Integrated Facade System in High Rise Office Buildings
in Tropical Climate Condition

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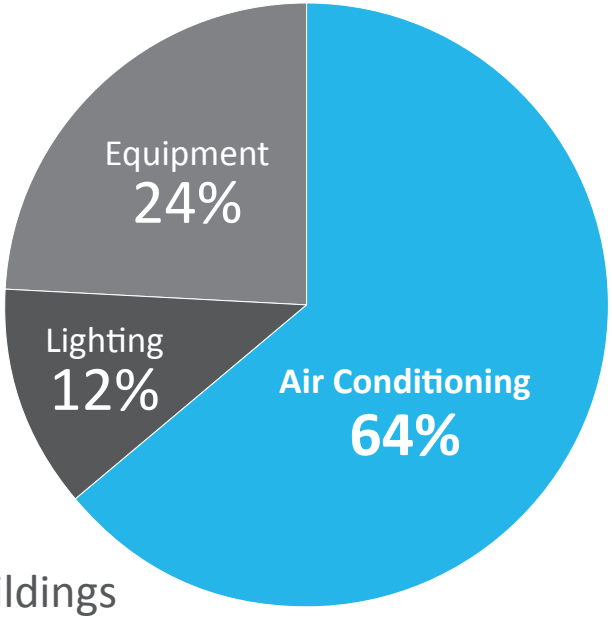
Building Technology Track
Graduation studio

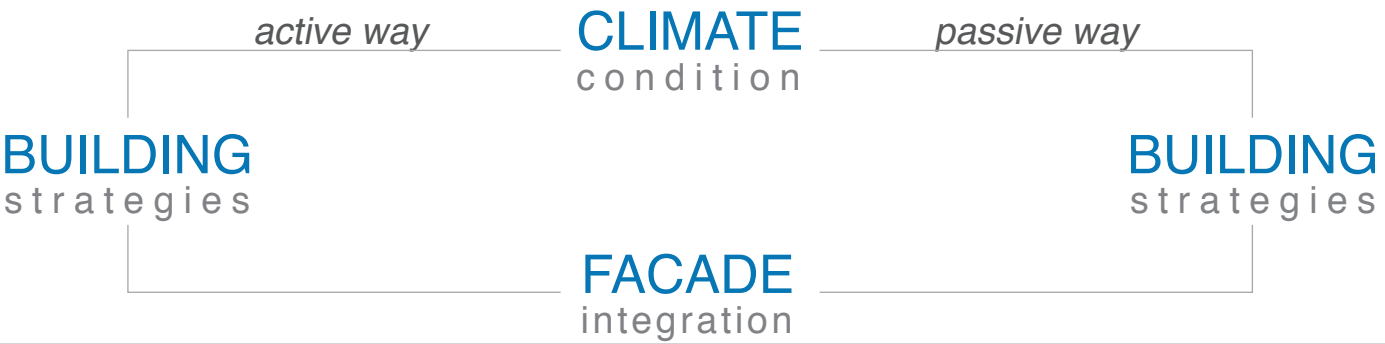
Responsible for 40% of the global primary energy consumption



Energy Consumption in Office Buildings

"To what extent building strategies can be integrated as facade system which able to reduce cooling energy demand in high rise office buildings in hot and humid tropical climate condition?"

PARAMETERS	**REDUCTION** on cooling load demand	**COMFORT** level	**CONSTRUCTION** feasibility
TOOLS	**LITERATURE** studies	**BUILDING** simulation	**ENERGY** calculation



STRATEGIES

FINAL product

END PROCESS

CLIMATE
condition

World Map of Köppen−Geiger Climate Classification

updated with CRU TS 2.1 temperature and VASClimO v1.1 precipitation data 1951 to 2000

Af	Am	As	Aw	BWk	BWh	BSk	BSh	Cfa	Cfb	Cfc	Csa	Csb	Csc	Cwa
Cwb	Cwc	Dfa	Dfb	Dfc	Dfd	Dsa	Dsb	Dsc	Dsd	Dwa	Dwb	Dwc	Dwd	EF	ET
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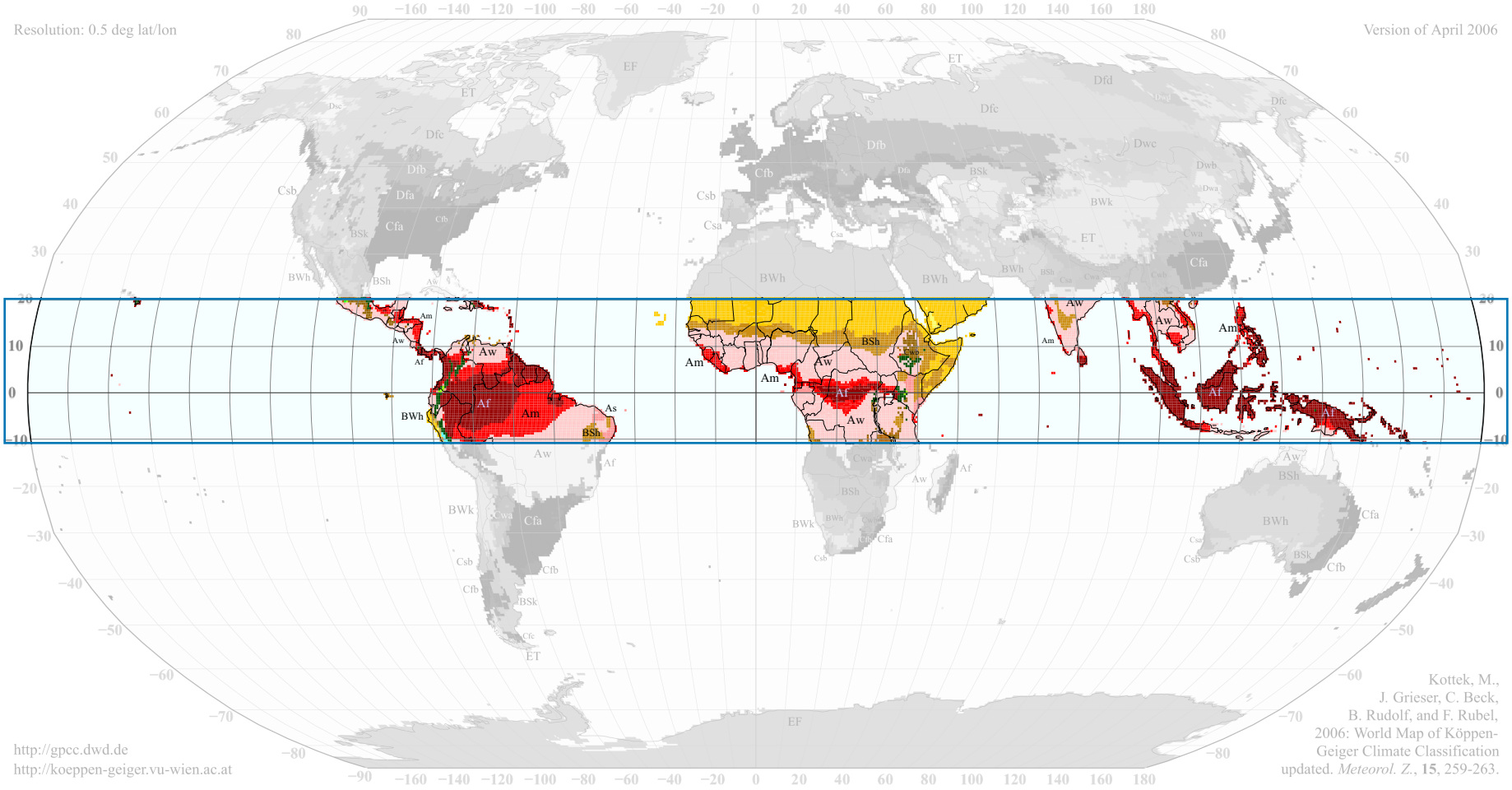
Main climates
- A: equatorial
- B: arid
- C: warm temperate
- D: snow
- E: polar

Precipitation
- W: desert
- S: steppe
- f: fully humid
- s: summer dry
- w: winter dry
- m: monsoonal

Temperature
- h: hot arid
- k: cold arid
- a: hot summer
- b: warm summer
- c: cool summer
- d: extremely continental
- F: polar frost
- T: polar tundra

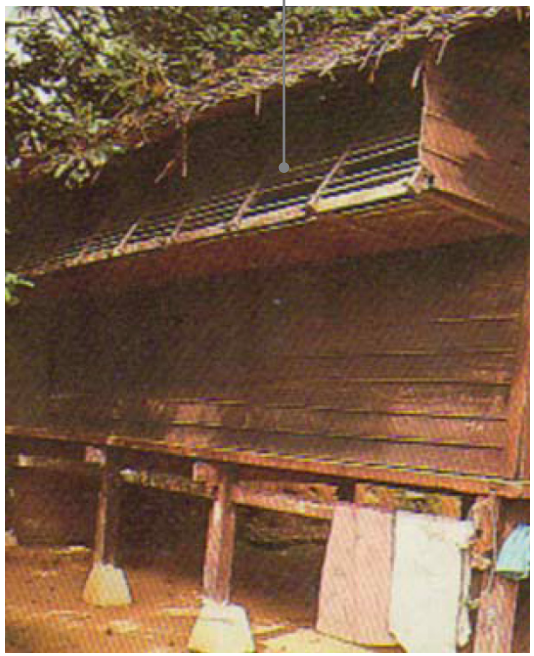


Monsoon window

- Air temperature drop when its raining (to 24°C-27°C)
- Allows the outdoor air flows when its raining outside

Roof and eave

- Rainwater runs off faster
- Shade the building from direct sun radiation



Sun shading device

cover the whole facade area

Layout configuration

create shading on each floor

Sun shading device

follow the sun path

Full glazed facade

Low-e double glass unit

Full glazed facade

Low-e coated glass

Jakarta

climate data

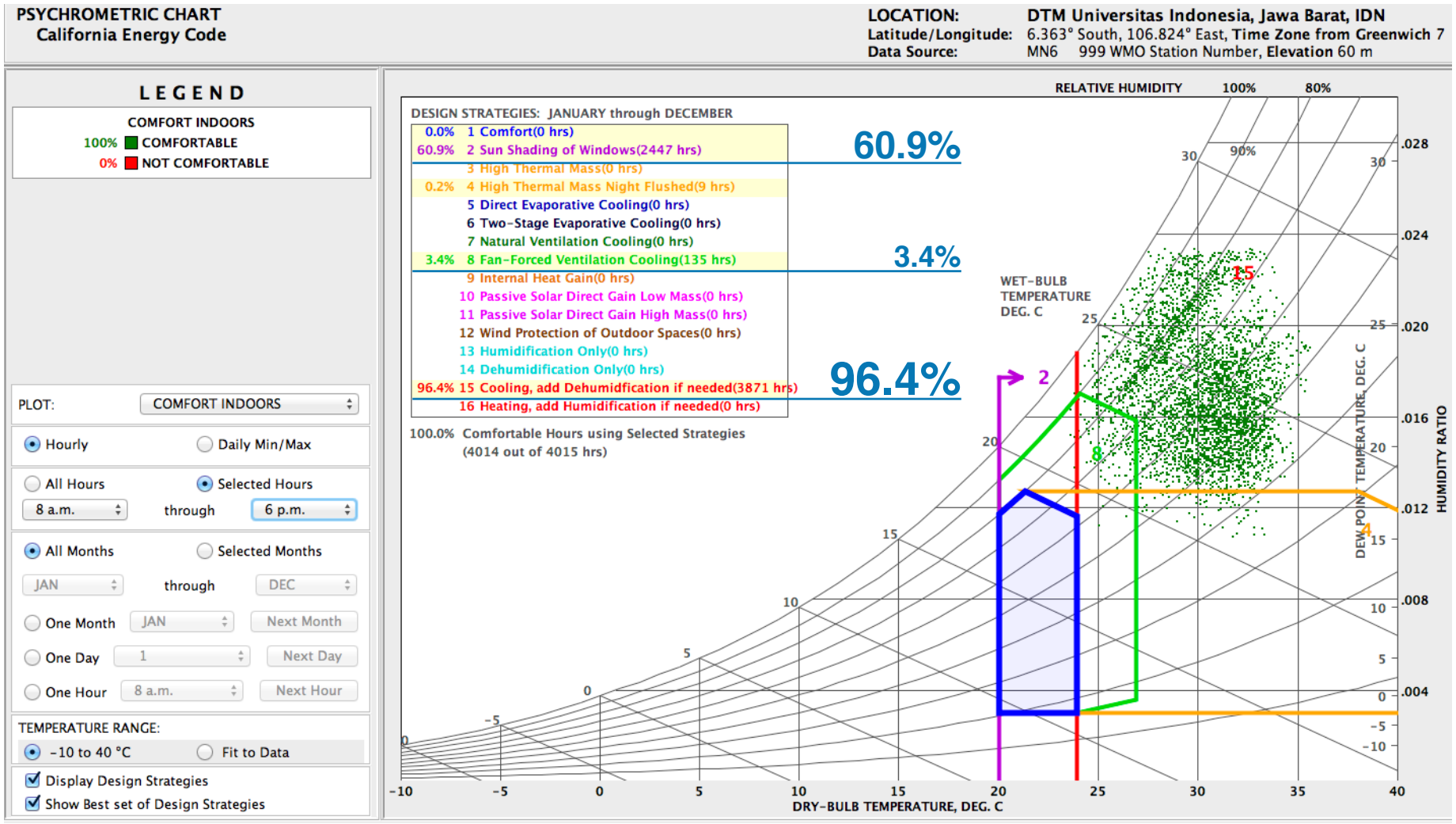
	Temperature (°C)				Average Precipitation (mm)	Average Sunlight (hours)	Wet Days (+0.1 mm)	Relative Humidity (%)			Monthly Ave. Clear Sky (days)
	Average		Record					AM	PM	Average	
	Min	Max	Min	Max							
Jan	23	29	21	34	300	5	18	95	75	80.4	1
Feb	23	29	21	33	300	5	17	95	75	81	2
Mar	23	30	21	33	211	6	15	94	73	80.3	4
Apr	24	31	21	34	147	7	11	94	71	79.8	4
May	24	31	21	34	114	7	9	94	69	80	2
Jun	23	31	19	34	97	7	7	93	67	79.6	1
Jul	23	31	19	33	64	7	5	92	64	79.1	2
Aug	23	31	19	34	43	8	4	90	61	79.1	1
Sep	23	31	19	36	66	8	5	90	62	79.3	1
Oct	23	31	21	37	112	7	8	90	64	81.9	1
Nov	23	30	20	36	142	6	12	92	68	82.5	1
Dec	23	29	19	34	203	5	14	92	71	80.5	0
Ave.	23.2	30.3	20.1	34.3	149.9	6.5	10.4	92.6	68.3	80.3	1.7

Adaptive thermal comfort

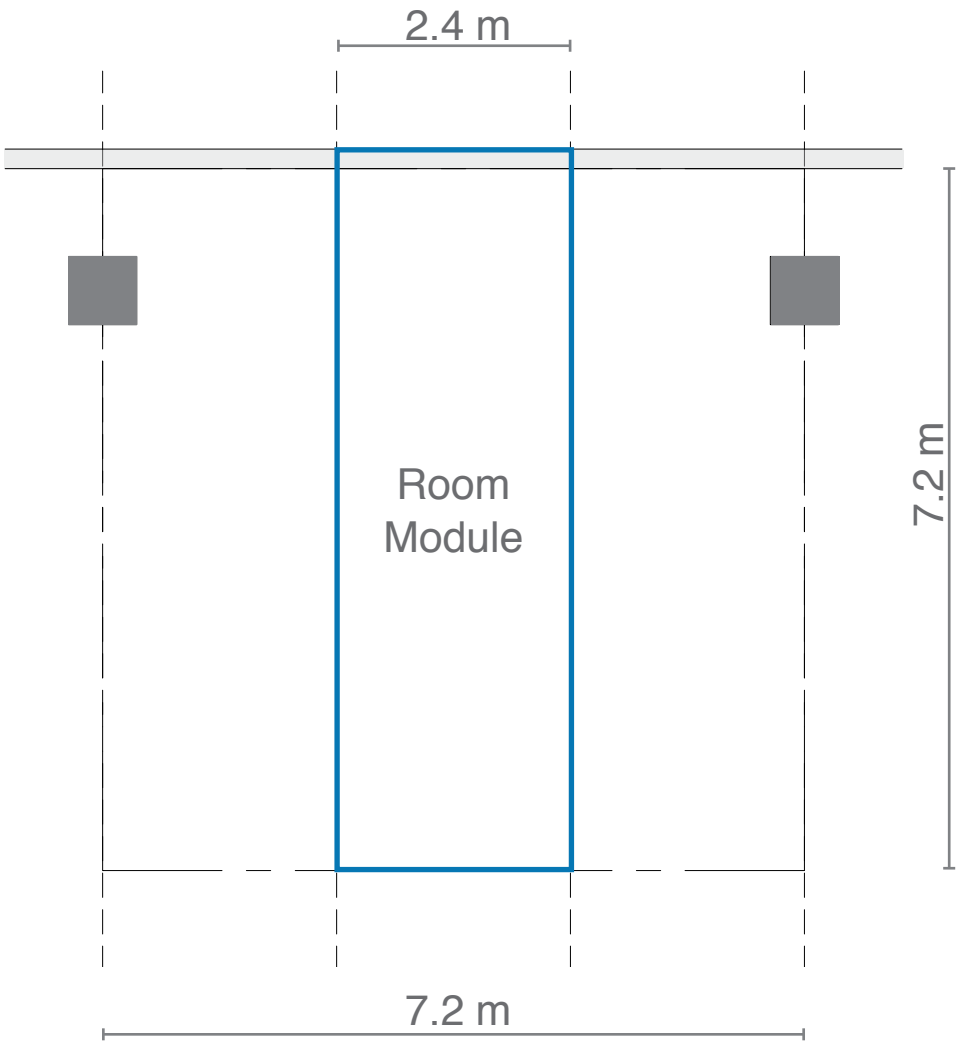
in office building in Jakarta

Neutral Temperature $T_{operative} = 26.70^{o}C$

Comfort Range $T_{operative} = 23.50^{o}C - 29.90^{o}C$


PSYCHROMETRIC CHART
California Energy Code
LOCATION: DTM Universitas Indonesia, Jawa Barat, IDN
Latitude/Longitude: 6.363° South, 106.824° East, Time Zone from Greenwich 7
Data Source: MN6 999 WMO Station Number, Elevation 60 m
LEGEND
COMFORT INDOORS
100% COMFORTABLE
0% NOT COMFORTABLE
PLOT: COMFORT INDOORS
Hourly
Daily Min/Max
All Hours
Selected Hours
8 a.m.
through
6 p.m.
All Months
Selected Months
JAN
through
DEC
One Month
JAN
Next Month
One Day
1
Next Day
One Hour
8 a.m.
Next Hour
TEMPERATURE RANGE:
-10 to 40 °C
Fit to Data
Display Design Strategies
Show Best set of Design Strategies
DESIGN STRATEGIES: JANUARY through DECEMBER
0.0% 1 Comfort(0 hrs)
60.9% 2 Sun Shading of Windows(2447 hrs)
3 High Thermal Mass(0 hrs)
0.2% 4 High Thermal Mass Night Flushed(9 hrs)
5 Direct Evaporative Cooling(0 hrs)
6 Two-Stage Evaporative Cooling(0 hrs)
7 Natural Ventilation Cooling(0 hrs)
3.4% 8 Fan-Forced Ventilation Cooling(135 hrs)
9 Internal Heat Gain(0 hrs)
10 Passive Solar Direct Gain Low Mass(0 hrs)
11 Passive Solar Direct Gain High Mass(0 hrs)
12 Wind Protection of Outdoor Spaces(0 hrs)
13 Humidification Only(0 hrs)
14 Dehumidification Only(0 hrs)
96.4% 15 Cooling, add Dehumidfication if needed(3871 hrs)
16 Heating, add Humidification if needed(0 hrs)
100.0% Comfortable Hours using Selected Strategies
(4014 out of 4015 hrs)
60.9%
3.4%
96.4%
RELATIVE HUMIDITY
100%
80%
90%
WET-BULB TEMPERATURE DEG. C
DEW POINT TEMPERATURE, DEG. C
HUMIDITY RATIO
DRY-BULB TEMPERATURE, DEG. C
2
8
15
4

BUILDING
strategies



Floor to ceiling height	= 3.2	m
Orientation	= West	
Room volume	= 55.30	m^3
Room floor area	= 17.28	m^2
Indoor set point temperature	= 26.7	^oC
Indoor set point RH%	= 60	%

PASSIVE WAY	SUN SHADING device system	
ACTIVE WAY	DEHUMIDIFICATION system	INDIRECT EVAPORATIVE cooling system

TOOLS	LITERATURE studies	BUILDING simulation	ENERGY calculation
RESULT	INTEGRATED facade system		

PASSIVE WAY

PARAMETERS

PERFORMANCE

- Reduction on cooling load in the space inside
- Shading performance

INTEGRATION

- Able to be integrated with other systems
- Possible dimension and shape

COMFORT

- Daylight factor
- Illuminance

Improvement in the numbers of comfor hours (egg crate type)

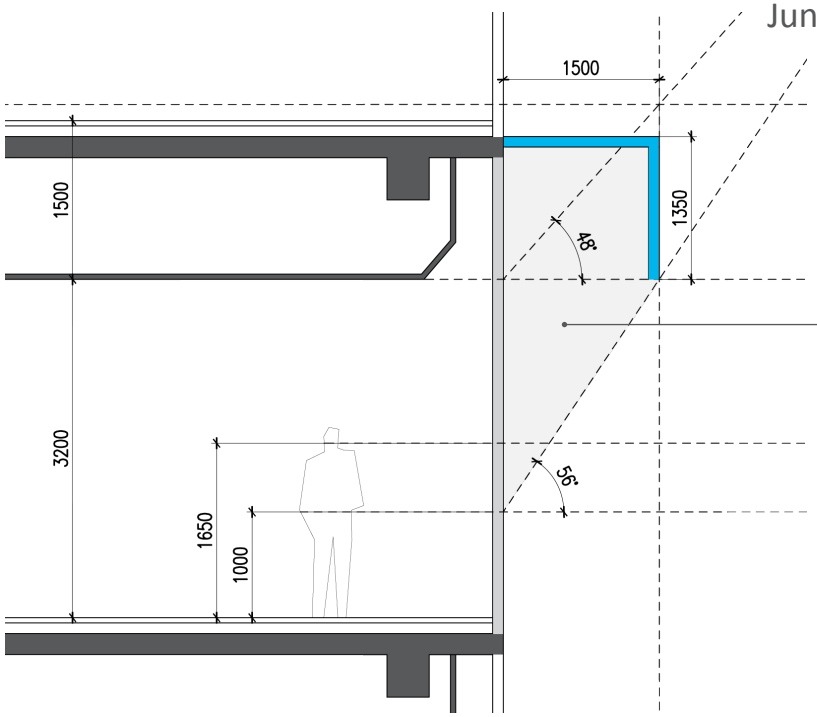
26%

Reduction on heat impact

1/3

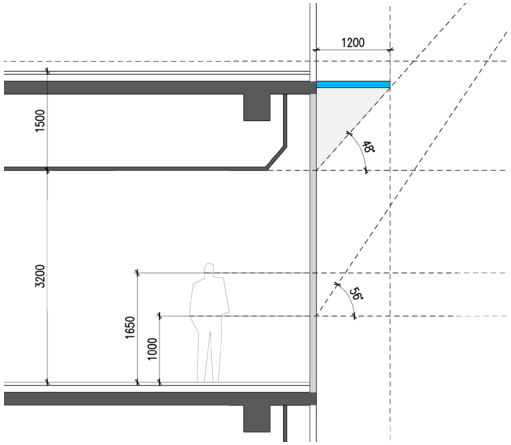
Olgyay, V. (1962). Design with climate-bioclimatic approach to architectural regionalism

