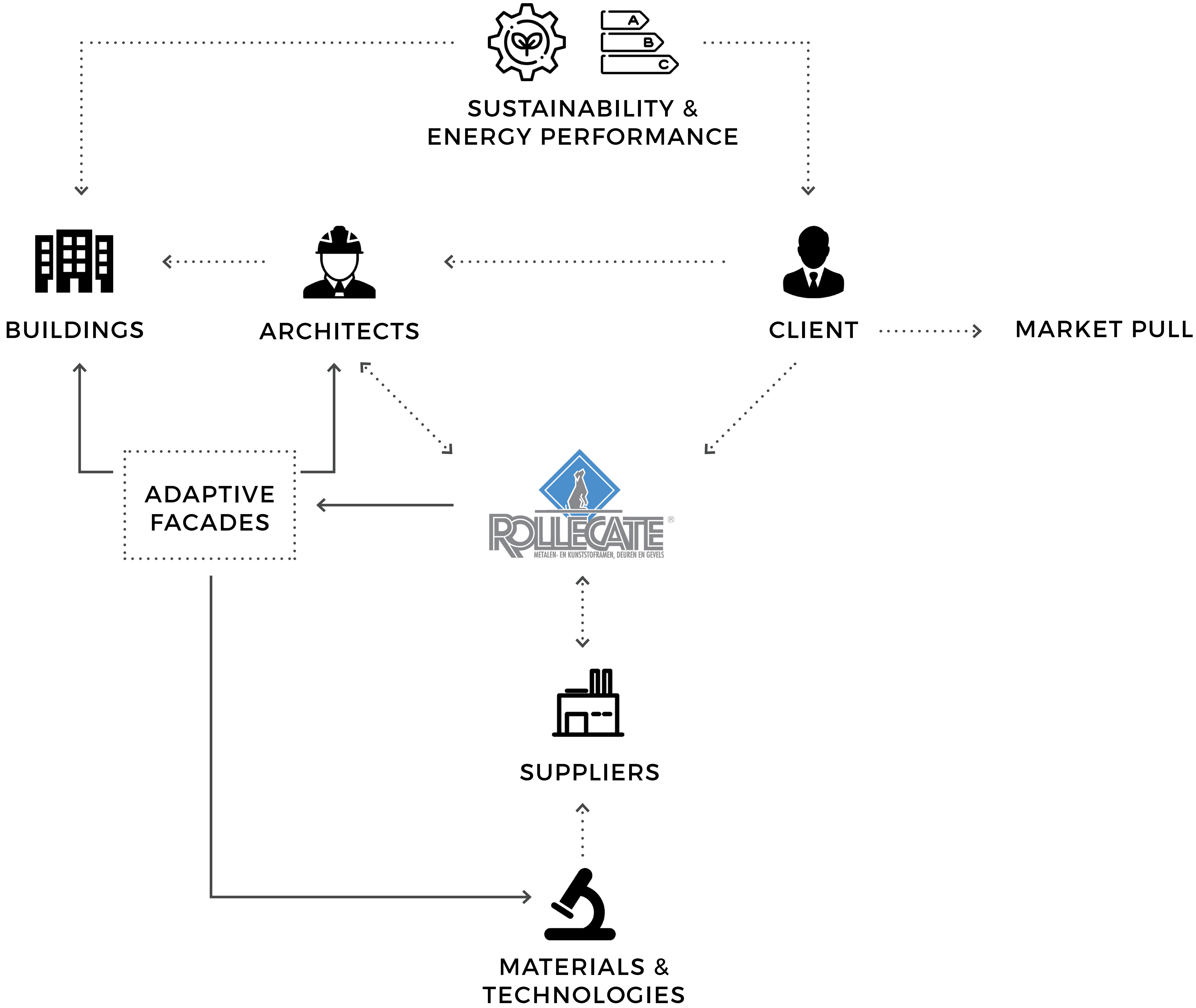
MULTI-FUNCTIONAL FACADE MODULE

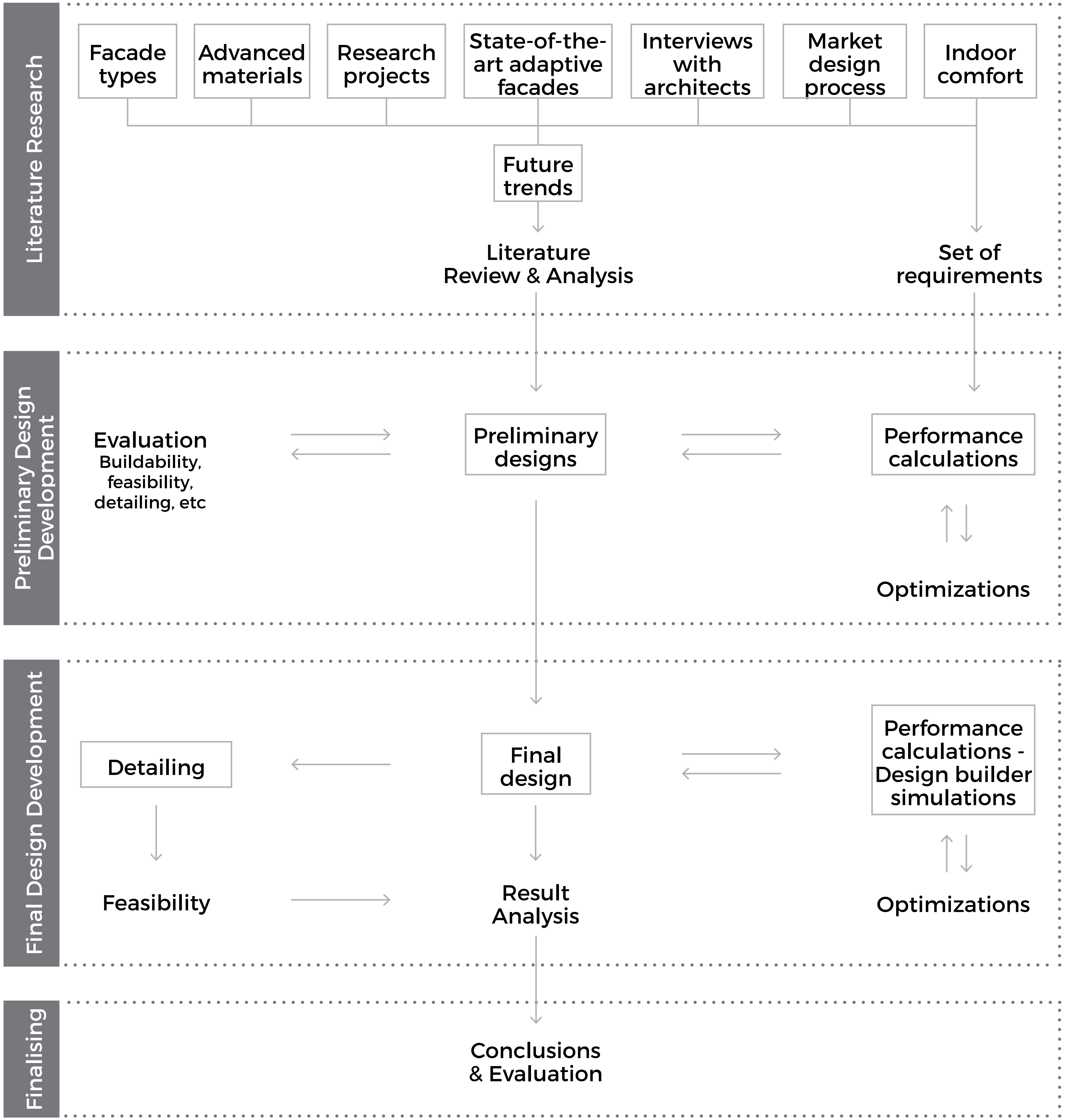
FOR DIFFERENT CLIMATE CONDITIONS

Maria Mourtzouchou
Student No. 4621484
First Mentor: Dr.ir. Tillmann Klein
Second Mentor: Ir. Eric van den Ham
External Examiner: Ir. Jelle Koolwijk

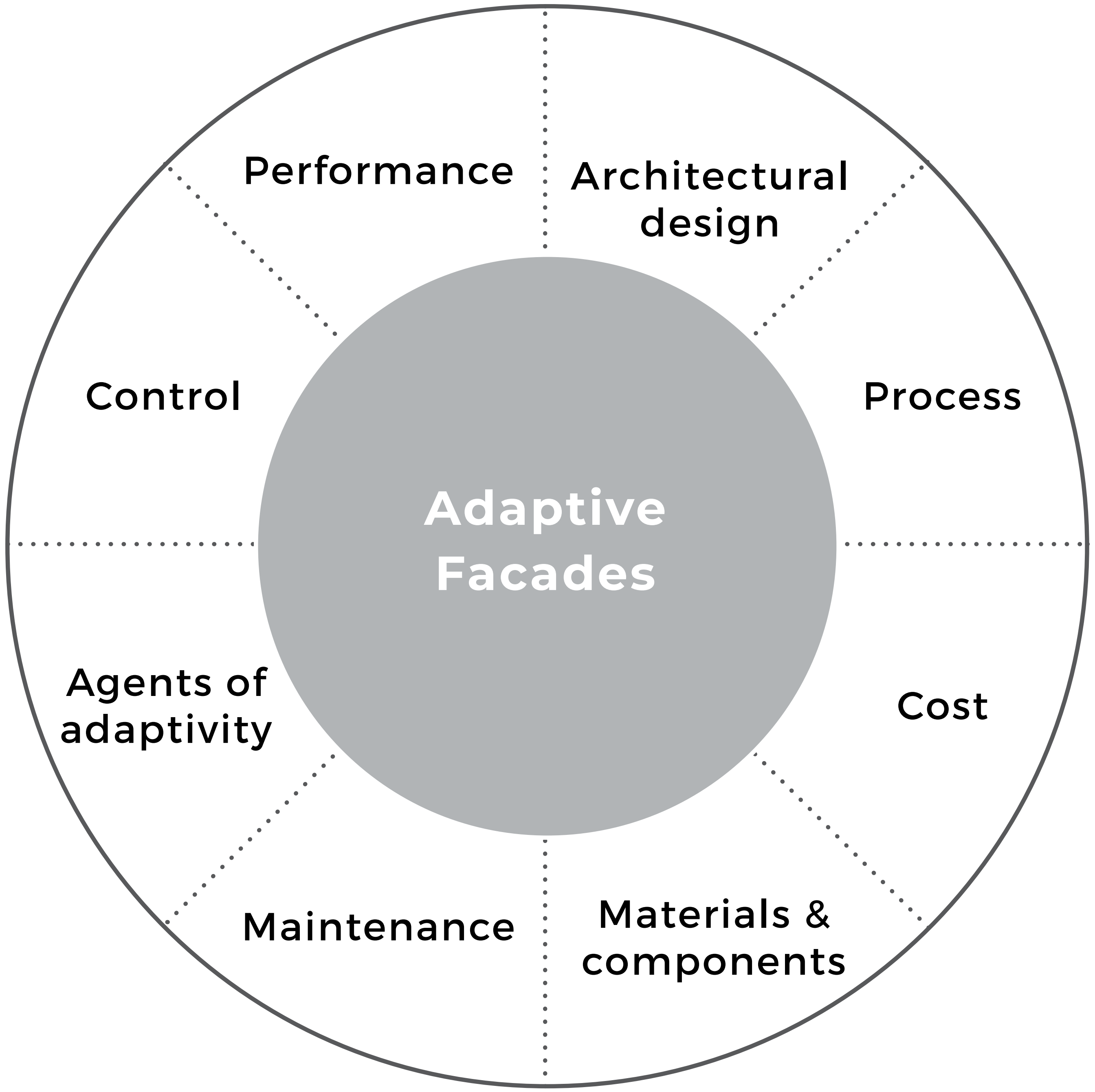
OVERVIEW


SUSTAINABILITY &
ENERGY PERFORMANCE
BUILDINGS
ARCHITECTS
CLIENT
MARKET PULL
ADAPTIVE
FACADES
ROLLECATE
SUPPLIERS
MATERIALS &
TECHNOLOGIES

RESEARCH METHODOLOGY



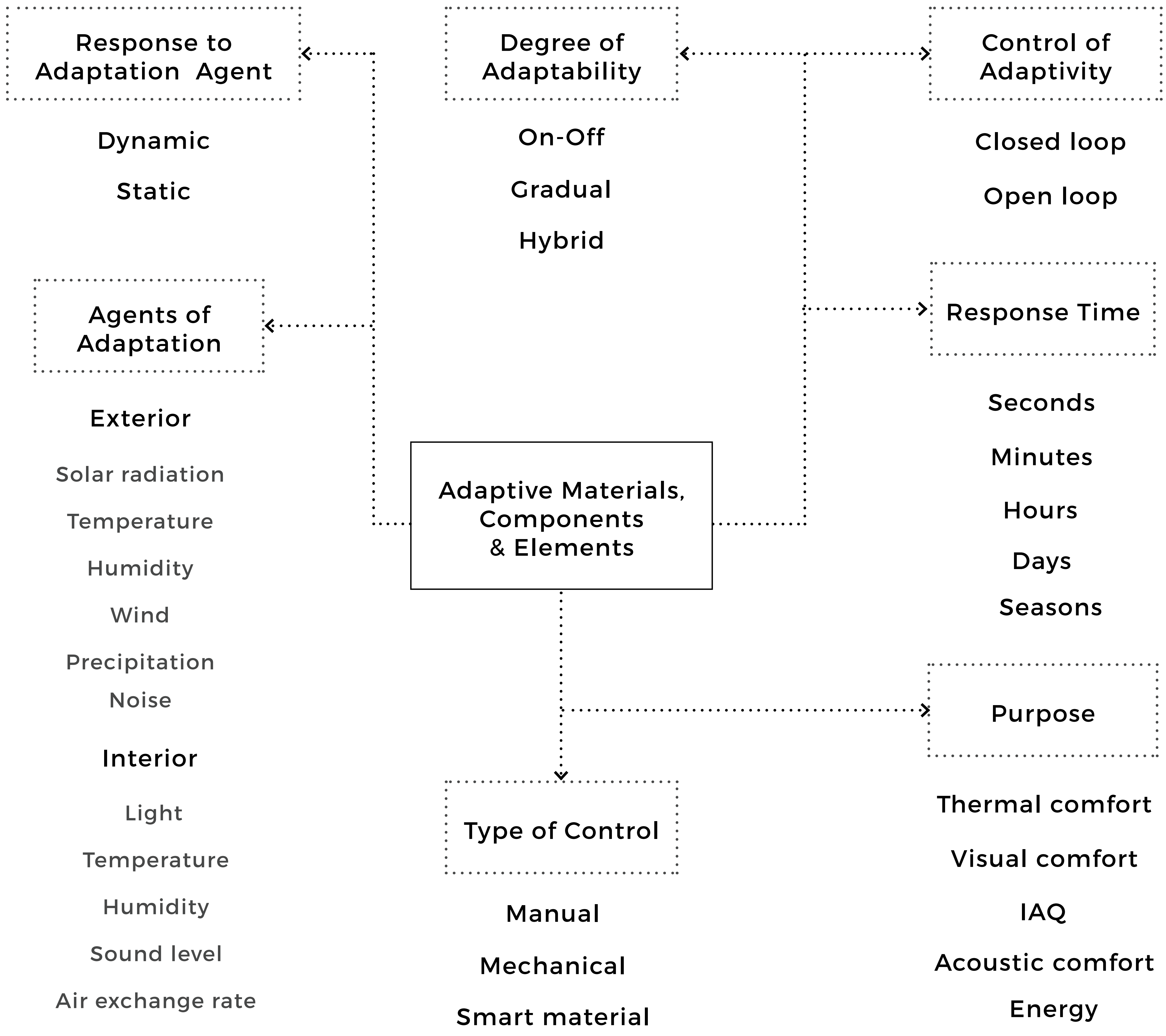
WHAT IS AN ADAPTIVE FACADE?



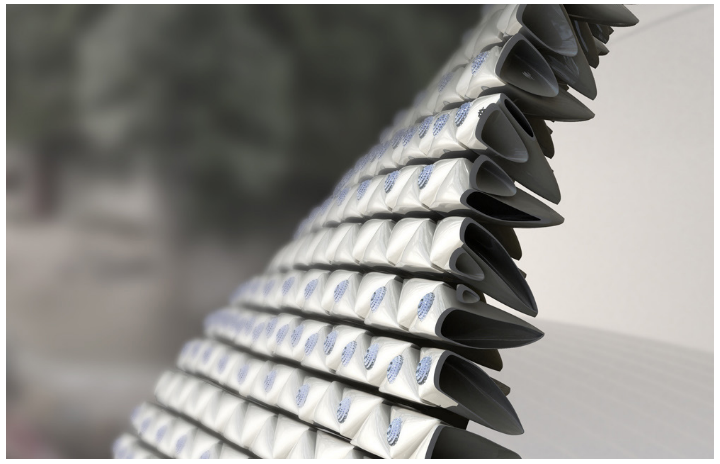
In this Thesis:

Adaptive façades are envelopes that respond both to indoor and outdoor stimuli and change configuration – both physically or chemically - to take advantage of the outdoor climate and offer a systematic flexibility that responds situationally in relation to specific points in time with the aim to improve both the building performance and the user comfort.

MATERIALS & TECHNOLOGIES



REFERENCE PROJECTS



SABER (Self-Activated Building Envelope Regulation)

BIOMS team of researchers

University of California, Berkeley

2014

Response to Adaptation Agent

● Dynamic ○ Static

SABER is a new membrane that wraps around a building and it is inspired by the human skin that is able to breathe with the aim of a fully self-regulating system. Resembling the pores of the skin, the membrane is filled with micro-scale valves and lenses that open and close as they sense light, heat, and humidity. It works with a geometrical network of a temperature-responsive phase-change hydrogel capable of swelling or shrinking at a given temperature, releasing or absorbing water vapour. The facade does not require an external power and it offers hygrothermal and light transmission control. This membrane is a net zero cooling option, which doesn't actually cool the air, but it makes buildings in hot, humid tropical countries more comfortable.

Exterior Agent of Adaptation
- ● Solar radiation
- ● Temperature
- ● Humidity
- ○ Wind
- ○ Precipitation
- ○ Noise

Interior Agent of Adaptation
- ● Temperature
- ○ Humidity
- ○ Light
- ● Air exchange rate
- ○ Sound level

Purpose
- ● Thermal comfort
- ● IAQ
- ● Visual and Lighting
- ○ Acoustic
- ○ Energy production

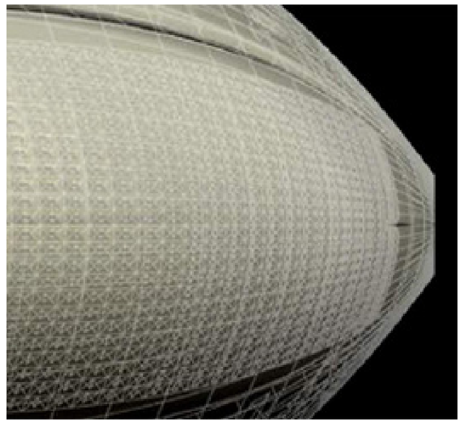
Control of Adaptivity
- ○ Closed loop
- ● Open loop

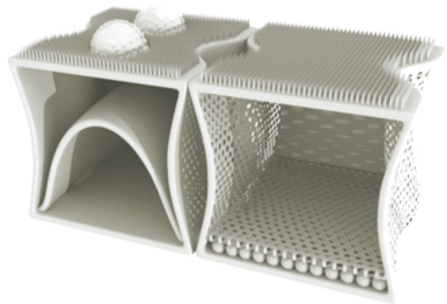
Energy

○ - ● 0 ○ +

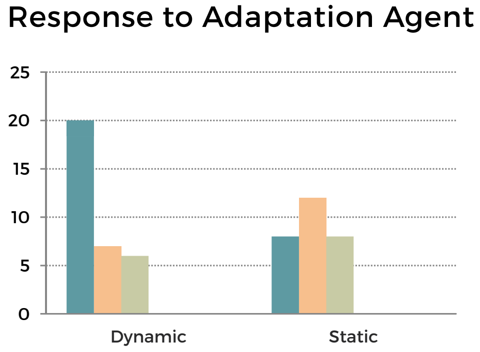
Highest cost
- ○ Materials
- ● Production
- ○ Assembly
- ○ Maintenance

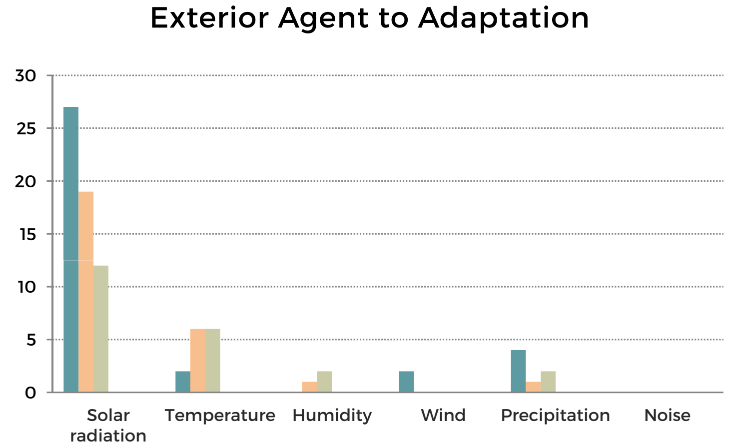
Architecture design freedom
- ○ Low
- ● Medium
- ○ High

