INVESTIGATION AND IMPLEMENTATION OF 'PV-CHIMNEY' SYSTEM ON BUILDING ENVELOPES

Gratuation project
2018-2019
Program: Building Technology Track

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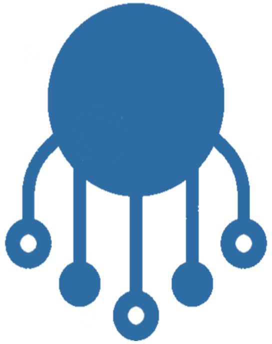
TU Delft

01

FRAMEWORK

Population growth causes environmental problems….

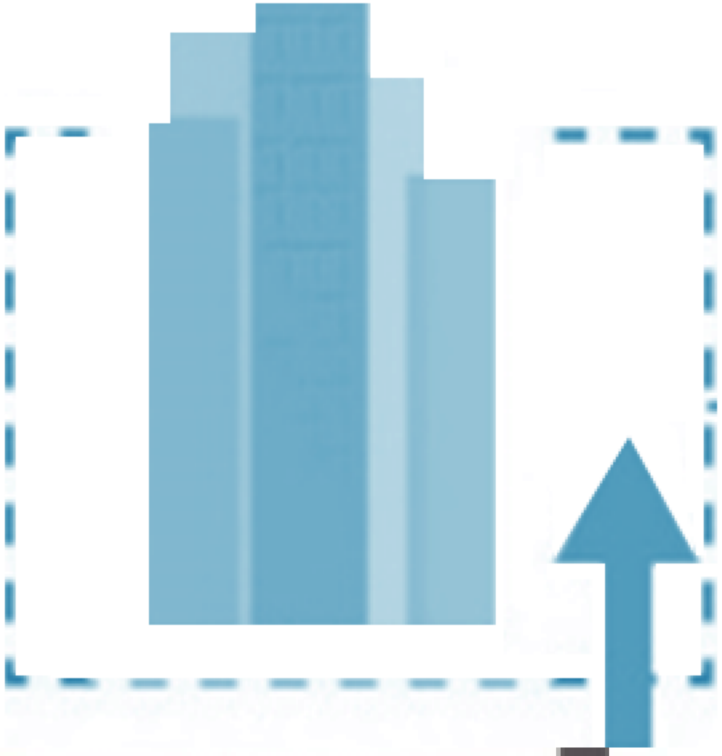


35% GLOBAL RESOURCES

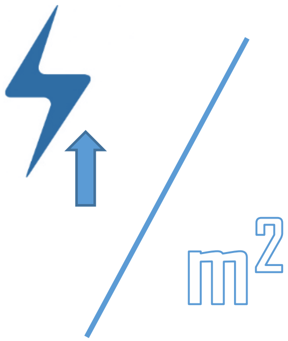
40% OF THE ENERGY

40% GLOBAL CARBON EMISSIONS

Intensification of urbanization enhances the vertical development ...

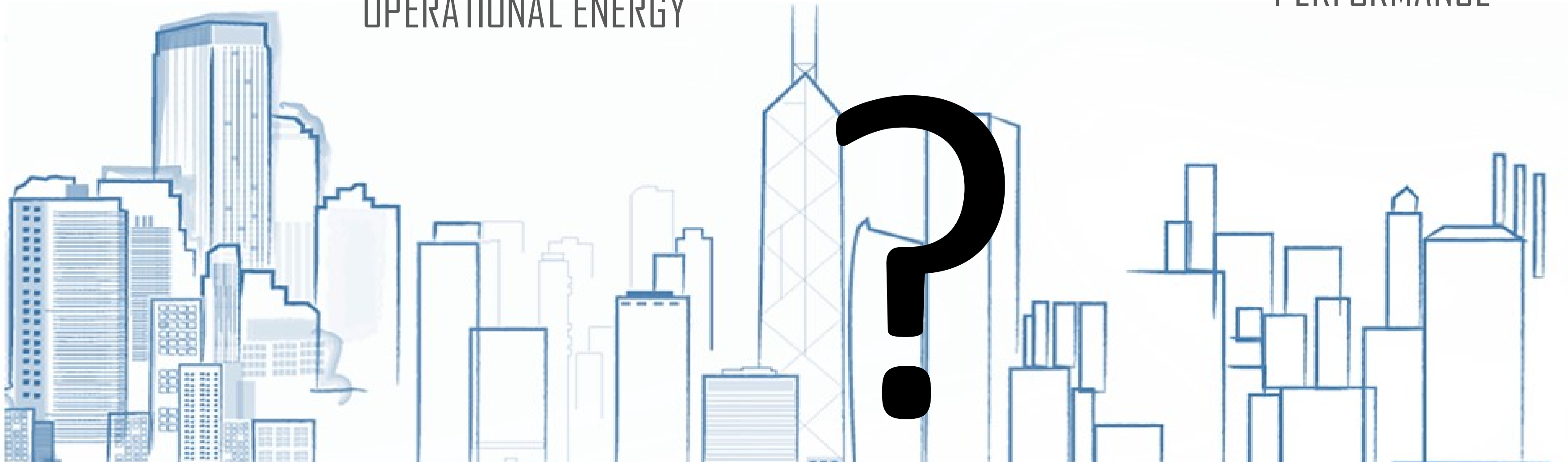


FRAMEWORK



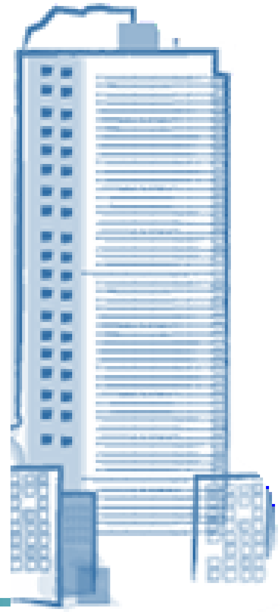
HIGHER
OPERATIONAL ENERGY

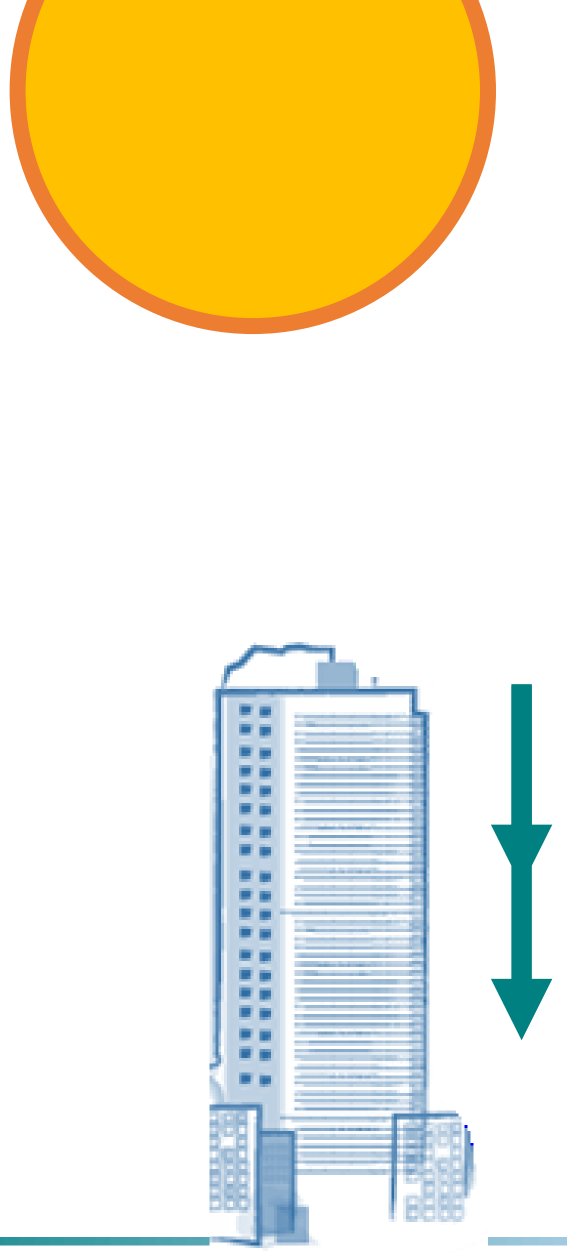
HIGHER ENERGY
PERFORMANCE



RESEARCH PROBLEM

USE of renewable sources is a necessity





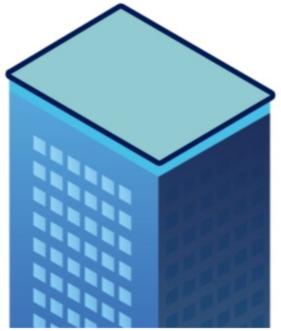
RESEARCH PROBLEM

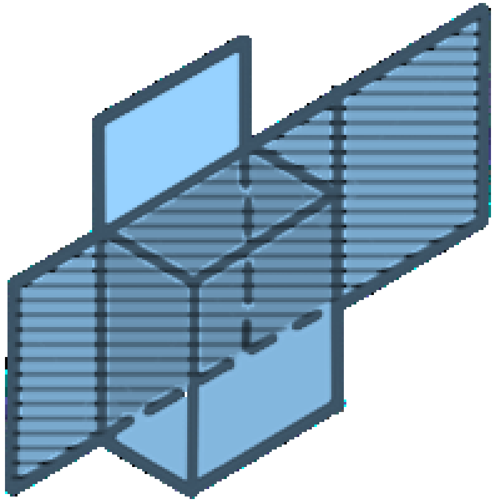
USE of renewable sources is a necessity

+

PRODUCE energy

FRAMEWORK





LIMITED ROOF

surface area

↓

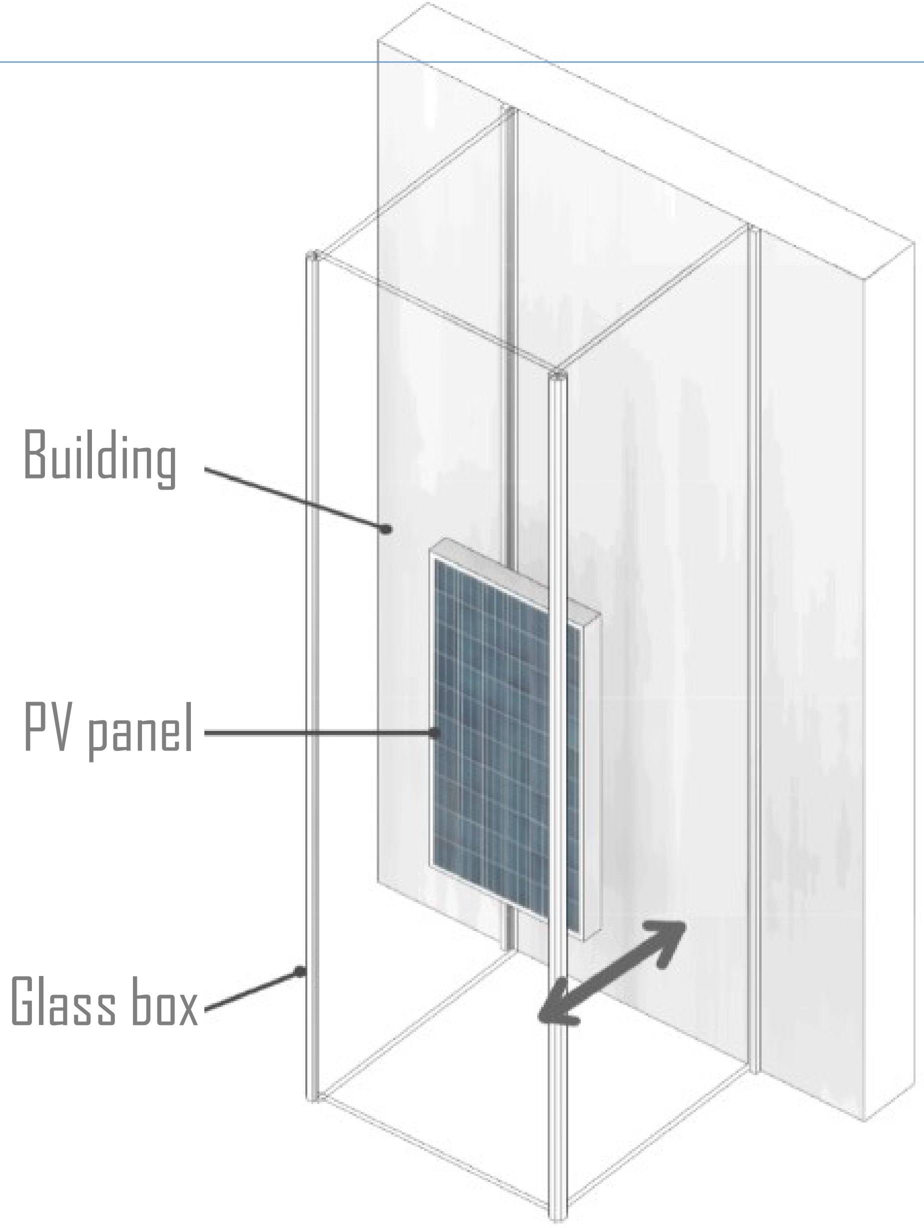
FAÇADE

offers large available surface area

FRAMEWORK

Implementation of solar systems
on facades

PV+CHIMNEY
RESEARCH PROGRAMME



FRAMEWORK

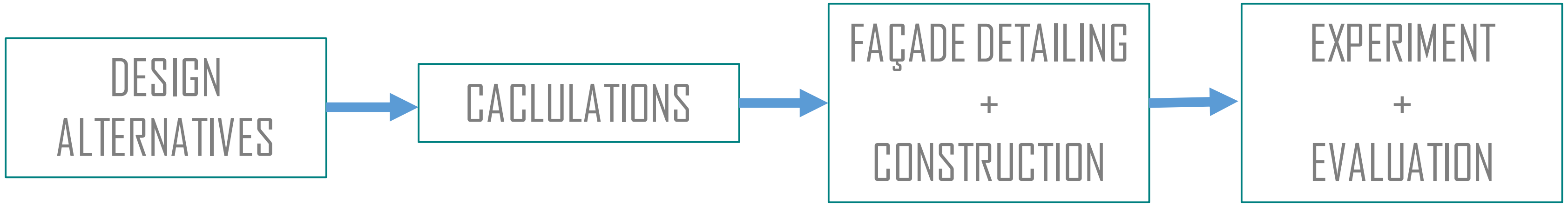
ARCHITECTURE ⟷ PERFORMANCE

RESEARCH QUESTION

How can the proposed PV-chimney technology be **designed, optimized** and **integrated** on a multi-floor building envelope by maintaining the basic functions of the facade and high aesthetic values and improving the **energy performance** of the building?

RESEARCH QUESTION

FRAMEWORK



How can the proposed PV-chimney technology be **designed, optimized** and **integrated** on a multi-floor building envelope by maintaining the basic functions of the facade and high aesthetic values and improving the **energy performance** of the building?

02

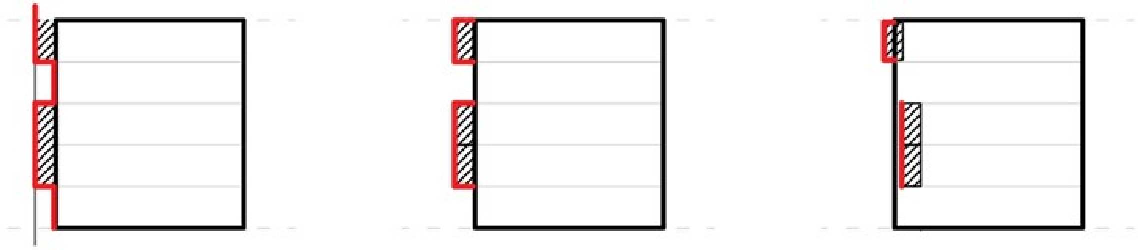
SYSTEM EXPLORATION

ARCHITECTURE ⟷ PERFORMANCE

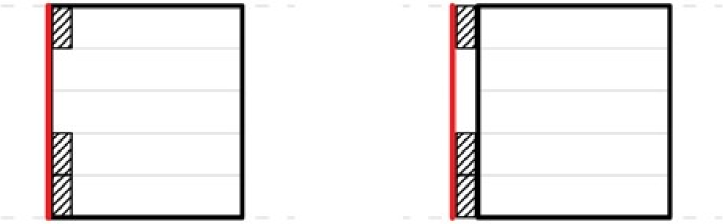
TYPOLOGIES

SYSTEM EXPLORATION

MASK

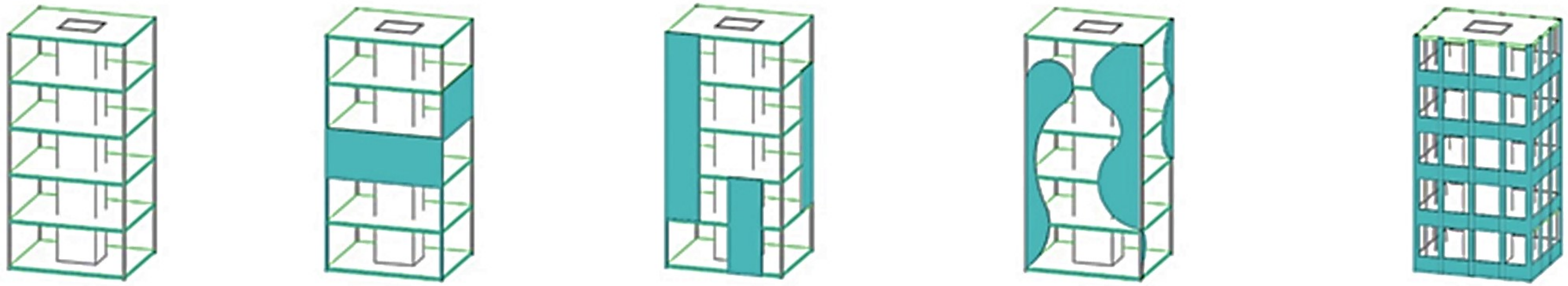


FULL CLOSED MASK



SYSTEM
EXPLORATION

PATTERNS



TRANSPARENT   HORIZONTAL DESIGN   VERTICAL DESIGN   FREE FORM DESIGN   GRID DESIGN

SYSTEM
EXPLORATION

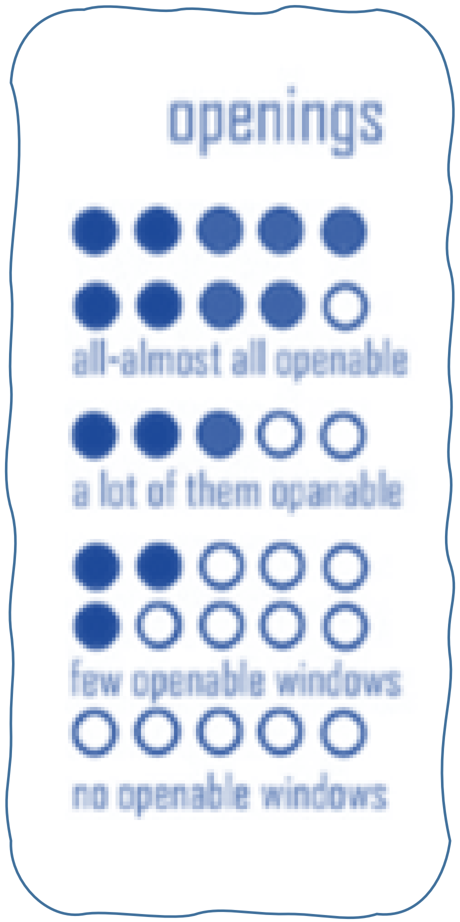
DISCUSSION CRITERIA

NATURAL LIGHTING

OPENIGNS

GEOMETRY

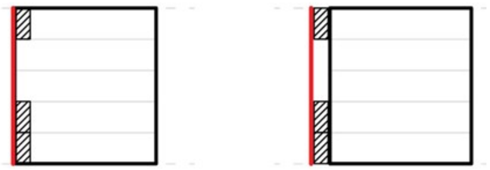
CLIMATE



SYSTEM
EXPLORATION

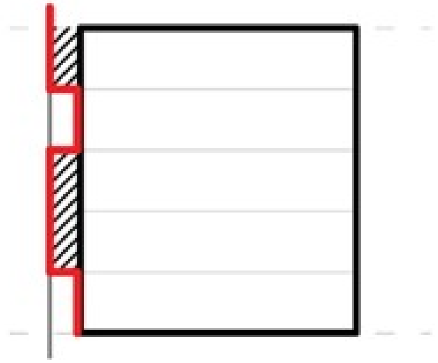
DESIGN ALTERNATIVES

FULL CLOSED MASK



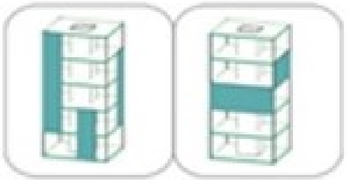
MASK

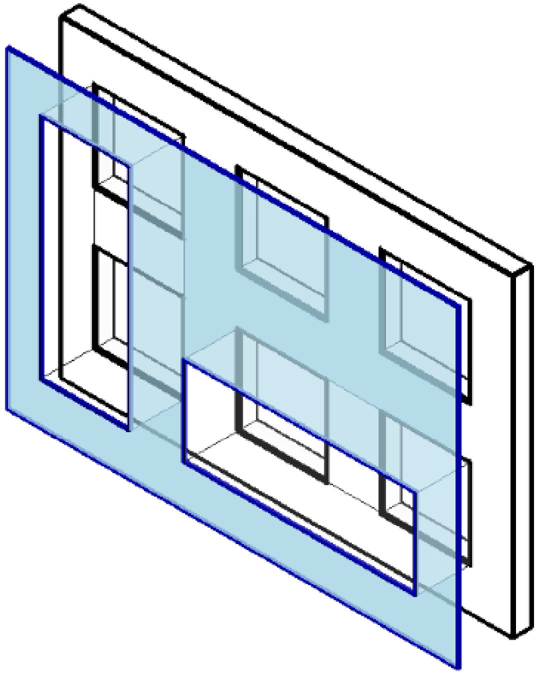
DESIGN EXPLORATION



The building is covered and some parts are breathing

SYSTEM
EXPLORATION



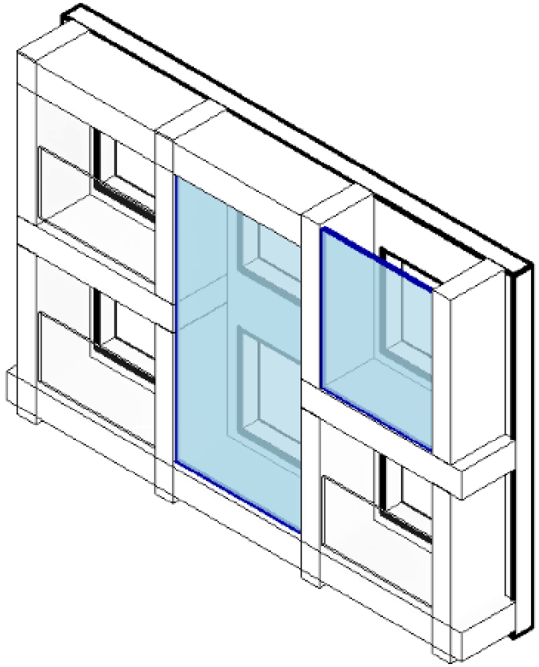


Functional

natural lighting ●●●●○ openings ●●●○○

Performance

depth ●●●○○ height ●●●●● width ●●●●● climate



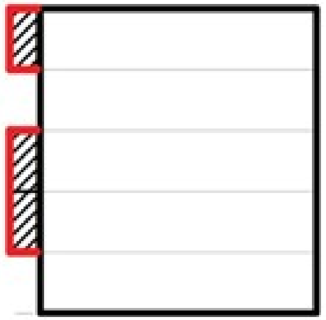
Functional

natural lighting ●●●●○ openings ●●●○○

Performance

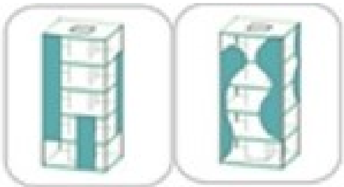
depth ●●●○○ height ●●●●● width ●●●●● climate

