

SOLAR DESICCANT COOLING INTEGRATED FACADE DESIGN

Exploration potential for minimizing cooling energy consumption
in office buildings in hot-humid climate

Weili Huang

Introduction

Climate

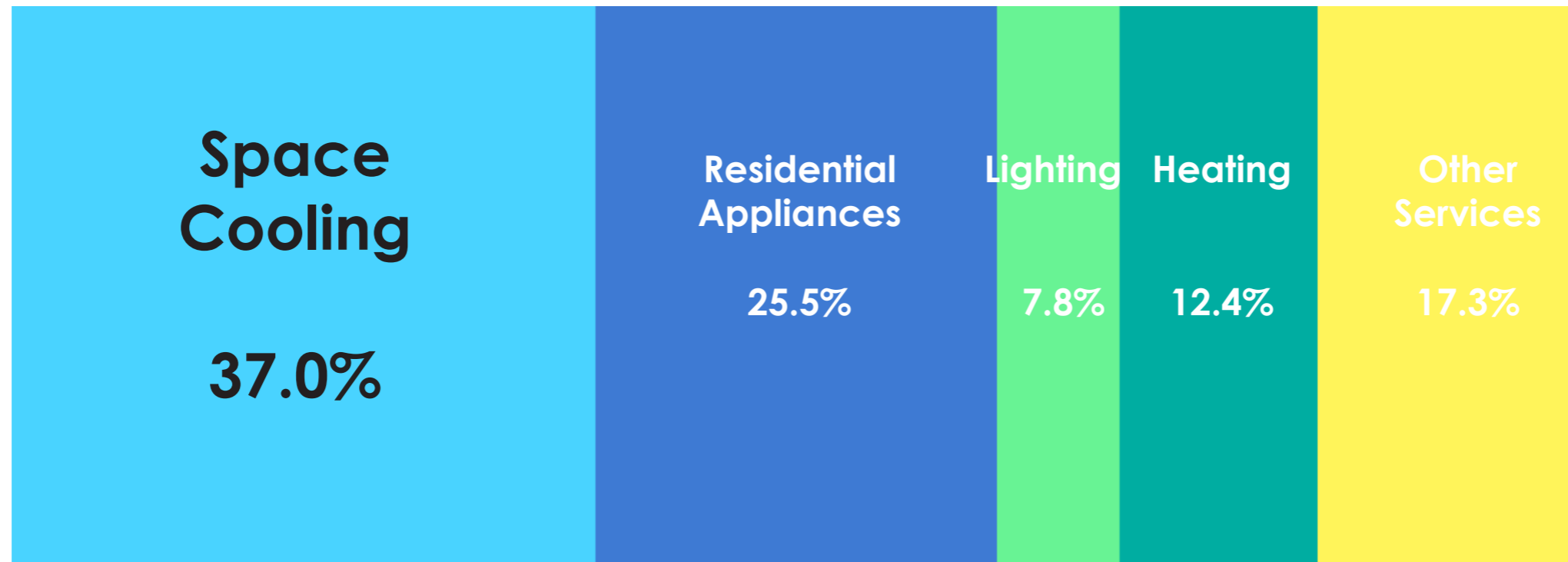
Solar Cooling Technology

Facade Integration

Performance Assessment

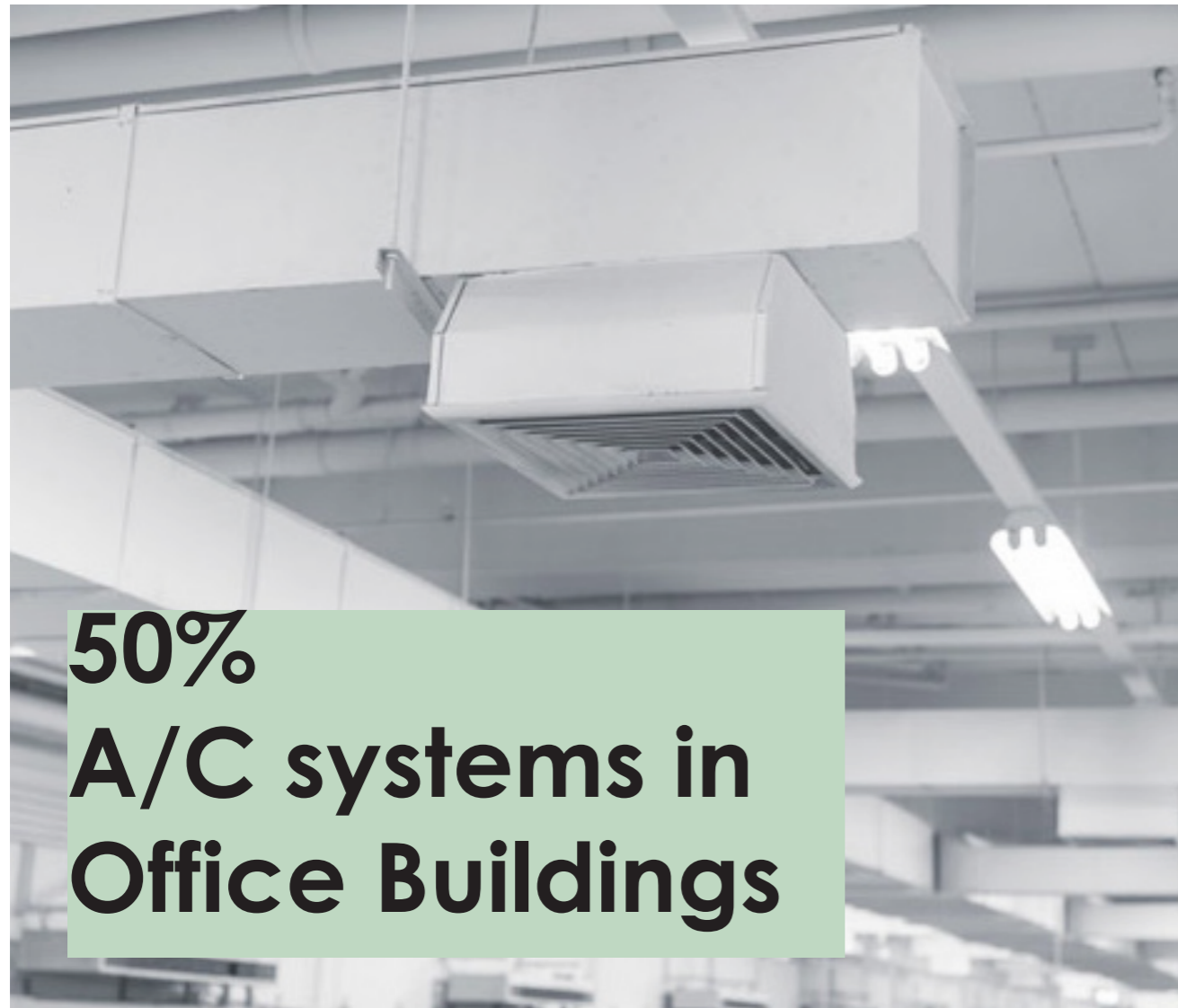
Conclusion

Growth of global energy consumption to 2050

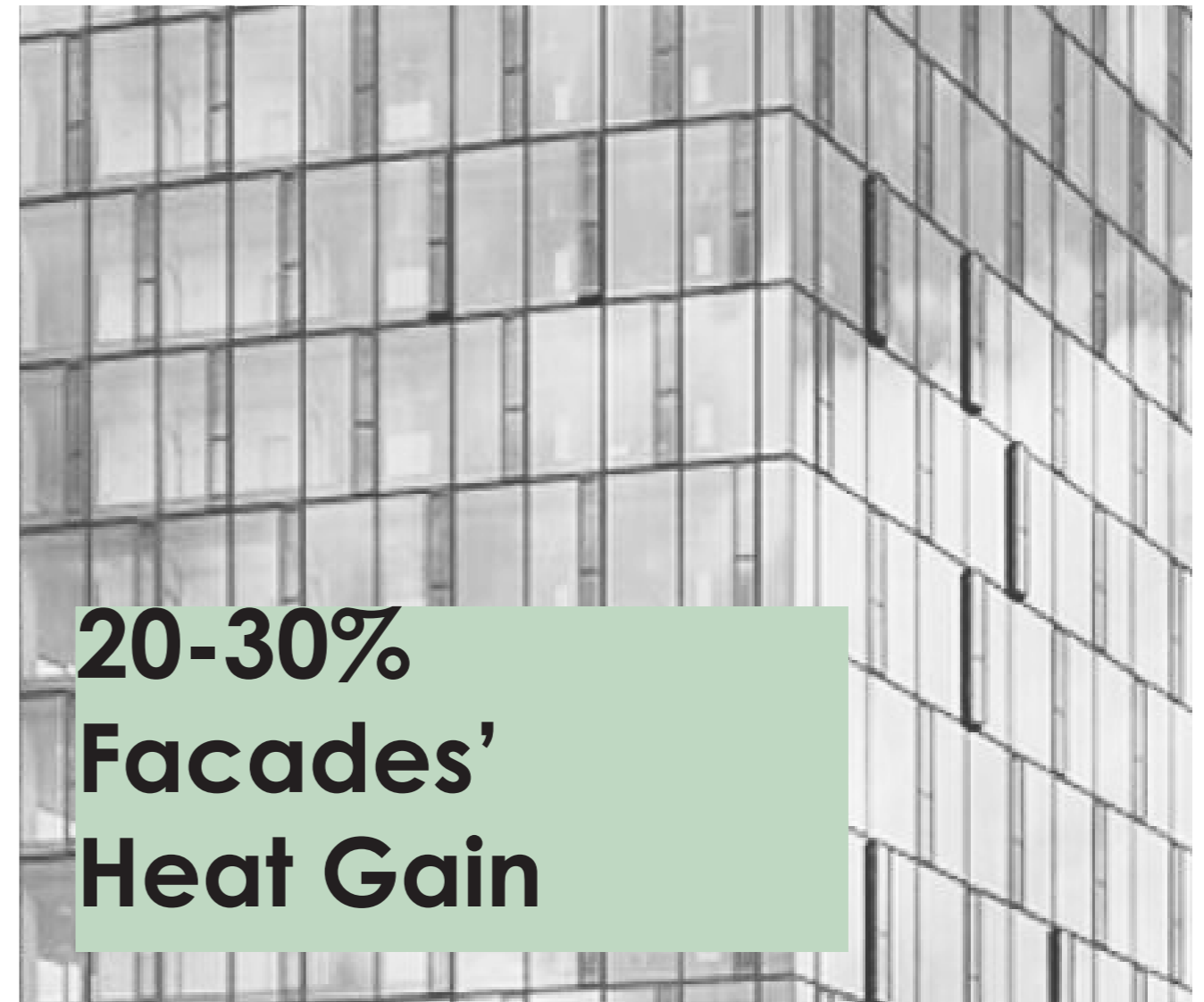


(Source: IEA, *The Future of Cooling*, 2018)

Energy consumption in buildings

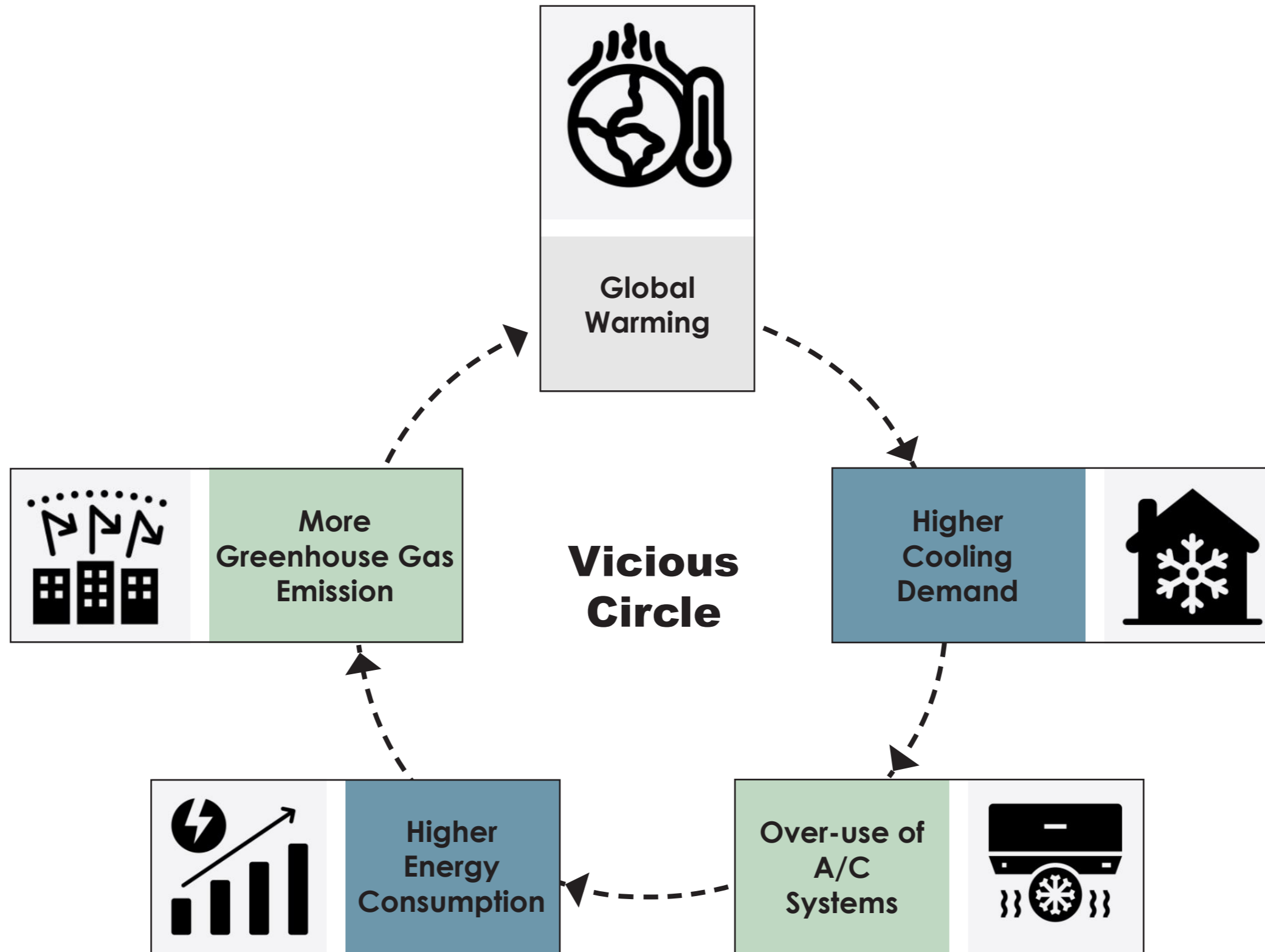


**50%
A/C systems in
Office Buildings**

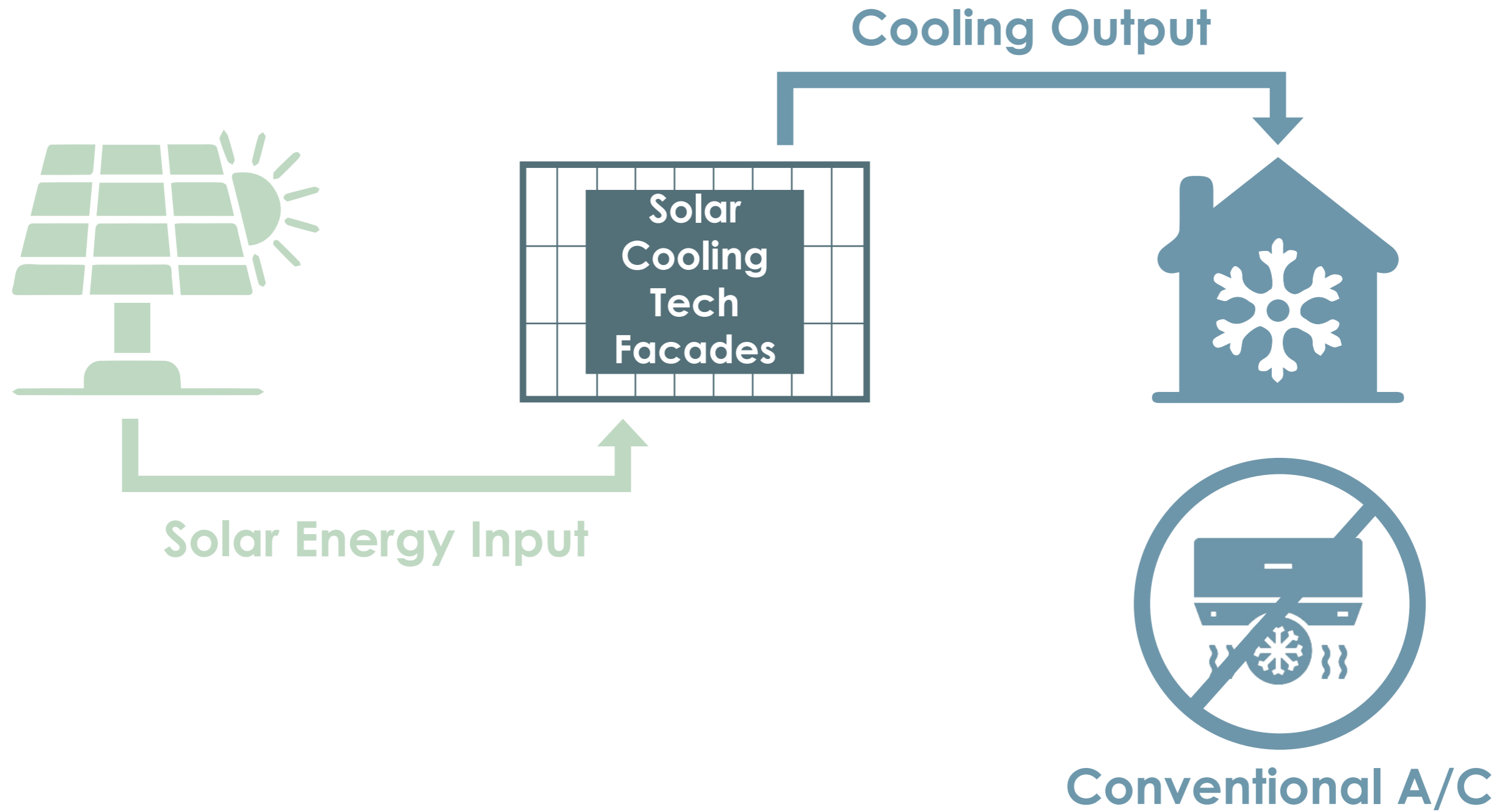


**20-30%
Facades' Heat Gain**

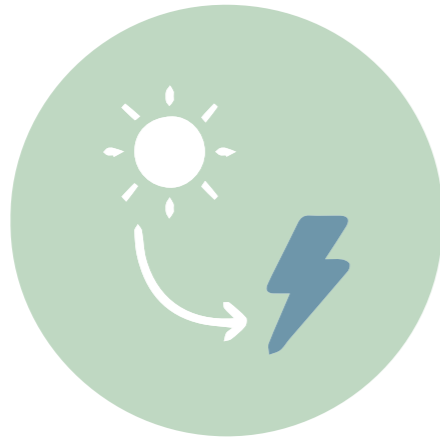
(Source: Qi, 2006; Prieto, 2018; Dall'O', Galante, & Pasetti, 2012)



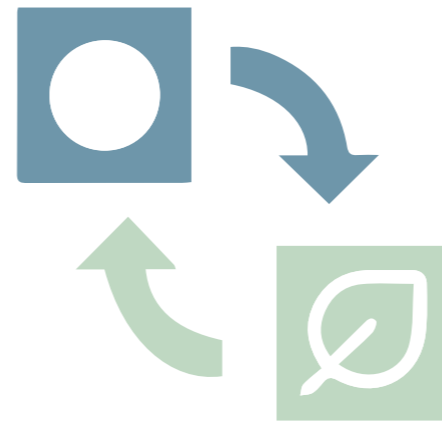
A potential alternative to conventional A/C



Benefits of solar cooling technology



**Renewable solar energy
payback**



**Refrigerant-free
cooling**



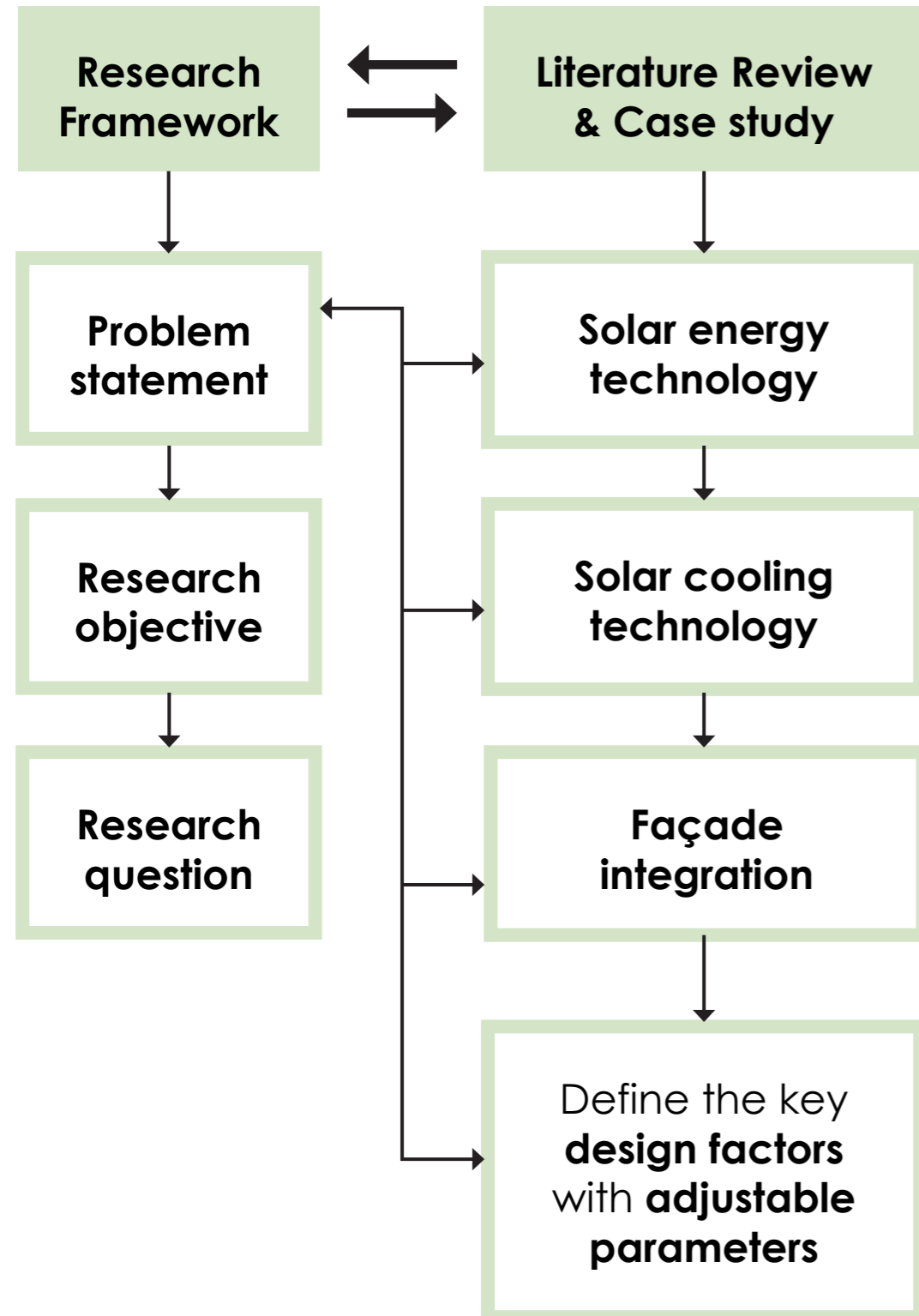
**Cooling energy autonomy
by facades**

Research question:

“ In hot-humid climate, how can the design application of solar cooling integrated facades minimize the cooling energy consumption for office buildings and optimize the indoor thermal comfort? ”

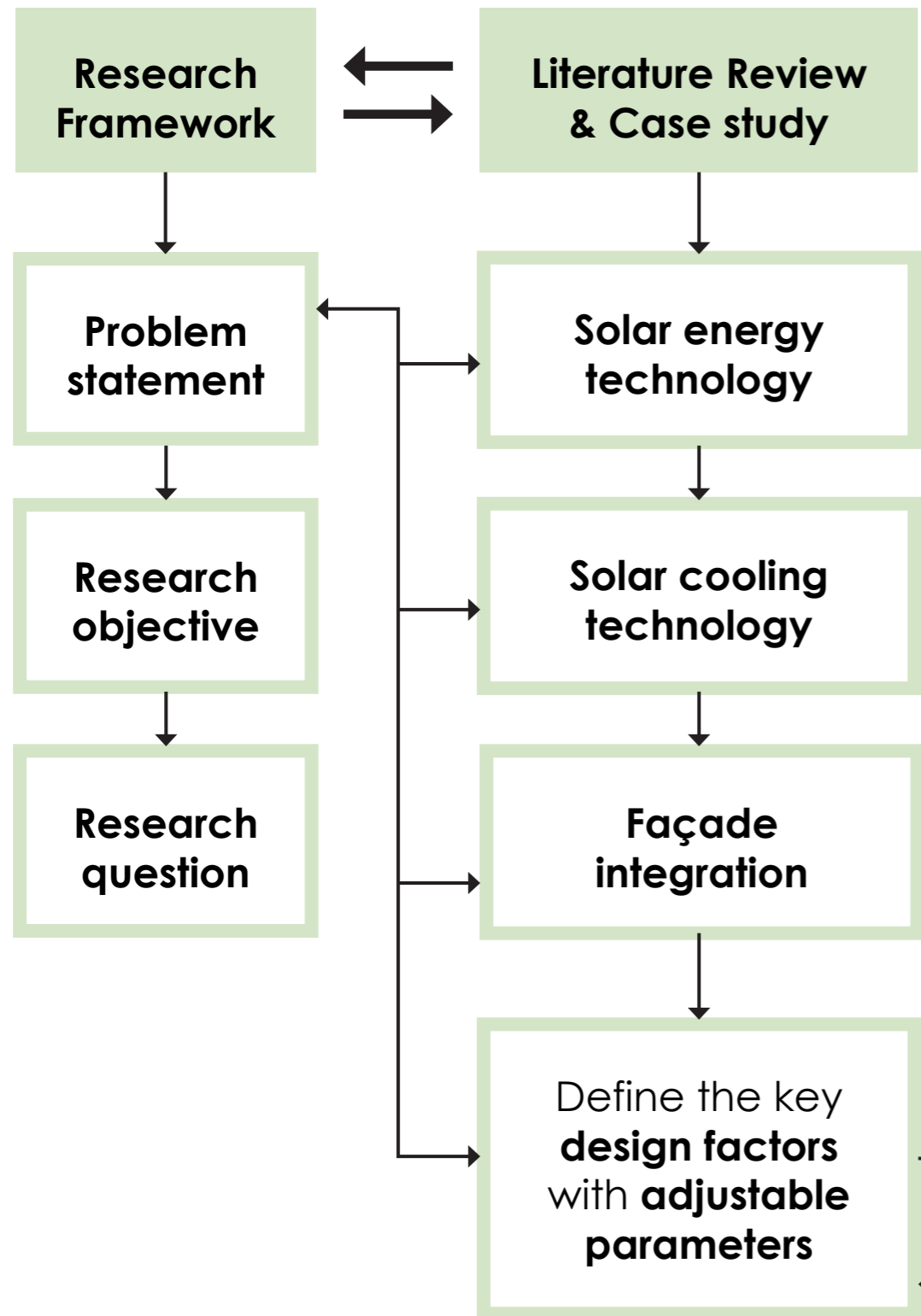
Research methodology

[RESEARCH]

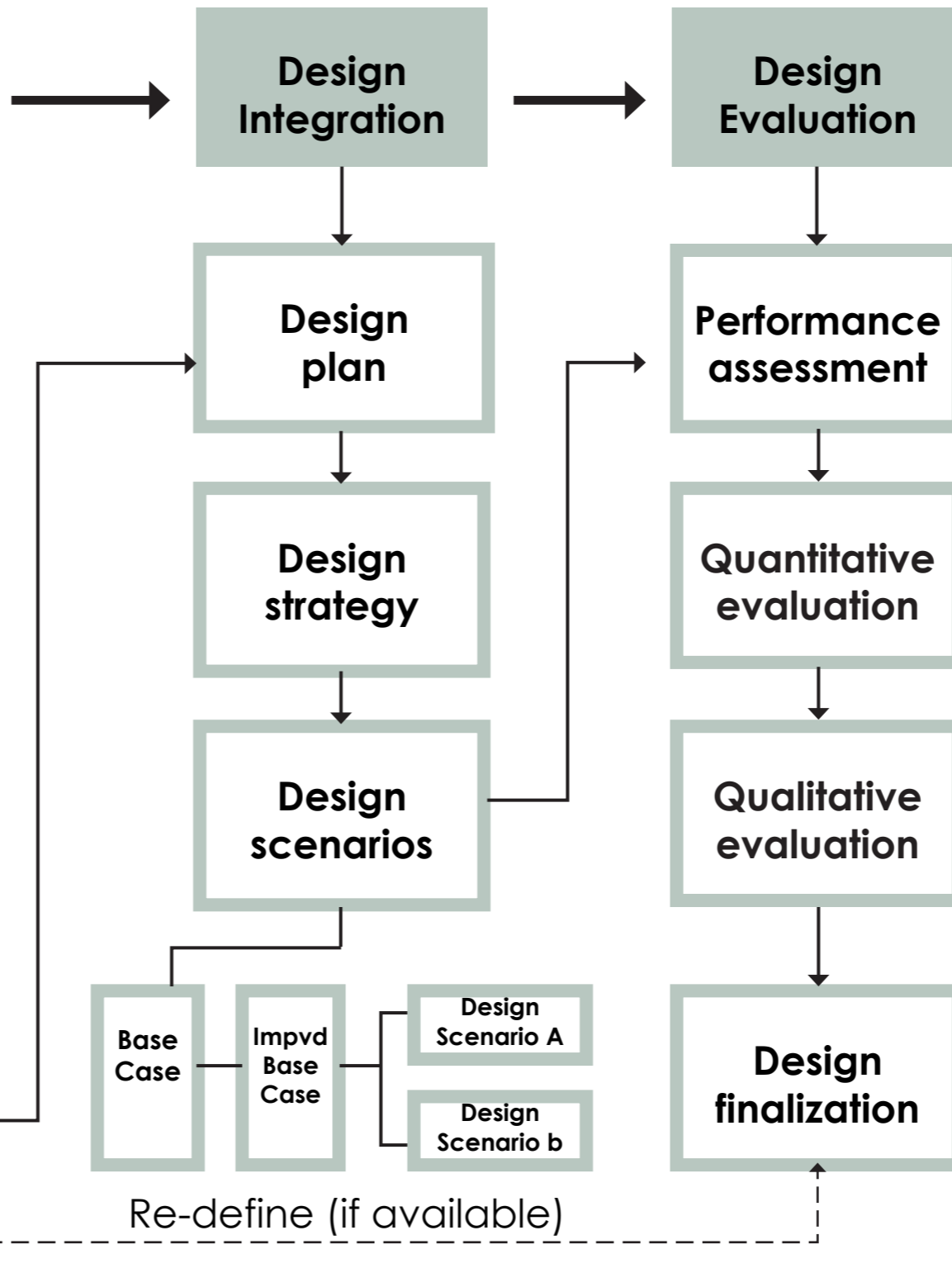


Research methodology

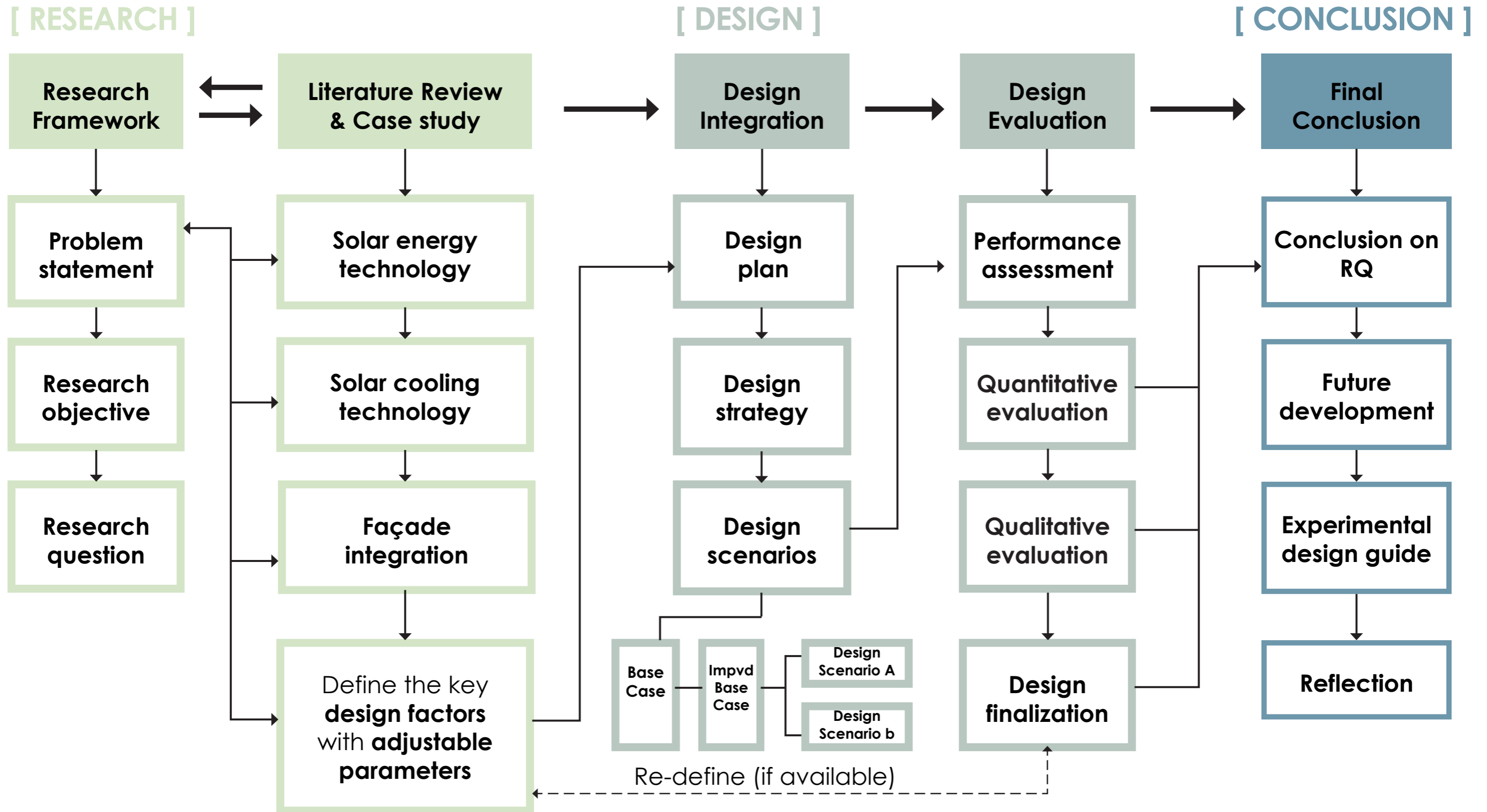
[RESEARCH]