S. Fadzil & N. Al-Tamimi (2011). The Potential of Shading Devices for Temperature reduction in high rise residential buildings in the tropic

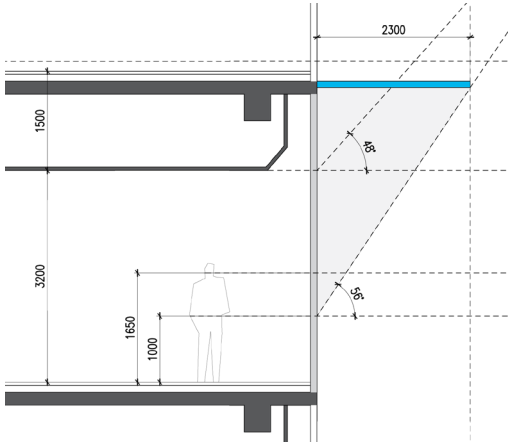


Solar Altitude Angle

Jakarta, Indonesia
10.00 - 14.00



1



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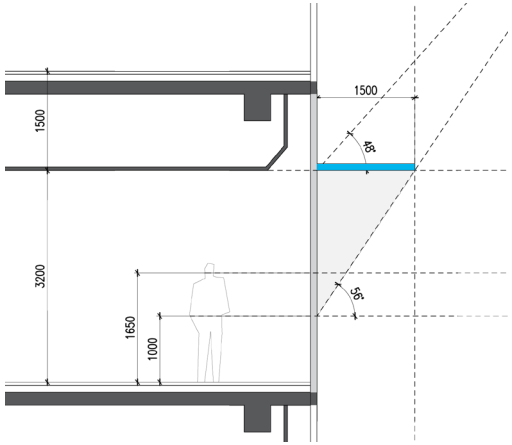
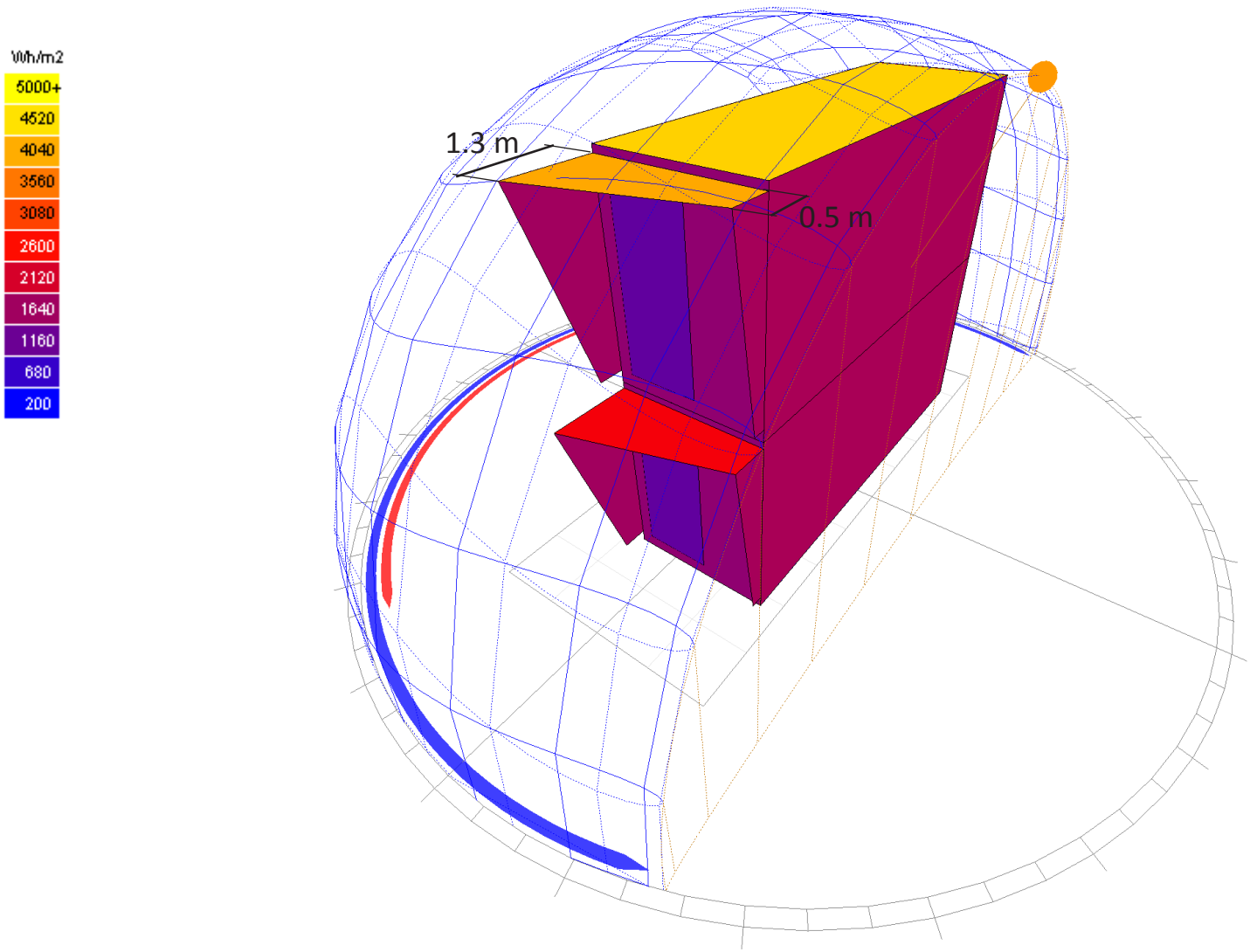


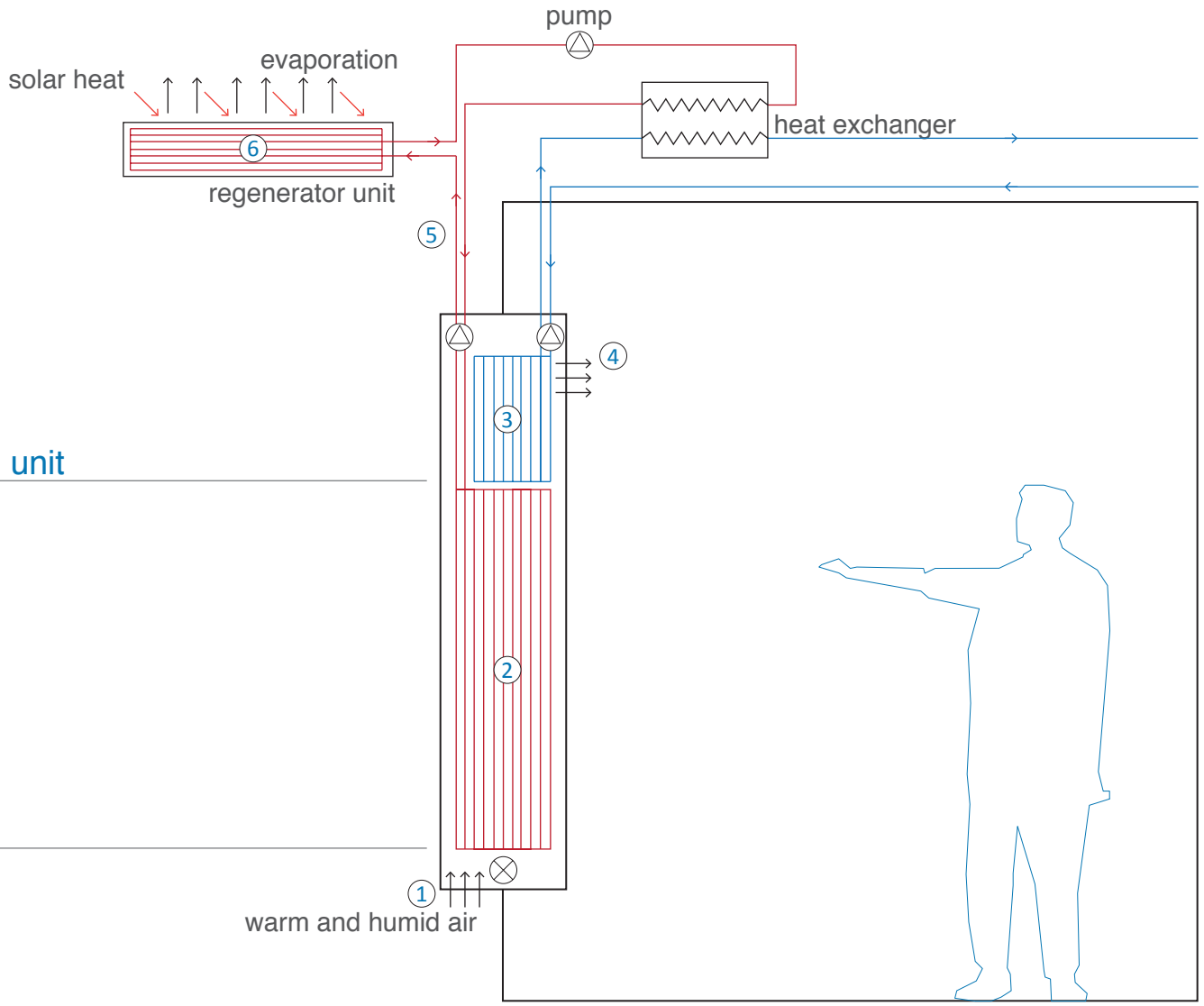
3

Optimized shading device

surrounding shade with verticals



ACTIVE WAY



Indirect evaporative cooling unit

Dehumidification unit

DESICCANT DEHUMIDIFICATION

attract moisture from the air by creating an area of low surface vapor pressure at the surface of the desiccant

PARAMETERS

PERFORMANCE

- Reduction on relative humidity inside the space
- Energy sources

INTEGRATION

- Possible integration with cooling system
- Possible integration in the fadace system

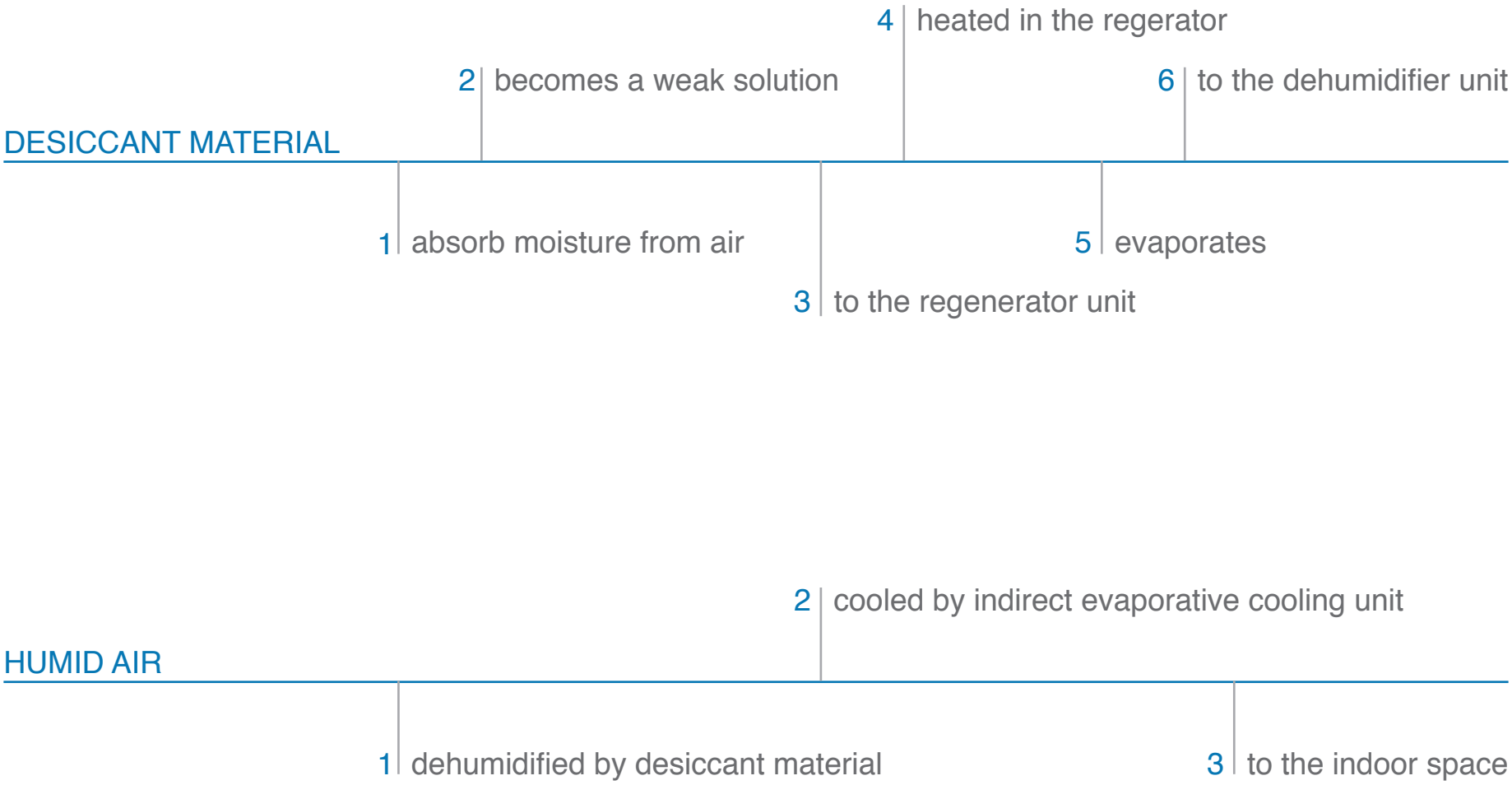
APPLICABILITY

- Desiccant material
- Working principle
- Possible dimension and size

Energy savings 40-80%

Electrical energy demand reduction 80%

J. Woods & E. Kozubal (2011). Desiccant Enhanced Evaporative Air Conditioning. NREL.


4 heated in the regerator
2 becomes a weak solution
6 to the dehumidifier unit
DESICCANT MATERIAL
1 absorb moisture from air
5 evaporates
3 to the regenerator unit
2 cooled by indirect evaporative cooling unit
HUMID AIR
1 dehumidified by desiccant material
3 to the indoor space

MATERIAL

SOLID

silica gel

LIQUID

- Triethylene Glycol (TEG)
- Calcium Chloride ($CaCl_2$)
- Lithium Chloride (LiCl)

SYSTEM

HYBRID

- Vapor Compression System
- Vapor Absorption System

STAND ALONE

- Spray Tower
- Packed Bed Tower
- Wetted Wall Column

SOURCE

NATURAL GAS

ELECTRICITY

SOLAR ENERGY

- PV Panel
- Solar Thermal Collector

LIQUID desiccant

Calcium Chloride ($CaCl_2$)

- more data in literature about its material properties are available
- cheaper than TEG and LiCl for its moisture absorption and low corrosive

STAND ALONE system

Spray

- low cost
- compact size
- low effectiveness

Packed Bed

- compact size
- high effectiveness
- health and corrosion issues
- unable to be integrated with cooling system

Wetted Wall

- high effectiveness
- no health and corrosion issues
- easier maintenance
- able to be integrated with cooling system

Solar source

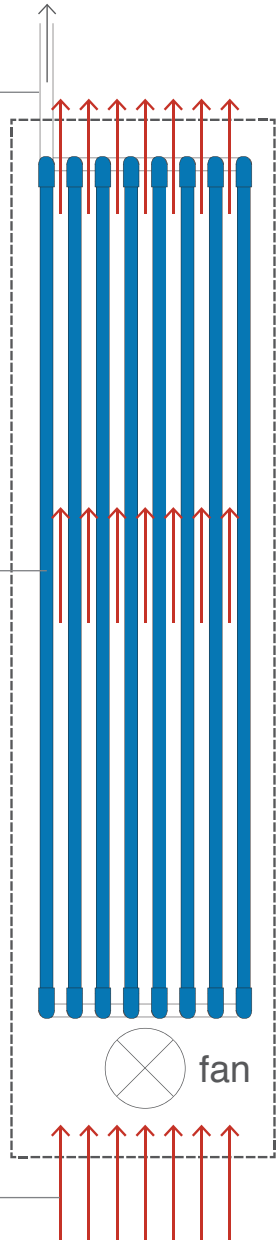
Solar Thermal Collector

- the most efficient
- proven by several built references

3 regenerator unit

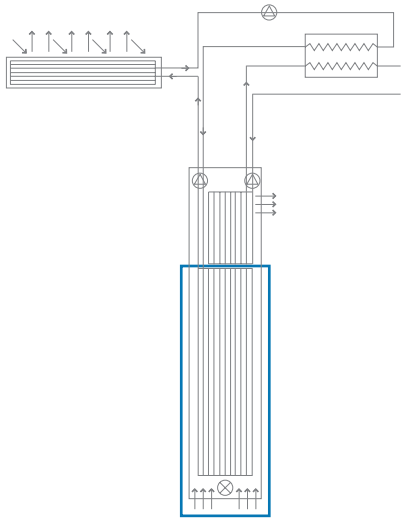
2 liquid desiccant media

1 intake air hot and humid air



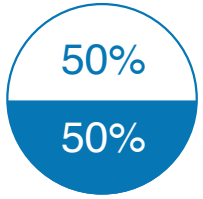
liquid desiccant (solution)

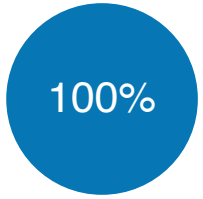
warm and humid air

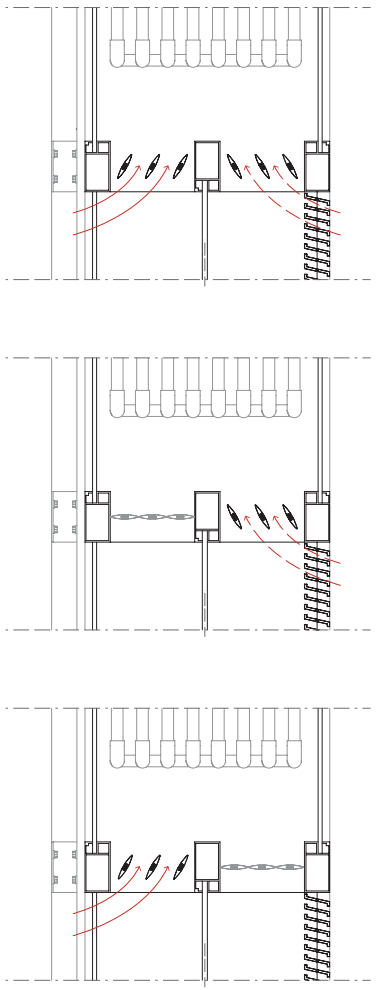


Intake air

hot and humid air

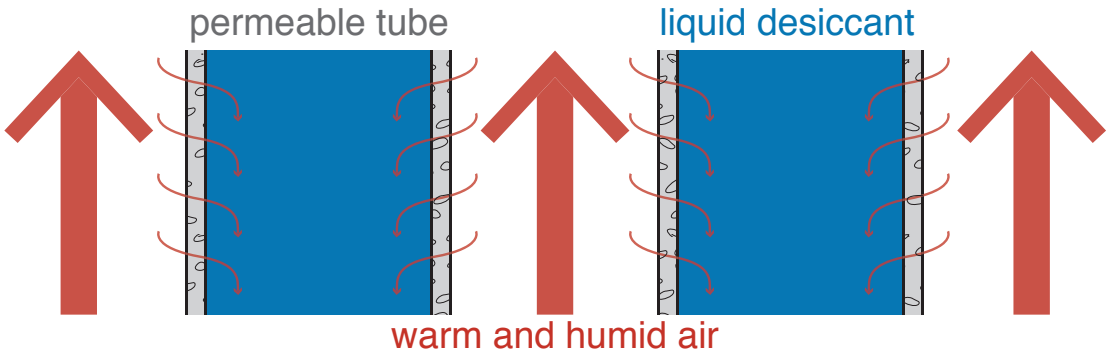


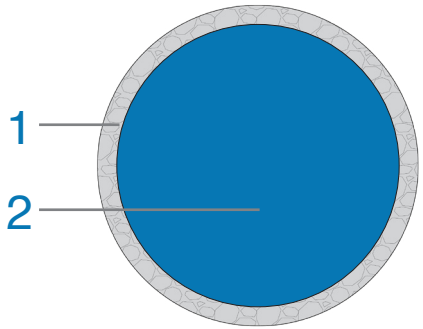




Indoor Air

Outdoor Air





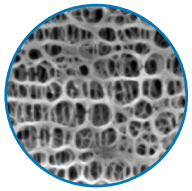
Liquid desiccant

media

2

$CaCl_2$

1



Micro porous polypropylene membrane

- permeable to water vapor
- impermeable to liquid desiccant

TEMPERATURE	30.3°C	26.7°C
	outdoor max ave. temperature	indoor comfort temperature
RELATIVE HUMIDITY	80%	60%
	outdoor ave. relative humidity	indoor relative humidity