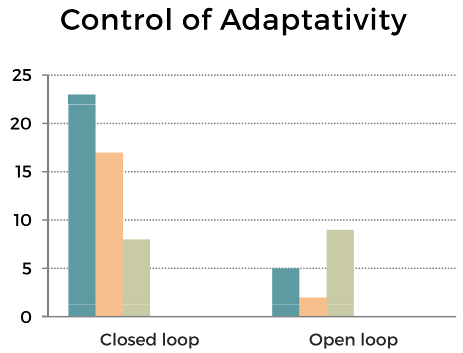


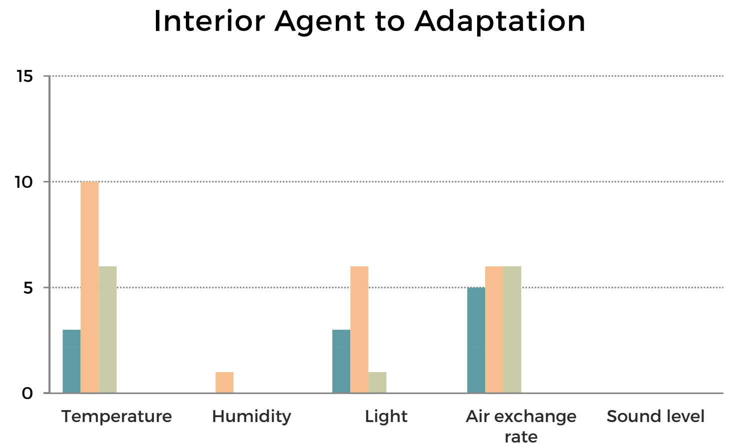


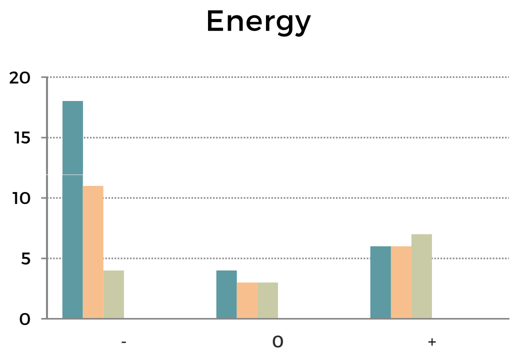
Buildings Products Research Projects

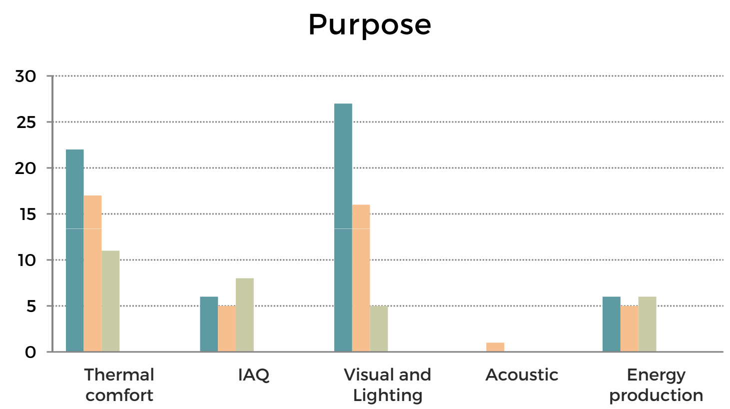


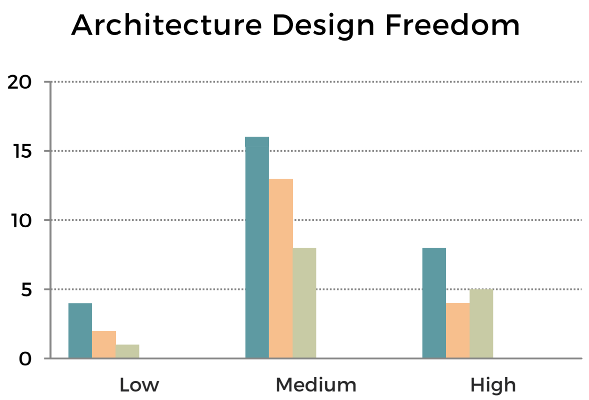


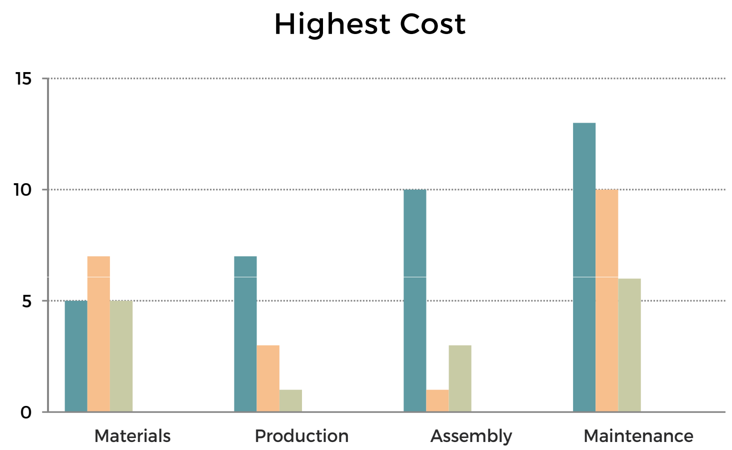






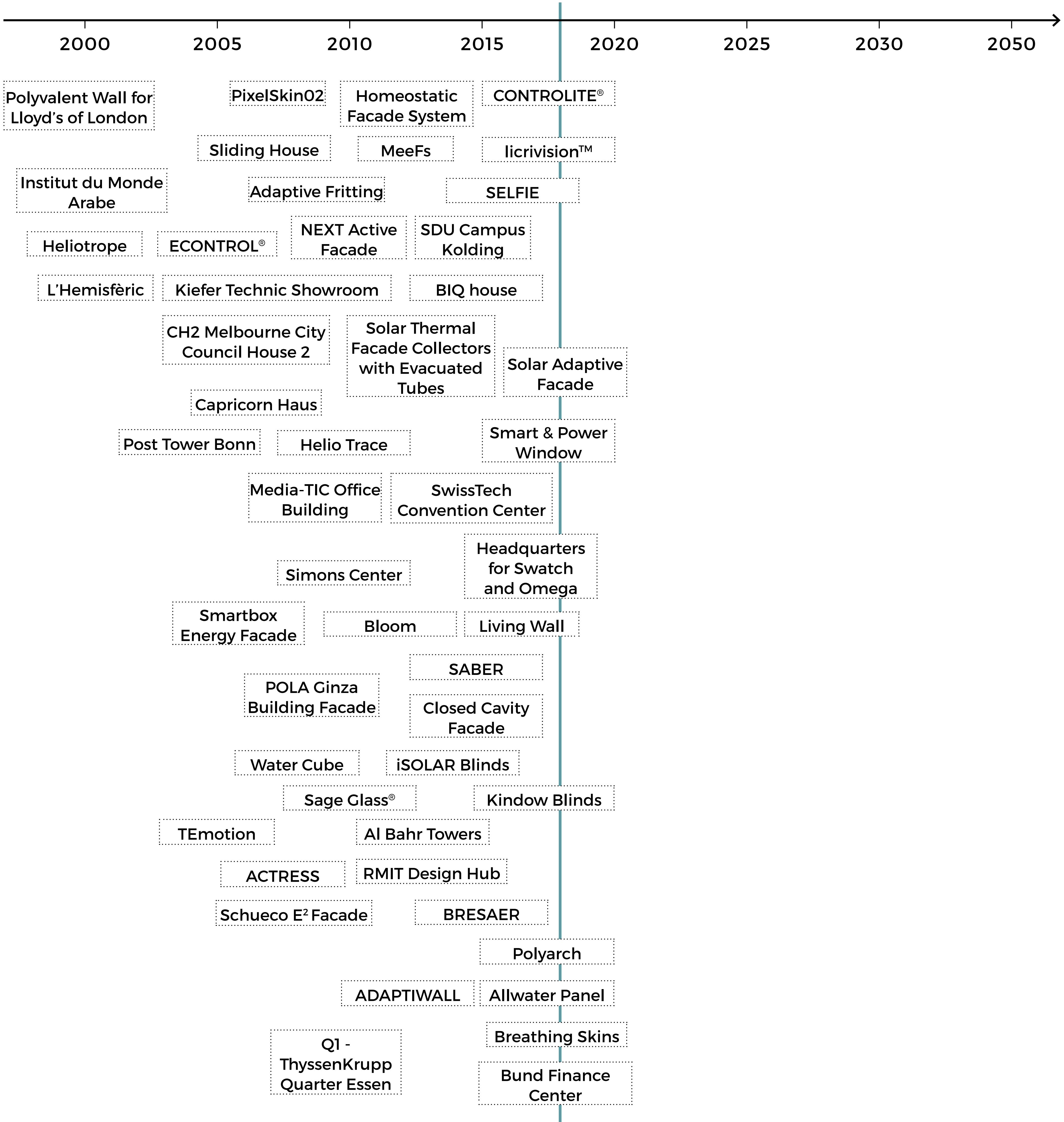




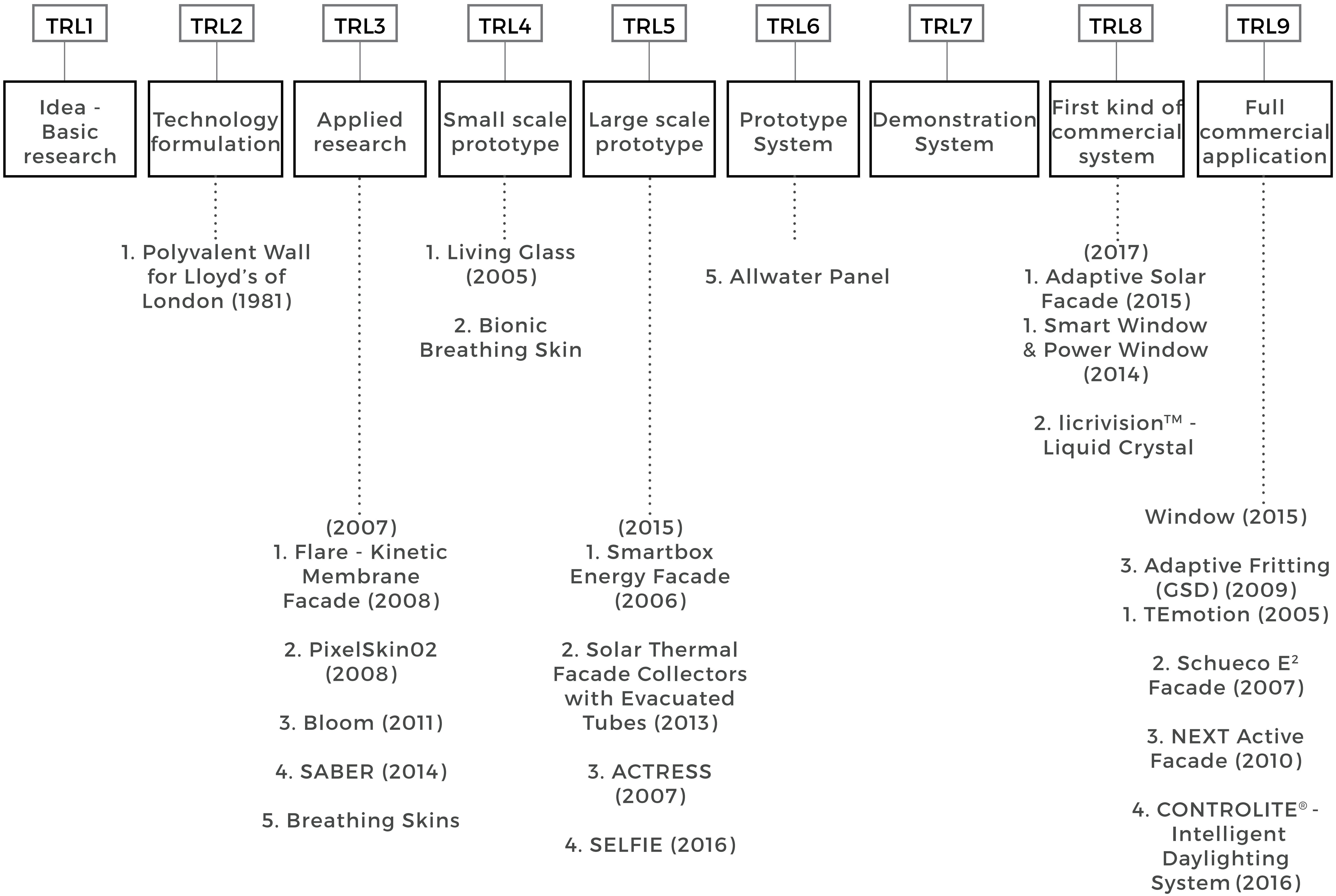


REFERENCE PROJECTS

Thermal Comfort

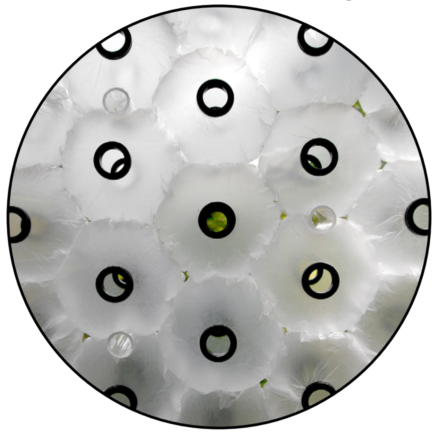


TECHNOLOGY READINESS LEVELS



CONCEPTS OF ADAPTIVITY

Biomimicry

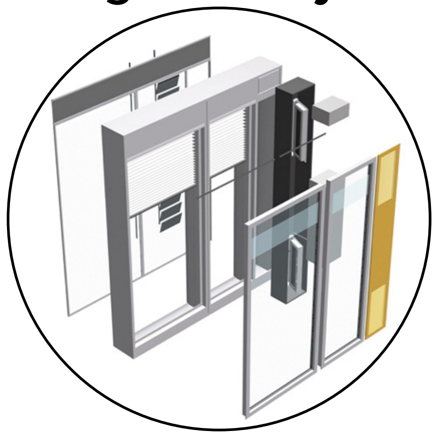


Smart materials

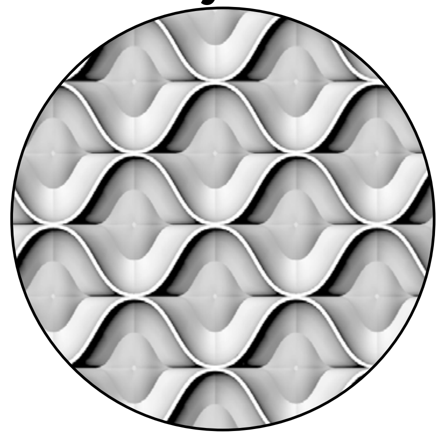
Nanotechnology

Sensors

Integrated system

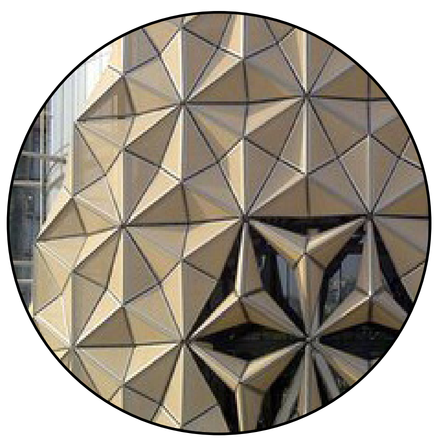


Layers



Low-tech

Aesthetics



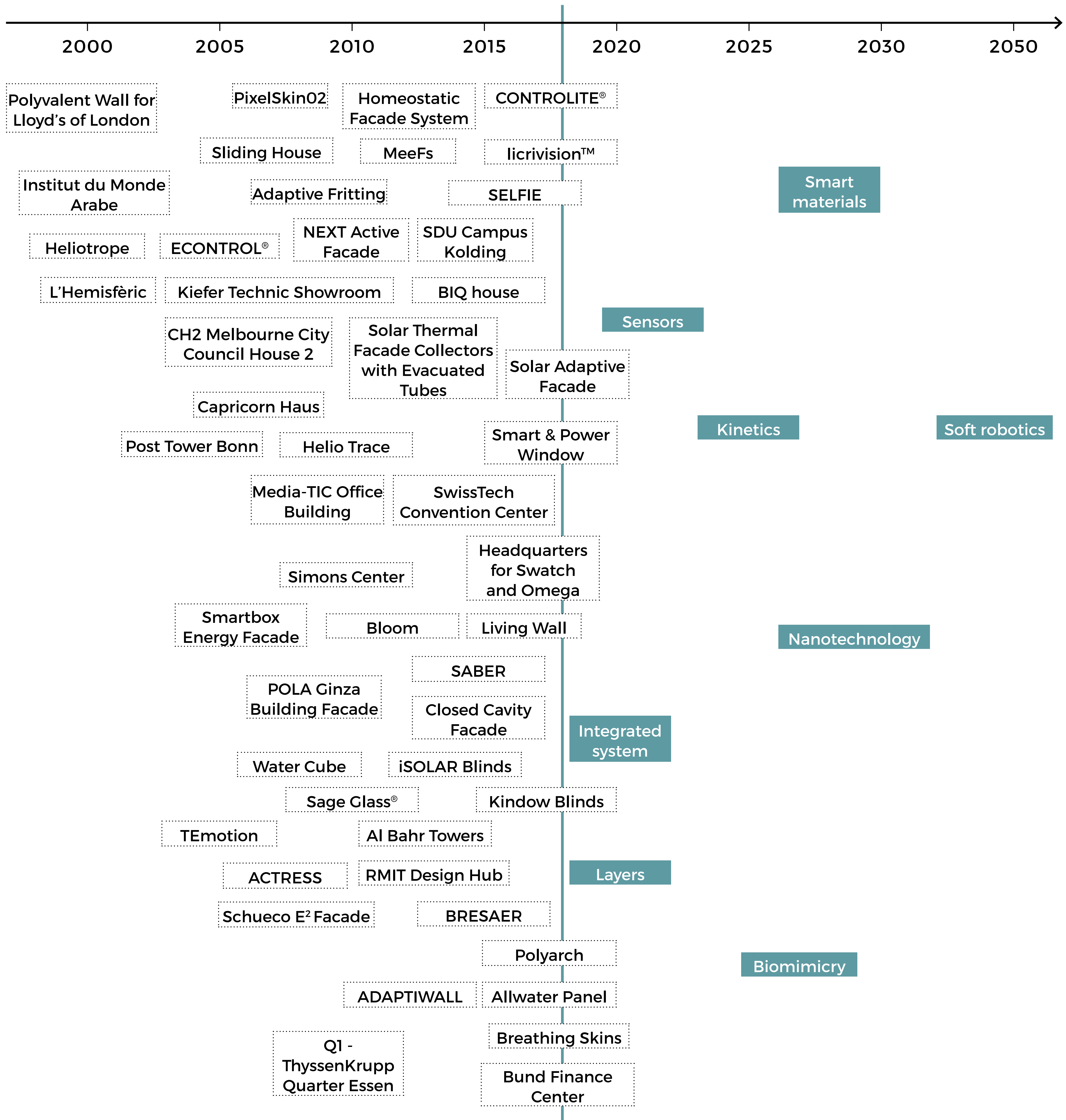
Kinetics

Soft robotics

High transparency

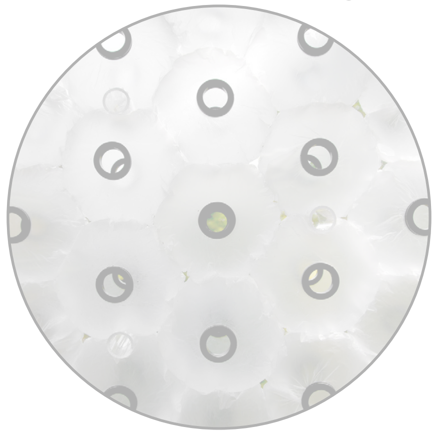
Energy generator

FUTURE TRENDS



NEAR FUTURE CONCEPTS

Biomimicry

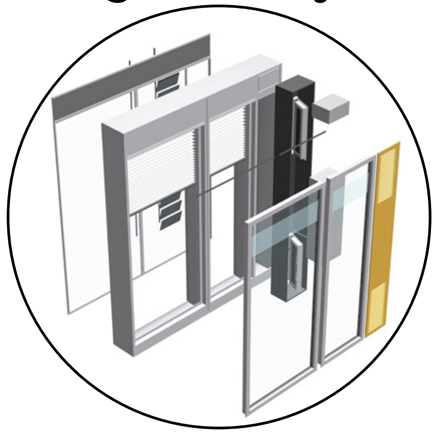


Smart materials

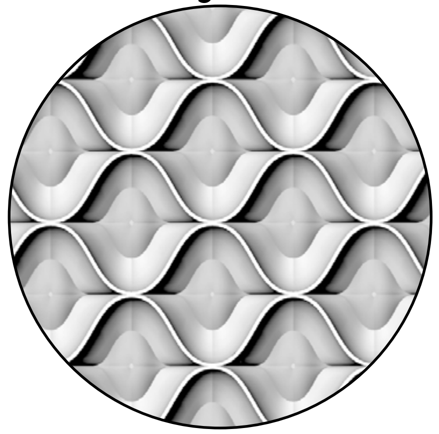
Nanotechnology

Sensors

Integrated system

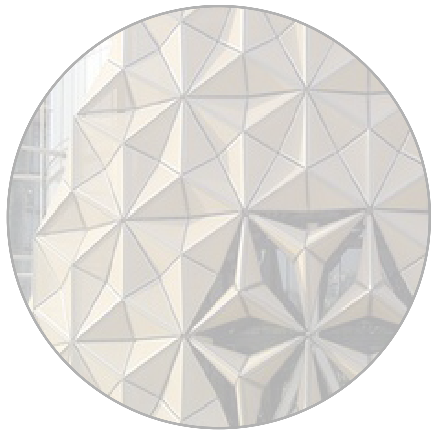


Layers



Low-tech

Aesthetics



Kinetics

Soft robotics

High transparency

Energy generator

RESEARCH QUESTION ?

How can an adaptive multi-functional façade module be designed taking advantage of integral and layered product architecture in order to respond to different climate conditions and provide thermal comfort whilst minimizing the energy demand of an office building in the Netherlands?

LAYERED ARCHITECTURE

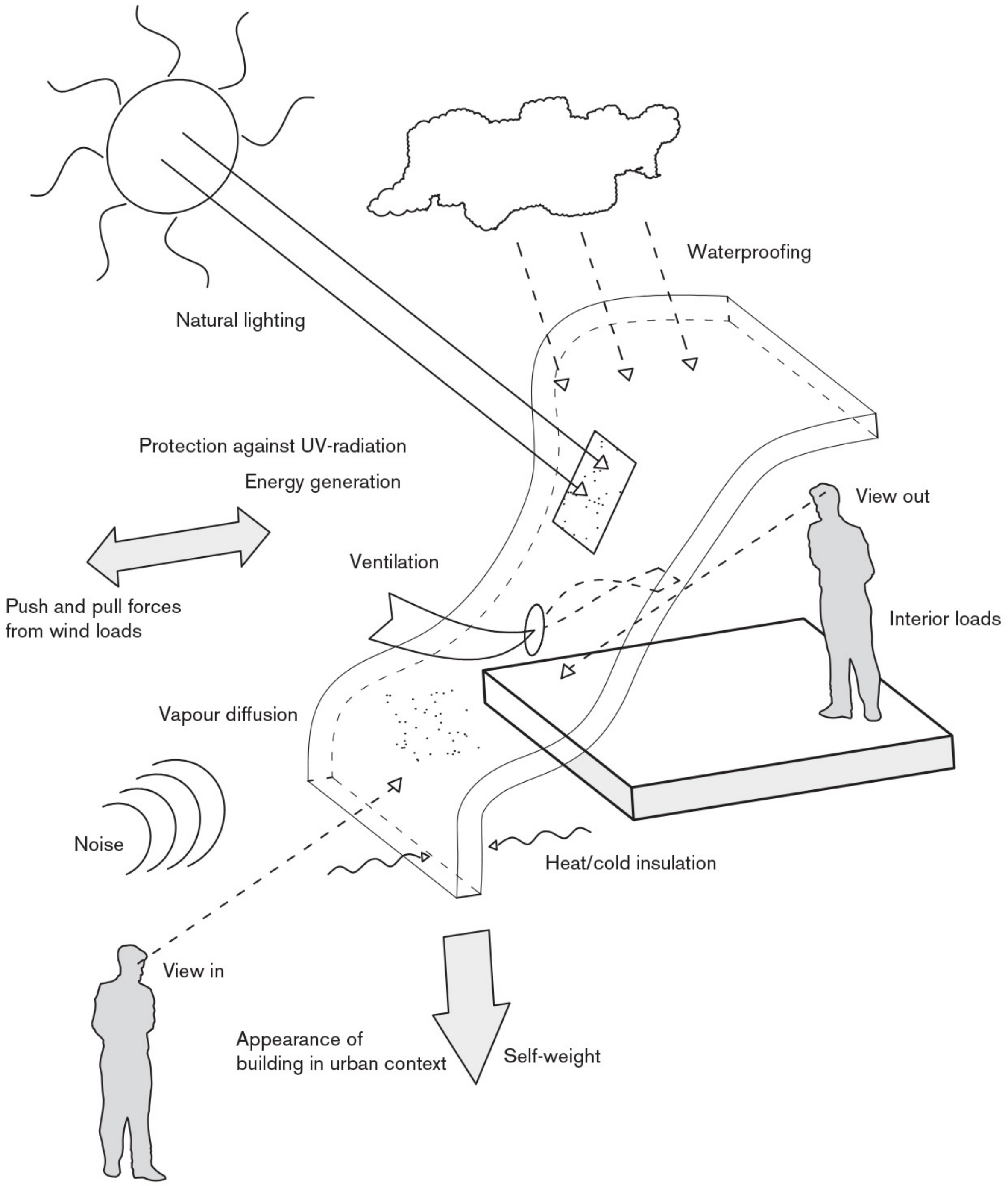
Multi-dimensional facade functions

Technology Integration

outside

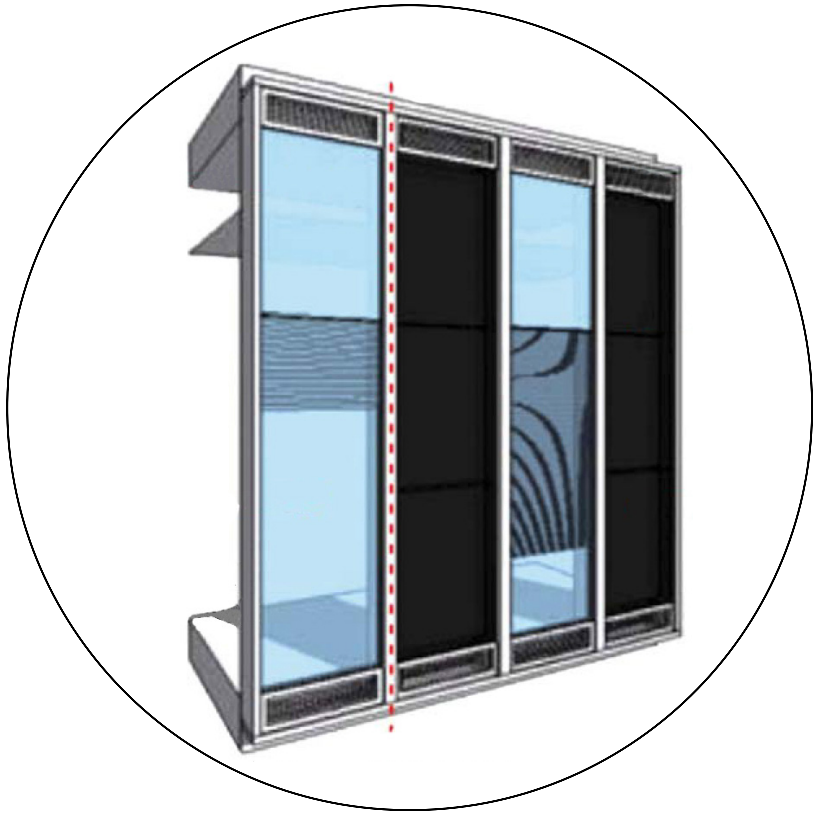
Generator	Photovoltaic Biofuel/Biomass CO2 absorption
Stimulator	Diversified experience
Filter	Light/Heat/ Sound/Wind
Barrier	Shelter

inside



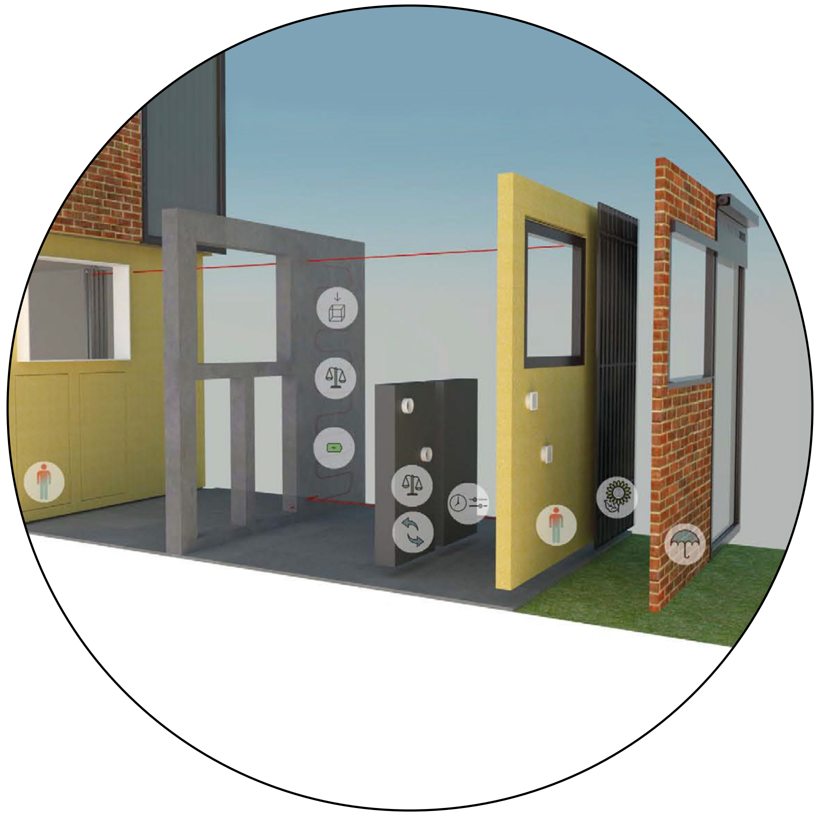
REFERENCE PROJECTS

ACTRESS



SELFIE

ADAPTIWALL



BRESAER

MeeFS

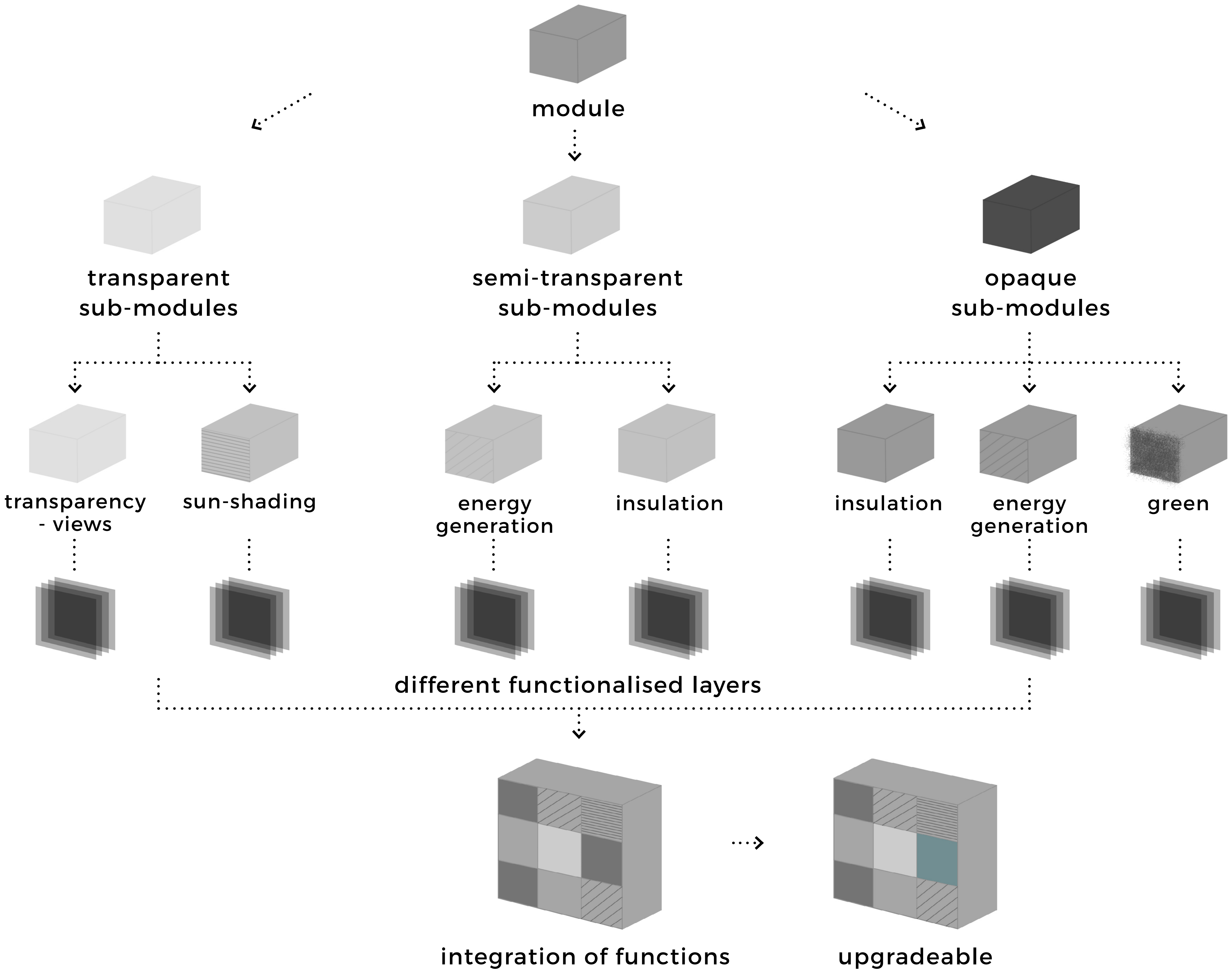
“Rollecate’s” requirements

- Low complexity
- Minimum dimensions and thickness of materials
- Lightweight
- Avoid the use of liquids
- Well integrated wiring if used
- Low cost