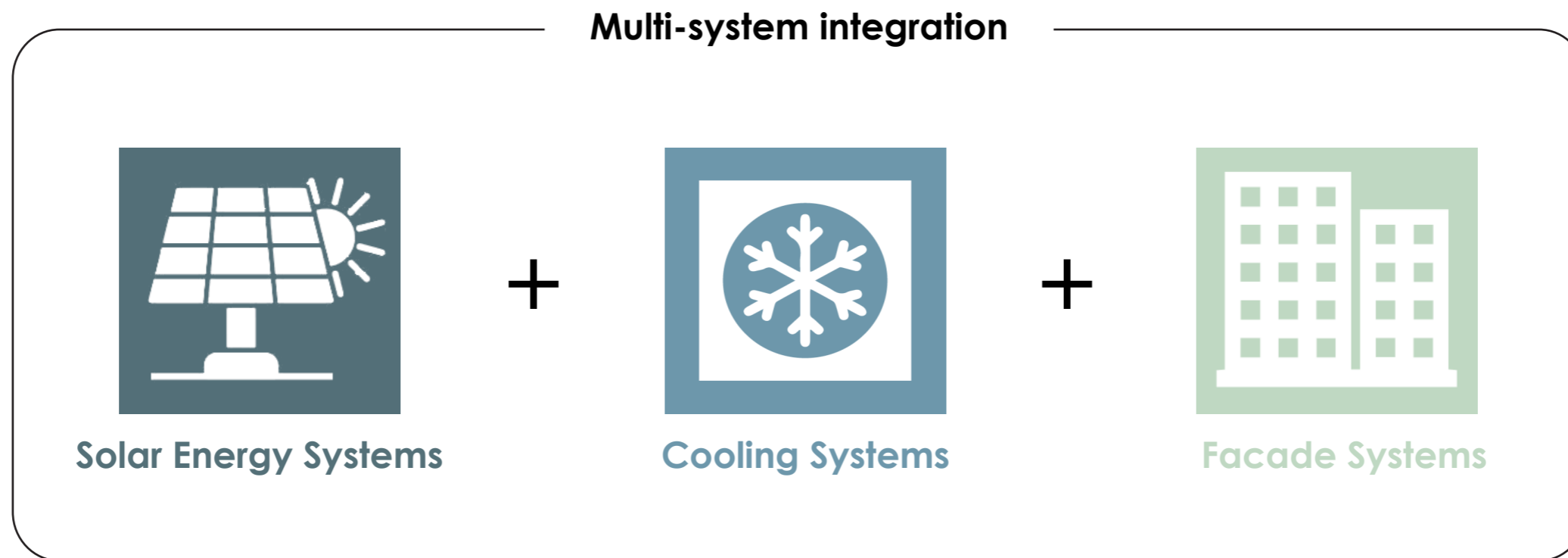
[DESIGN]



Research methodology



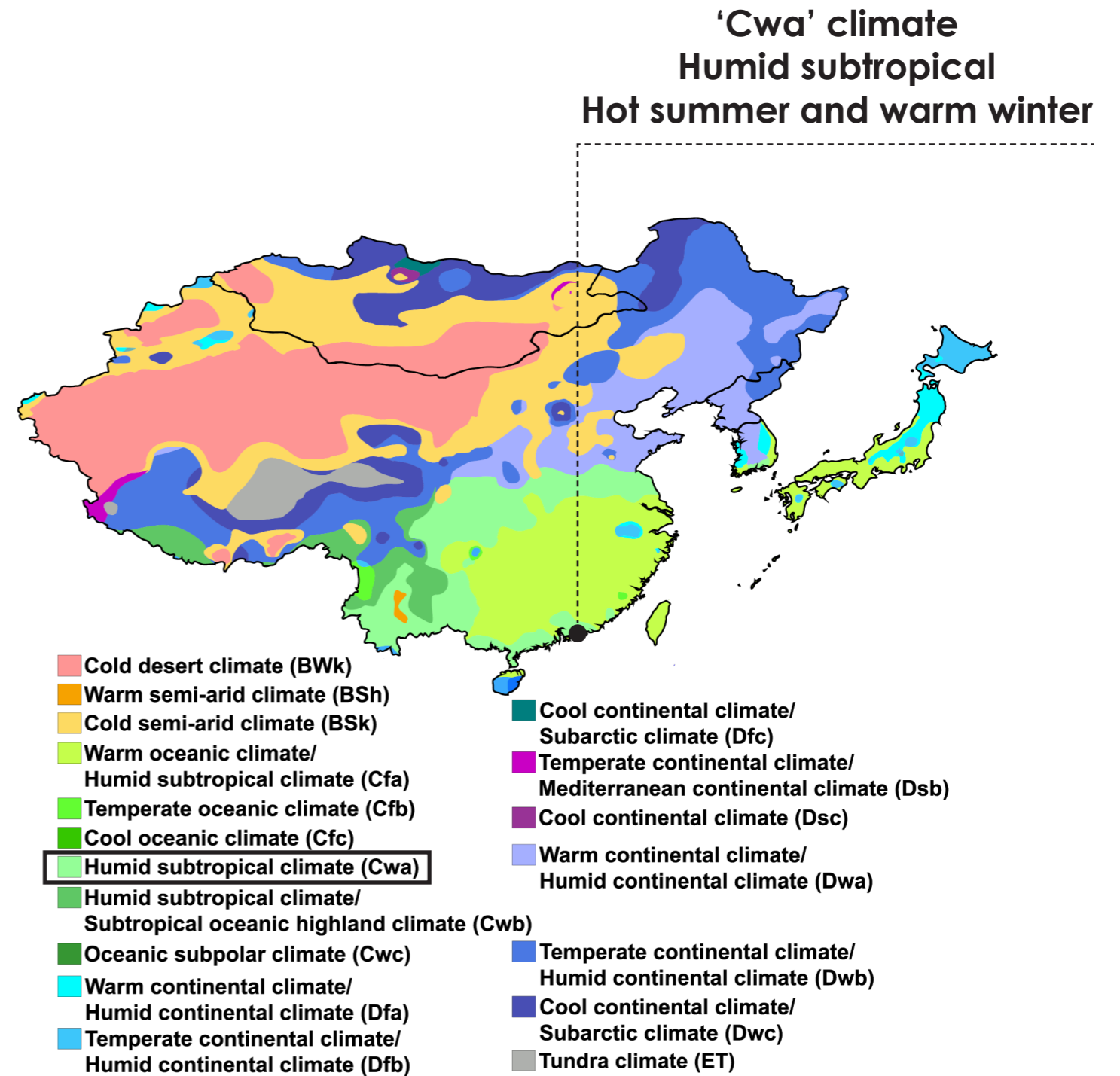
What to consider when designing solar cooling integrated facades?



The target city - Shenzhen, China



Target city: Shenzhen, China

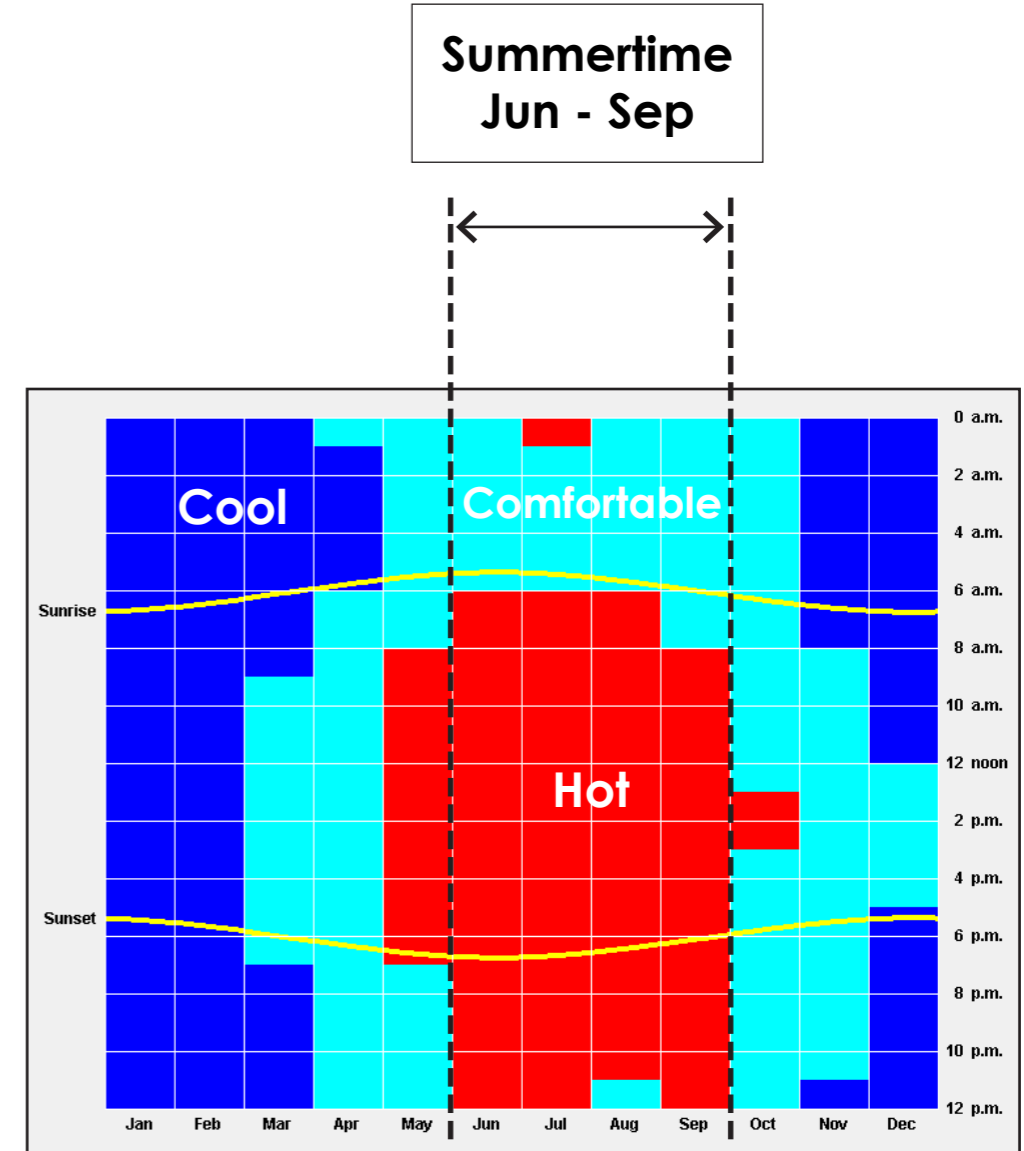


Köppen climate classification

July Harsh month
 T_{mean} **29C°**
 RH_{mean} **79%**

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Record high °C (°F)	29.1 (84.4)	28.9 (84.0)	32.0 (89.6)	34.0 (93.2)	36.8 (98.2)	36.9 (98.4)	38.7 (101.7)	37.1 (98.8)	36.9 (98.4)	35.2 (95.4)	33.1 (91.6)	29.8 (85.6)
Mean daily maximum °C (°F)	19.8 (67.6)	20.8 (69.4)	23.2 (73.8)	26.7 (80.1)	29.7 (85.5)	31.3 (88.3)	32.3 (90.1)	32.2 (90.0)	31.5 (88.7)	29.2 (84.6)	25.7 (78.3)	21.5 (70.7)
Daily mean °C (°F)	15.7 (60.3)	16.8 (62.2)	19.4 (66.9)	23.1 (73.6)	26.4 (79.5)	28.3 (82.9)	29.0 (84.2)	28.8 (83.8)	27.9 (82.2)	25.5 (77.9)	21.7 (71.1)	17.4 (63.3)
Mean daily minimum °C (°F)	13.0 (55.4)	14.2 (57.6)	17.0 (62.6)	20.7 (69.3)	24.0 (75.2)	26.0 (78.8)	26.6 (79.9)	26.3 (79.3)	25.5 (77.9)	22.9 (73.2)	19.0 (66.2)	14.5 (58.1)
Record low °C (°F)	0.9 (33.6)	0.2 (32.4)	3.4 (38.1)	8.7 (47.7)	14.8 (58.6)	19.0 (66.2)	20.0 (68.0)	21.1 (70.0)	16.9 (62.4)	9.3 (48.7)	4.9 (40.8)	1.7 (35.1)
Average rainfall mm (inches)	35.2 (1.39)	36.8 (1.45)	64.0 (2.52)	140.1 (5.52)	237.1 (9.33)	368.7 (14.52)	309.5 (12.19)	364.3 (14.34)	242.5 (9.55)	73.4 (2.89)	31.7 (1.25)	29.6 (1.17)
Average rainy days (≥ 0.1 mm)	5.5	7.8	9.9	11.4	14.3	18.4	17.2	16.7	13.2	5.9	4.6	5.2
Average relative humidity (%)	68	74	77	79	79	80	79	79	75	67	67	64
Mean monthly sunshine hours	137.3	101.6	99.7	115.2	153.0	169.8	214.8	178.6	170.1	188.7	168.8	155.4
Percent possible sunshine	40	31	27	30	37	42	52	45	47	53	51	47

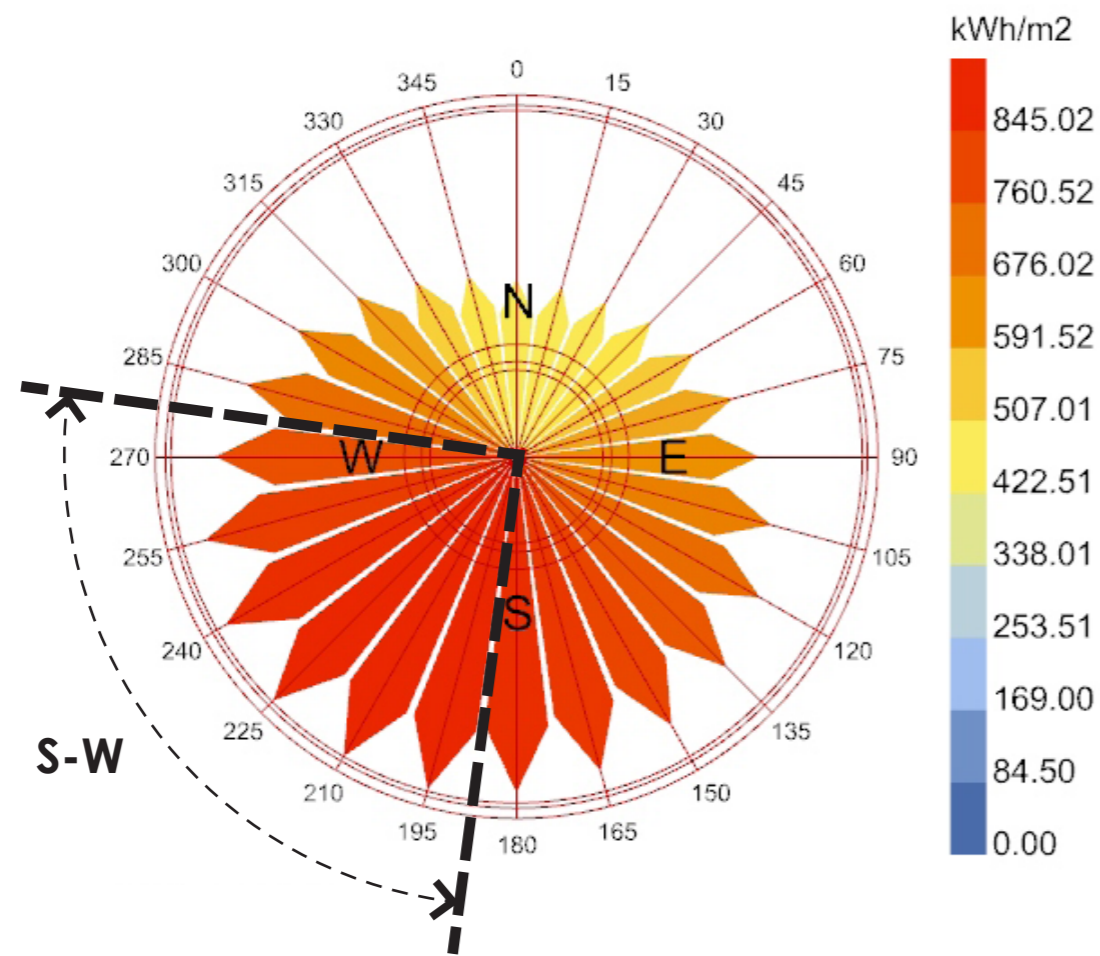
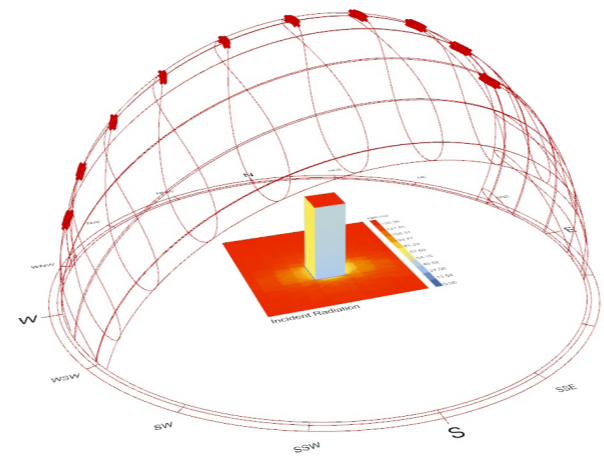
Climate data for Shenzhen (1991-2020)



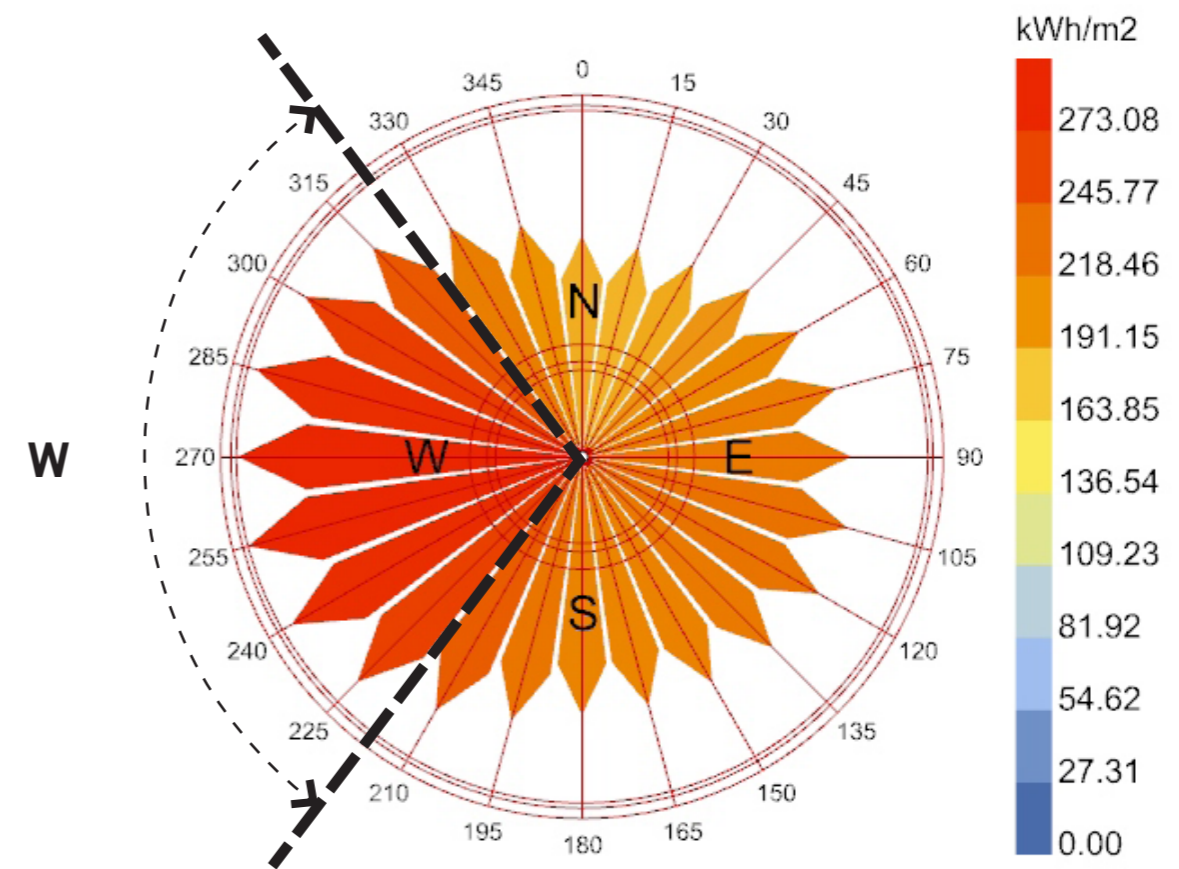
Discomfort zone

(Source: Wikipedia and Climate Consultant v6.0 program)

Solar radiation analysis



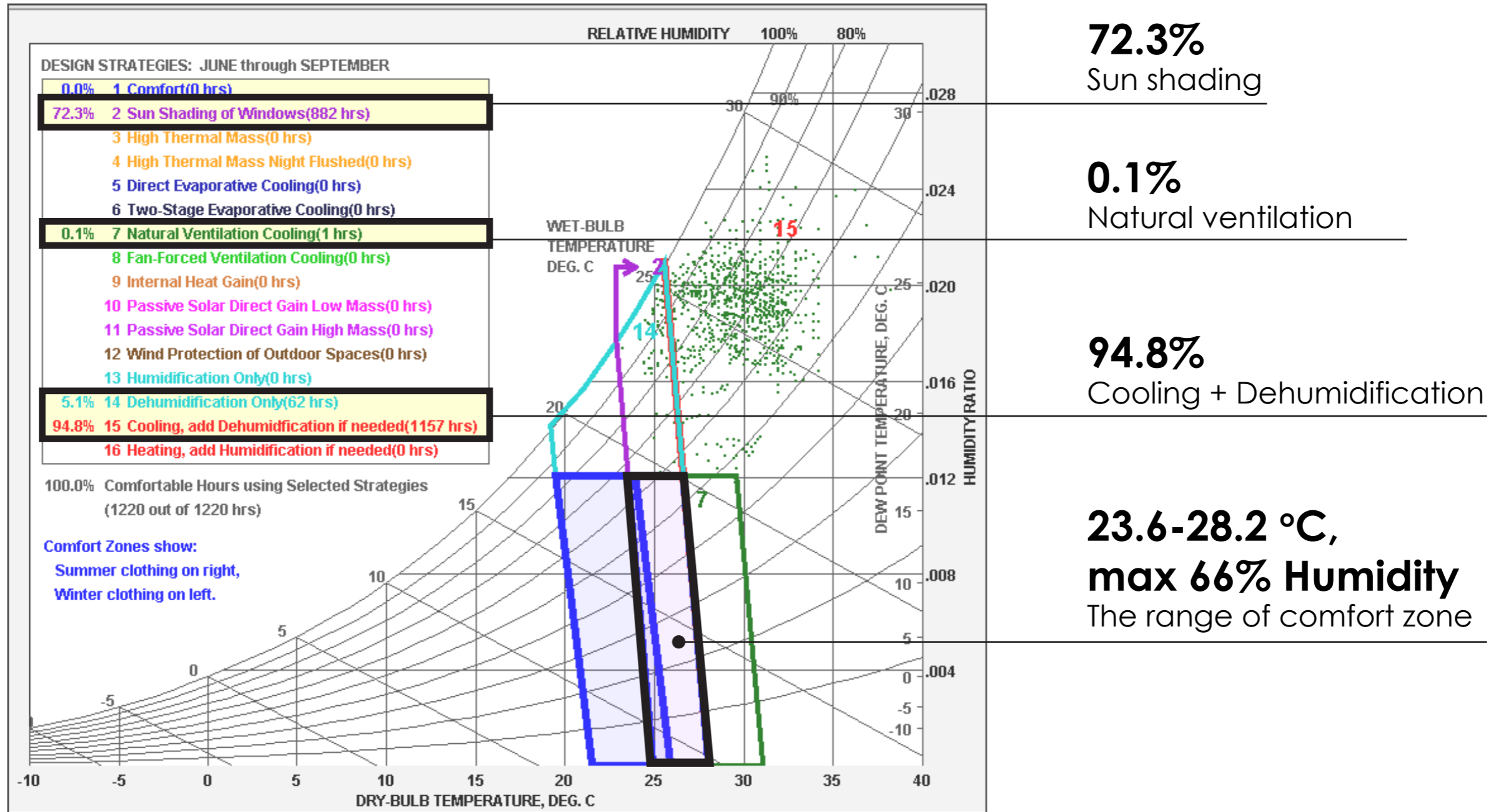
Annual analysis



Summertime analysis (Jun-Sep)

(Source: Grasshopper plug-in - Ladybug)

The weighting of the climate strategies for indoor comfort

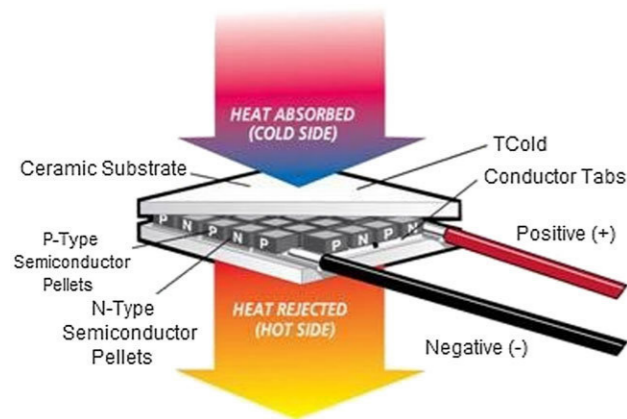


(Source: Climate Consultant v6.0 program)

How to choose the suitable solar cooling technologies?