9.47 g/m³

moisture to be removed

ROOM DATA	55.30 m²	0.05 m³/s
	room volume	air change rates

38.02 litres/day

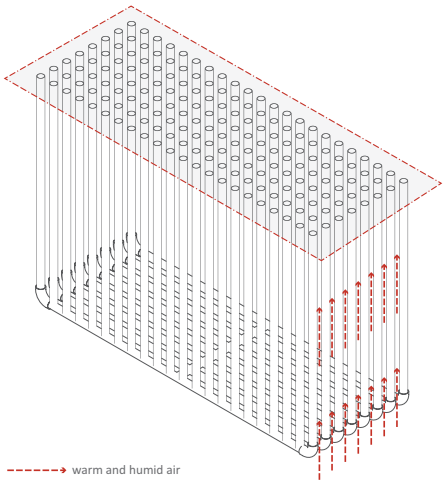
(for 100% indoor dehumidification 1/4 less)

total moisture removal

56.17 litres/day

(for 100% indoor dehumidification 1/4 less)

total volume of liquid desiccant needed



height = 1.50 m²

volume = 0.000471 m³

176 tubes

total tubes to be provided

Regenerator

PARAMETERS

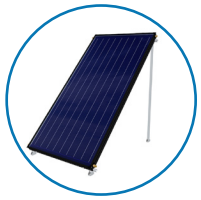
unit

PERFORMANCE

Able to provide thermal energy to regenerate the liquid desiccant

APPLICABILITY

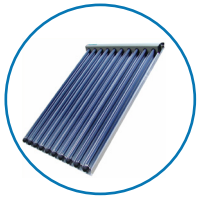
Ideal location



SYSTEM

2 Evacuated tube solar thermal collector

1 Flat plate solar thermal collector



LOCATION

1 Integrated in the facade system

+ Decentralized system
+ Bigger surface area
- More complex maintenance
- Less efficiency

2 Centralized on top of the building roof

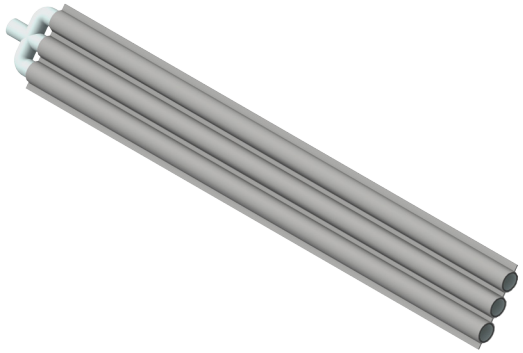
+ Easier maintenance
+ Higher efficiency
- Centralized system
- Less surface area

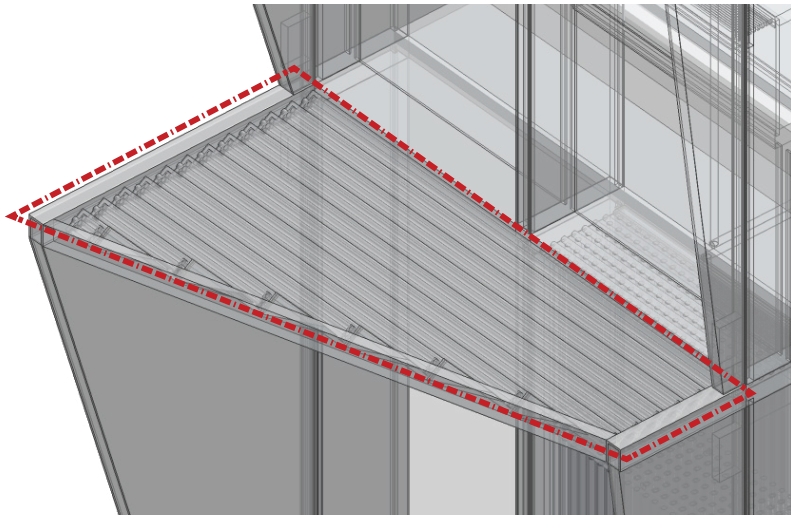
DEHUMIDIFICATION SYSTEM

INTEGRATED

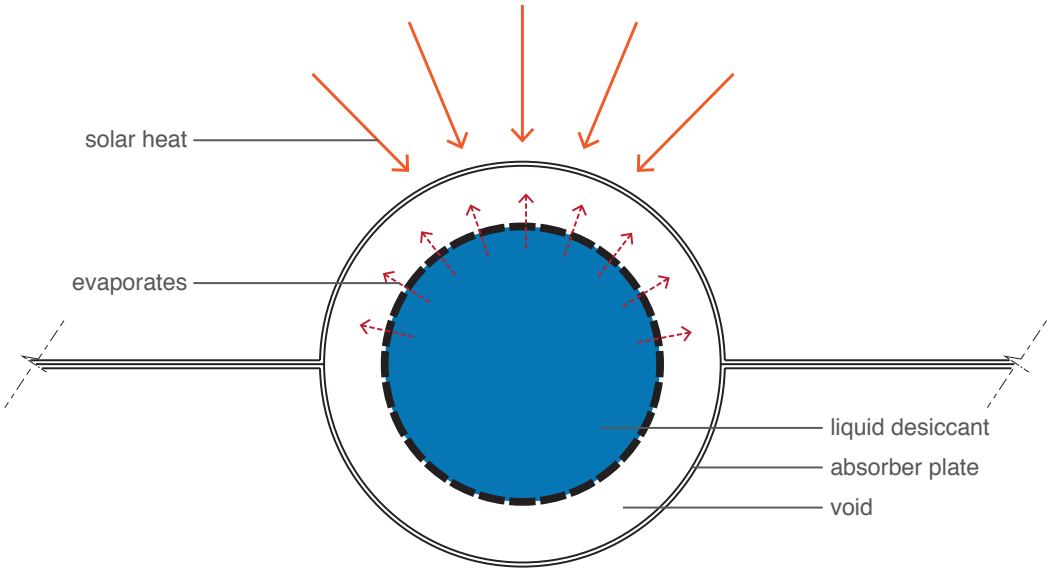
with sun shading device

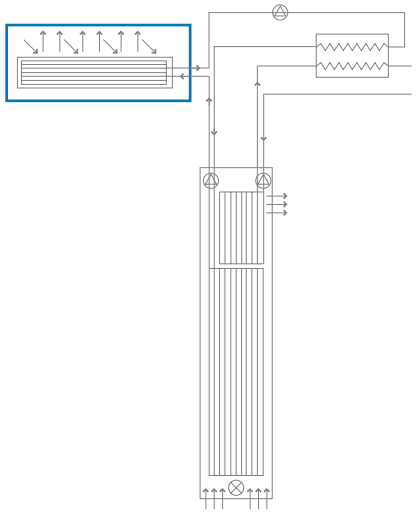
as louvre





cross section





DEHUMIDIFICATION SYSTEM

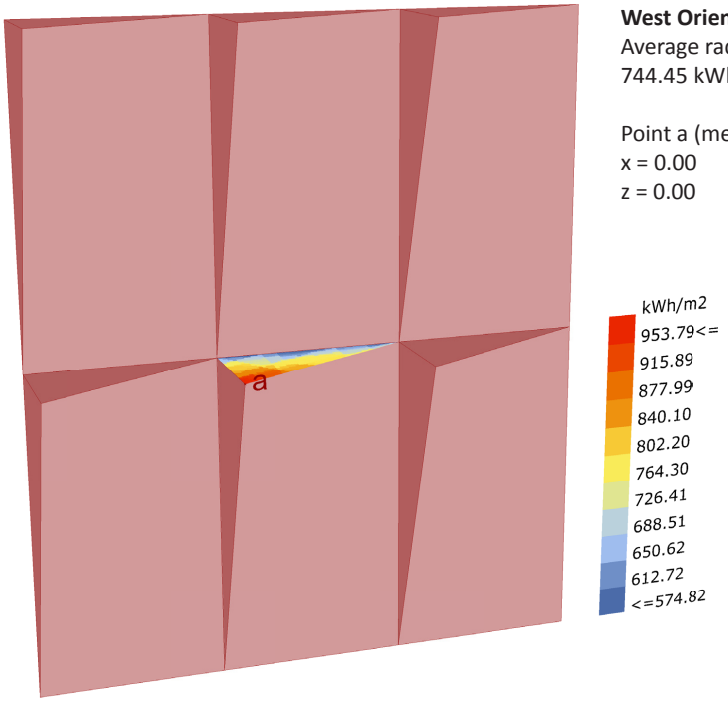
SURFACE AREA 1.97 m²
per facade module

LIQUID DESICCANT 38.02 litres/day
to be regenerated

24.49 kWh/day
to evaporate 38.02 liters of liquid desicccant

(for 100% indoor dehumidification 1/4 less)

12.43 kWh/m².day
need to be provided



2.48 kWh/m².day
able to be provided

1/5
of the total required energy

(for 100% indoor dehumidification it can covers 1/3 of the required energy)

INDIRECT EVAPORATIVE COOLING

reduce the dry bulb air temperature without adding more moisture in the supply air

PARAMETERS

PERFORMANCE

Comparable to normal vapor compression system

INTEGRATION

- Possible integration with dehumidication system
- Possible integration in the fadace system

APPLICABILITY

- Working principle
- Possible dimension and size

More energy and requires bigger space

Vapor Compression

30.3°C drop to 28.32°C

(with assumption efficiency of 60%)

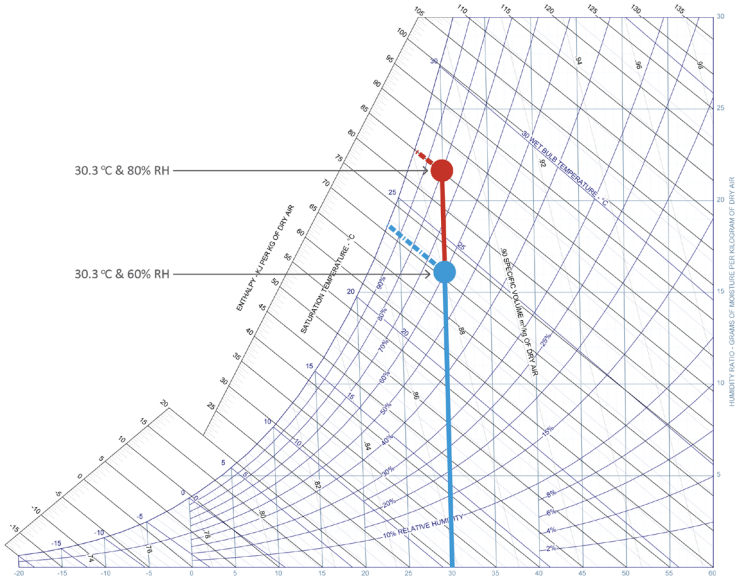
Indirect Evaporative Cooling

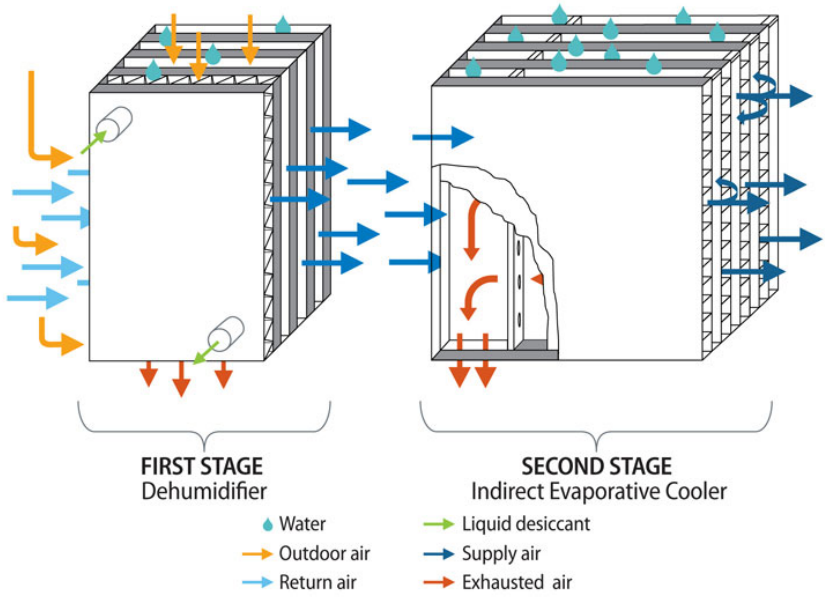
30.3°C drop to 26.52°C

(with assumption efficiency of 60%)

Dehumidi-fication

Indirect Evaporative Cooling





30.3°C drop to 26.52°C

(with assumption efficiency of 60%)

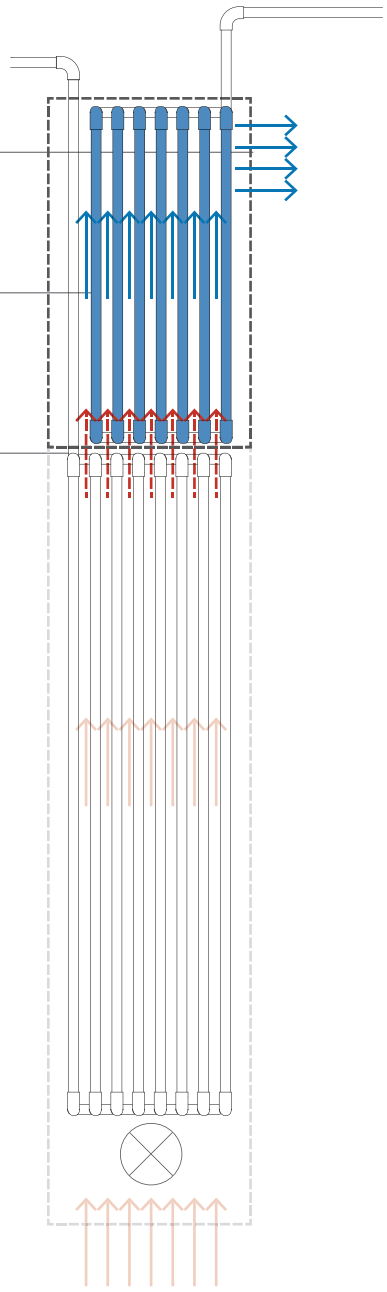
Dehumidi-fication

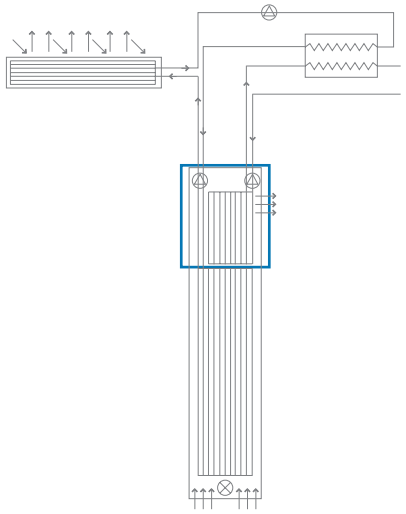
Indirect Evaporative Cooling

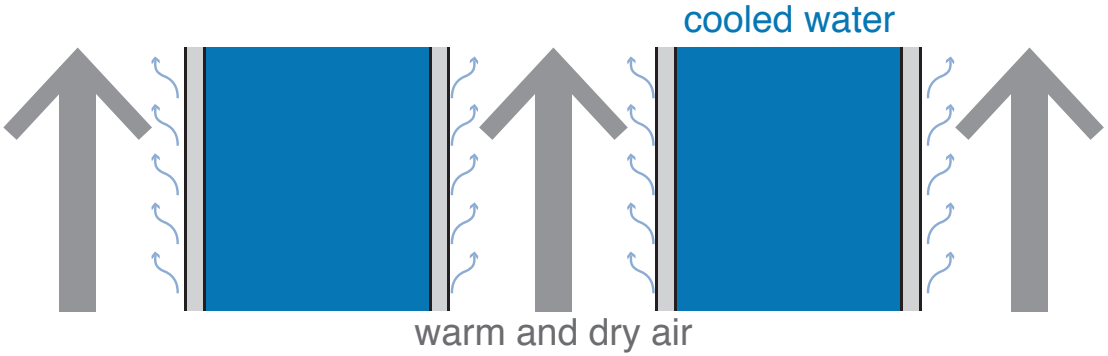
3 outake air
cool and dry air

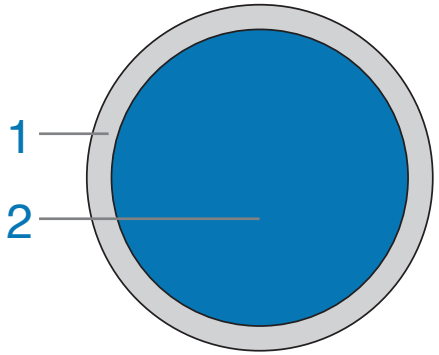
2 indirect evaporative cooling
media

1 intake air
hot and dry air









Indirect evaporative cooling

media

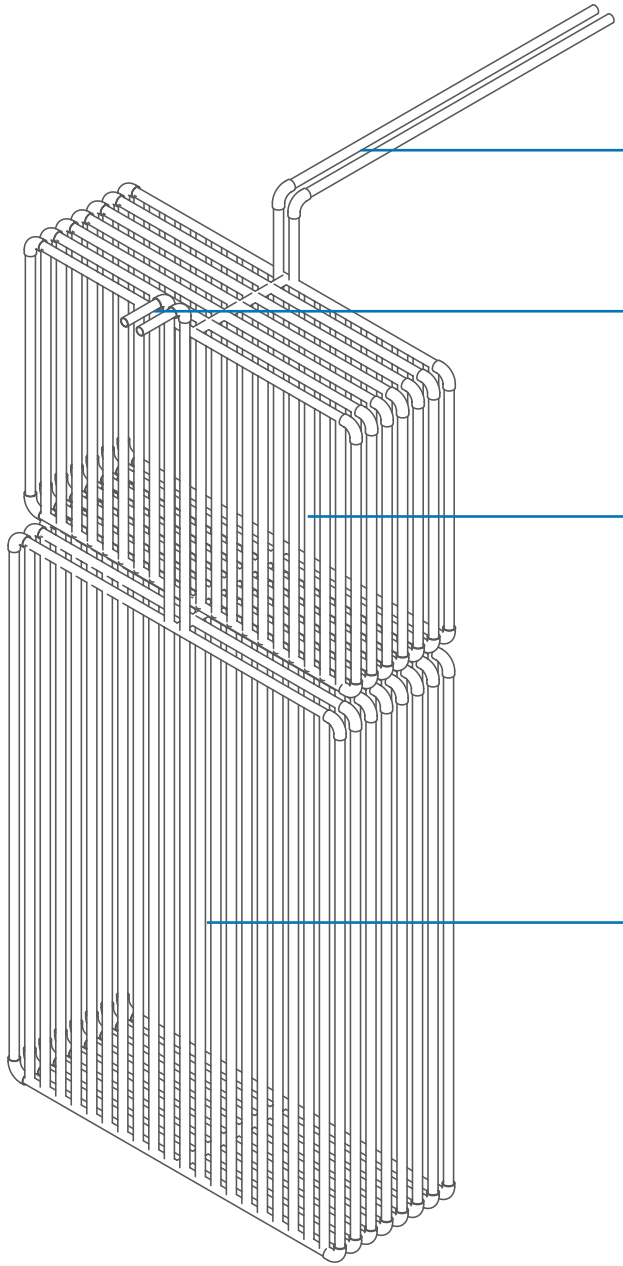
2

cool water

1

Polyphenylene sulfide (PPS)
- lightweight
- thermally conductive

INDIRECT EVAPORATIVE COOLING



to and from centralized supply

to and from the regenerator

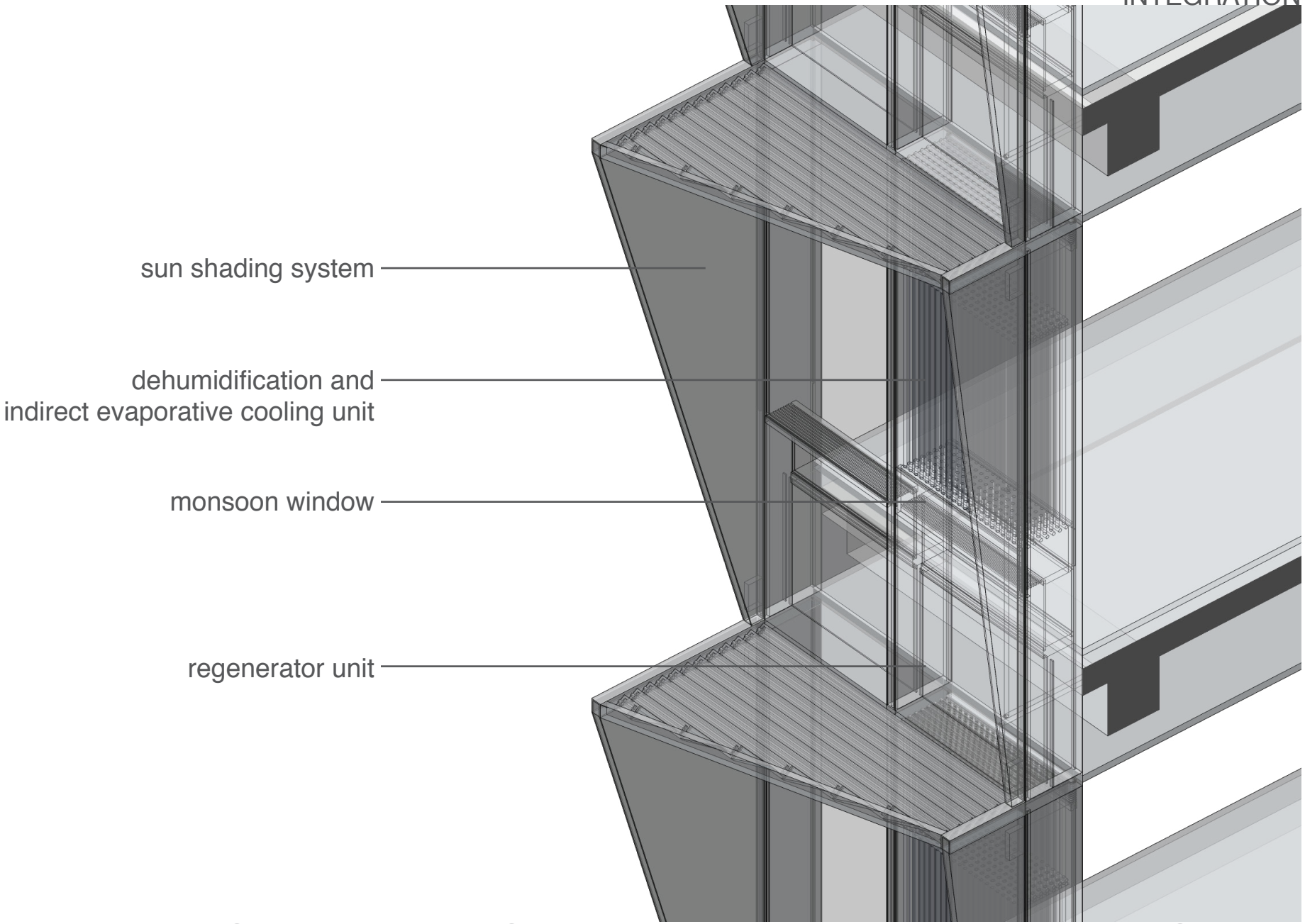
indirect evaporative cooling unit
(154 tubes)

