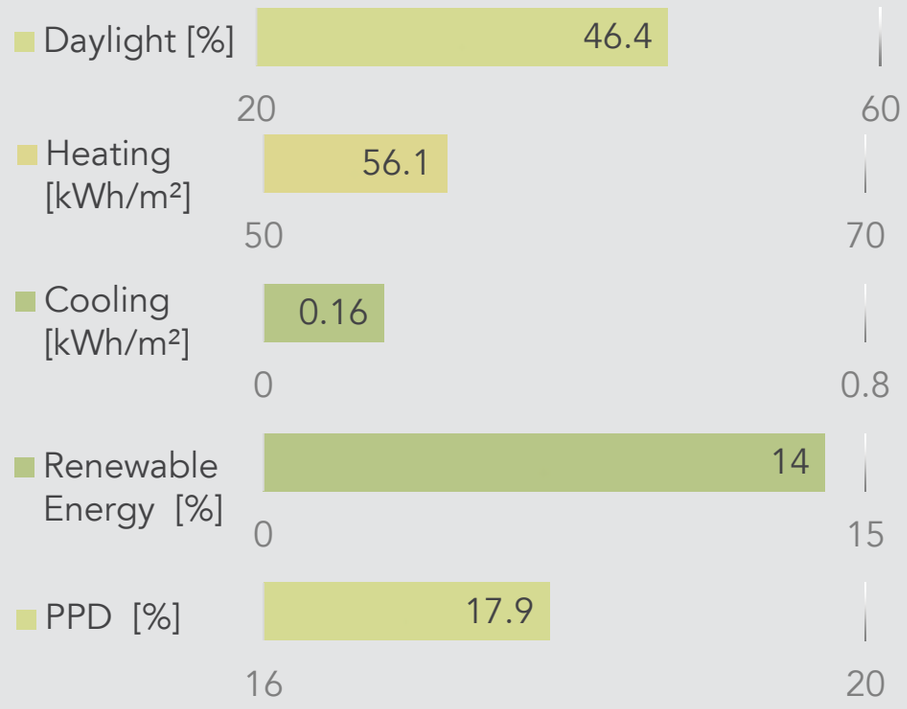
PERFORMANCE



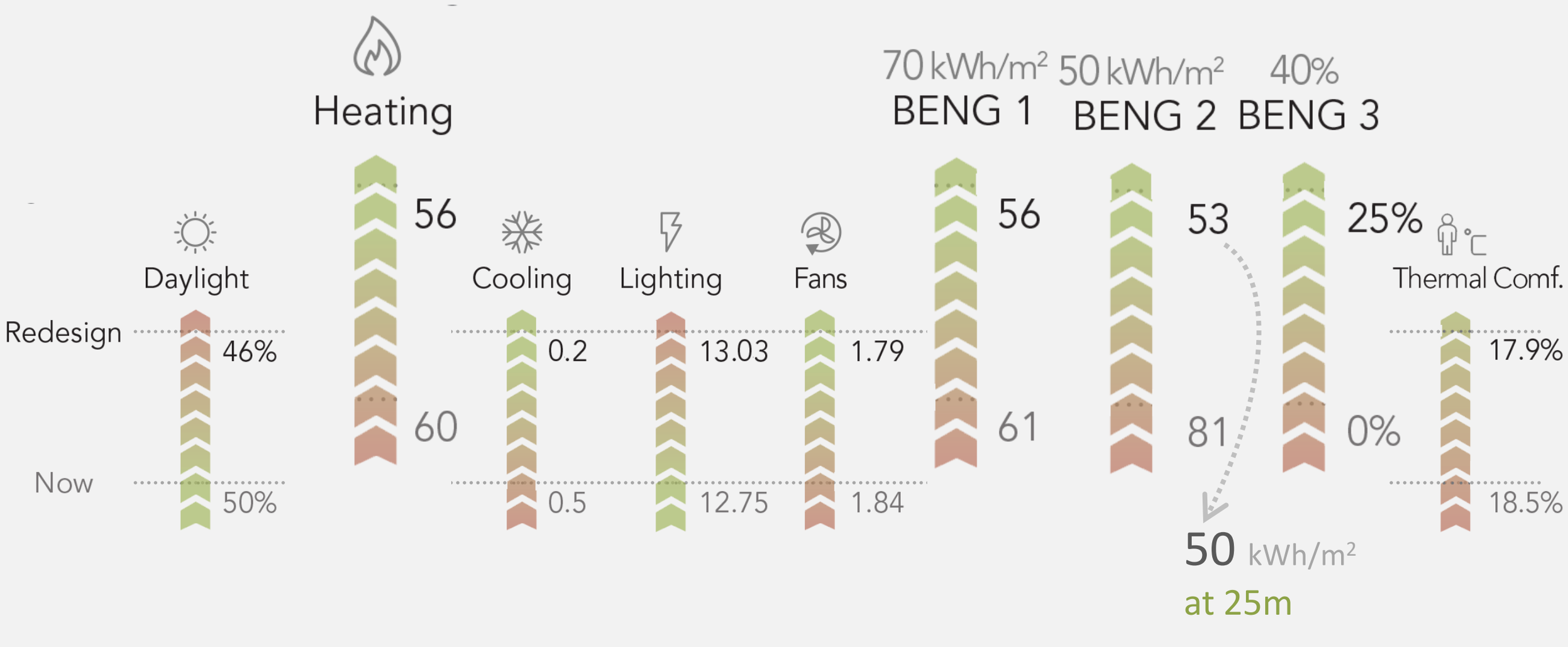
Redesign

Redesign

WWR: 65%
Energy: PVT Shading
Glazing: Triple Glz 0.9, 0.6, 80
Shade: Exterior PVT Shading
NatVent: Open. W. + Vegetation
Insulation: 6.0 m^2K/W