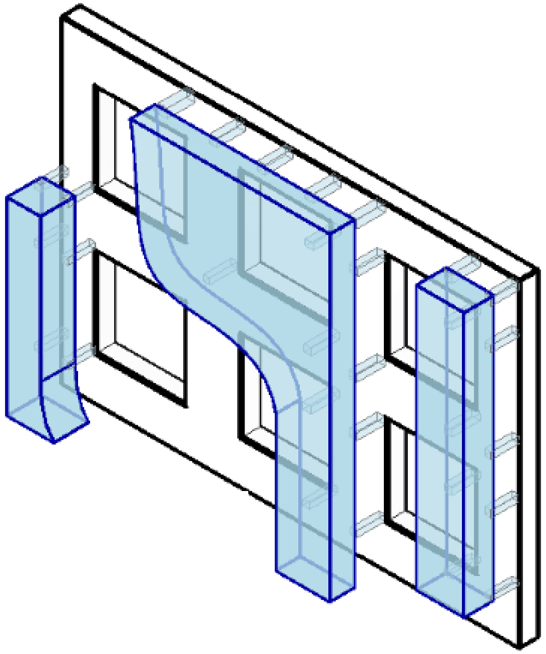
MASK



The system is attached to the building

SYSTEM
EXPLORATION



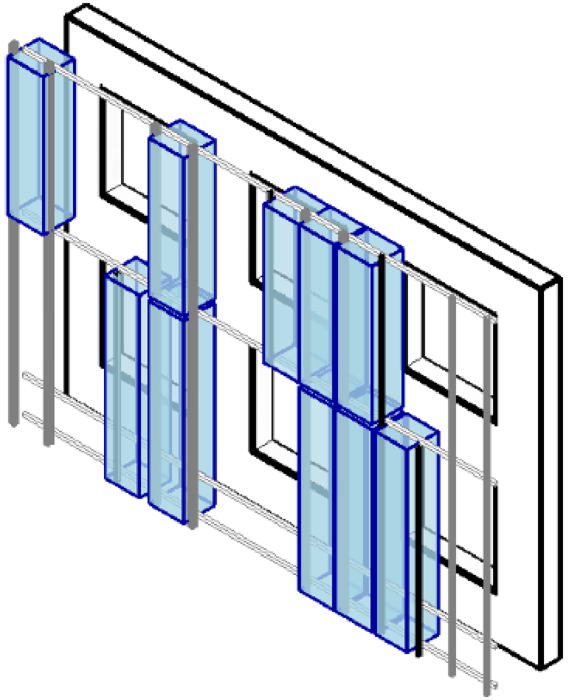


Functional

natural lighting ●●●○○ openings ●●●●●

Performance

depth ●●●●● height ●●●●● width ●●●●● climate



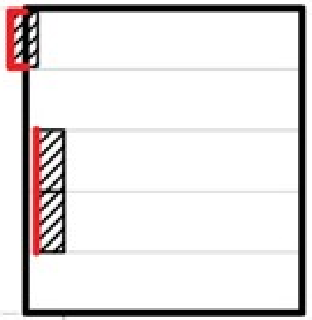
Functional

natural lighting ●●●○○ openings ●●●●●

Performance

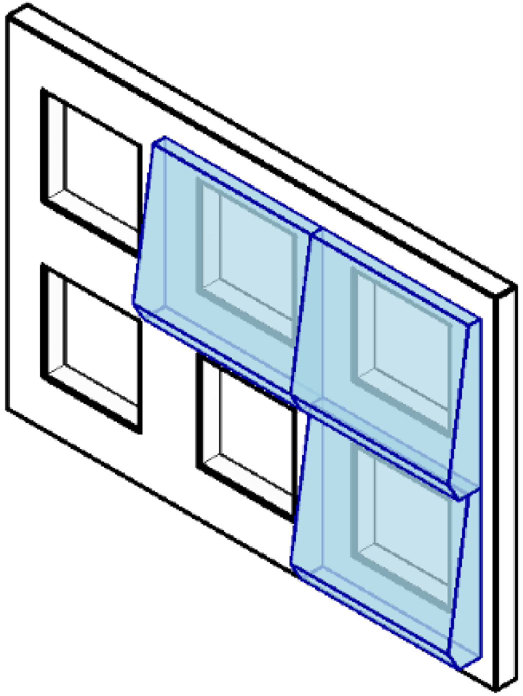
depth ●●●●● height ●●●●● width ●●●●● climate

MASK



The system is mounted on the building

SYSTEM
EXPLORATION

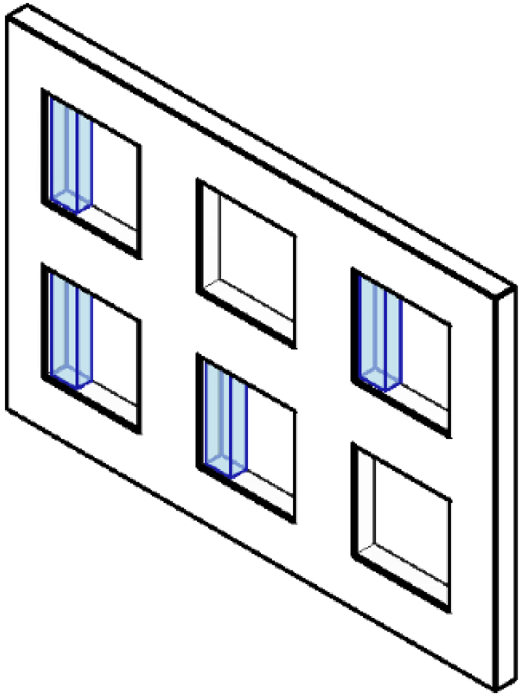


Functional

natural lighting ●●●○○ openings ●●●○○

Performance

depth ●●○○○ height ●○○○○ width ●○○○○ climate



Functional

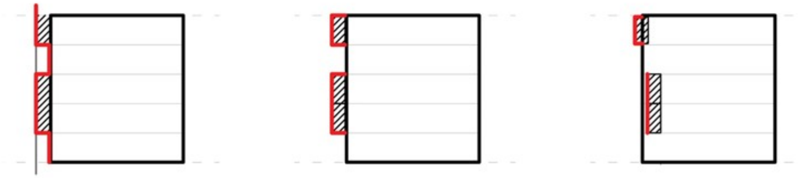
natural lighting ●●●○○ openings ●●●●●

Performance

depth ●○○○○ height ○○○○○ width ●●○○○

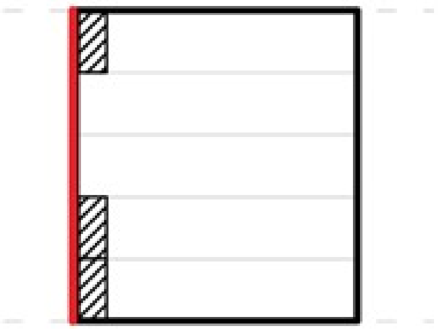
SYSTEM
EXPLORATION

DESIGN ALTERNATIVES



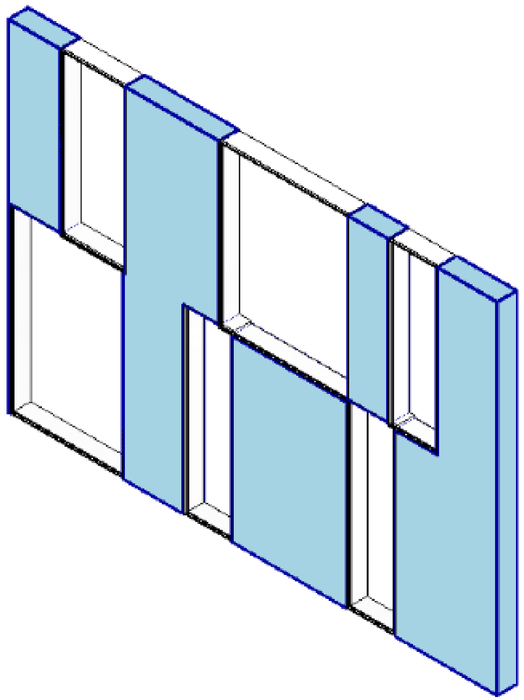
FULL CLOSED MASK

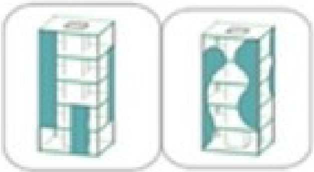
DESIGN EXPLORATION



The system as part of the cladding

SYSTEM
EXPLORATION





Functional

natural lighting ●●●●●

openings ●●●●●

Performance

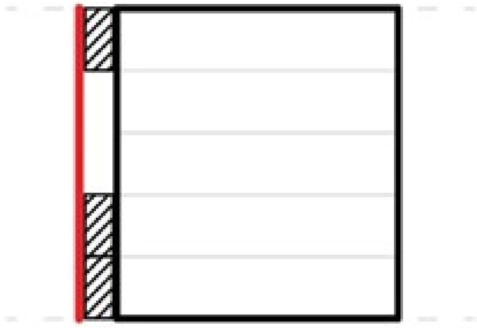
depth ●●●○○

height ●○○○○

width ●●●○○

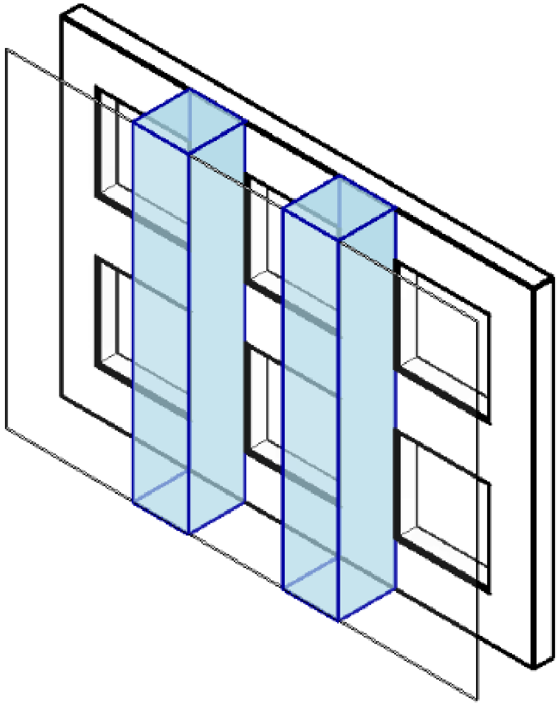
climate

MASK



The system as second façade layer

SYSTEM
EXPLORATION

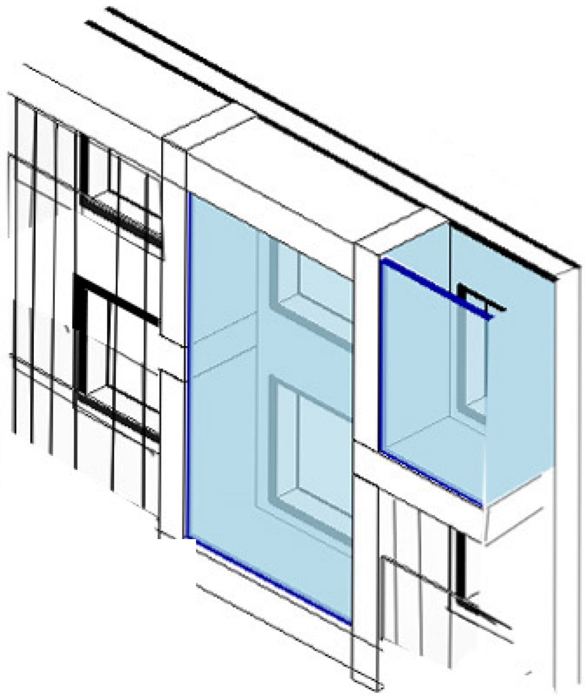


Functional

natural lighting ●●●○○ openings ●●●●●

Performance

depth ●●●●○ height ●●○○○ width ●●●○○ climate



Functional

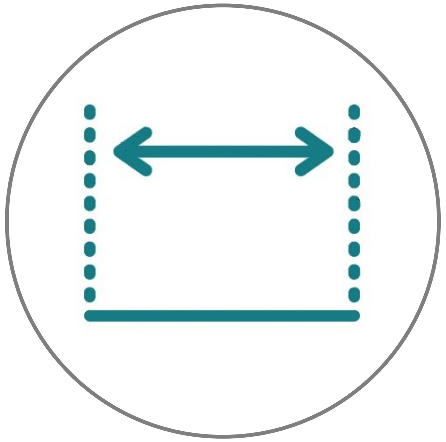
natural lighting ●●●○○ openings ●●●●●

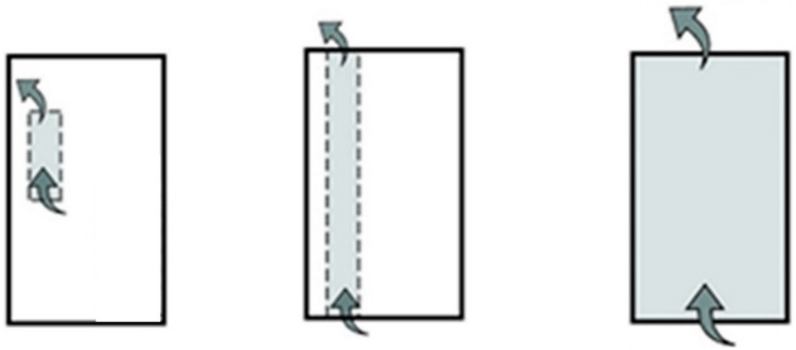
Performance

depth ●●●○○ height ●●●●○ width ●●●○○ climate

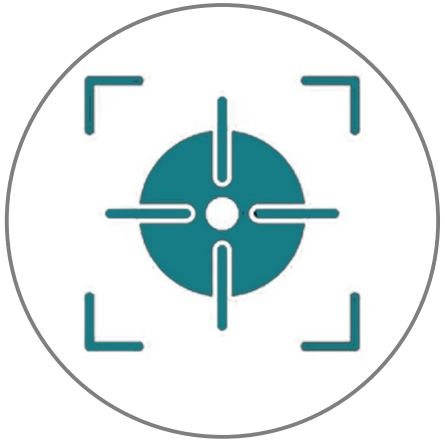
CONCLUSIONS

PV-CHIMNEY SCALE





FACADE PATTERN



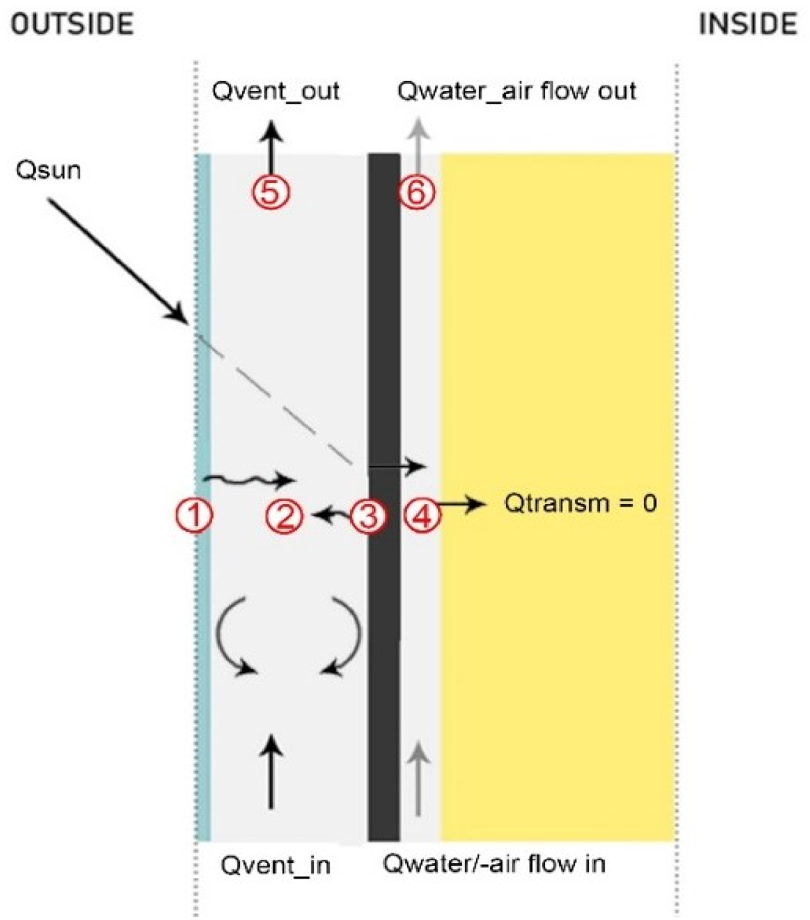
SYSTEM EXPLORATION

ARCHITECTURE ⟷ PERFORMANCE

MODEL

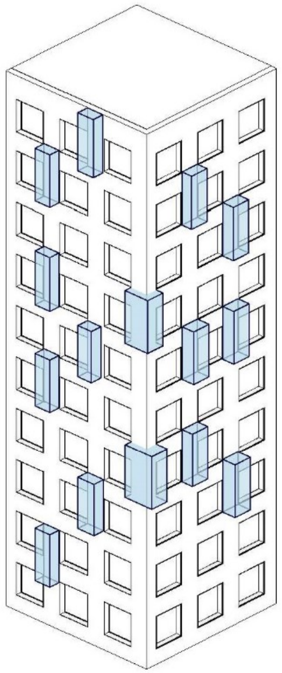
SYSTEM EXPLORATION

node1: T_{glass}
node2: T_{air}
node3: T_{pv}
node4: T_{water}
node5: T_{air_out}
node6: T_{water_out}



SCALES_DIFFERENT HEIGHTS AND WIDTHS

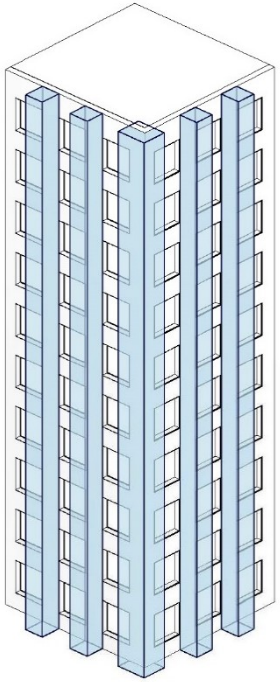
SYSTEM
EXPLORATION



FLOOR CHIMNEY

Chimney dimensions:

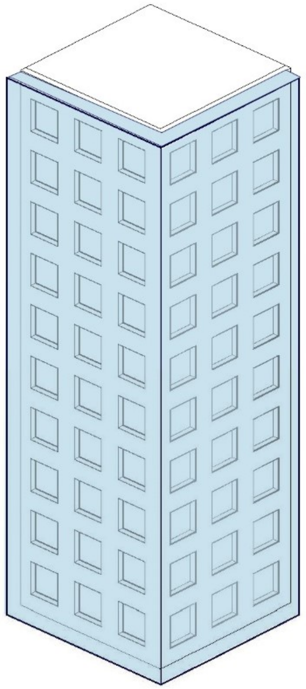
1 x 4.35 m



COLUMN CHIMNEY

Chimney dimensions:

1 x 95 m

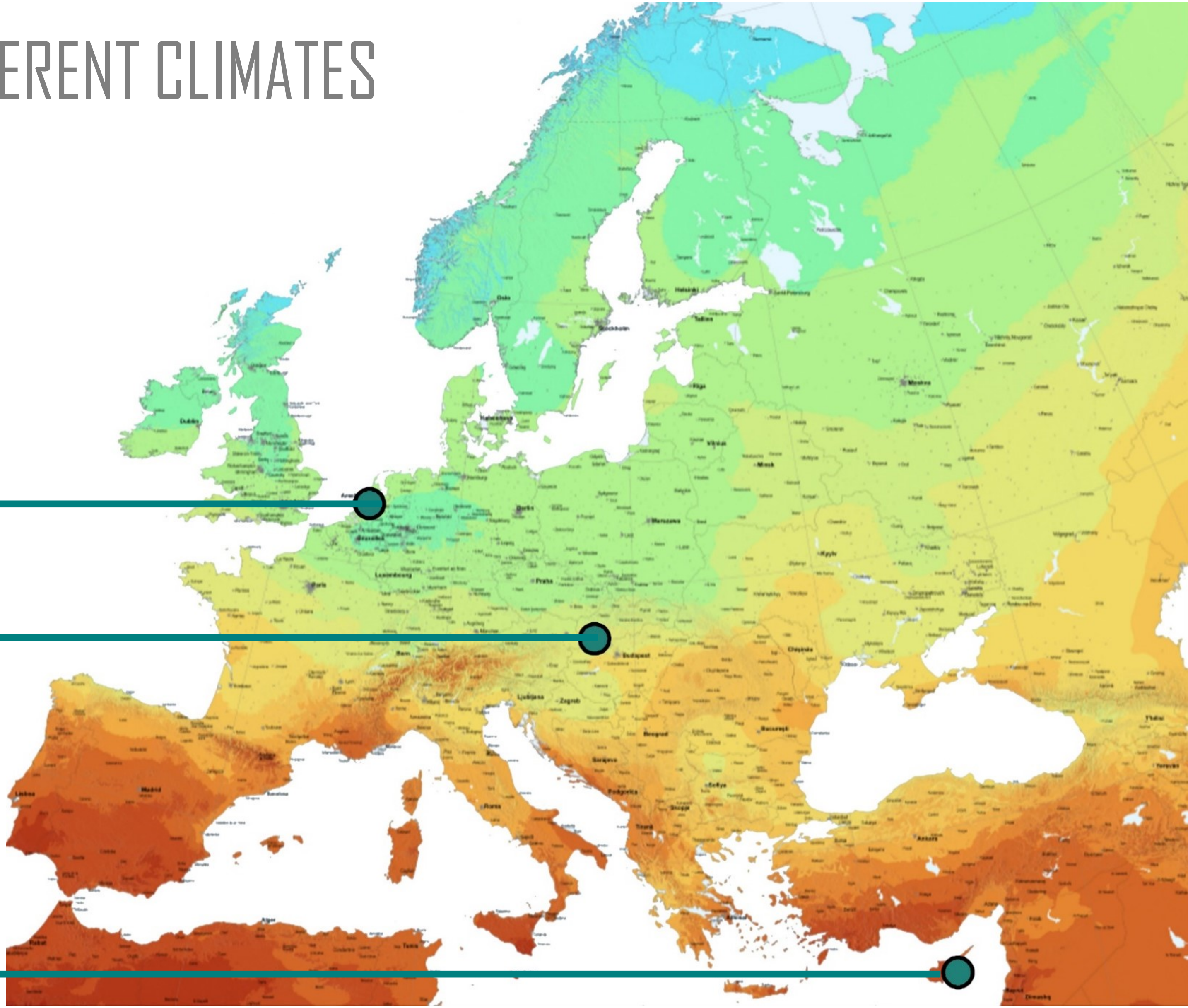


BUILDING CHIMNEY

Chimney dimensions:

33 x 95 m

DIFFERENT CLIMATES

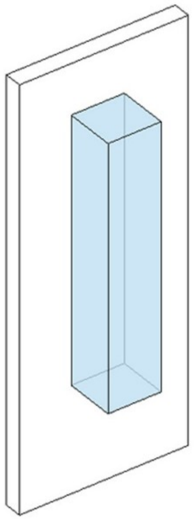


NETHERLANDS
MODERATE

HUNGARY
TEMPERATE

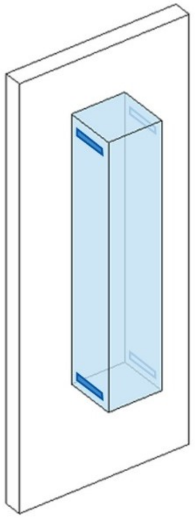
CYPRUS
MEDITERRENEAN

DIFFERENT VENTS



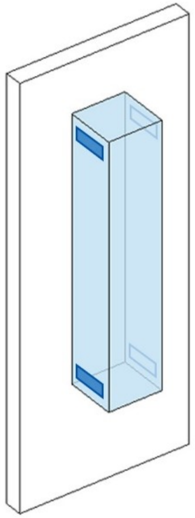
VENT 0

No ventilation



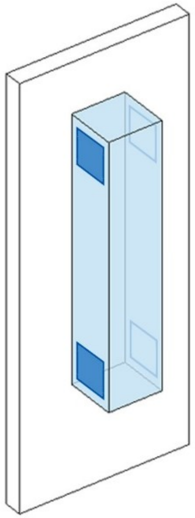
VENT 1

Vent dimensions:
0.9 or 33 x 0.05 m



VENT 2

Vent dimensions:
0.9 or 33 x 0.1 m

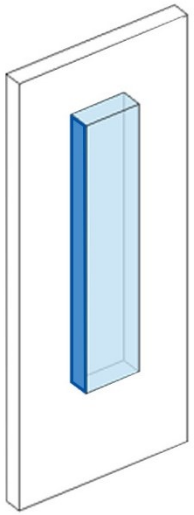


VENT 3

Vent dimensions:
0.9 or 33 x 0.5 m

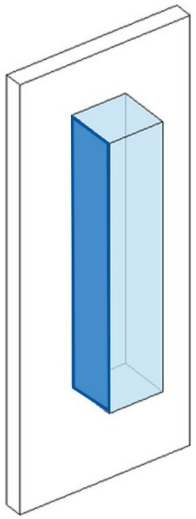
DIFFERENT DEPTHS

SYSTEM
EXPLORATION



DEPTH 1

Depth:
0.2 m

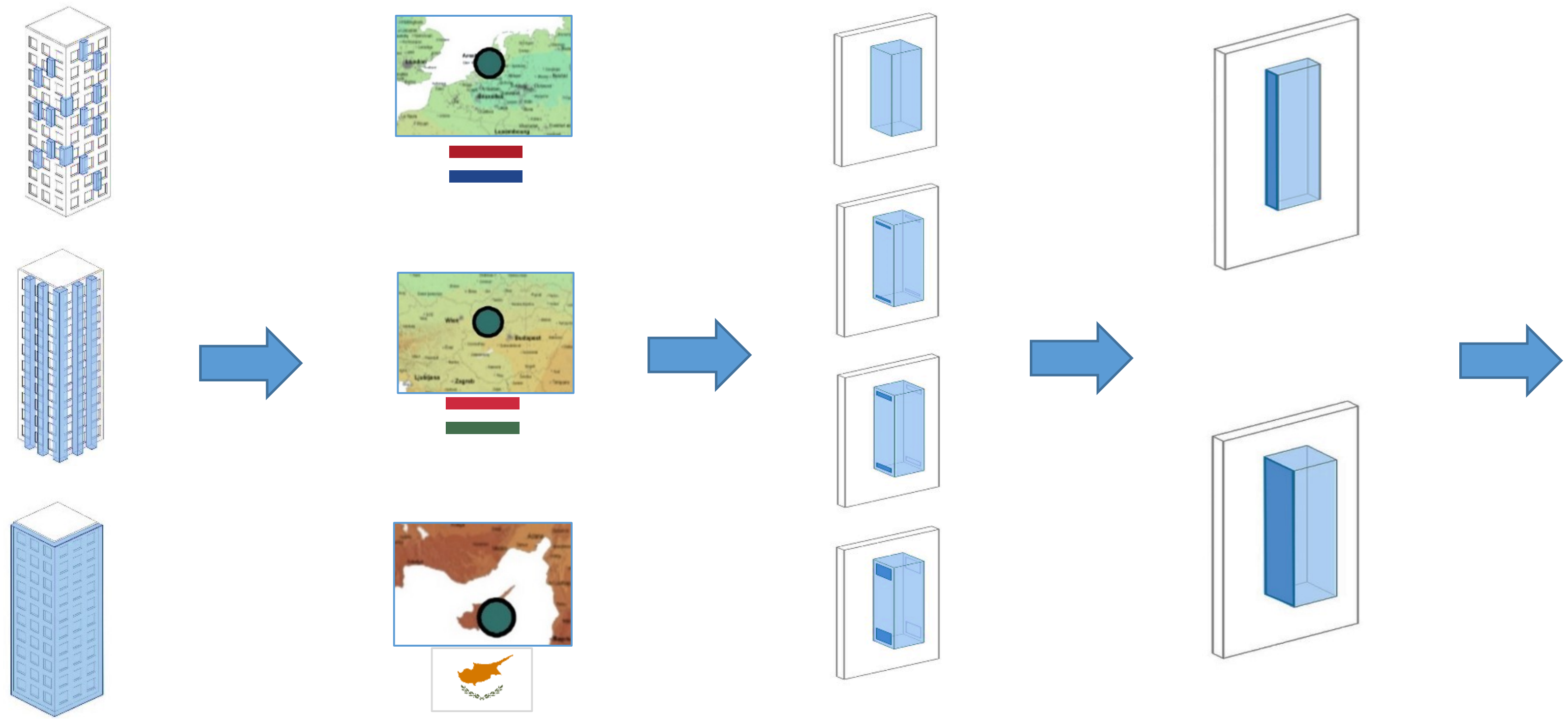


VENT 2

Depth:
0.4m

SYSTEM EXPLORATION

SCENARIOS



3x SCALES

3x CLIMATES

4x VENTS

2x DEPTHS

- CAVITY TEMPERATURE
- PV TEMPERATURE
- PRESSURE DIFFERENCE
- AIR FLOW
- AIR VELOCITY

METHODOLOGY

SYSTEM
EXPLORATION

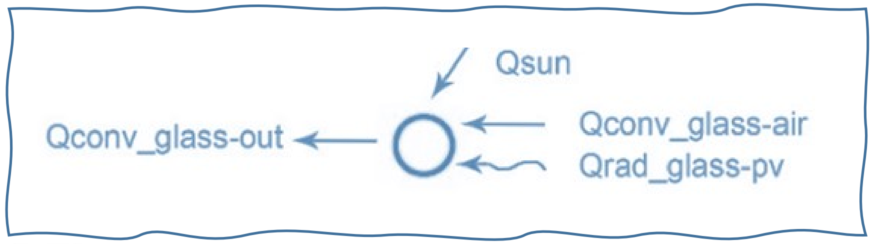
TEMPERATURES

$$\sum Q = 0$$

$$q_{convection} = \alpha_{convection} \left(T_{sheet} - T_{air}\right)$$

$$q_{radiation} = \alpha_{radiation} \left(T_{sheet1} - T_{sheet2}\right)$$

$$q_{conduction} = \alpha_{condiction} \left(T_{material1} - T_{material2}\right)$$



PRESSURE DIFFERENCE

$$\Delta P = \rho g h \frac{\Delta T}{T}$$

AIR FLOW

$$Q = A_{eff} C_d \sqrt{\frac{2\Delta P}{\rho}}$$

AIR VELOCITY

$$v = \sqrt{\frac{2\Delta P}{\rho}}$$

Temperatures

- Cavity air
- PV
- Water

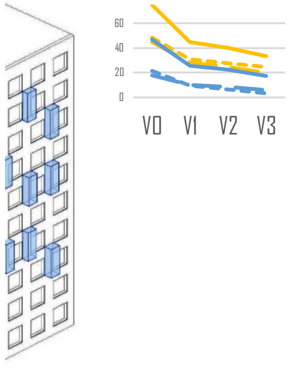
Air

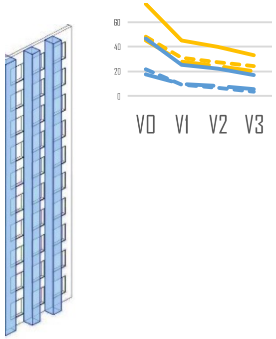
- Air flow
- Velocity

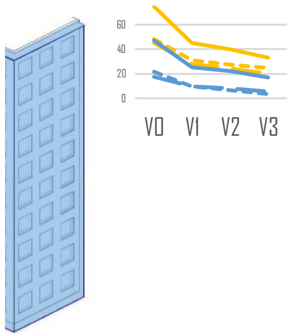
RESULTS

Temperatures [ºC]_CAVITY AIR

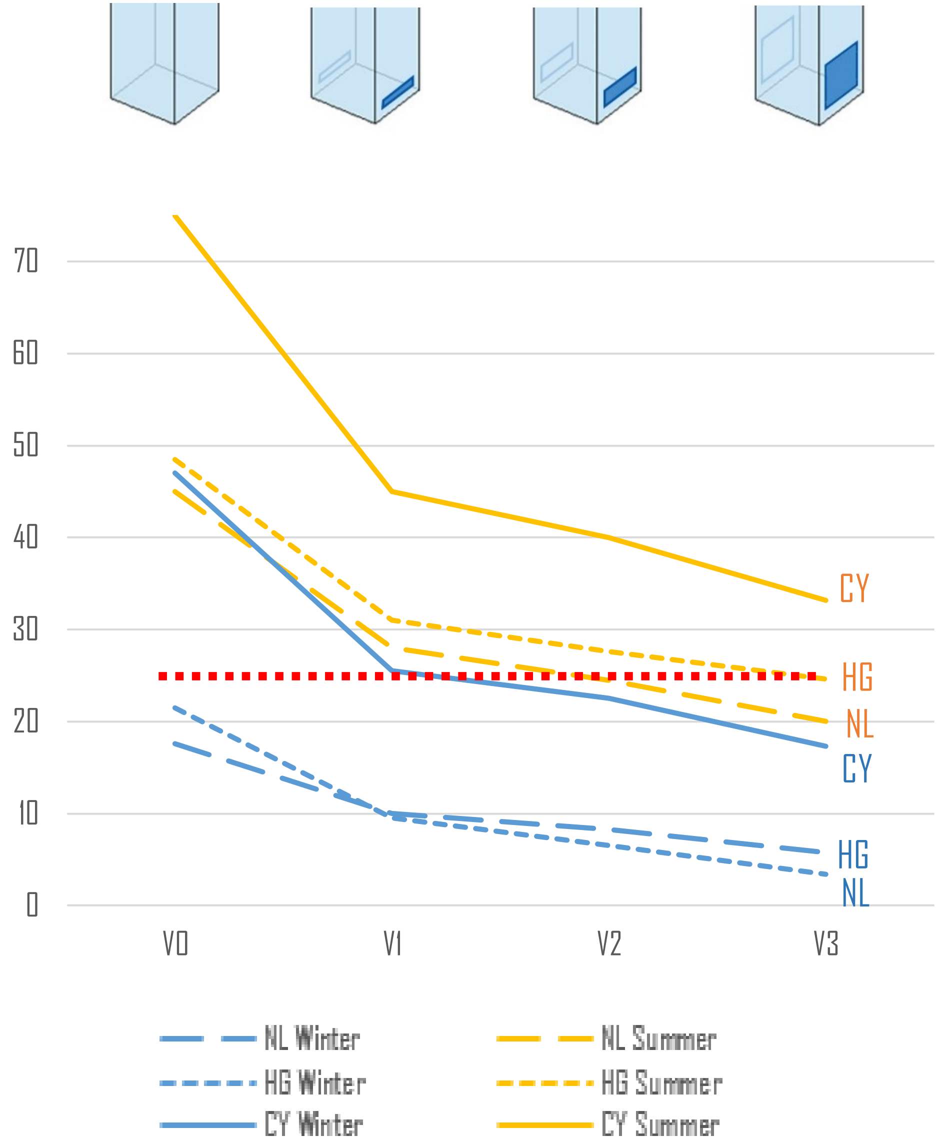
SYSTEM EXPLORATION







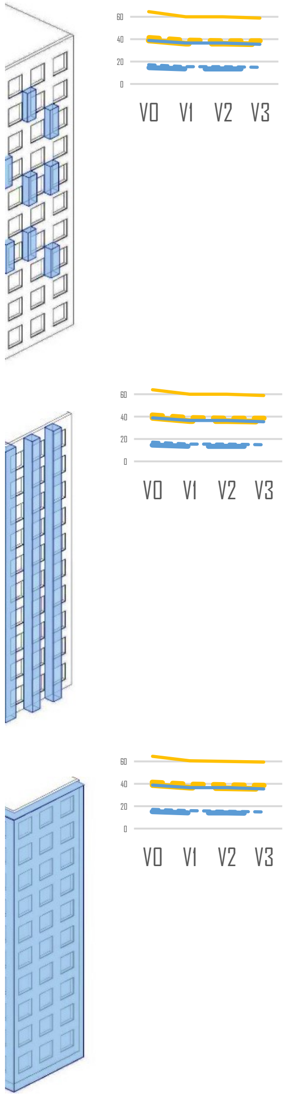
ambient T[ºC]	W	S
NL	4	17
HG	1	20
CY	14	29

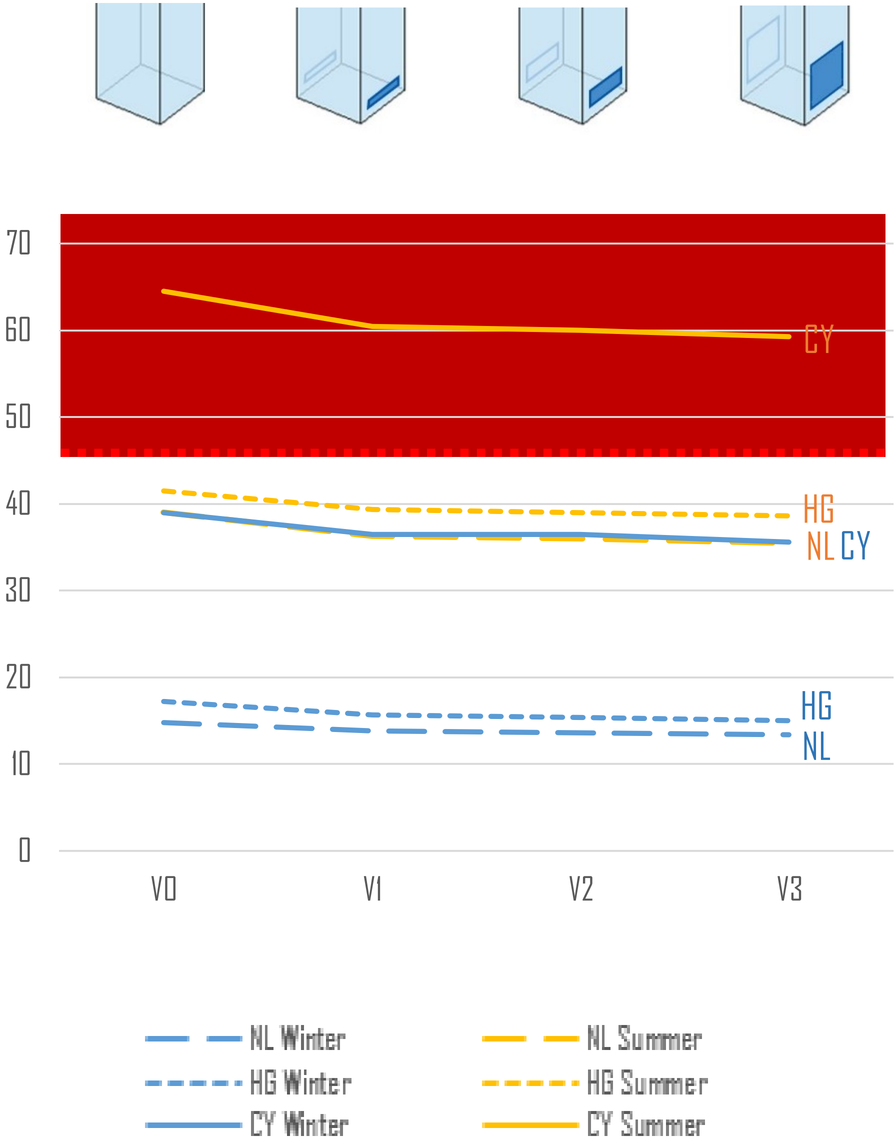


RESULTS

Temperatures [°C]_PV

SYSTEM
EXPLORATION



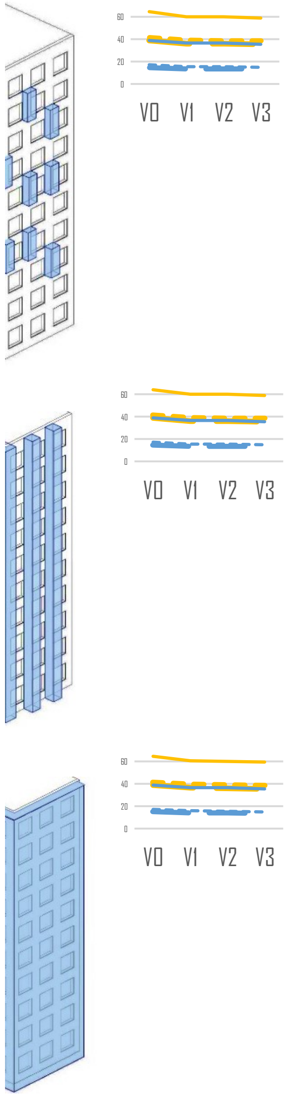


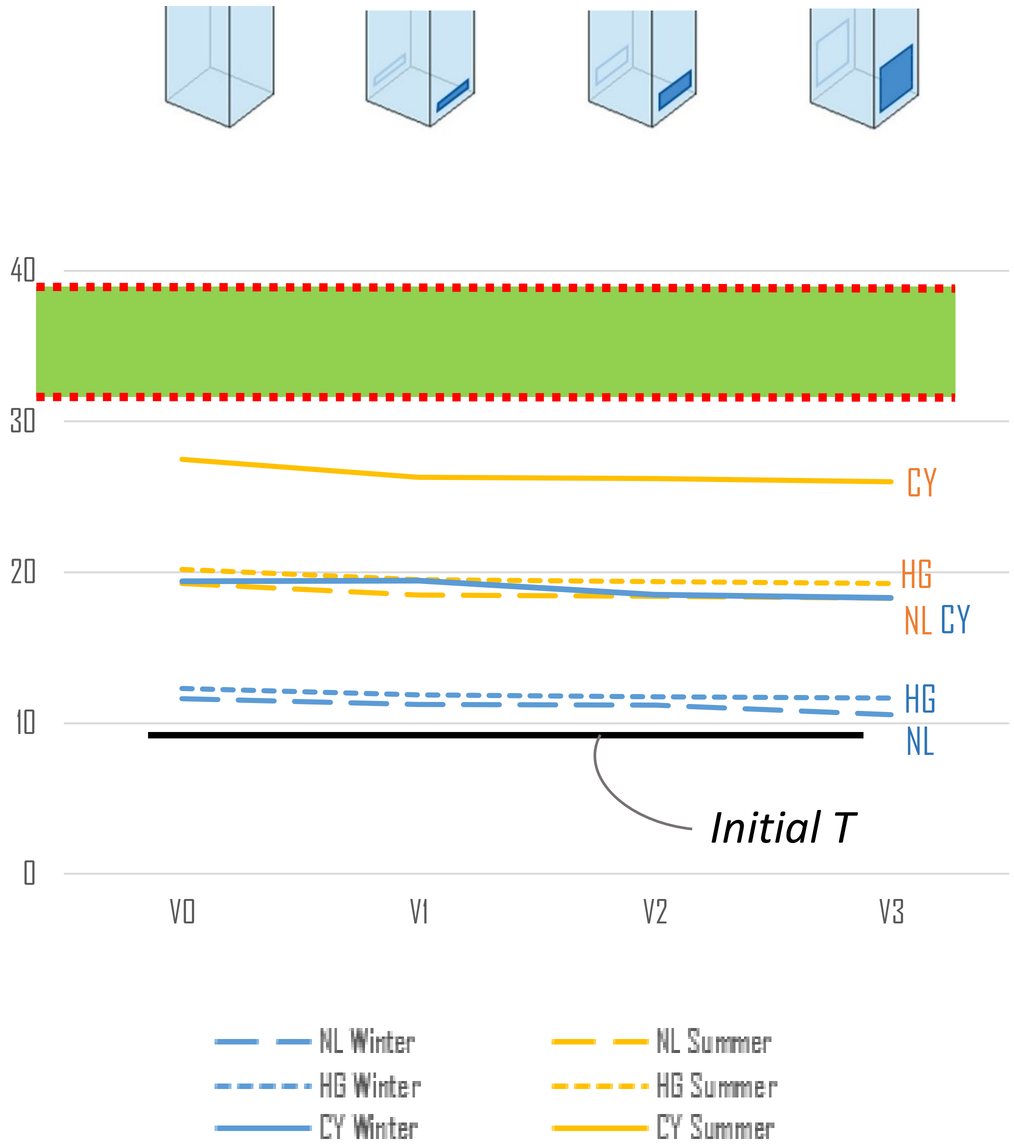
ambient T[°C]	W	S
NL	4	17
HG	1	20
CY	14	29