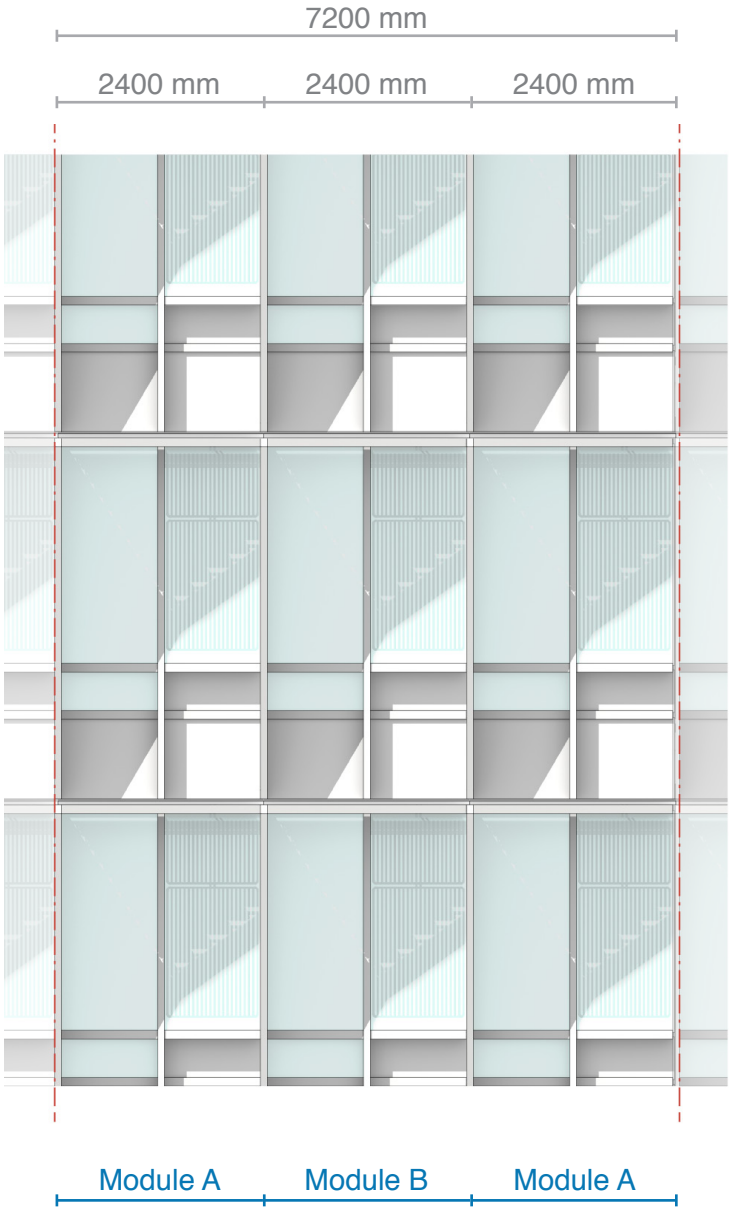
dehumidification unit
(176 tubes)

FACADE

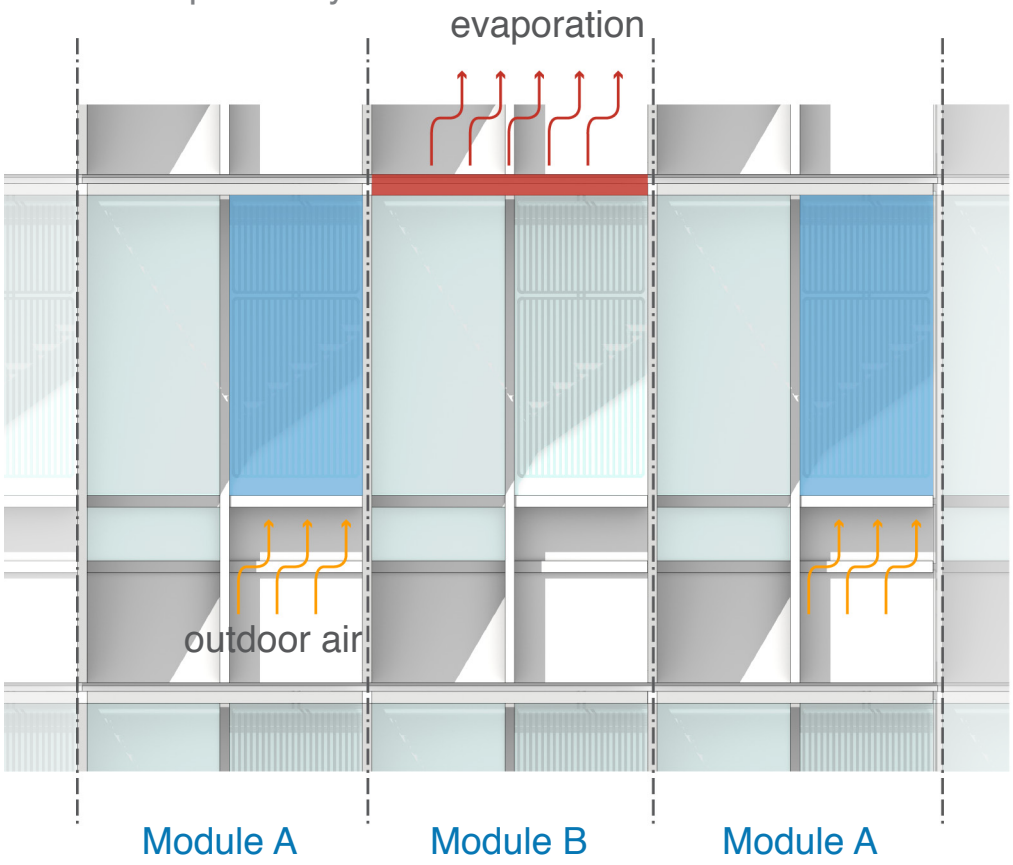
integration

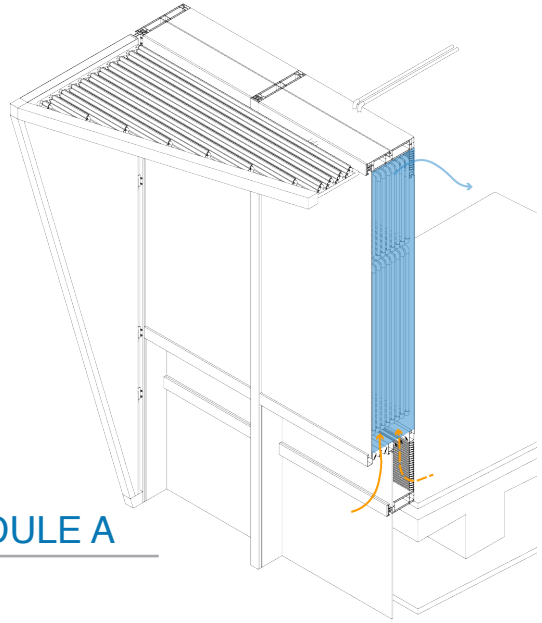
PASSIVE WAY	SUN SHADING device system	
ACTIVE WAY	DEHUMIDIFICATION system	INDIRECT EVAPORATIVE cooling system
TOOLS	LITERATURE studies	BUILDING simulation ENERGY calculation
RESULT	INTEGRATED facade system	


sun shading system
dehumidification and
indirect evaporative cooling unit
monsoon window
regenerator unit

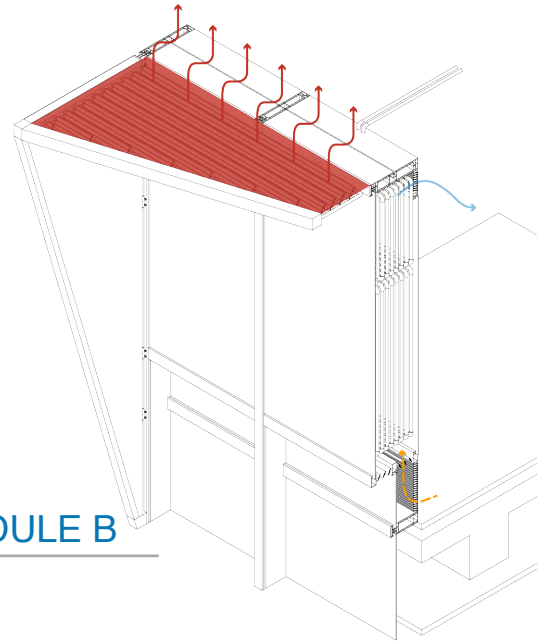

7200 mm
2400 mm
2400 mm
2400 mm
Module A
Module B
Module A

Intake air optional system





50% 50% MODULE A



100% MODULE B

Reduce the risk of a mix intake air between outdoor air and humid air from evaporation

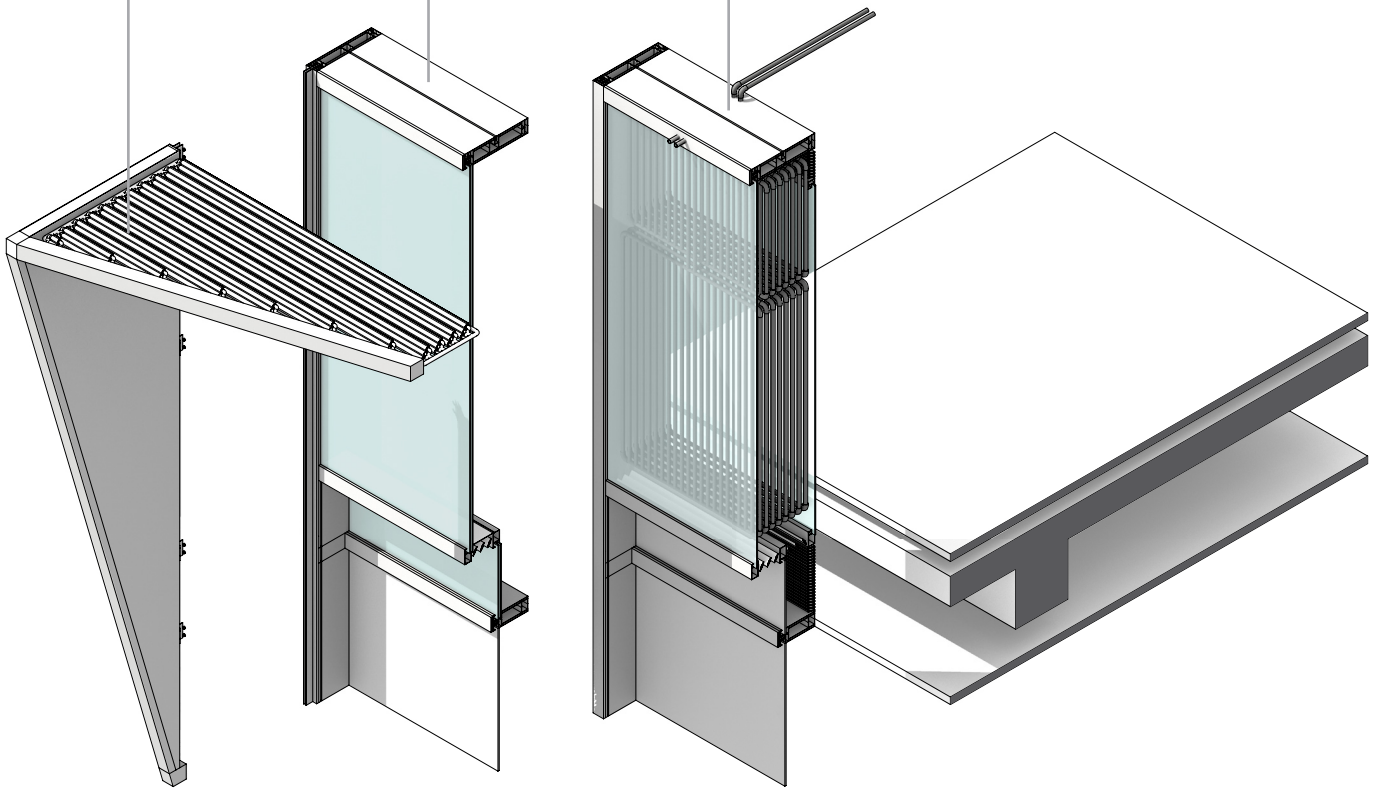
- Indoor Air
- Outdoor Air

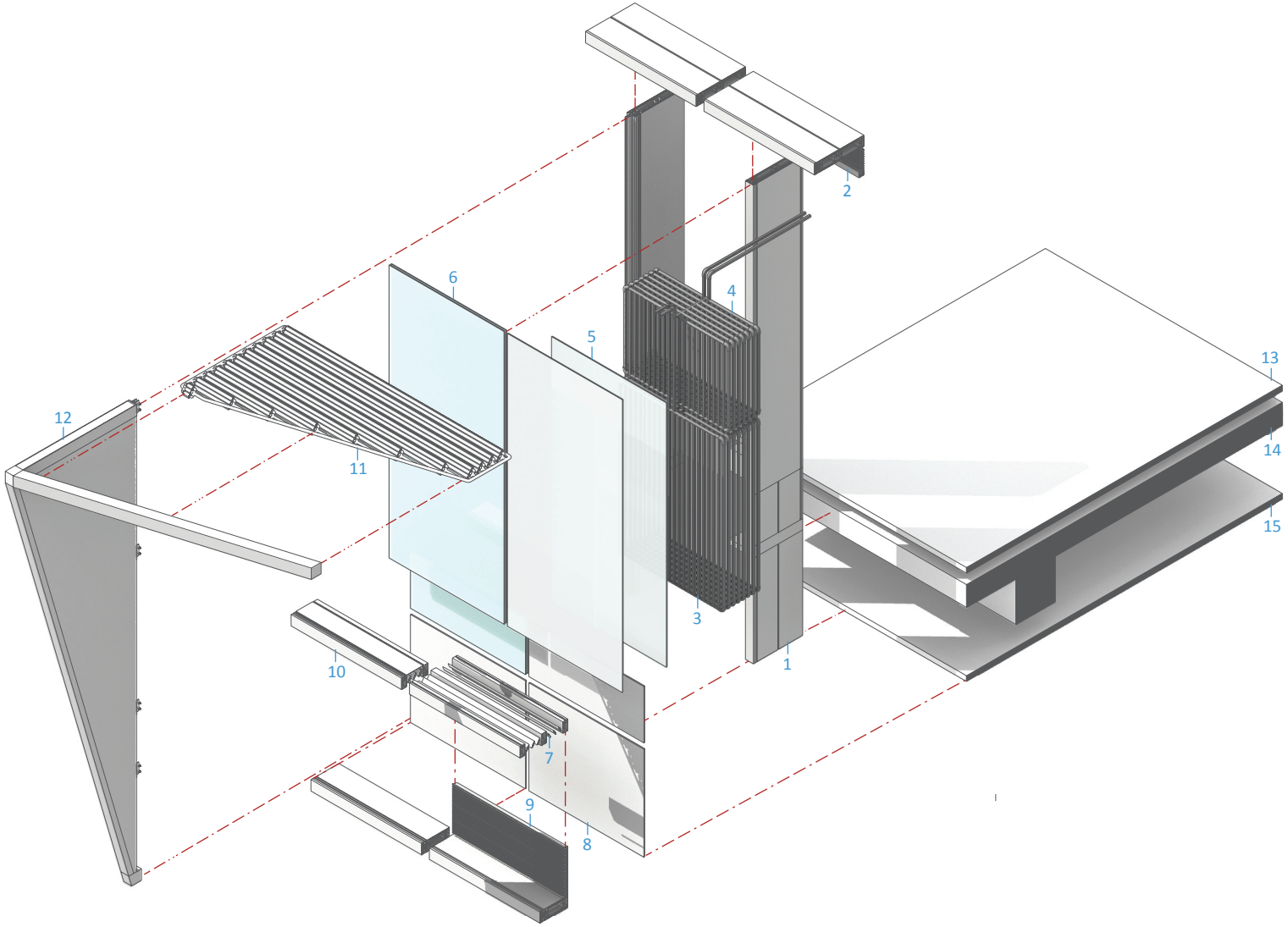
COMPO

Sun shading

Visible

Opaque




1
2
3
4
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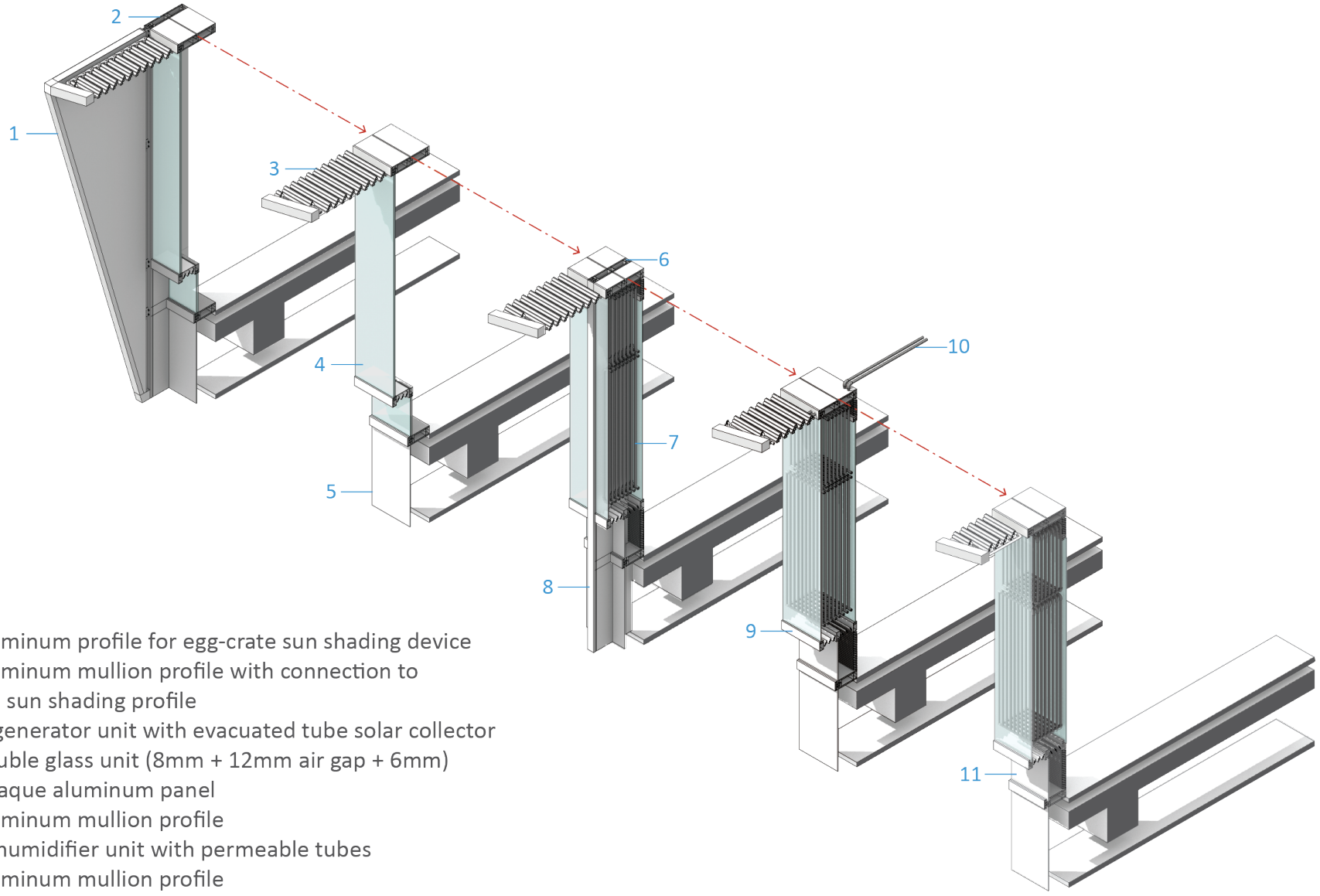
12
13
14
15

EXPLODED VIEW



1 Aluminum profile for egg-crate sun shading device
2 Aluminum mullion profile with connection to the sun shading profile
3 Regenerator unit with evacuated tube solar collector
4 Double glass unit (8mm + 12mm air gap + 6mm)
5 Opaque aluminum panel
6 Aluminum mullion profile
7 Dehumidifier unit with permeable tubes
8 Aluminum mullion profile
9 Aluminum transom profile
10 Pipe to and from heat exchanger for cool water
11 Opaque aluminum panel

monsoon window for intake air

indoor intake air

floor structure

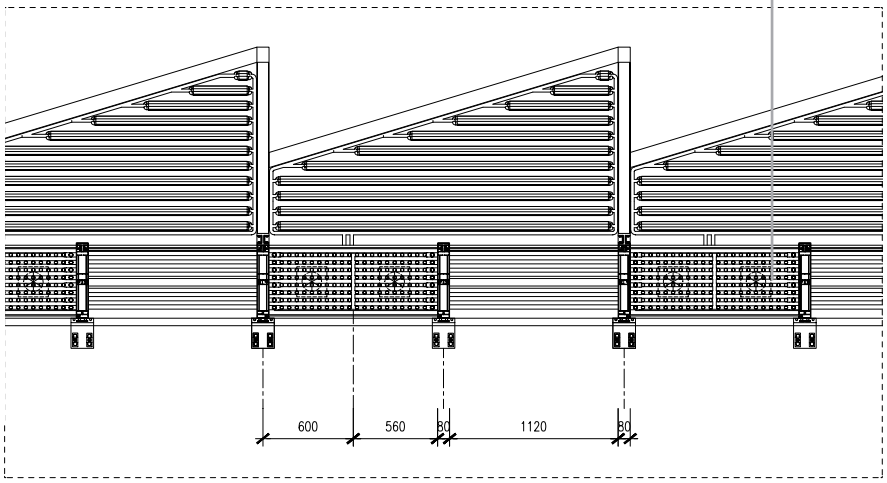
integrated sun shading and regenerator unit