PERFORMANCE



*including the energy produced on the façade and the balconies

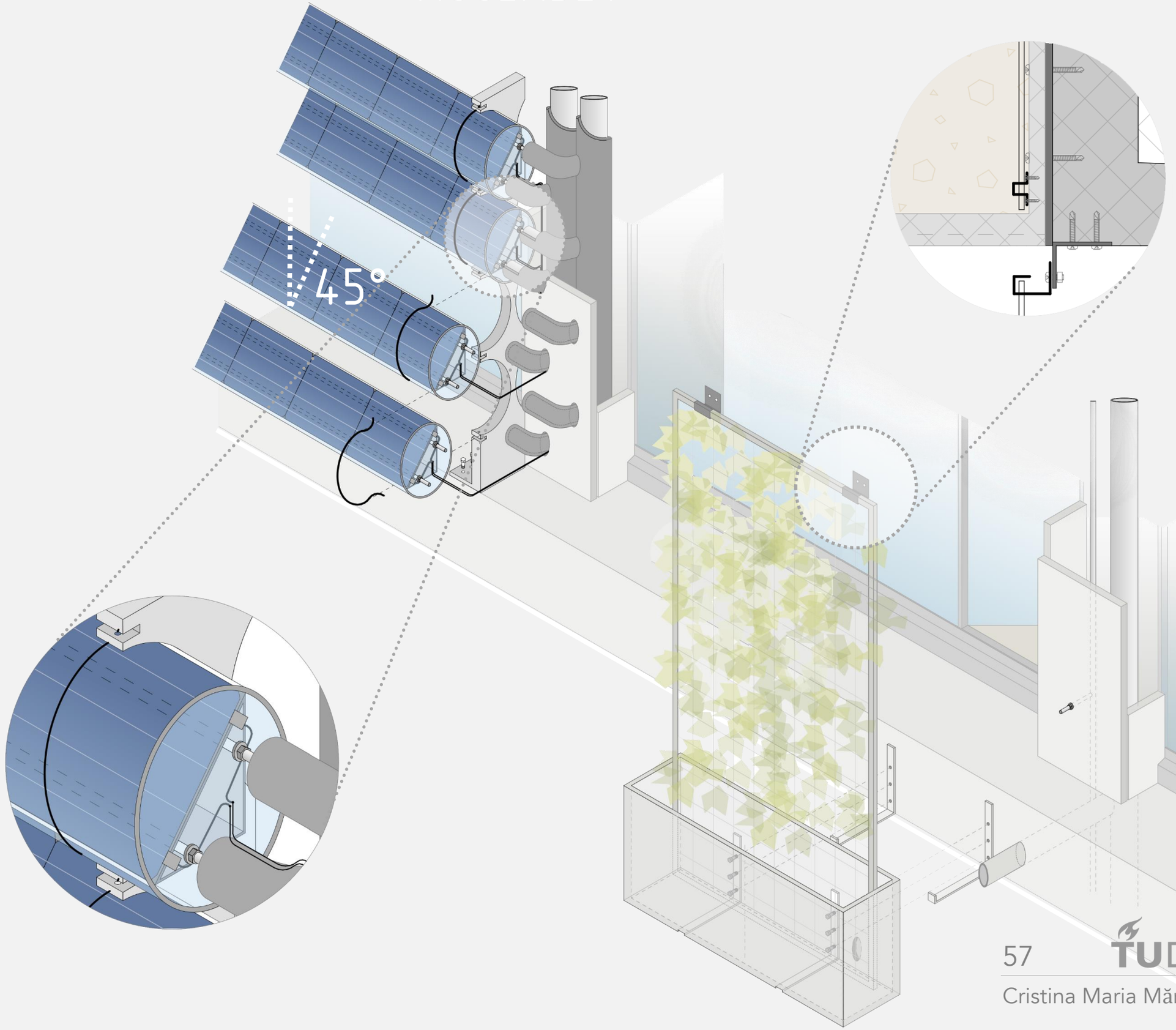
Before

After

V8 Architects

V8 Architects (Redesign)