RESULTS

Temperatures [^{o}C]_Water

SYSTEM
EXPLORATION





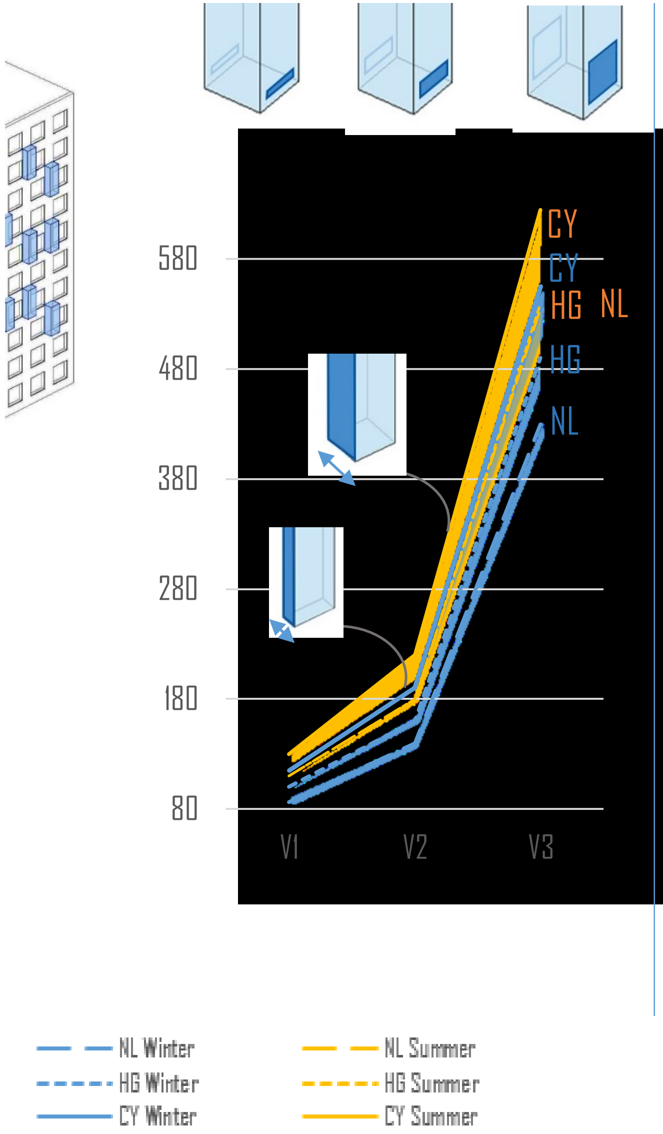
Initial temperature:
10^{o}C

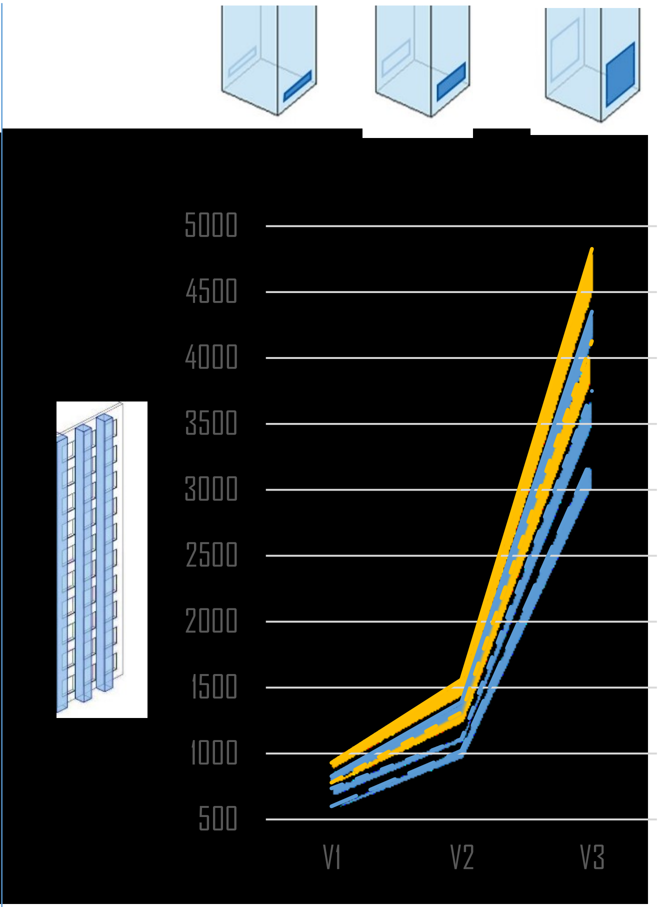
Water velocity:
0.1m/s

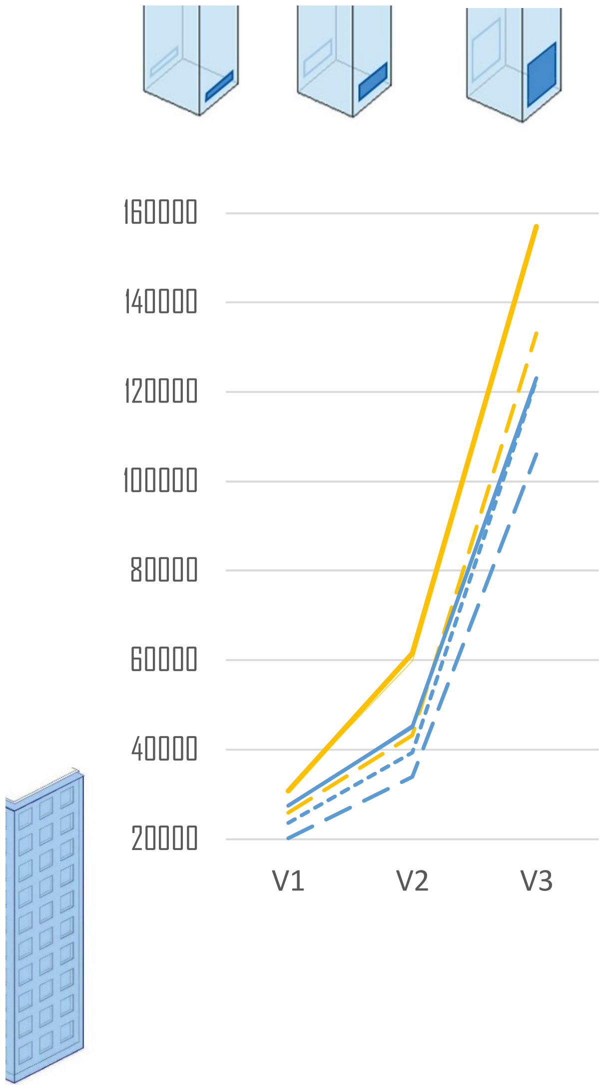
ambient T[^{o}C]	W	S
NL	4	17
HG	1	20
CY	14	29

RESULTS

AIR FLOW[m^3/h]







Depth
increase

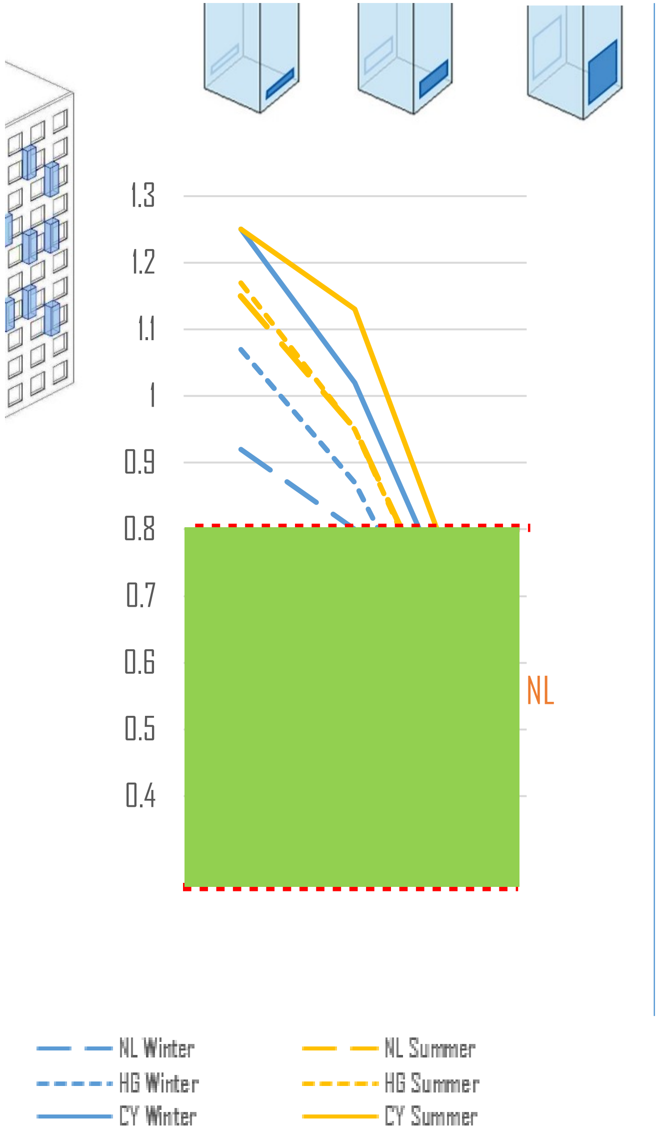
Vent
Important
increase

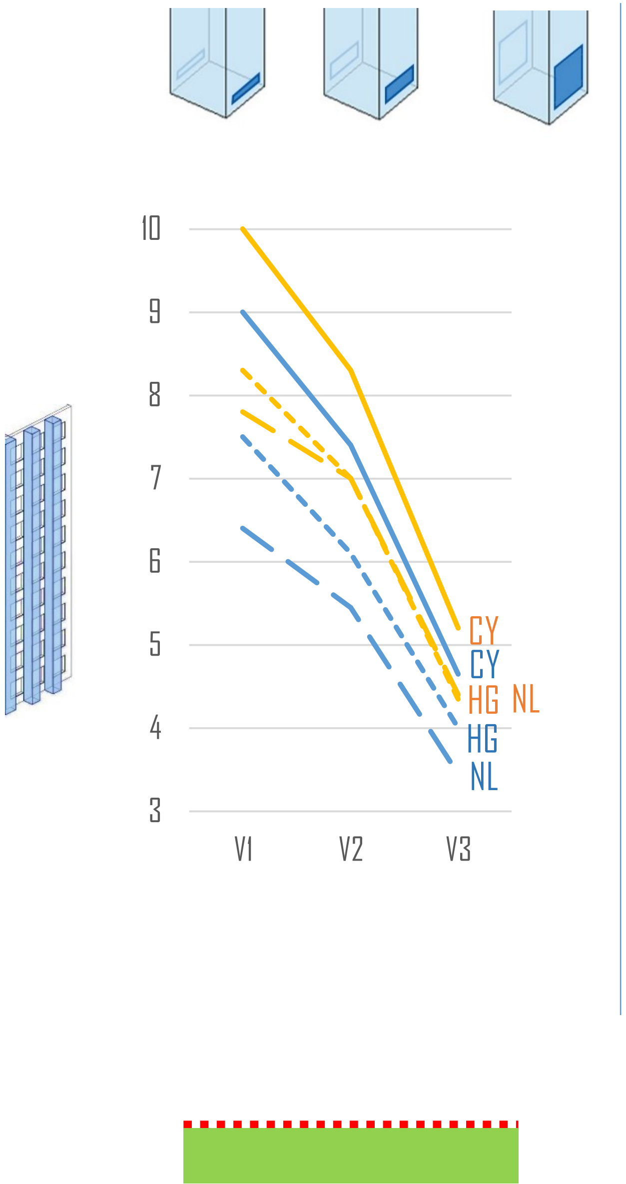
Height
Important
increase

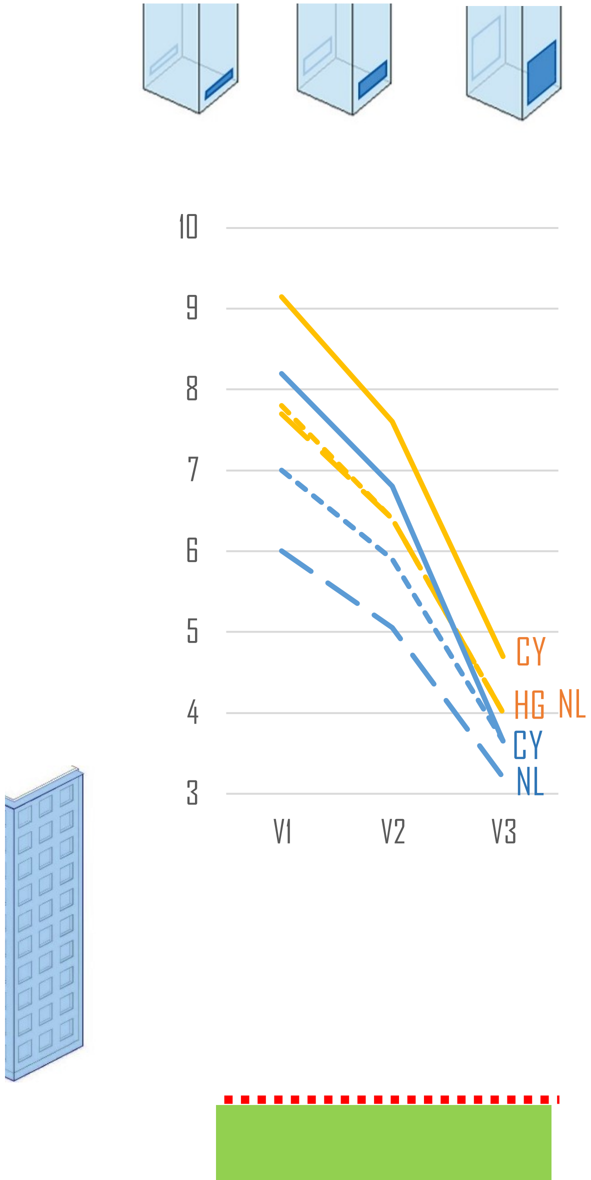
Width
Slight increase

RESULTS

AIR FLOW[m^3/h]







Depth
Slight increase

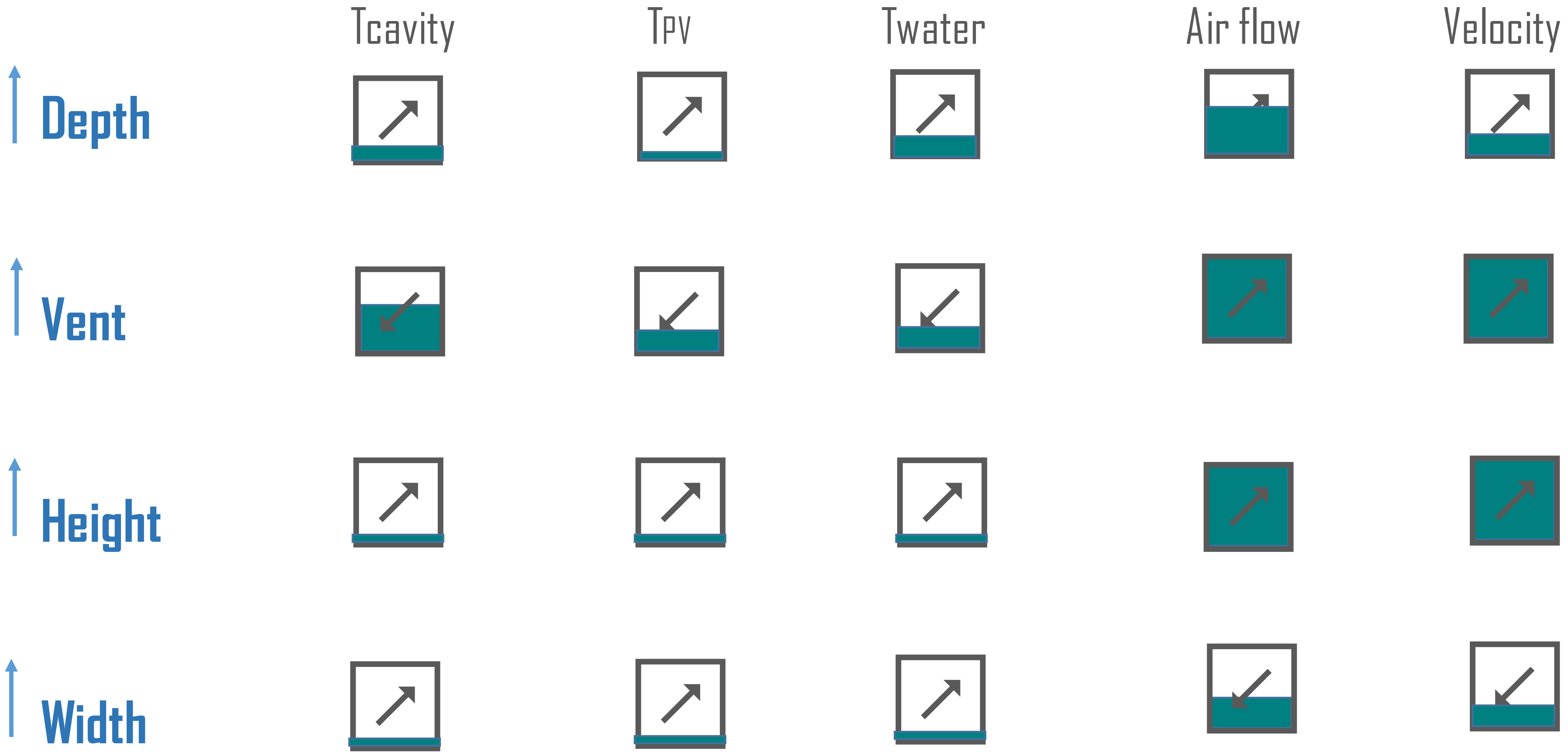
Vent
Important increase

Height
Important increase

Width
Slight increase

Summarizing...

SYSTEM EXPLORATION



CONCLUSION

Climate	Height/Width	Depth	Vent	PASSIVE?
Moderate climate Netherlands	Floor chimneys	0.4m	**Summer** >=0.09m^2	✓
			Winter close vents	✗
Temperate climate Hungary	Floor chimneys	0.2m	**Summer** >=0.45m^2	✓
			Winter close vents	✗
Mediterennean climate Cyprus	Floor chimneys	0.2m	**Summer**	✗
			Winter <=0.09m^2	✓