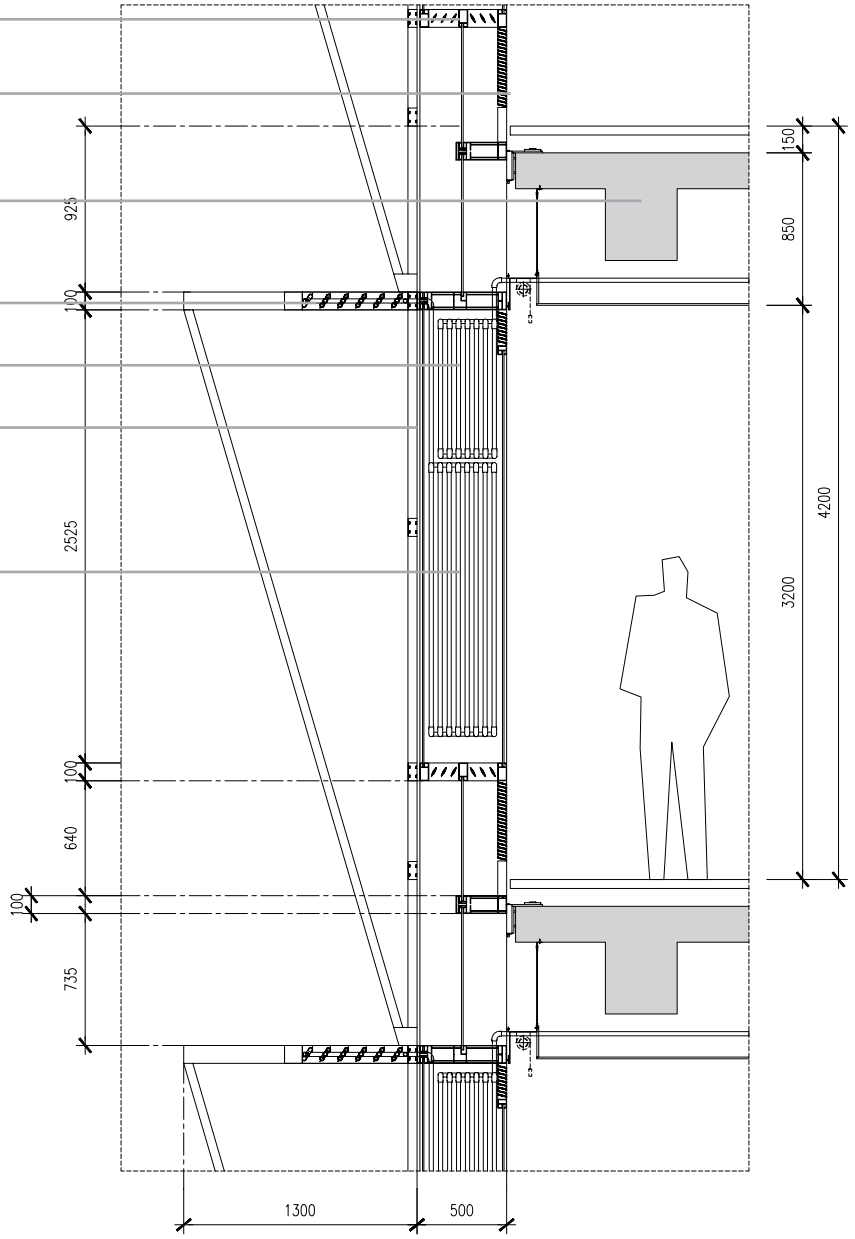
indirect evaporative cooling unit

opaque panel

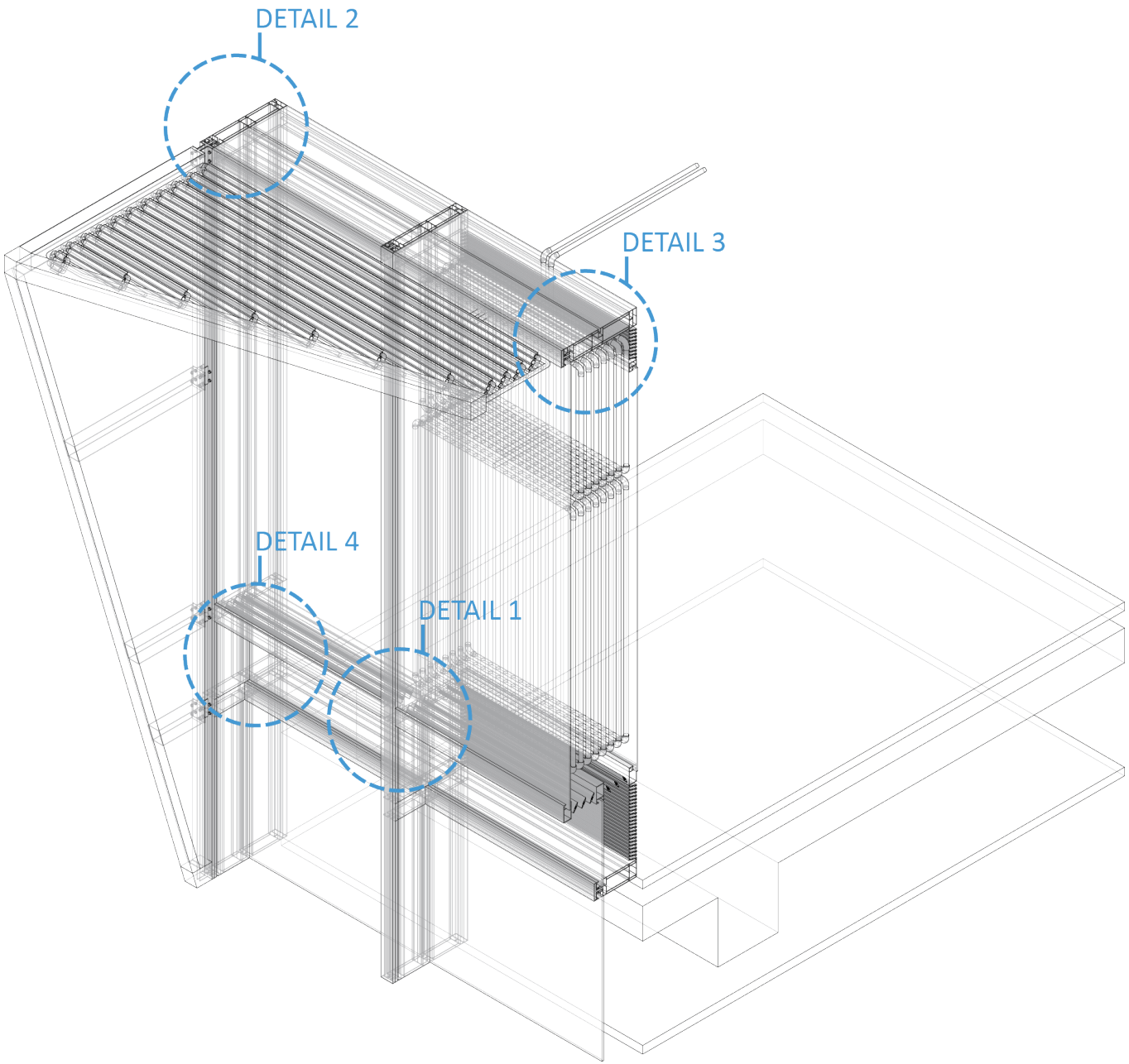
dehumidification unit

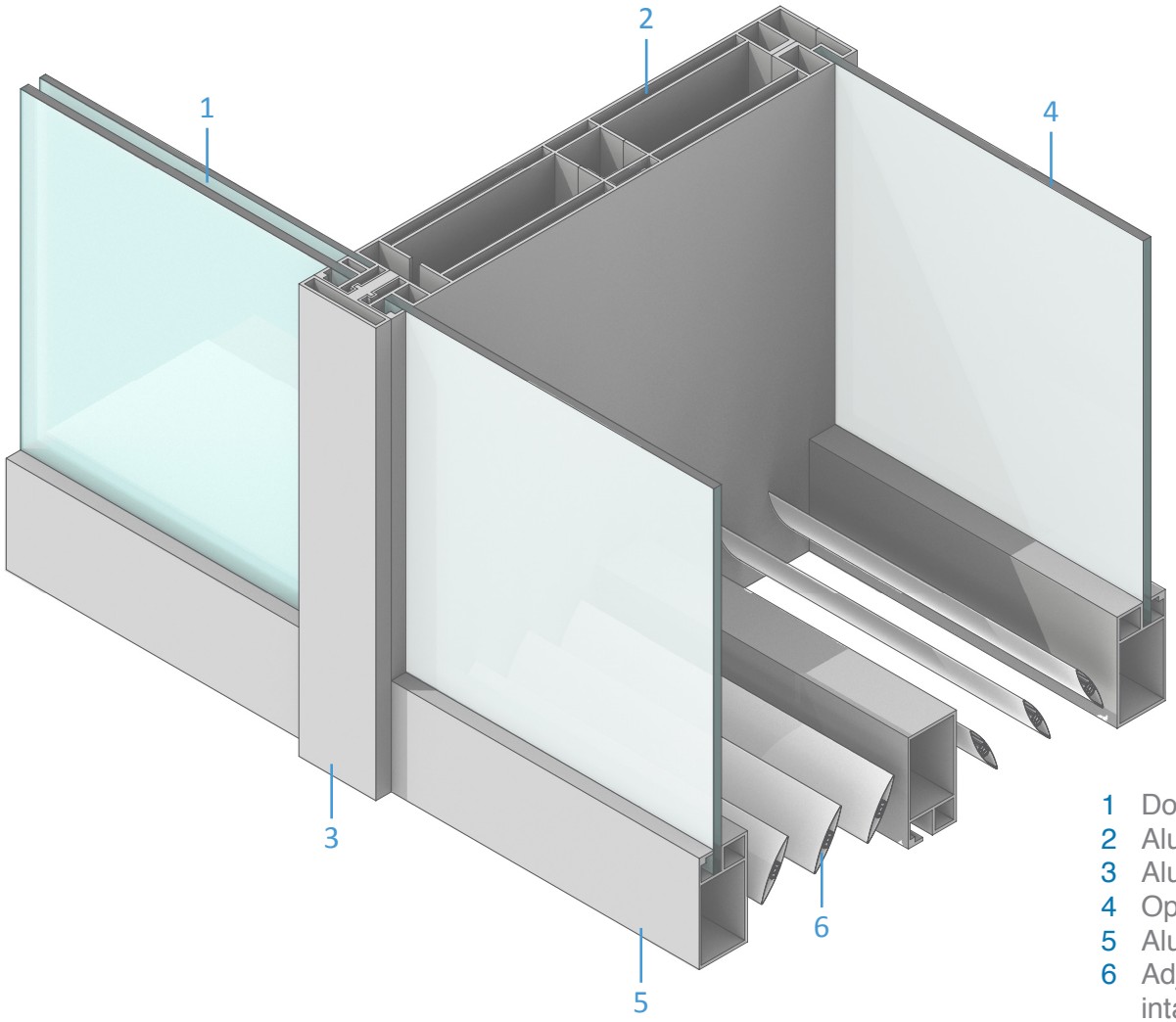
fan unit



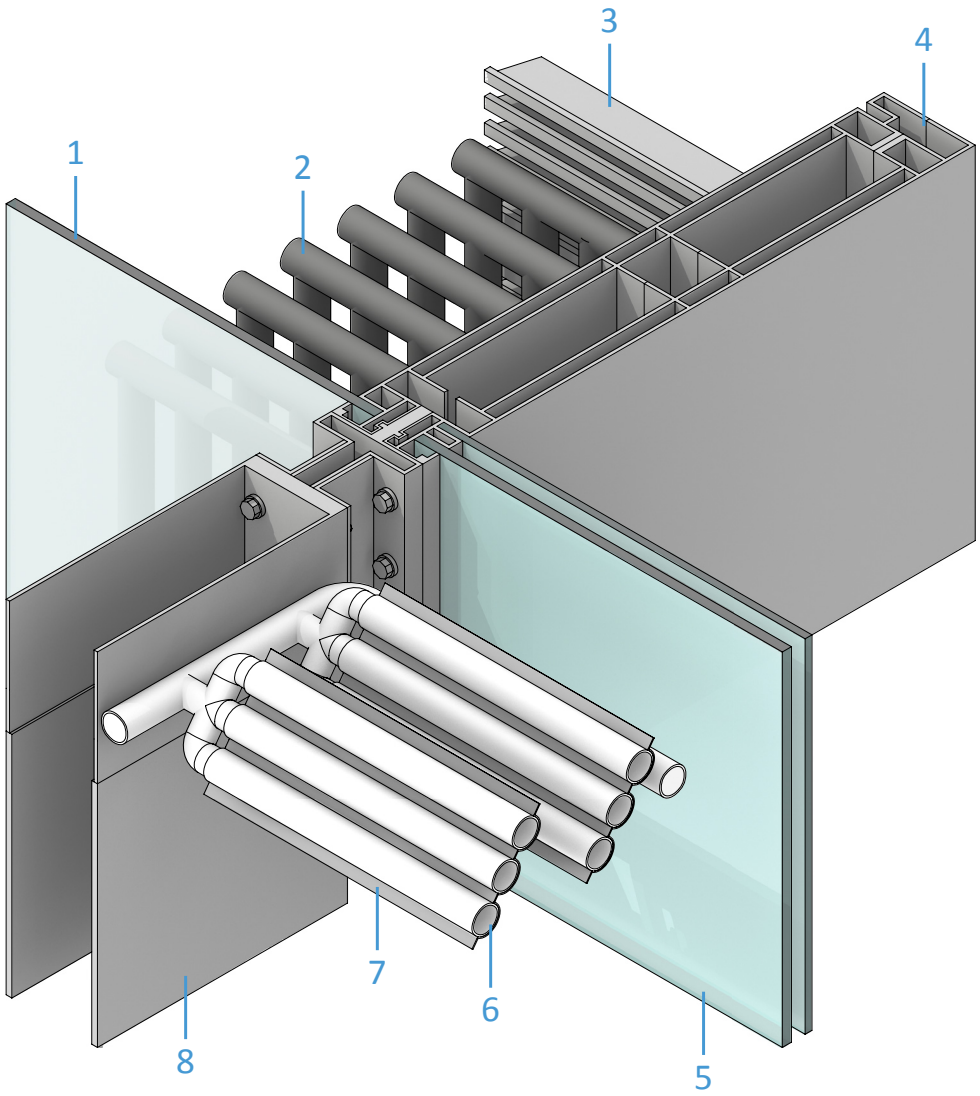


DETAILS

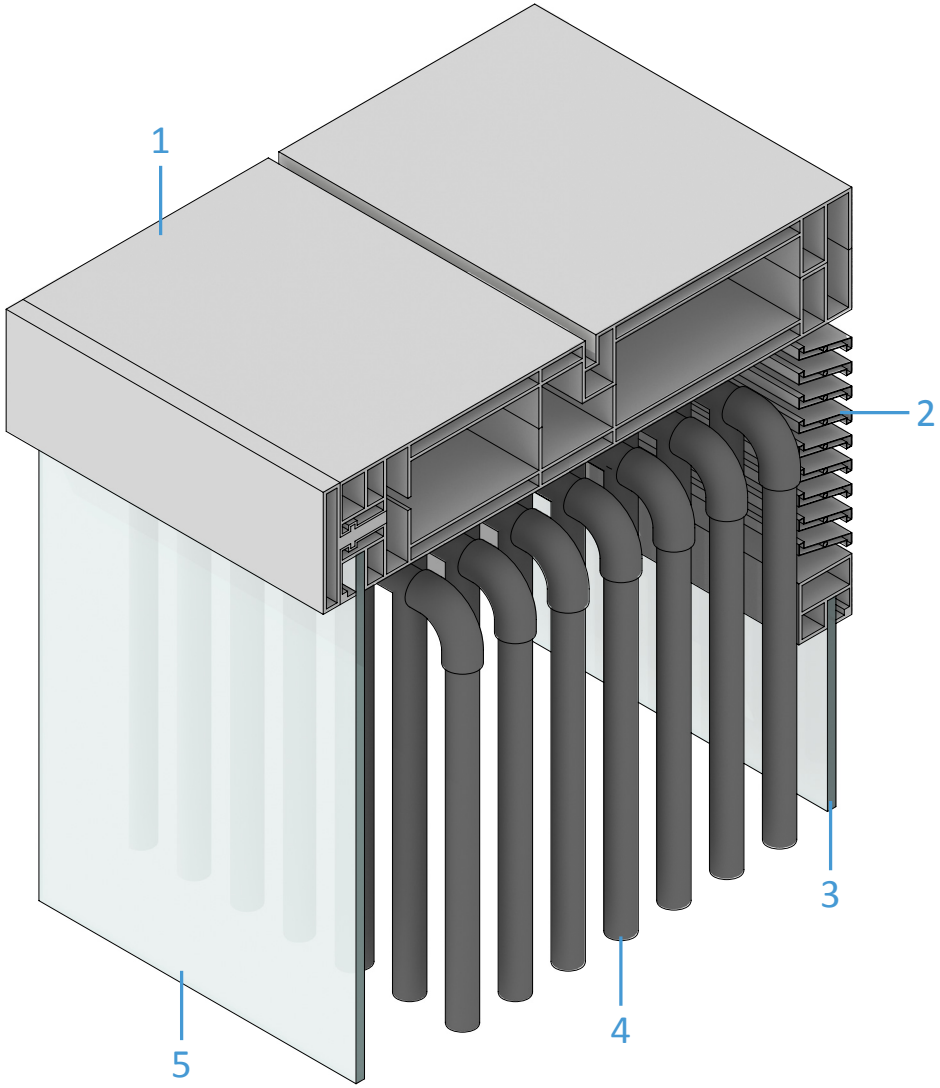

DETAIL 2
DETAIL 3
DETAIL 4
DETAIL 1



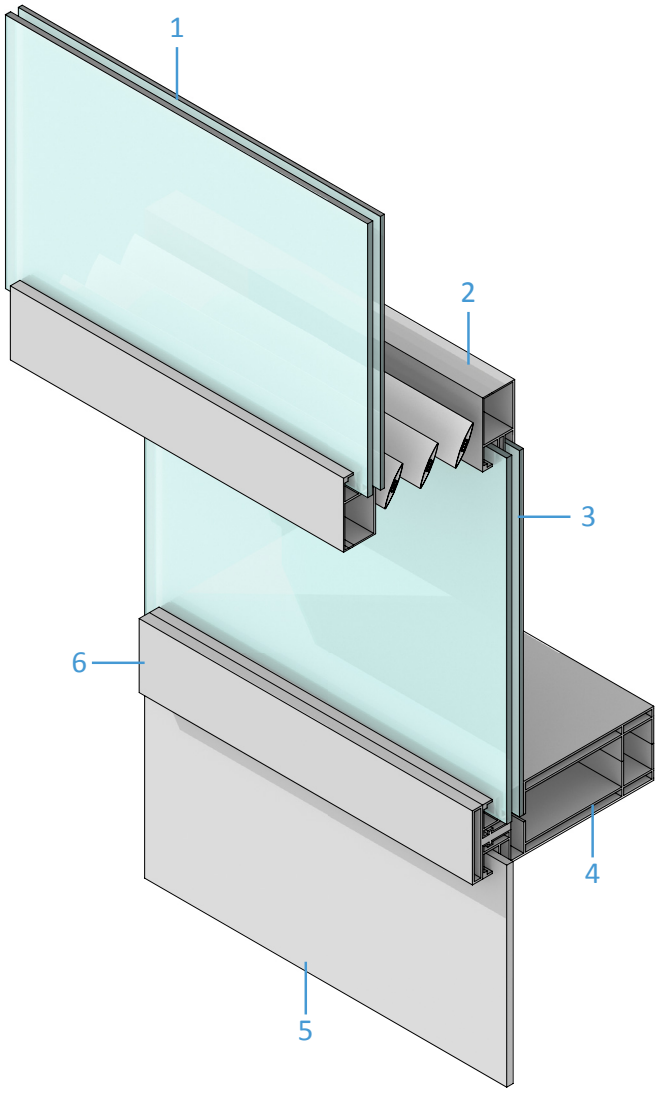
1 Double glass unit (8mm + 12mm air gap + 6mm)
2 Aluminium mullion profile
3 Aluminium mullion profile cap
4 Opaque panel 8mm
5 Aluminium transom profile
6 Adjustable aluminium grill for dehumidification intake air (monsoon window)



1 Opaque panel 8mm
2 Microporous polypropylene tube
3 Aluminium grill for outake air to indoor space
4 Aluminium mullion profile
5 Double glass unit (8mm + 12mm air gap + 6mm)
6 Regenerator unit
7 Sun shading louver
8 Aluminium profile for sun shading panel



1 Aluminium transom profile
2 Aluminium grill for outake air to indoor space
3 Opaque panel 8mm (inner pane)
4 Microporous polypropylene tube
5 Opaque panel 8mm (outer pane)



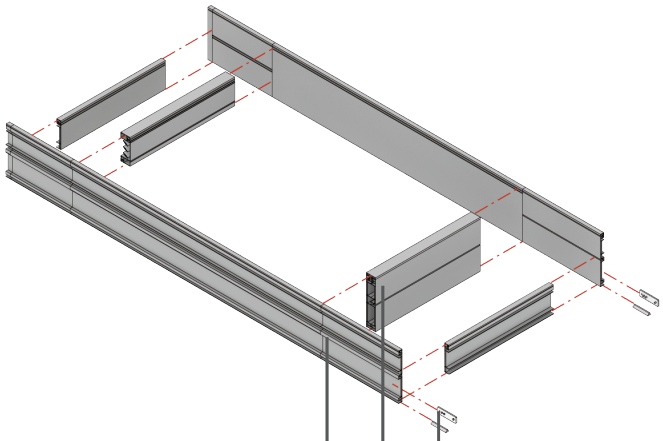
1 Double glass unit (8mm + 12mm air gap + 6mm)
2 Aluminium transom profile
3 Double glass unit (8mm + 12mm air gap + 6mm)
4 Aluminium transom profile
5 Aluminium composite panel
6 Aluminium transom cap profile