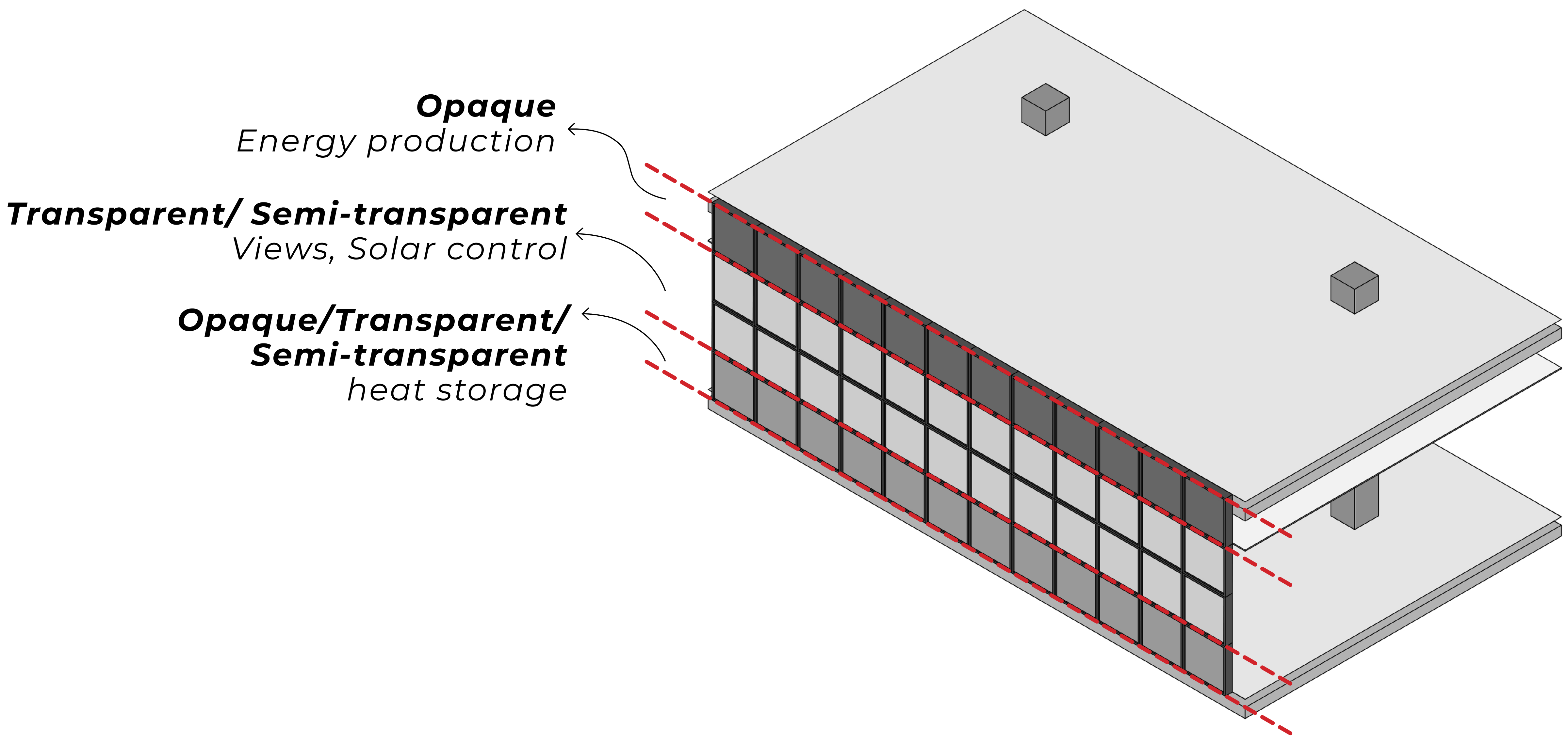
Facade system

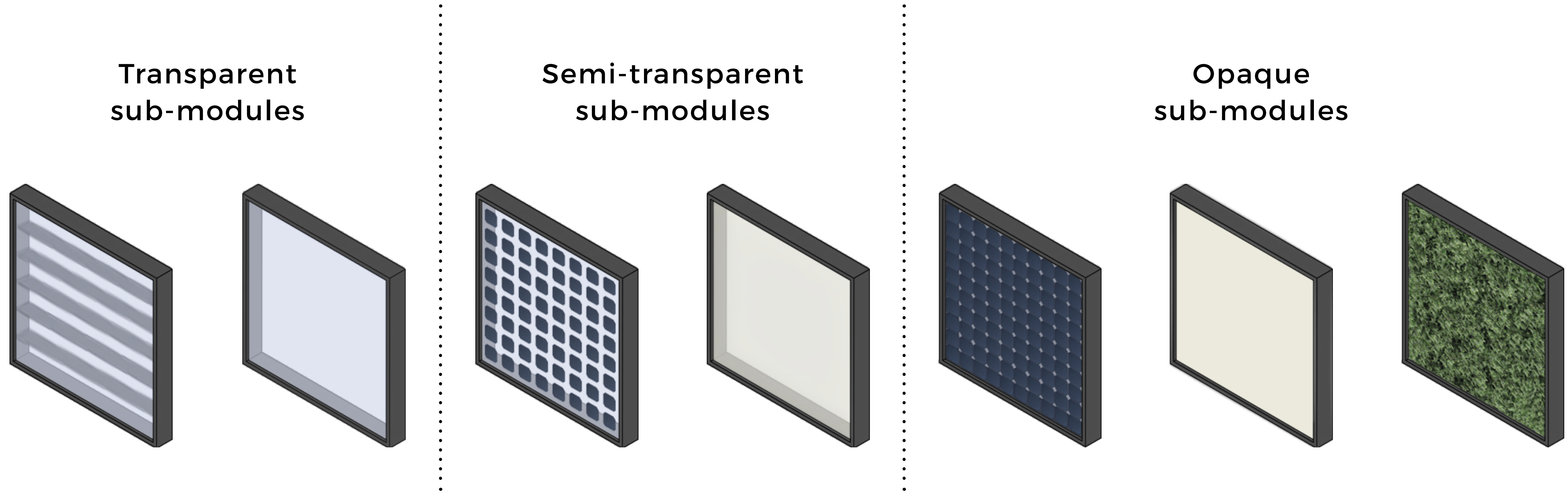
- Unitised curtain wall system
- Integration of functions
- Technically upgradeable
- Flexible in use
- Plug & Play nature
- Architectural design freedom
- Easy maintenance
- Not complex

DESIGN PRINCIPLES



APPLICATION PRINCIPLES





Comfort

Netherlands office standards

R-value for closed parts:

$R_{c;facade}$ = 5,0 W/m²K or more

U-value for windows and doors:

$U_{w;max}$ = 1,65 m²K/W

$U_{w;average}$ = 1,20 m²K/W or lower

Indoor Temperatures:

T_{winter}: 20-24°C [$T_{set\text{-}point}$: 21°C]

T_{summer}: 23-26°C [$T_{set\text{-}point}$: 24.5°C]

Practical

Safety

Air tightness

Water tightness

Robustness

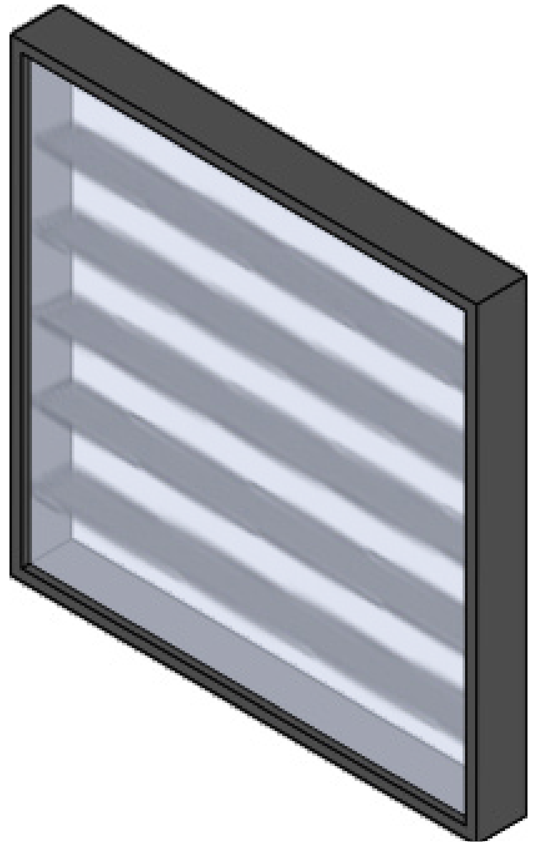
Fire resistance

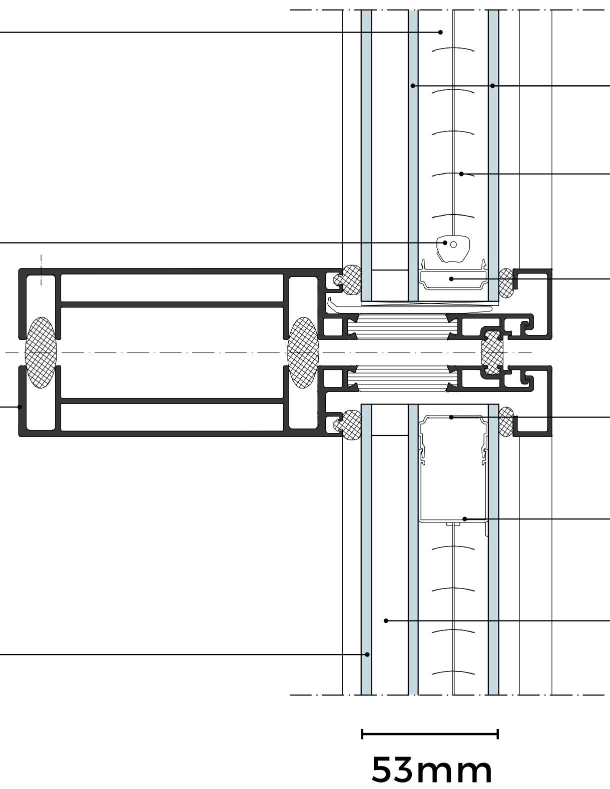
Easy maintenance

Architectural design freedom

Integrated blinds

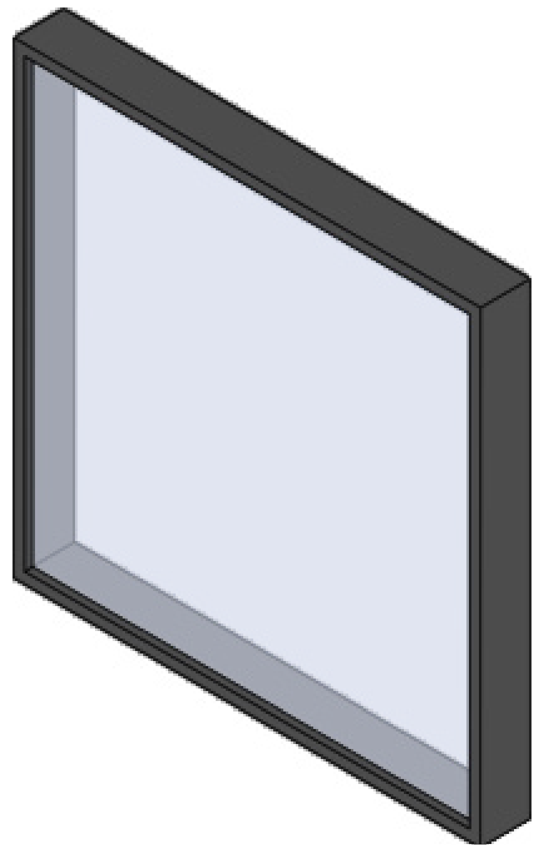
- favor solar gain in winter
- reduce solar gain in summer
- heat, glare and light protection
- energy savings
- lower risk for damage
- lower maintenance requirements
- U-value = 1,4W/m²K
- g value = 0,34



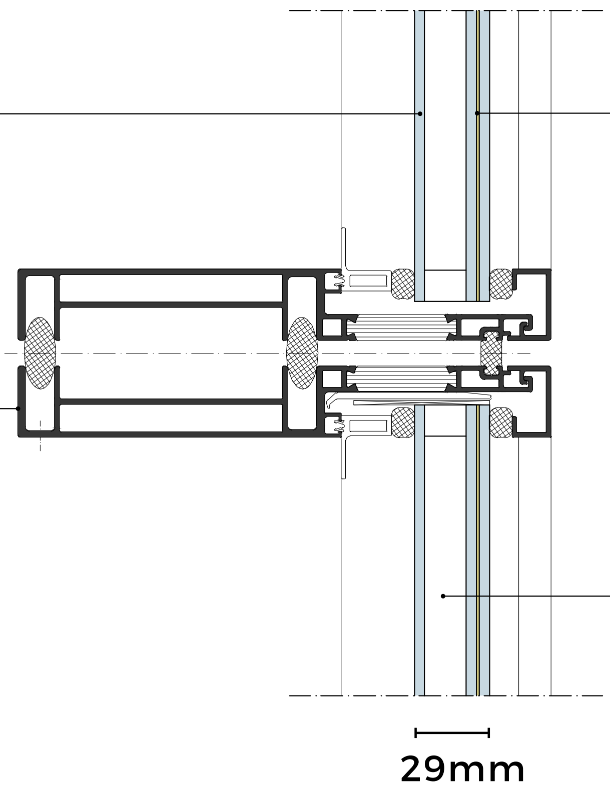


TRANSPARENT - GLAZING

Electrochromic window



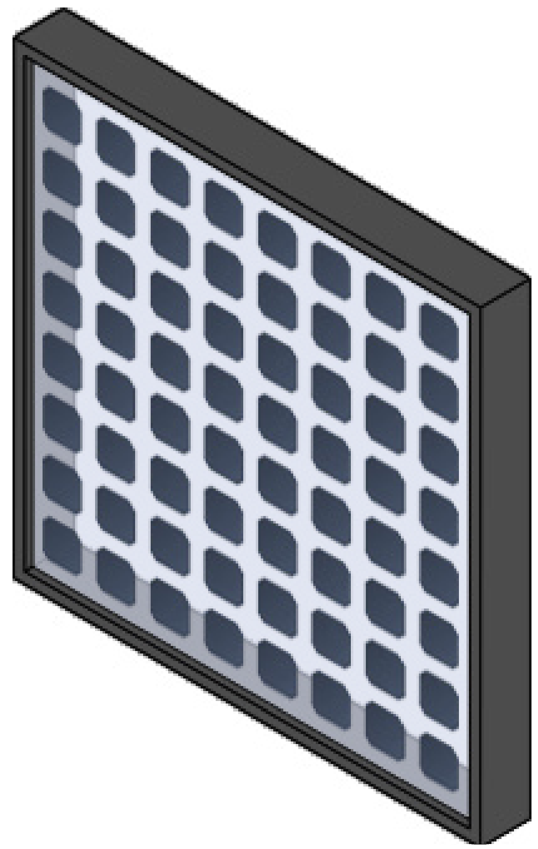
- active solar control device
- glazing switches between a clear and transparent blue-gray tinted state
- application of a low voltage (typically 1-5V DC)
- no power needed to maintain the desired state
- spectral transmission during changing transparency levels
- U-value = 1,1W/m²K
- g value (colored) = 0,1
- g value (bleached) = 0,34

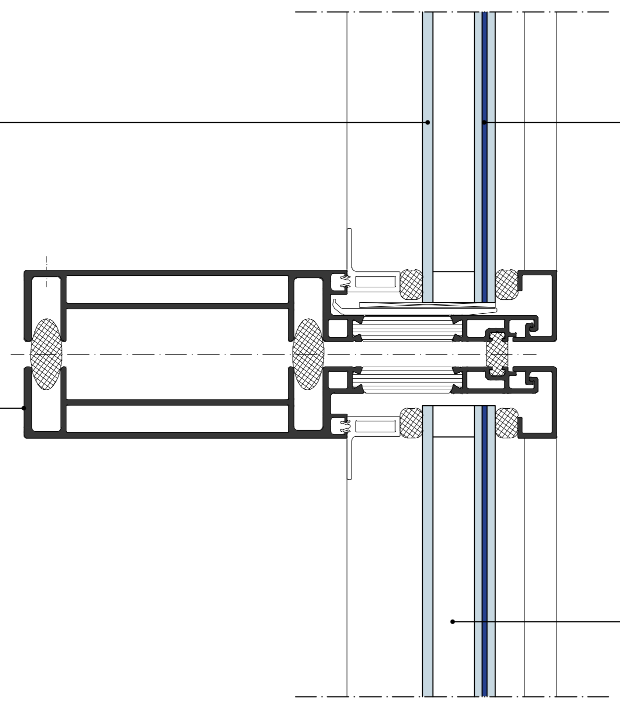


SEMI-TRANSPARENT - ENERGY

BIPV

- renewable energy source
- 36% transparency
- 90 kWh/y per module
- 36 W per module for heating season
- U-value = 1,5W/m^{2}K
- g value = 0,29

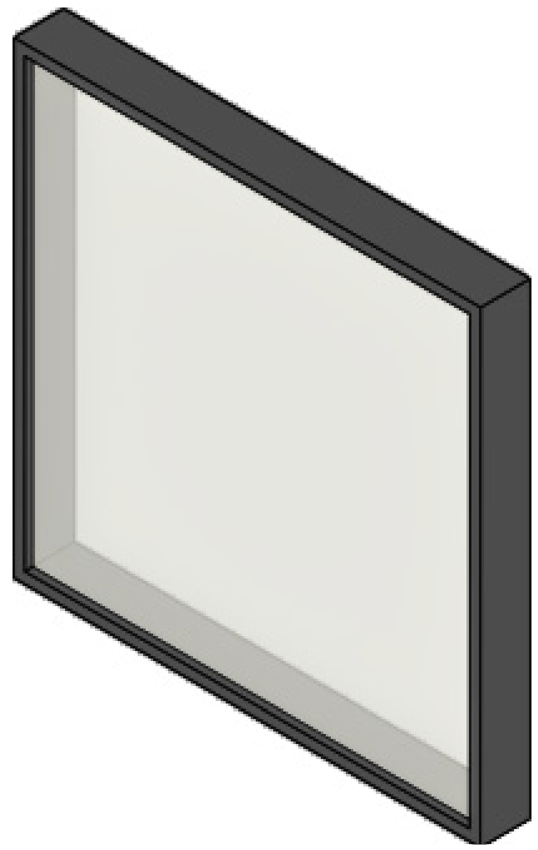


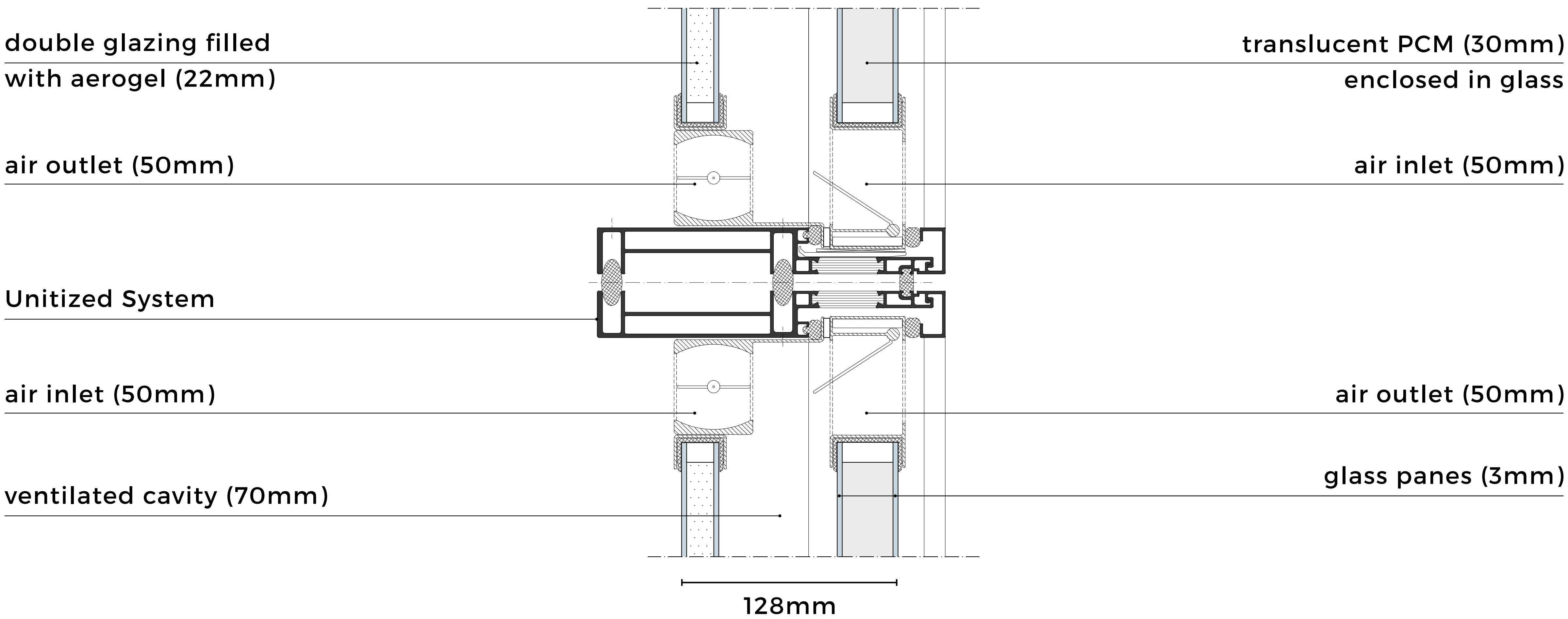


SEMI-TRANSPARENT - INSULATION

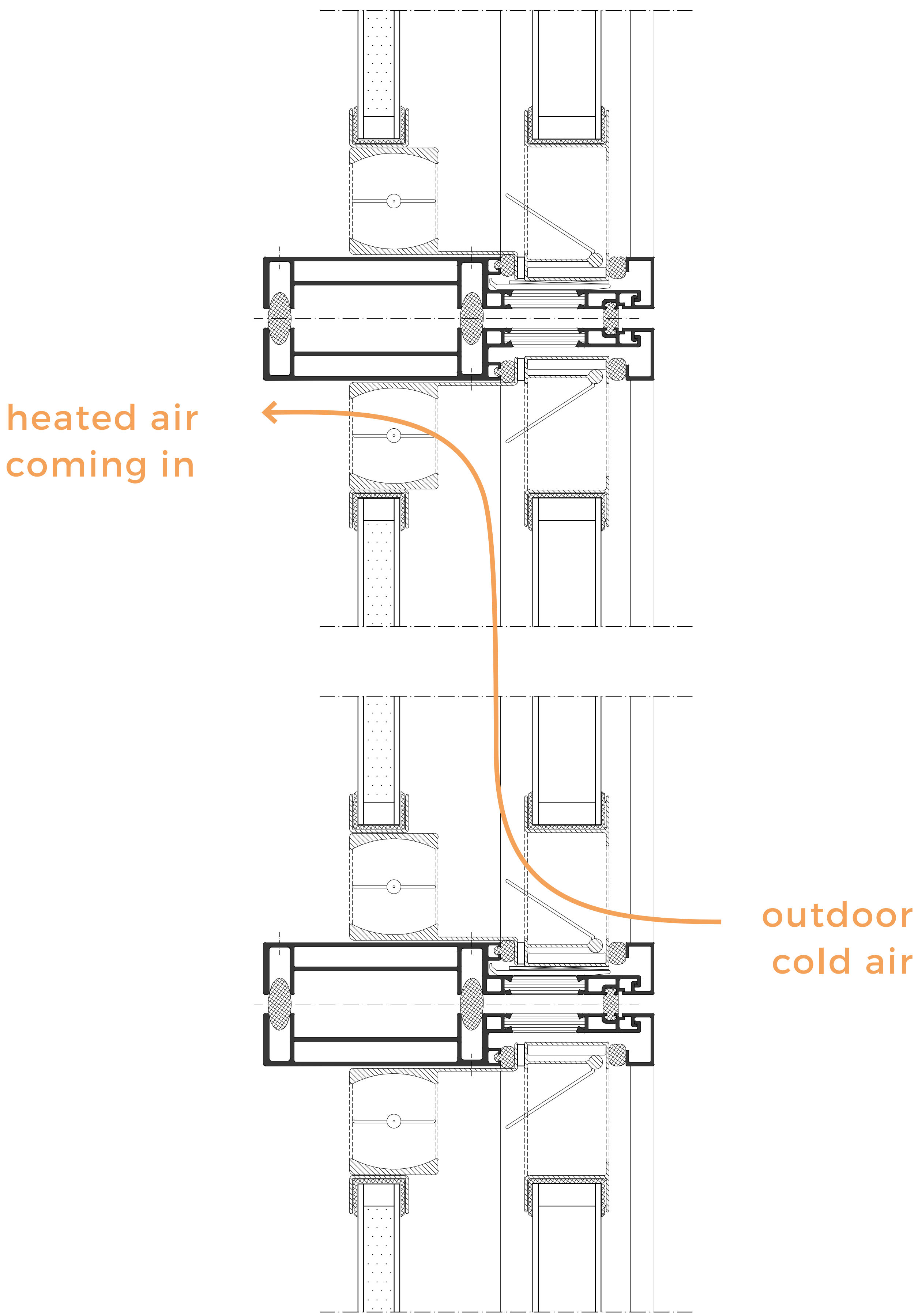
Translucent PCM

- principle of thermal mass wall
- solar passive heating without increasing mass
- air cavity for PCM temperature regulation
- reduction of heating loads
- no off-peak cooling loads
- interior temperature stabilization
- U-value = 1,1W/m²K
- g value (solid) = 0,17
- g value (liquid) = 0,20