03

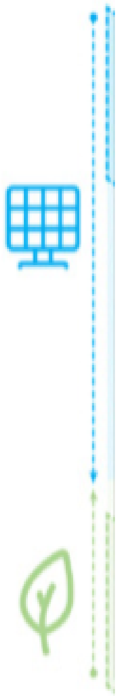
DESIGN IMPLEMENTATION

FACADE CONCEPT

DESIGN
IMPLEMENTATION

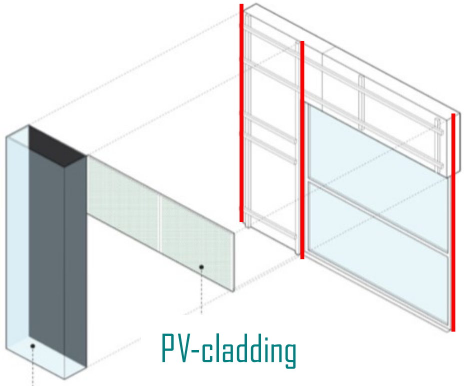
FAÇADE CONCEPT

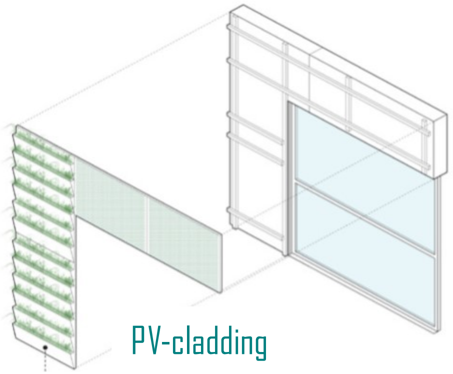
DESIGN
IMPLEMENTATION

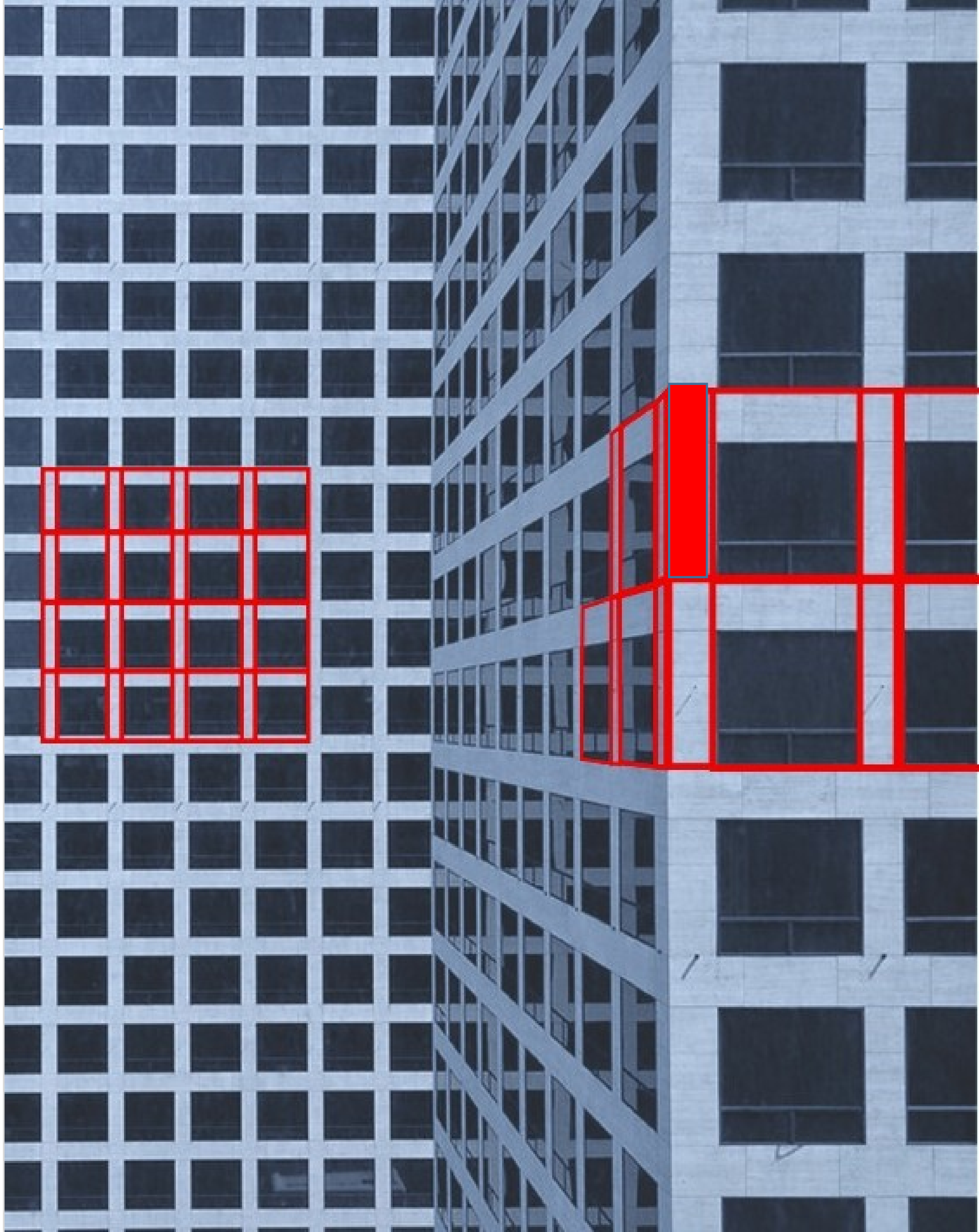


FACADE UNITIZED SYSTEM

DESIGN
IMPLEMENTATION





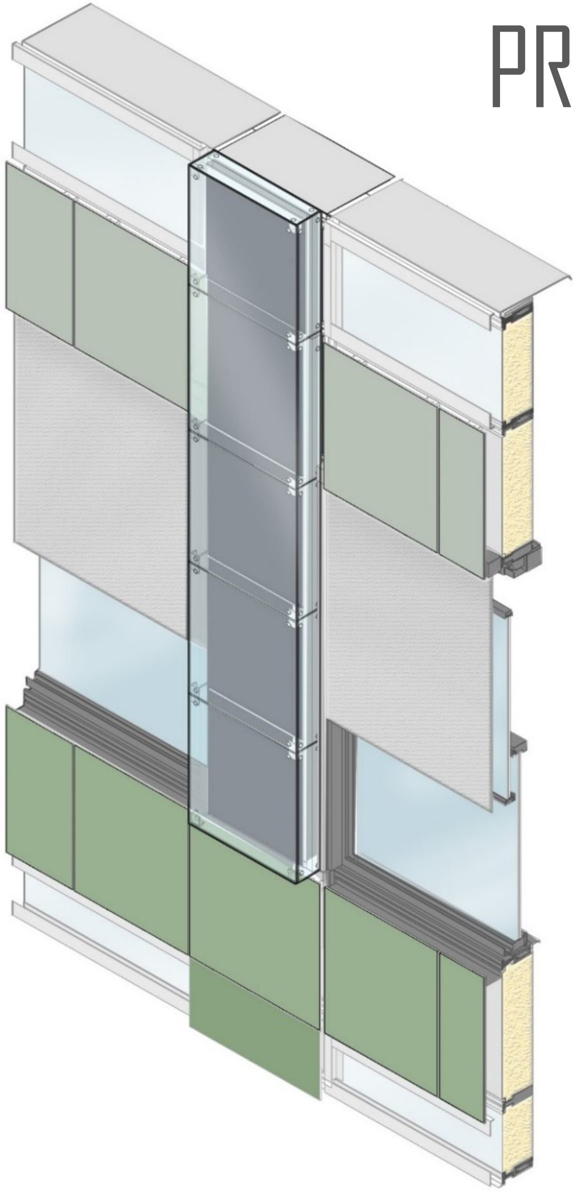


PV/T-CHIMNEY

DESIGN
IMPLEMENTATION

- FLOOR CHIMNEY
- MASK DESIGN
- ADDITIONAL ELEMENT

PROPOSAL



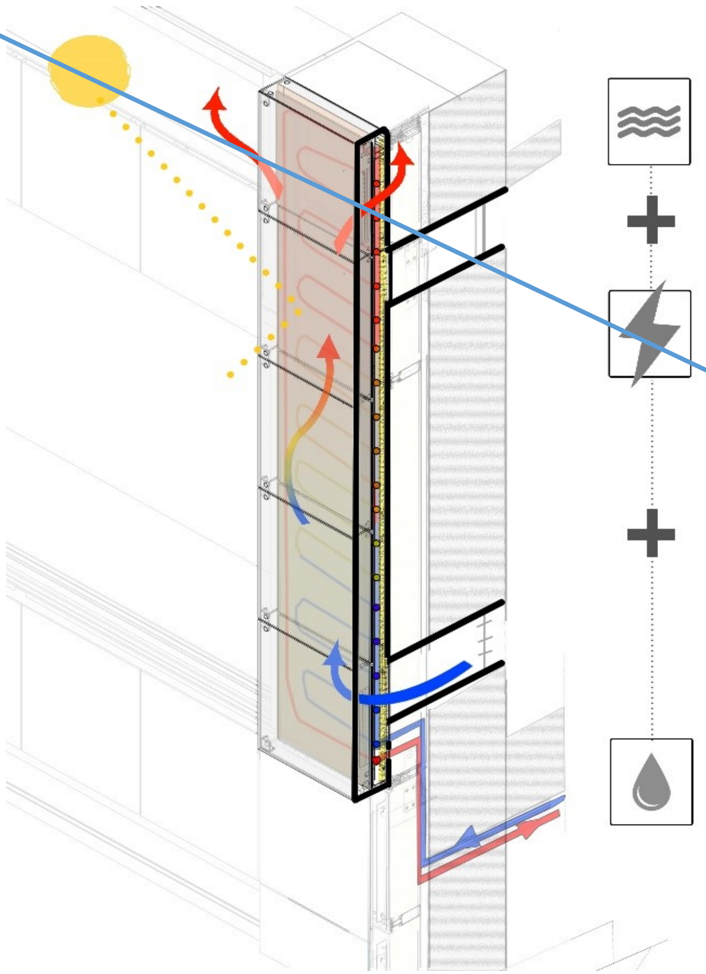
PV/T - chimney solution

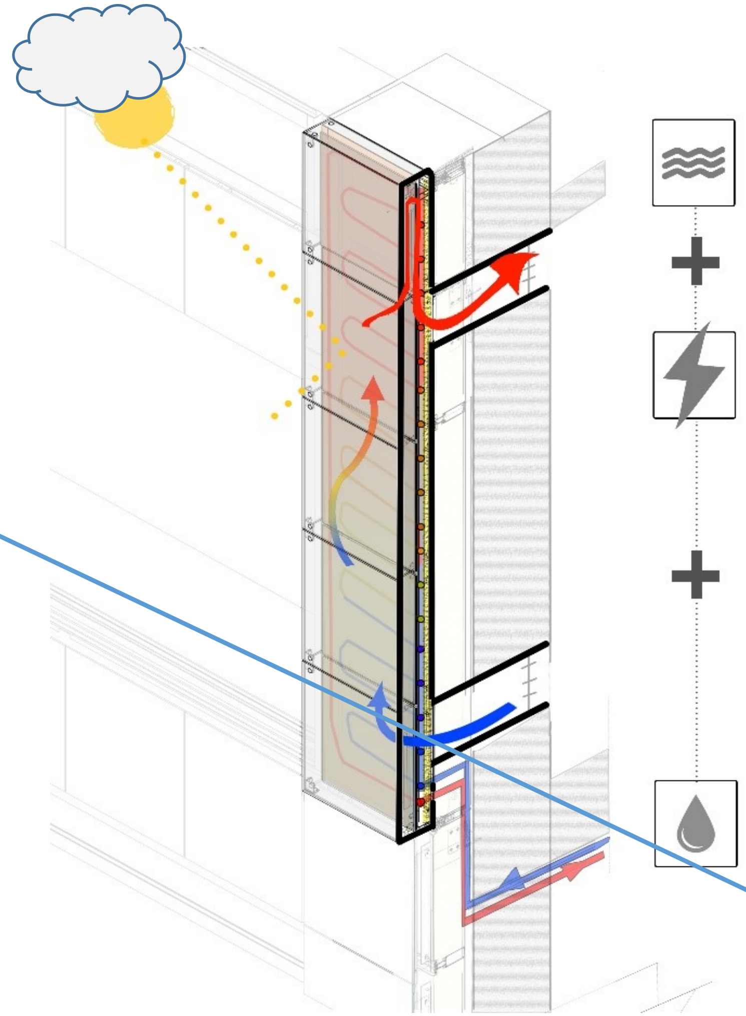
Height: 4.35 m
Width: 0.815 m
Depth: - with PV/T: 0.24 m
- cavity: 0.11 m
Vents: 0.072 m^2
Glazing: - single 0.08 mm
- g-value: 0.9

Structure: aluminum
PV: ColarBlast (black ,13% effic.)
PV/T: -cooper pipes 12 mm diam.
-cooper plate 3 mm
Insulation: Rockwool

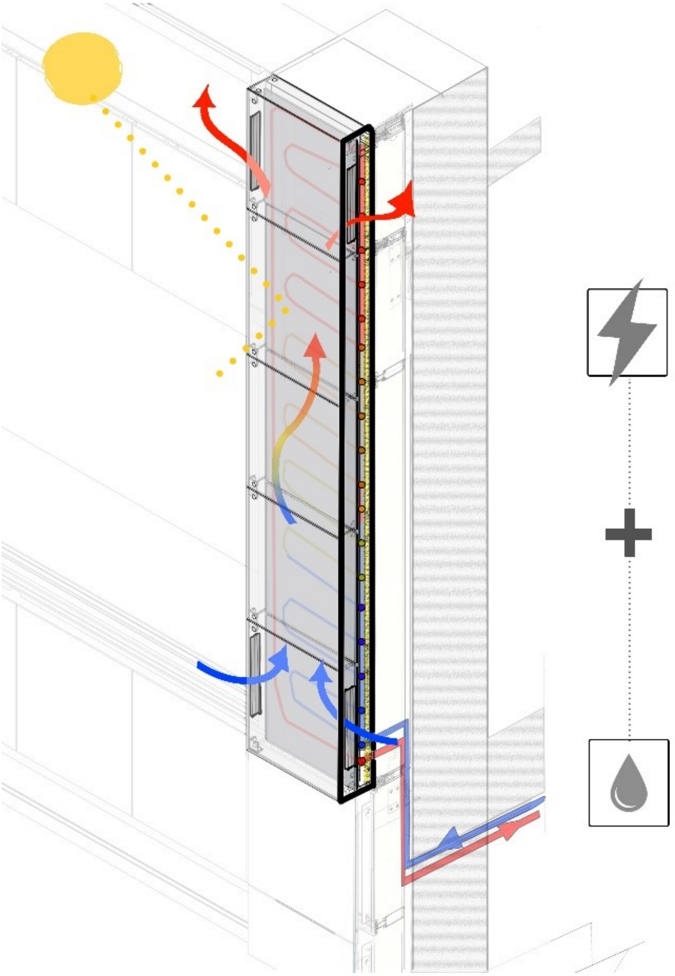
Initial...

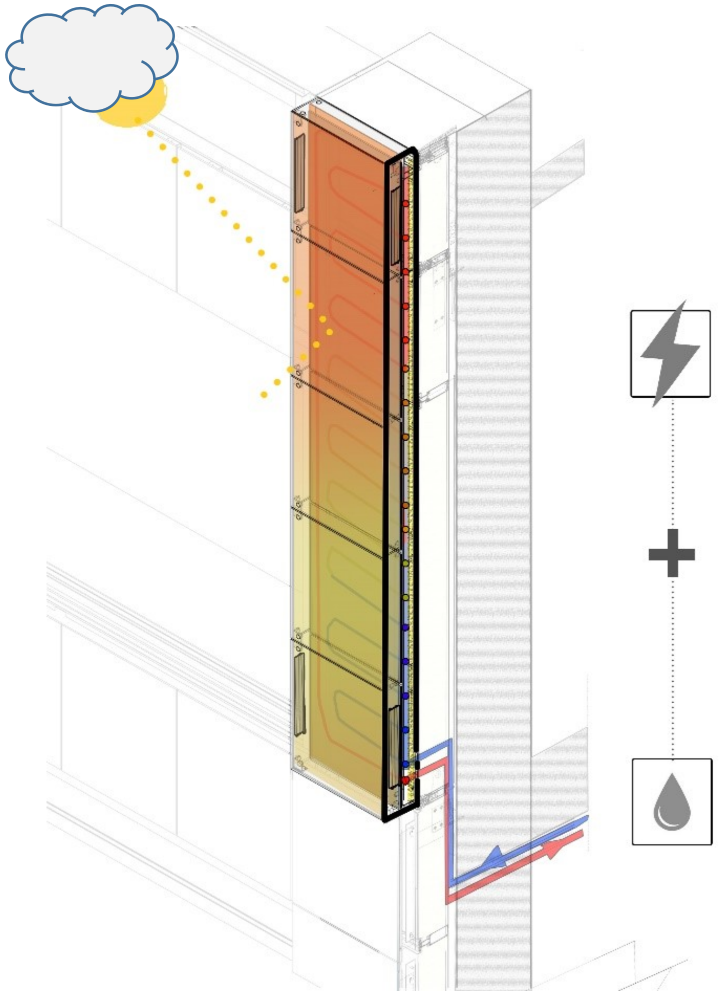
OPERATION



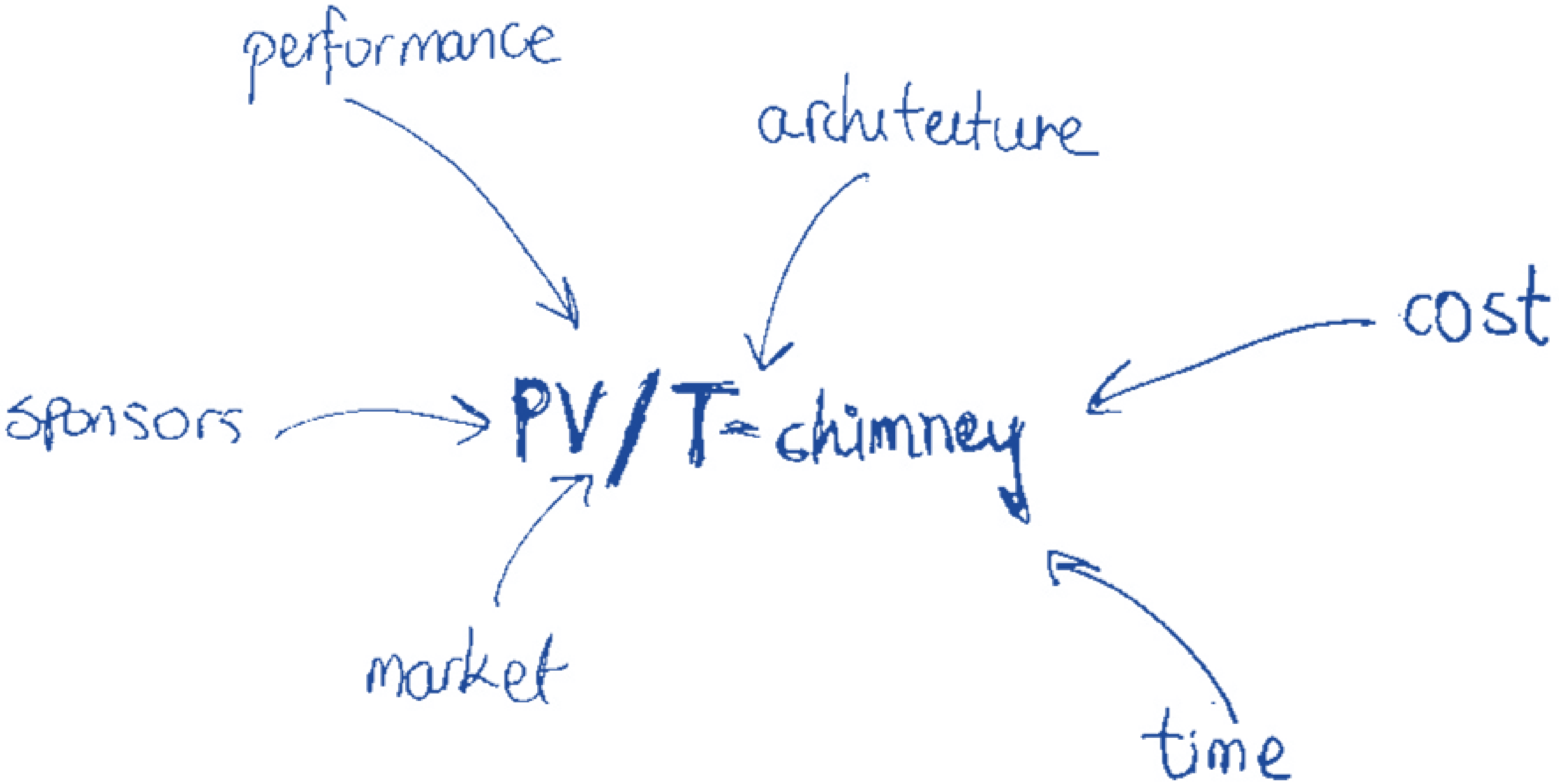


OPERATION





DESIGN
IMPLEMENTATION



DESIGN DESICIONS

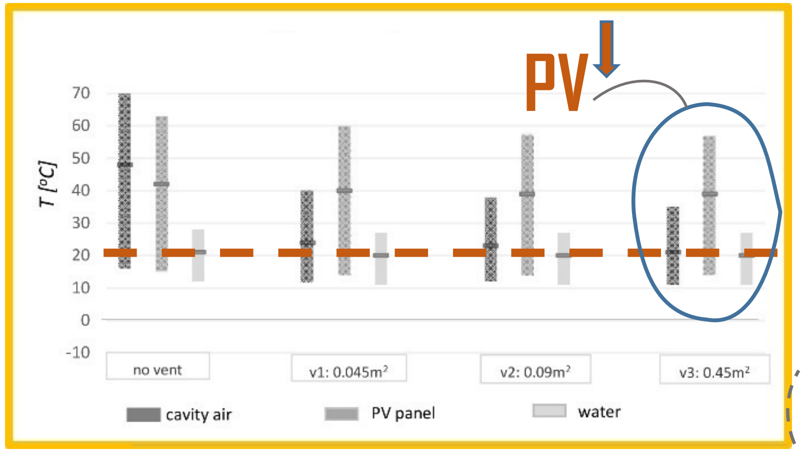
DESIGN
IMPLEMENTATION

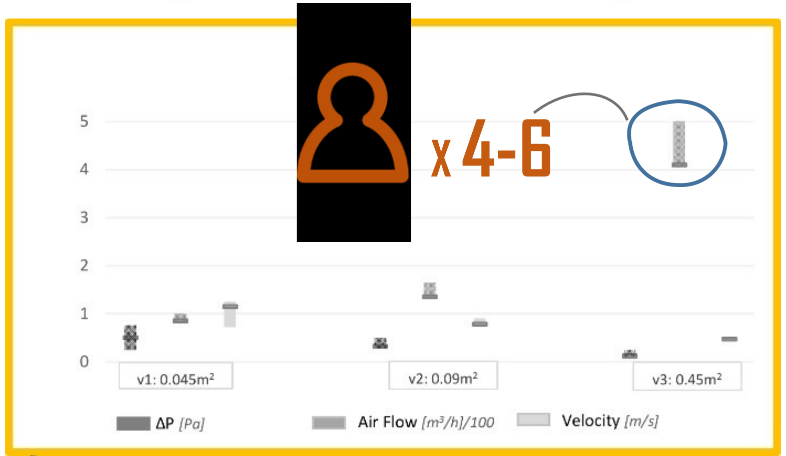
- VENTS
- DEPTH
- GLAZING
- PV/T

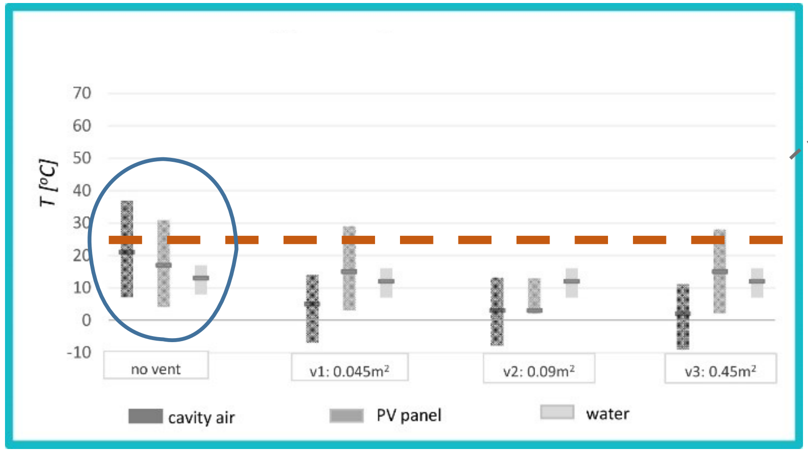
VENTS

PERFORMANCE

DESIGN IMPLEMENTATION



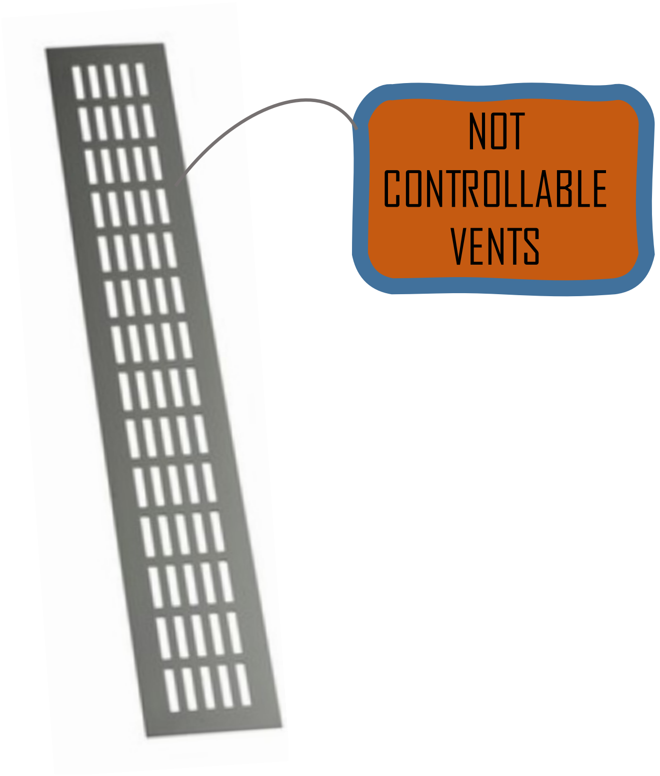




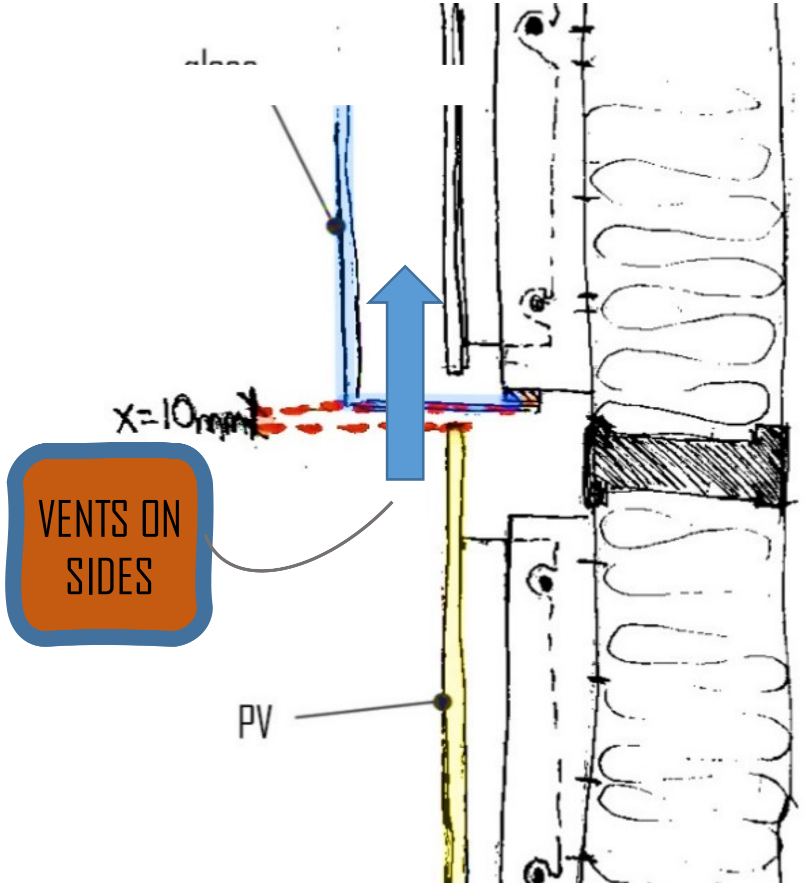
Vent size: $>0.45m^2$

DESIGN DESICIONS

COST_TIME_MARKET



PRACTICE



DEPTH

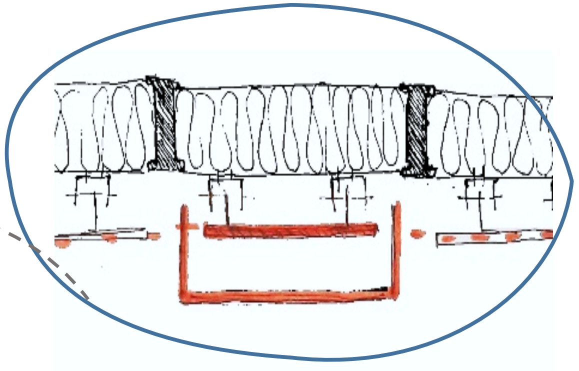
The depth has **negligible** impact on its performance