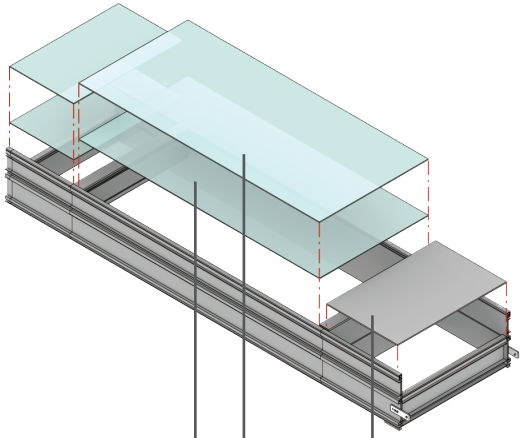
ASSEMBLY PROCESS

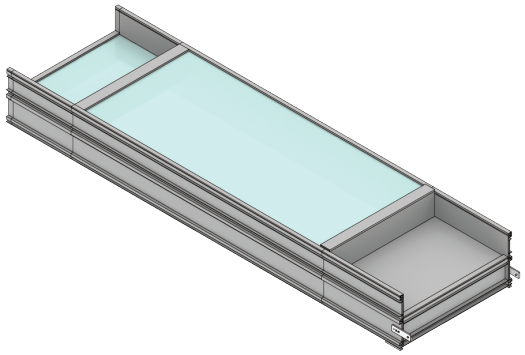
Component 1

assembly process

1 2 3







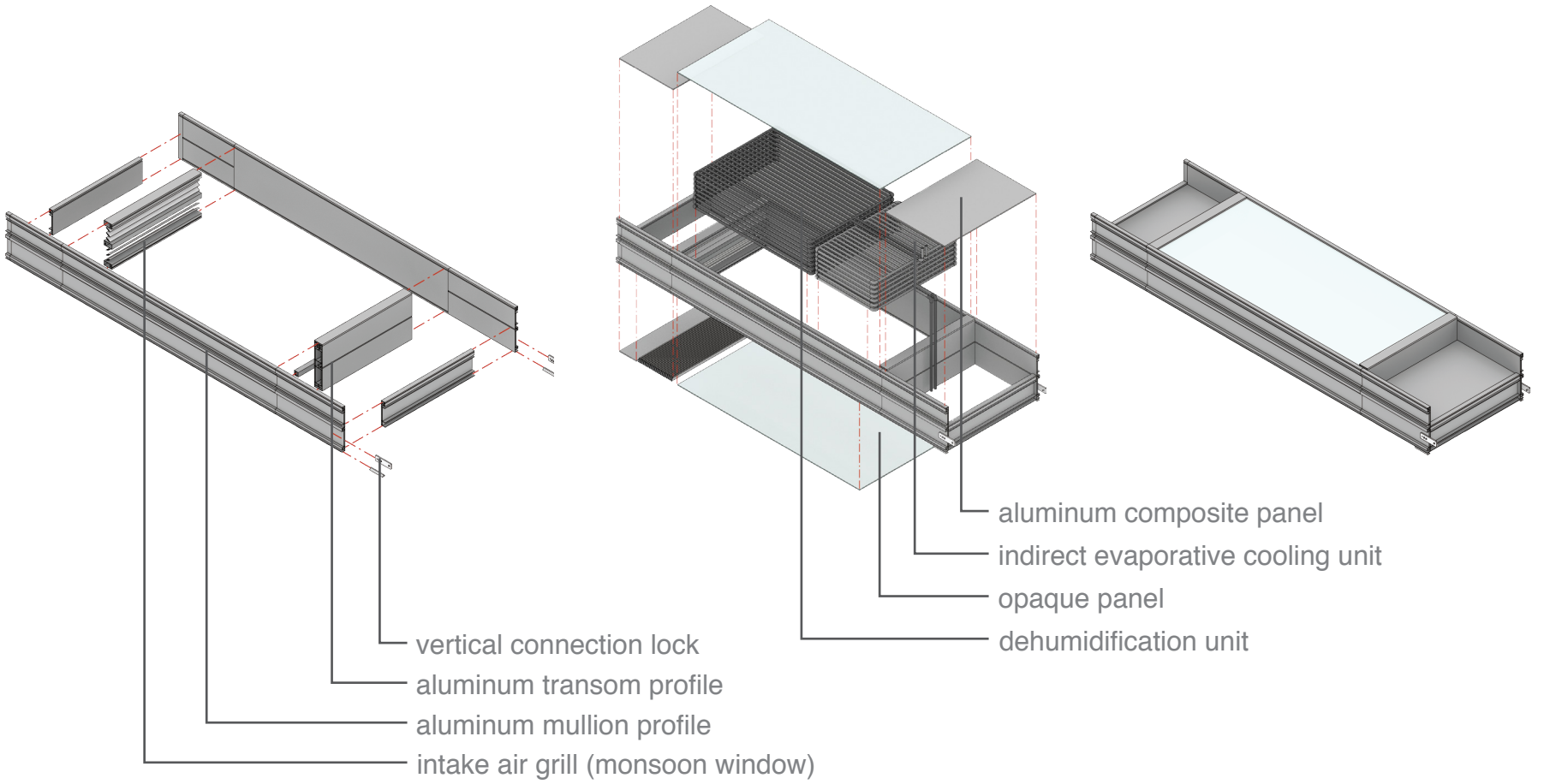
aluminum composite panel
clear glass (8mm)
clear glass (6mm)