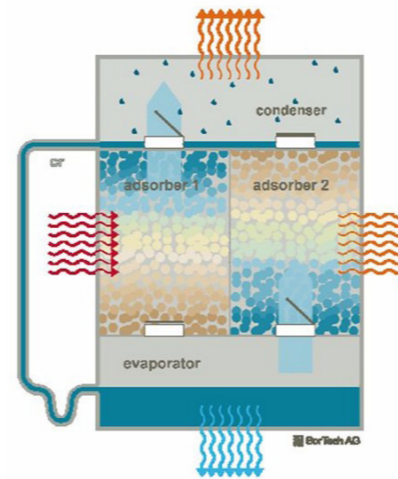


THEMOELECTRIC cooling



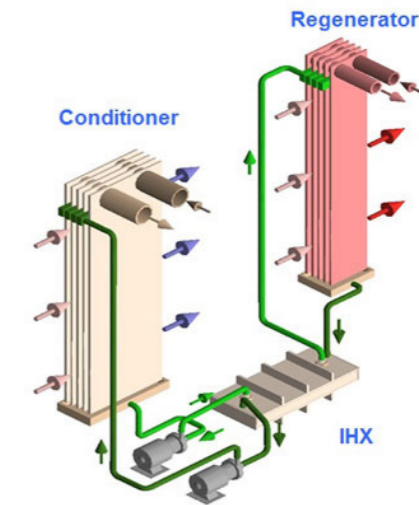
- Hot-acid
- Hot-humid
- Temperate-dry
- Temperate-humid

SORPTION (absorption/adsorption) cooling



- Hot-acid
- Hot-humid
- Temperate-dry
- Temperate-humid

DESICCANT (solid/liquid desiccant) cooling



- Hot-acid
- Hot-humid (Tropical)
- Temperate-dry
- Temperate-humid (Sub-tropical)

(Source: Prieto, 2018)

SOLID DESICCANT



e.g. **Silica gel**

Lower performance
in Dehumidification

LIQUID DESICCANT

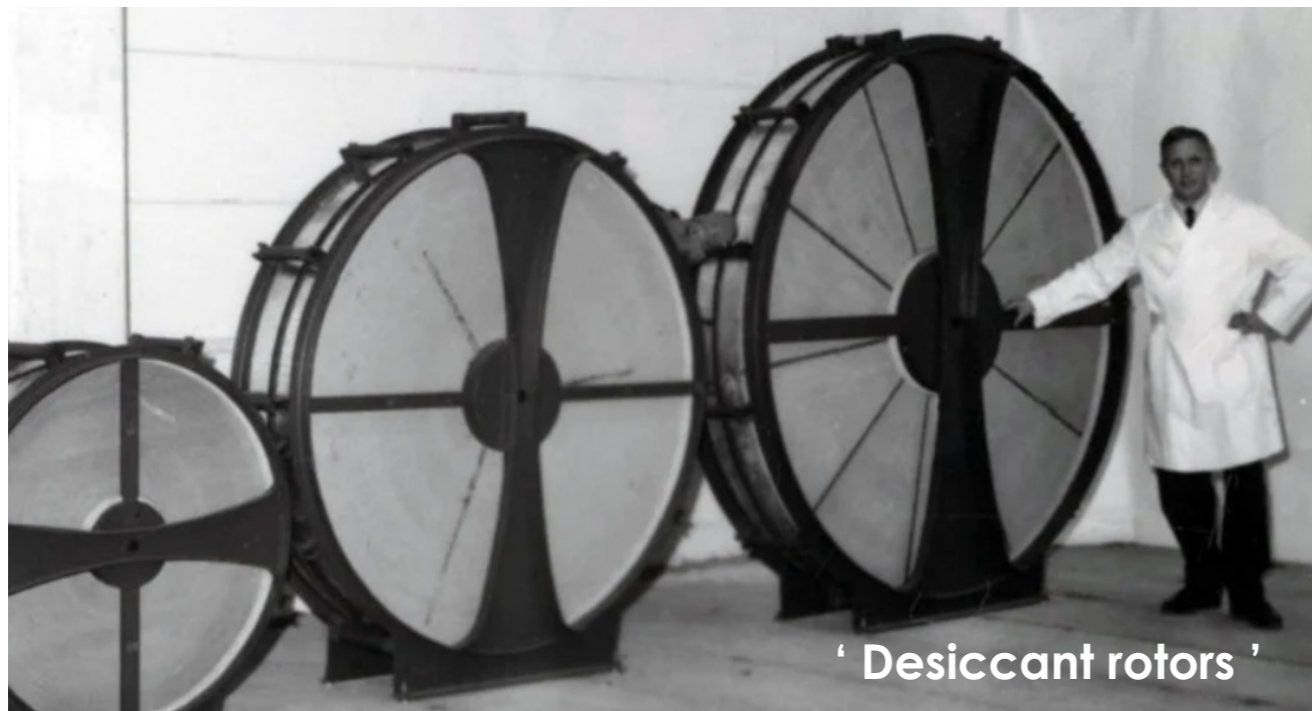


e.g. **CHKO₂ solution**

Higher performance
in Dehumidification

Lower material cost

VS



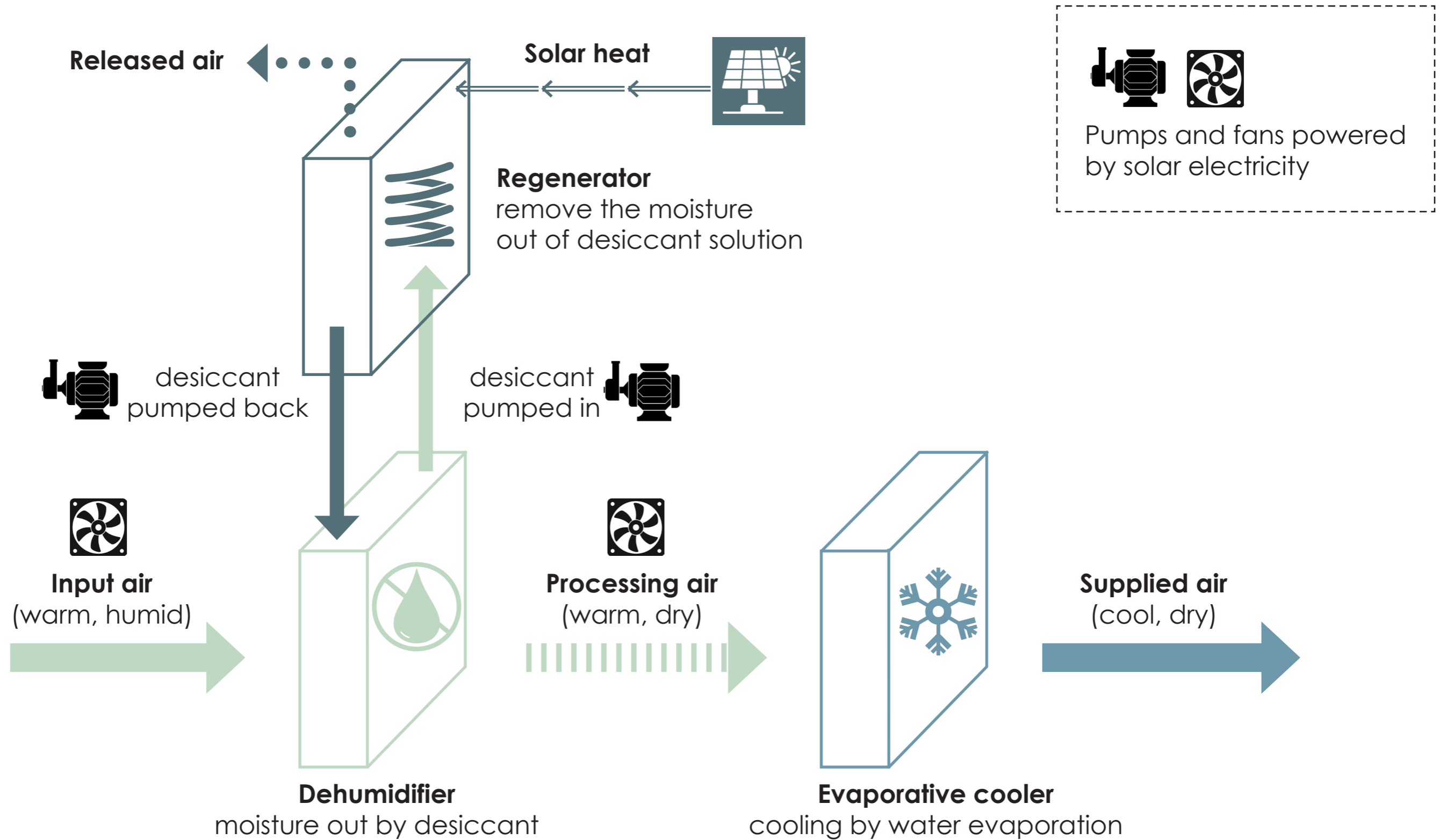
**Heavy, large size,
complicated system for facade integration**



**Lightweight, more compact size
good for facade integration**

*(Source: Prieto, 2018; Vivek et al., 2018; Elmer et al., 2016;
Kohlenbach & Jakob, 2014; Daou et al. 2004)*

LDEVap - Liquid Desiccant Enhanced Evaporative Cooling



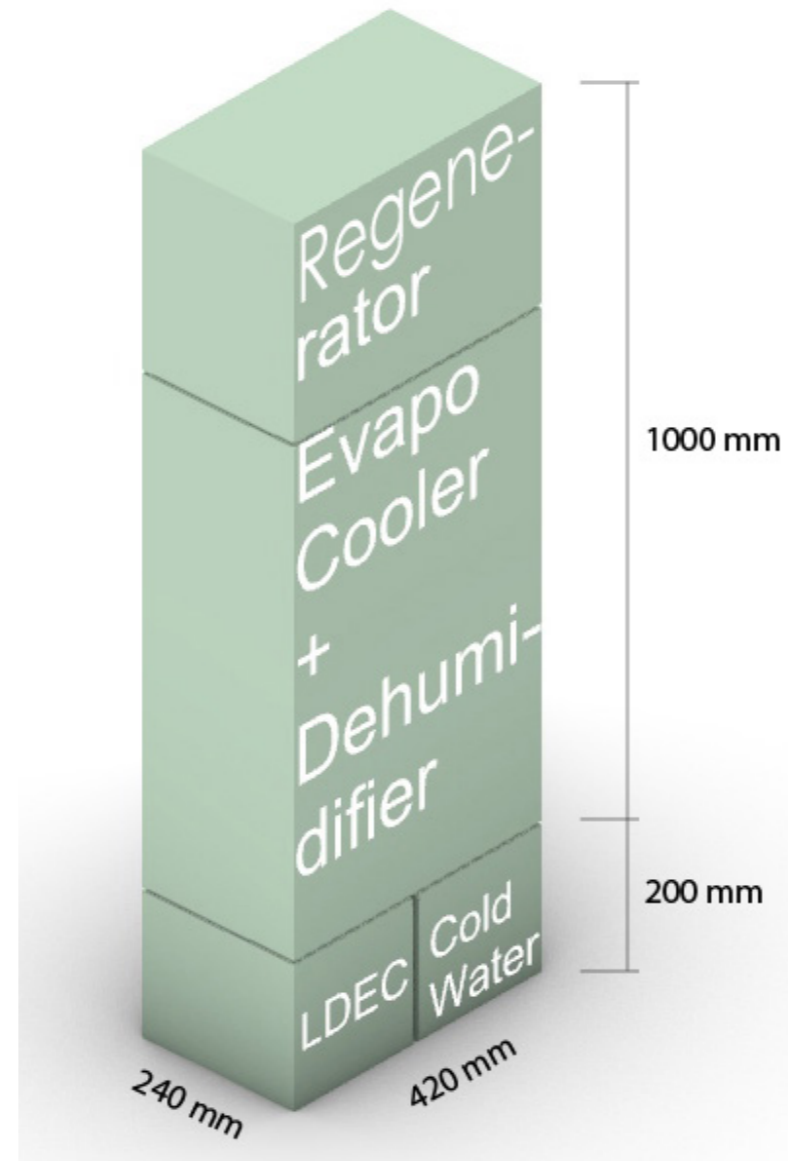
LDEVap cooling unit by Elmer et al. (2016)

Compact size:
1200(h)x420(w)x240(d) mm

Cooling capacity: **1.1 kw** (avg.)

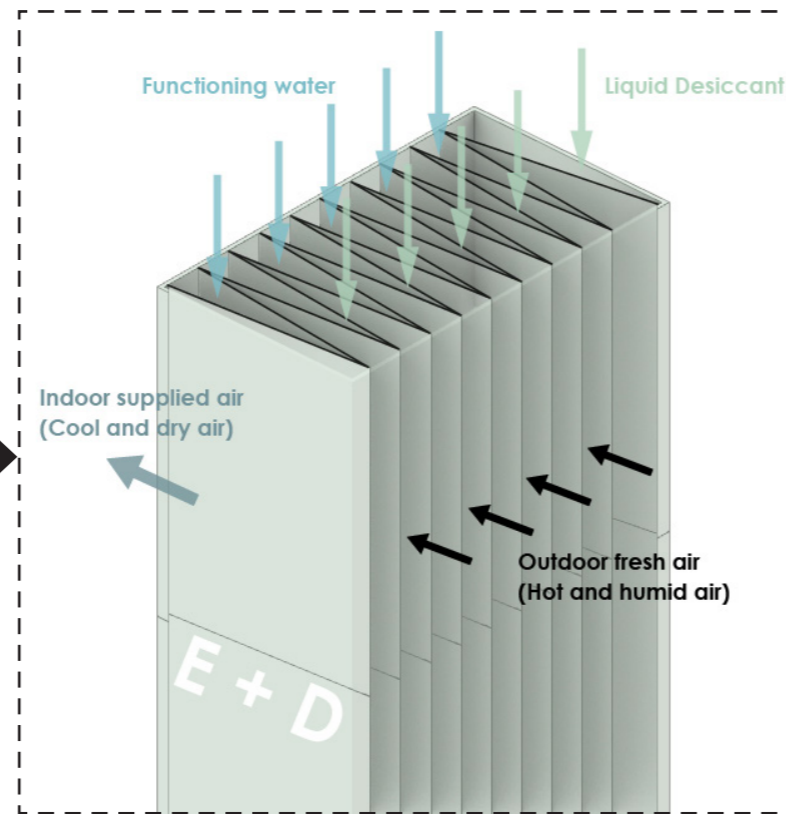
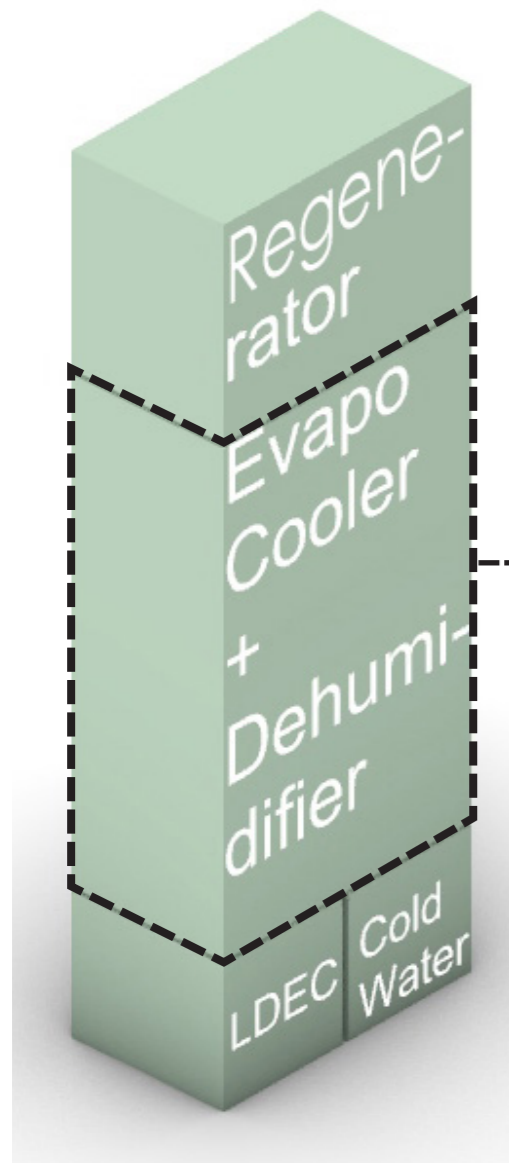
Dehumidification ability:
approx. **40%** (avg.)

COP_{thermal} : **0.72** (avg.)

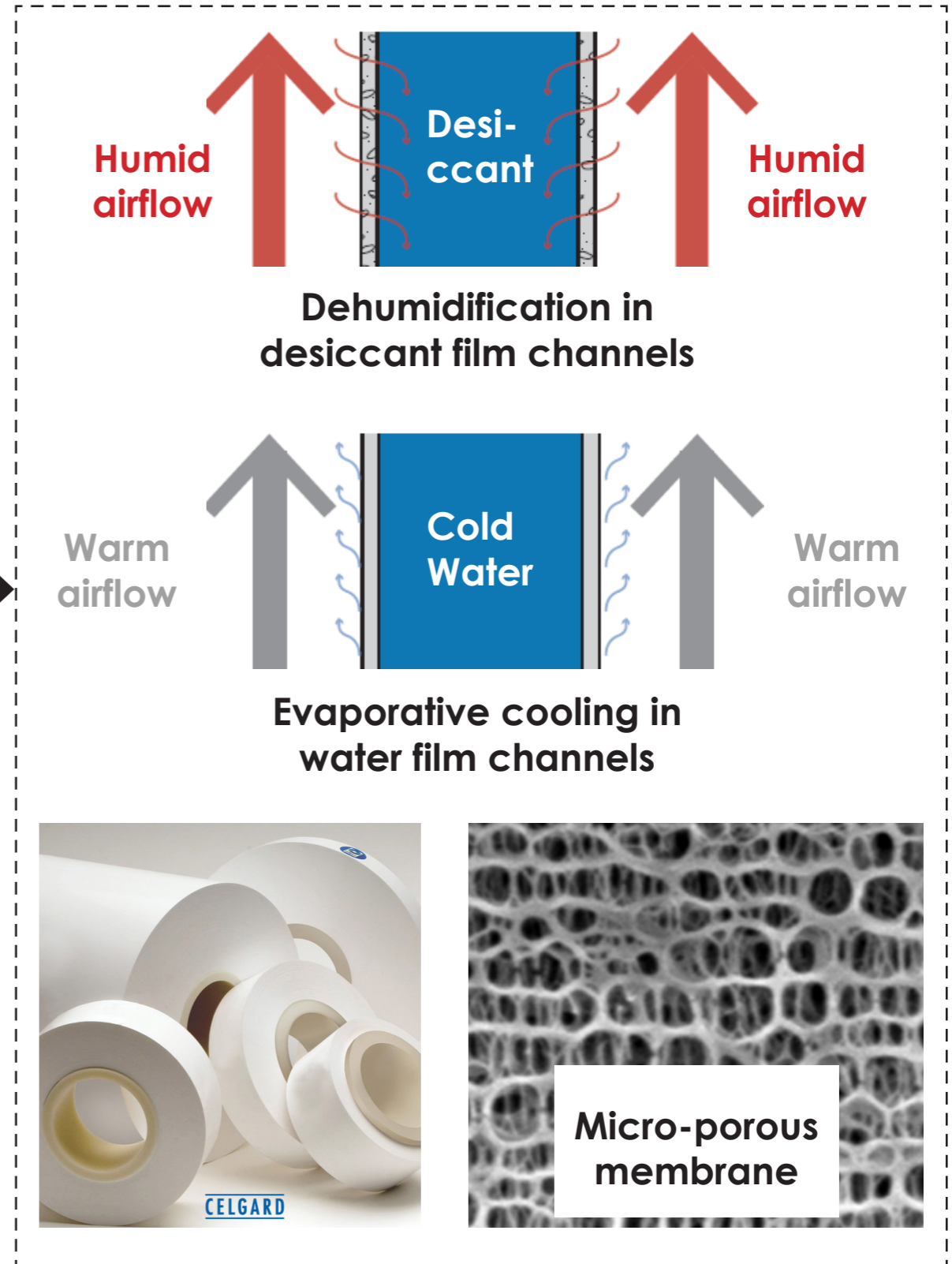


(Source: Elmer et al., 2016)