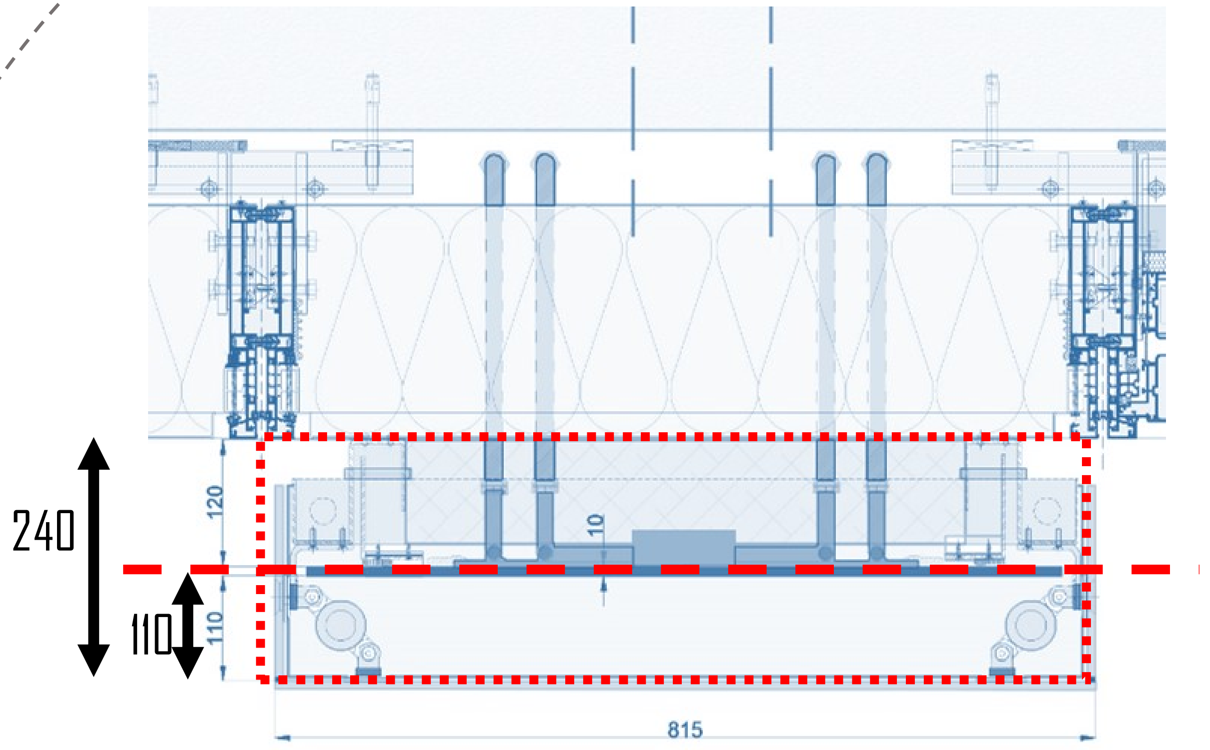
DESIGN
IMPLEMENTATION

ARCHITECTURAL INTENTION → **FLAT FACADE**

+

LITERATURE→ **OPTIMAL RATIO** (HEIGHT/DEPTH)





GLAZING

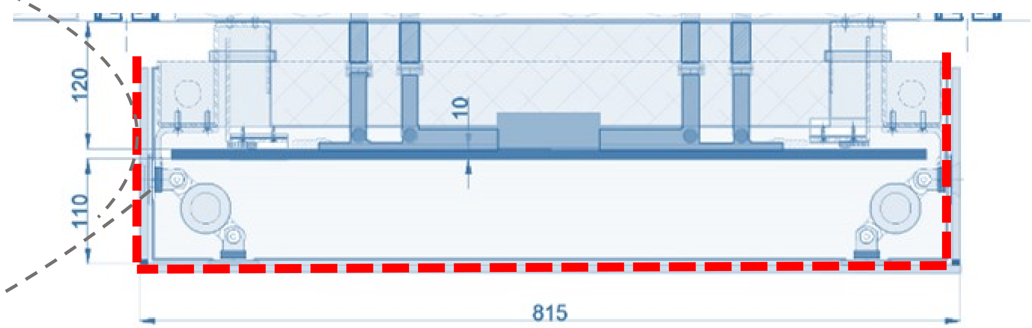
PERFORMANCE

COST DELIVERY TIME

LITERATURE

DESIGN
IMPLEMENTATION

SINGLE GLAZING



DESIGN DESICIONS

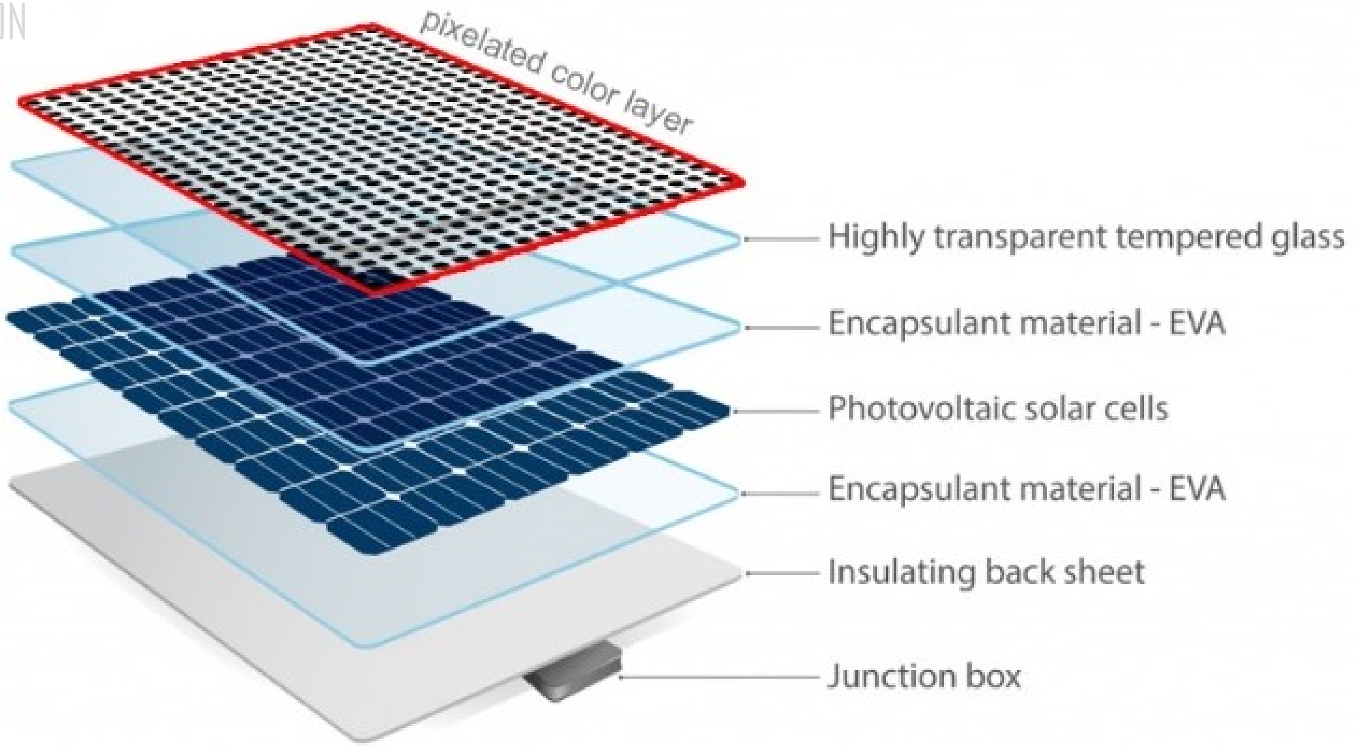
PV/T

PVs

ARCHITECTURAL INTENTION → GRID LINES AND TEXTURE

KAMELEON SOLAR PVs

DESIGN IMPLEMENTATION



PV/T

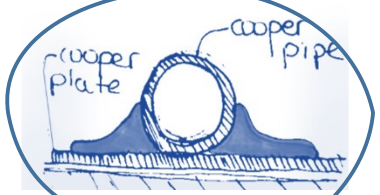
Thermal collector

ϕ12
Usual in conventional PV/Ts
- Market availability
- Bending tools

COOPER
λ= 385 W/mK — **GOOD** thermal properties

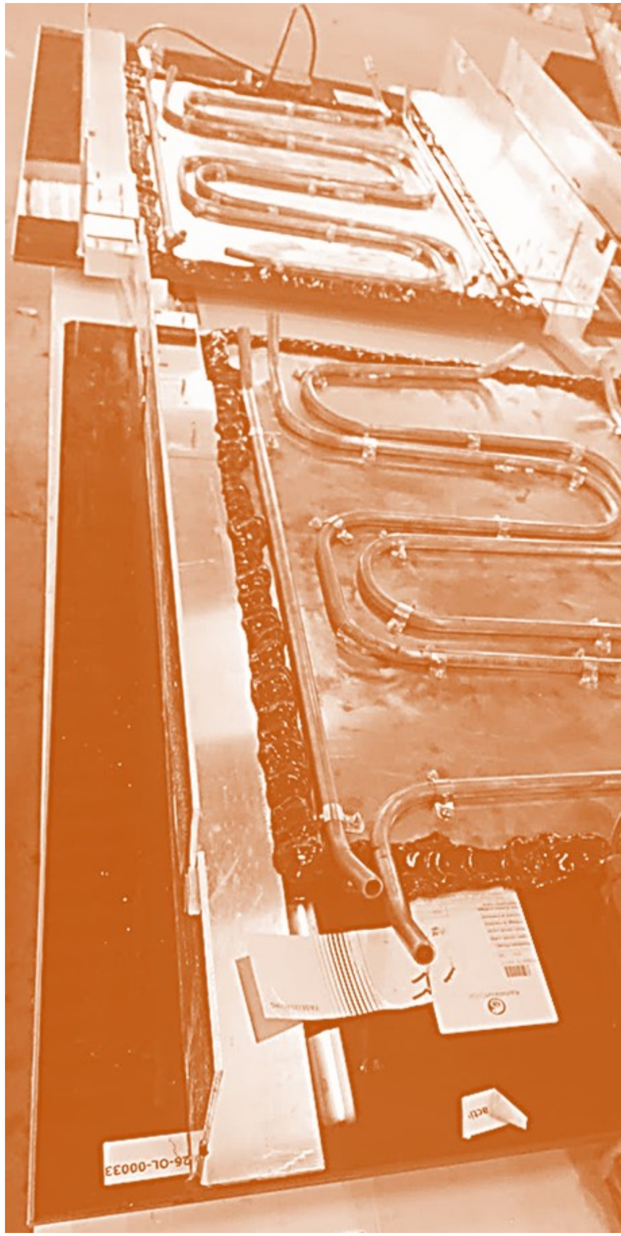
COOPER plate — **BETTER** distribution

SOLTERING — **ENHANCE** heat transfer



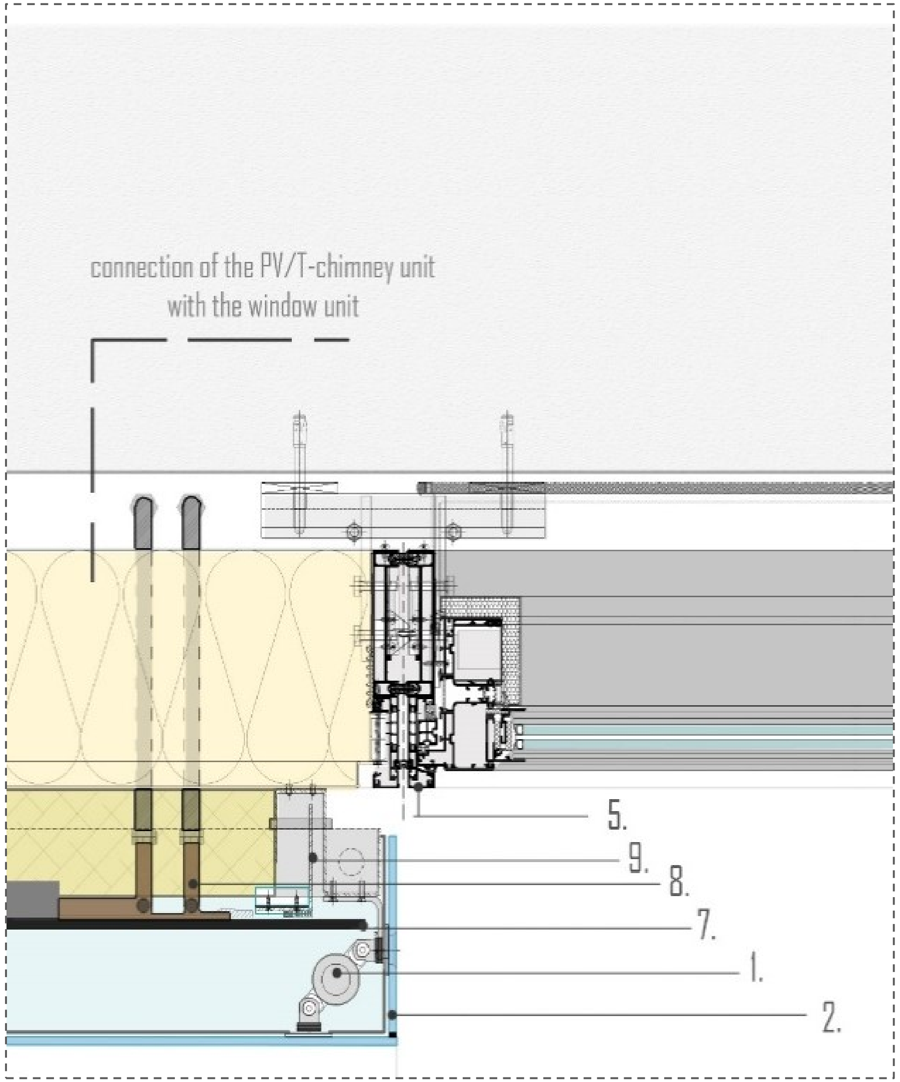
DOUBLE PIPING — **ENHANCE** absorption
+ more water

+ INSULATION

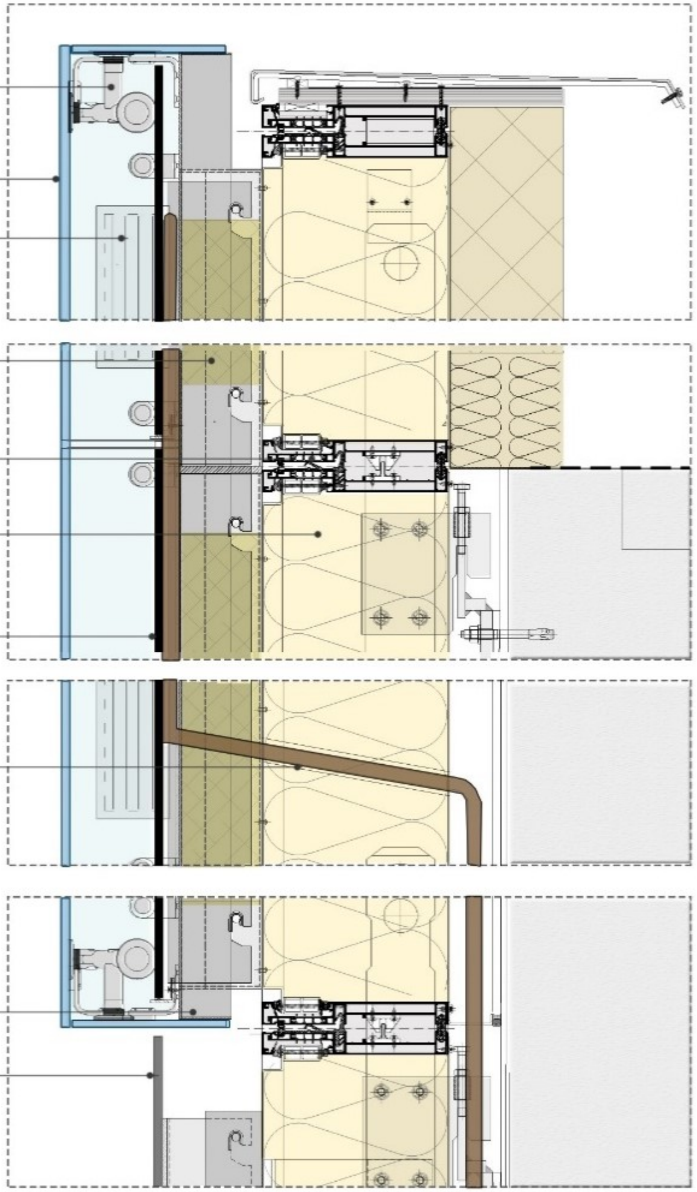


DETAILING

DESIGN IMPLEMENTATION



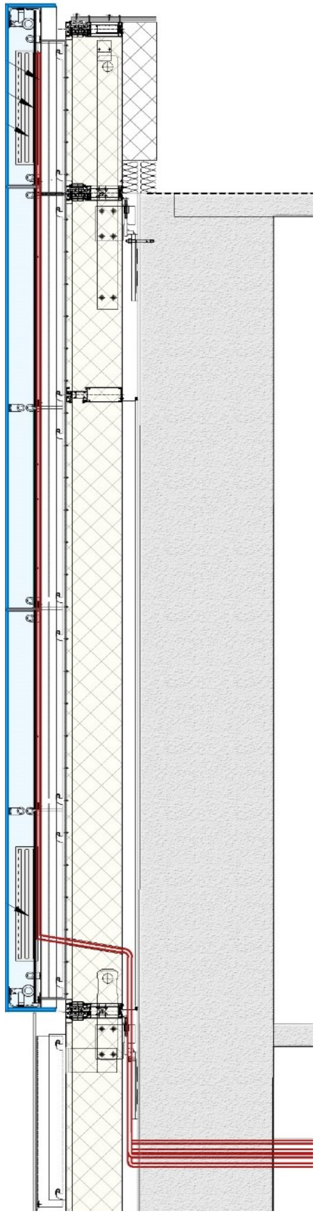
1. Spider _glass to glass connectors
2. Safety glass 8mm
   -g-value:0.9
3. Permanent aluminum vents (0.08x0.46m)
4. Rockwool Insulation
   λ=0.035 W/mK
5. Schuco Profile (331990)
6. Spandrel panel
   -thick. 226mm
   -Rockwool
   -λ=0.035 W/mK
7. Color Blast PV cladding
   -thick. 10mm
   -black colour
8. Cooper pipes and plate
   -pipes :12 mm diameter
   -cooper plate 3mm
9. PV/T-chimney structure aluminum frame
10. Color Blast PV cladding
   -thick. 10mm