vertical connection lock
aluminum transom profile
aluminum mullion profile

Component 2

assembly process

1 2 3

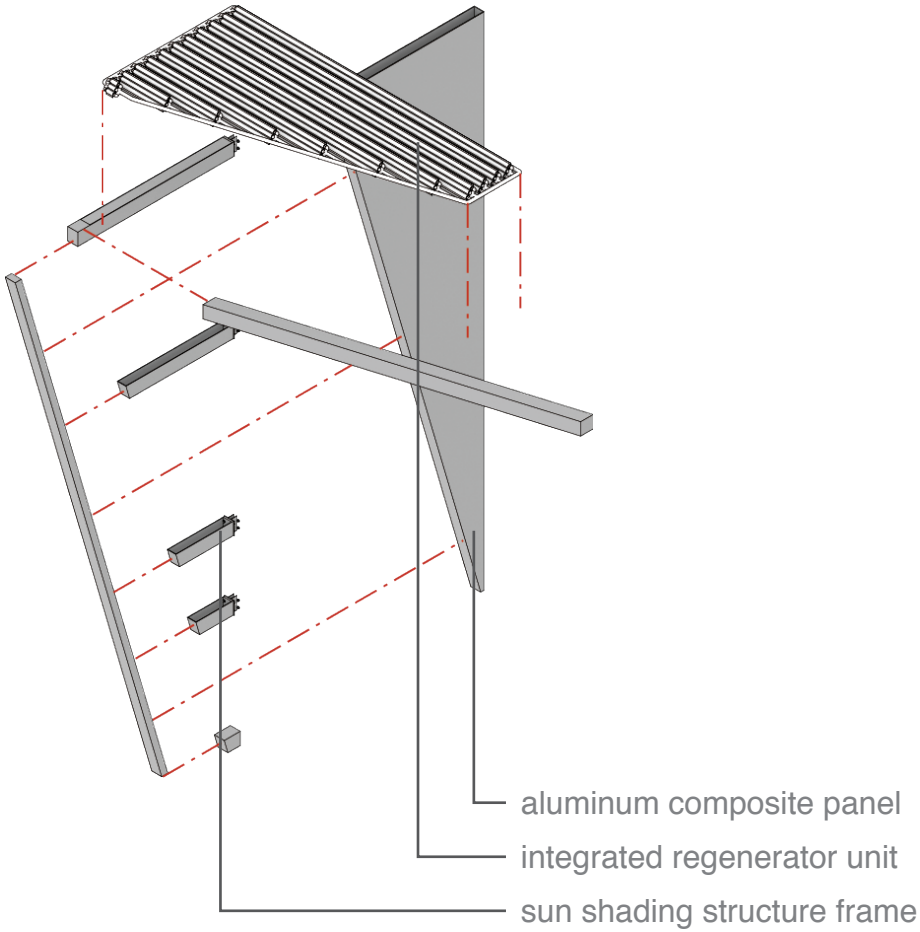


Component 3

assembly process

1

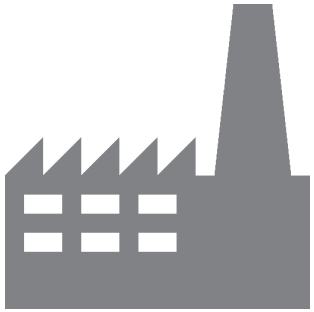
2

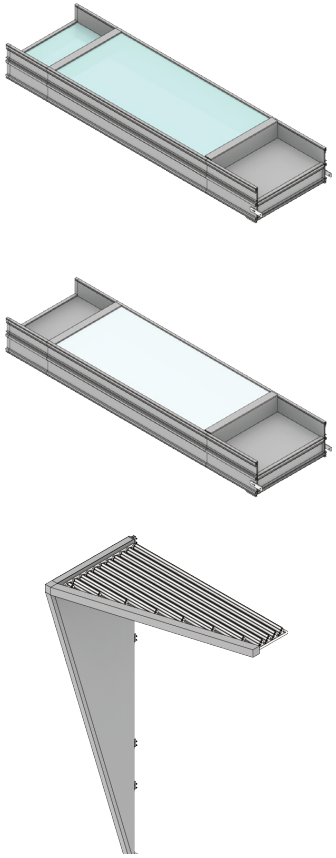


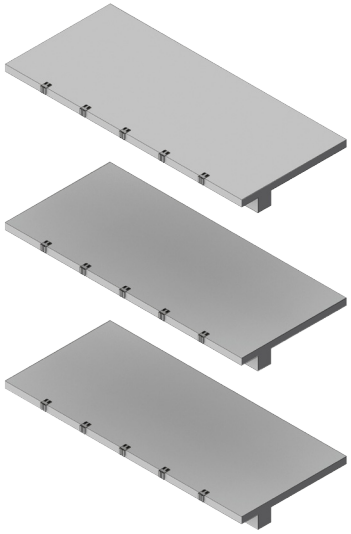
Pre-assembled

manufacture and transportation

1 2 3



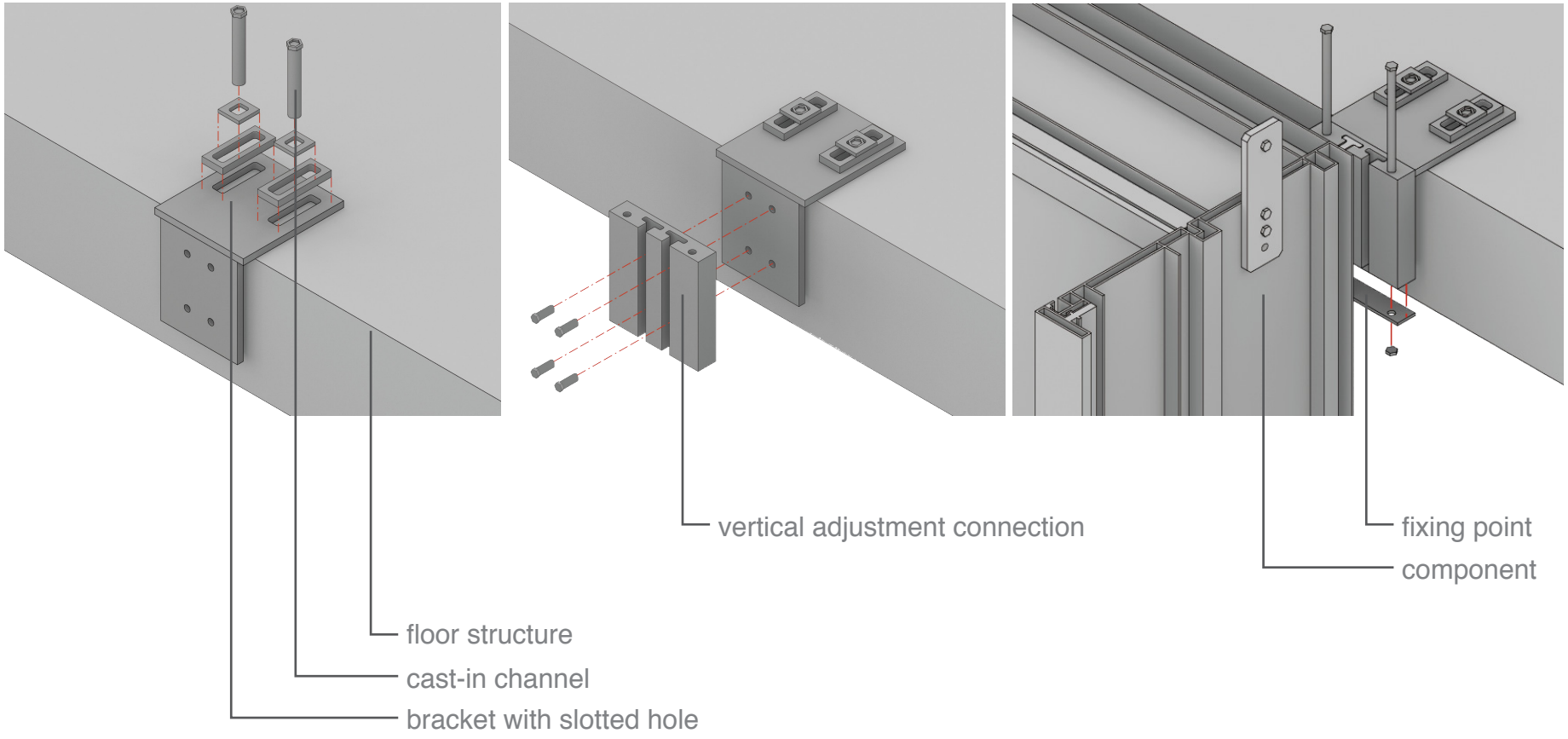




On-site

bracket fixing

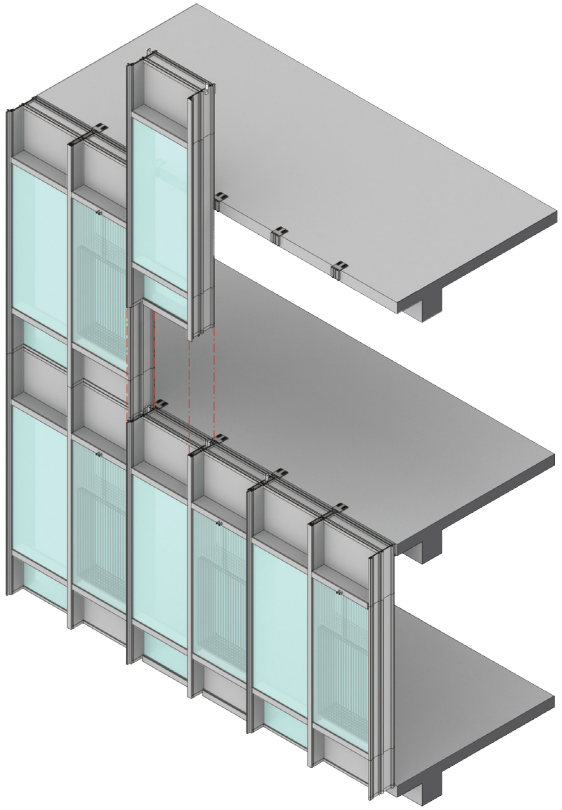
1 2 3



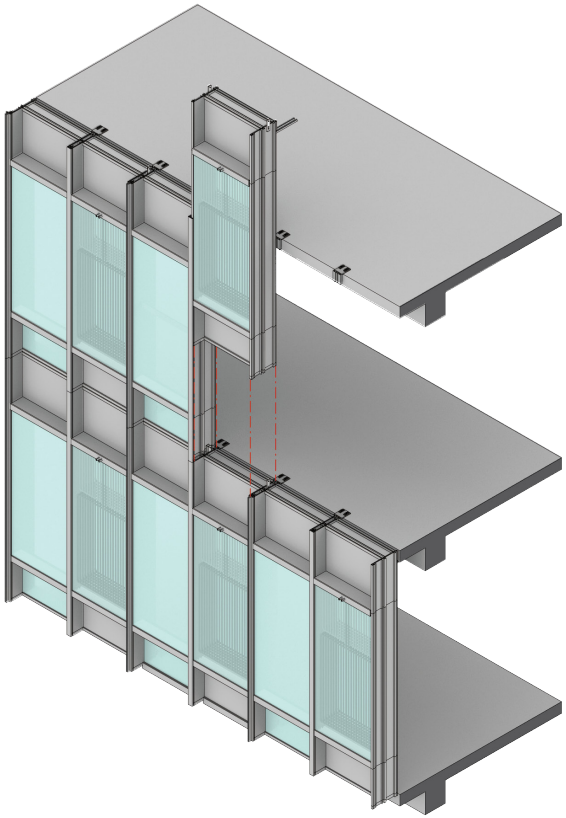
On-site

assembly process

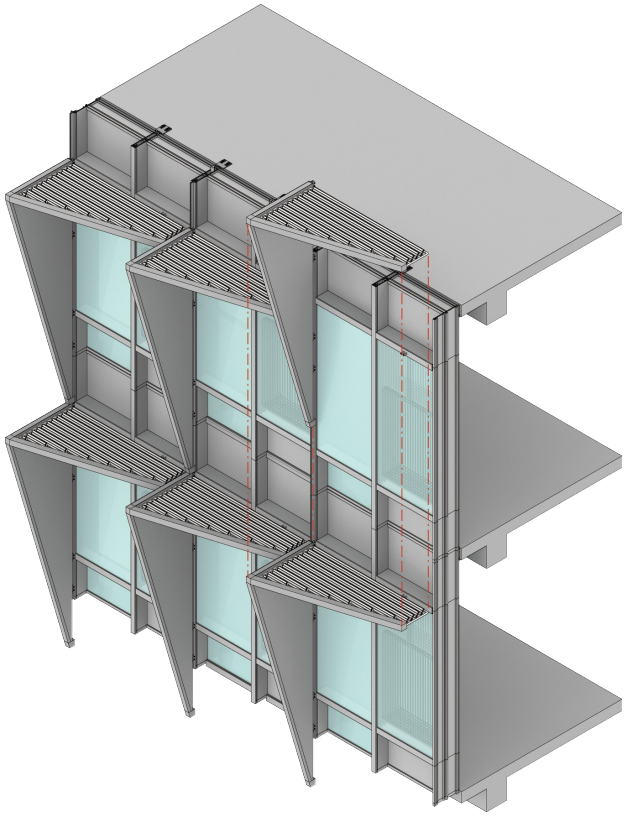
1

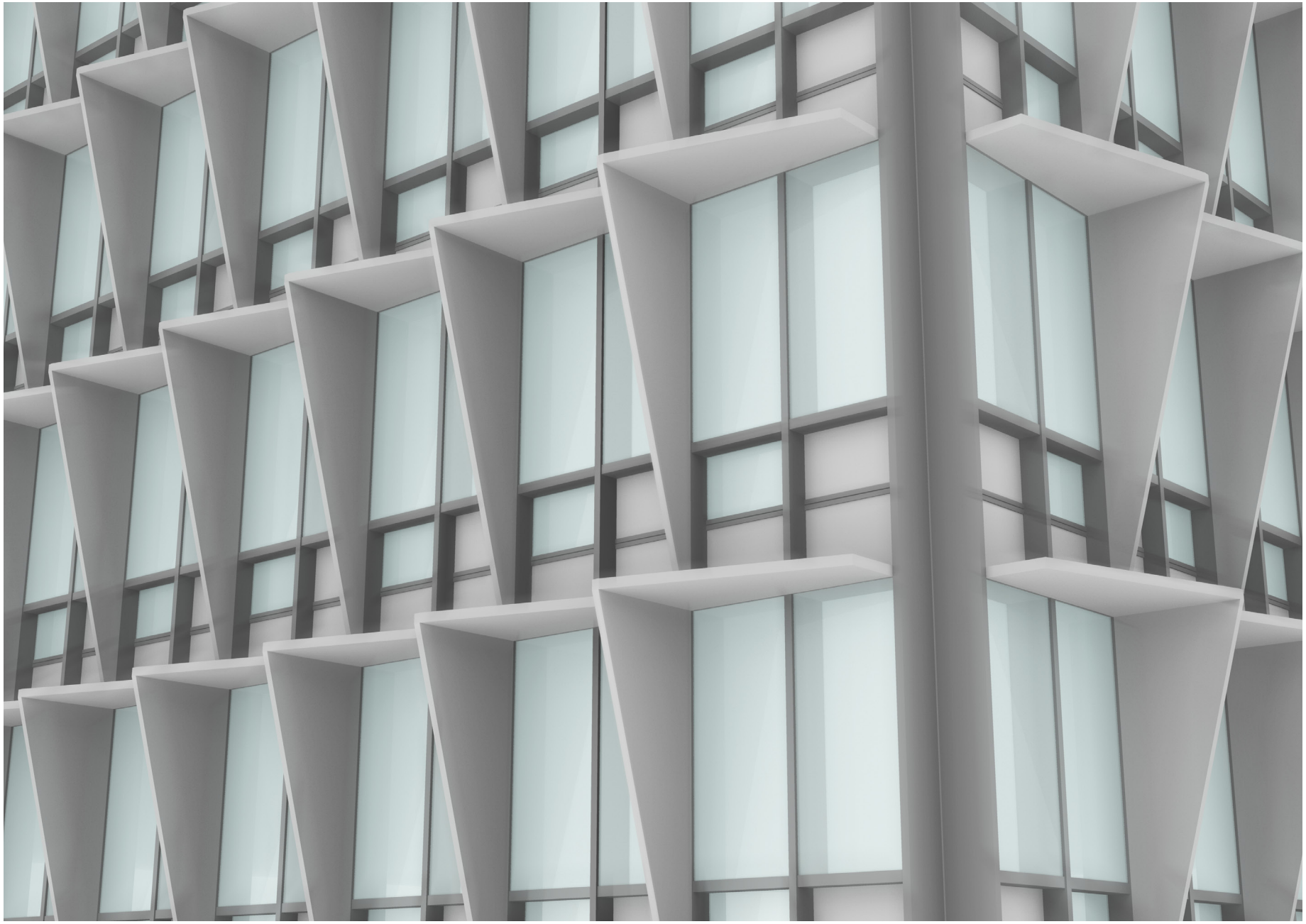


2



3

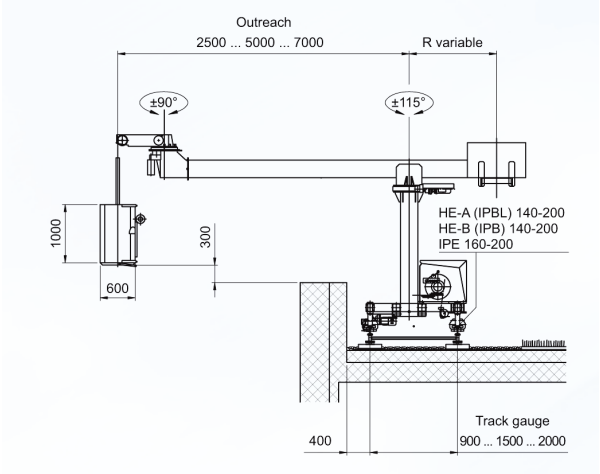




Building Maintenace Unit

Compact Crane Type

adaptable to non-flat building
max.reach of 6.5m

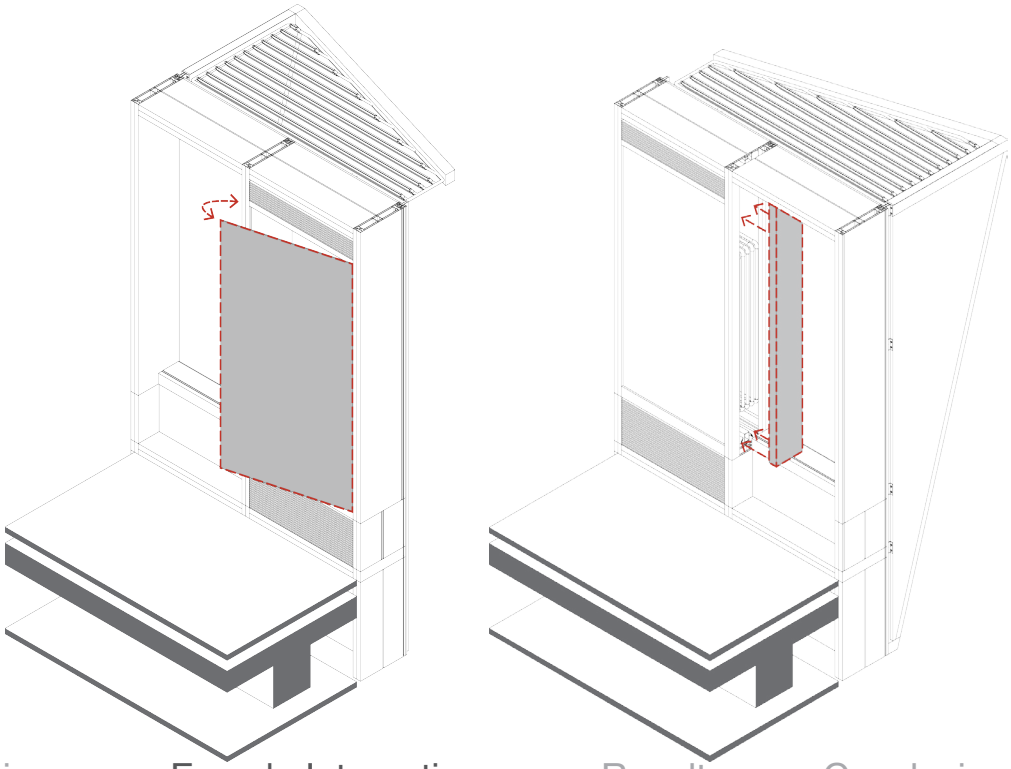


2 OUTDOOR

Maintenance

process

1 INDOOR

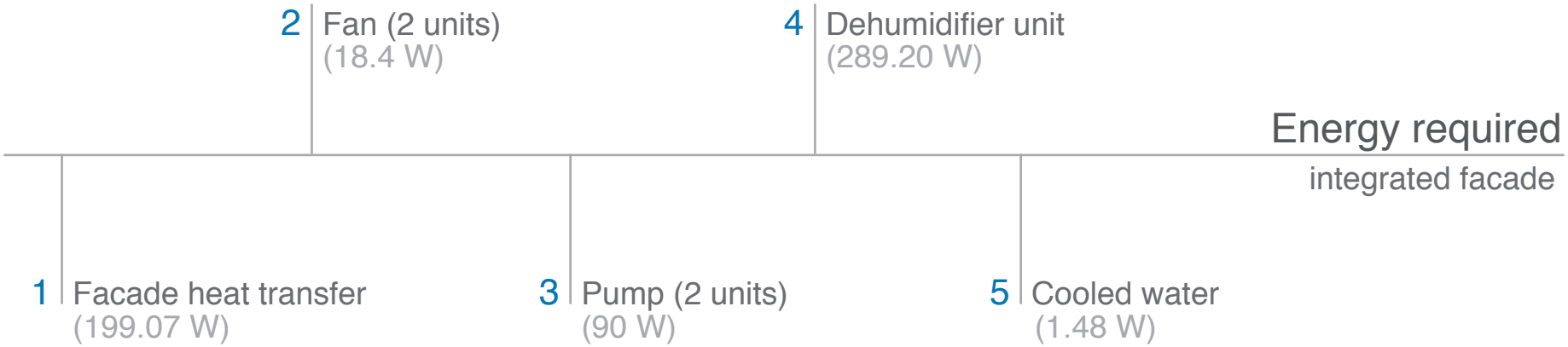


SIMULATION AND CALCULATION

analysis

PASSIVE WAY	SUN SHADING device system	
ACTIVE WAY	DEHUMIDIFICATION system	INDIRECT EVAPORATIVE cooling system
TOOLS	LITERATURE studies	BUILDING simulation ENERGY calculation
RESULT	INTEGRATED facade system	

ENERGY CALCULATION



(2041.49 Btu/h)

598.15 W

$H_{facade} + H_{fan} + H_{pump} + H_{dehumidifier} + H_{cooled\ water}$

required energy for integrated facade

(6000 Btu/h)

1758.42 W

required energy for air conditioning

1/3

compared to required energy for air conditioning

BUILDING SIMULATION

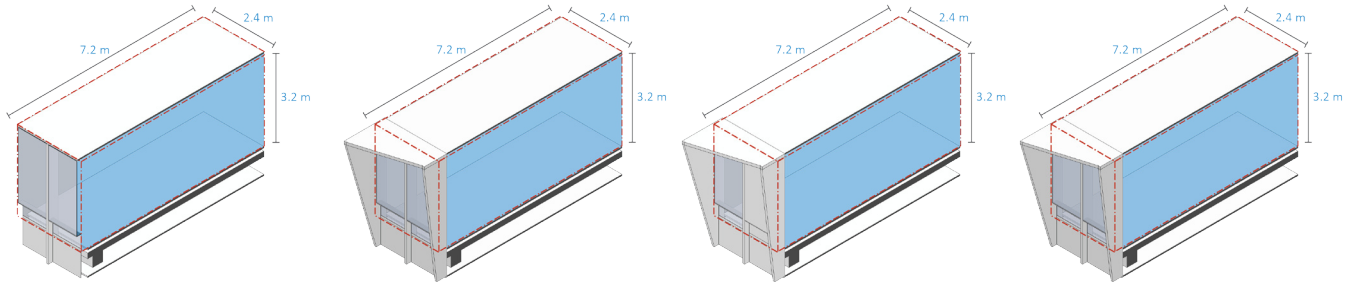
CONDITION

Orientation	Simulation date	Working hours	Set point temperature	Set point %RH
West	21 June	08:00-18:00	26.5°C	60 %

Models

settings

1 2 3 4

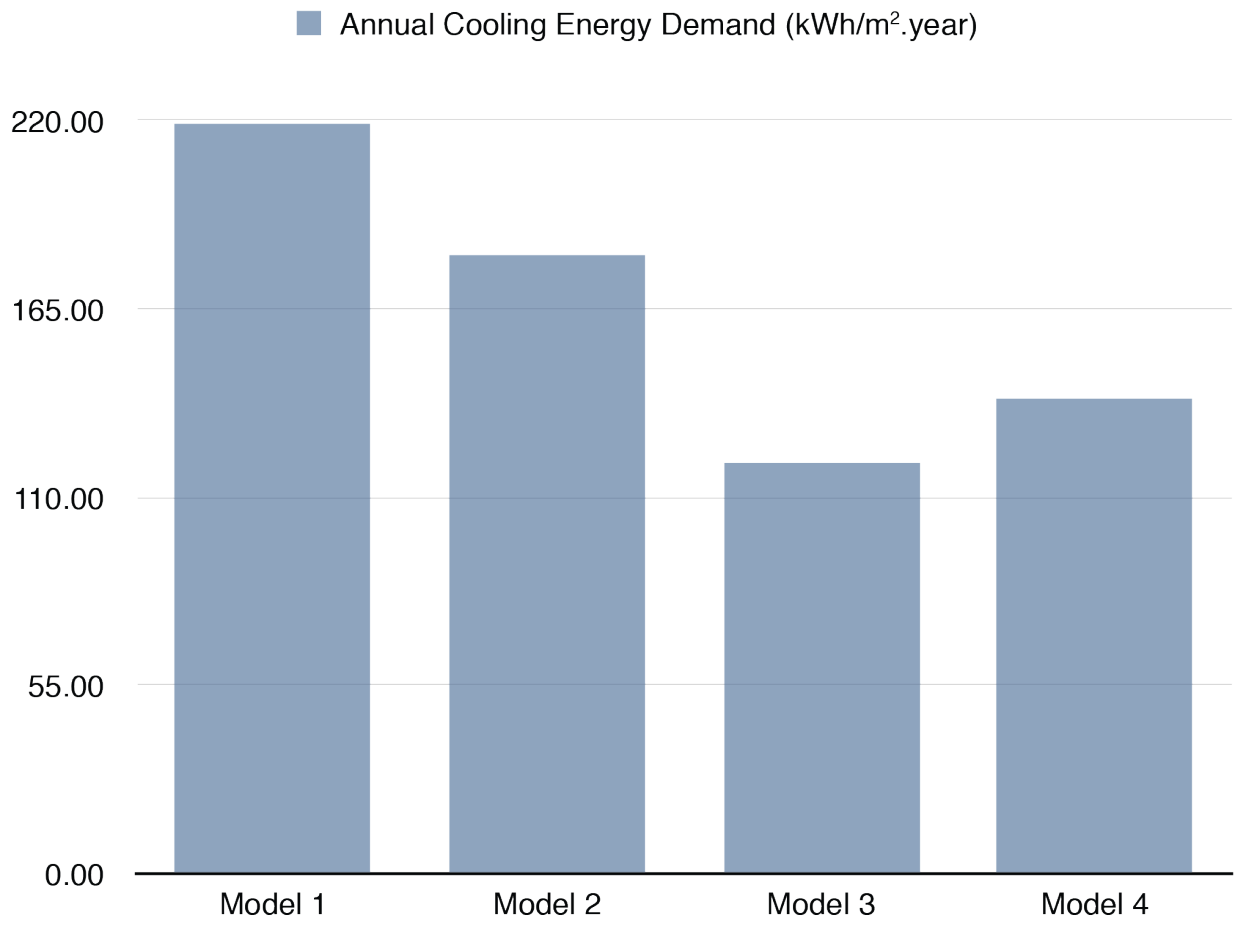


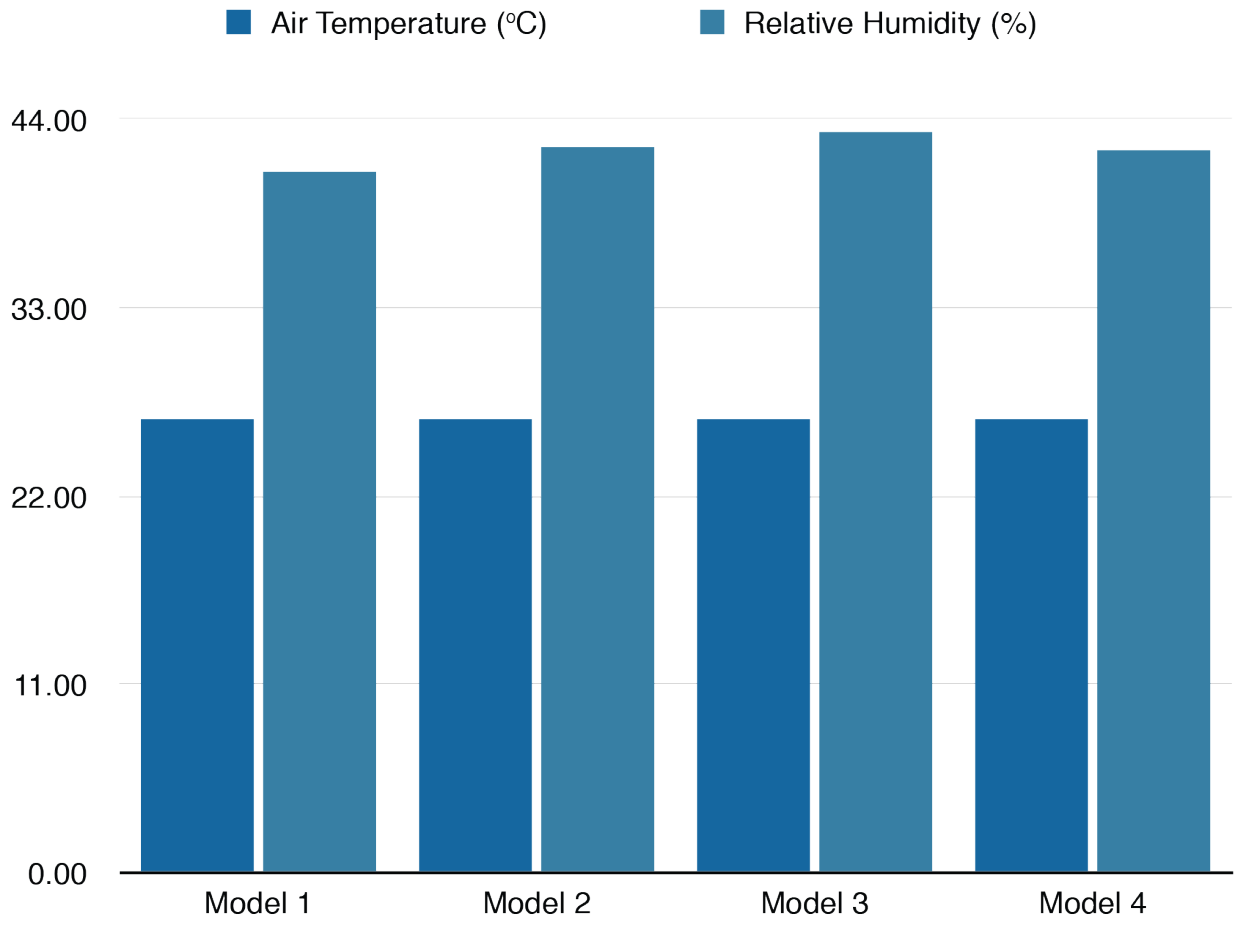
	Model 1	Model 2	Model 3	Model 4
Sun Shading Device	Not Applied	Applied	Applied	Applied
Window to Wall Ratio	32%	32%	16%	32%
External Windows	Double clear glass (6mm/13mm air)	Double clear glass (6mm/13mm air)	Double clear glass (6mm/13mm air)	Double tinted glass (6mm/13mm air)
HVAC Template	Fan-coil unit	Fan-coil unit	None	None
Mechanical Ventilation	On	On	Off	Off

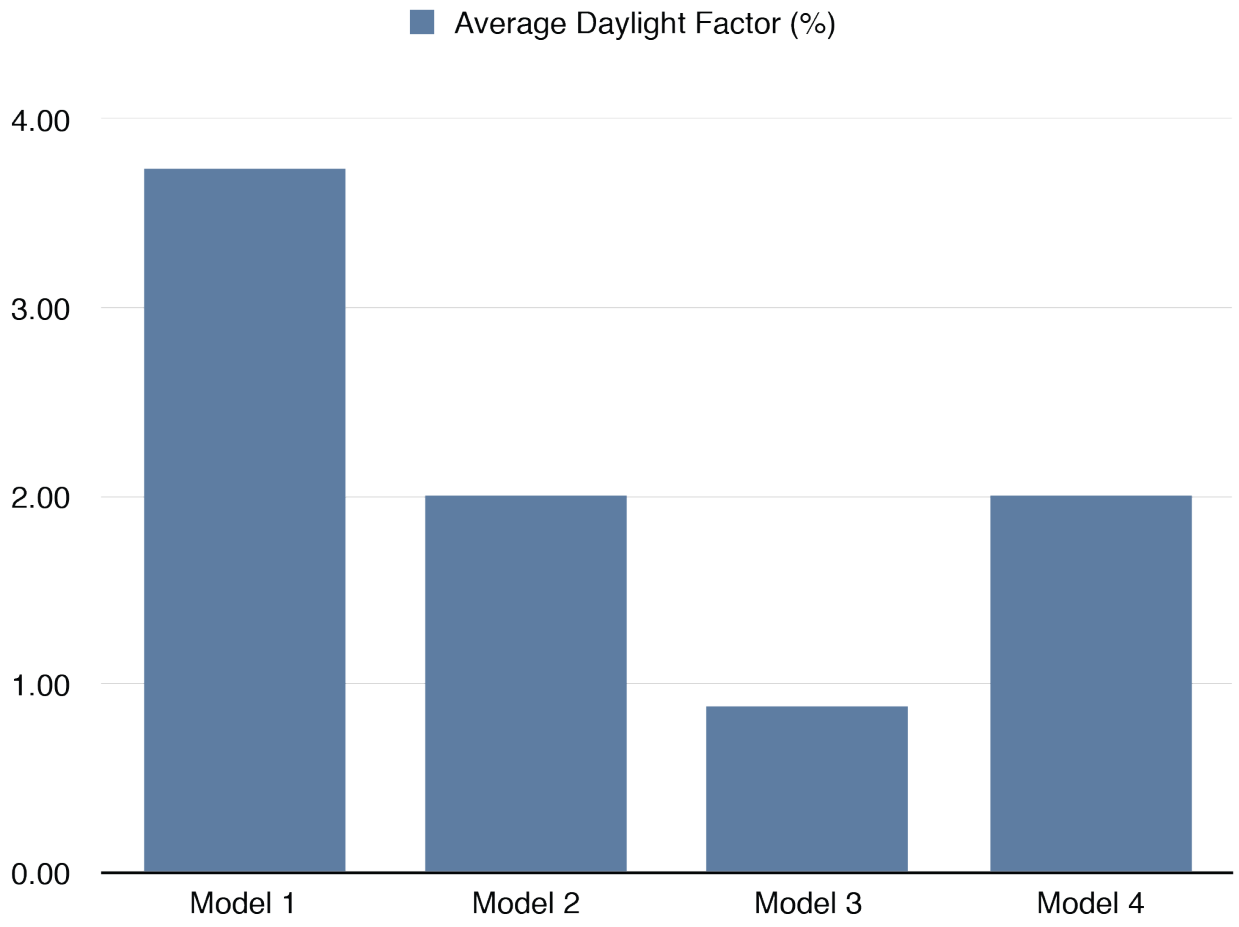
Summary

results

		Model 1	Model 2	Model 3	Model 4
Total Cooling Load	(kW)	3.11	2.57	1.71	1.97
Annual Cooling Energy Demand	($kWh/m^2.year$)	218.97	180.95	120.40	138.71
Relative Humidity	(%)	40.90	42.40	43.20	42.20
Max. Operative Temp. in Day	(^oC)	31.10	30.60	30.40	30.50
Average Daylight Factor	(%)	3.74	2.01	0.89	2.01
Maximum Illuminance	(lux)	2094.97	1401.09	1154.28	1313.22


Annual Cooling Energy Demand (kWh/m².year)
220.00
165.00
110.00
55.00
0.00
Model 1
Model 2
Model 3
Model 4

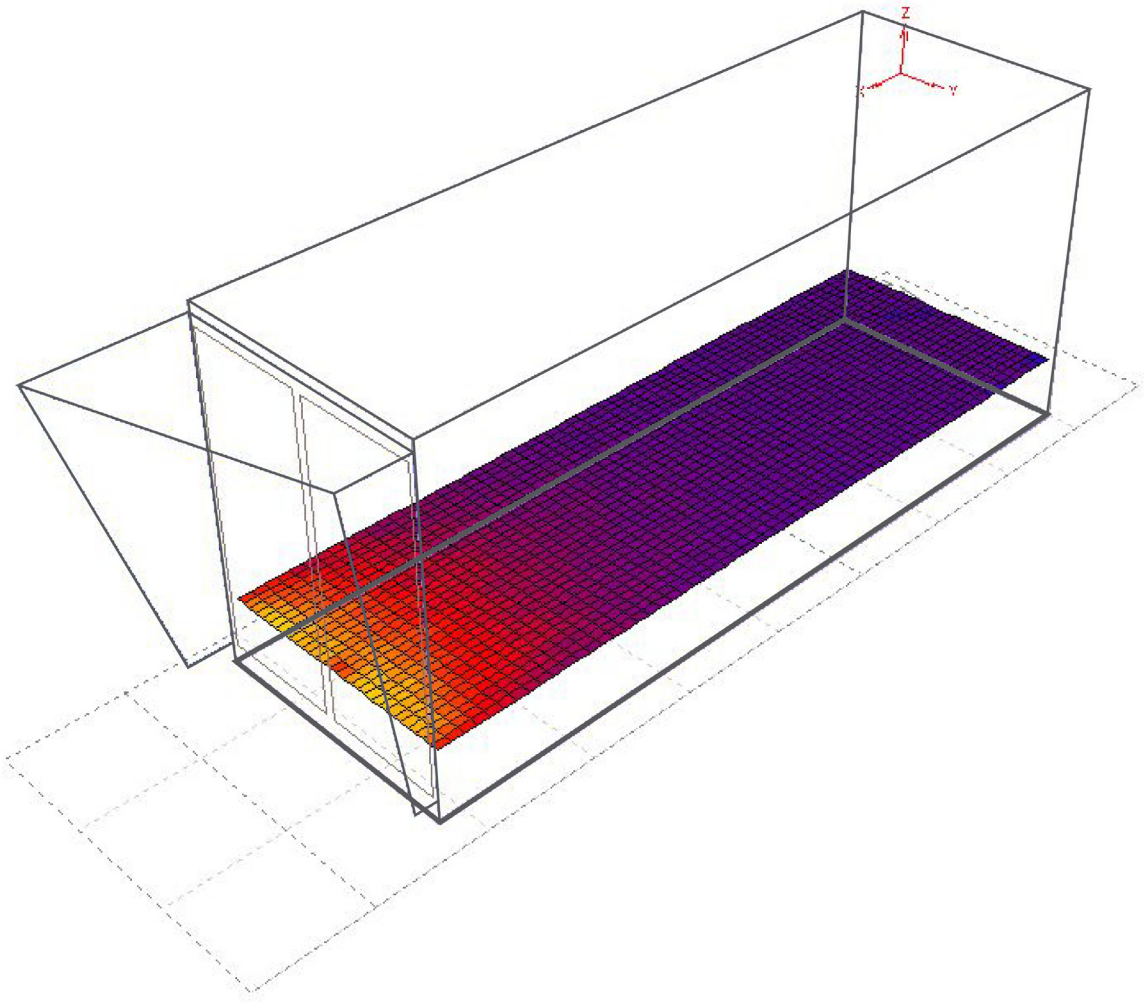

Air Temperature (°C)
Relative Humidity (%)
44.00
33.00
22.00
11.00
0.00
Model 1
Model 2
Model 3
Model 4

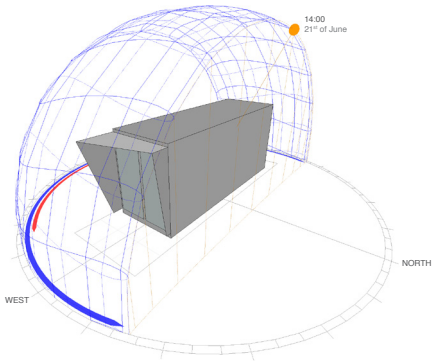

Average Daylight Factor (%)
4.00
3.00
2.00
1.00
0.00
Model 1
Model 2
Model 3
Model 4