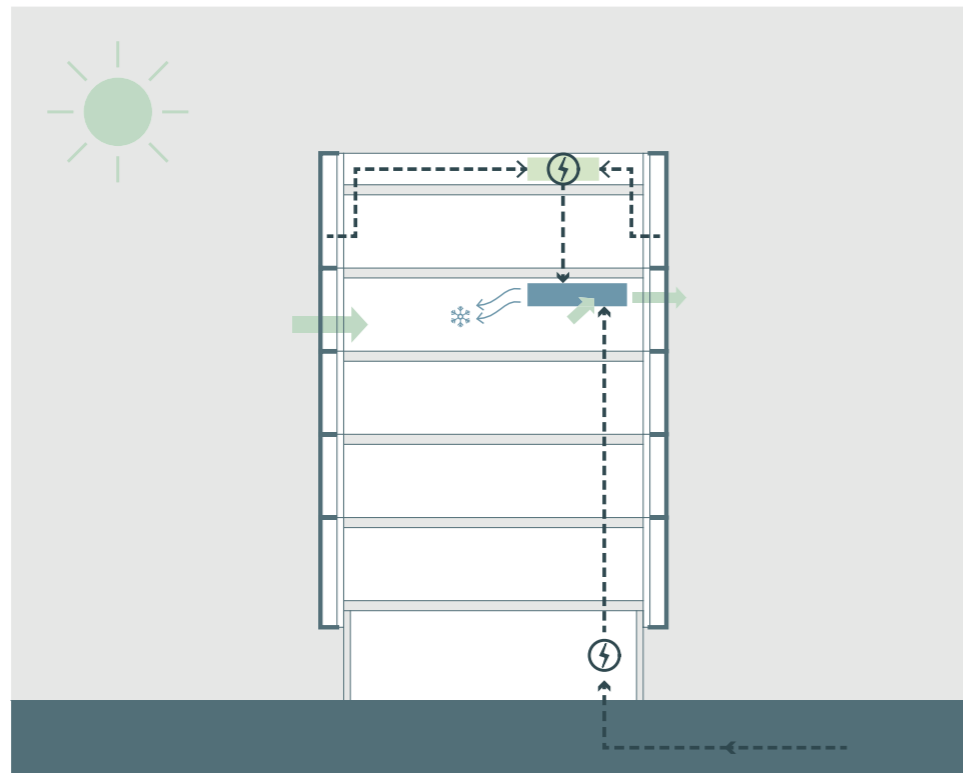
'Wet film' channels



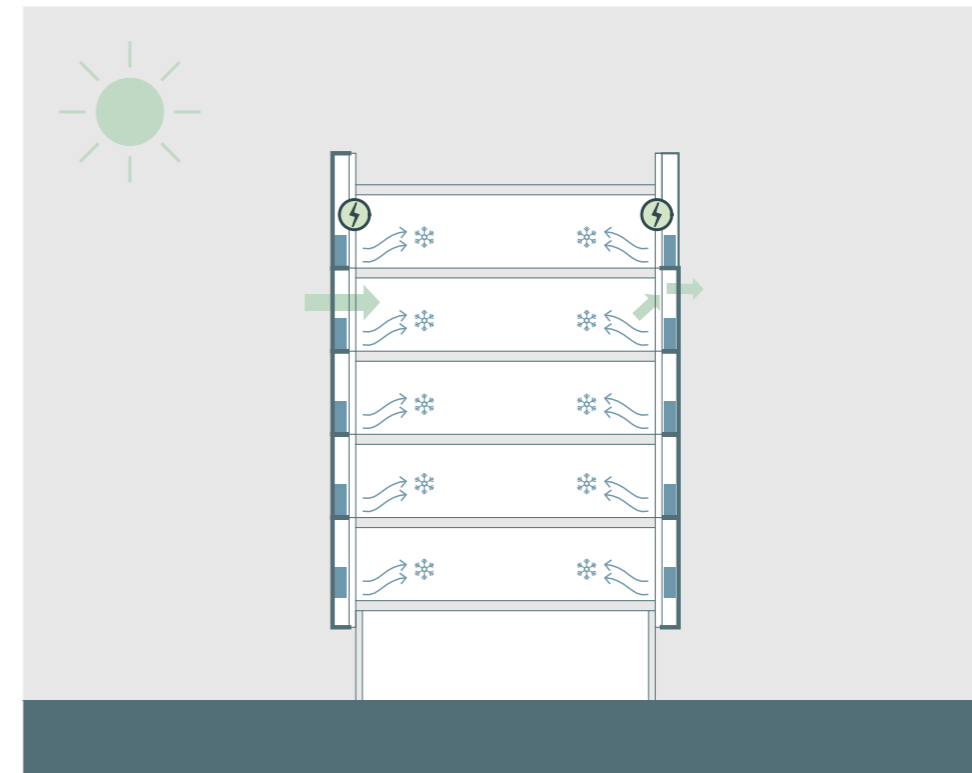
Happening inside the cooling core



Cooling modes conversion

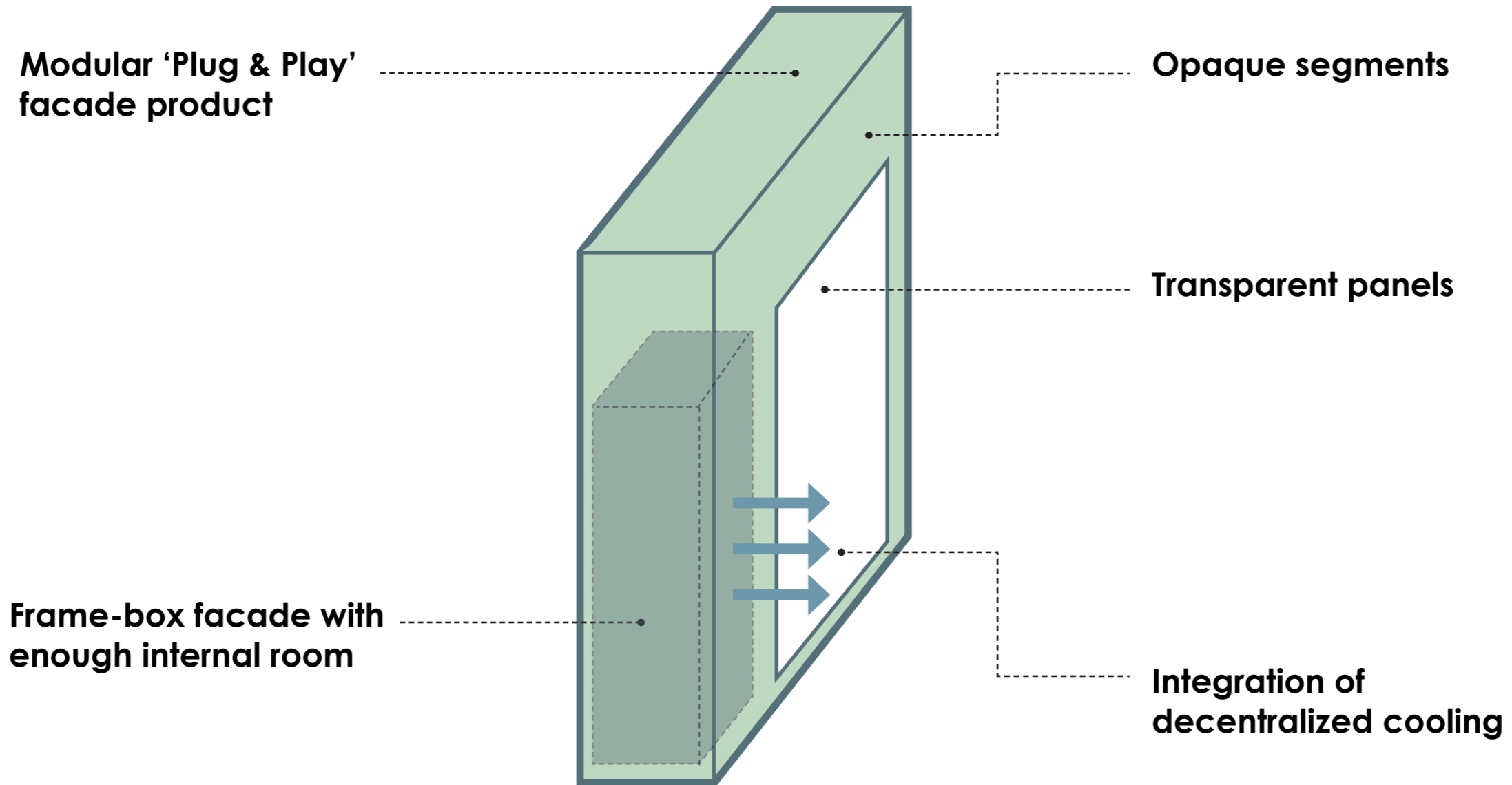


Centralized cooling



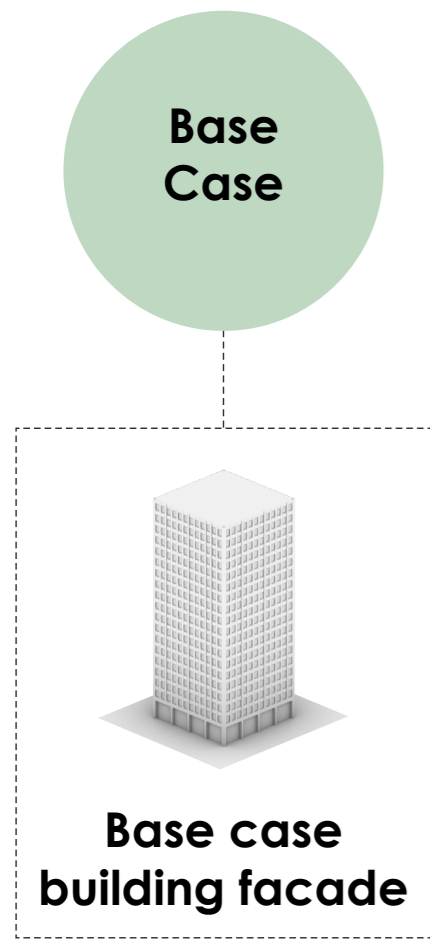
Decentralized cooling

Design concept

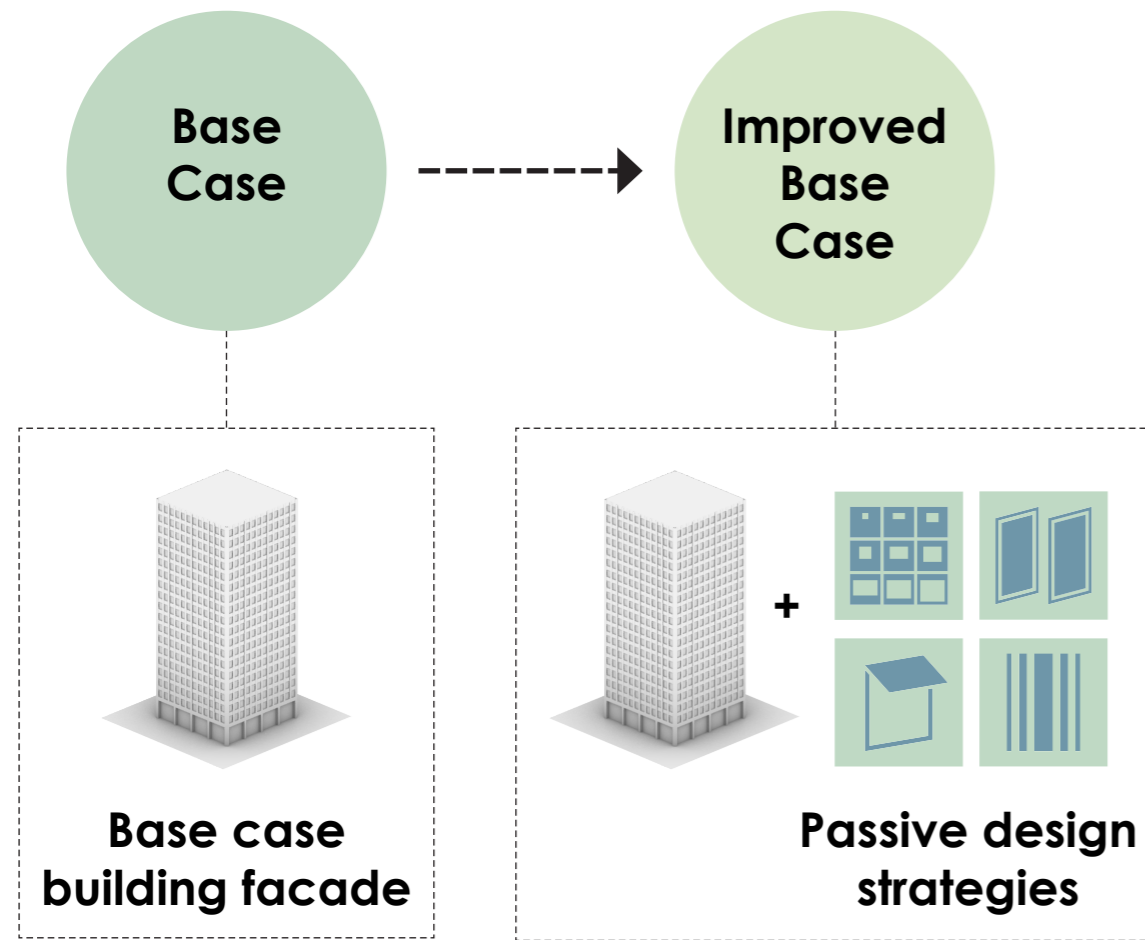


Design plan

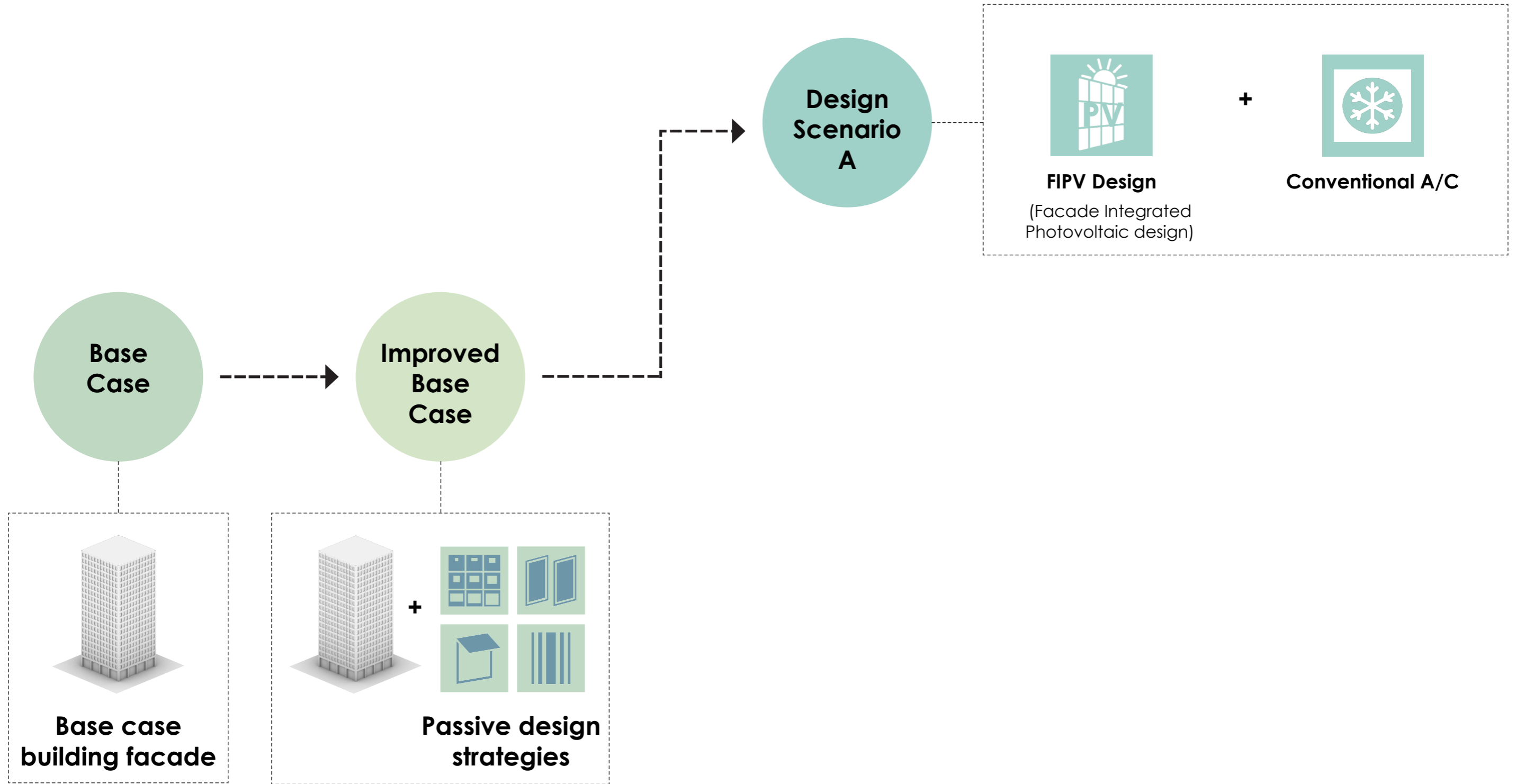
Design plan



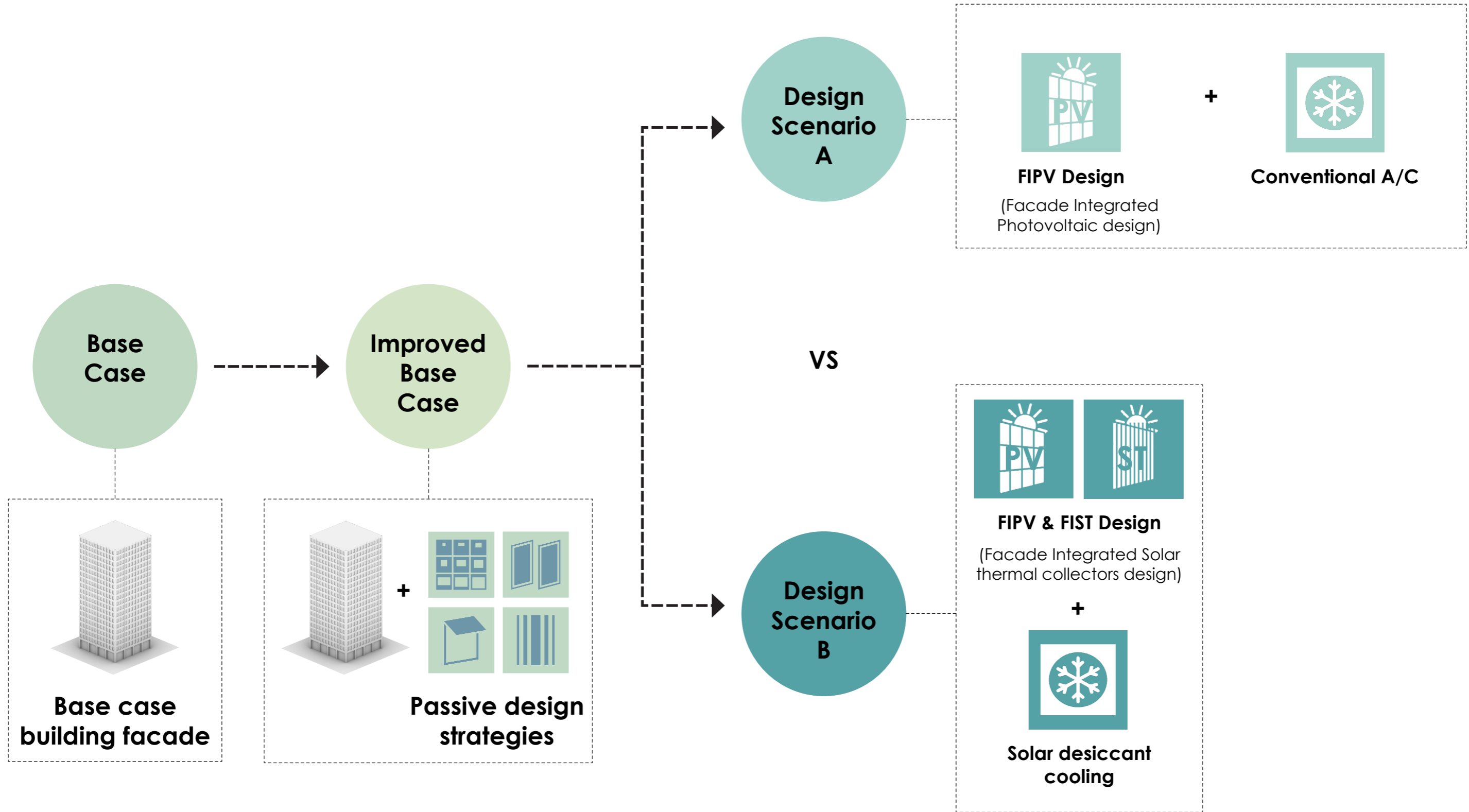
Design plan



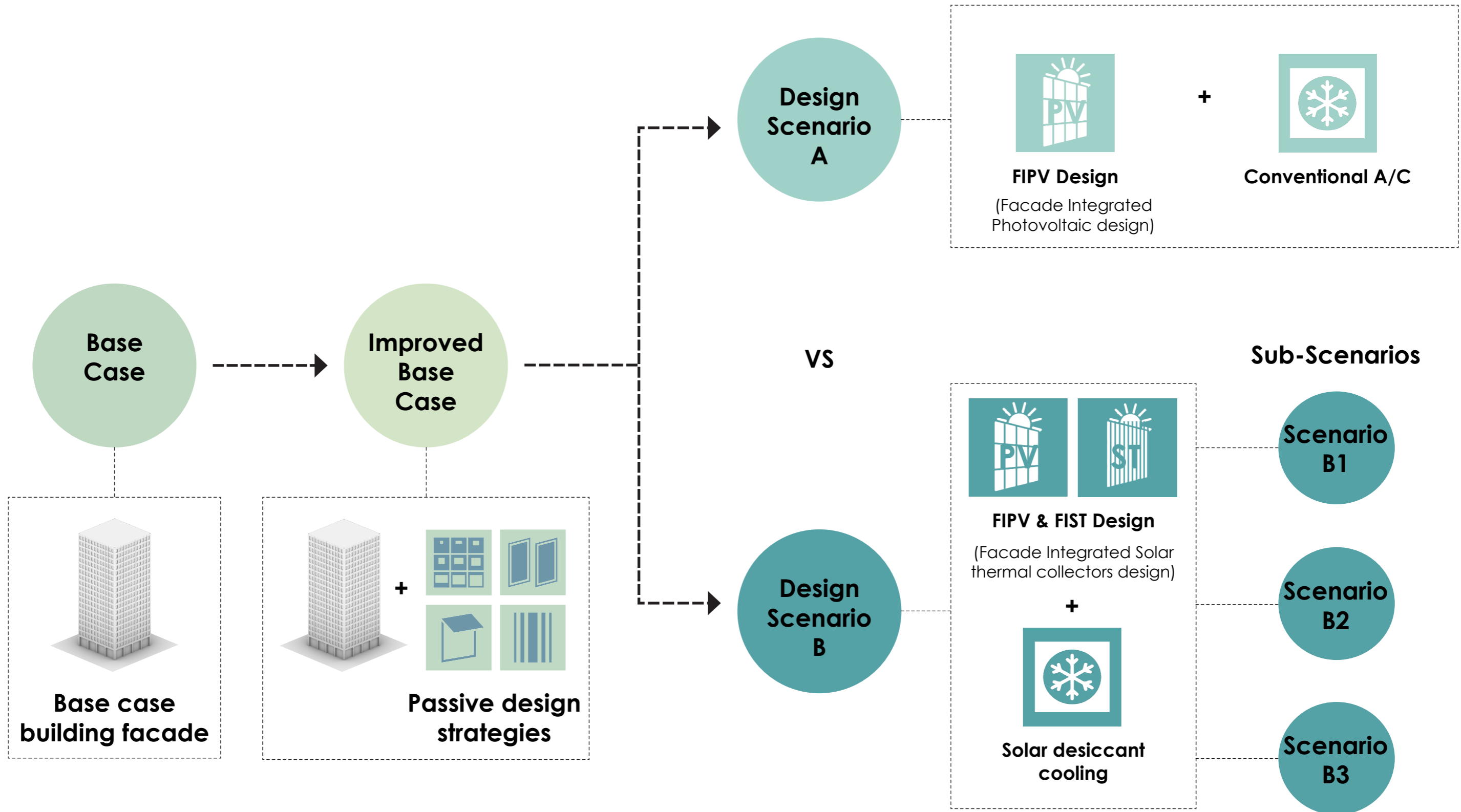
Design plan



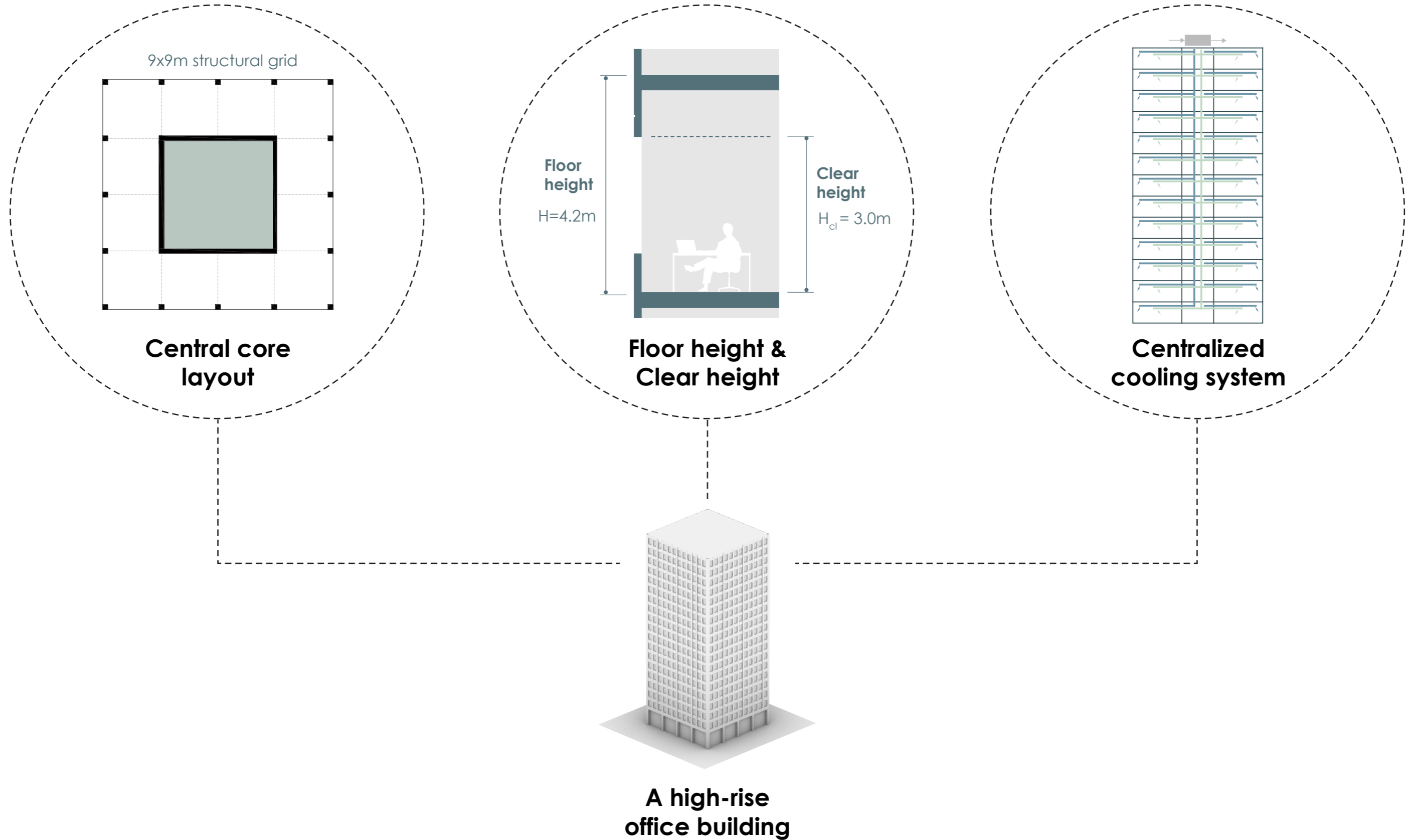
Design plan



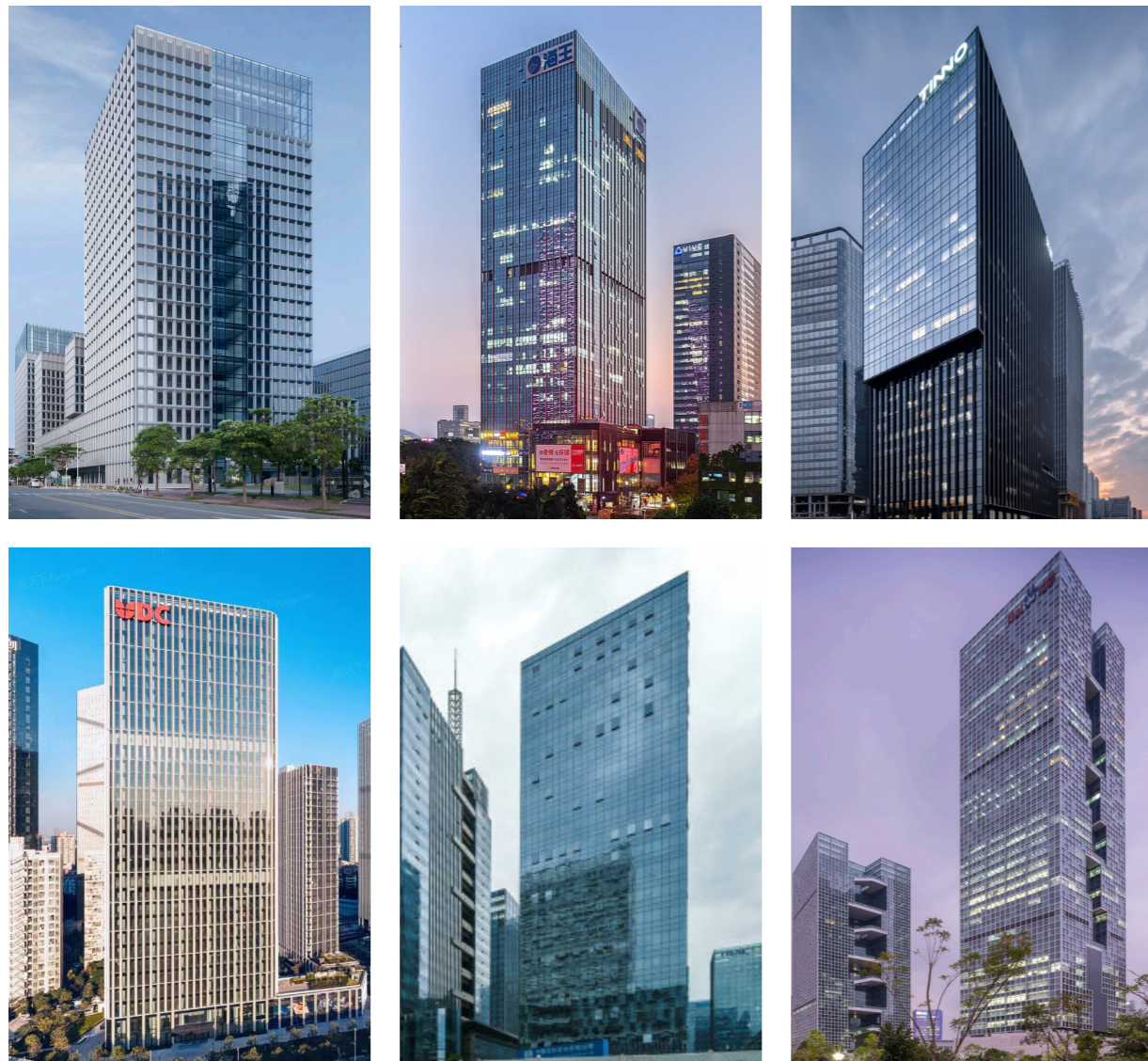
Design plan



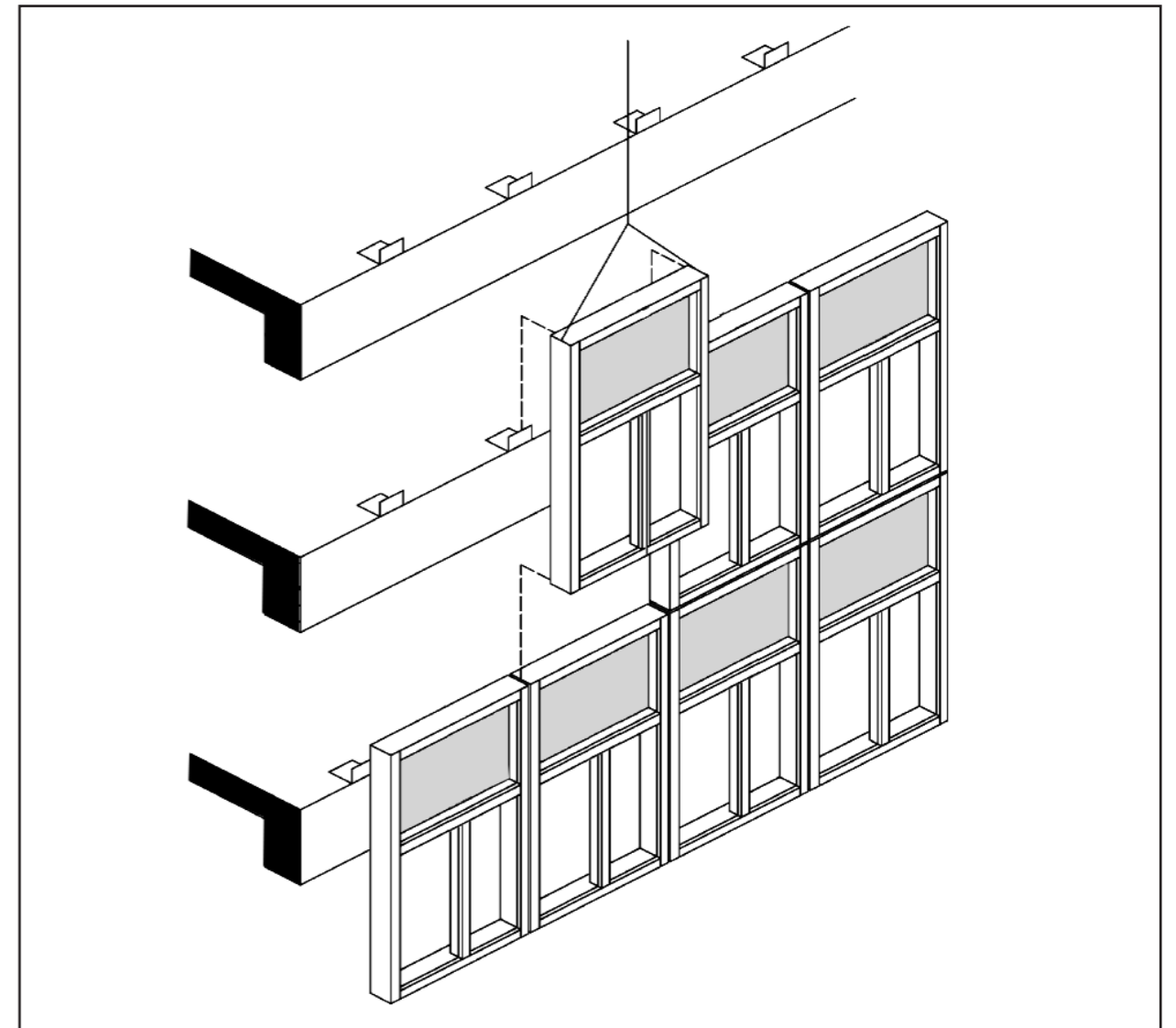
Base case - a generic high-rise office building in Shenzhen



Facade typology of base case building

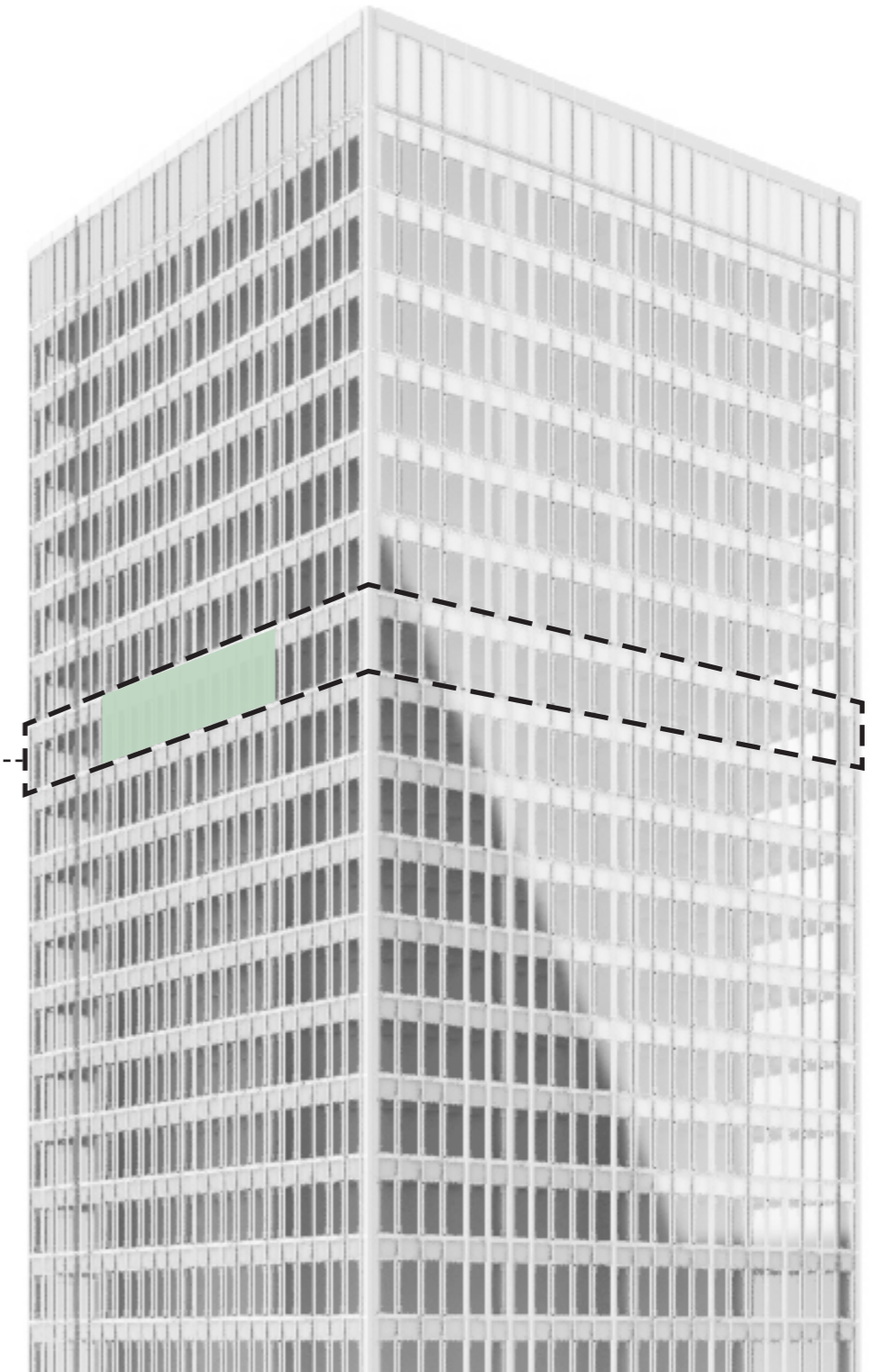
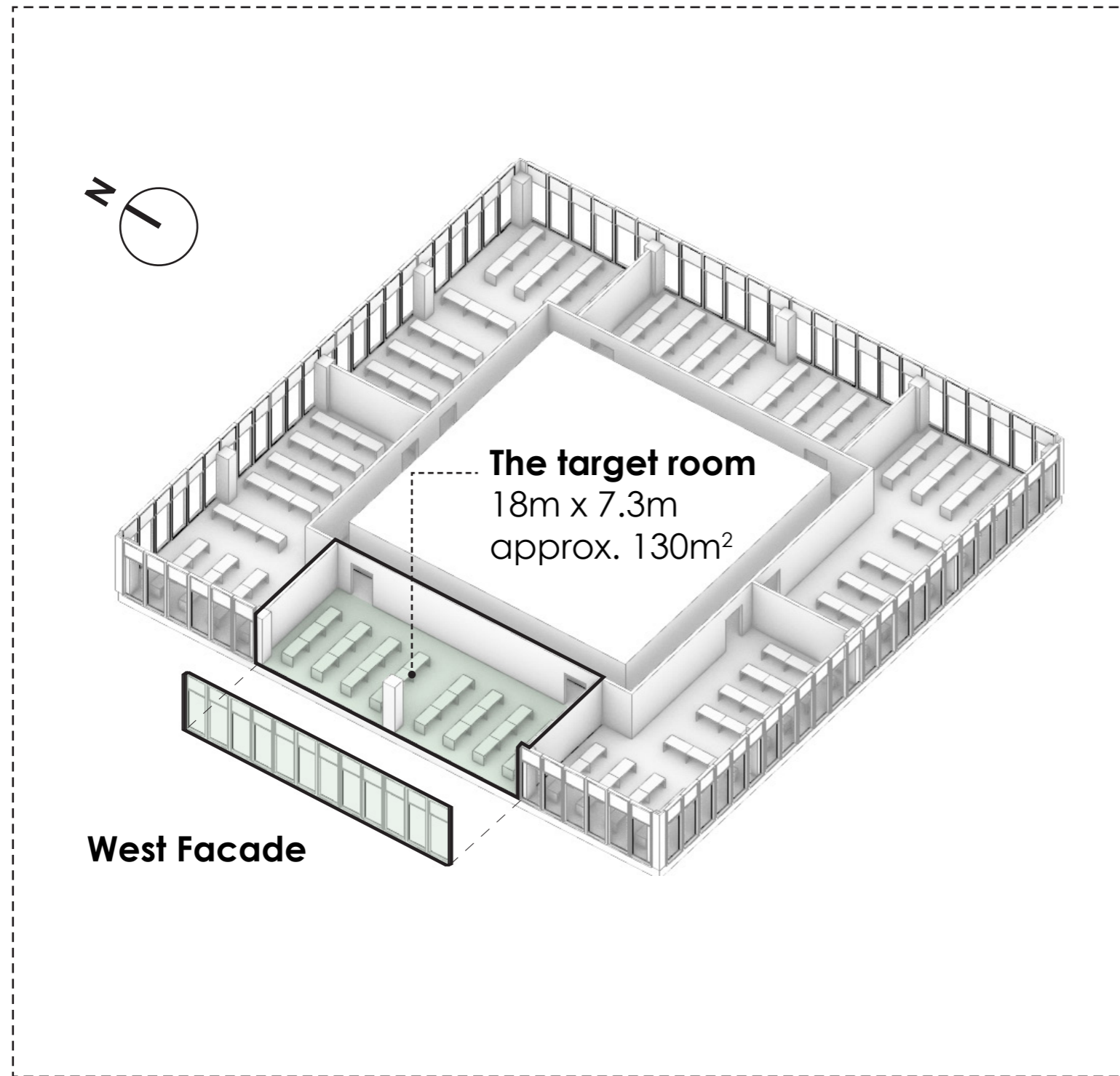


Representative office buildings' facade typology

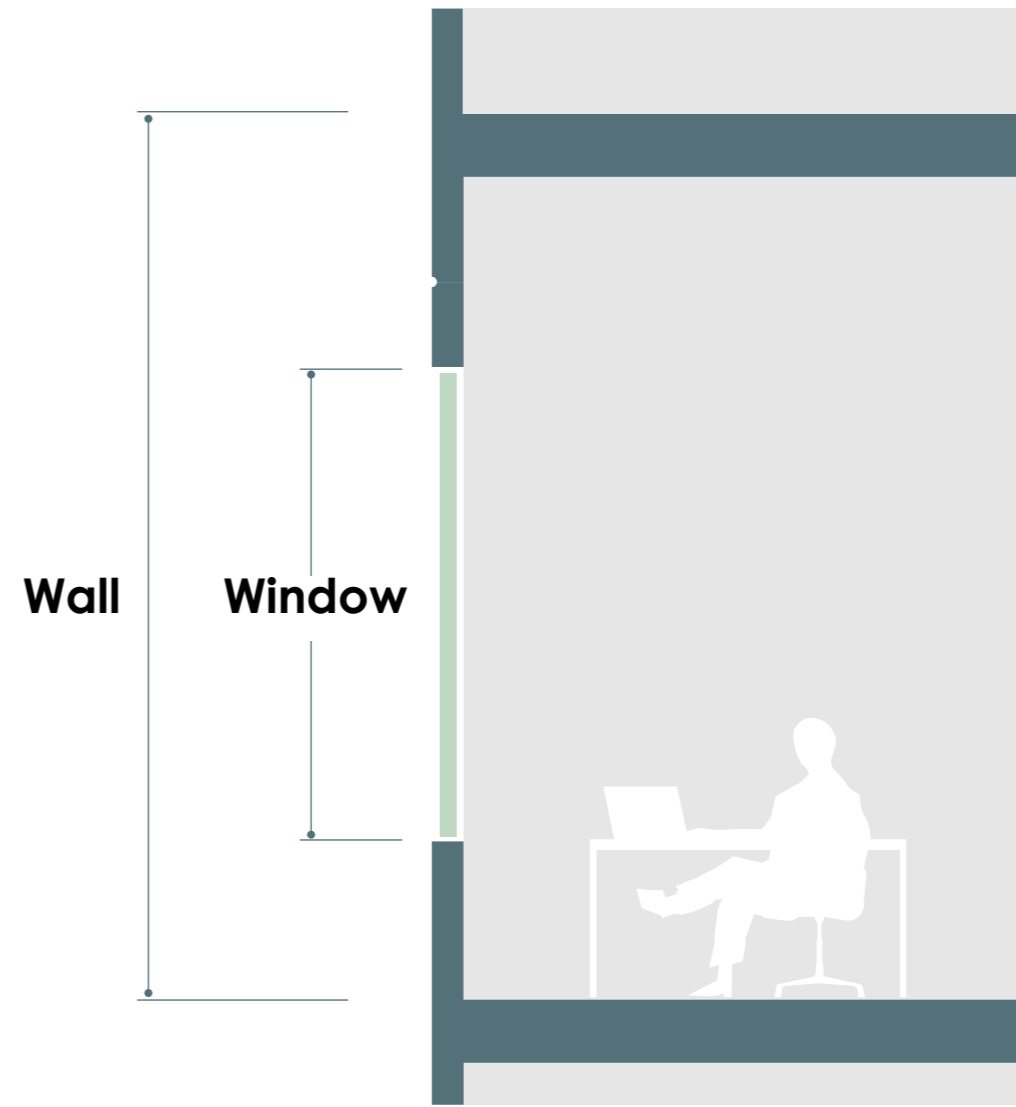
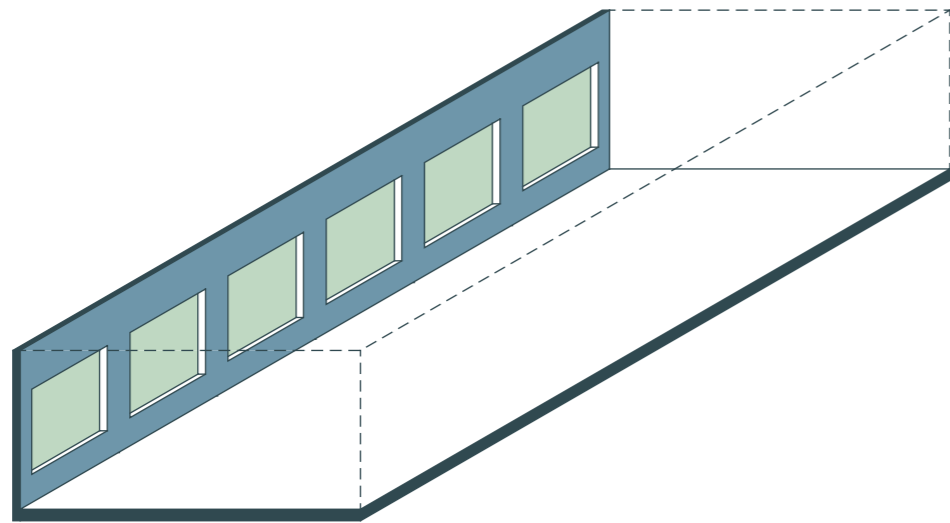
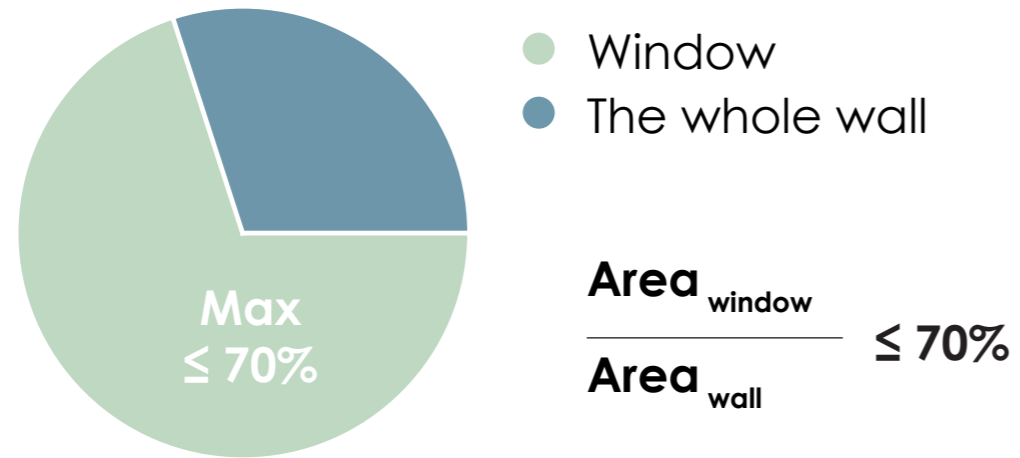