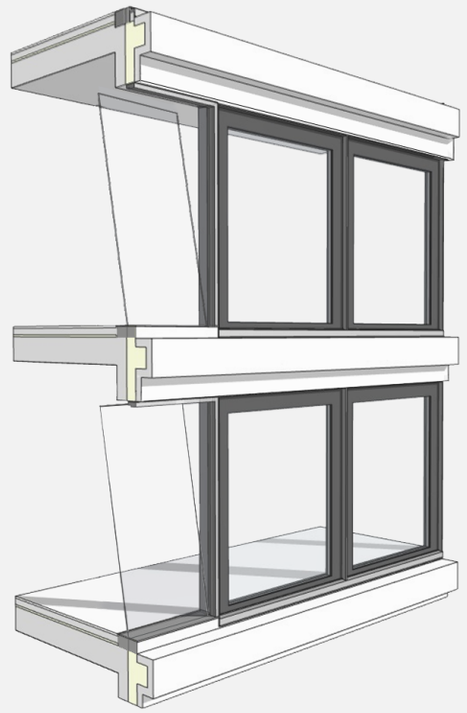
ASSEMBLY



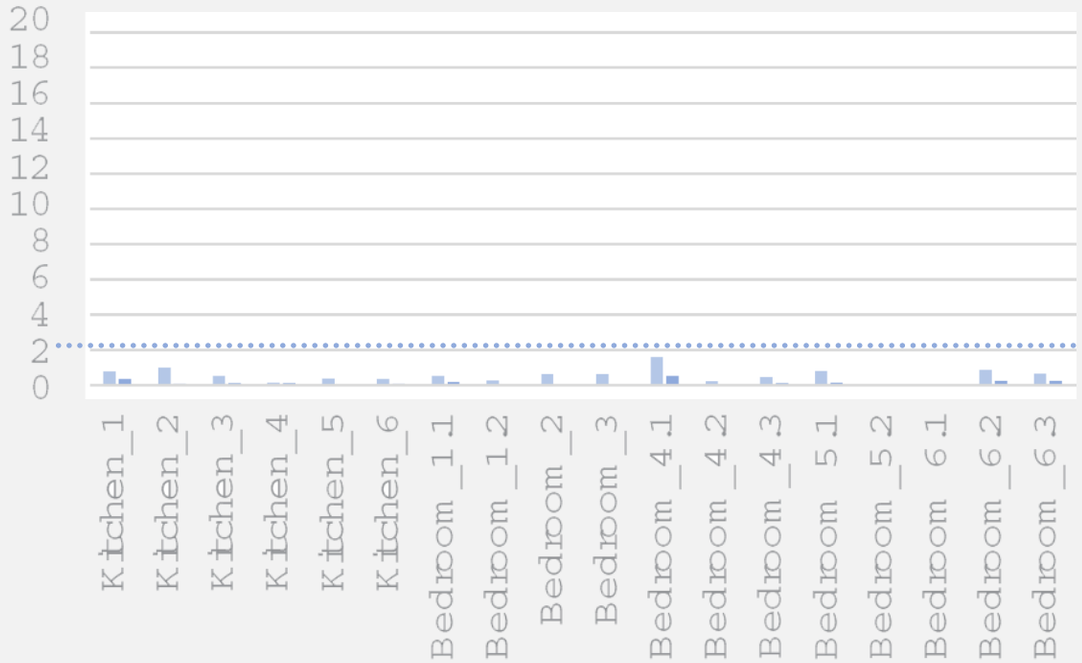
THERMAL

COMFORT

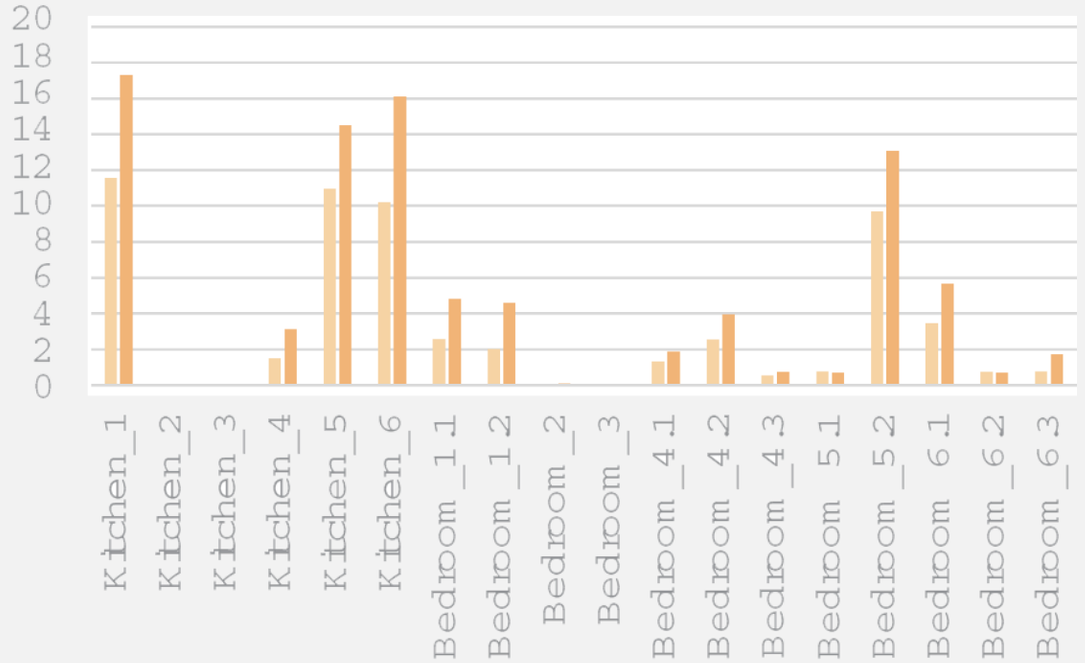
65% WWR, DoubleGlz, No Shading,
Tilting Windows, 4.5 m^2K/W