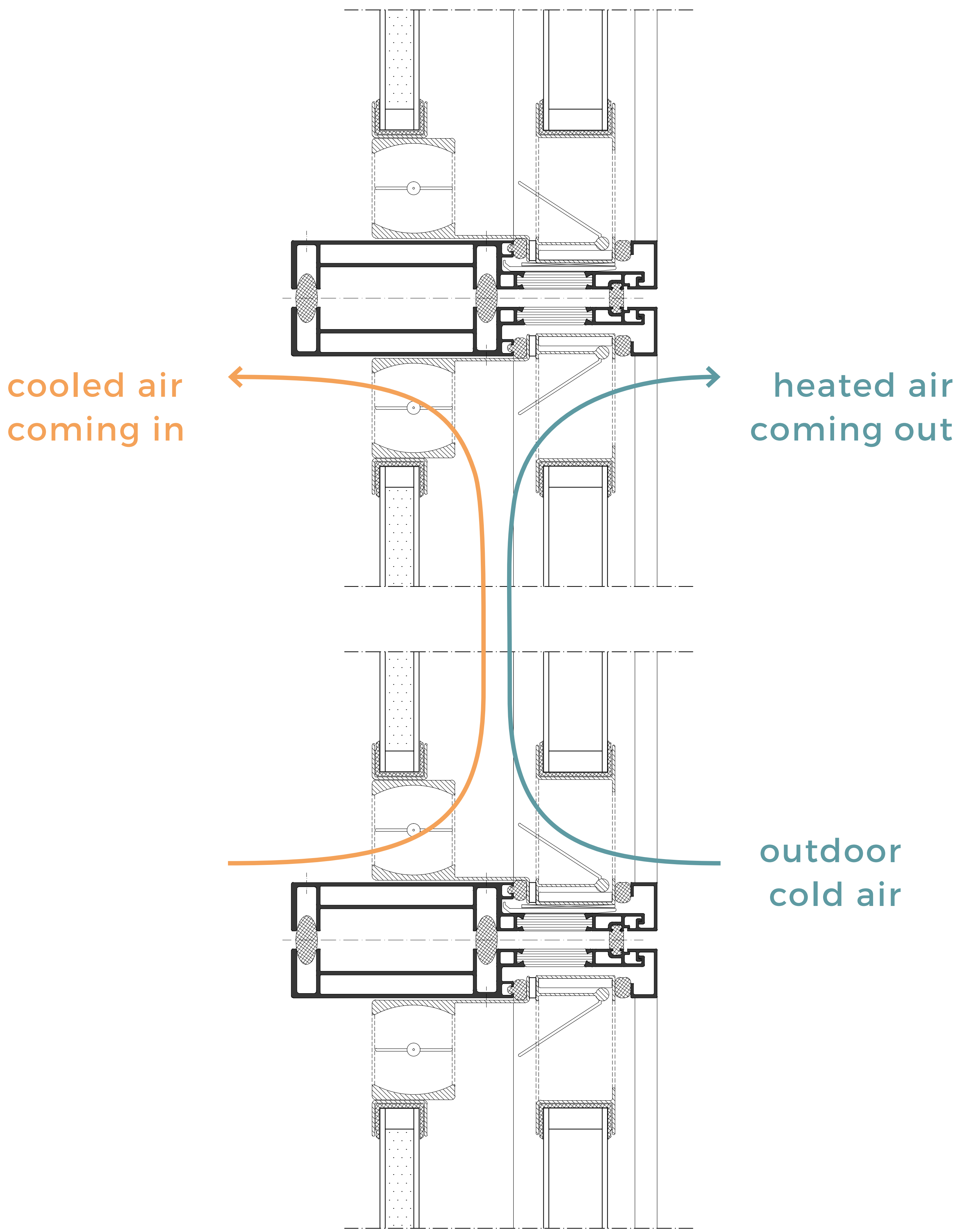




VENTILATION MODES



Heating season
Office hours mode
Night-time: closed

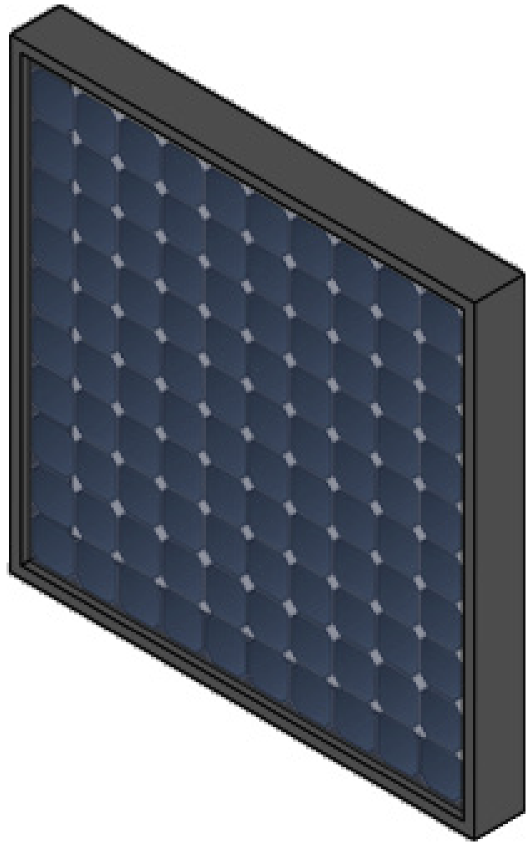


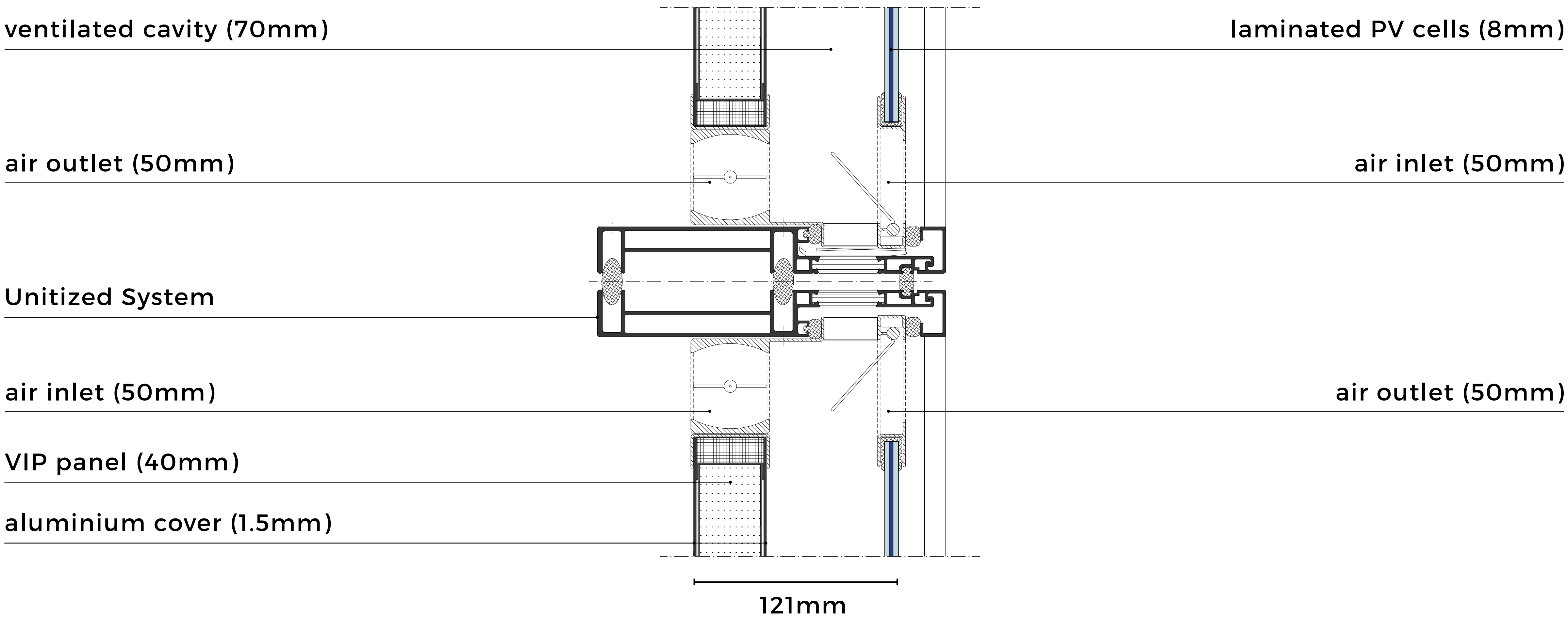
Cooling season
Office hours mode
Night-time mode

OPAQUE - ENERGY

BIPV/T

- renewable energy source
- 15% transparency
- 123 kWh/y per module
- 50 W per module for heating season
- R-value = 6,31m²K/W





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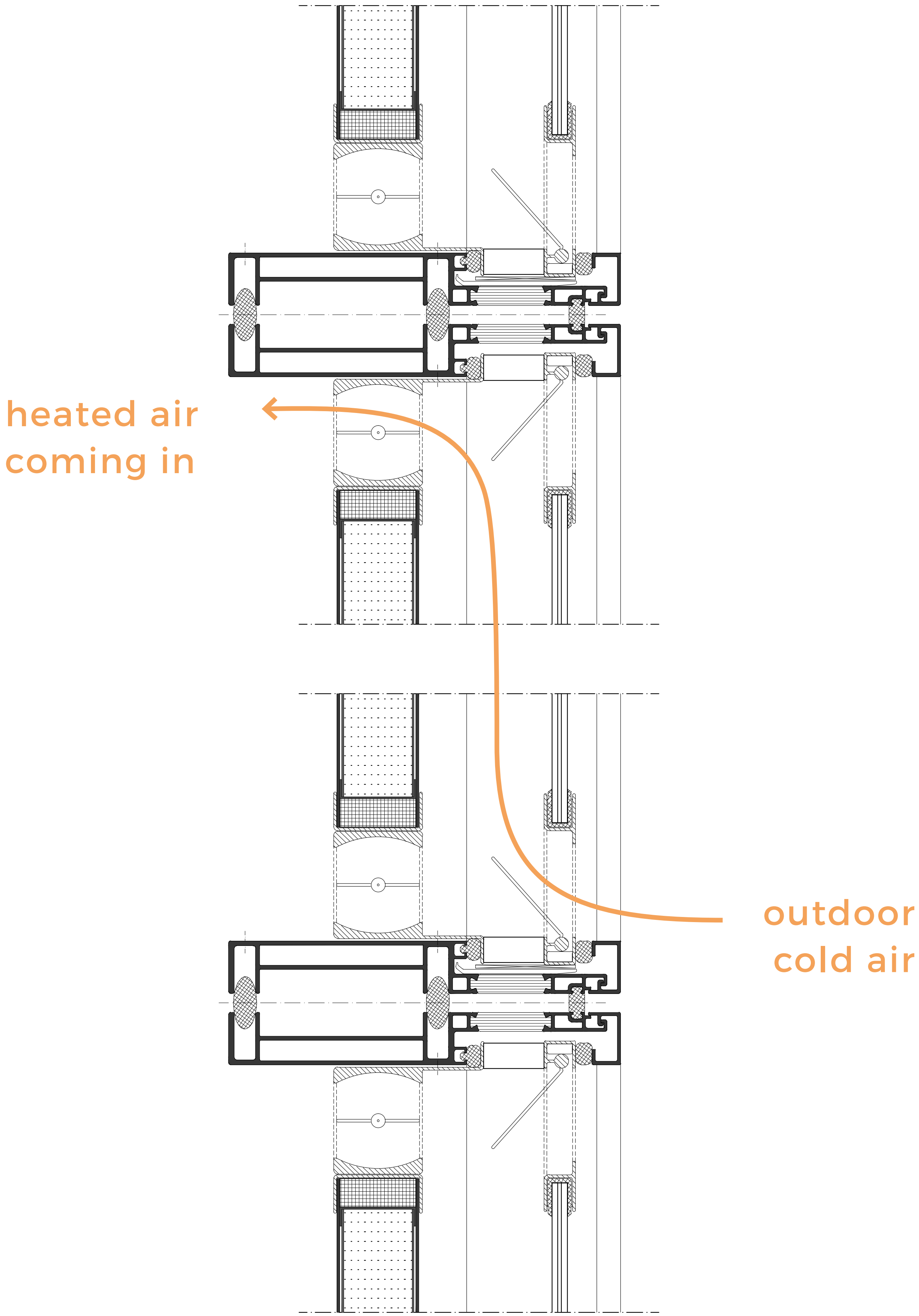
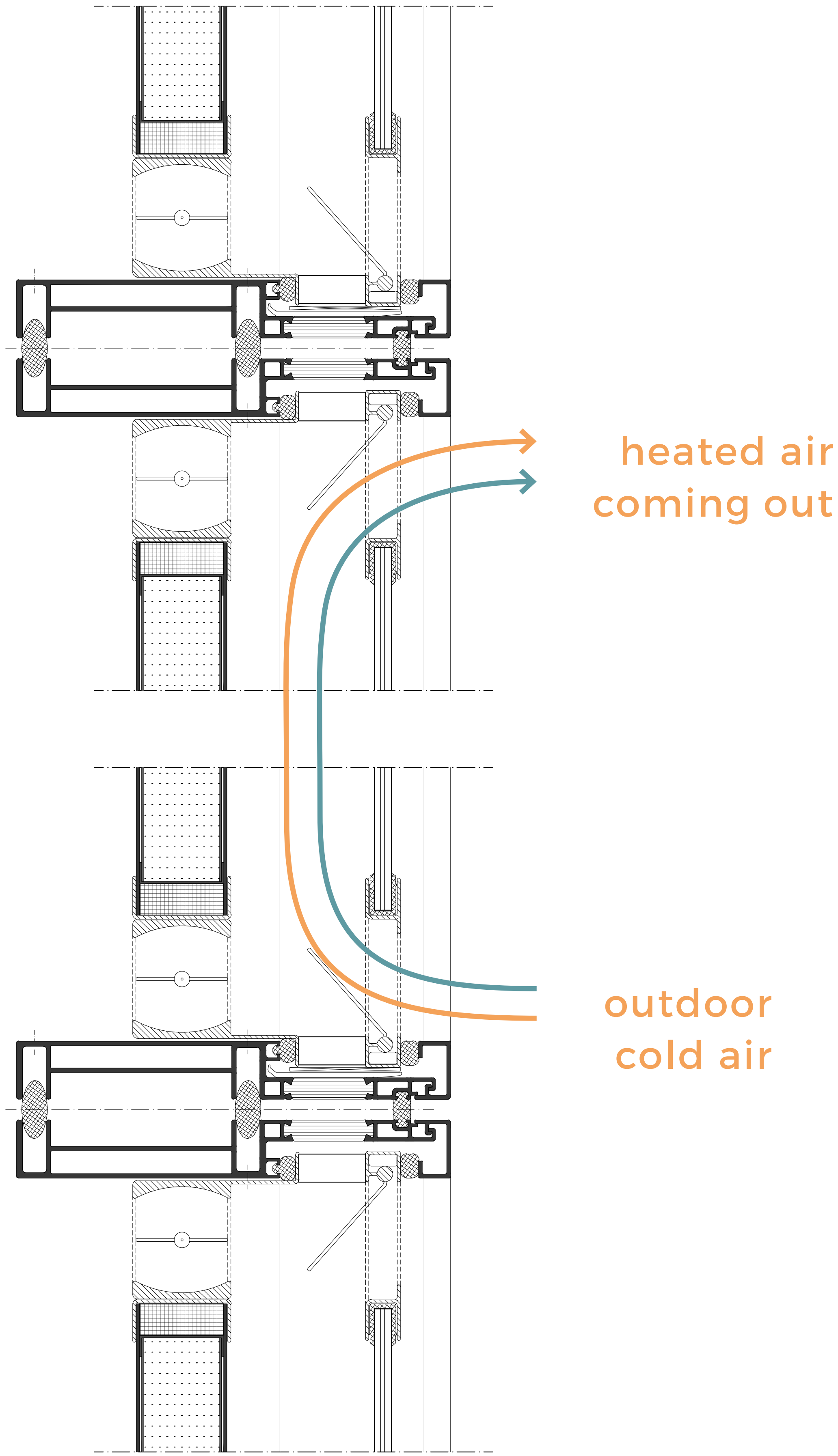


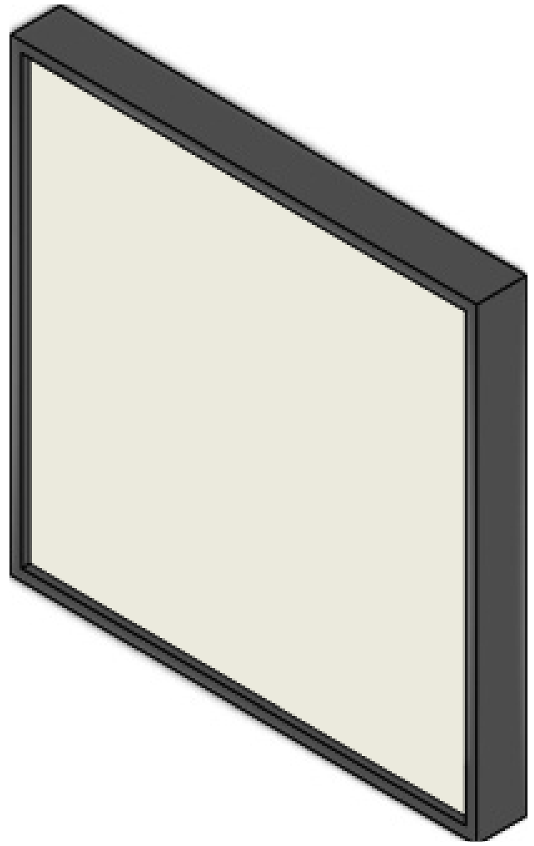
Heating season
Office hours mode
Night-time: closed

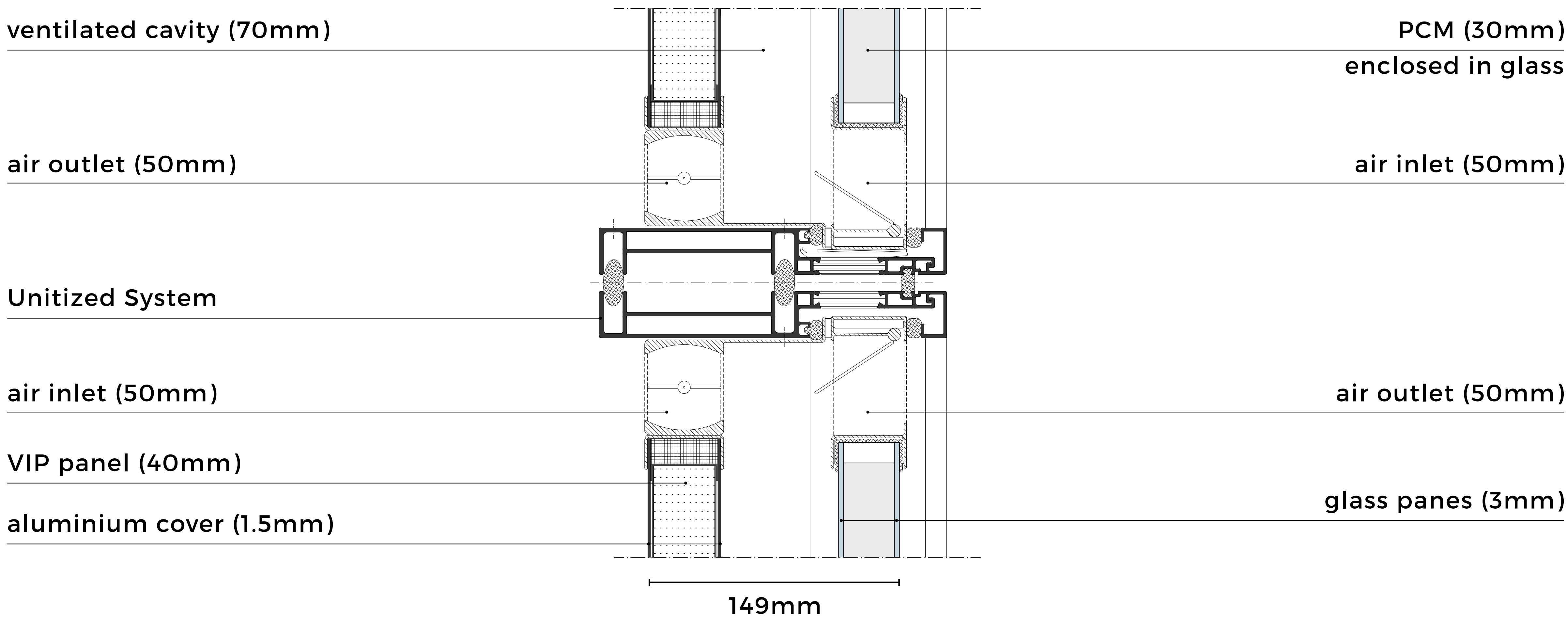


Cooling season
Office hours mode
All-day mode

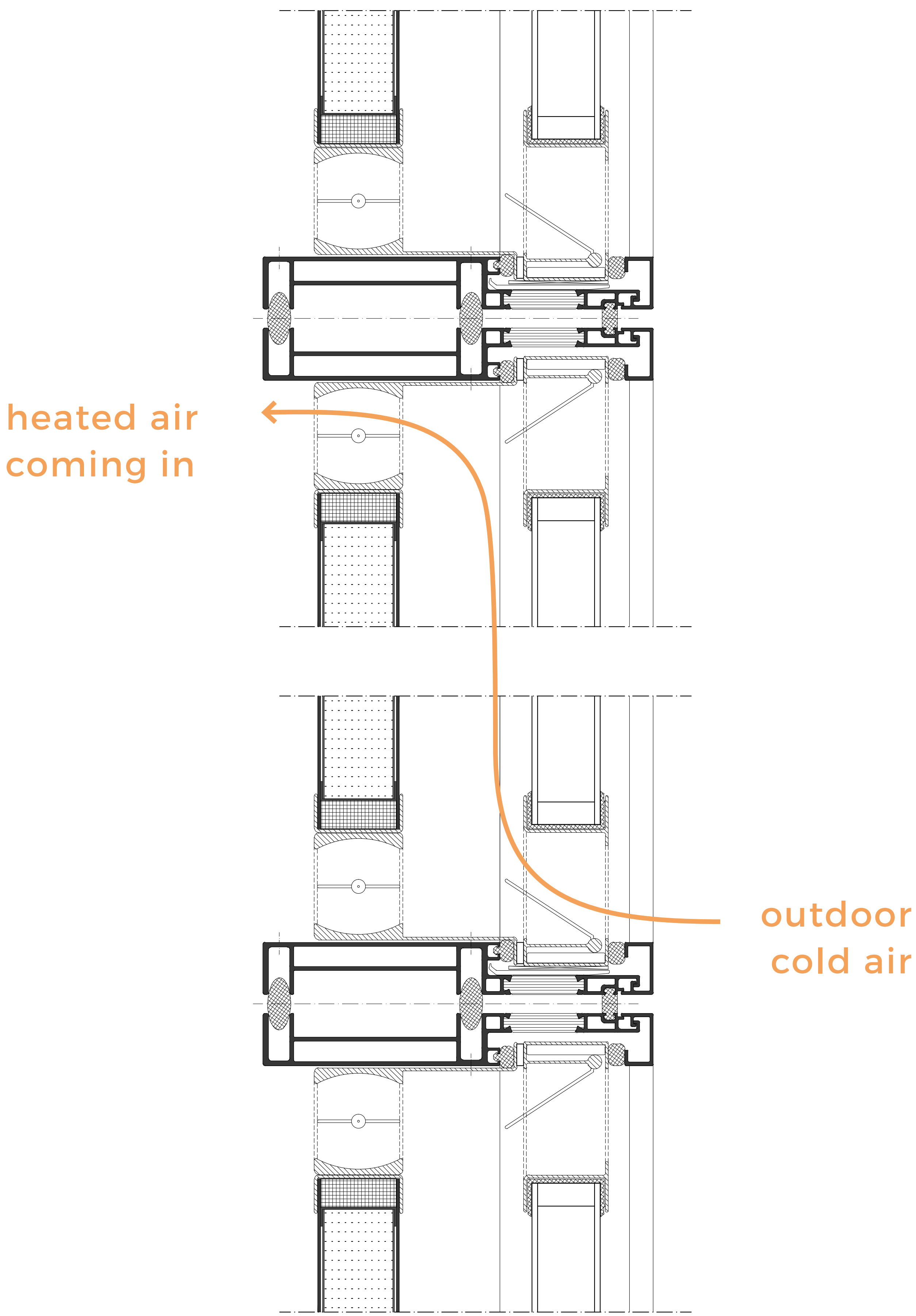
Opaque PCM

- principle of thermal mass wall
- solar passive heating without increasing mass
- air cavity for PCM temperature regulation
- reduction of heating loads
- no off-peak cooling loads
- interior temperature stabilization
- VIP: better insulating performance with reduced thickness
- R-value = 6,41m²K/W