Unitized aluminium frame - glass curtain wall system

The target room

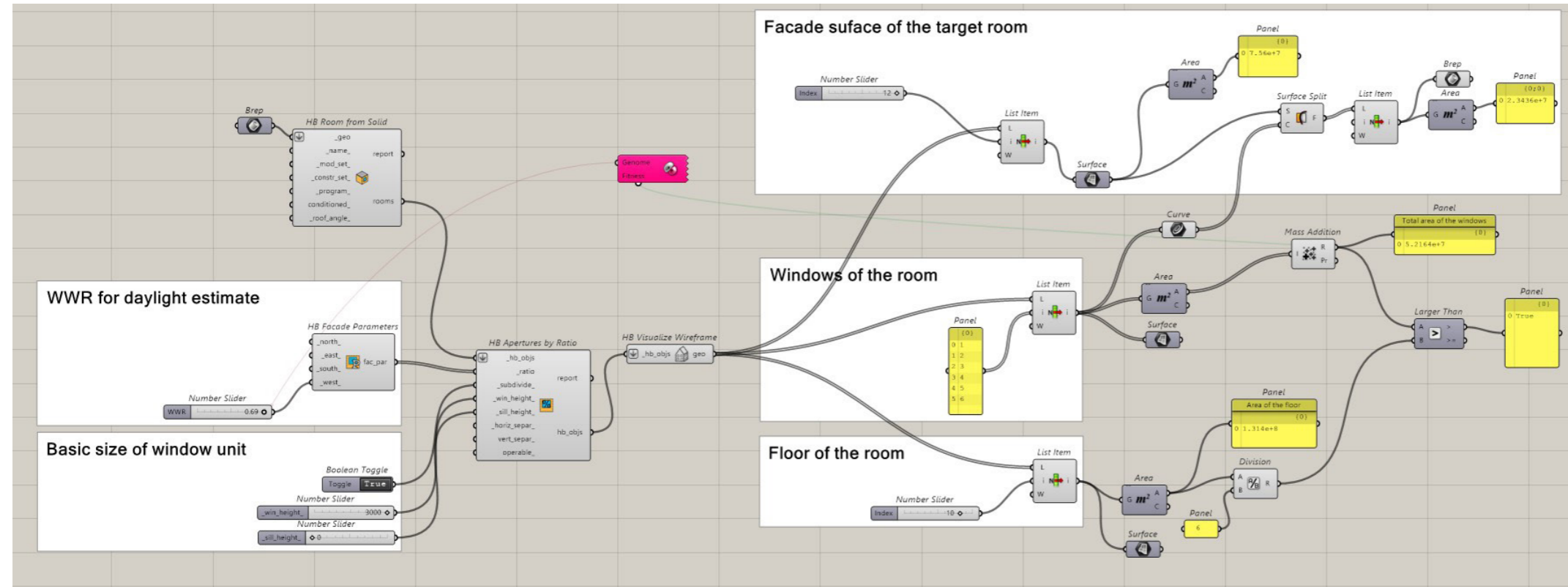


Regulation limit to window-to-wall ratio (WWR)

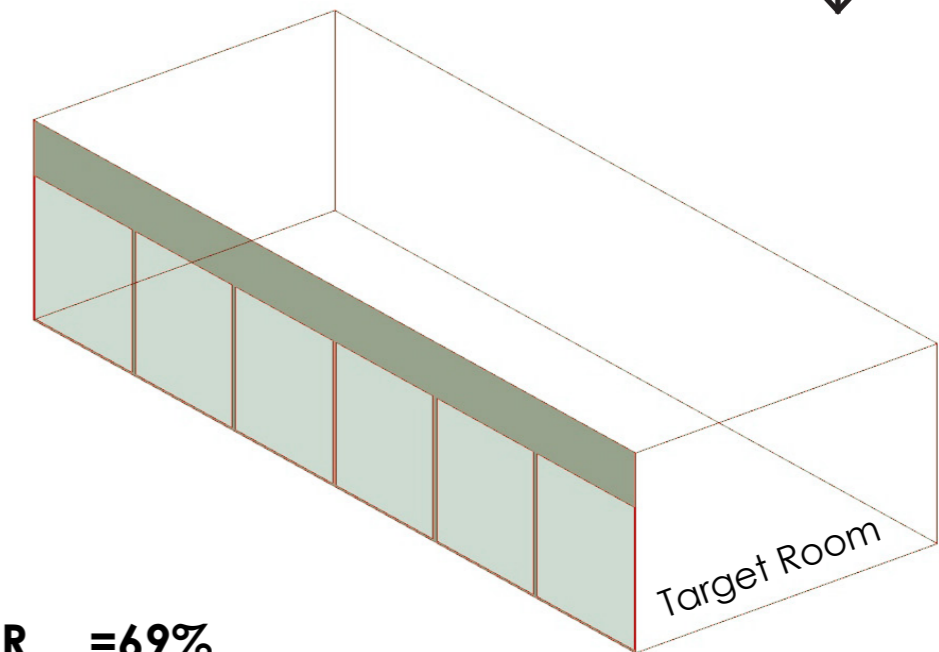
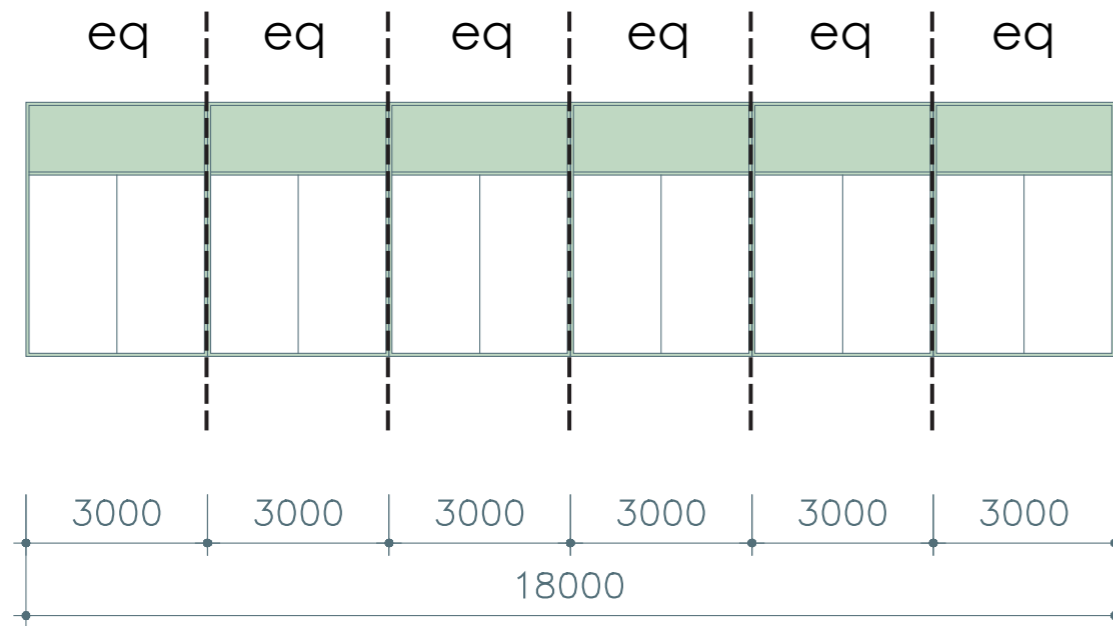


(Source: Chinese national design regulation - GB 50189 Design standard for energy efficiency of public buildings)

Facade divisions for the target room



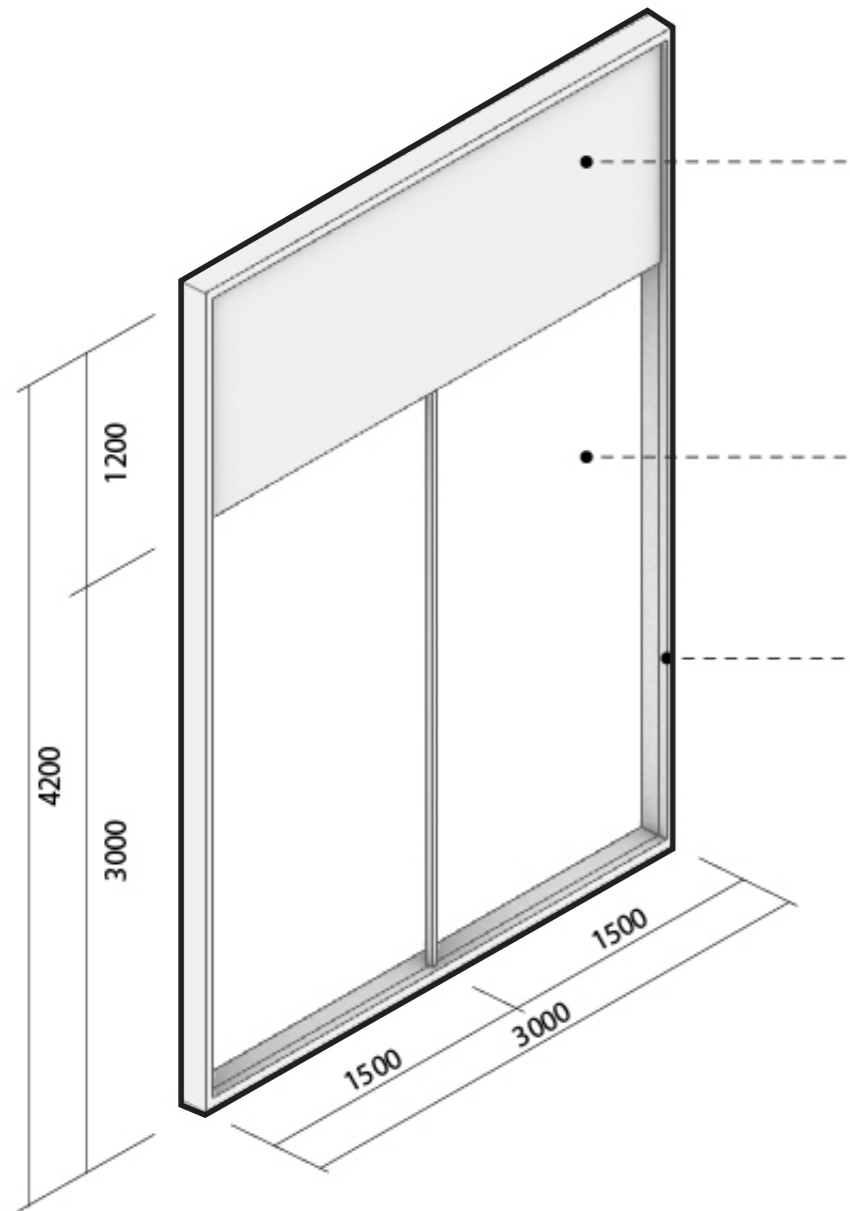
Facade division
(input WWR ≤ 70%)



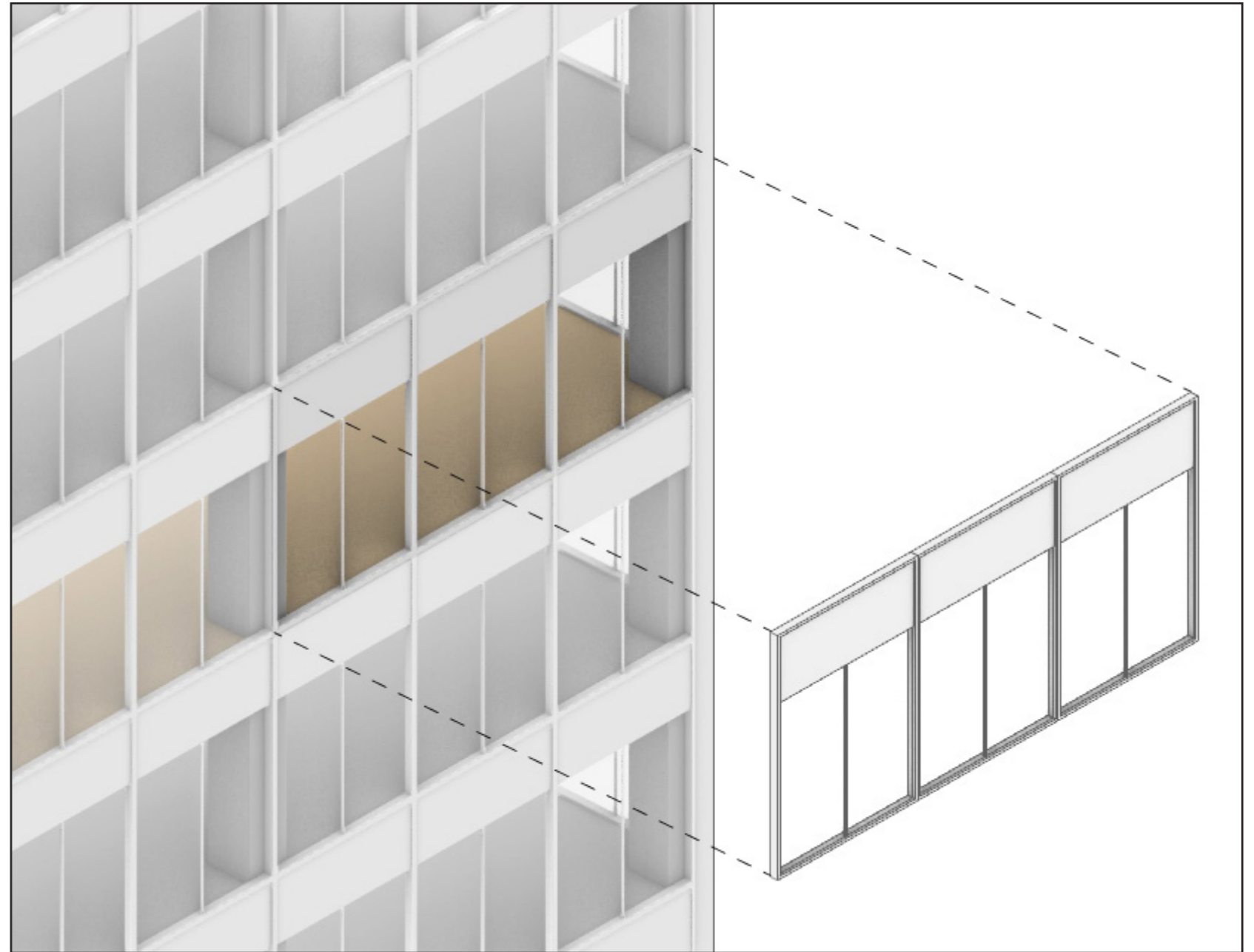
Result: **WWR_{max} = 69%**

(Source: Grasshopper-Honeybee)

Facade module for base case

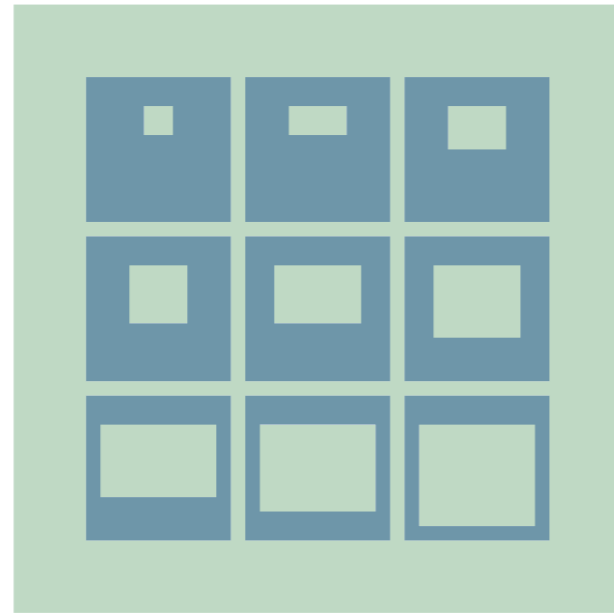


**Modular dimension:
3000(w) x 4200(h) x 150(d) mm**

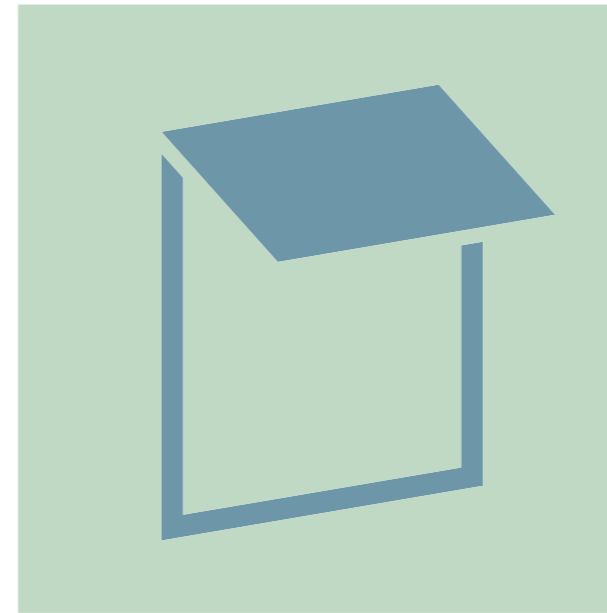


Facade module for the base case building

Passive design strategies

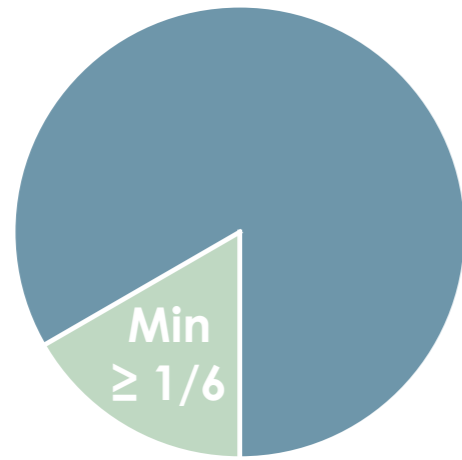


**Adjustment of
window-to-wall ratio**



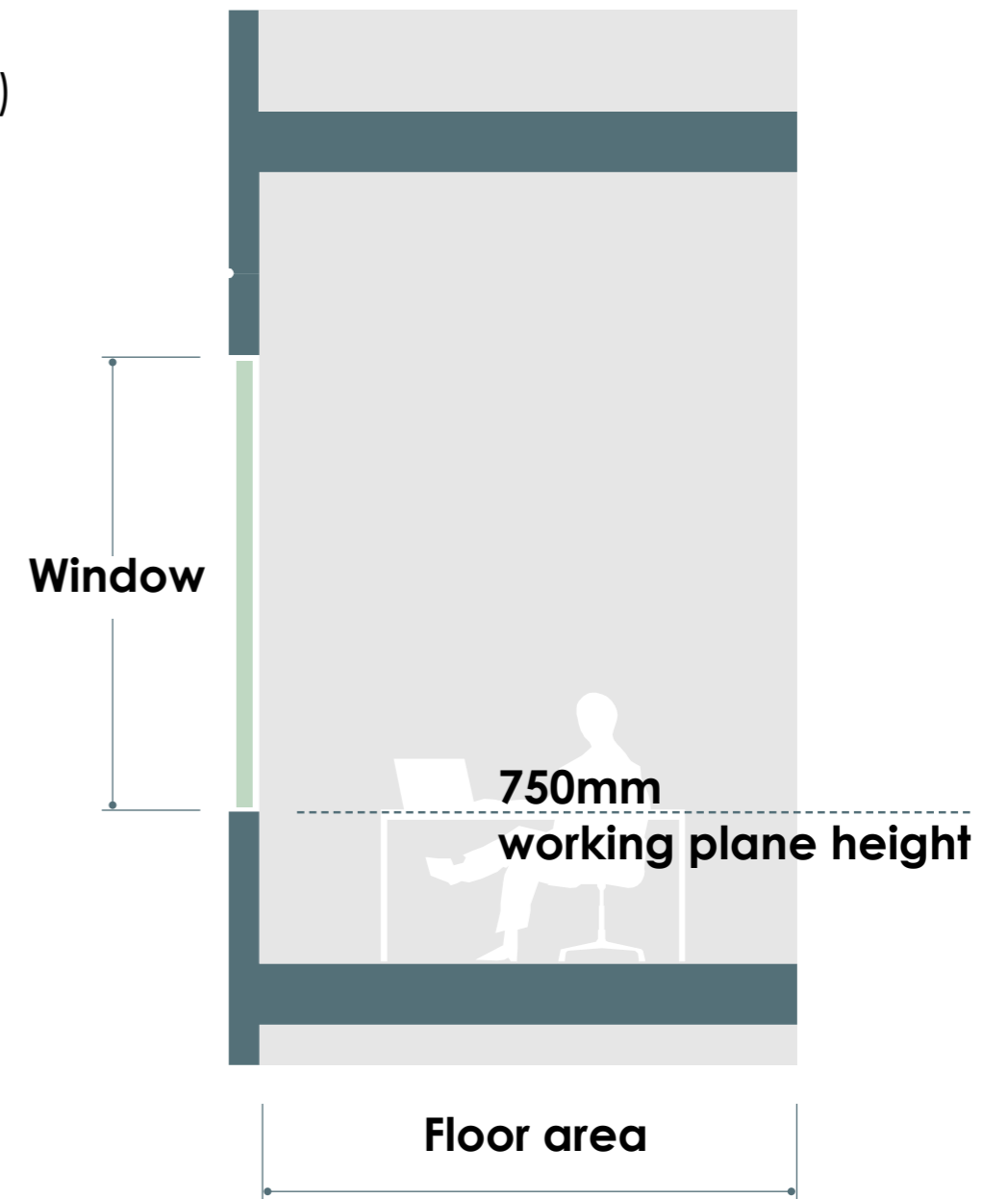
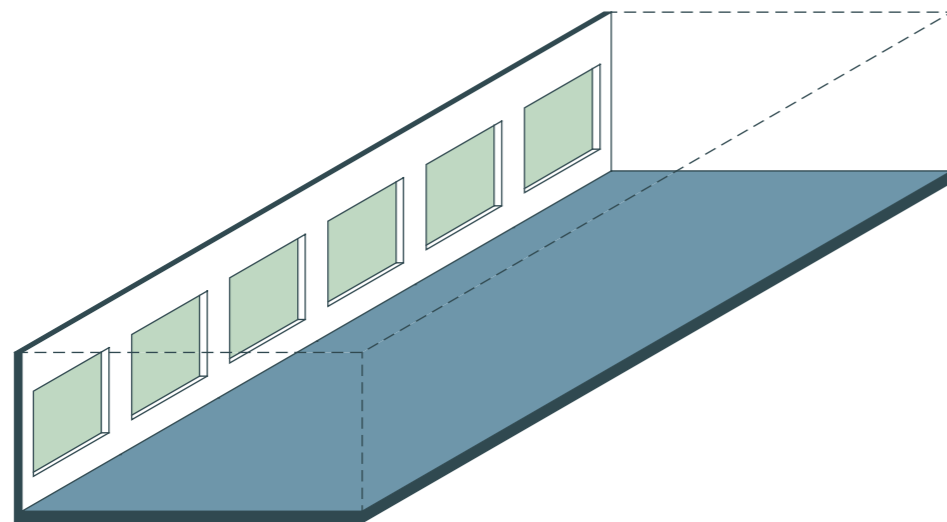
**Design of
sun shading elements**

Regulation limit to window-to-floor ratio (WFR)



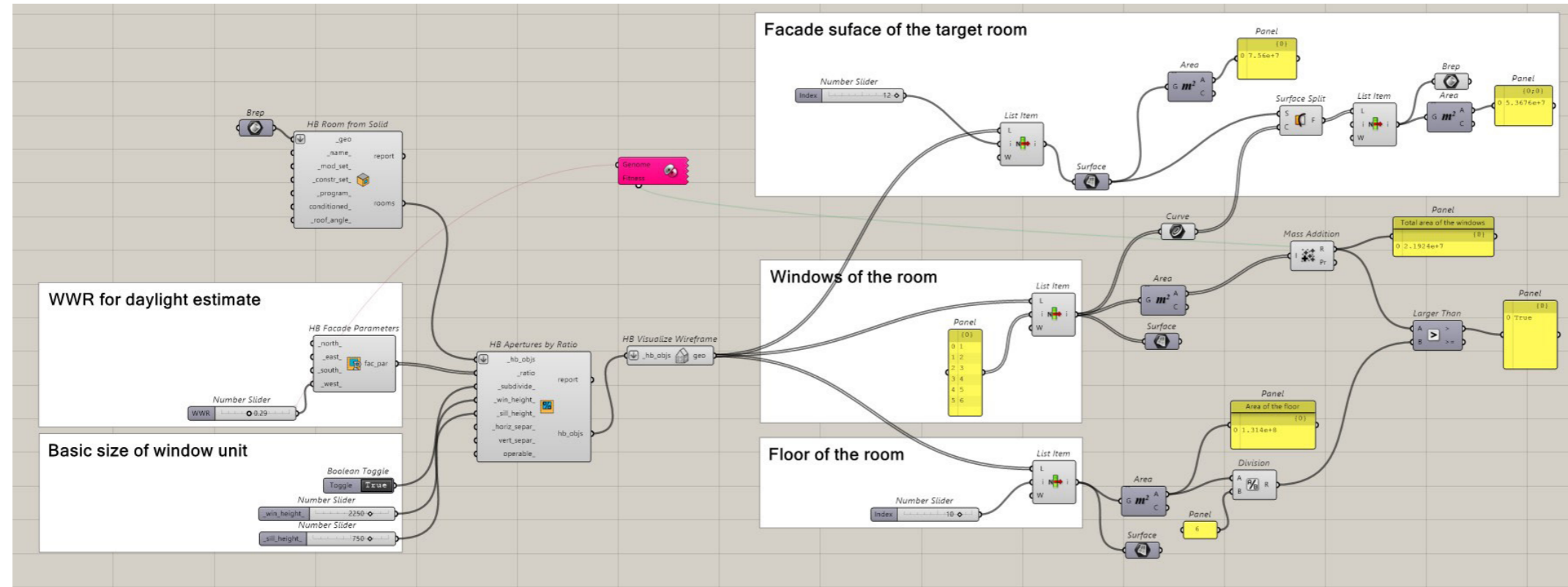
- Window area (above working plane height)
- Floor area

$$\frac{\text{Area}_{\text{window}}}{\text{Area}_{\text{floor}}} \geq 1/6$$

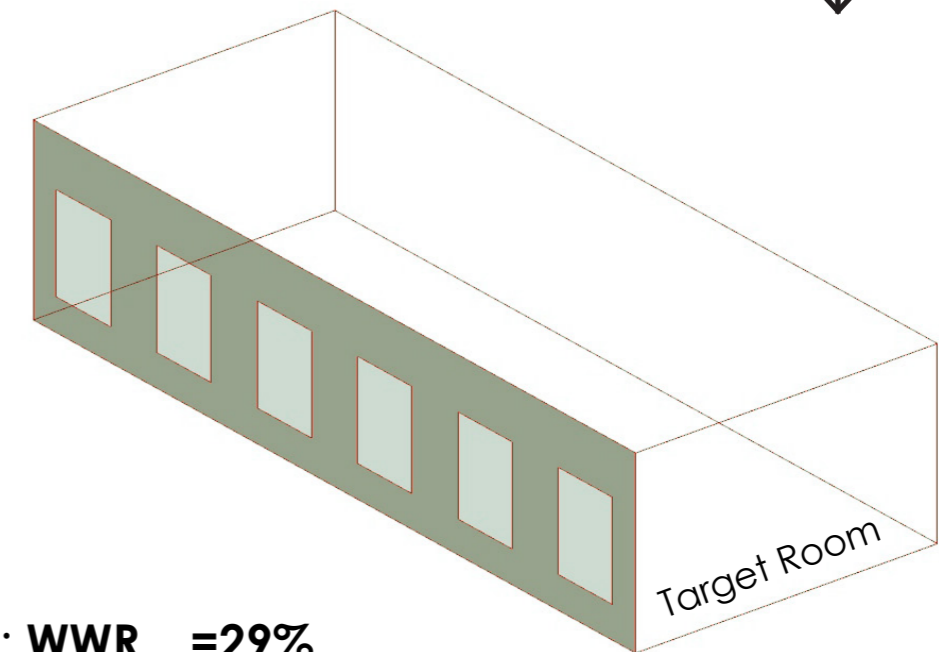
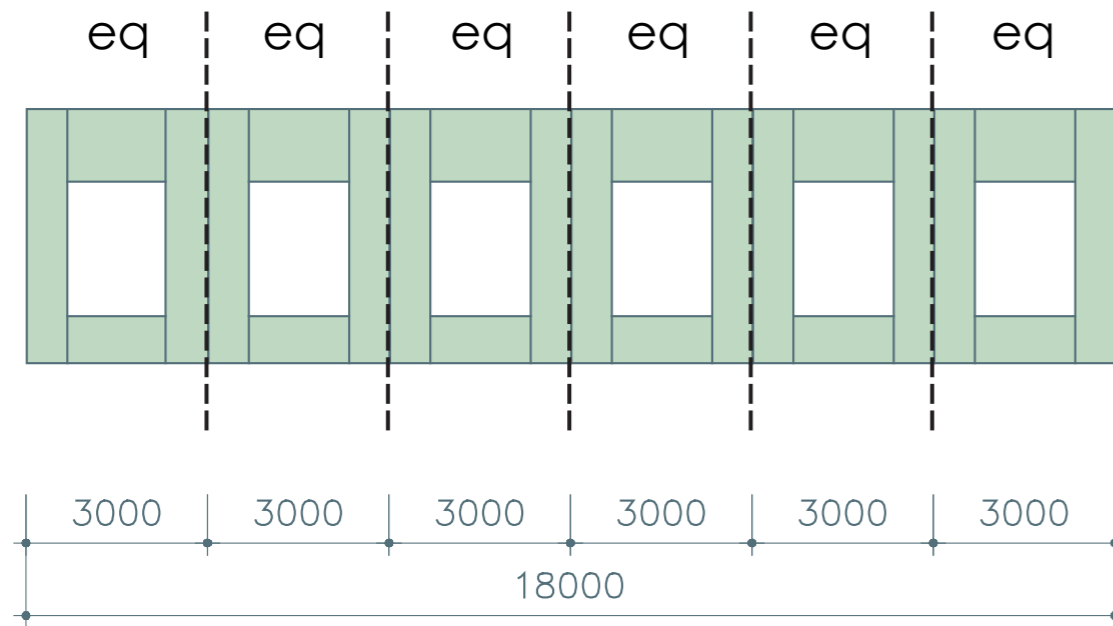


(Source: Chinese national design regulation GB 50033 Standard for daylighting design of buildings)