Current Situation



% Time Too COLD ■ 25m ■ 130m



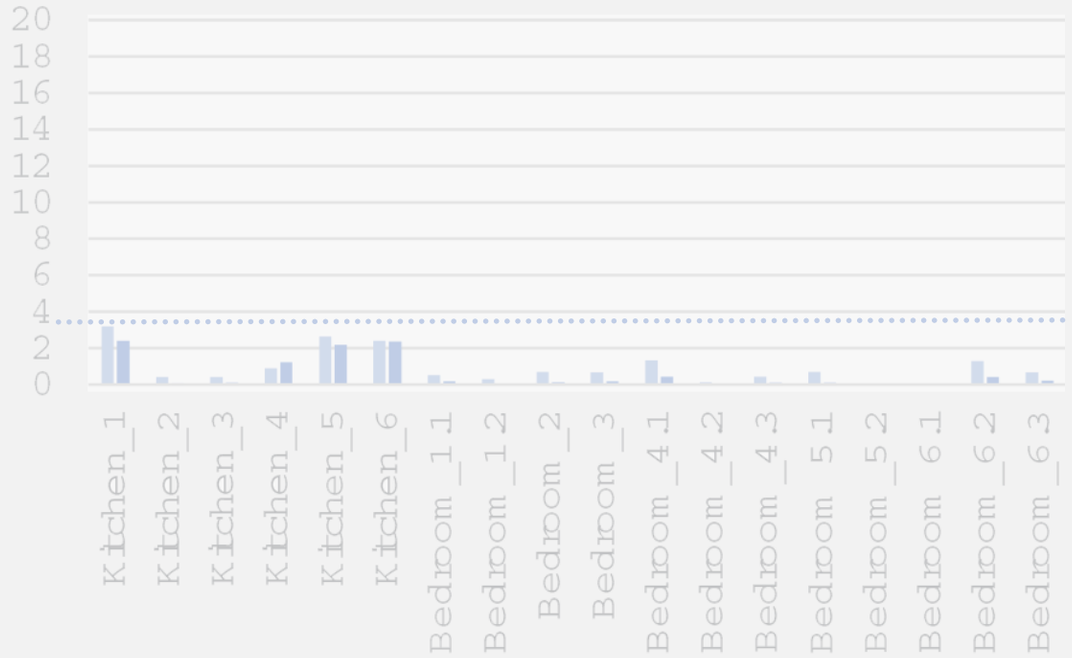
% Time Too HOT ■ 25m ■ 130m

THERMAL

COMFORT

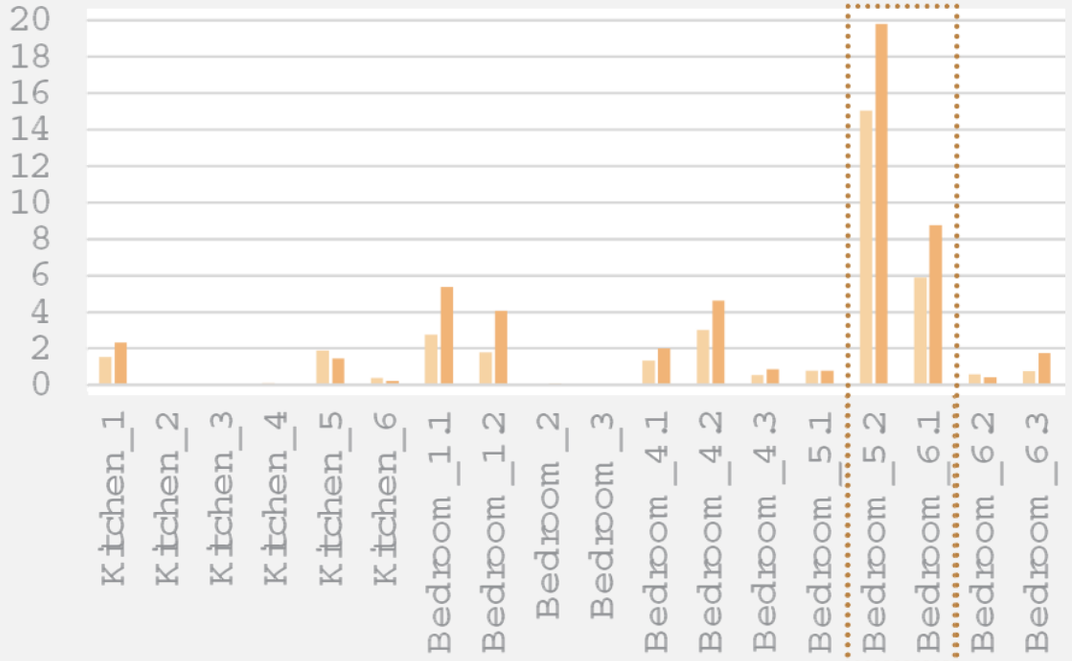
65% WWR, TripleGlz, PVT Shading,
NV with Vegetation, 6.0 m^2K/W