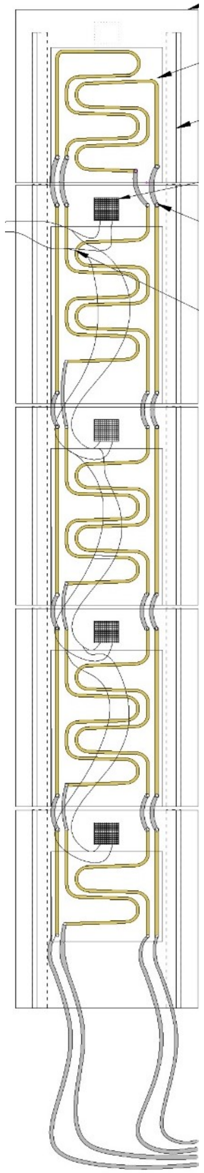


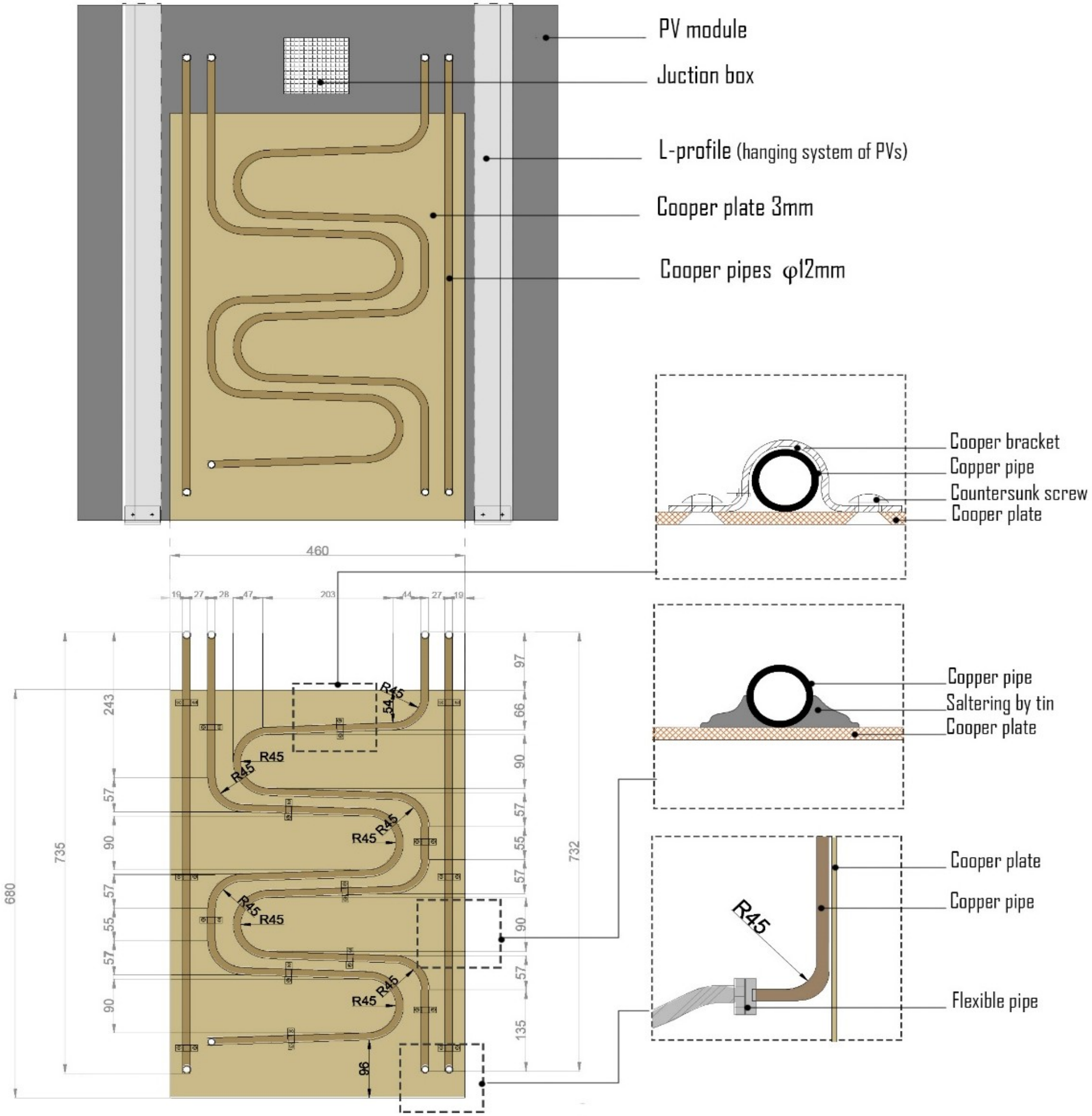
DESIGN

DETAILING

DESIGN
IMPLEMENTATION

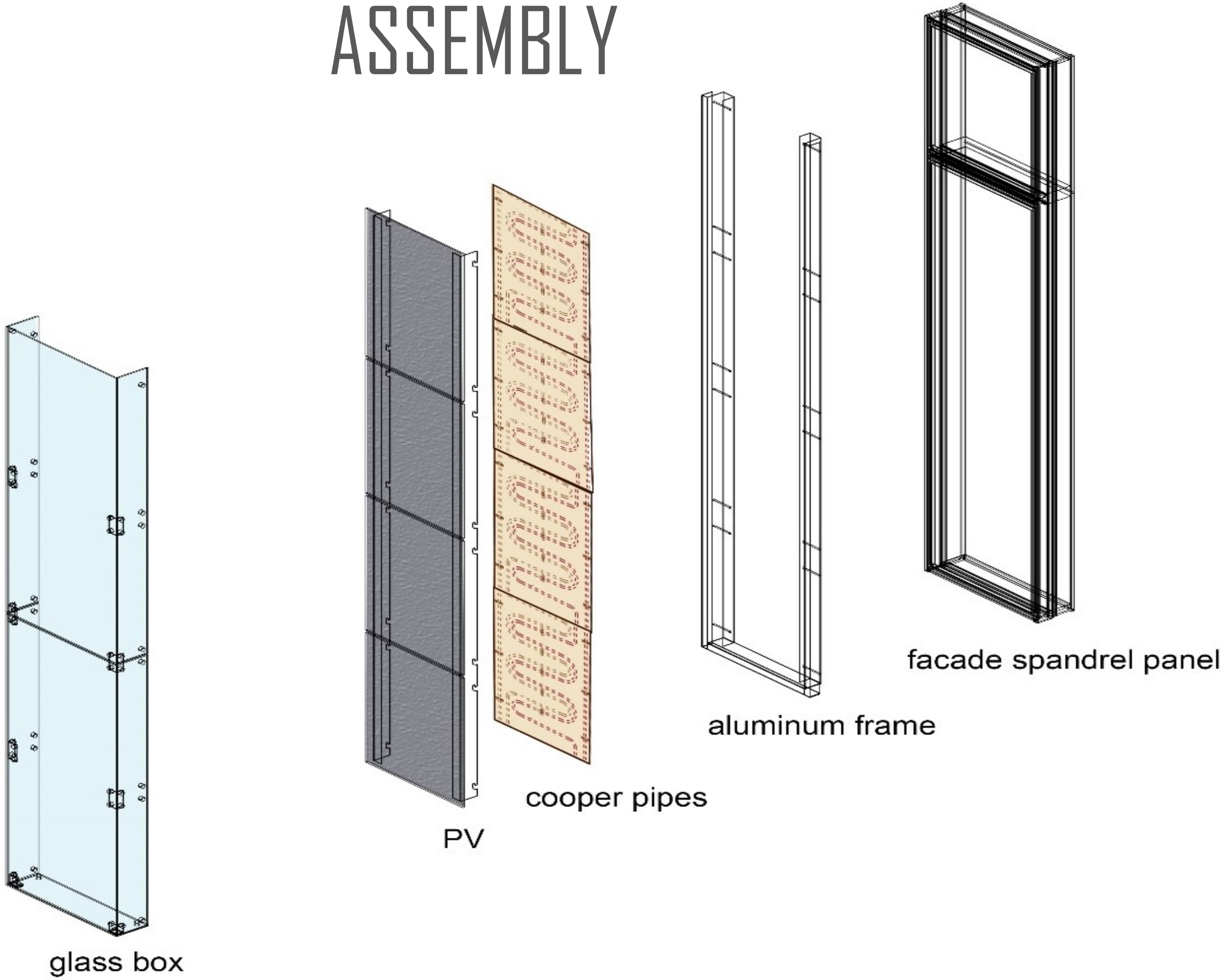






ASSEMBLY

DESIGN
IMPLEMENTATION



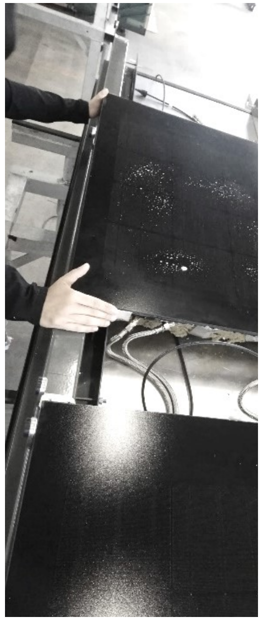
DESIGN

ASSEMBLY

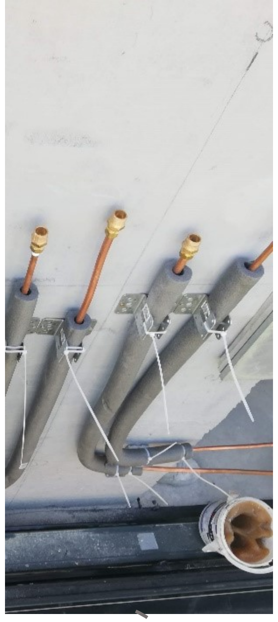
DESIGN IMPLEMENTATION

piping

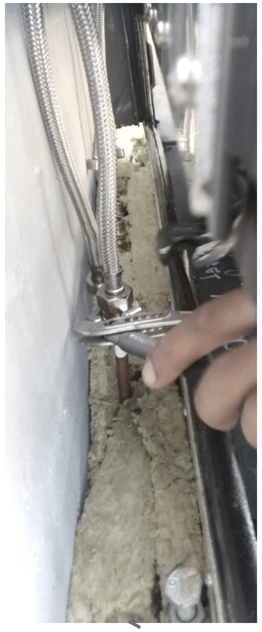
connection



stacking



preparation



On-site connection

assembly

piping

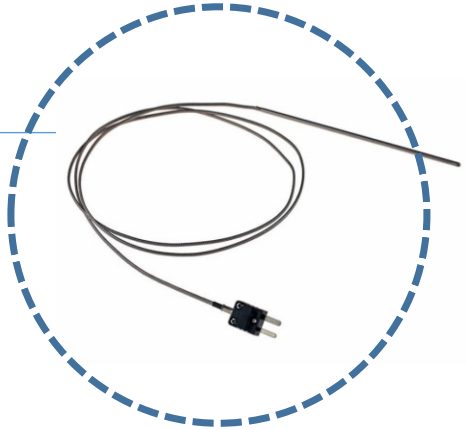
PROTOTYPE

DESIGN
IMPLEMENTATION

04

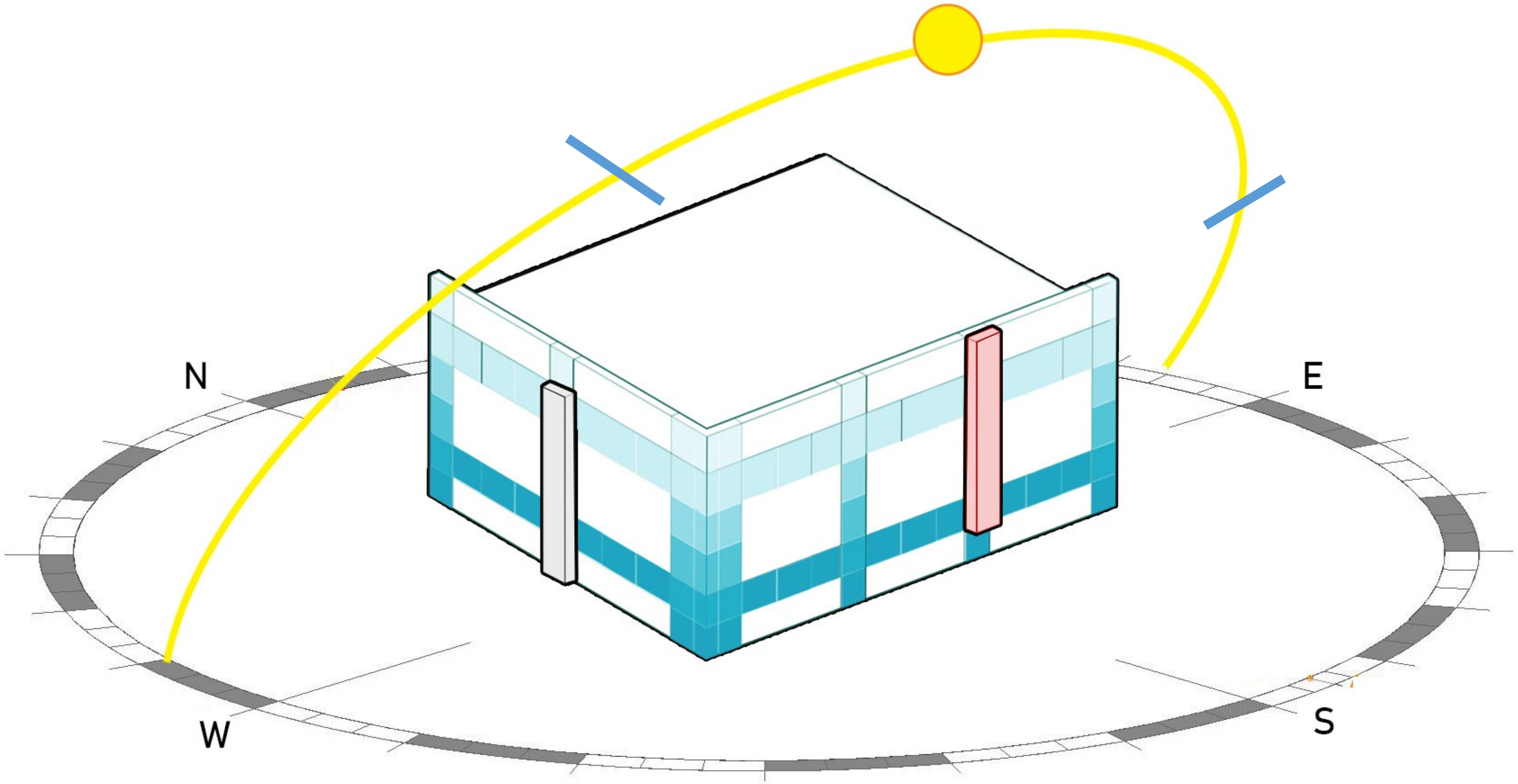
EXPERIMENT

TOOLS



EXPERIMENTAL SETUP

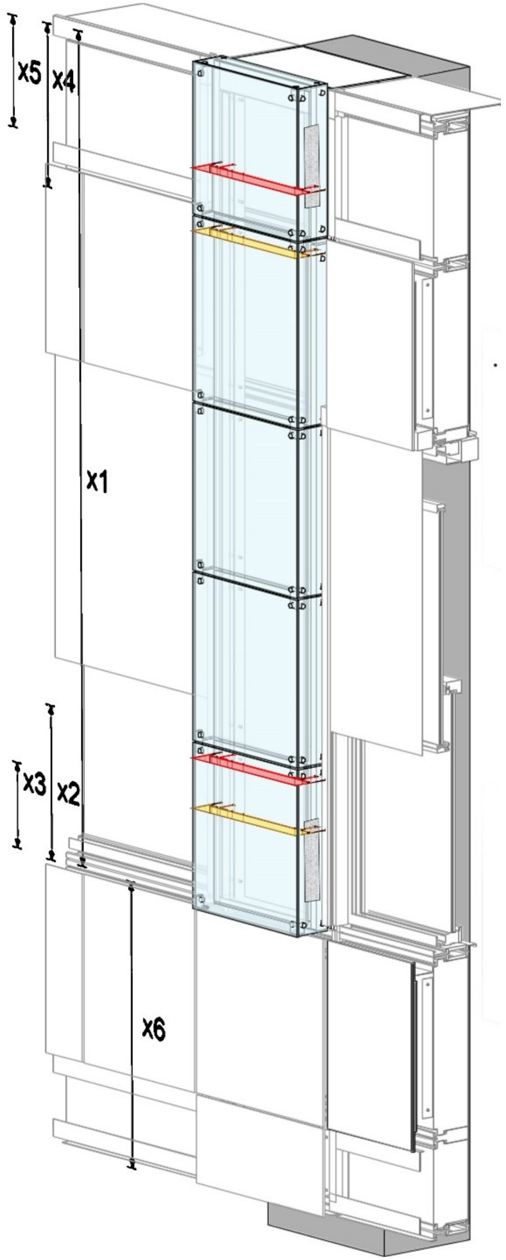
EXPERIMENT



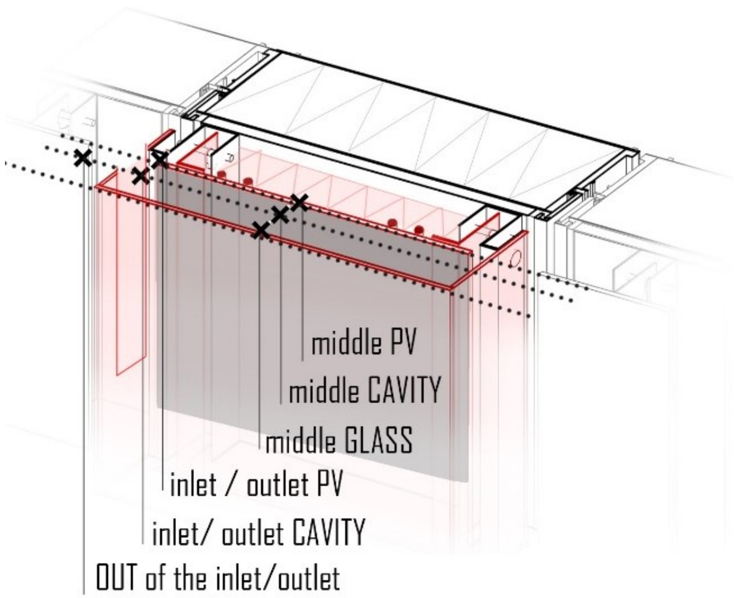
EXPERIMENTAL SETUP

EXPERIMENT

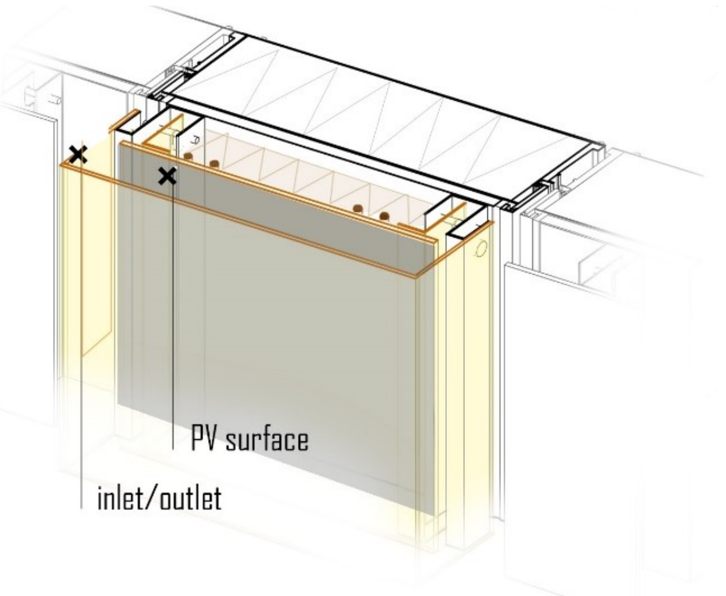
x1: 4.35m
x2: 0,82m
x3: 0.46m
x4: 0.90m
x5: 0.62m
x6: 1.45m