WWR adjustment for the target room

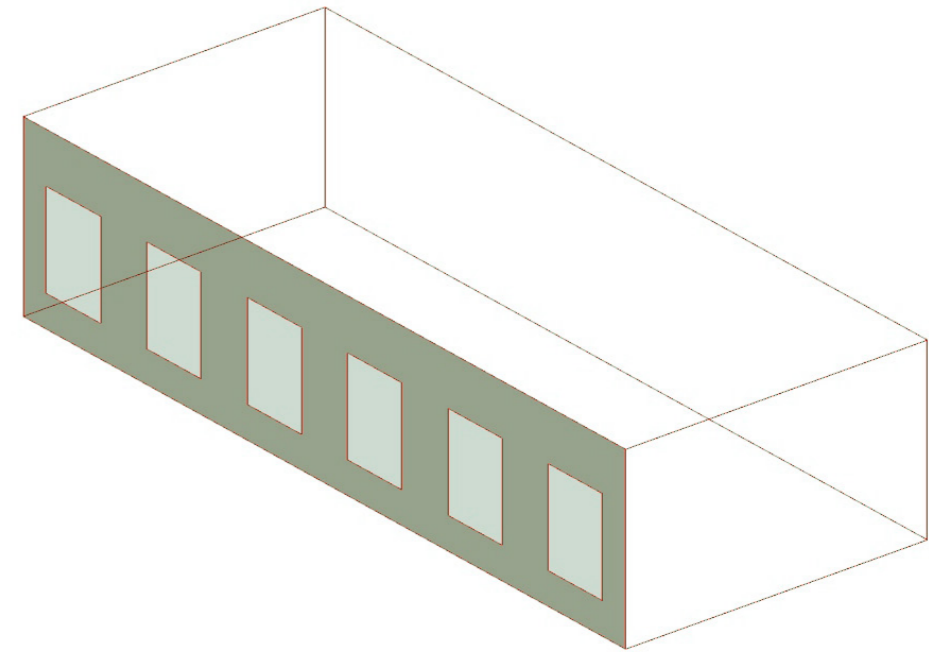
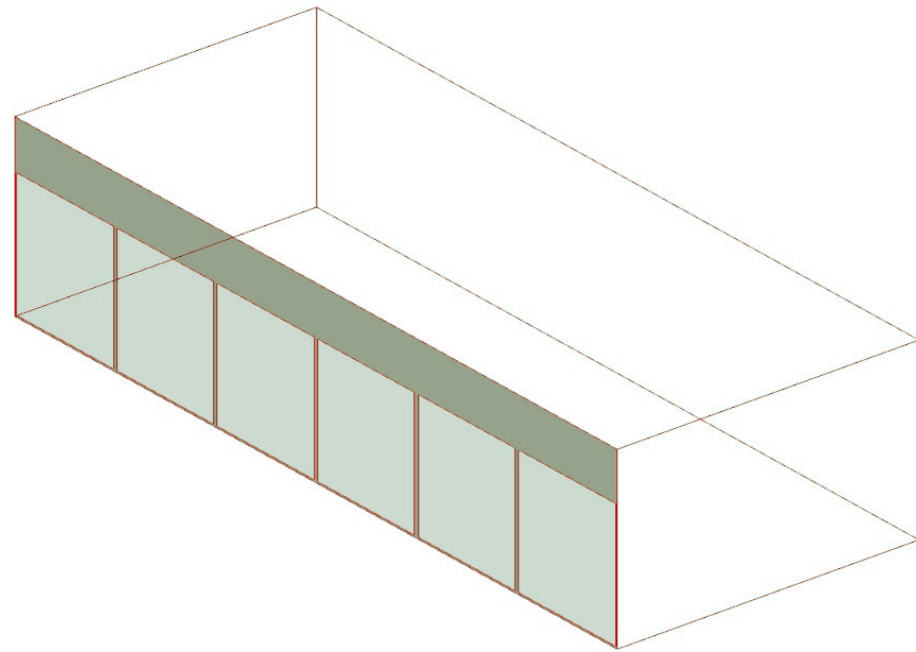
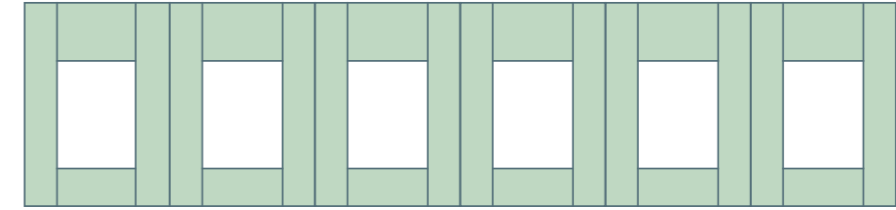
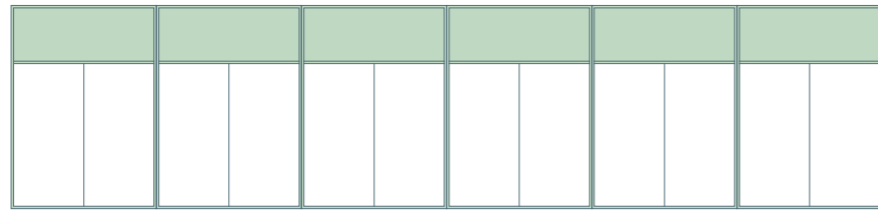


WWR adjustment
(input WFR $\geq 1/6$)



Result: **WWR_{min} = 29%**
(when WFR = 1/6)

WWR optimization



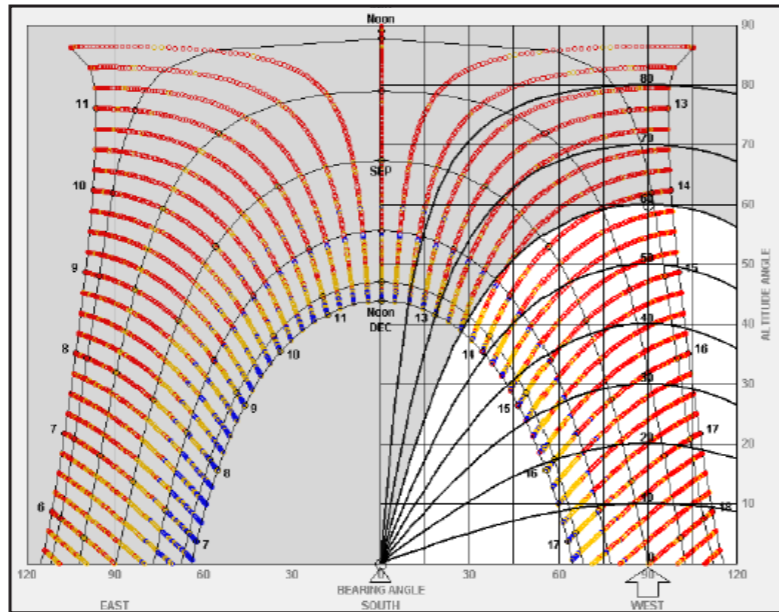
Base case
WWR 69%



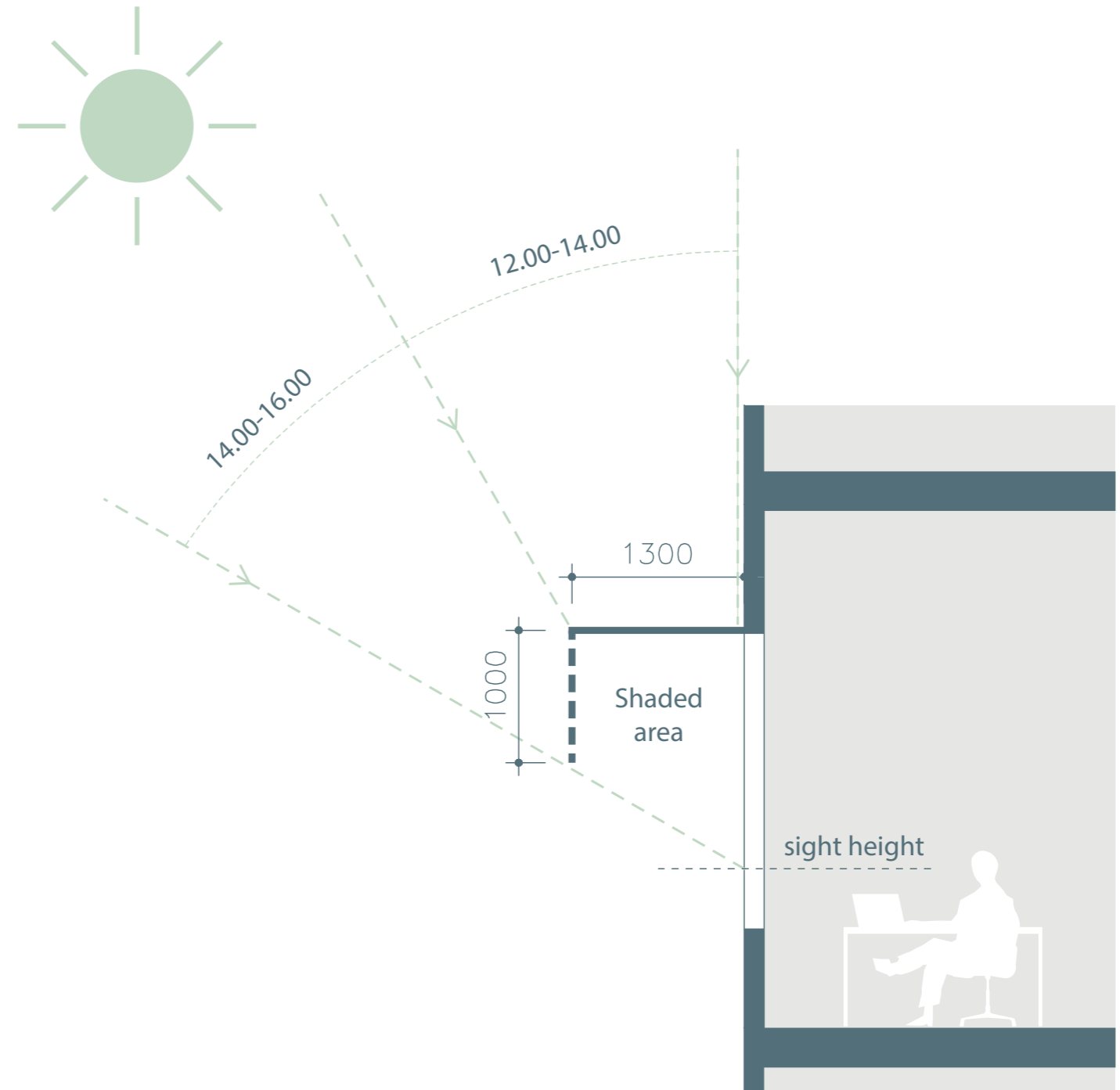
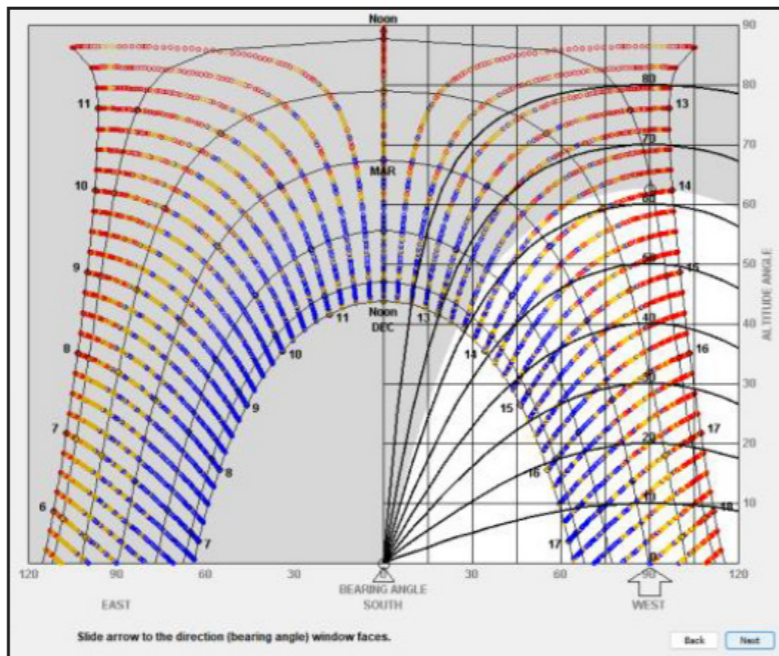
Improved Base Case
WWR 29%

Sun shading analysis

Summertime

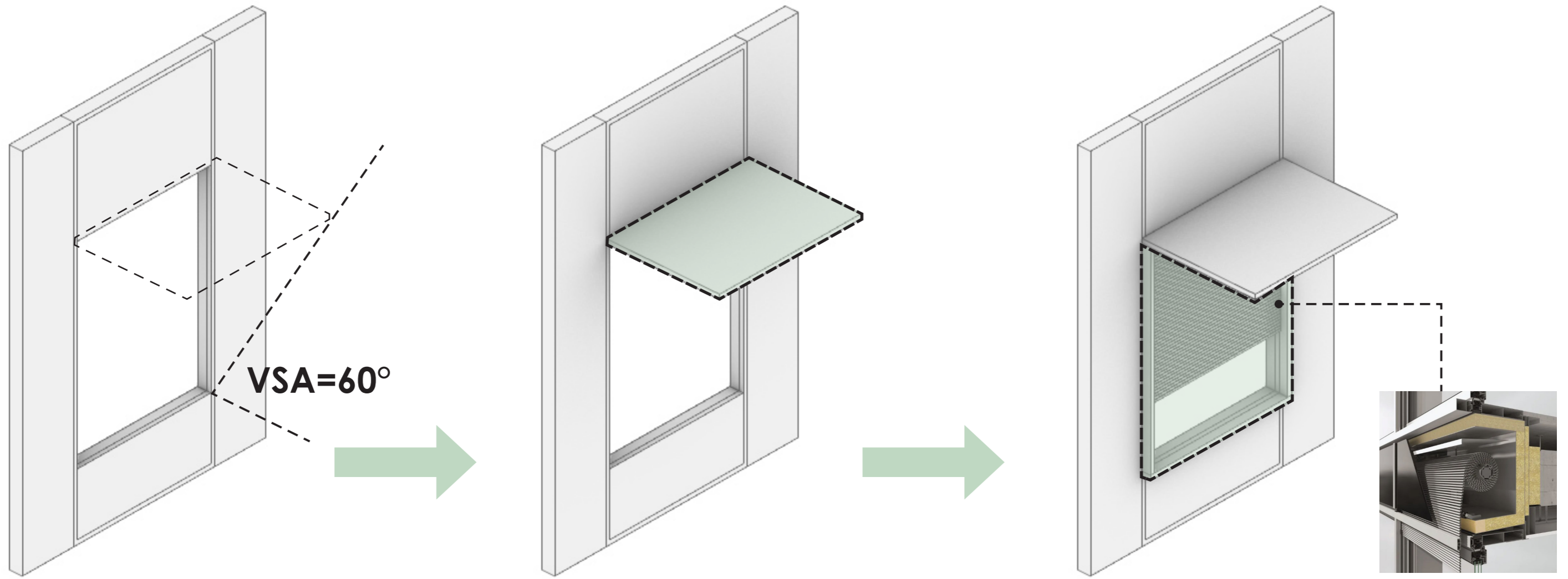


Wintertime



(Source: Climate Consultant v6.0 program)

Sun shading elements design

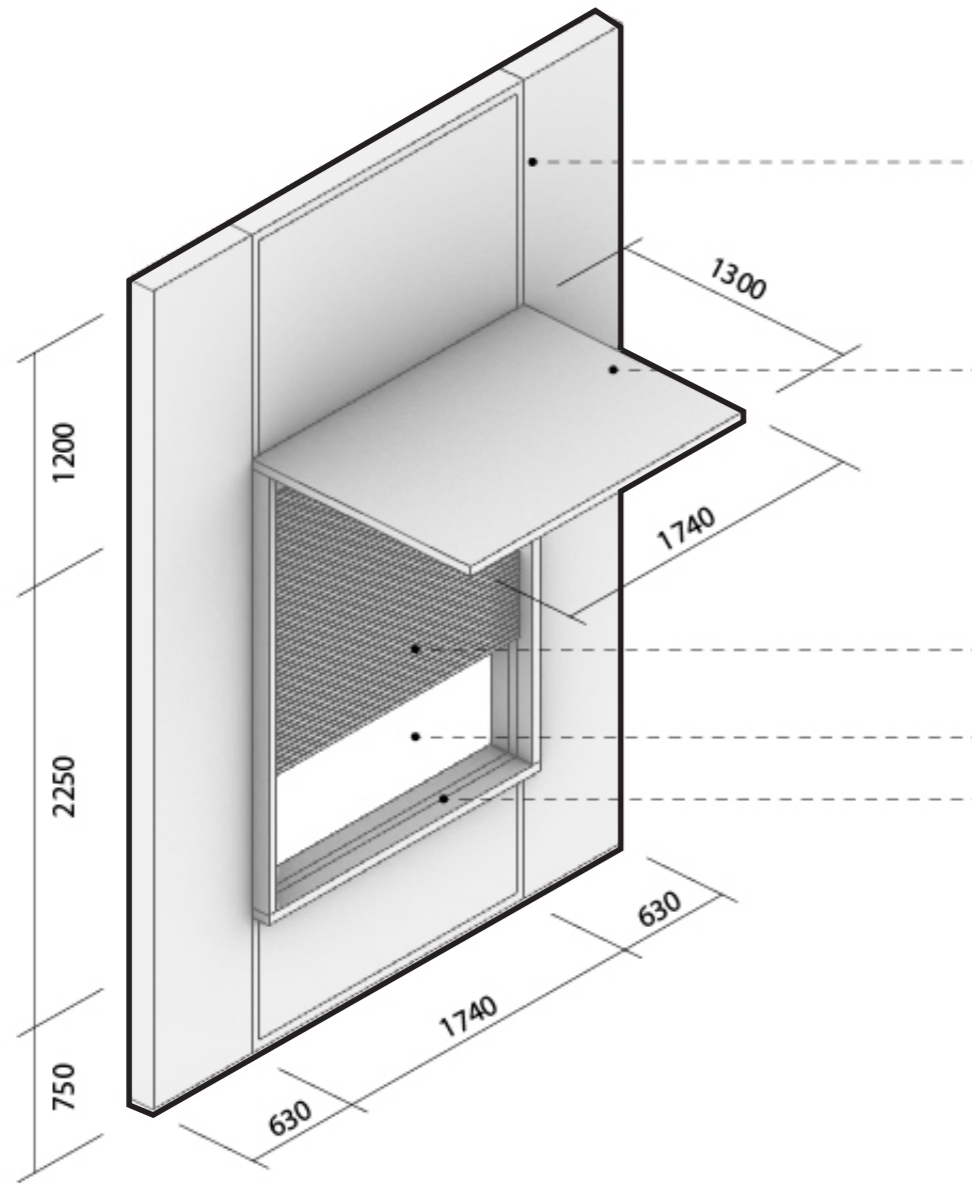


Vertical shadow angle

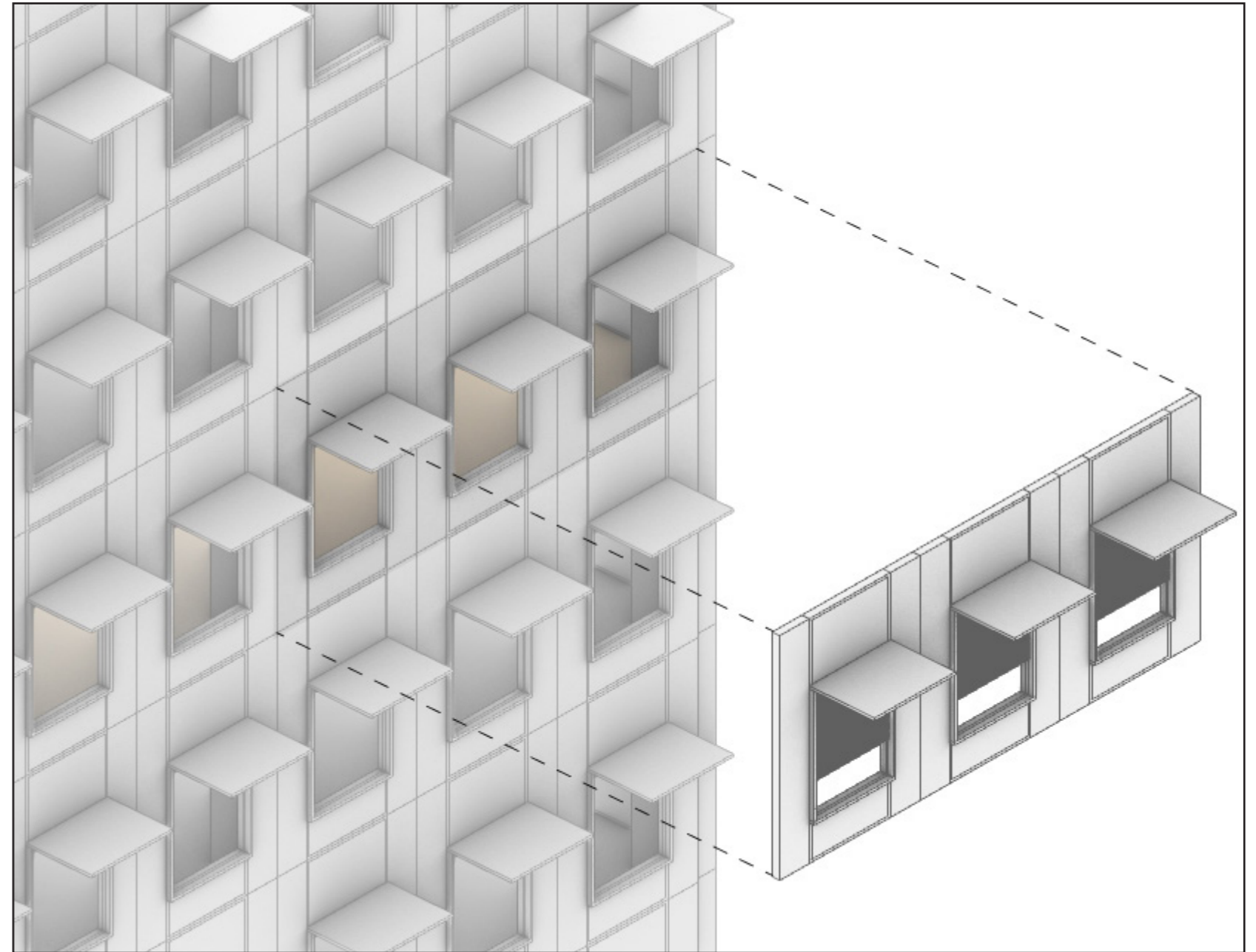
Fixed overhang shading panel

Non-fixed sun blind

Facade module for Improved base case

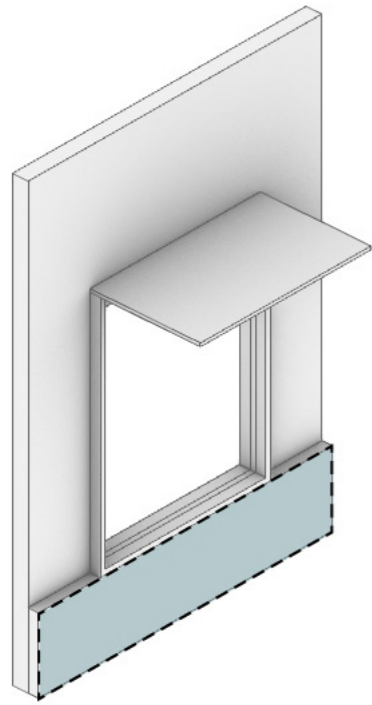


Modular dimension: 3000(d) x 4200(h) mm



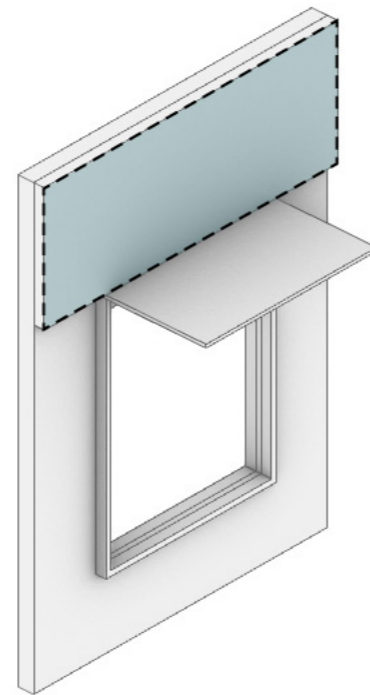
Facade module for Improved base case

FIPV (Facade Integrated PV) design options



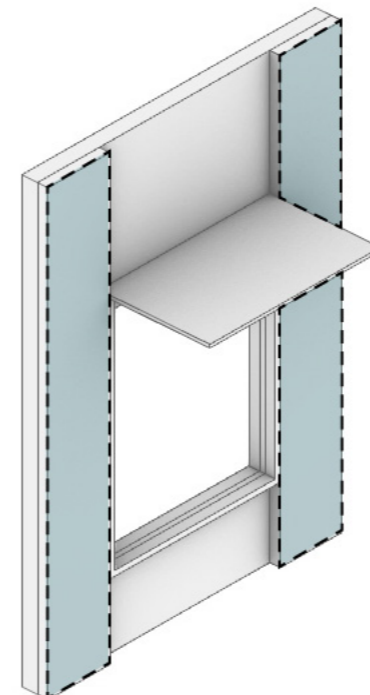
Option P1:

Available area: 2.1m²



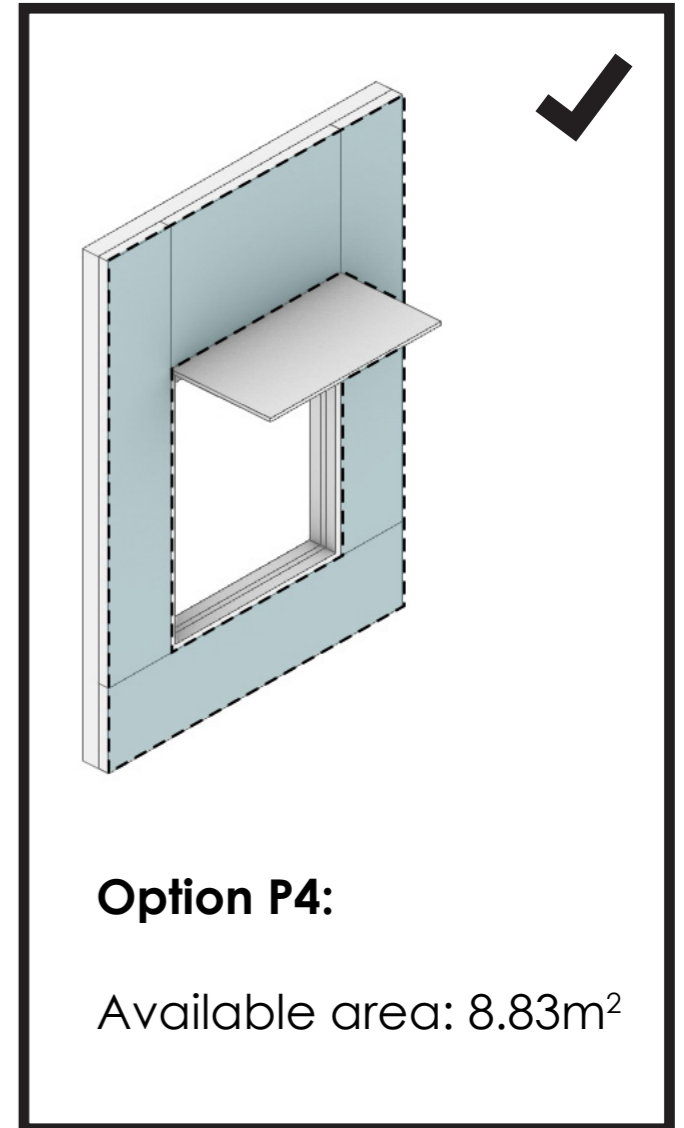
Option P2:

Available area: 3.45m²



Option P3:

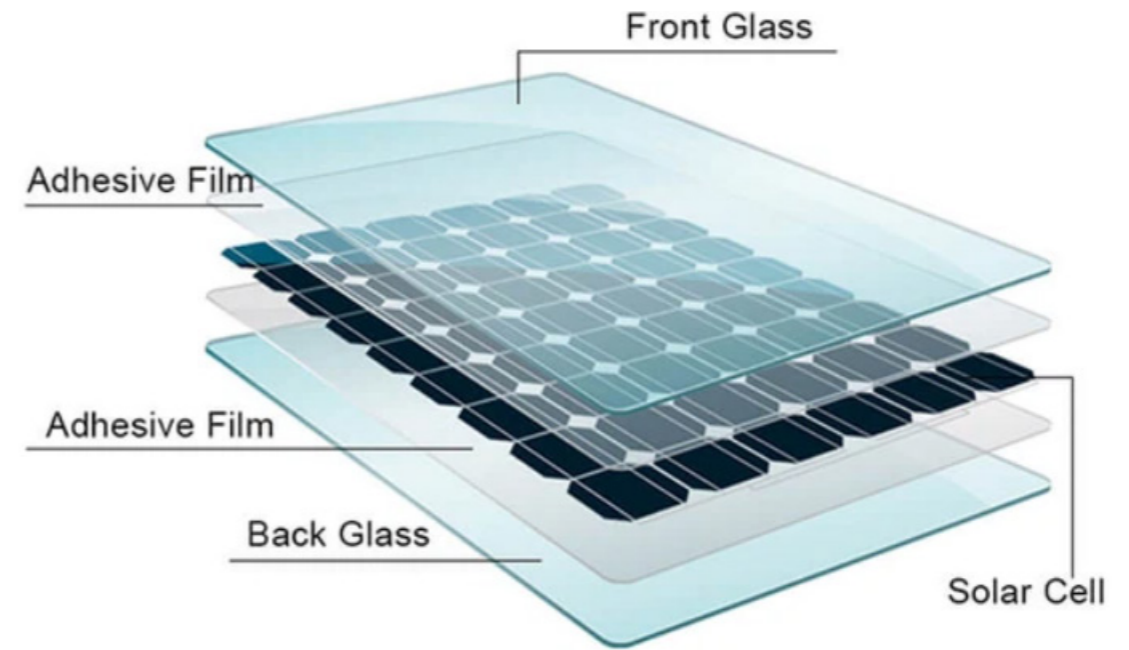
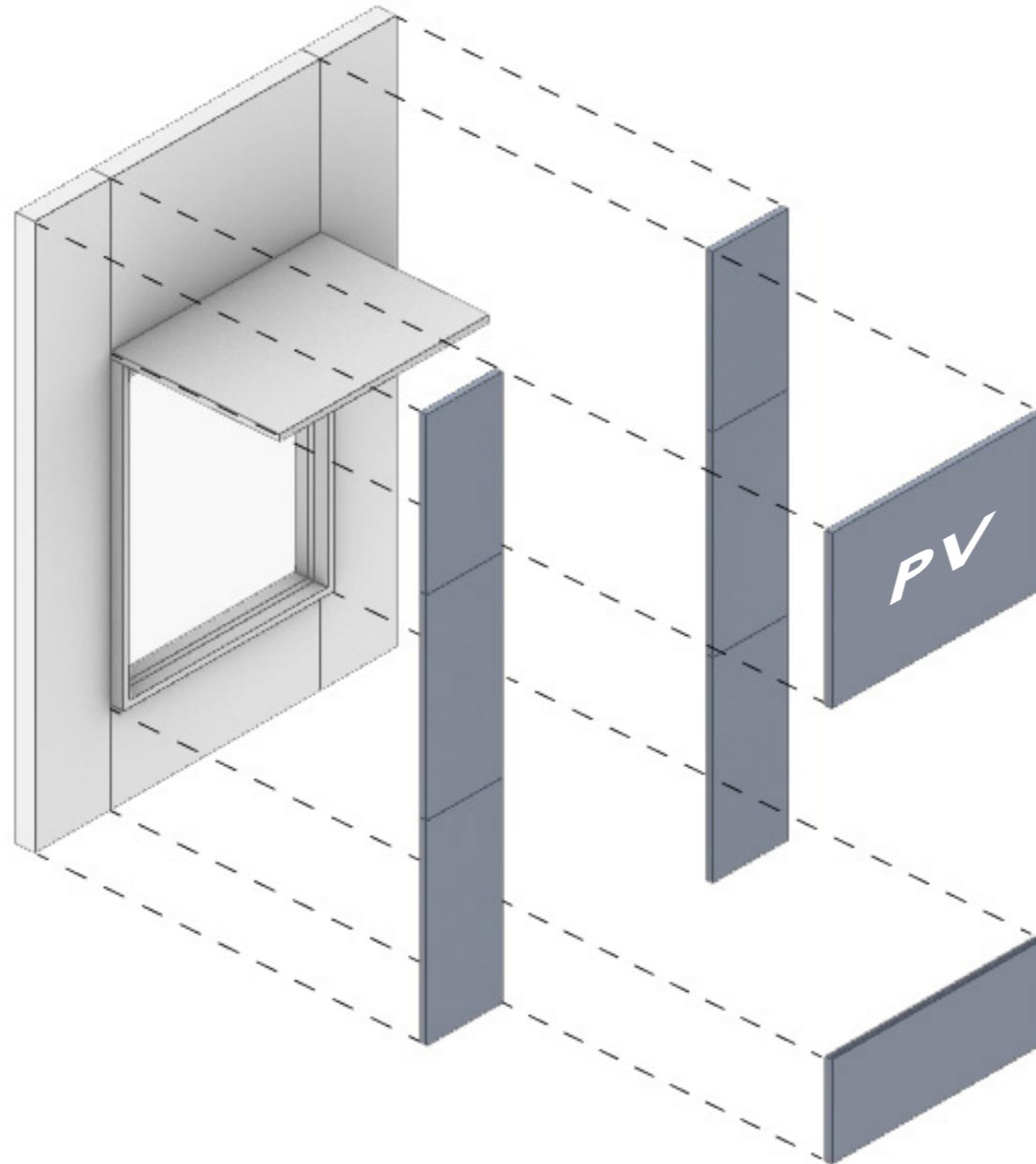
Available area: 5.29m²



Option P4:

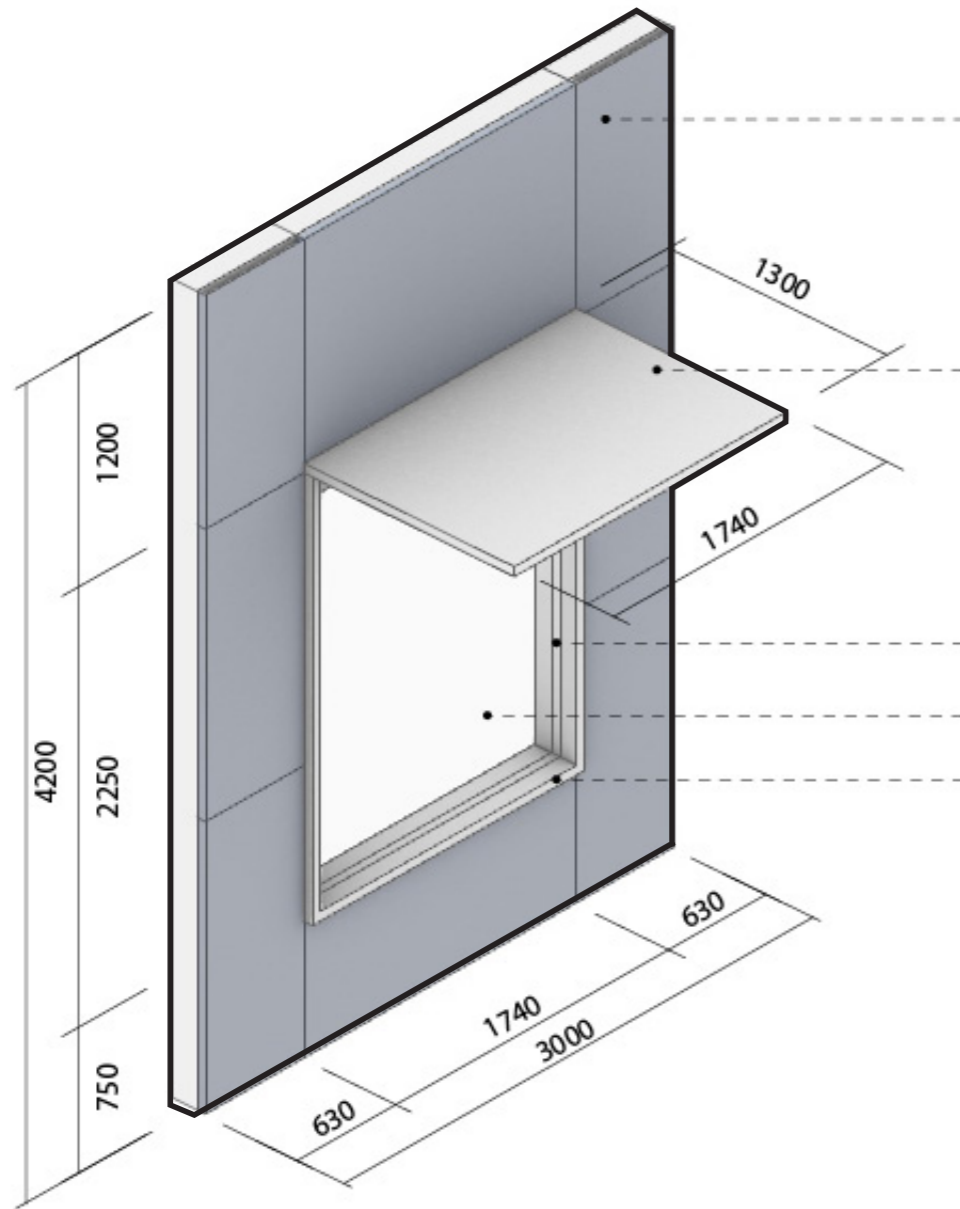
Available area: 8.83m²

Photovoltaic glazing panels

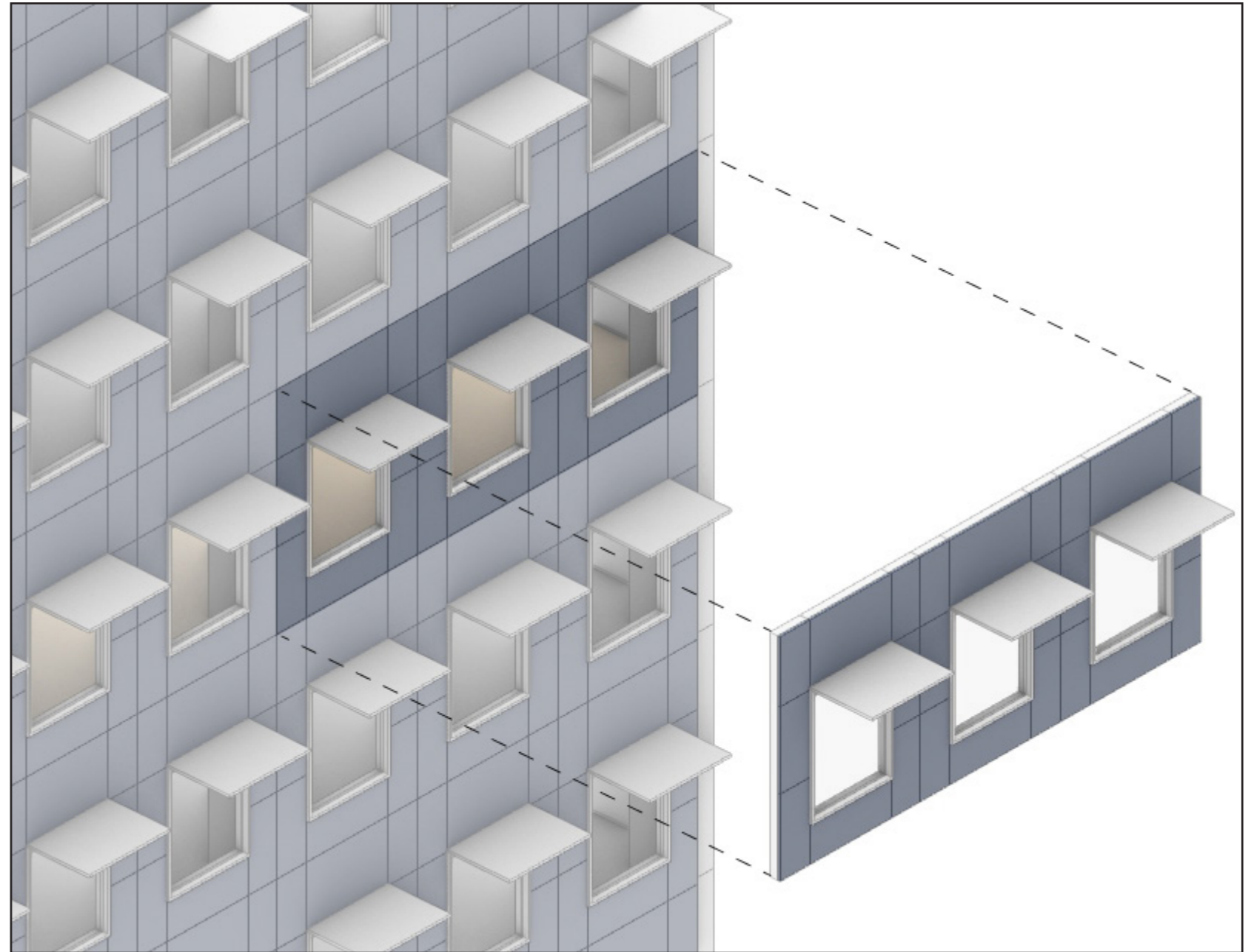


Photovoltaic glazing facade

Facade module for design scenario A

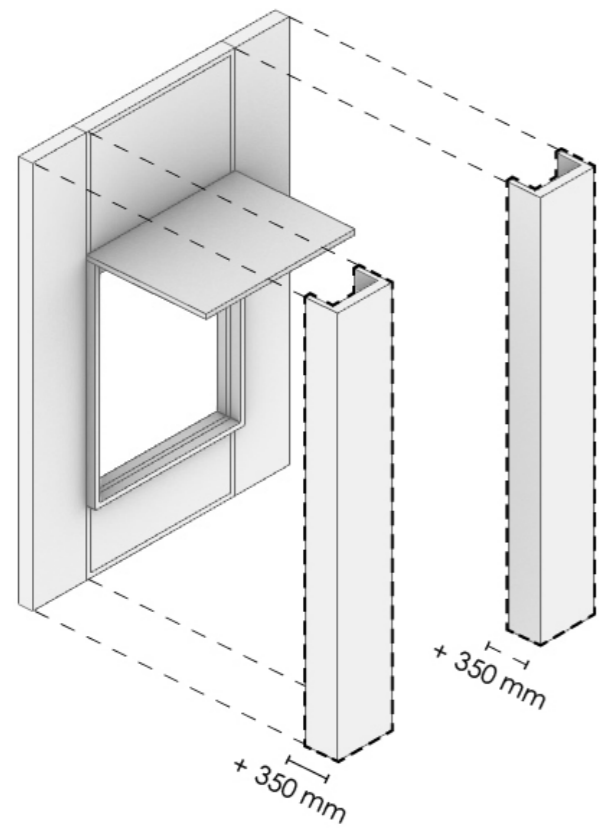


Full-coverage PV integration

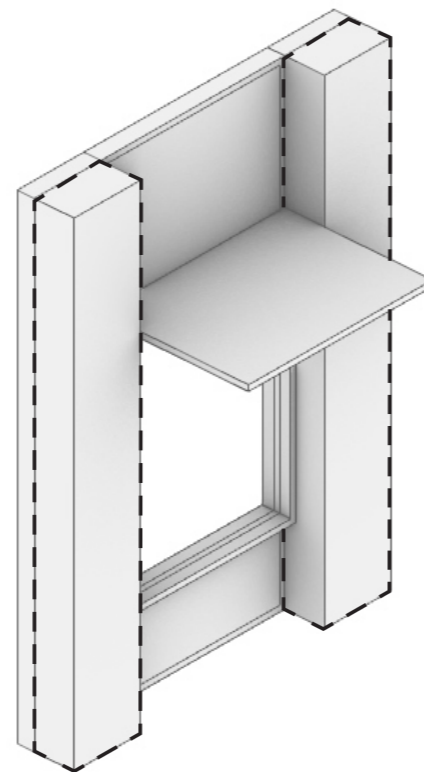
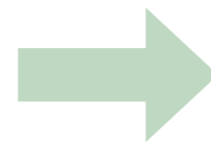


Facade module for design scenario A

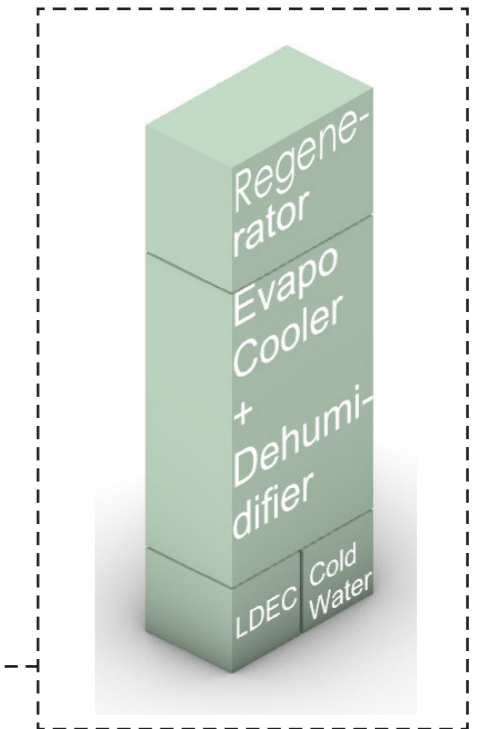
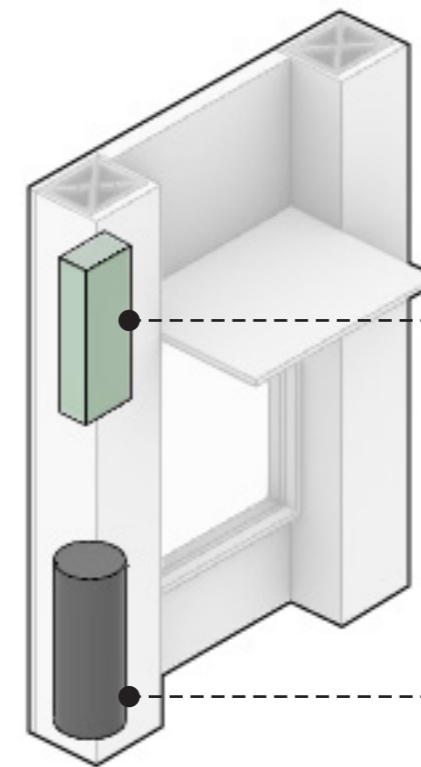
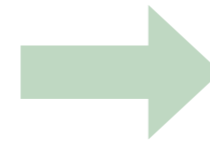
Re-sizing to accommodate the cooling systems



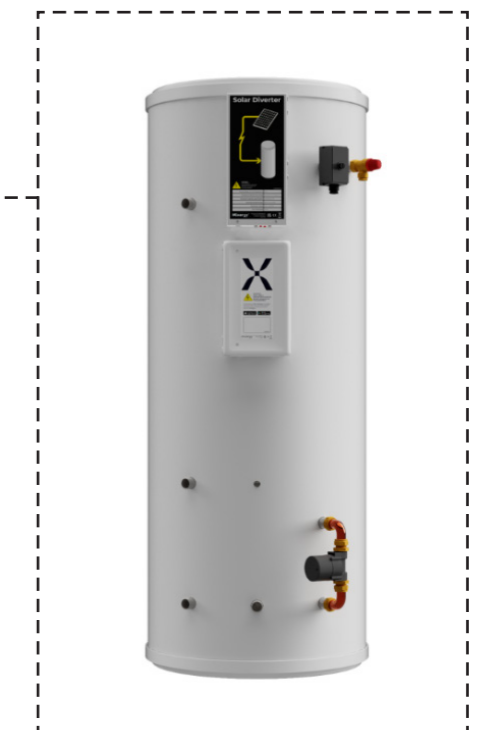
Add extra components



Create larger 'room'

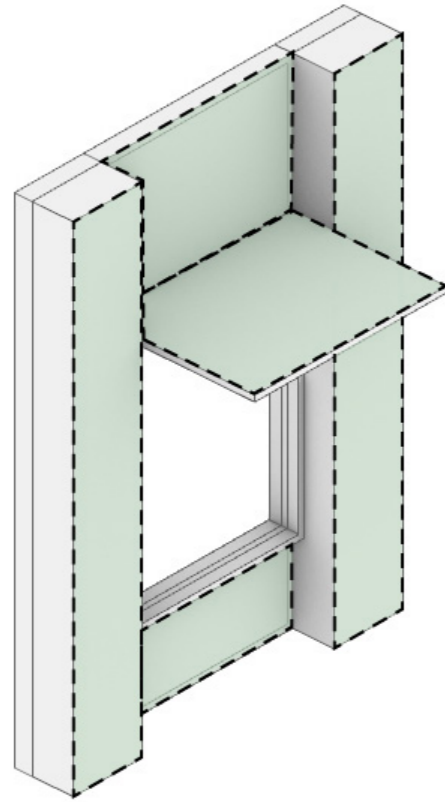


LDEVap cooling unit



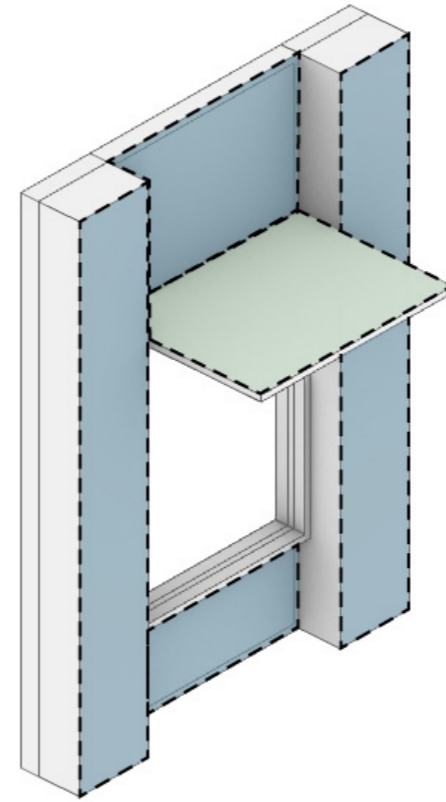
Hot water cylinder

Sub-scenarios based on different PV/ST coverage ratio



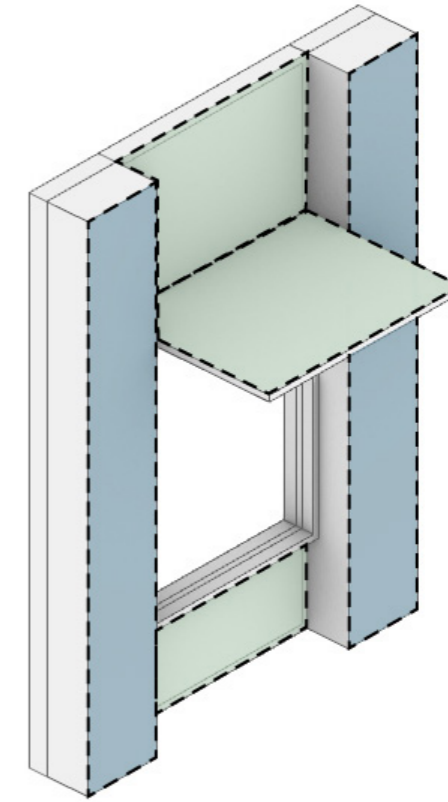
Sub-Scenario B1

● ST 100% Facade coverage



Sub-Scenario B2

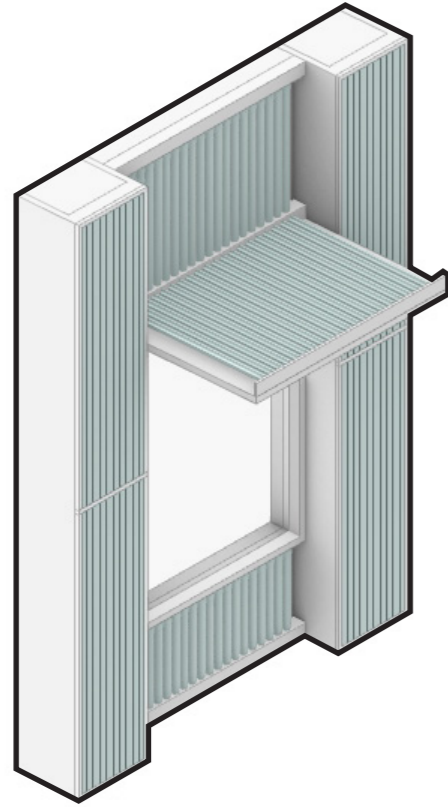
● ST Shading top
● PV 100% Facade coverage



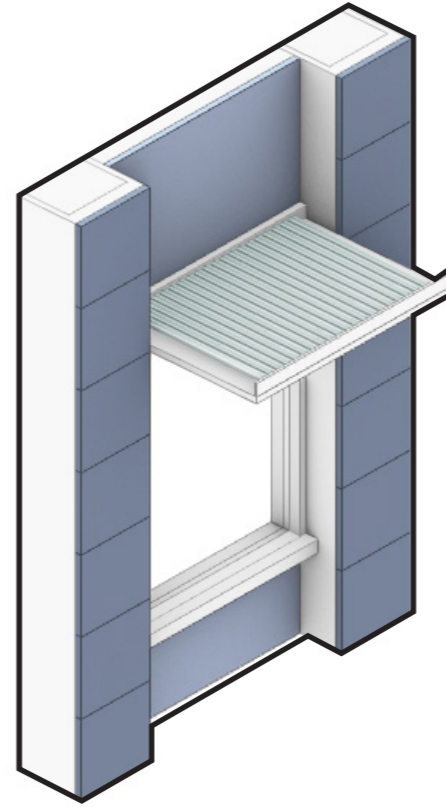
Sub-Scenario B3

● ST 40% Facade coverage
● PV 60% Facade coverage

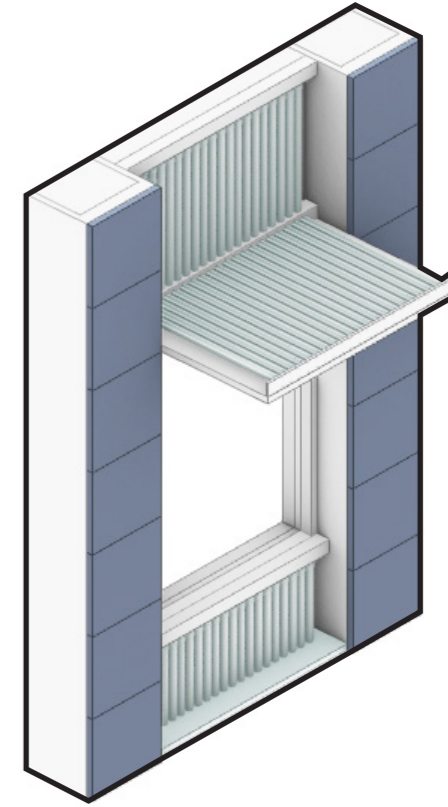
Design proposals for all sub-scenarios



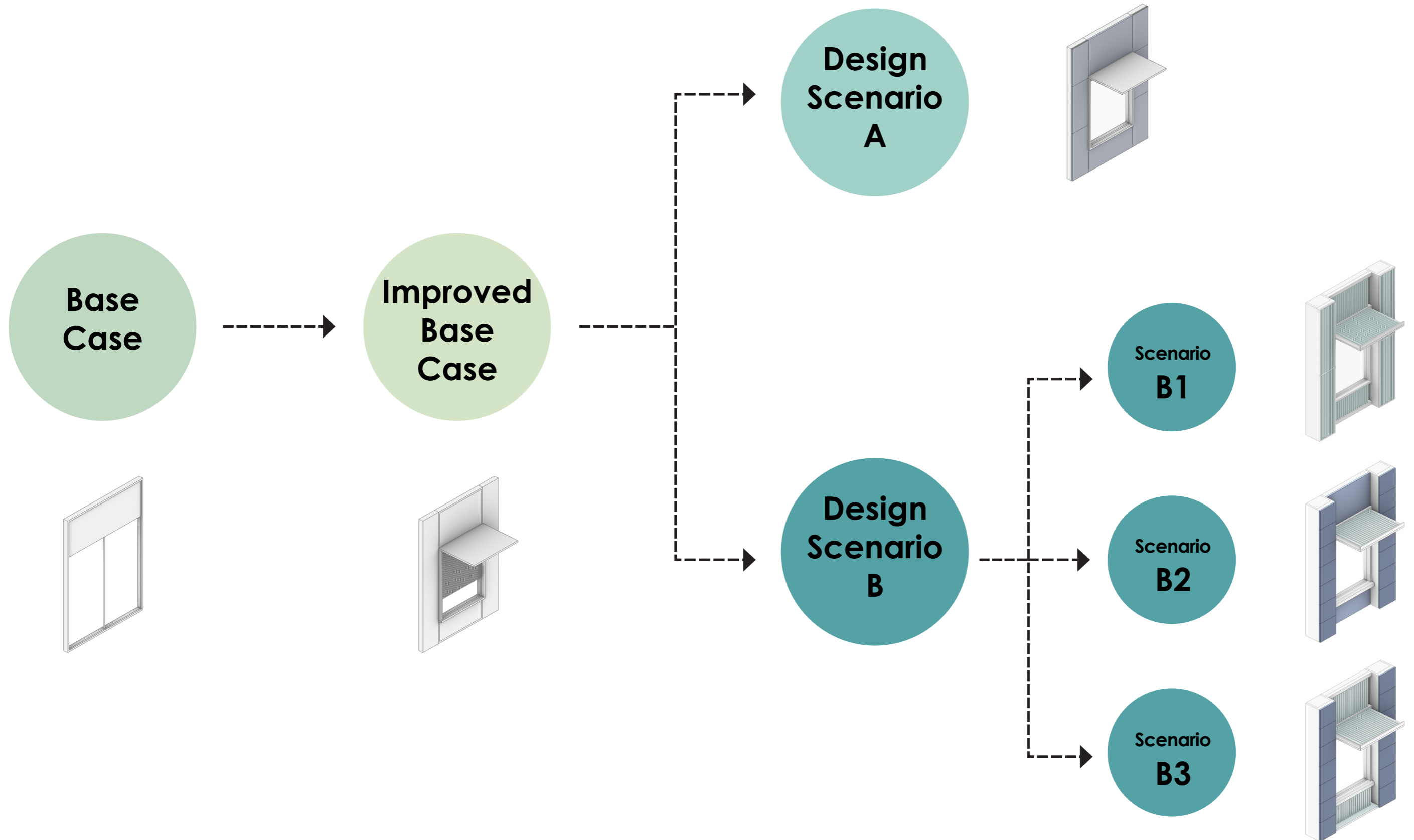
Design proposal for
Sub-Scenario B1



Design proposal for
Sub-Scenario B2



Design proposal for
Sub-Scenario B3



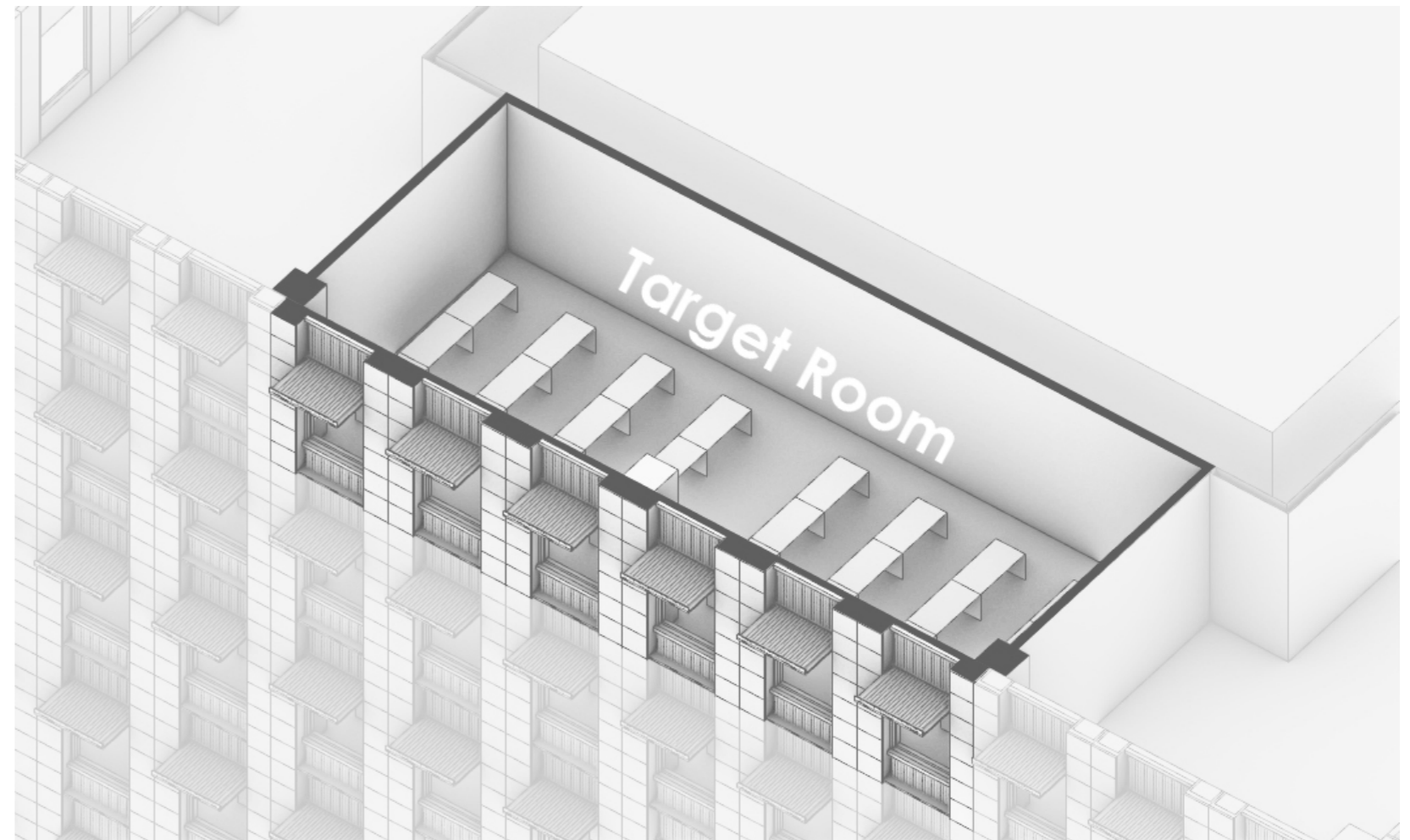
What to compare?