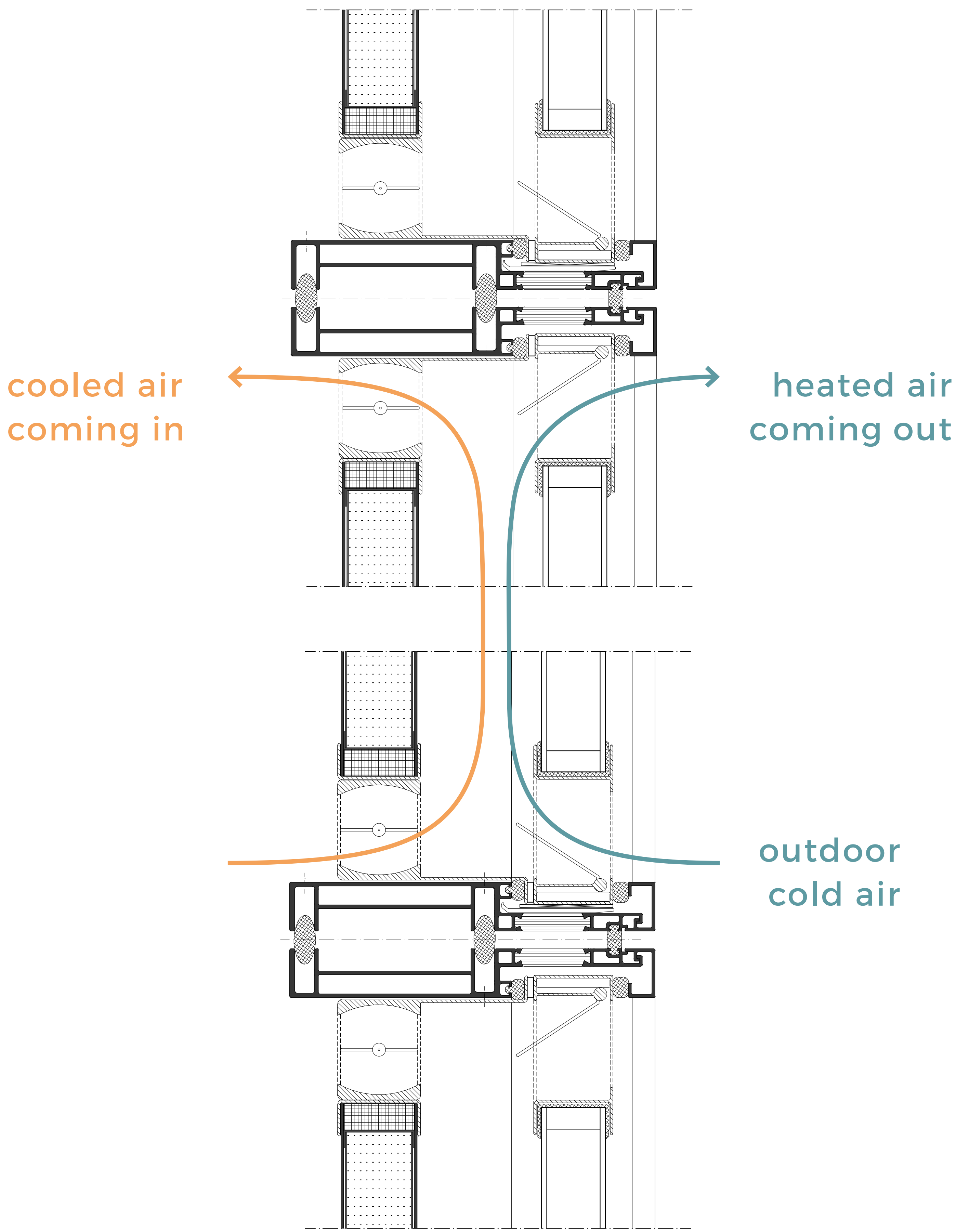




VENTILATION MODES



Heating season
Office hours mode
Night-time: closed

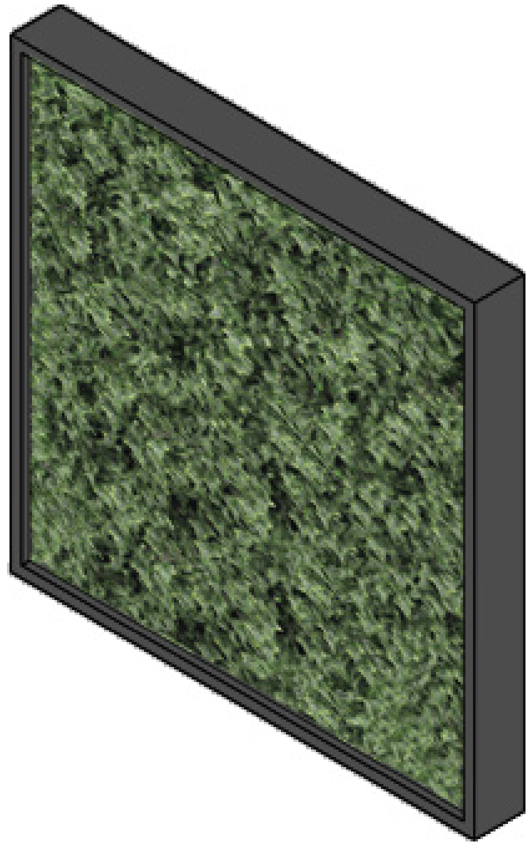


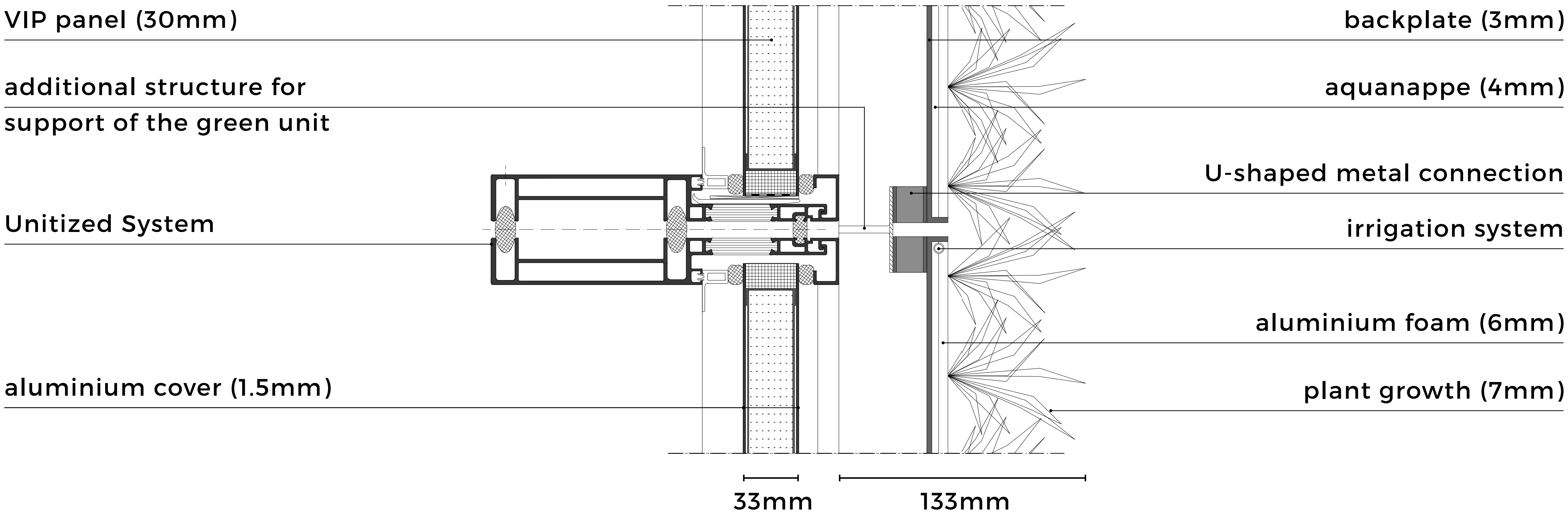
Cooling season
Office hours mode
Night-time mode

OPAQUE - GREEN

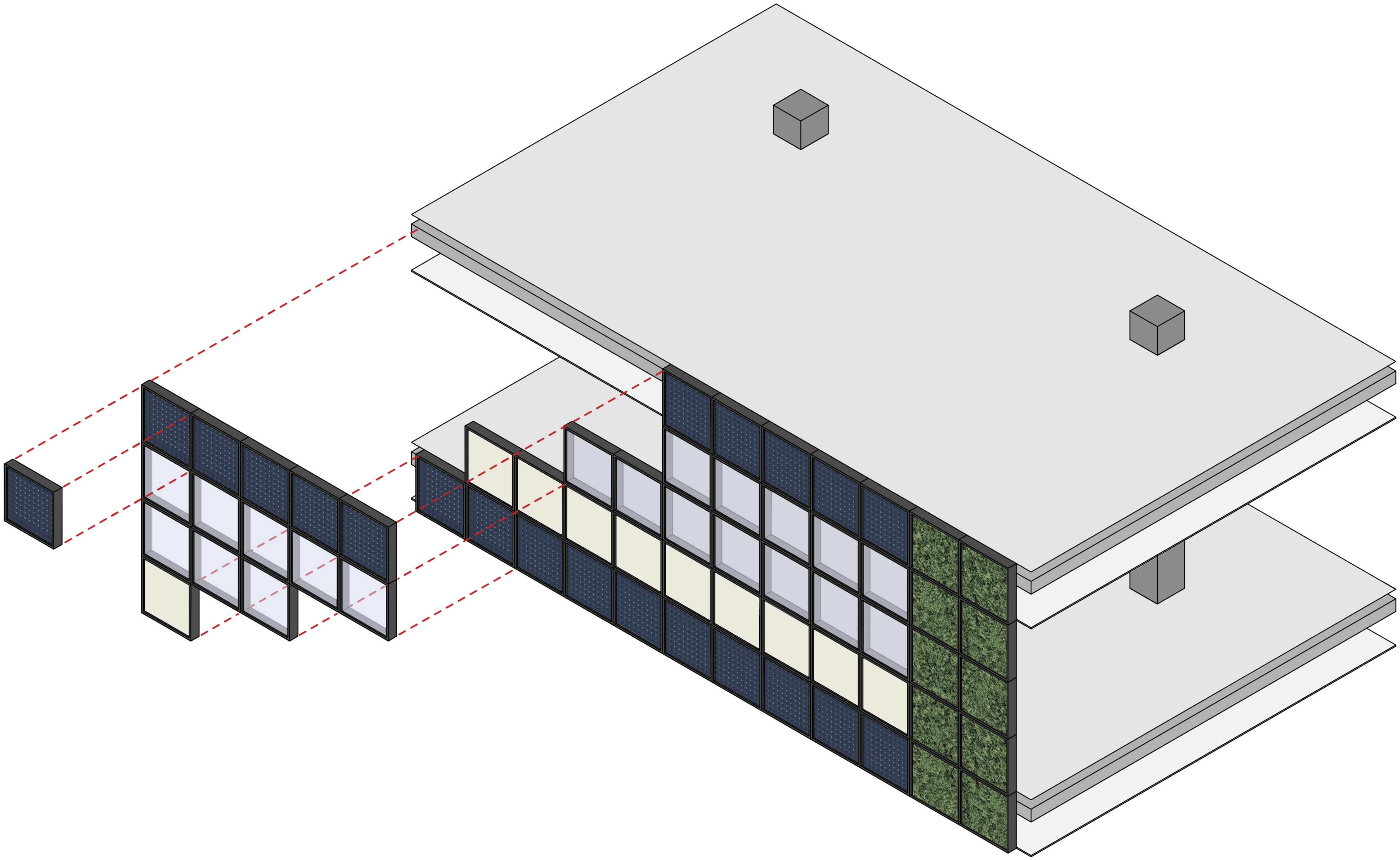
Living Wall

- zero-earth system
- use of hydroponics for nutrient and water delivery
- 90% reduction of water consumption
- protection of direct solar radiation
- reduction of incoming heat flow during summer
- cooling effect through evaporation
- reduction of cooling loads
- urban air quality improvement
- R-value = 5,46m²K/W





APPLICATION PRINCIPLES



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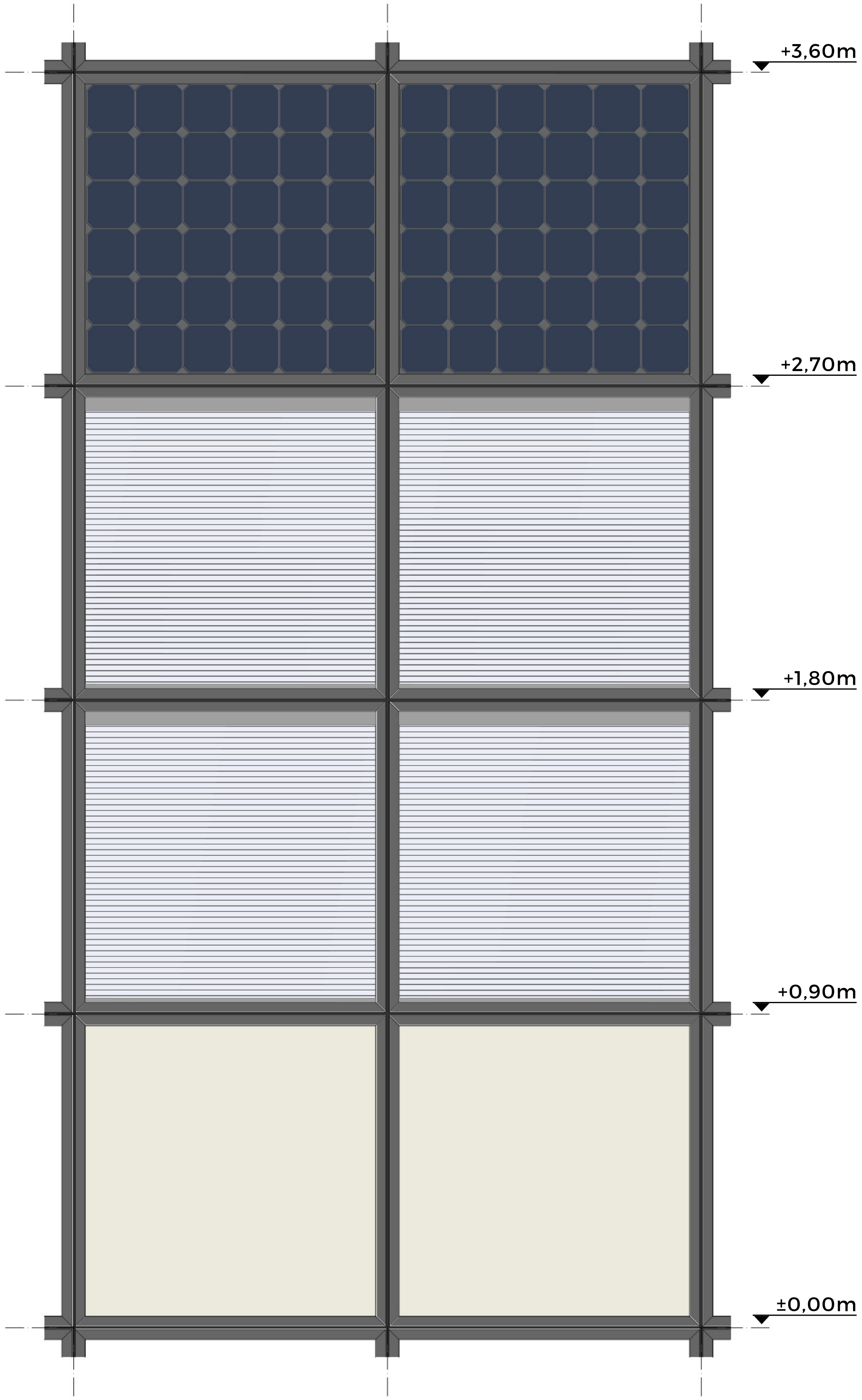
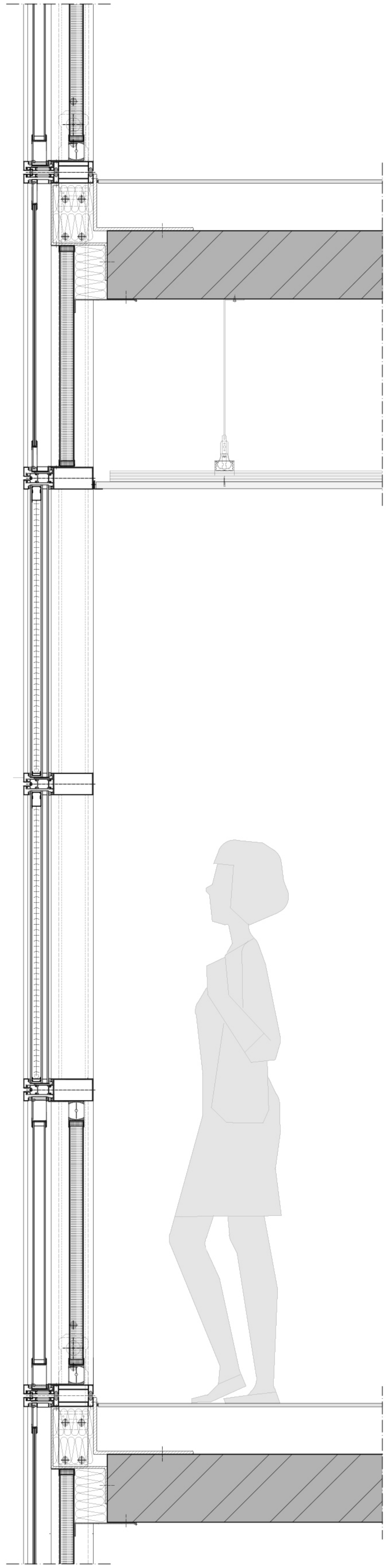




CALCULATIONS

Hand Calculations

BIPV & BIPV/T modules:

electricity generation

PCM & BIPV/T modules:

Air inlet-outlet height

Cavity width

All modules:

Heat balance equation

Simulations

All modules:

integrated blinds

electrochromic

BIPV

BIPV/T

opaque PCM

50% WWR:

Reference project

6 combinations

40% WWR:

Reference project

6 combinations

CALCULATIONS

Hand Calculations

BIPV & BIPV/T modules:
electricity generation

PCM & BIPV/T modules:
Air inlet-outlet height
Cavity width

All modules:
Heat balance equation

PCM & BIPV/T modules:
Heat provided by cavity ventilation

All simulated cases:
Energy performance

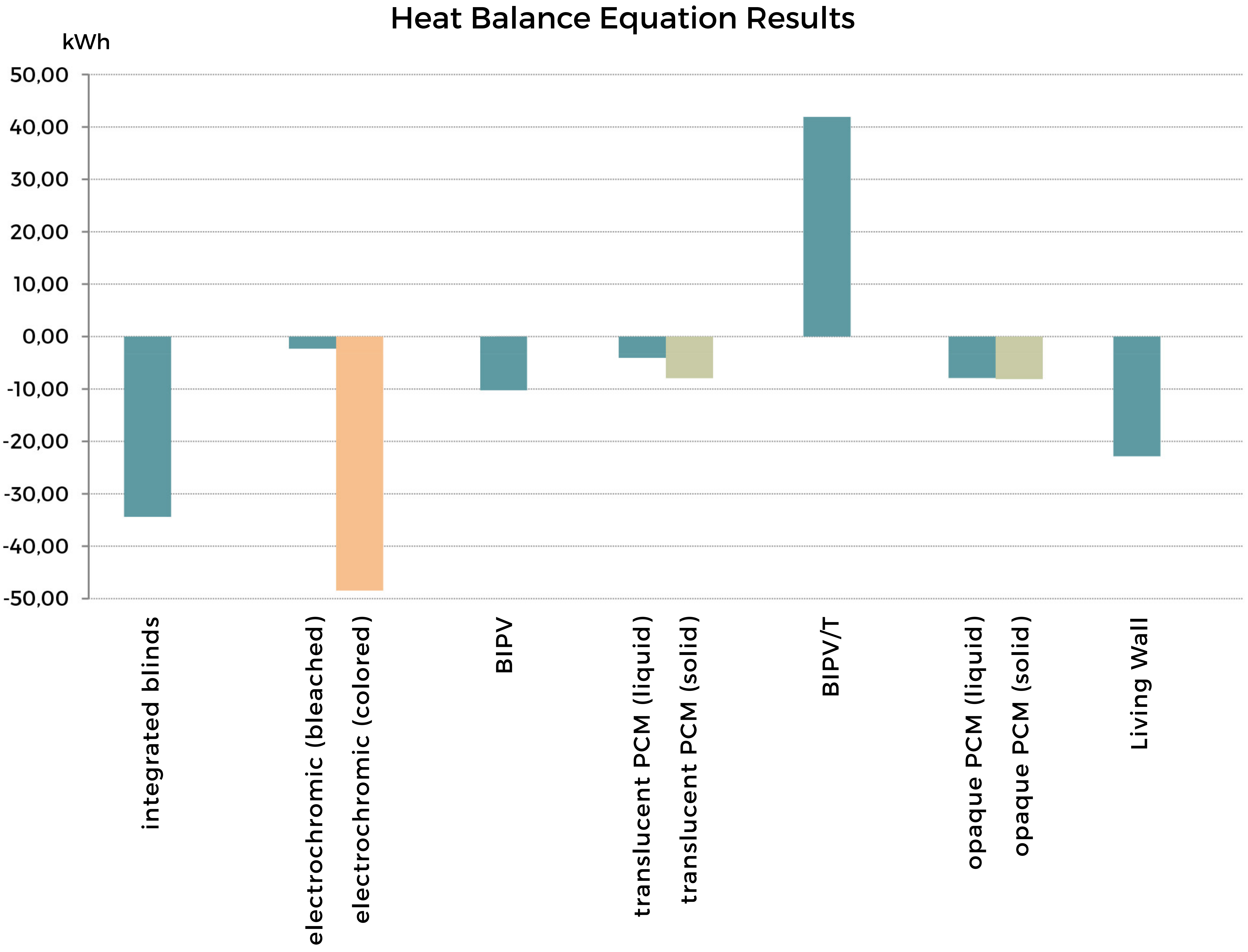
Simulations

All modules:
integrated blinds
electrochromic
BIPV
BIPV/T
opaque PCM

50% WWR:
Reference project
6 combinations

40% WWR:
Reference project
6 combinations

HAND CALCULATIONS



SIMULATION CONSTRAINTS

Amsterdam, Netherlands

Temperate maritime

2- 6 ºC

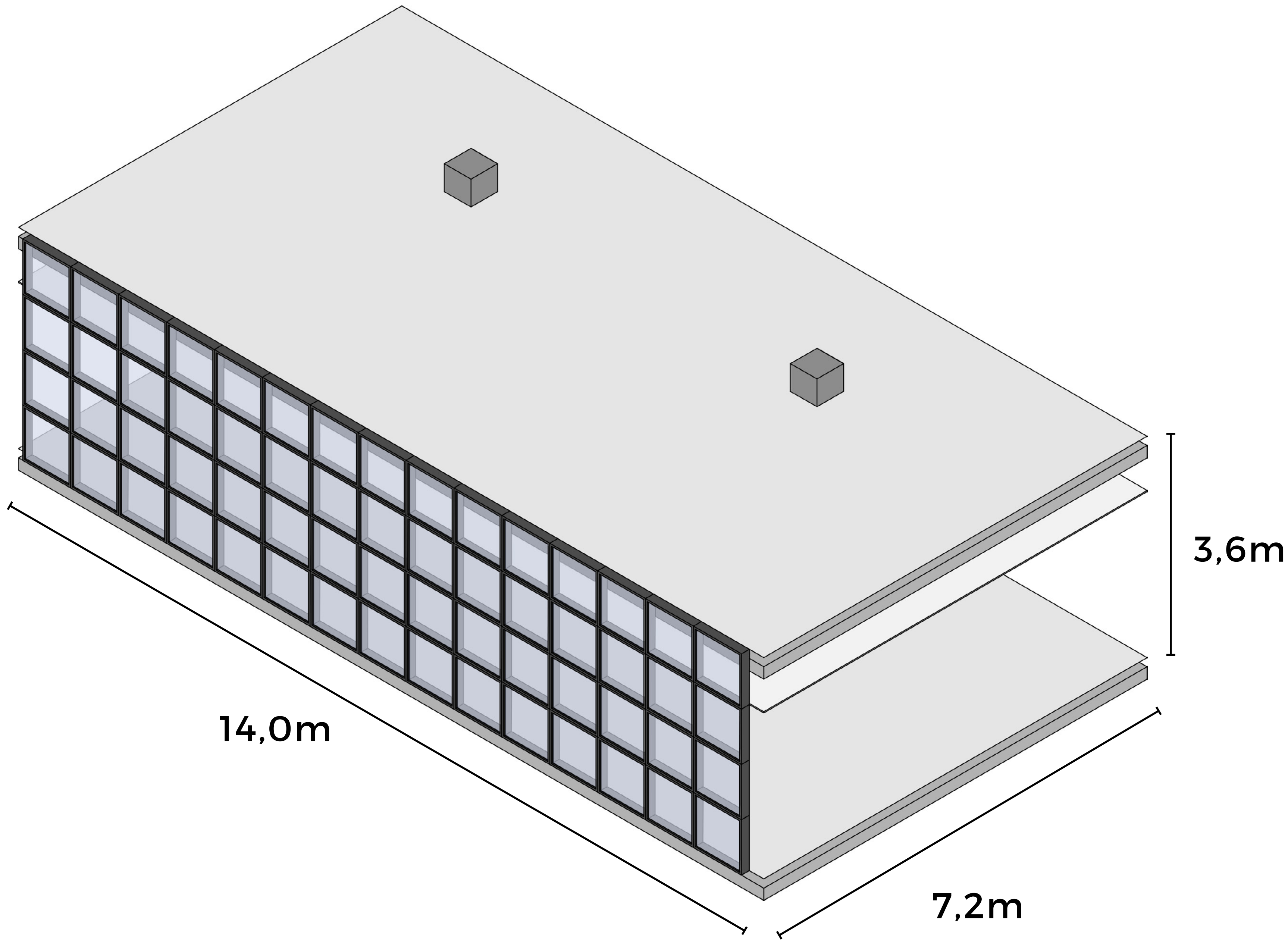
17- 20 ºC

10 ºC

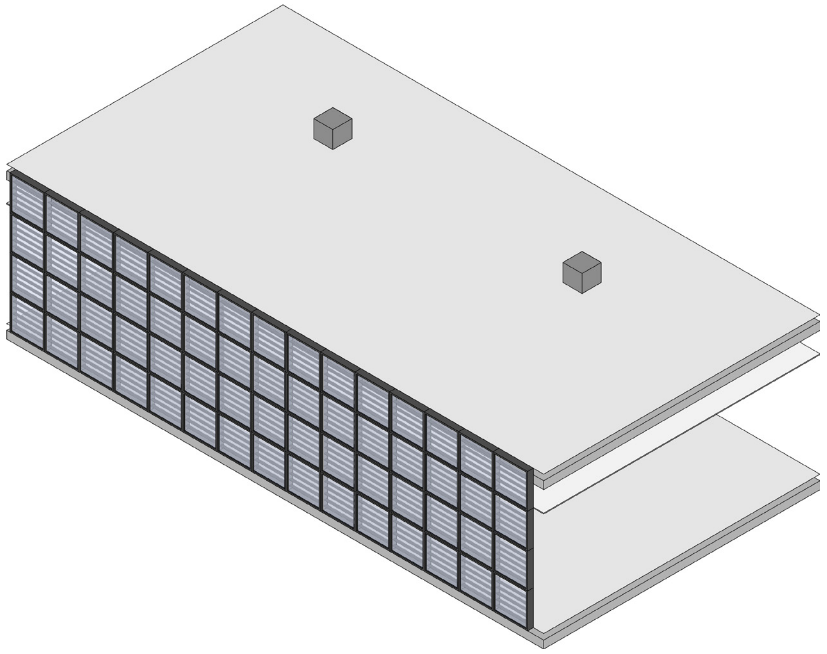
South

Office

60 modules

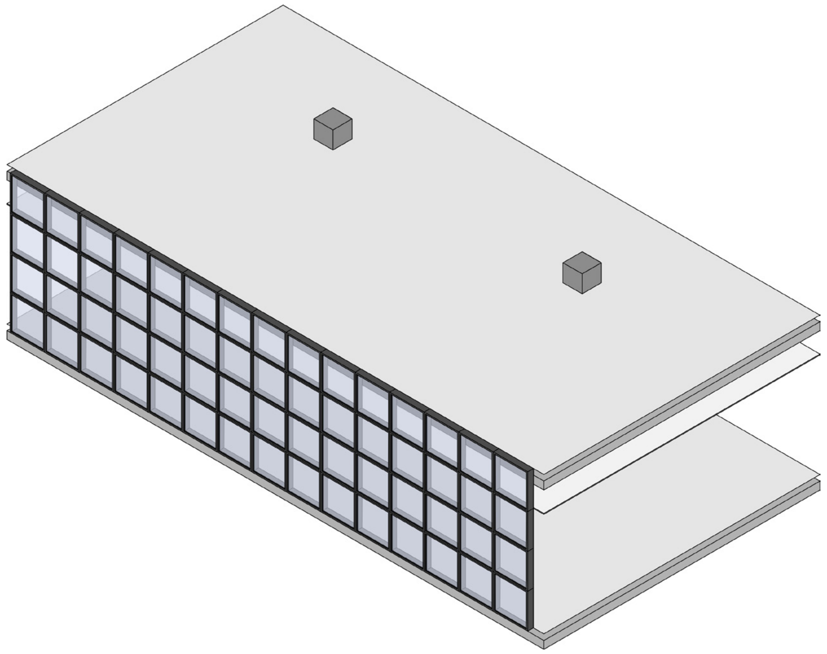


SIMULATED CASES



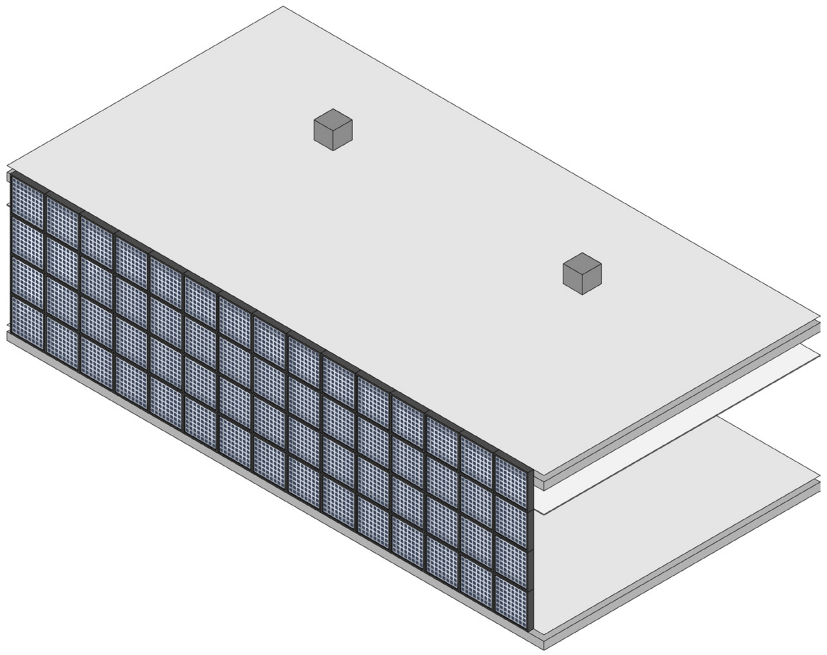
Blinds
WWR=100%

60 modules Blinds
A = 48,6 m^2



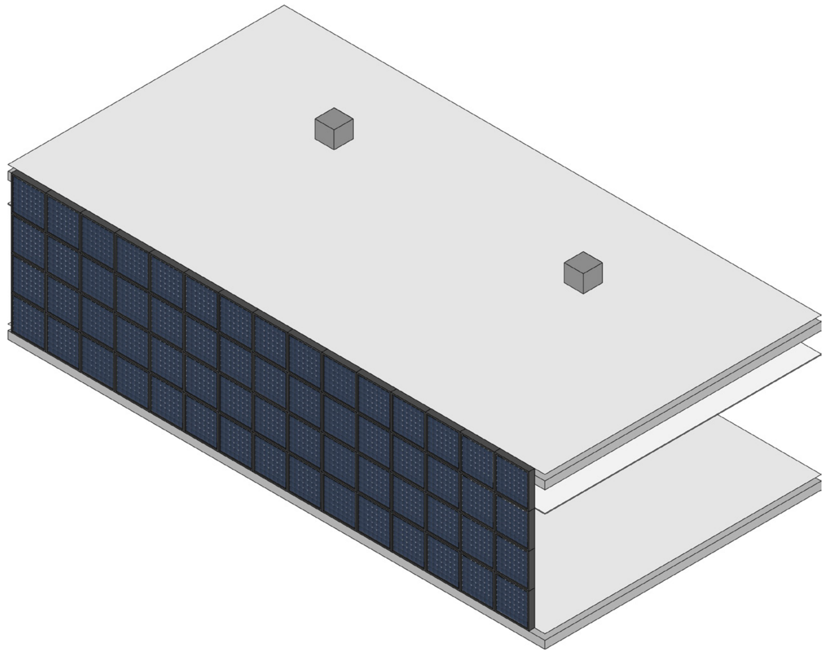
EC
WWR=100%

60 modules EC
A = 48,6 m^2



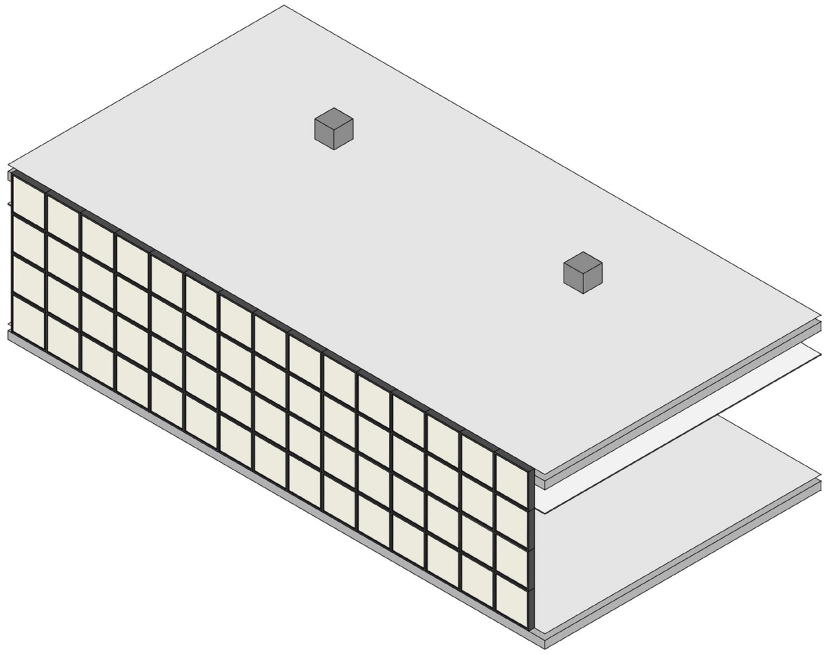
BIPV
WWR=100%

60 modules BIPV
A = 48,6 m^2



BIPV/T
WWR=0%

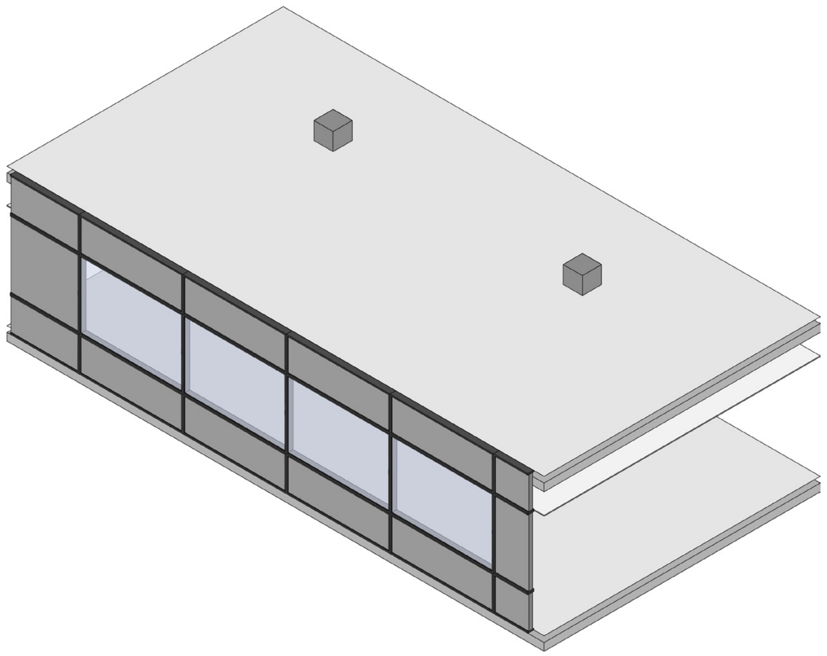
60 modules BIPV/T
A = 48,6 m^2



PCM
WWR=0%

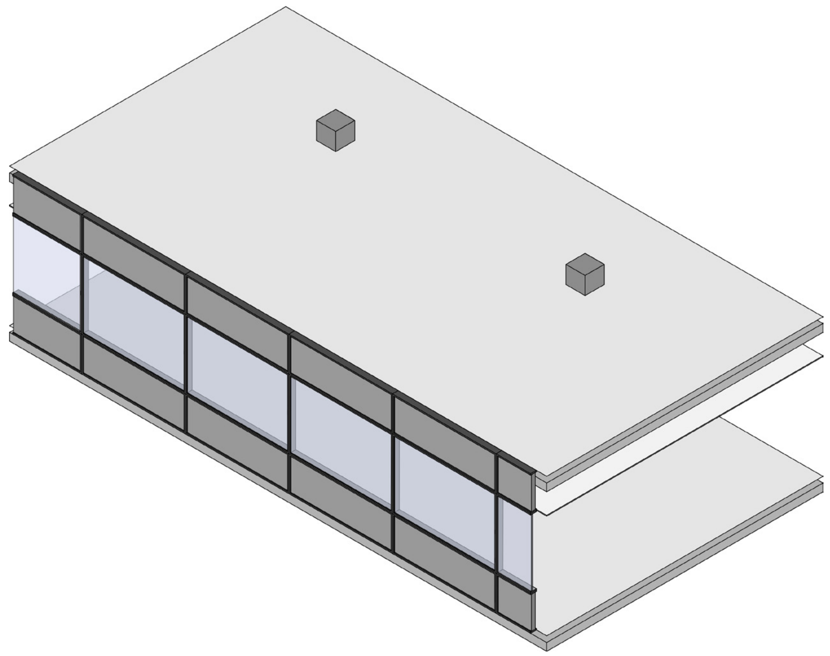
60 modules PCM
A = 48,6 m^2

SIMULATED CASES



reference project
WWR=40%

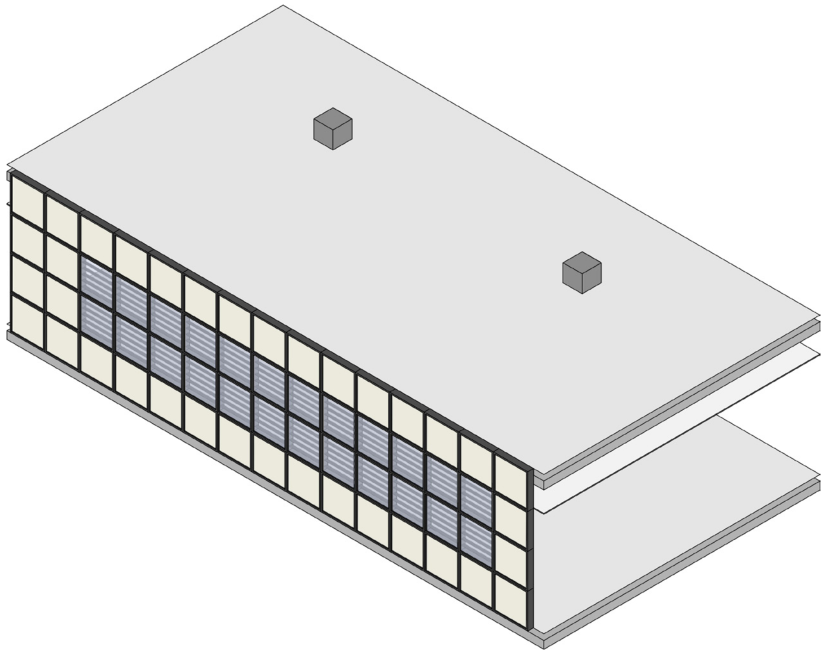
windows: HR++
A = 19,44 m²
wall: gypsum wall board, insulation, lightweight metal cladding
A = 29,16 m²



reference project
WWR=50%

windows: HR++
A = 24,30 m²
wall: gypsum wall board, insulation, lightweight metal cladding
A = 24,30 m²