Redesign



% Time Too COLD

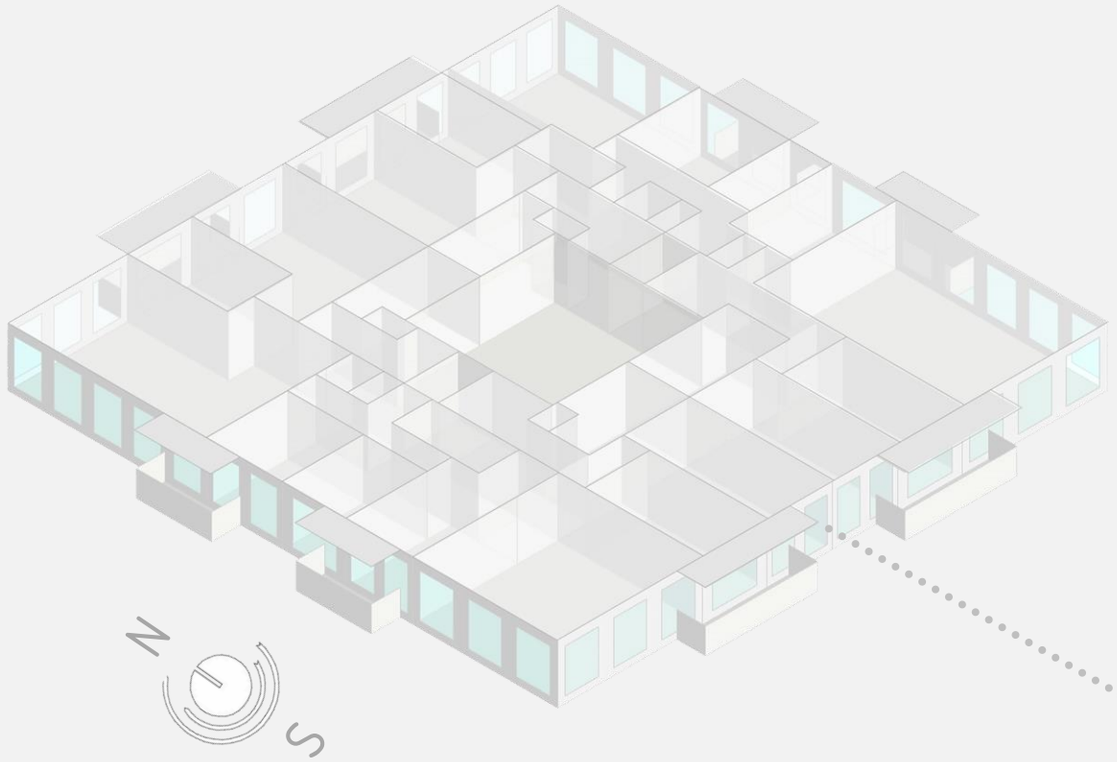
25m 130m



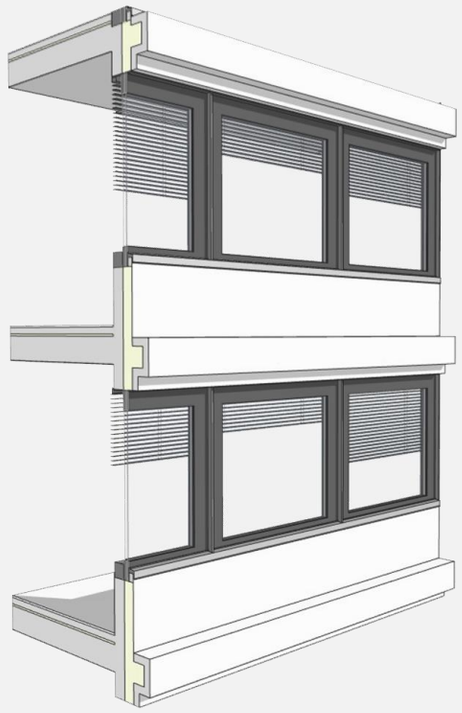
% Time Too HOT

25m 130m

THERMAL
COMFORT

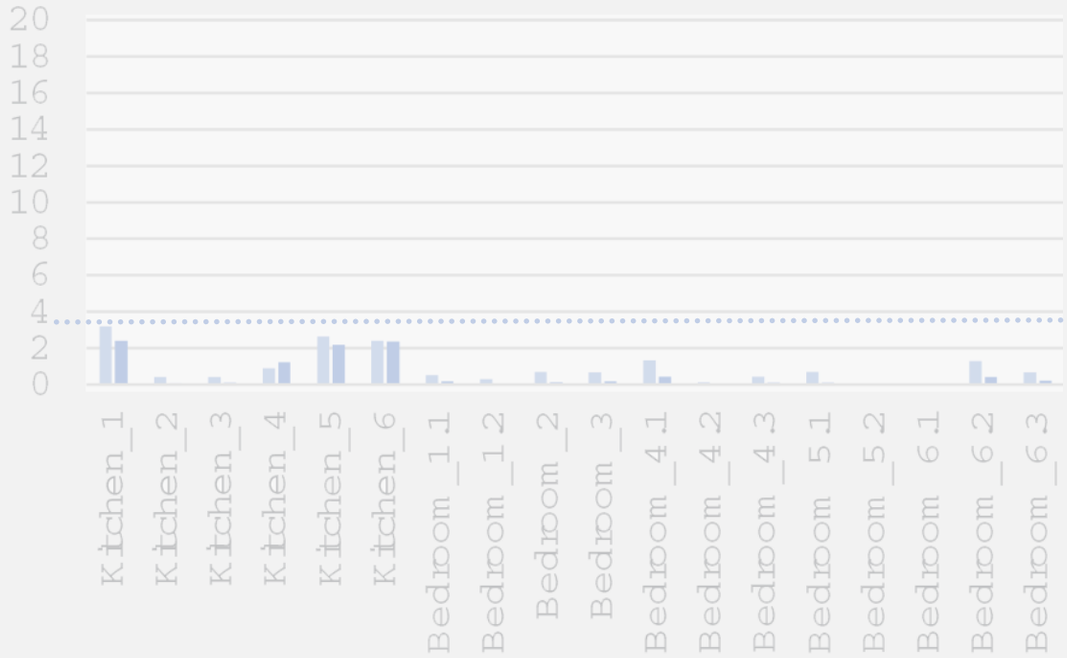


50% WWR, TripleGlz, Interior
Blinds, Tilting Windows, 6.0 m^2K/W

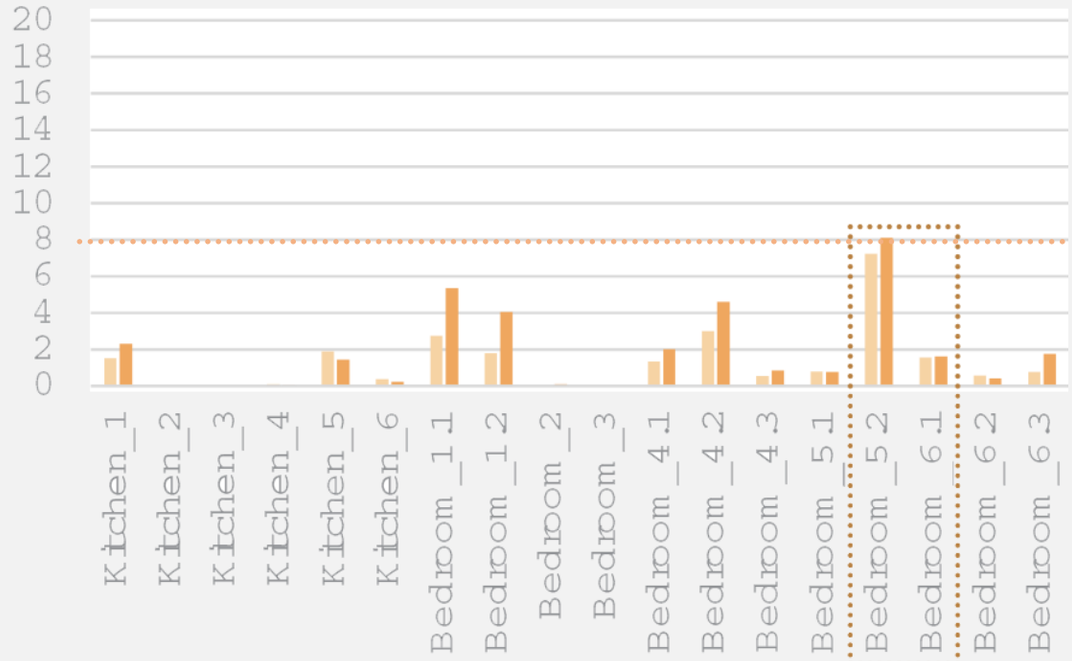


65% WWR, TripleGlz, PVT Shading,
NV with Vegetation, 6.0 m^2K/W

Redesign



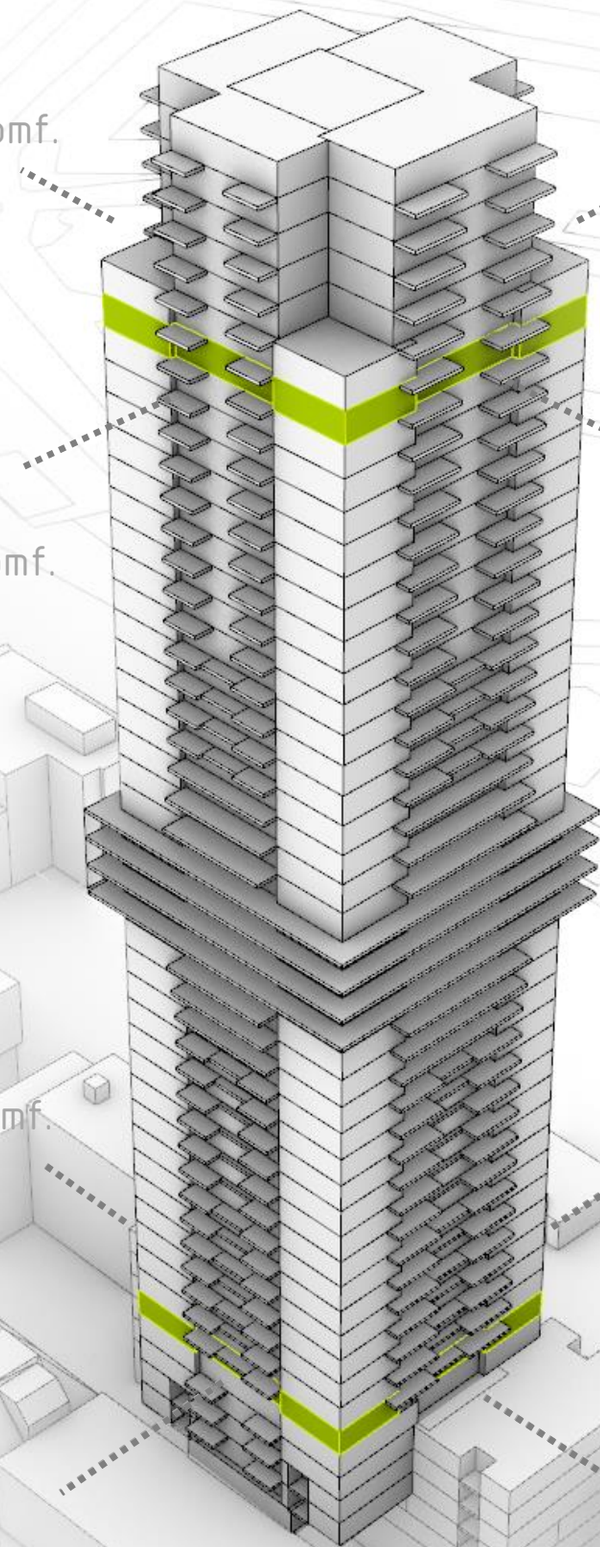
% Time Too COLD 25m 130m



% Time Too HOT 25m 130m

OUTDOOR COMFORT