Model 4

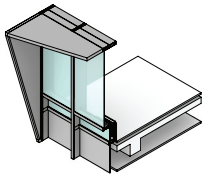
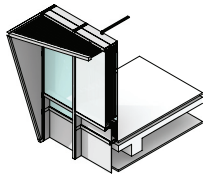
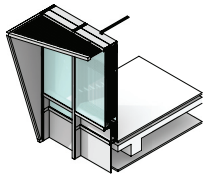
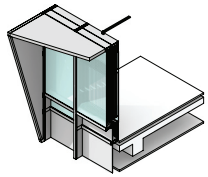
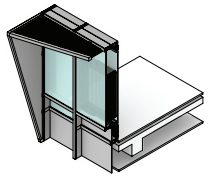
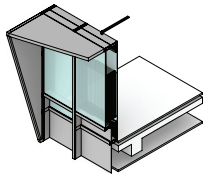
daylighting level

1440+
1320
1200
1080
980
840
720
600
480
360
240





CONCLUSION

	Option 0	Option 1	Option 2	Option 3	Option 4	Option 5
						
Sun Shading Device	applied	applied	applied	applied	applied	applied
Dehumidification	integrated in HVAC	applied	applied	applied	applied	applied
Indirect Evaporative Cooling	by vapor compression AC	applied	applied	applied	by vapor compression AC	by vapor compression AC
Regenerator Unit	not available	integrated (1/5)	integrated (1/5)	centralized	integrated (1/5)	centralized
Visual Comfort	+	-	+	+	+	+
Energy Performance	75% cooling energy demand	45% cooling load reduction	37% cooling load reduction	regeneration units require more space	better cooling performance	better cooling performance
		(better efficiency for DIEC)	(less efficiency for DIEC)	(less efficiency for DIEC)	(less efficiency for Dehumidification)	(less efficiency for Dehumidification)
Maintenance and Assembly	+++	-	-	+	-	++
Floor to Floor Height	> 4.5 m	≤ 4.5 m	≤ 4.5 m	4.5 m	> 4.5 m	> 4.5 m

There are several possible building strategies both active and passive way that are able to tackle the high cooling energy demand in high rise office building in hot and humid climate

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The integration between strategies can be accomplished under several conditions and requirements which resulted in difference level of performance

CLIMATE

Cooling and dehumidification
96.4%

Sun shading devices
60.9%

BUILDING STRATEGIES

Egg crate sun shading device
efficient shape and dimension

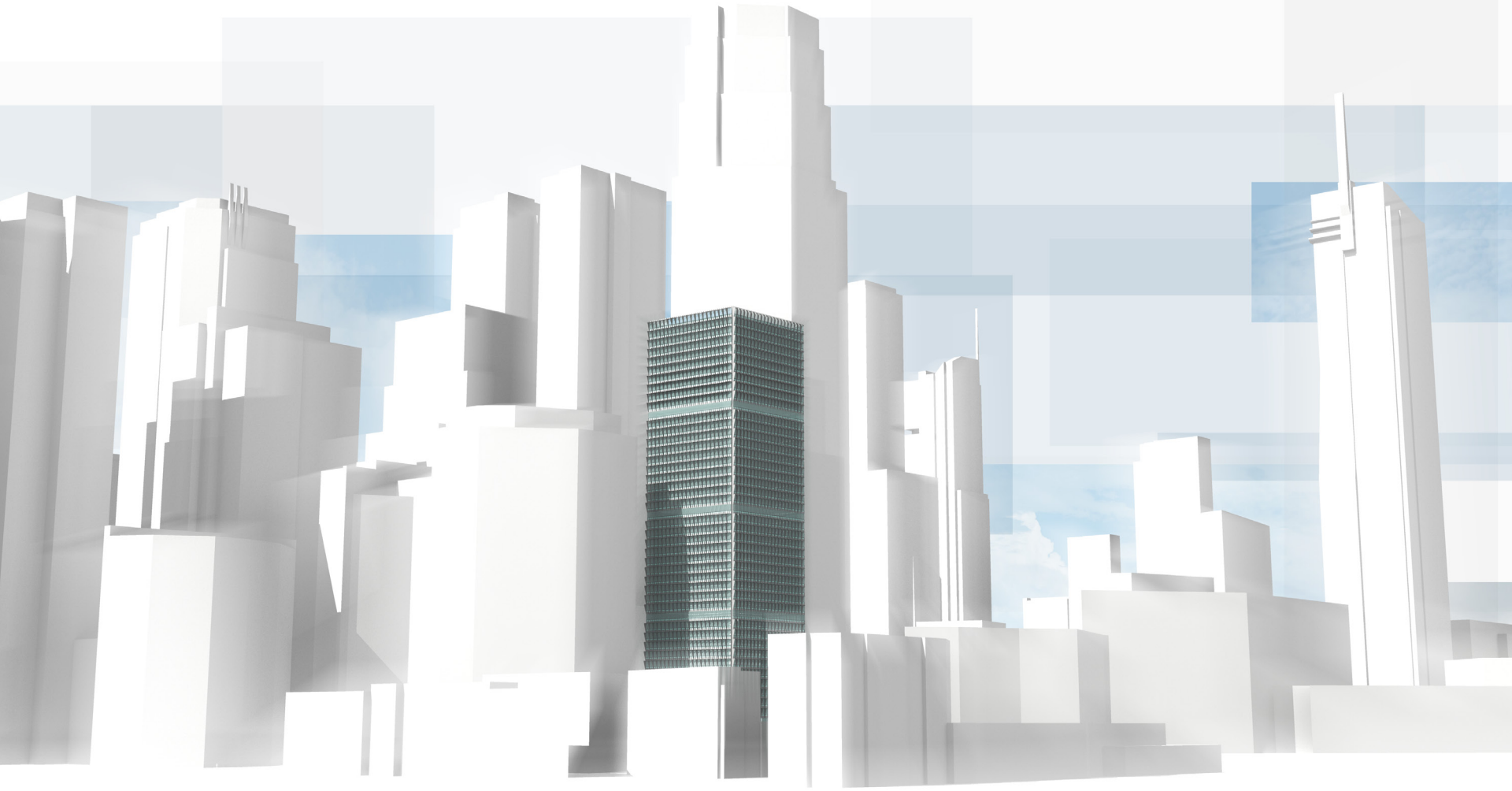
Indirect evaporative cooling
add no moisture

Desiccant dehumidification
renewable energy sources

FACADE INTEGRATION

Visual comfort
daylight and glare

Construction
difficulties



More complex maintenace

More complex construction process

Higher initial cost

37-45% less work for main cooling unit

37-45% less size for main cooling unit

Lower operation cost

RECOMMENDATION

for further development

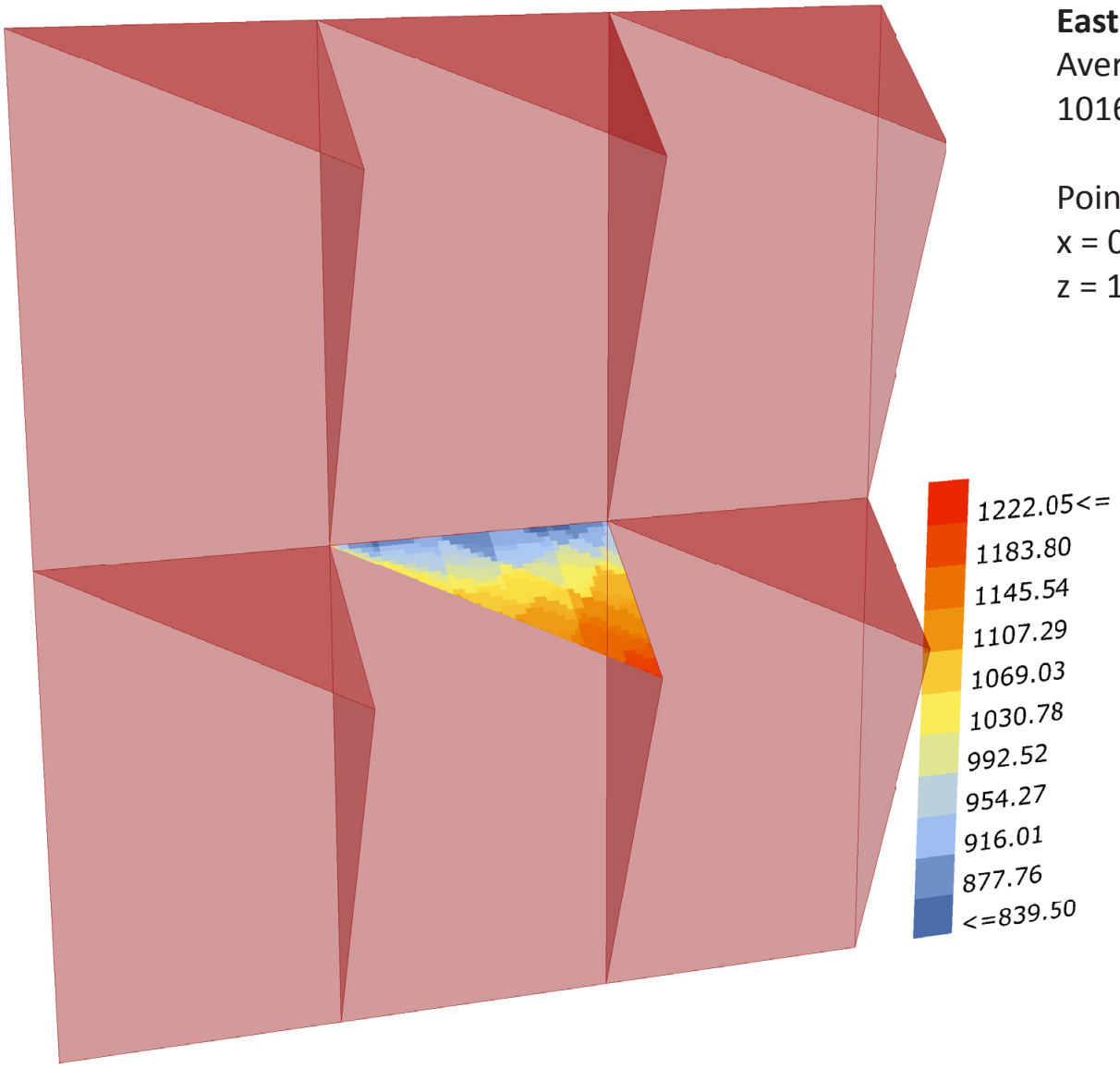
INTEGRATED FACADE SYSTEM

Physical Test

Cost Overview

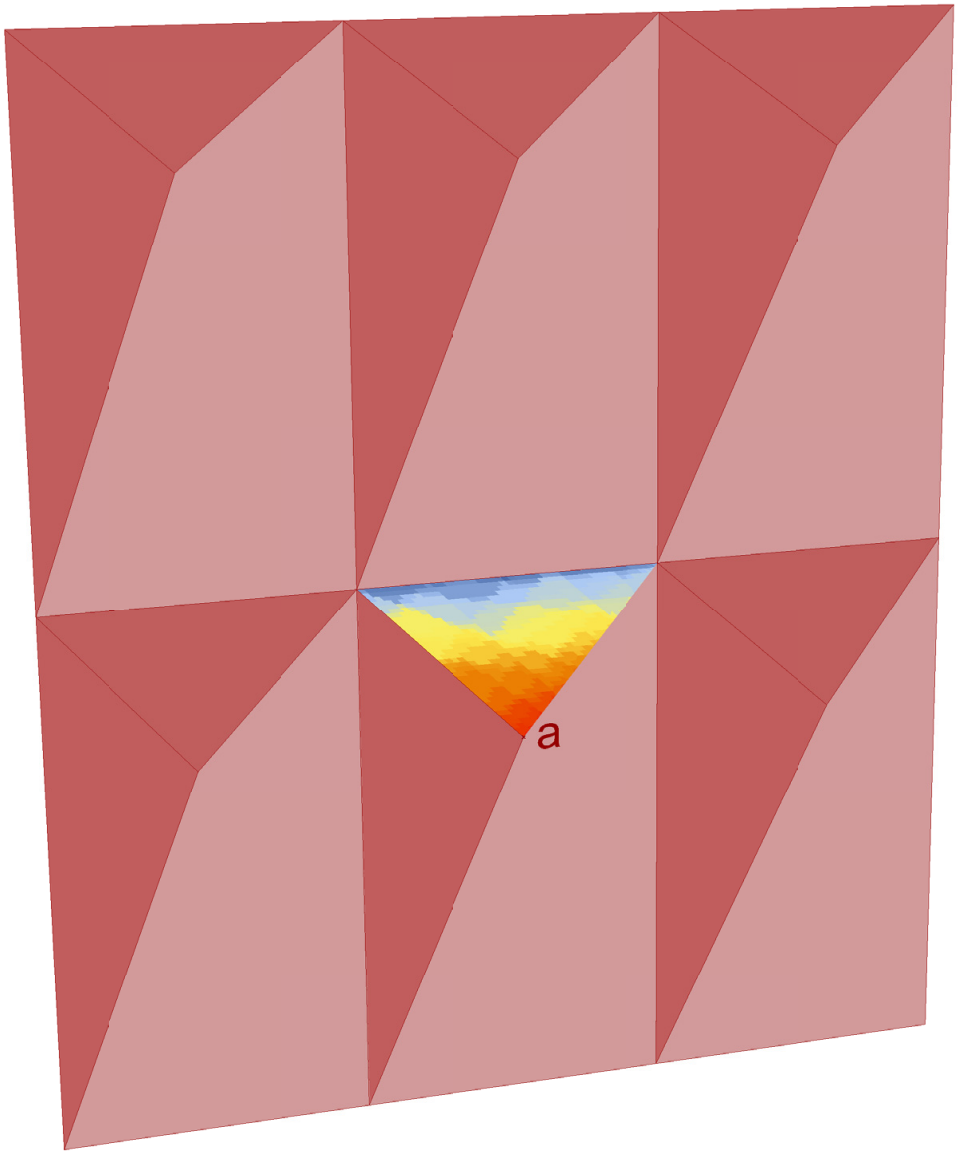
Solar Source Efficiency

SOLAR SOURCE OPTIMIZATION



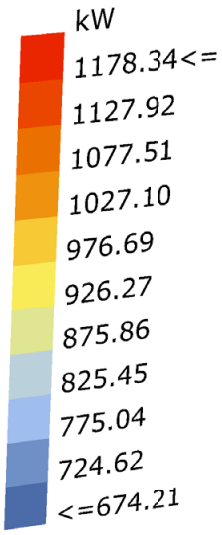
East Orientation
Average radiation
1016.70 kWh/m²

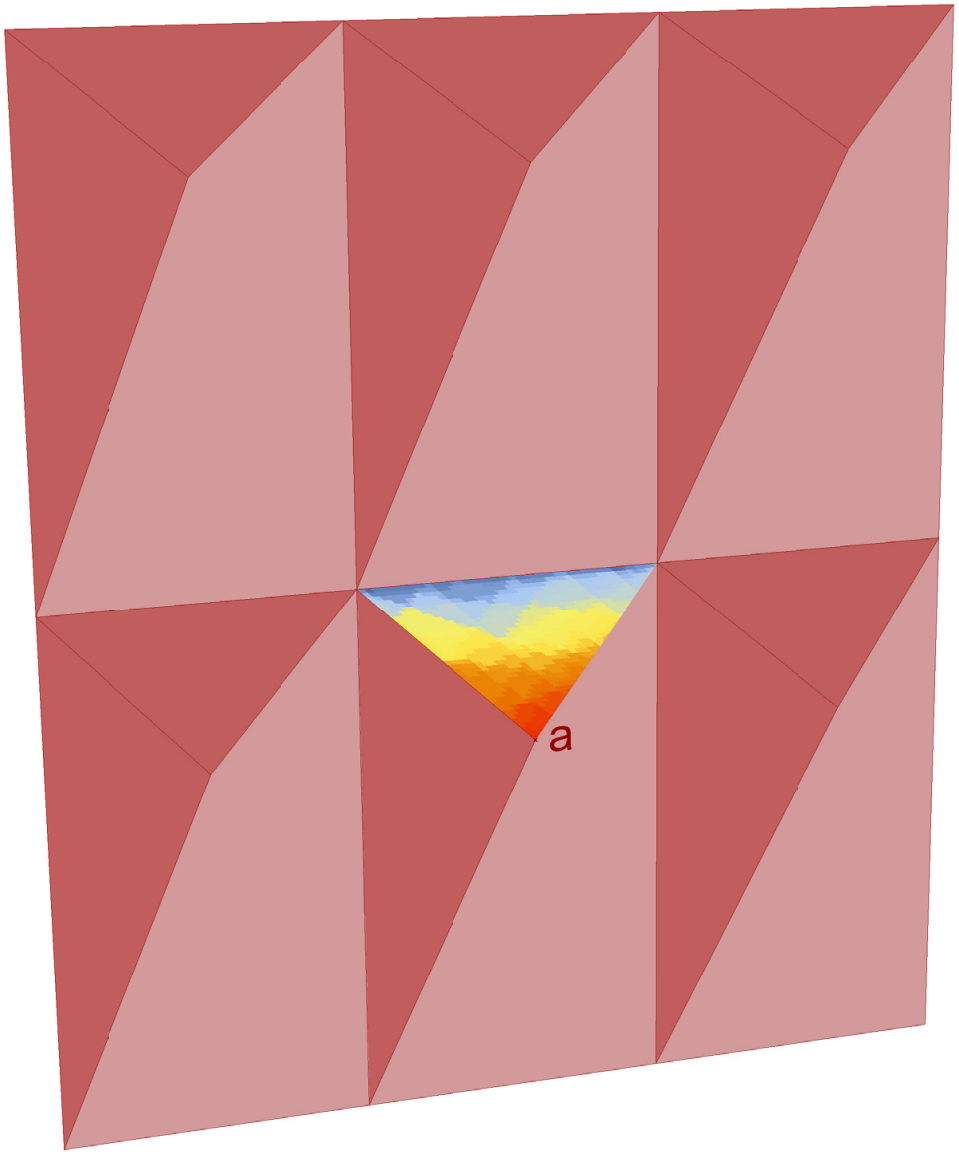
Point a (meter)
x = 0.00
z = 1.00



North Orientation
Average radiation
903.12 kWh/m²

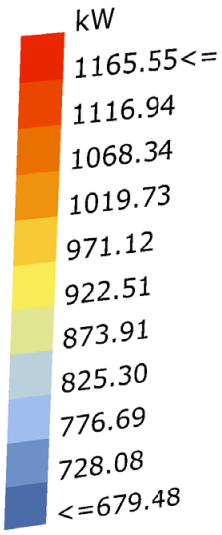
Point a (meter)
x = 0.89
z = 0.87

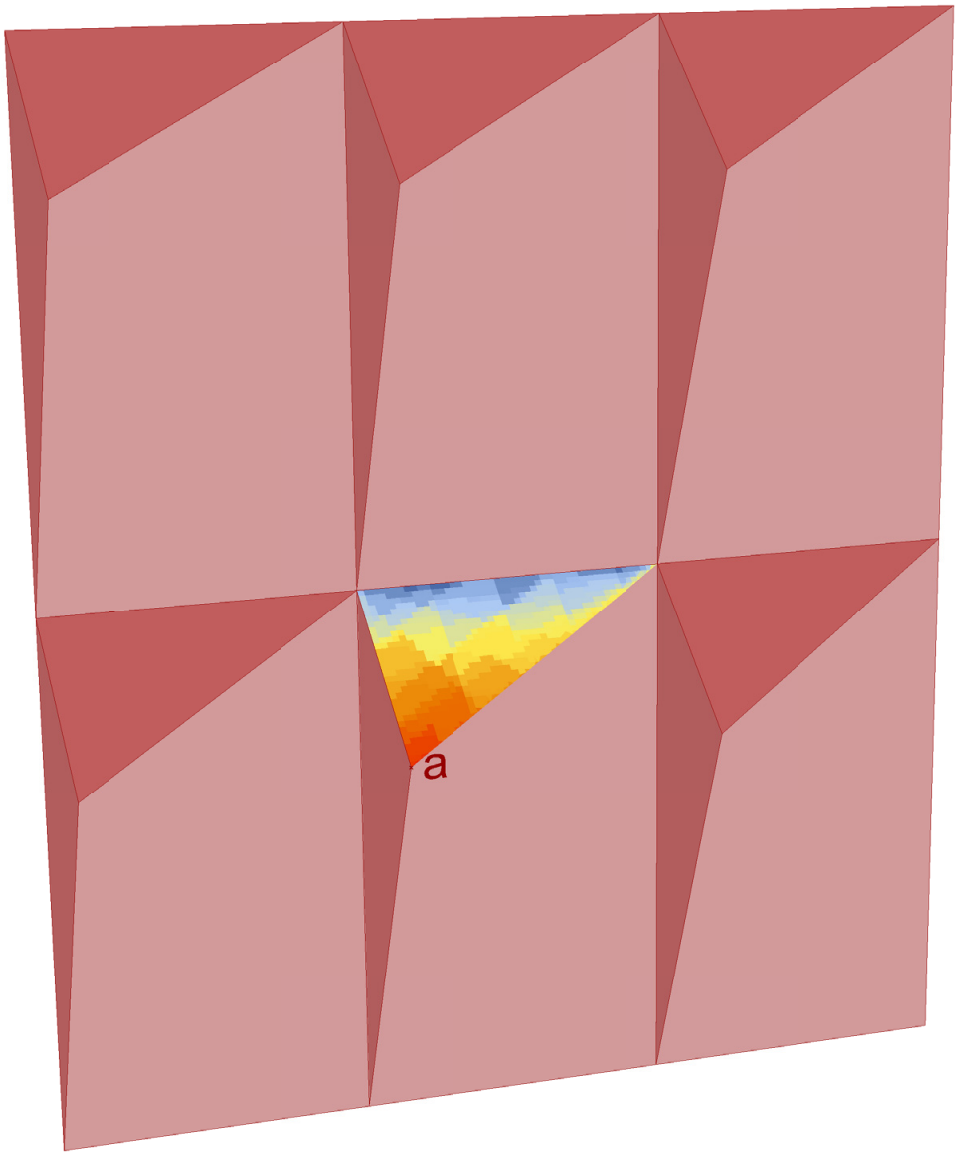




South Orientation
Average radiation
896.52 kWh/m²

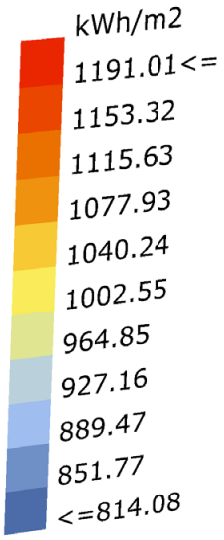
Point a (meter)
x = 0.98
z = 0.90





West Orientation
Average radiation
987.00 kWh/m²

Point a (meter)
x = 0.04
z = 1.00



THANK YOU