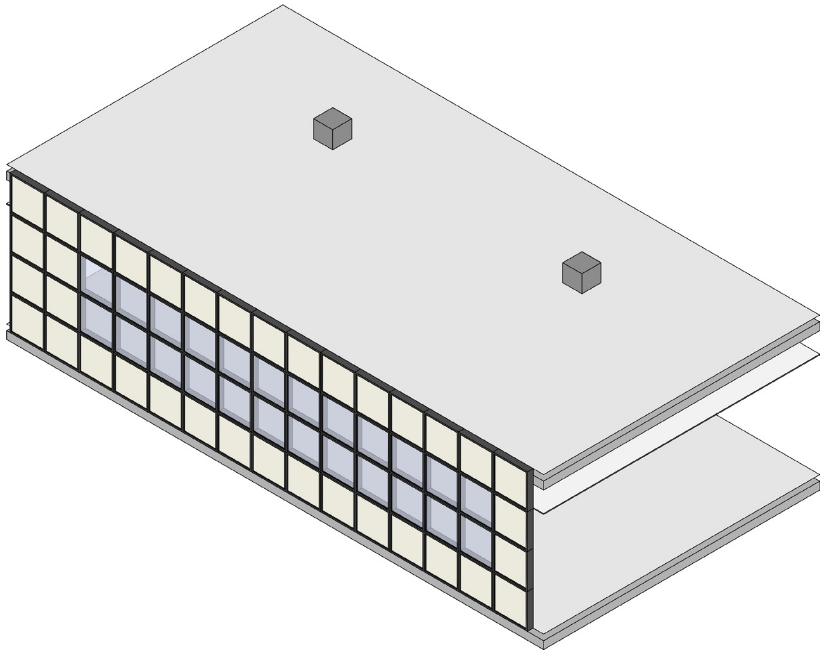
SIMULATED CASES



PCM+Blinds
WWR=40%

24 modules Blinds
A = 19,44 m^2

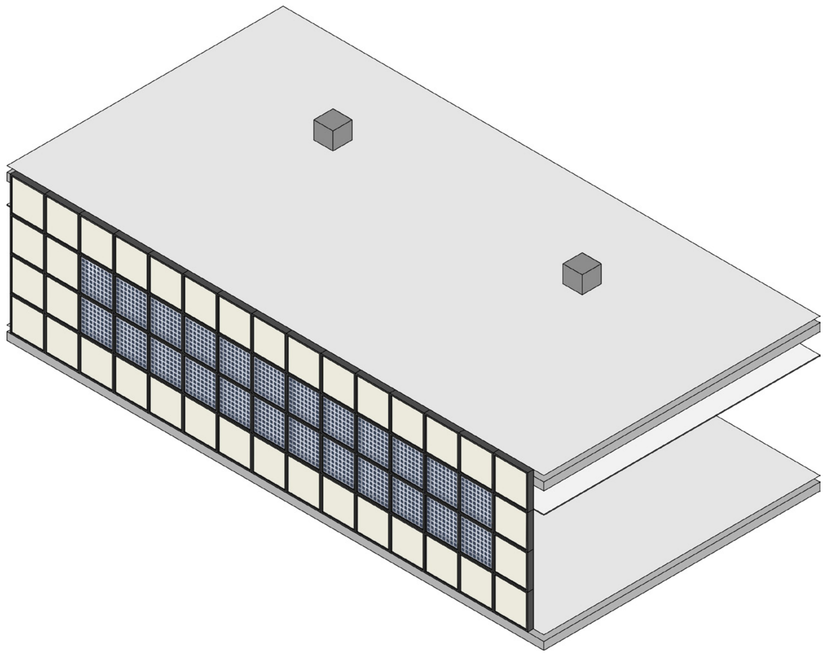
36 modules PCM
A = 29,16 m^2



PCM+EC
WWR=40%

24 modules EC
A = 19,44 m^2

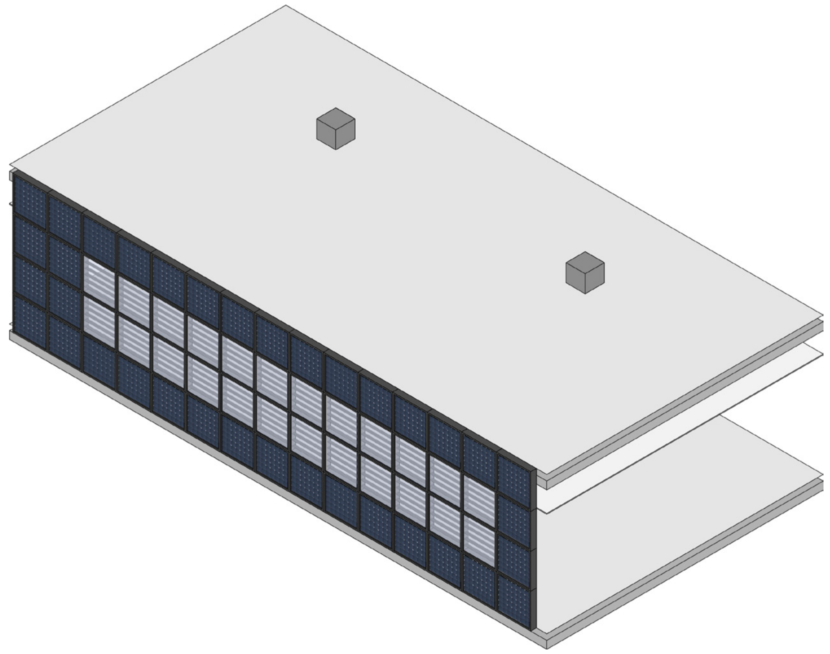
36 modules PCM
A = 29,16 m^2



PCM+BIPV
WWR=40%

24 modules BIPV
A = 19,44 m^2

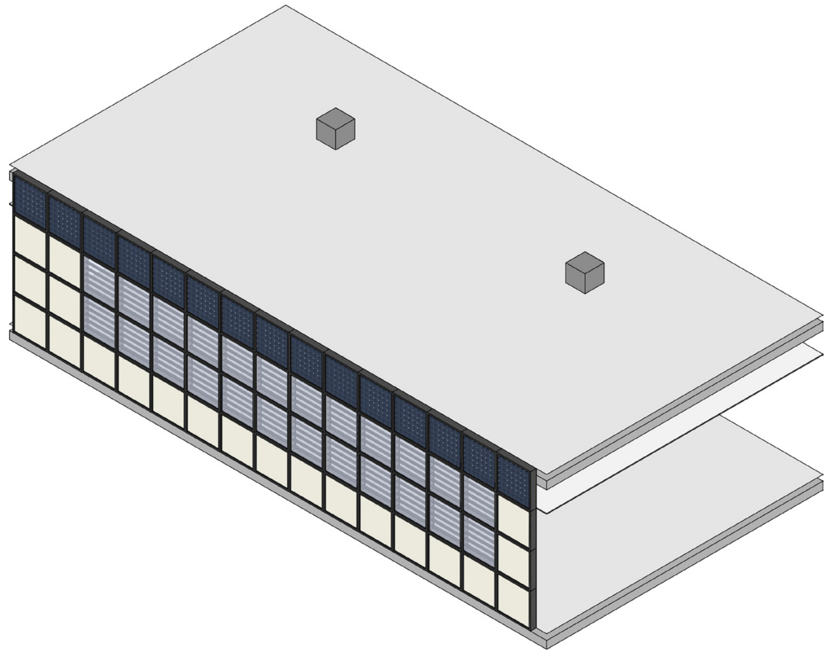
36 modules PCM
A = 29,16 m^2



BIPV/T+Blinds
WWR=40%

24 modules Blinds
A = 19,44 m^2

36 modules BIPV/T
A = 29,16 m^2

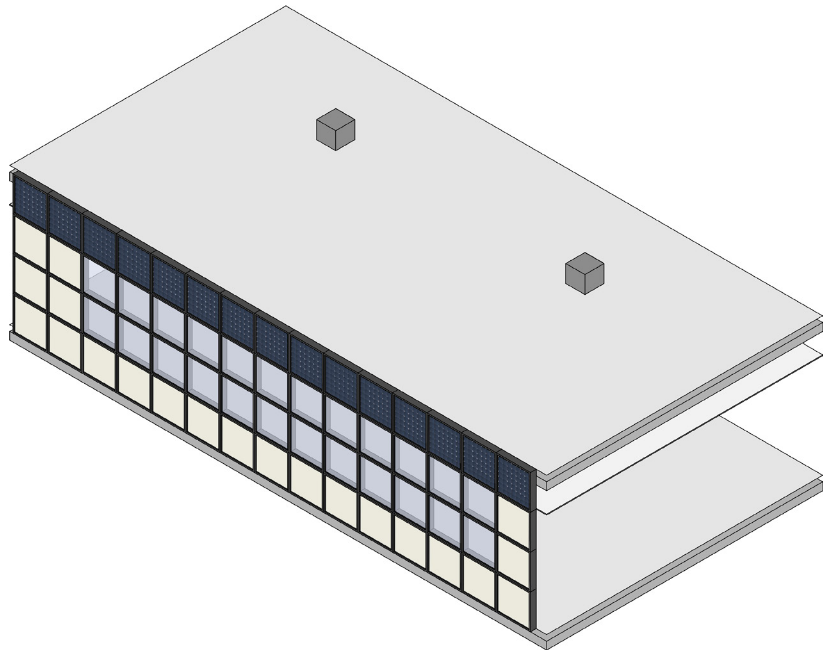


PCM+BIPV/T +Blinds
WWR=40%

24 modules Blinds
A = 19,44 m^2

15 modules BIPV/T
A = 12,15 m^2

21 modules PCM
A = 17,01 m^2



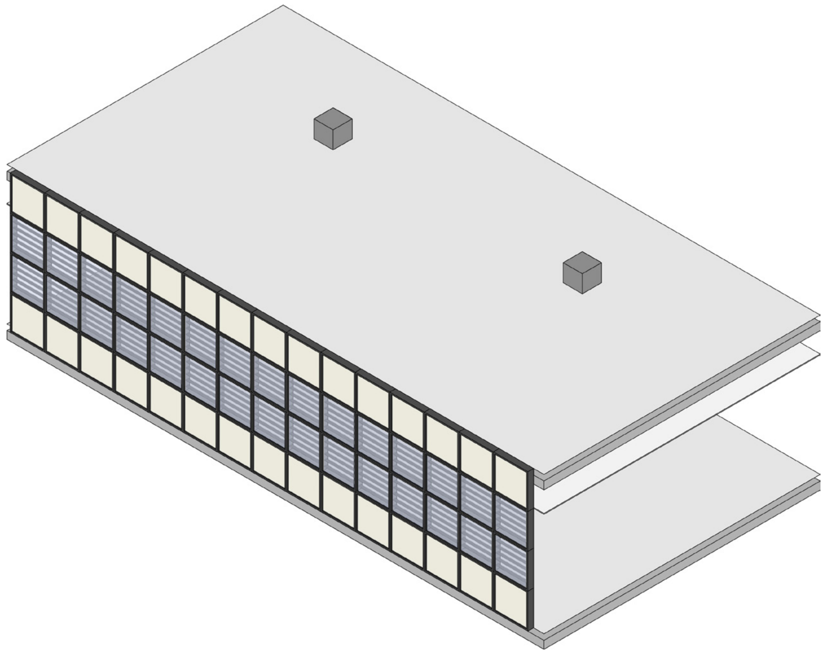
PCM+BIPV/T+EC
WWR=40%

24 modules EC
A = 19,44 m^2

15 modules BIPV/T
A = 12,15 m^2

21 modules PCM
A = 17,01 m^2

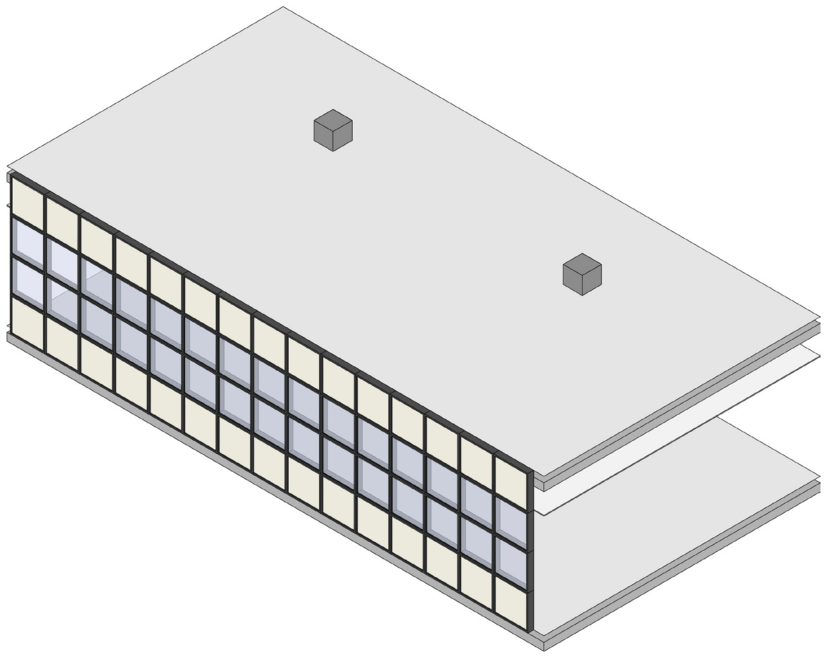
SIMULATED CASES



PCM+Blinds
WWR=50%

30 modules Blinds
A = 24,30 m^2

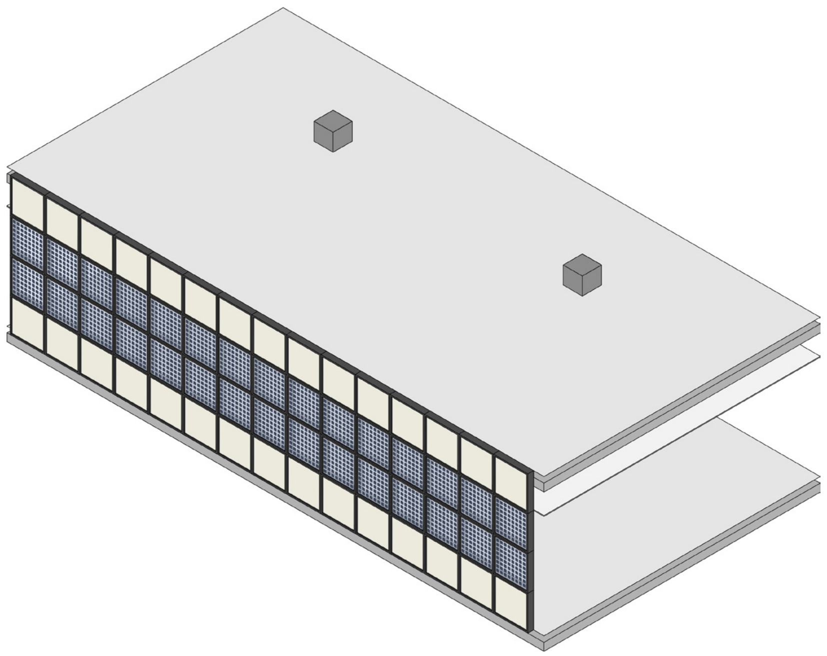
30 modules PCM
A = 24,30 m^2



PCM+EC
WWR=50%

30 modules EC
A = 24,30 m^2

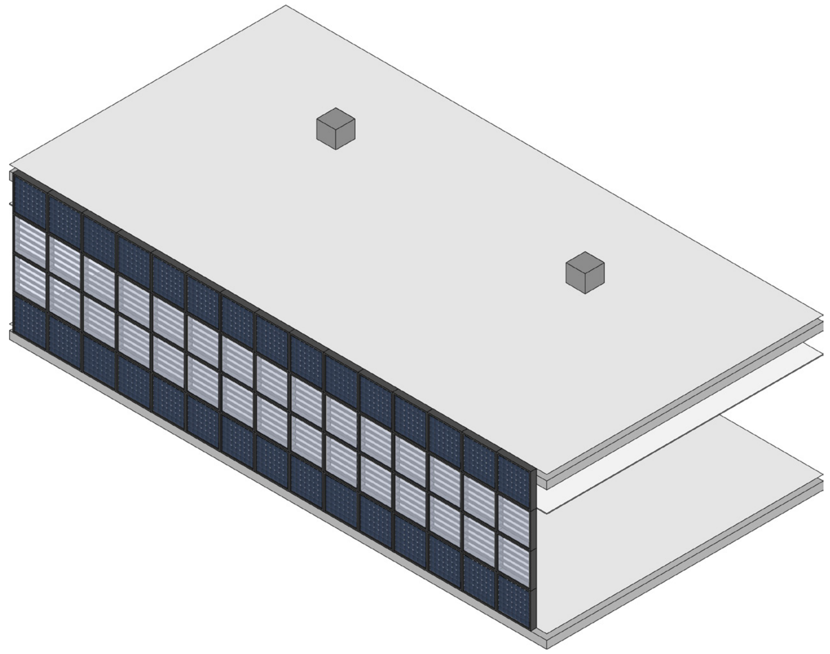
30 modules PCM
A = 24,30 m^2



PCM+BIPV
WWR=50%

30 modules BIPV
A = 24,30 m^2

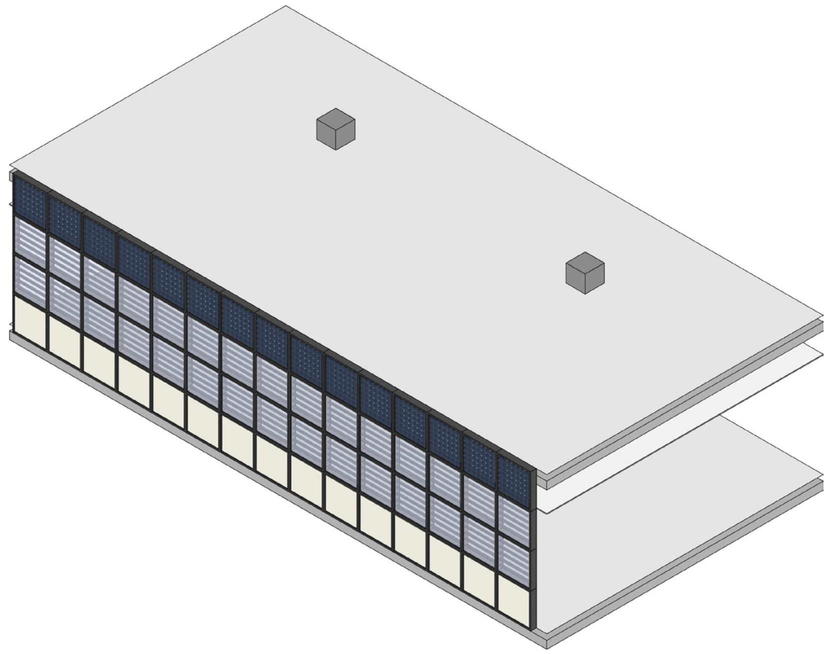
30 modules PCM
A = 24,30 m^2



BIPV/T+Blinds
WWR=50%

30 modules Blinds
A = 24,30 m^2

30 modules BIPV/T
A = 24,30 m^2

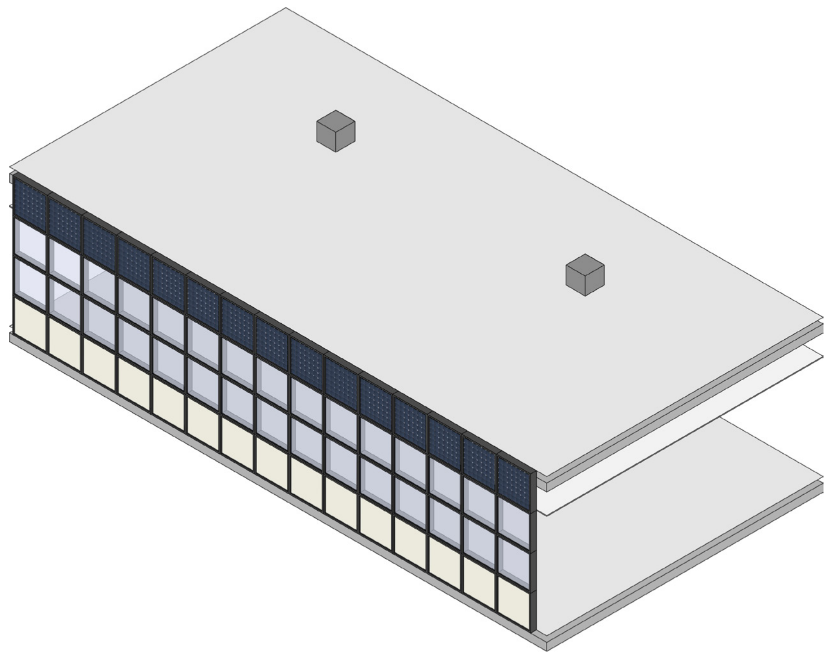


PCM+BIPV/T +Blinds
WWR=50%

30 modules Blinds
A = 24,30 m^2

15 modules BIPV/T
A = 12,15 m^2

15 modules PCM
A = 12,15 m^2



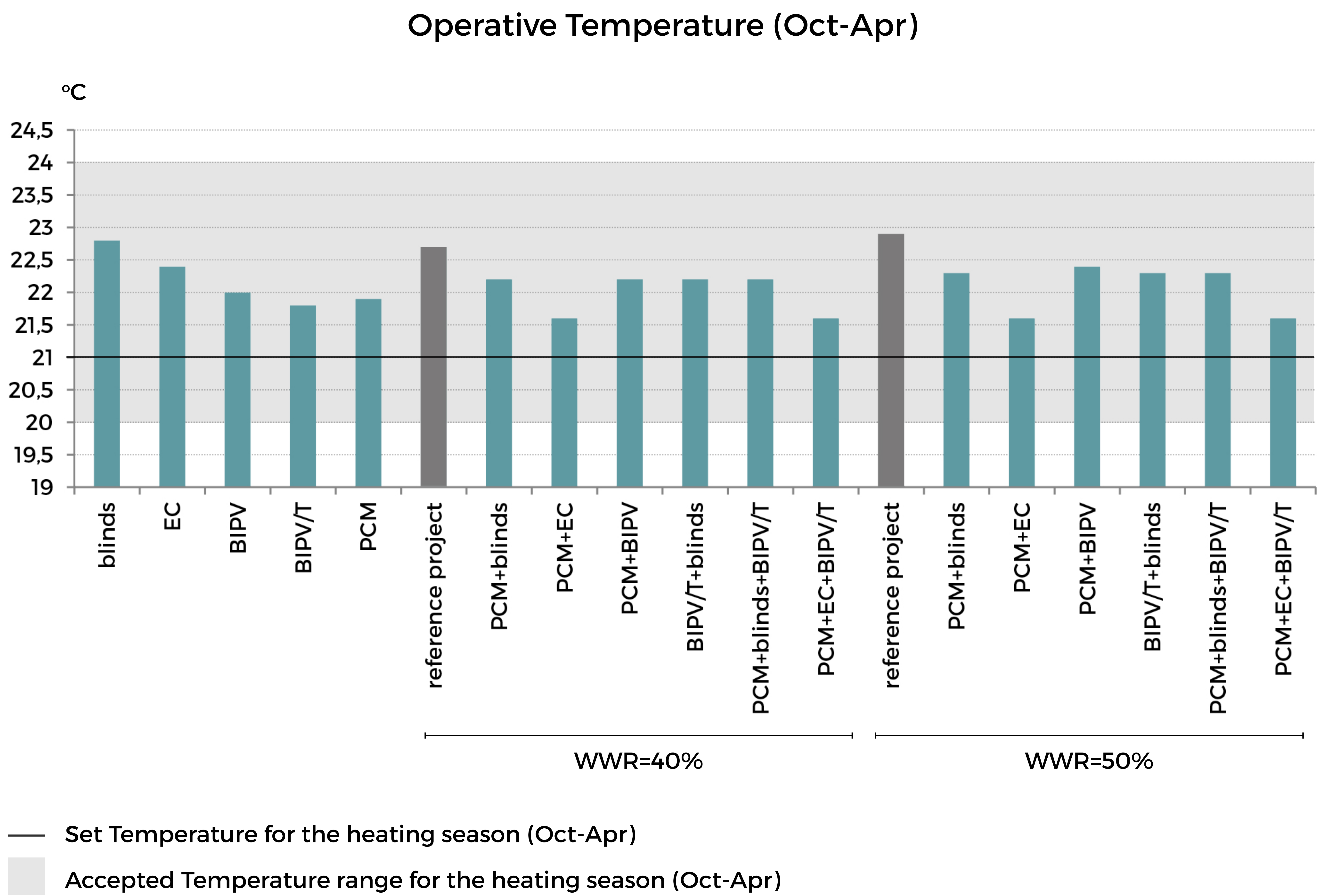
PCM+BIPV/T+EC
WWR=50%

30 modules EC
A = 24,30 m^2

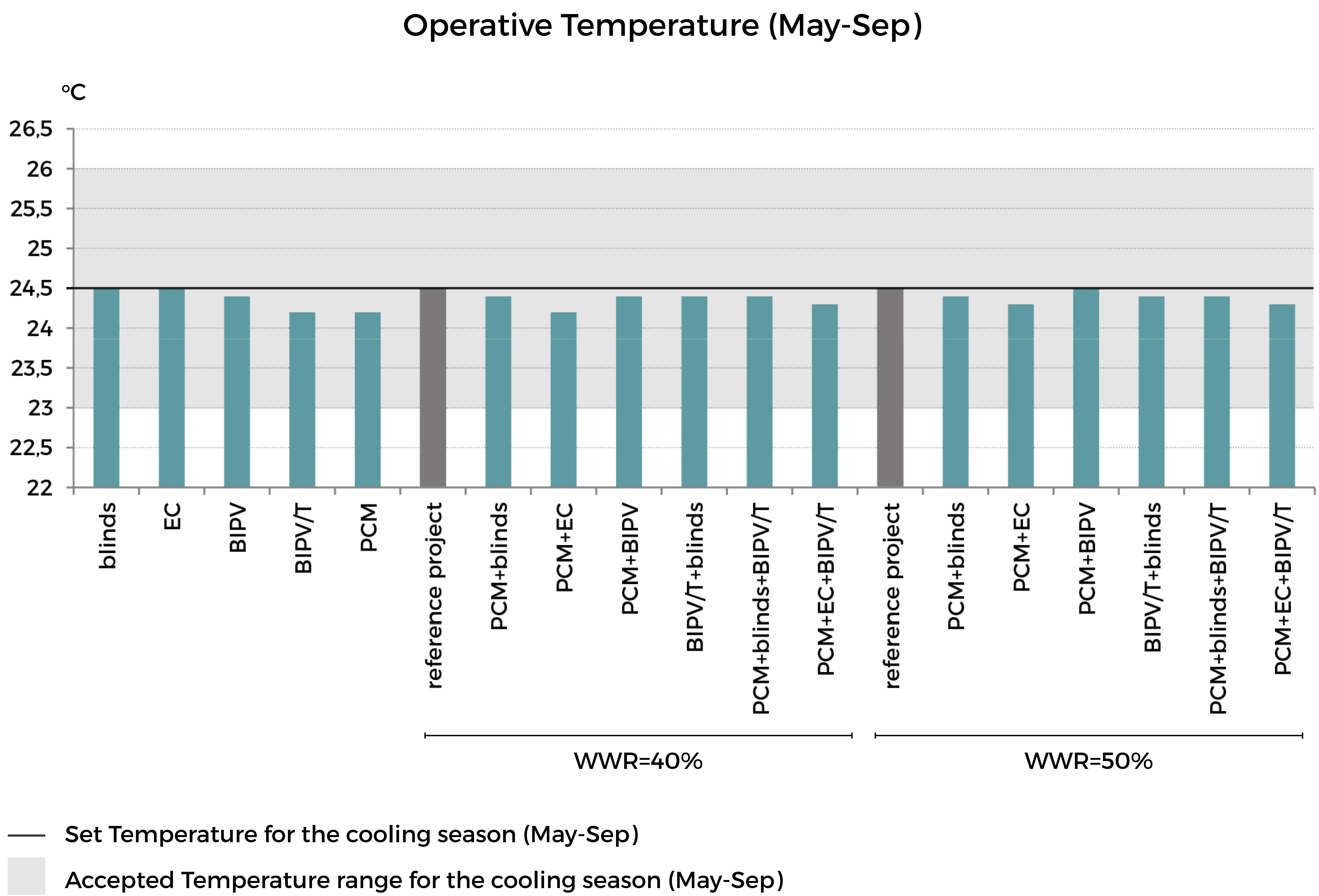
15 modules BIPV/T
A = 12,15 m^2

15 modules PCM