SUMMER



N
24% time comf.

E
53% time comf.

W
20% time comf.

S
31% time comf.

N
41% time comf.

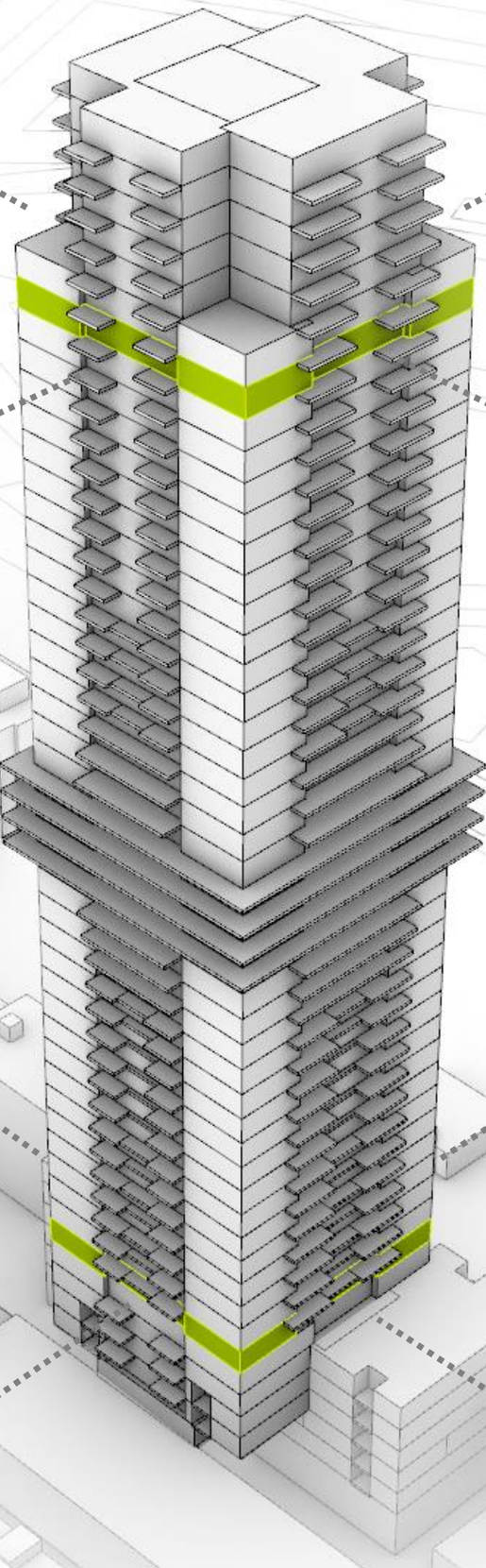
E
67% time comf.

W
40% time comf.

S
50% time comf.

OUTDOOR COMFORT

ANNUAL



N

24% time comf.

11% time comf.

E

53% time comf.

20% time comf.

W

20% time comf.

8% time comf.

S

31% time comf.

12% time comf.

N

41% time comf.

20% time comf.

E

67% time comf.

27% time comf.

W

40% time comf.

17% time comf.

S

50% time comf.

20% time comf.