Anemometer
measurements points



Thermocouple's
measurements points

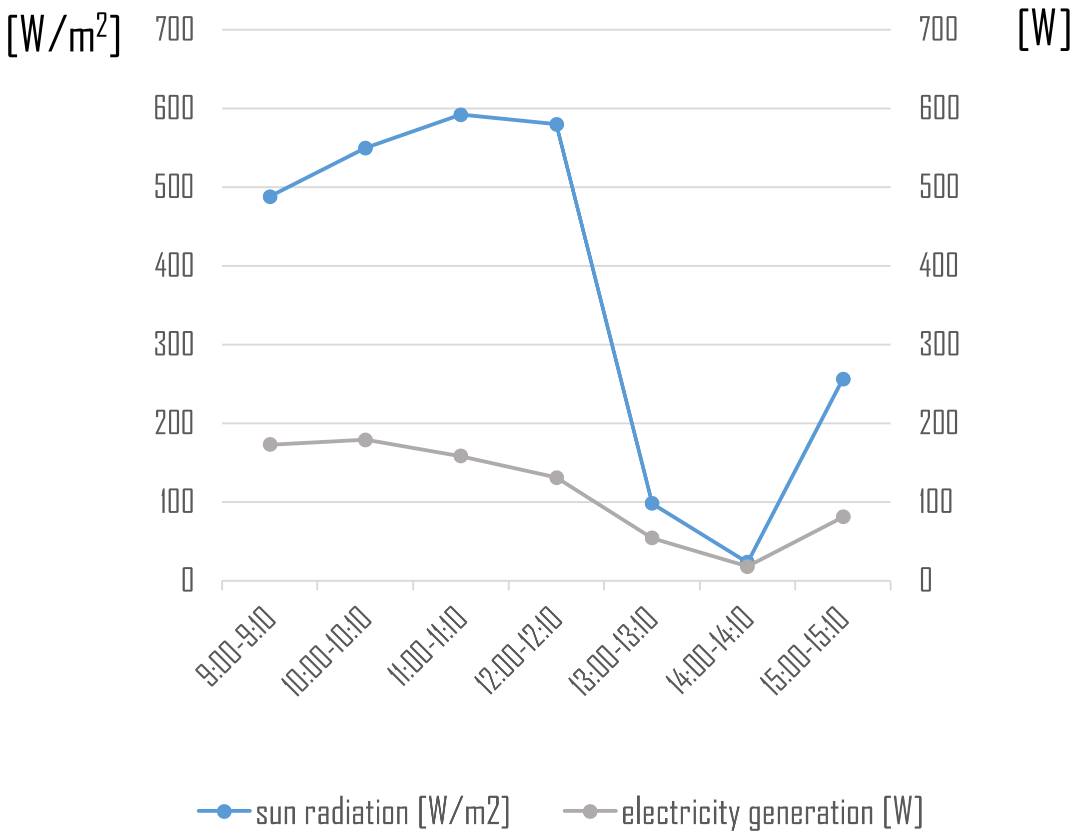


MEASUREMENTS

EXPERIMENT

SOLAR IRRADIANCE-ELECTRICITY

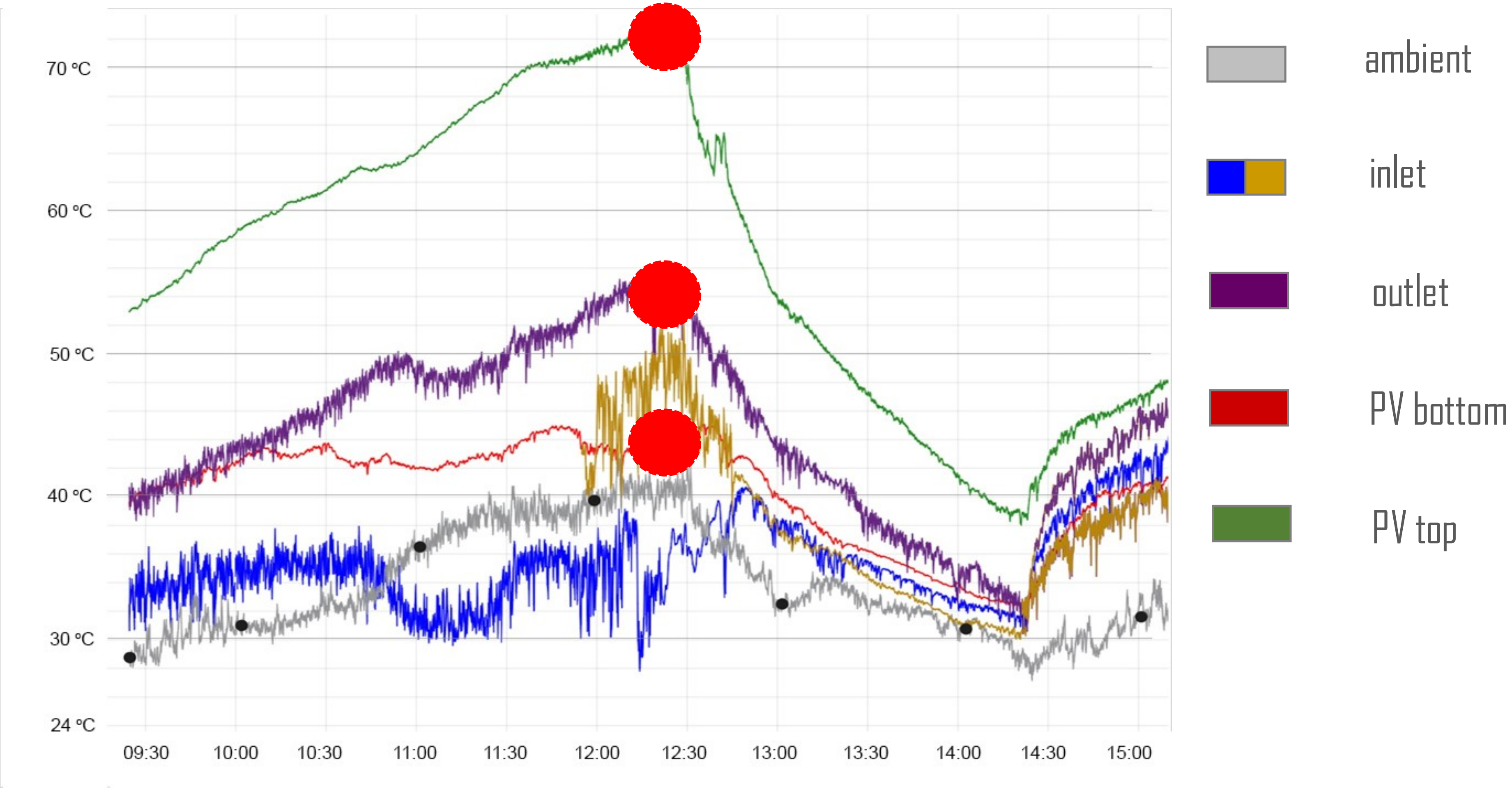
pyranometer



TEMPERATURE

thermocouples

EXPERIMENT

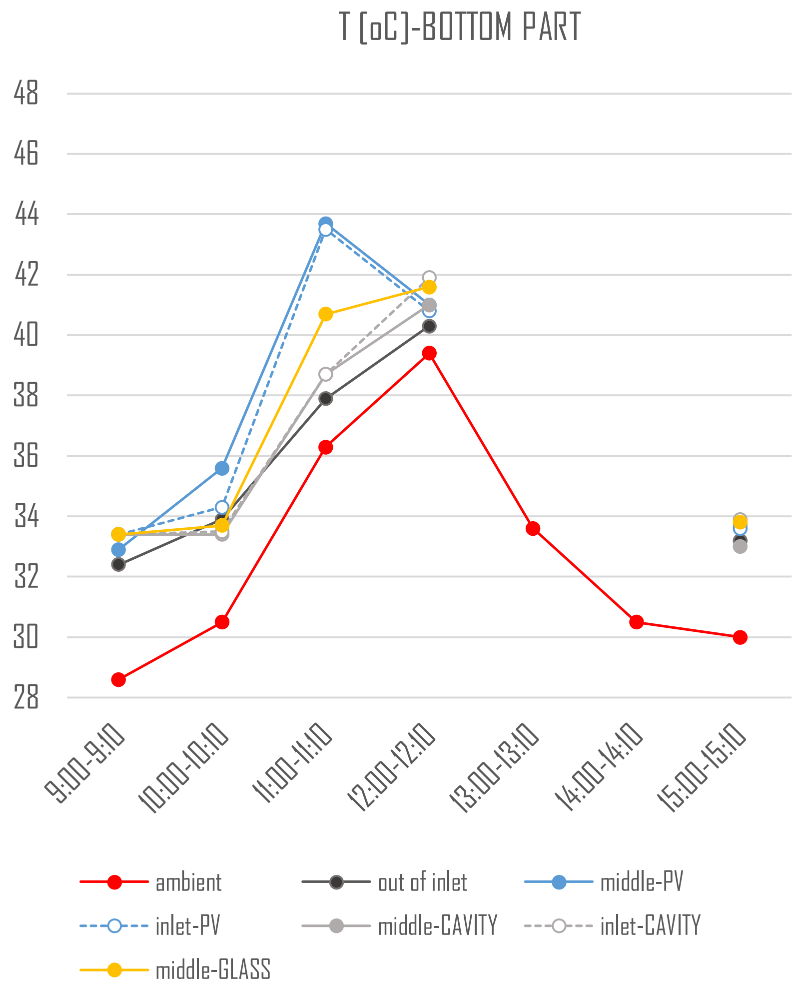


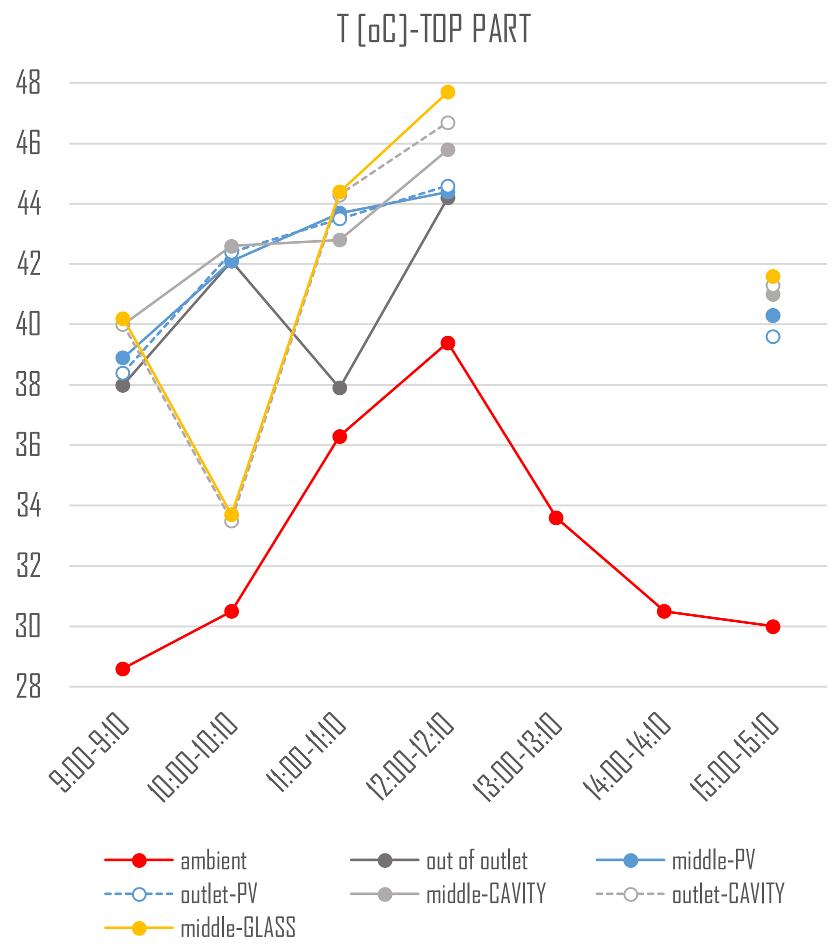
MEASUREMENTS

TEMPERATURE

anemometer

EXPERIMENT

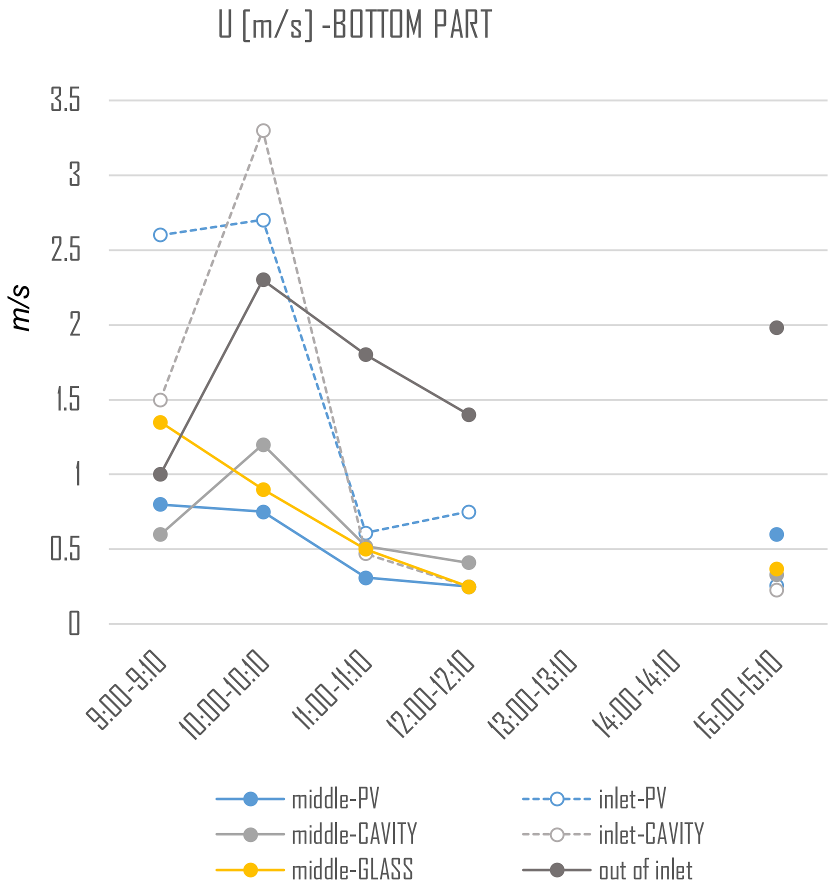


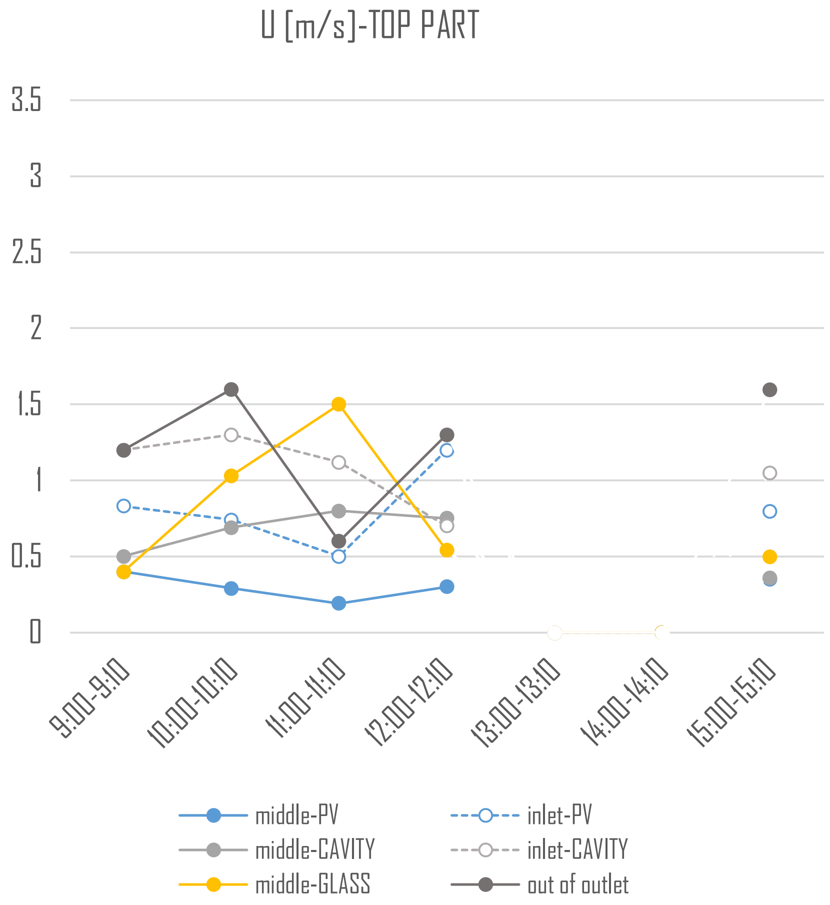


AIR VELOCITY

anemometer

EXPERIMENT





CONCLUSIONS

EXPERIMENT

- Bottom part follows the Tambient
- Top part T is influenced by the air input
- 13°C max difference from ambient
- Tpv max: 72°C (PV/T ???)

- Bottom part:
  follows the air input with lower values (except the air velocity close to the inlet)
- Top part:
  Fluctuated –turbulence (except the air close to glass)
- Outlet: till 1.3m/s

COMPARISON WITH SIMULATIONS

EXPERIMENT

Tair [ºC]

Time:	anemometer	thermocouples	stationary calc.
9:00	40	40.05	34
10:00	33.5	43.5	35
11:00	44.3	49.5	40
12:00	46.7	52.4	42

Air Velocity

time:	anemometer		stationary calc.
9:00	1.2		1.15
10:00	1.6		1.4
11:00	0.6		1.8
12:00	1.4		2

Temperature +/- 5-10ºC

Air velocity +/- 0.05-0.6m/s

05

EVALUATION

METHOD

Comparison of expected and the measured power

$$E = A * r * H * PR$$

EVALUATION

Where:

E= Energy (kWh)

A=Total solar panel Area (m^2)

r=solar panel yield (%)

H = Annual average irradiation on tilted panels (shadings not included) *

PR = Performance ratio, coefficient for losses (range between 0.9 and 0.5, default value = 0.75)

Comparison of the losses with thermal gains

$$Q=m\ (Tout-Tin)*Cp*A$$

Where:

Q= power (kW)

Tin=the temperature of the supplied fluid

Tout= the final temperature

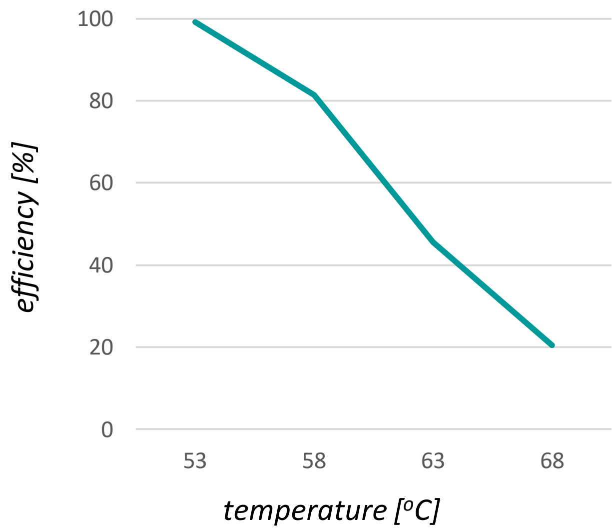
Cp = Heat capacity (KJ/kgK)

A= supply surface area (m^2)

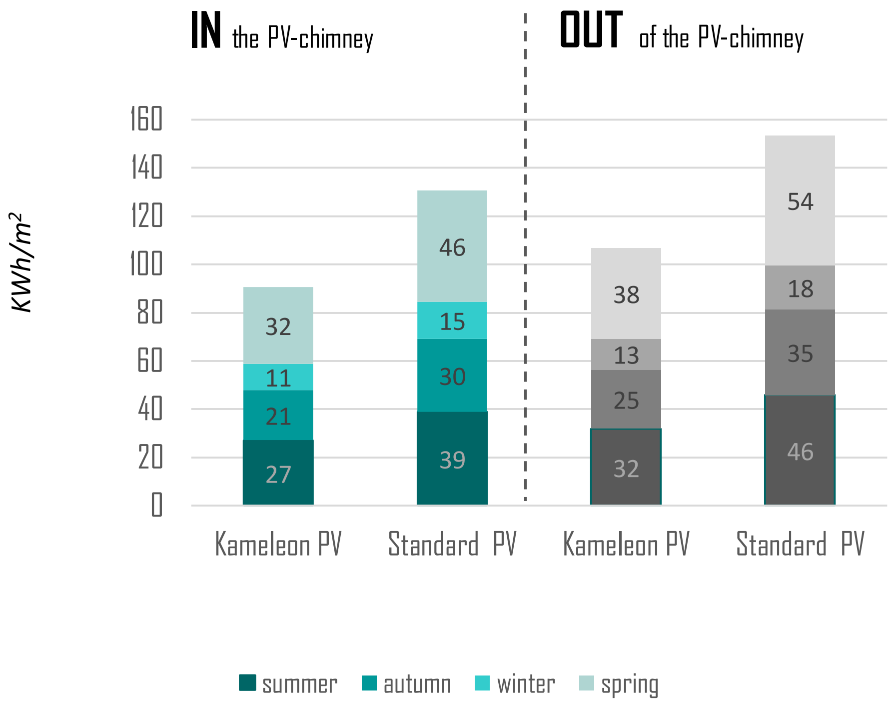
m=ρ*Volume/A*t

COMPARISON

Electrical Efficiency

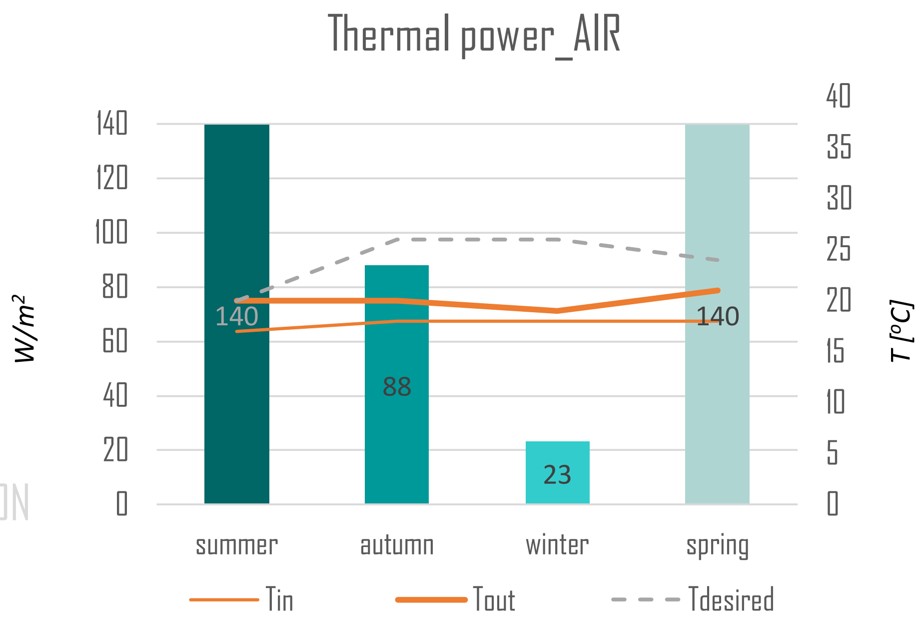


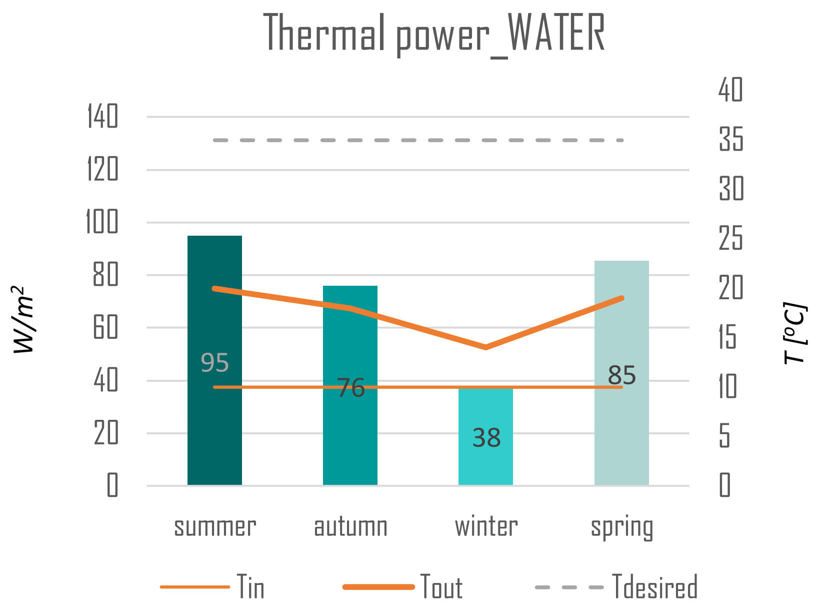
Annual Electricity generation



EVALUATION

COMPARISON

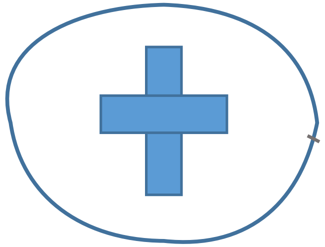




EVALUATION

CONCLUSIONS

- IMPORTANT losses due to high temperatures (>53°C)
- 30% annual losses due to product choice
- 15% losses due to the system



- The thermal gains are higher than the losses of electricity

-good to investigate the thermal losses due to the connection of the system with the HVAC system

06

CONCLUSION

CONCLUSIONS

- The system seems to have positive sign

- To make sure that the system can be part of the future net positive energy strategies, a lot more parameters should be investigated

  - Operational losses
  - Embodied energy
  - Energy footprint

Lesson to be learn……

Product design:

- **Formation** of the architectural inventions ➡ conceptual phase ✓
- **Physics** confirmation ➡ simulation phase ✓
- **Practical** inventiveness ➡ product development phase ✓
- **Economic, technical** and **time** effectiveness ➡ construction and assembly phase ✓

Thank you for your attention

Prof. Dr. Andy van den Dobbelsteen

Dr. Regina.M.J. Bokel

Zoheir Haghighi