A = 12,15 m^2

SIMULATION RESULTS

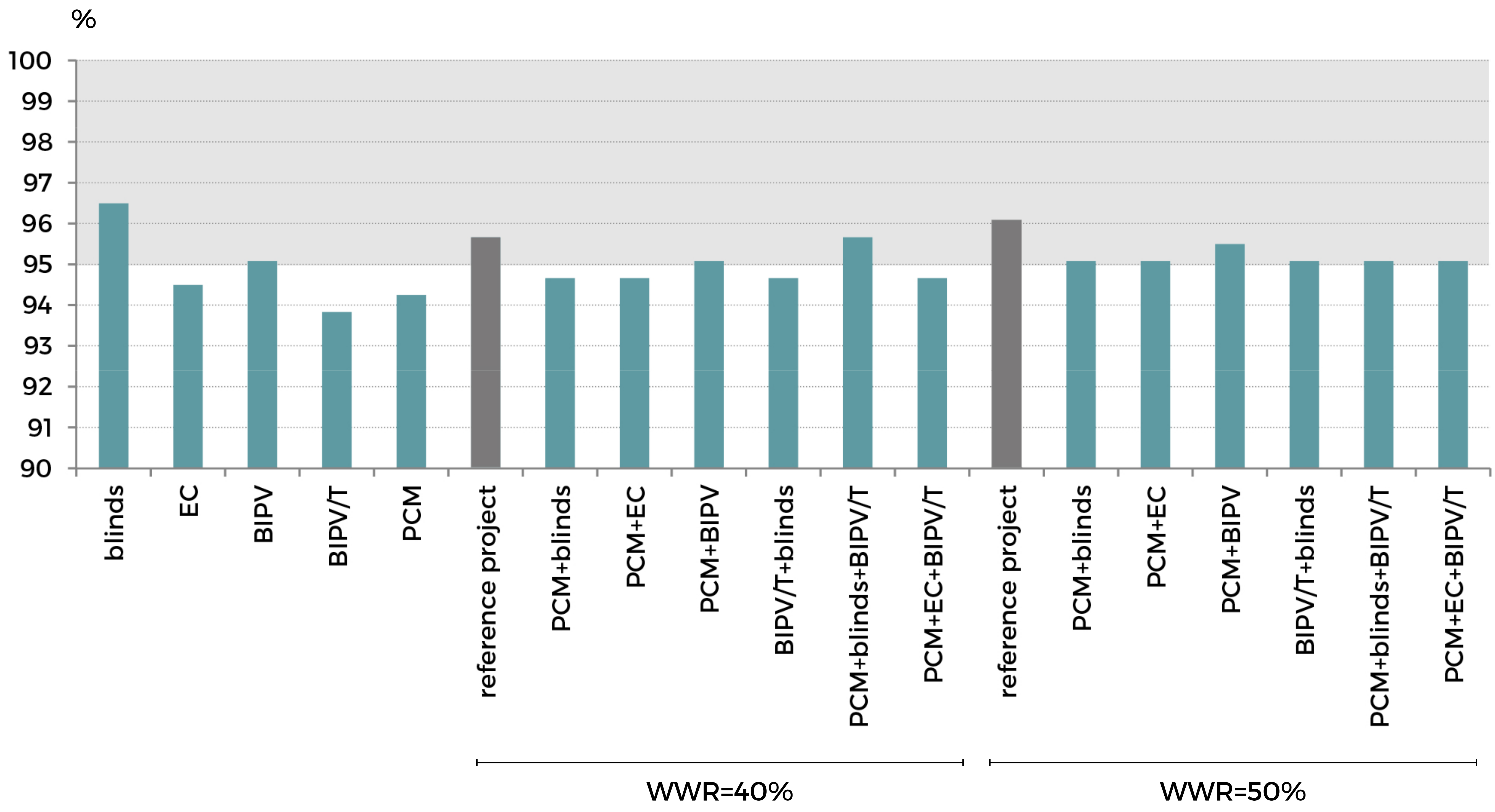


SIMULATION RESULTS

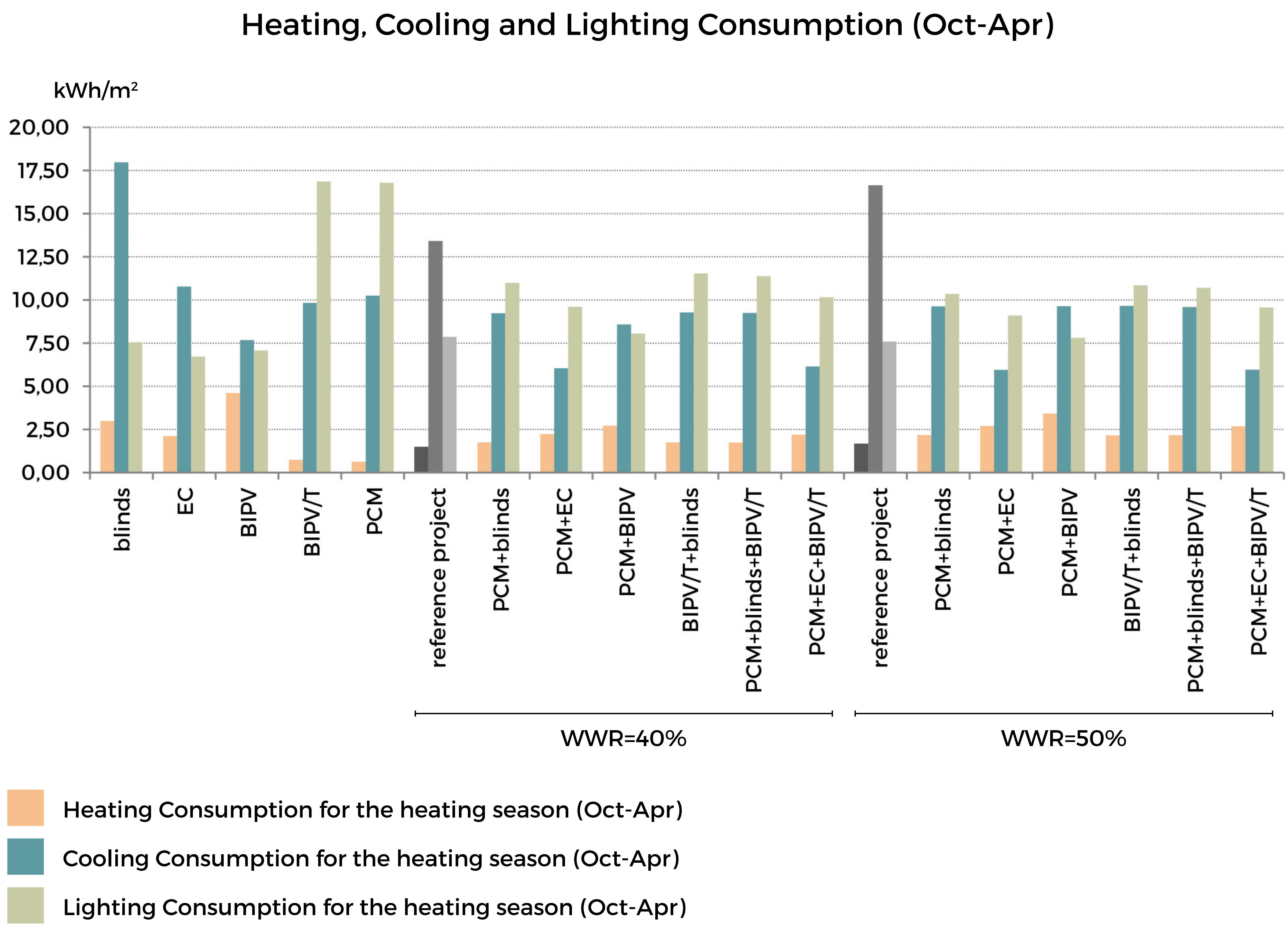


SIMULATION RESULTS

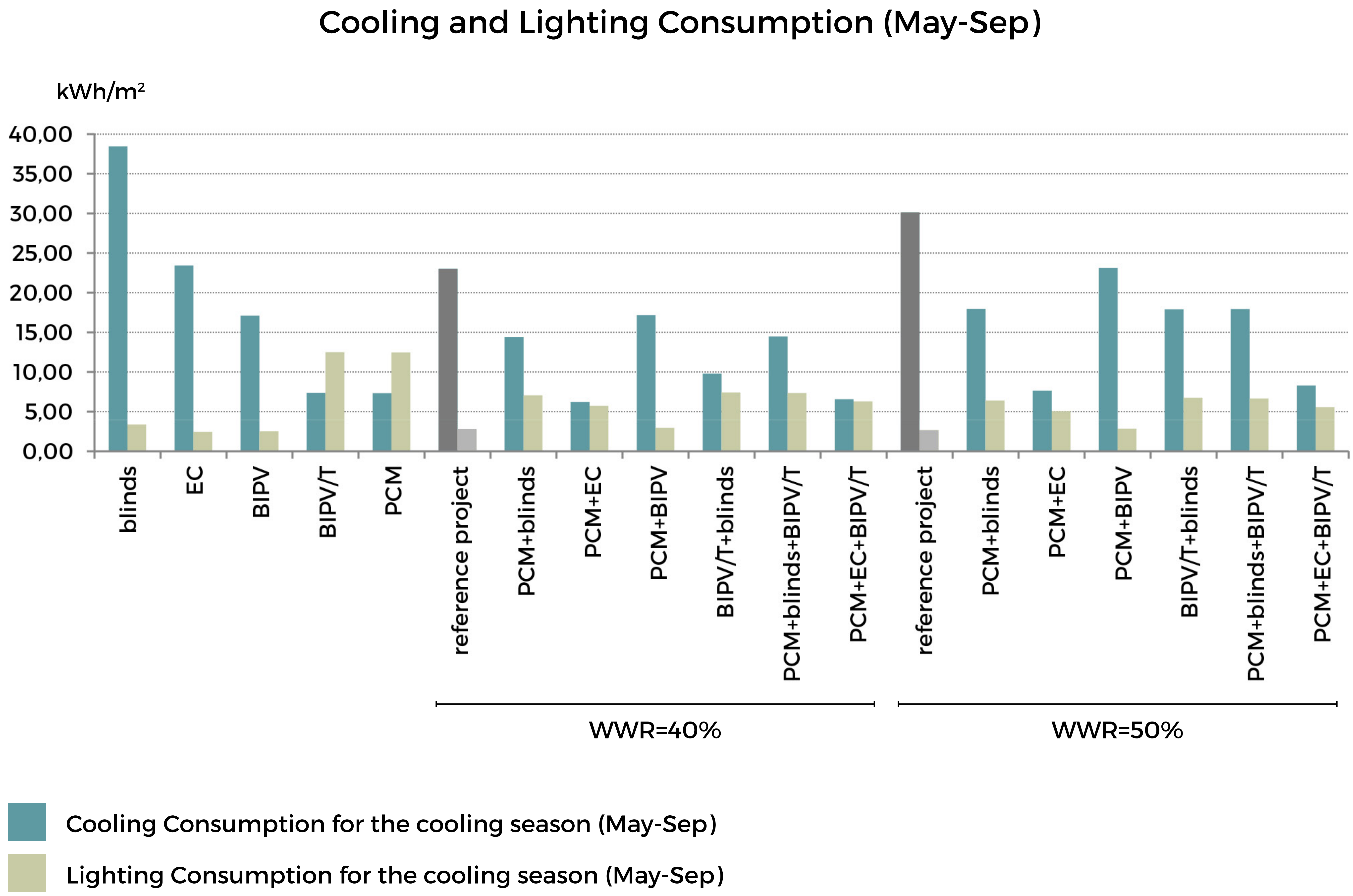
Annual Comfort



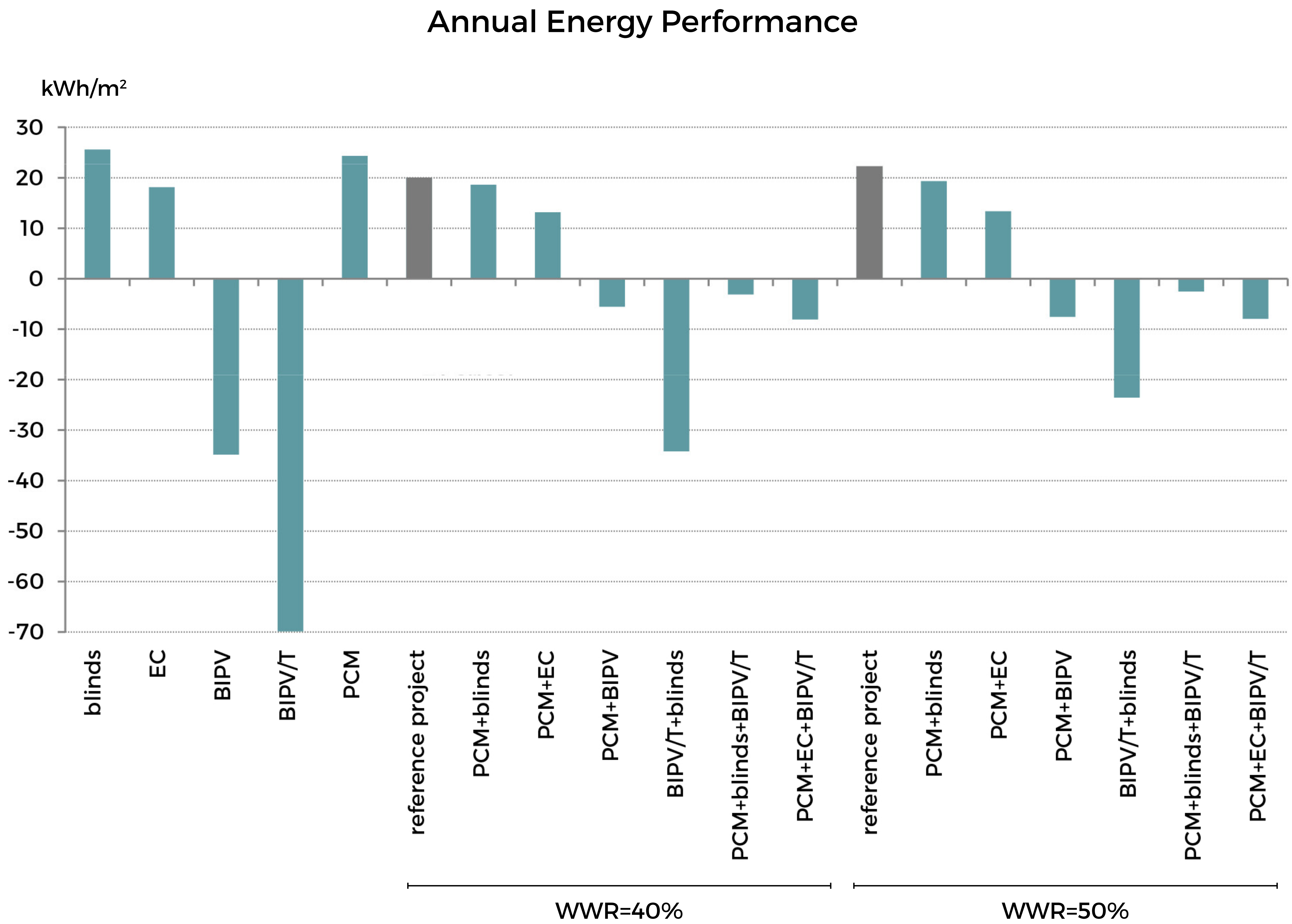
SIMULATION RESULTS



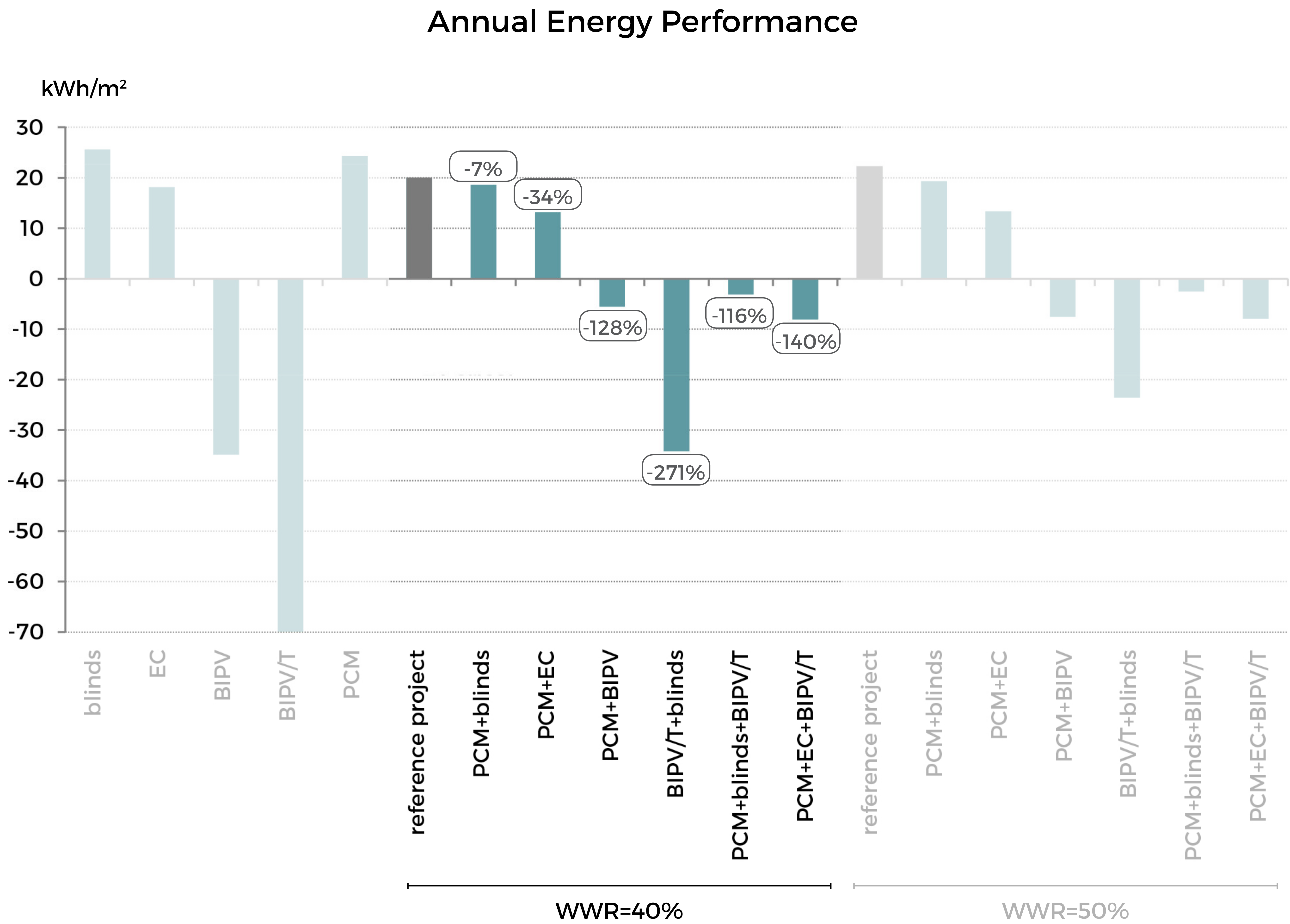
SIMULATION RESULTS



SIMULATION RESULTS

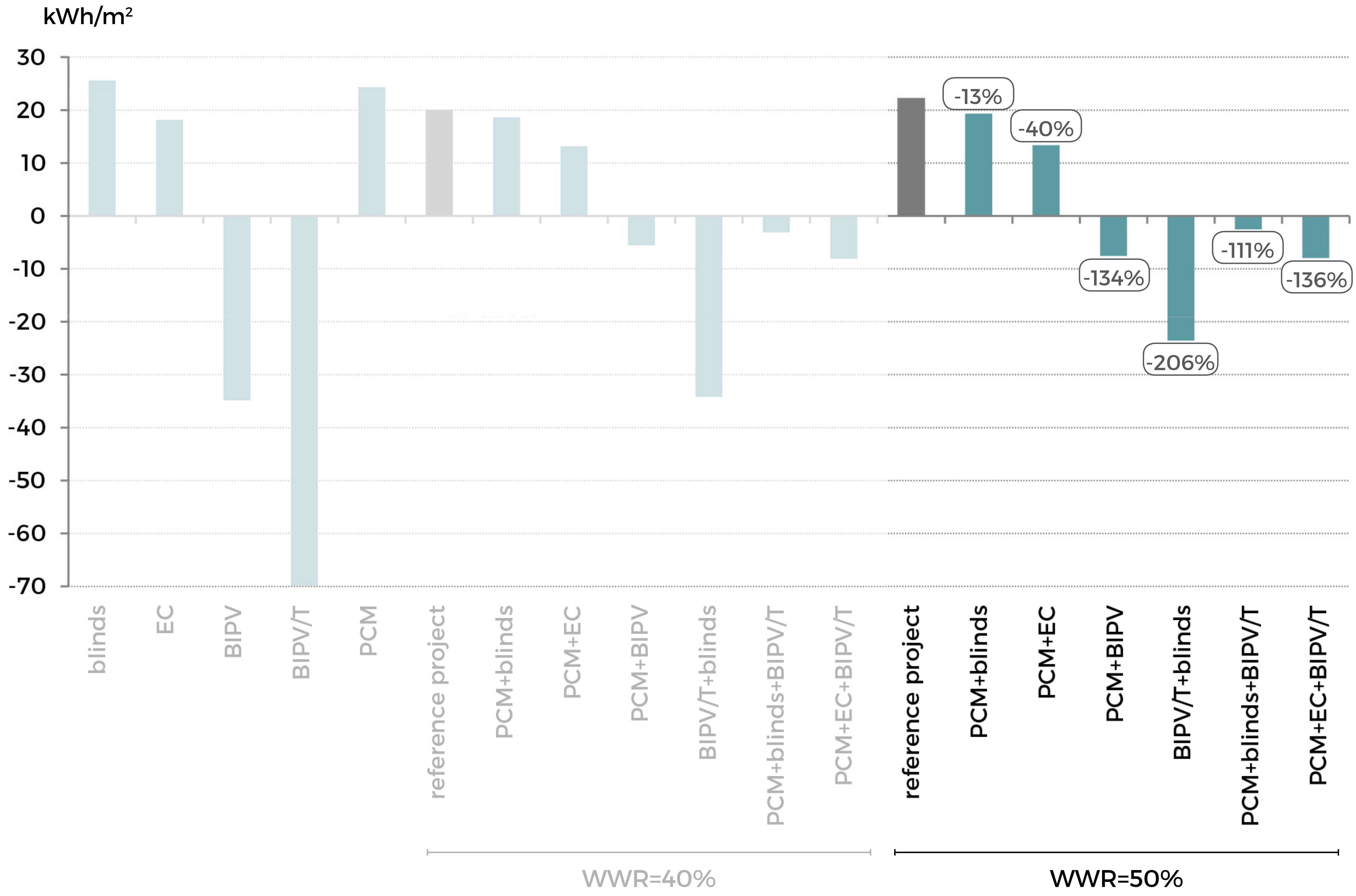


SIMULATION RESULTS



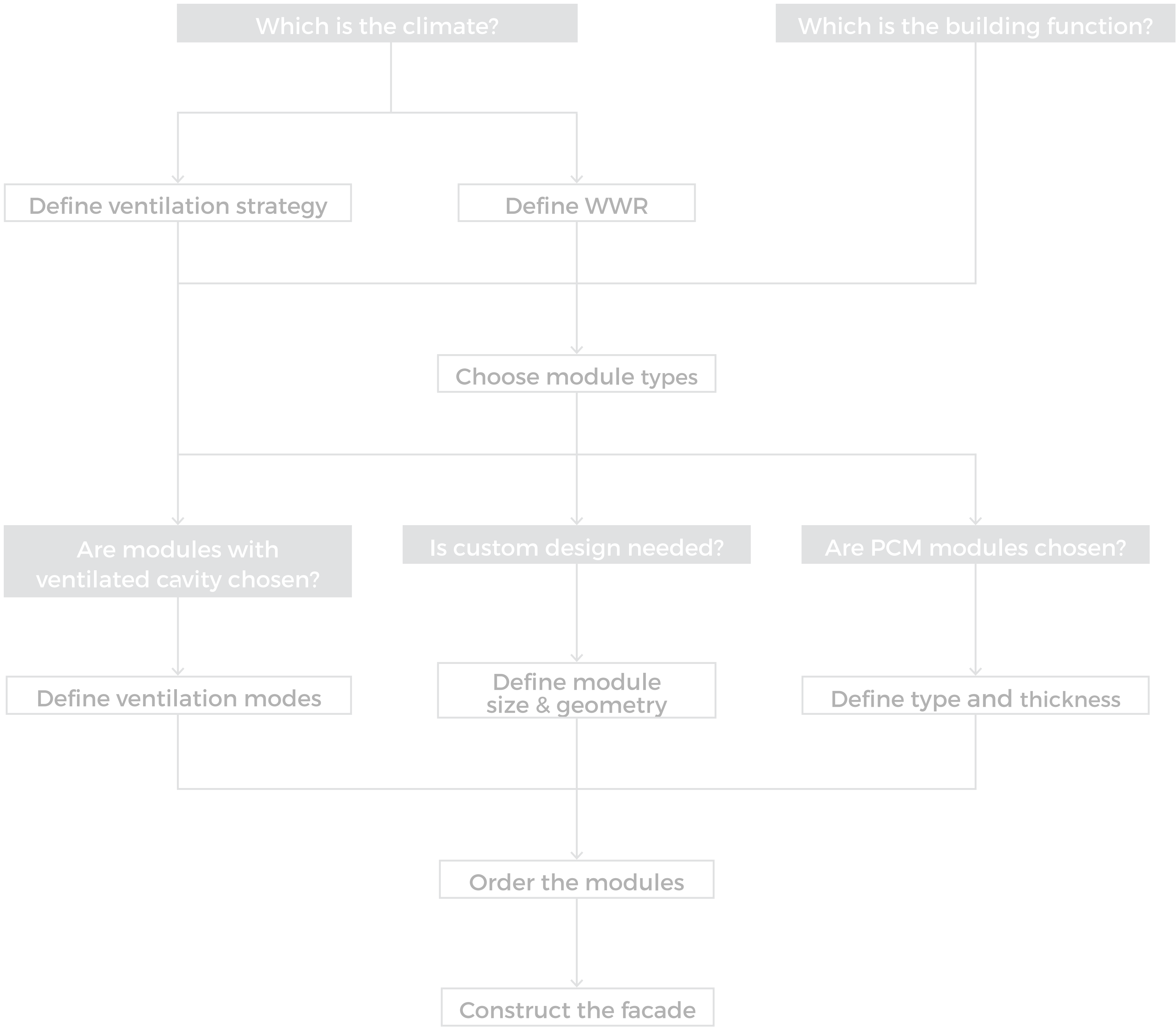
SIMULATION RESULTS

Annual Energy Performance

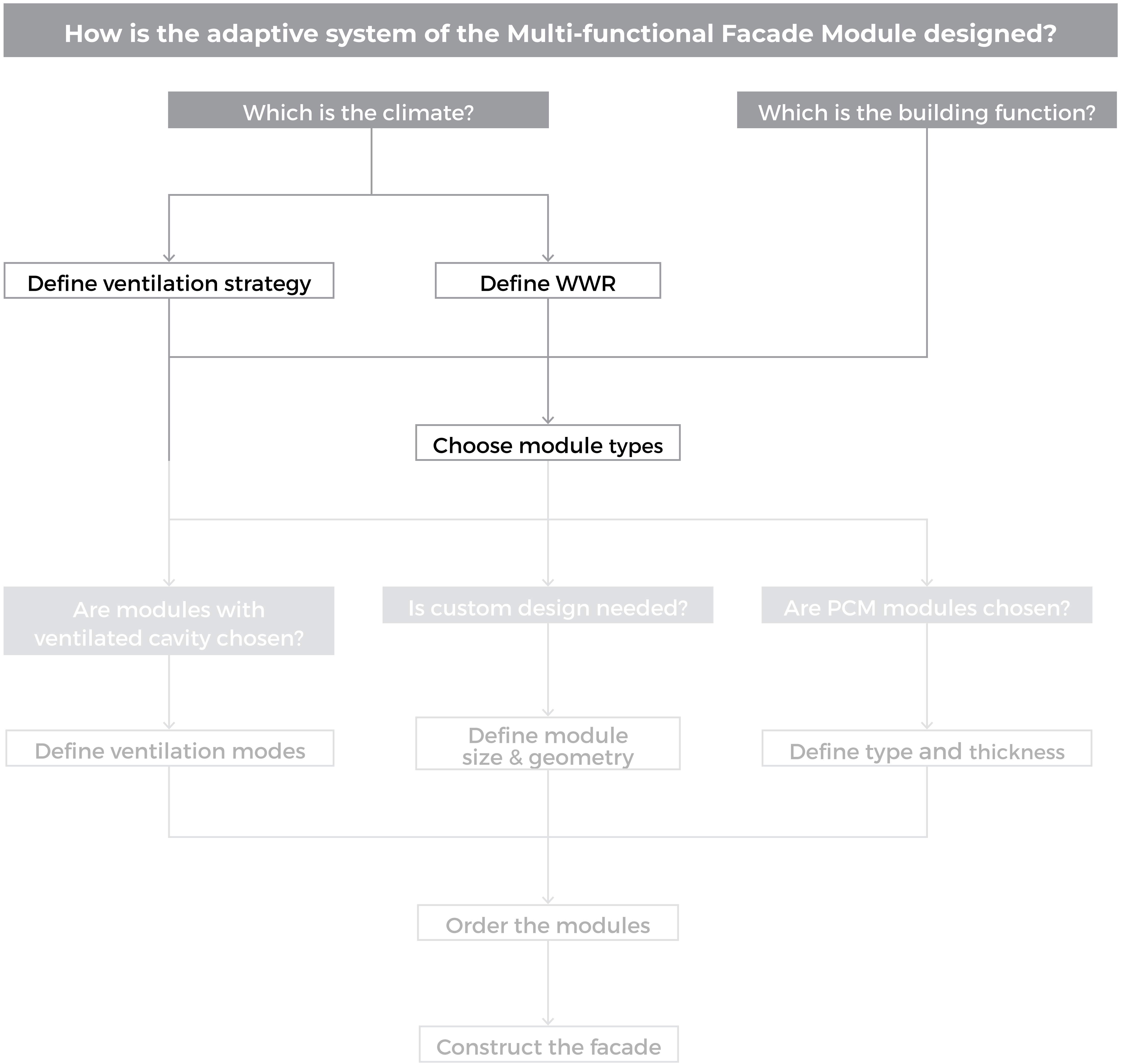


? RESEARCH QUESTION

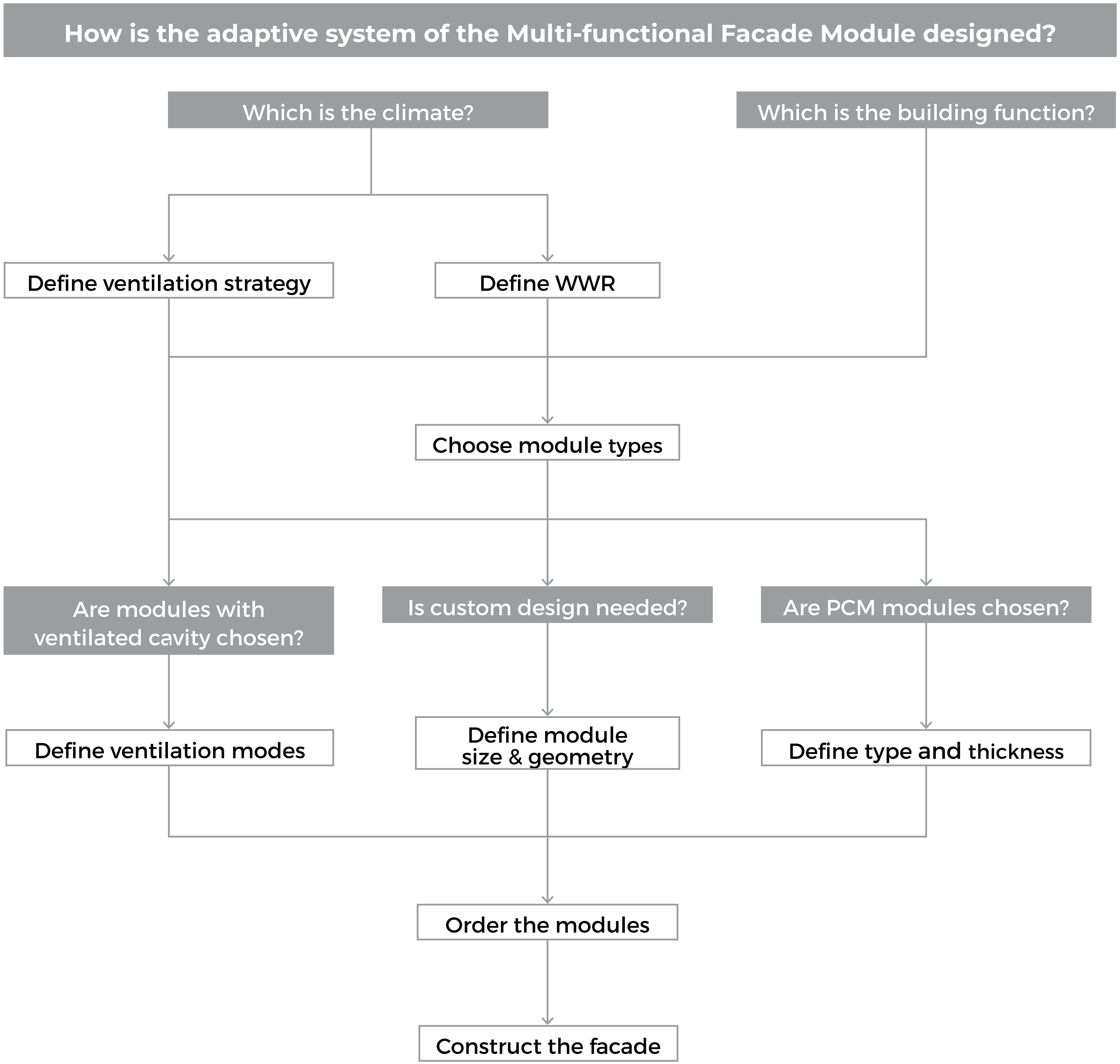
How is the adaptive system of the Multi-functional Facade Module designed?



RESEARCH QUESTION ?



RESEARCH QUESTION ?



CONCLUSIONS

Overall assessment

- nearly zero-energy or positive energy performance

- official comfort and temperature requirements achieved

- heating and lighting are a bit higher due to the solar control systems

- much higher impact on cooling

- the more modules are combined, the better the results of energy performance and comfort

- energy production is an essential aspect

- 40% WWR has a better energy performance than 50%

- 50% WWR has slightly better comfort than 40%

- promising future concept

Future Developments

- PCM shading strategy according to the climate applied

- structural calculations

- more simulations including the non-simulated modules and also for different climates and different WWR

- simulation for a full scale building model

- automated management system

Rollecate

- synchronisation of different functions

- more close collaboration with other stakeholders (material science, building physics, etc)