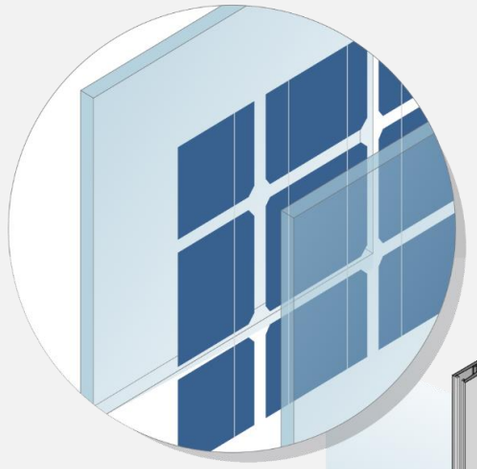
PV Glazing 43 m^2

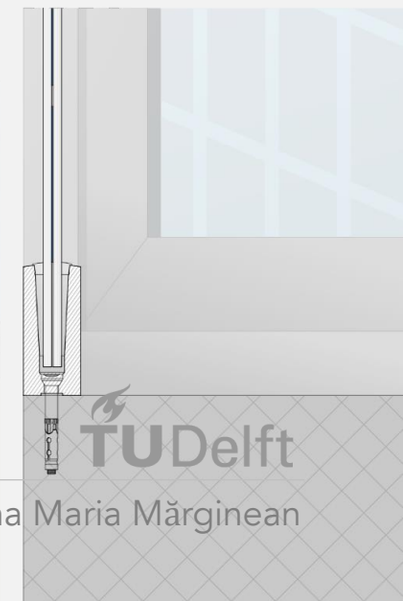
7890 kWh/floor

PV/T Tubes 68 m^2

9786 kWh/floor

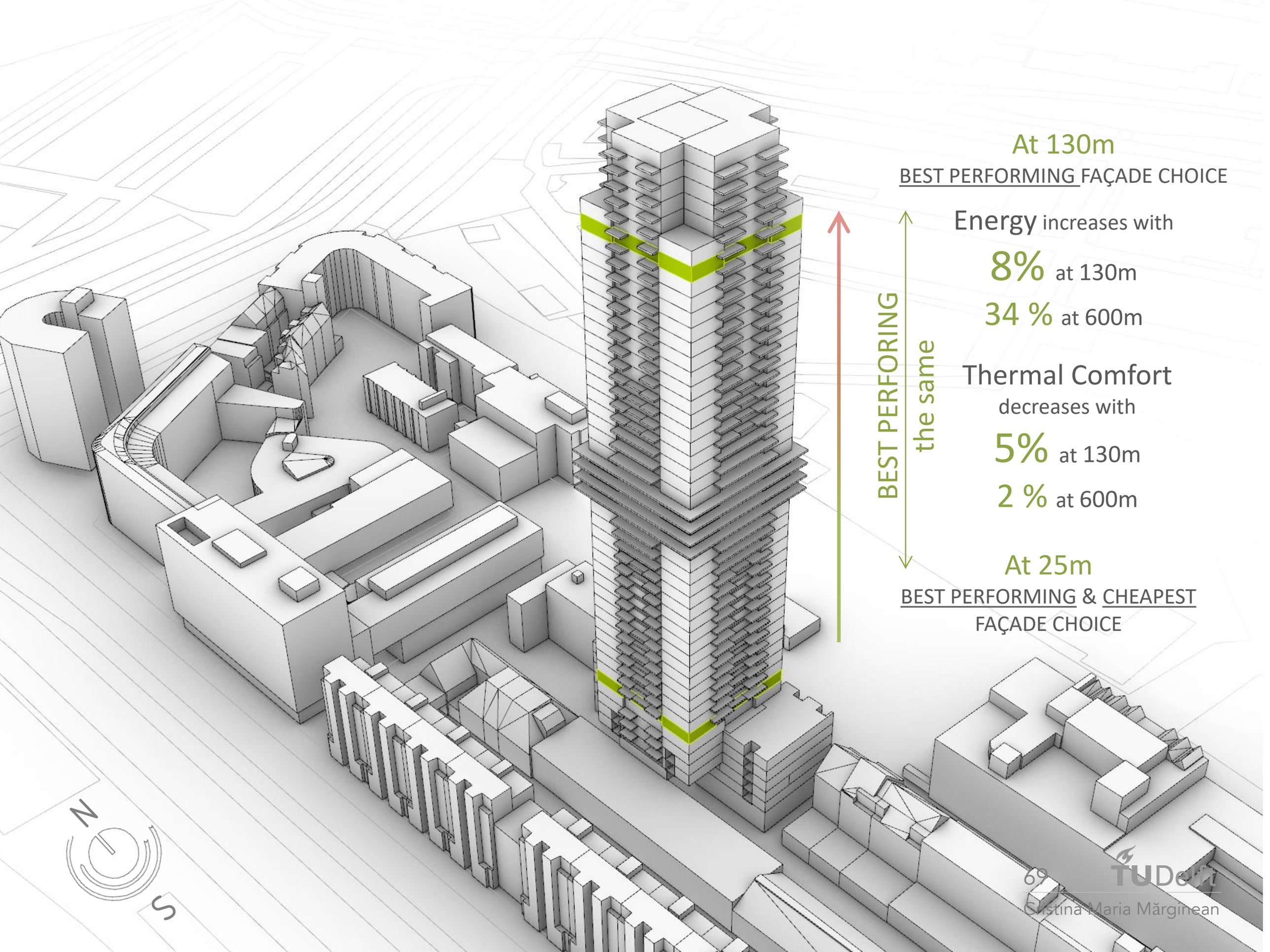
-24 kWh/floor





6 Conclusion

‘What is the impact of facade design on energy, daylight and thermal comfort to achieve a nearly zero-energy residential high-rise building in a temperate climate?’


At 130m
BEST PERFORMING FAÇADE CHOICE
Energy increases with
8% at 130m
34 % at 600m
Thermal Comfort
decreases with
5% at 130m
2 % at 600m
BEST PERFORING
the same
At 25m
BEST PERFORMING & CHEAPEST
FAÇADE CHOICE
N
S

NORTH

WWR 50%

Interior Blinds

Triple Glazing

Perf. Screen/Vegetation

Insul. 4.5/6.0 m^2K/W

WEST | EAST

WWR 65%

PVT Exterior Shading

Triple Glazing

Perf. Screen/Vegetation

Insul. 4.5/6.0 m^2K/W

SOUTH

WWR 50% & 65%

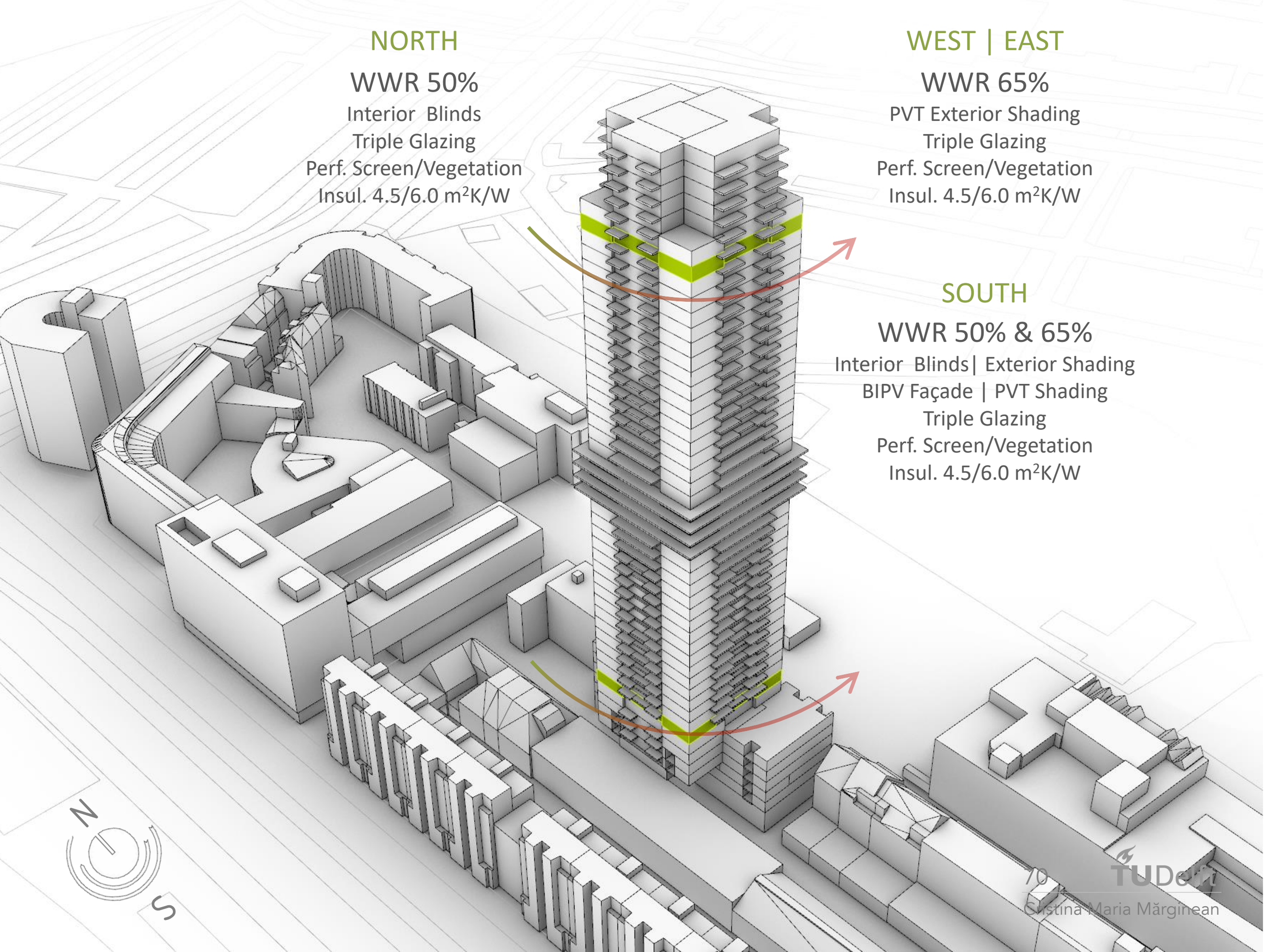
Interior Blinds| Exterior Shading

BIPV Façade | PVT Shading

Triple Glazing

Perf. Screen/Vegetation

Insul. 4.5/6.0 m^2K/W



PARAMETER

IMPACT

Individual Energy Reduction

-12% Window to Wall Ratio

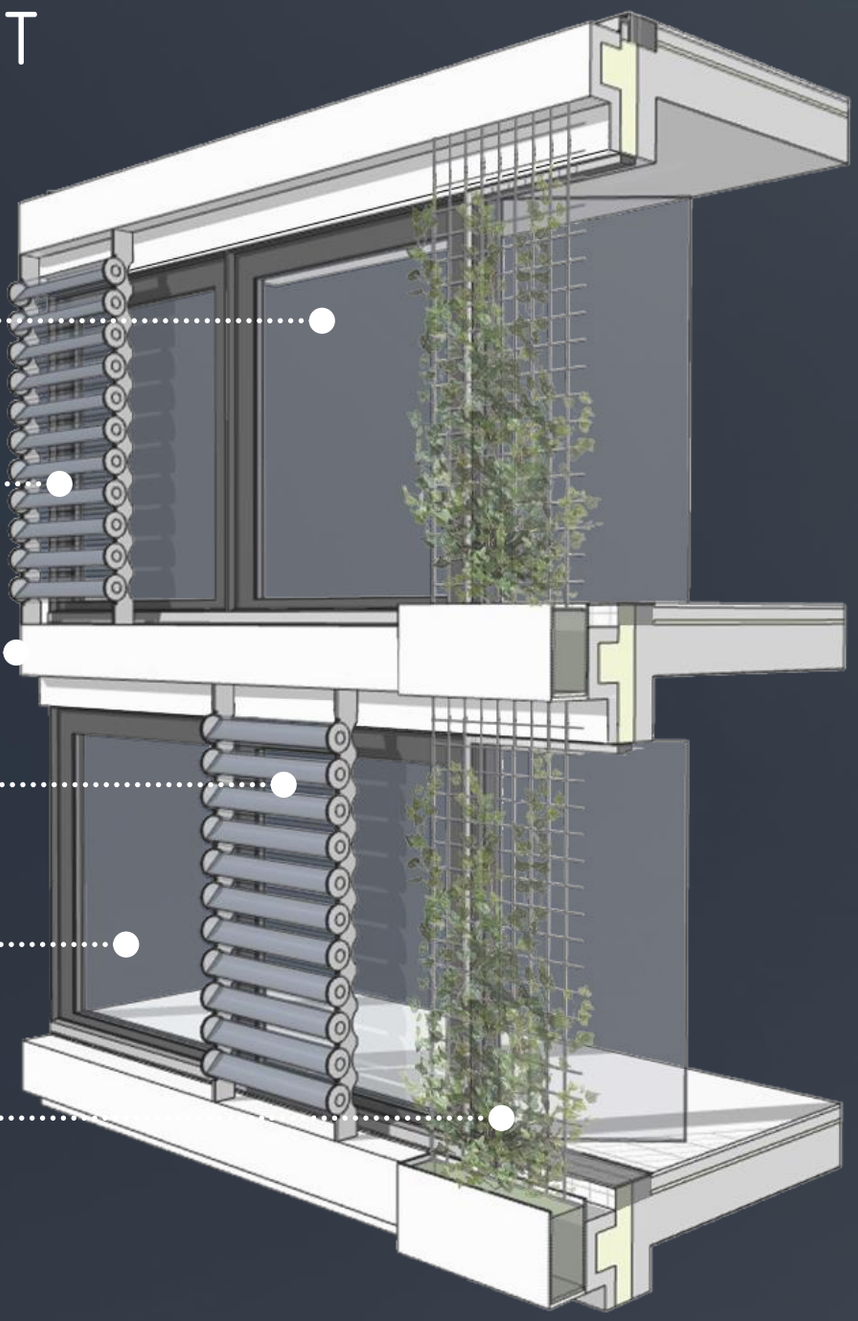
-20% Energy Production

-1.5% Thermal Insulation

-9% Shading System

-10% Glazing Type

-3% Natural Ventilation



Combined

ENERGY

-35%

-30 kWh/m²

THERMAL COMFORT

+15%

DAYLIGHT

-4%

TUDelft
Cristina Maria Mărginean

Witteveen + Bos

TU Delft
Delft
University of
Technology