Duration: Summer design week

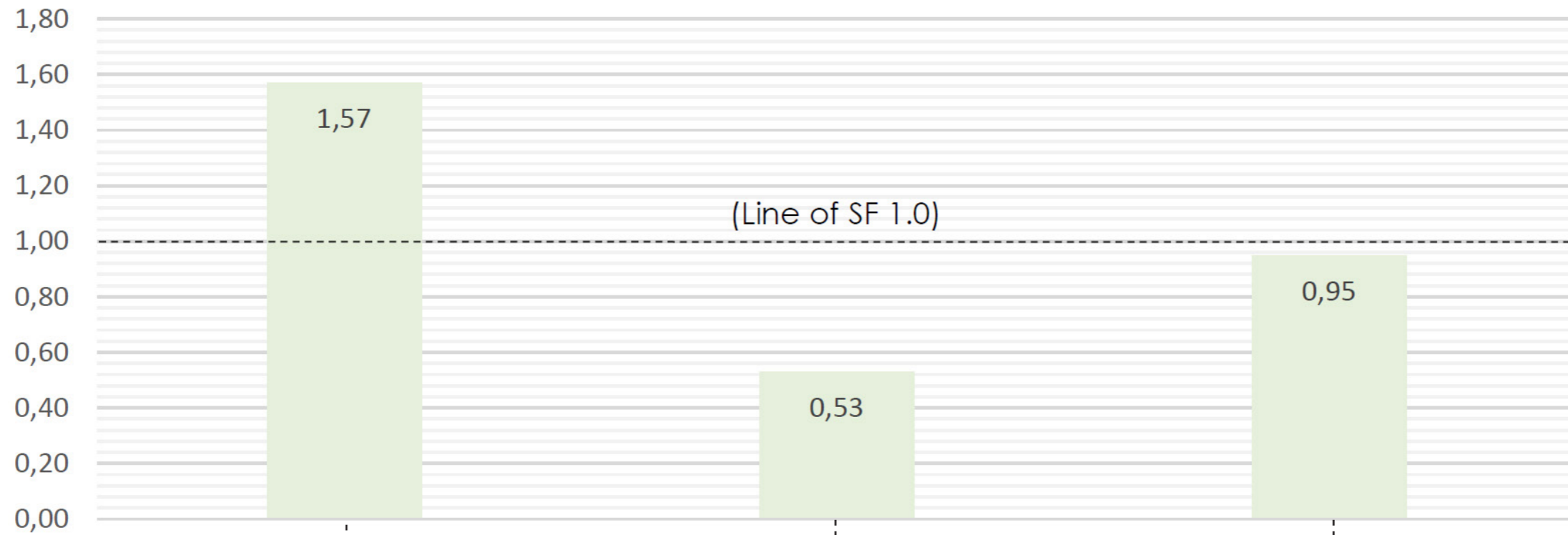
Object: The west-orientated target room

Area: 129.14m²

Simulation Items: Solar Fraction Assessment,
Cooling Demand,
Cooling Electricity,
Renewable Energy Generation

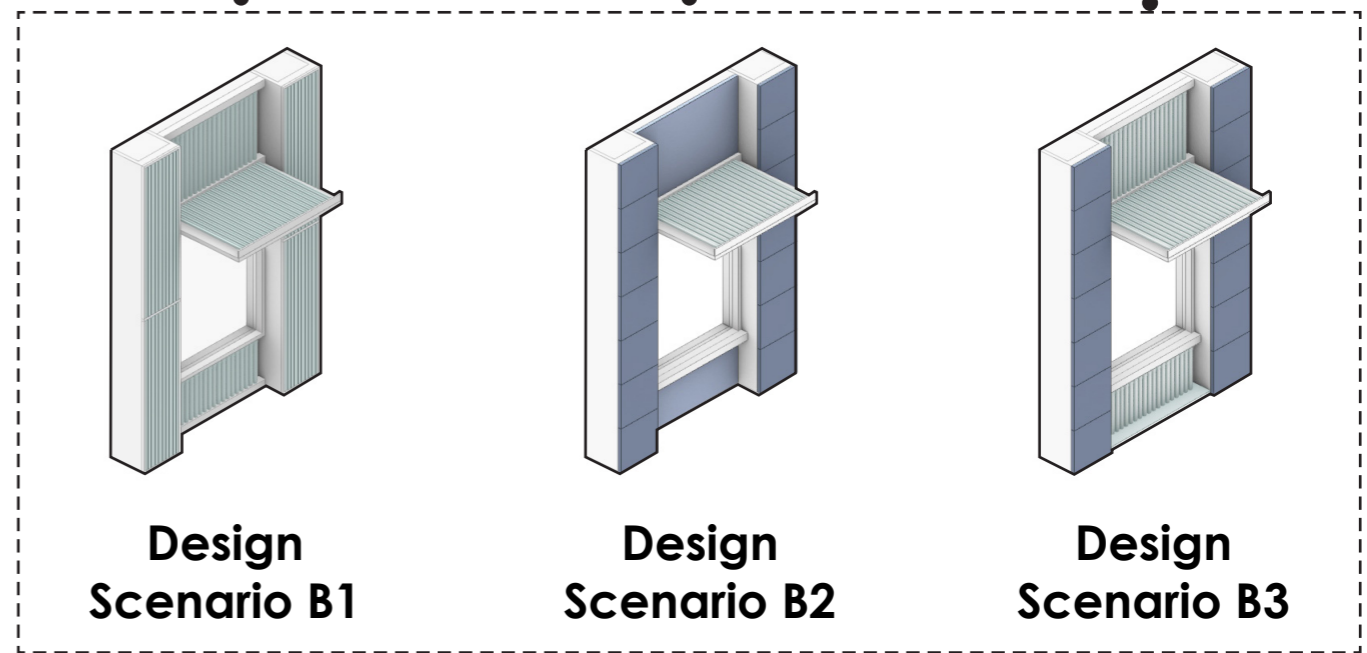


Solar fraction assessment

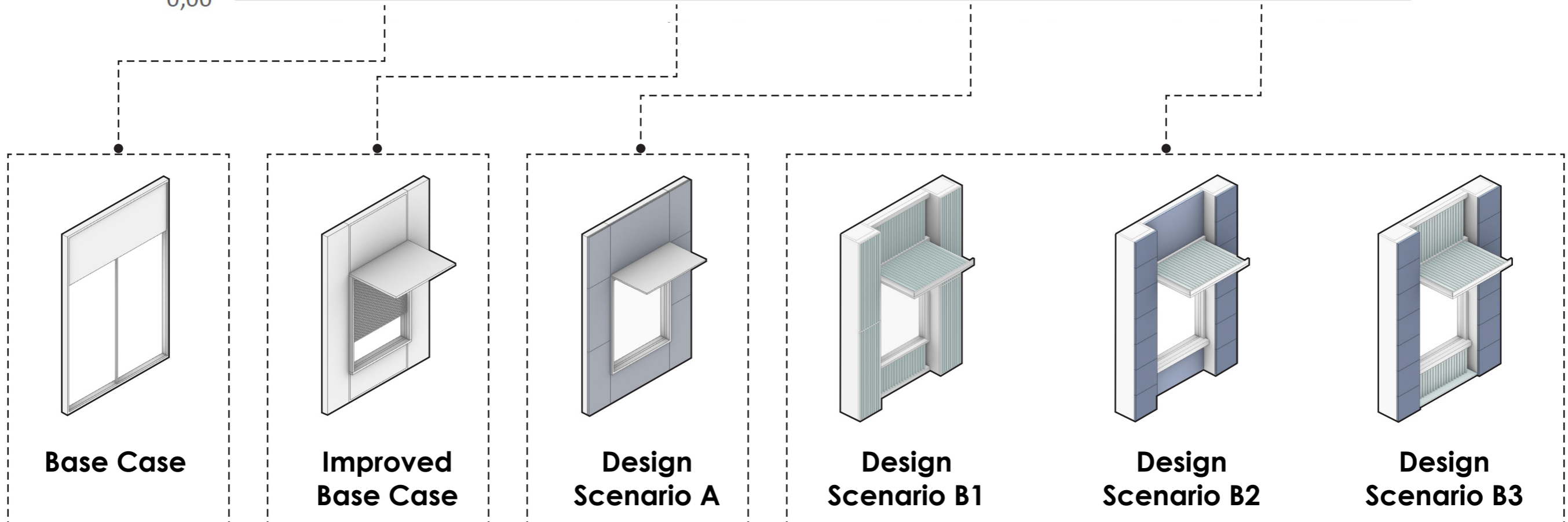
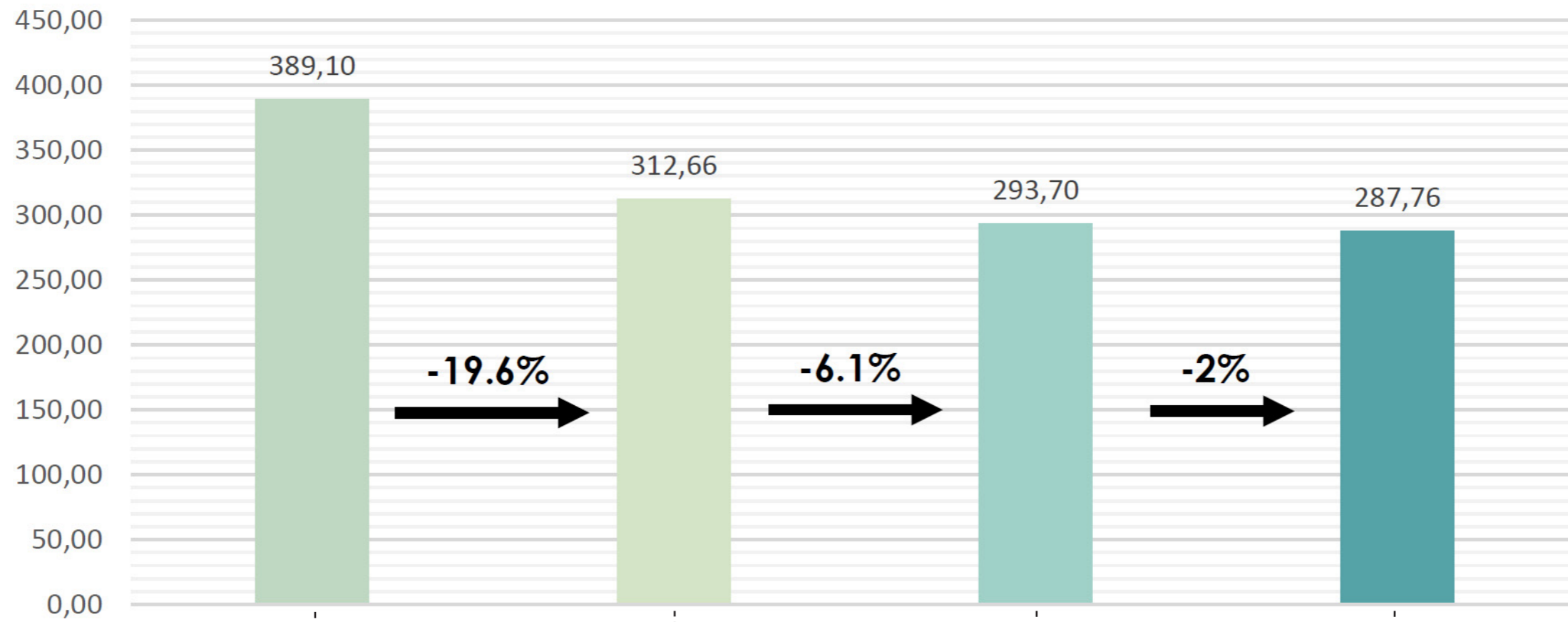


$$SF = \frac{S_{cool\ out}}{Cool\ req}$$

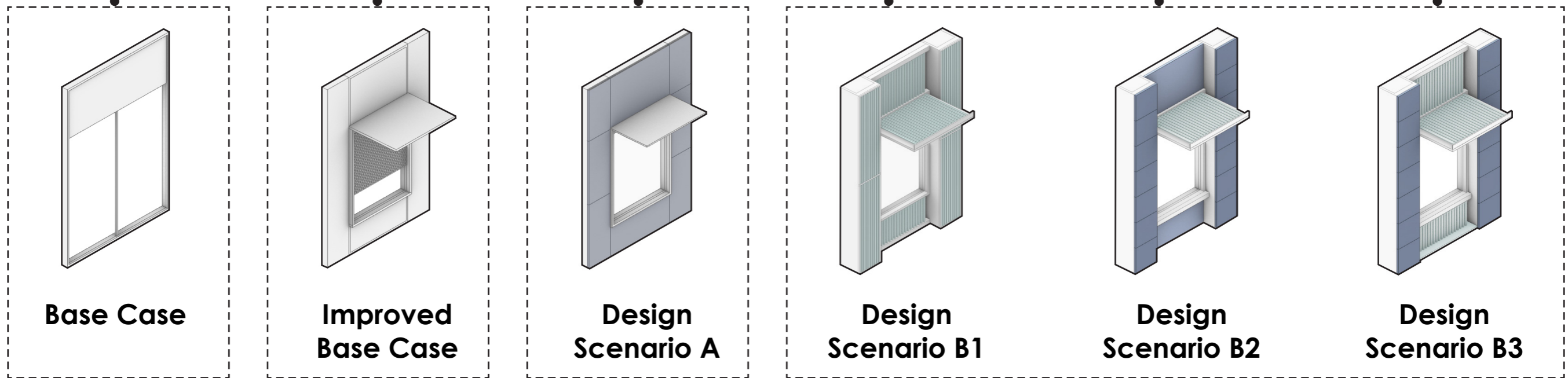
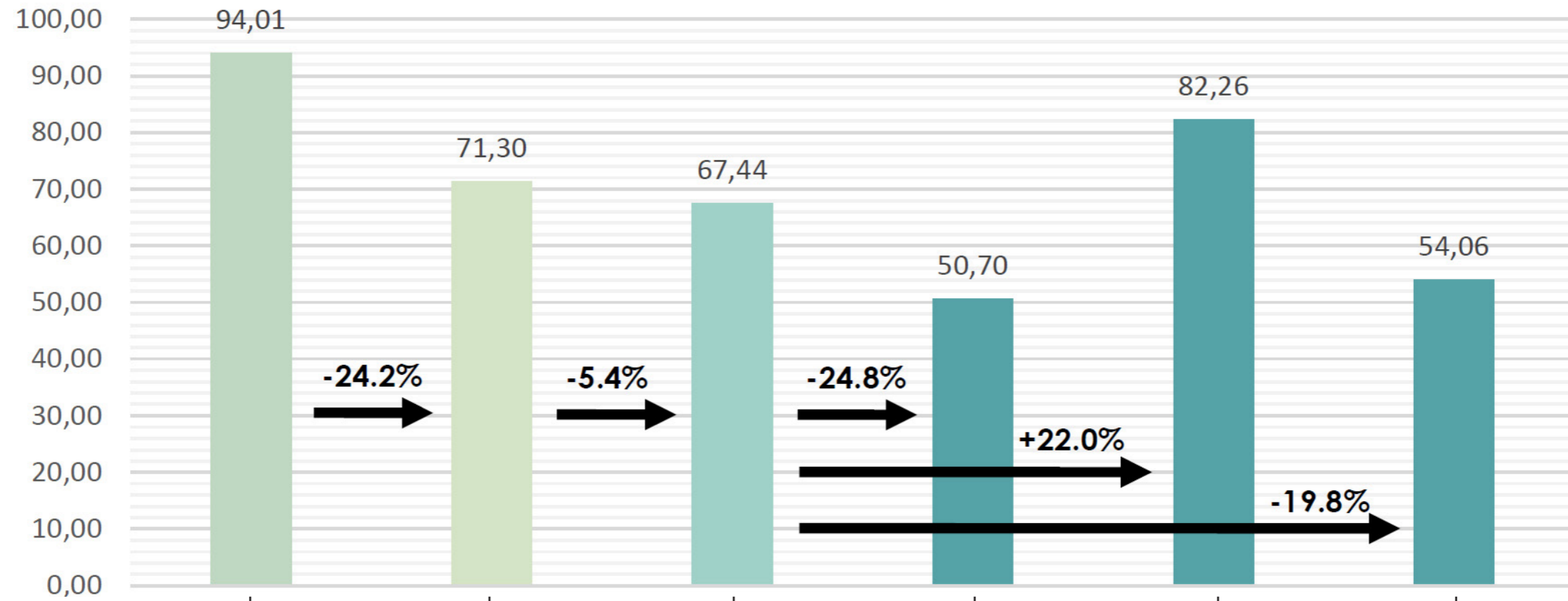
Solar fraction (SF) is used to measure whether a solar-powered cooling system meets the cooling requirements under the corresponding conditions.



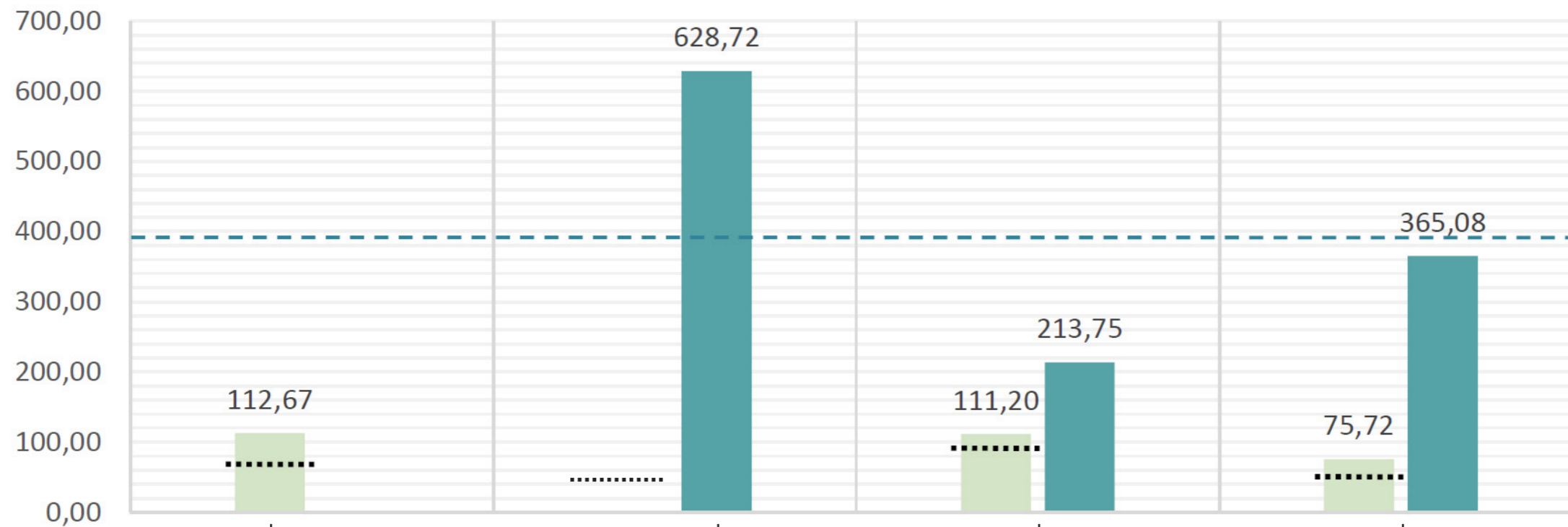
Cooling Demand [kwh/week]



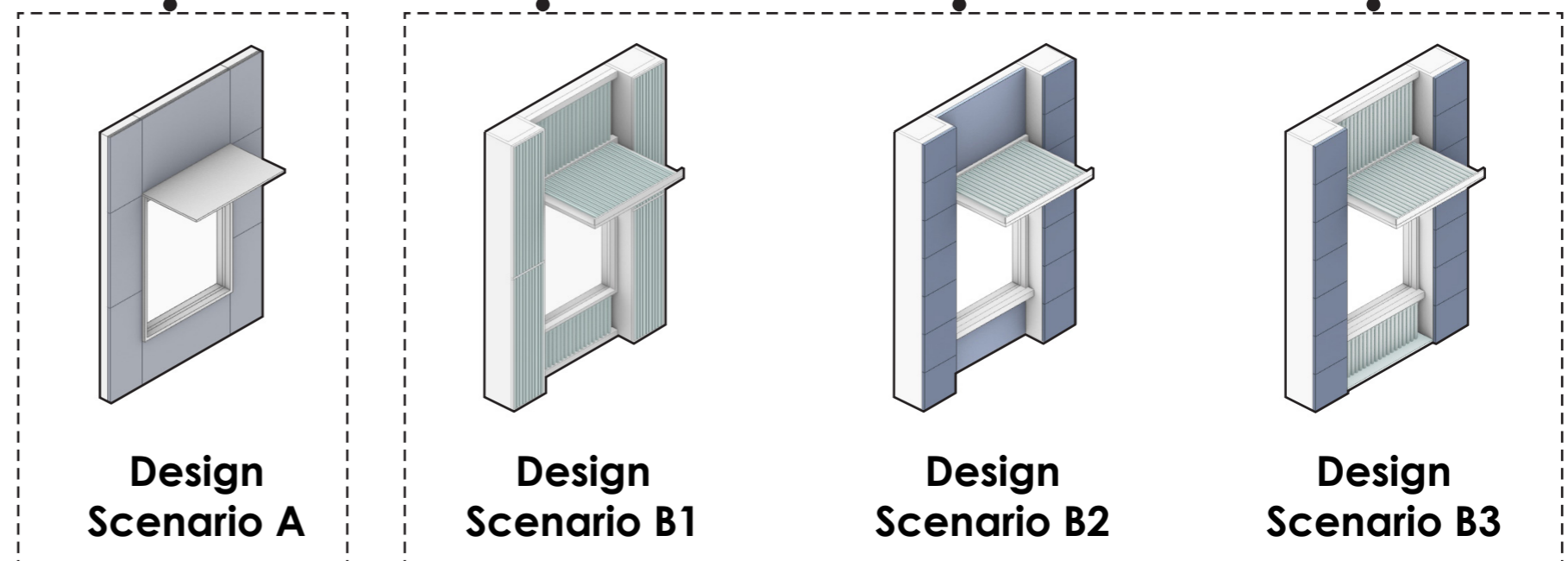
Cooling Electricity Consumption [kwh/week]



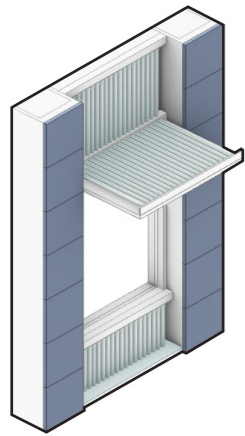
Renewable Energy Generation [kwh/week]



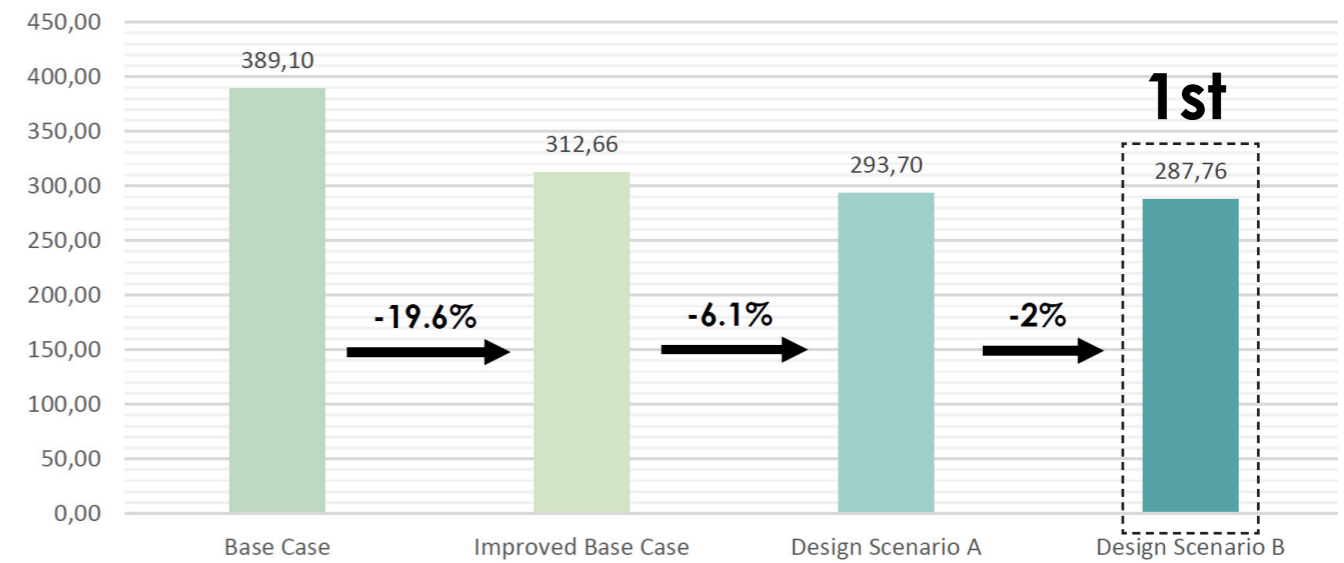
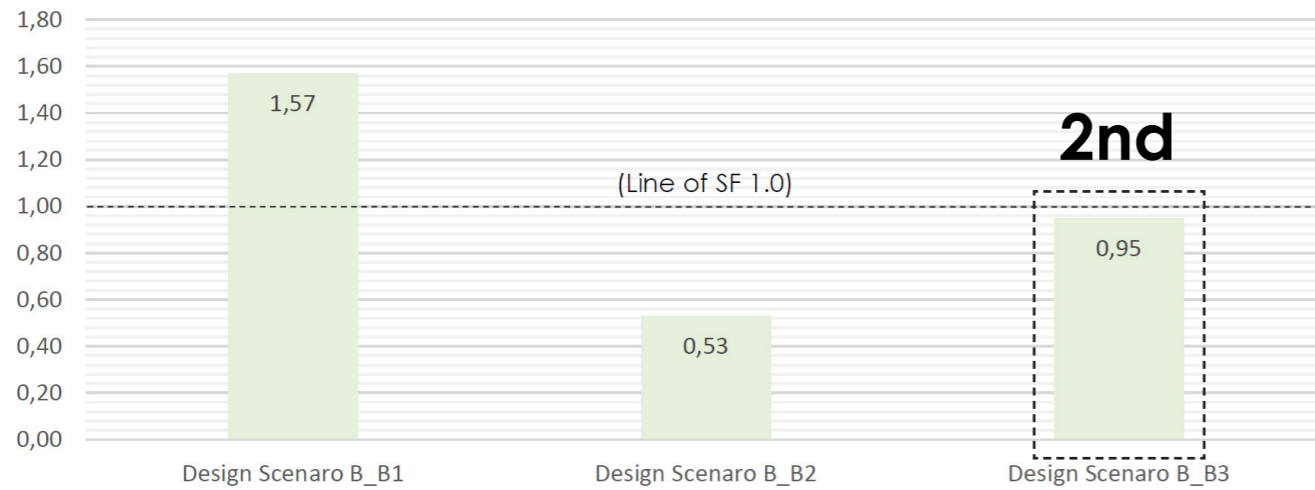
- Solar Electricity
- Solar Heat
- Baseline of required heat for cooling purpose
- Baseline of required electricity for cooling purpose



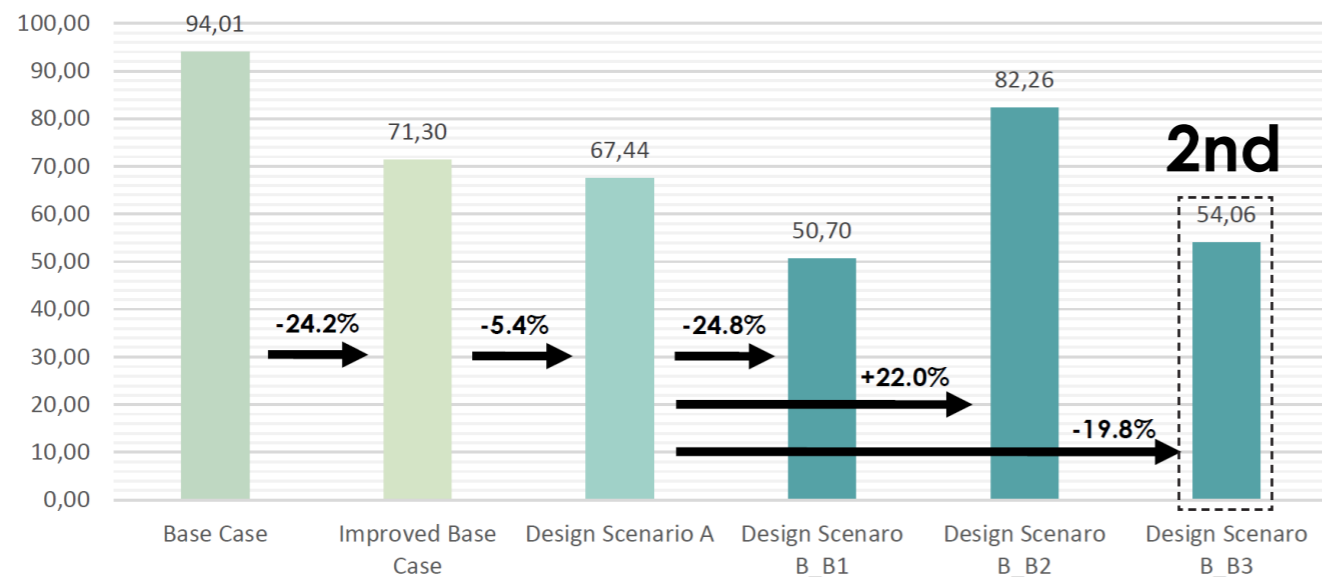
Comparisons of performance



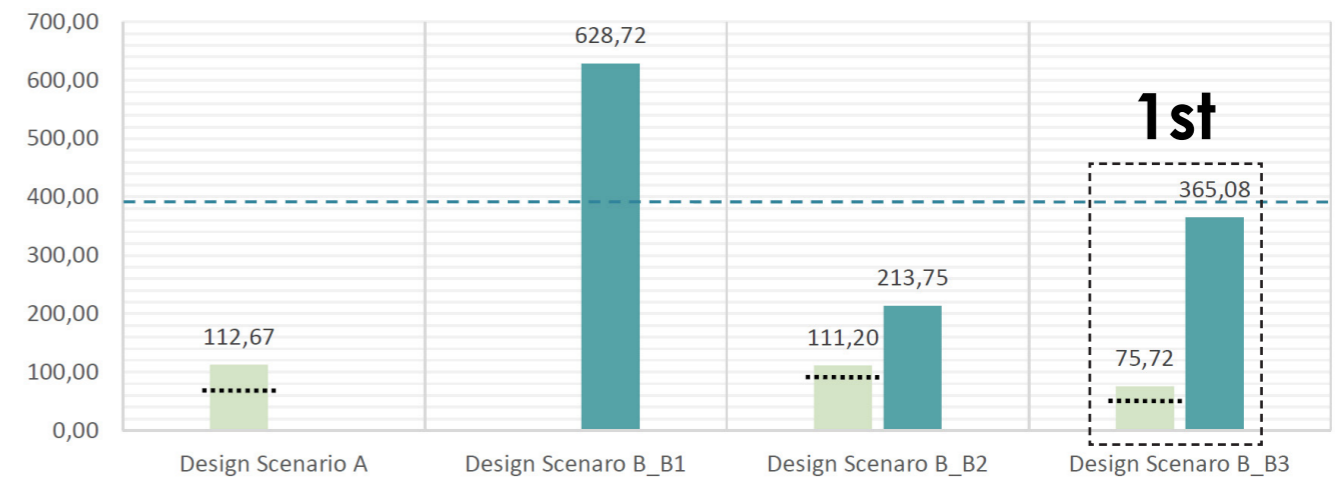
Design proposal for Scenario **B3** has the best comprehensive performance



Solar fraction assessment



Cooling demand

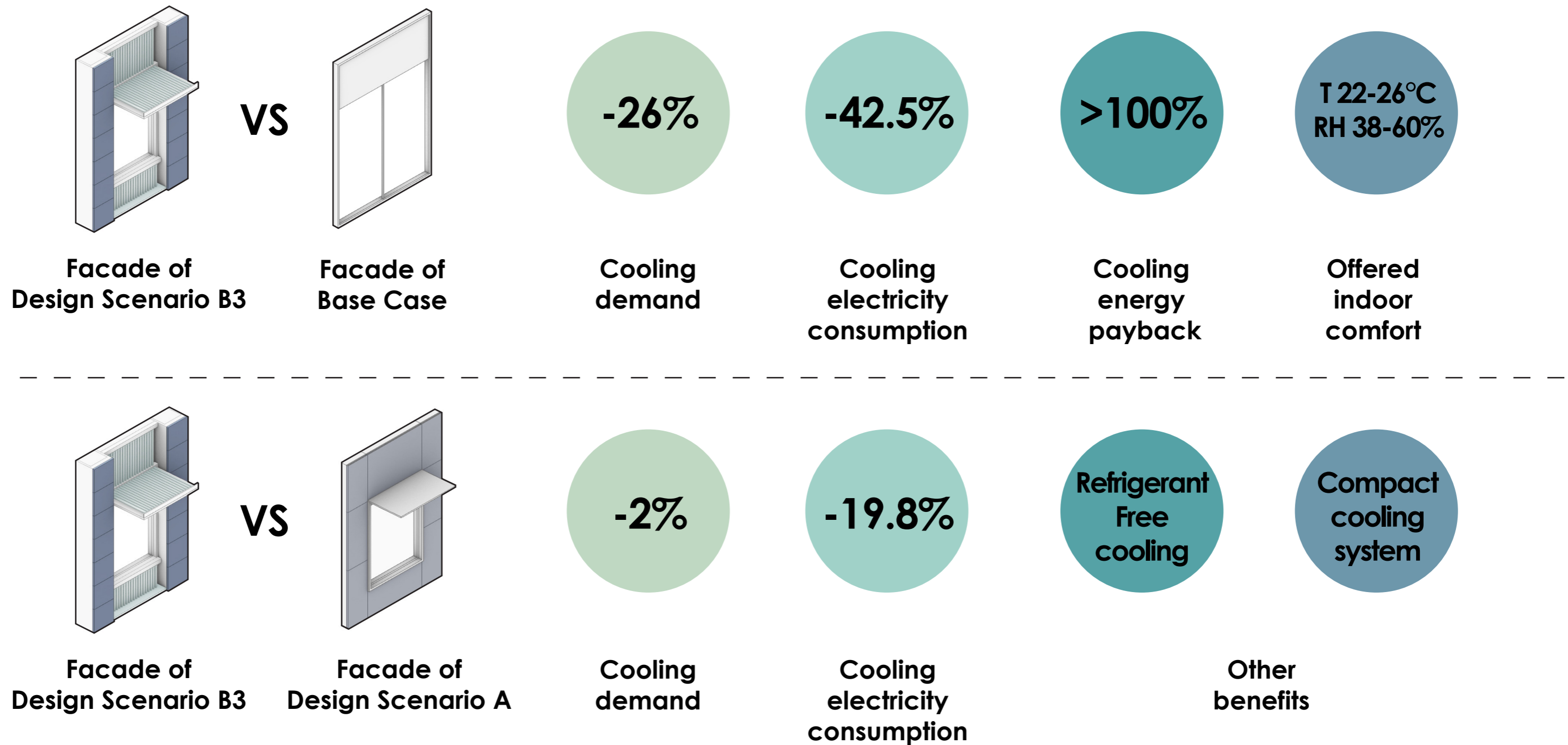


Cooling electricity consumption

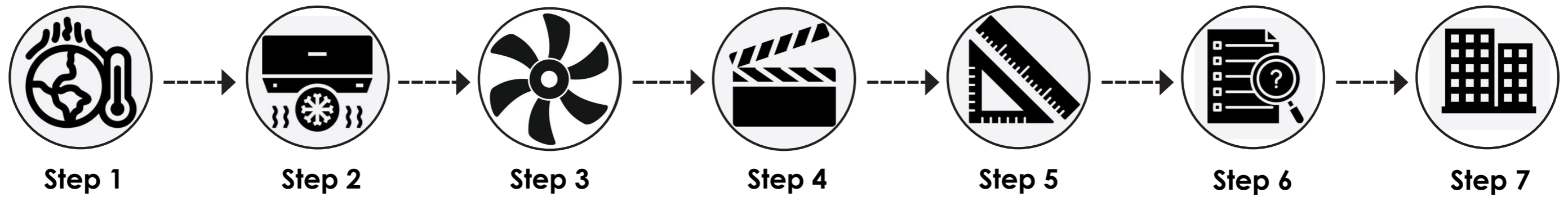
Renewable energy generation

Response to the research question

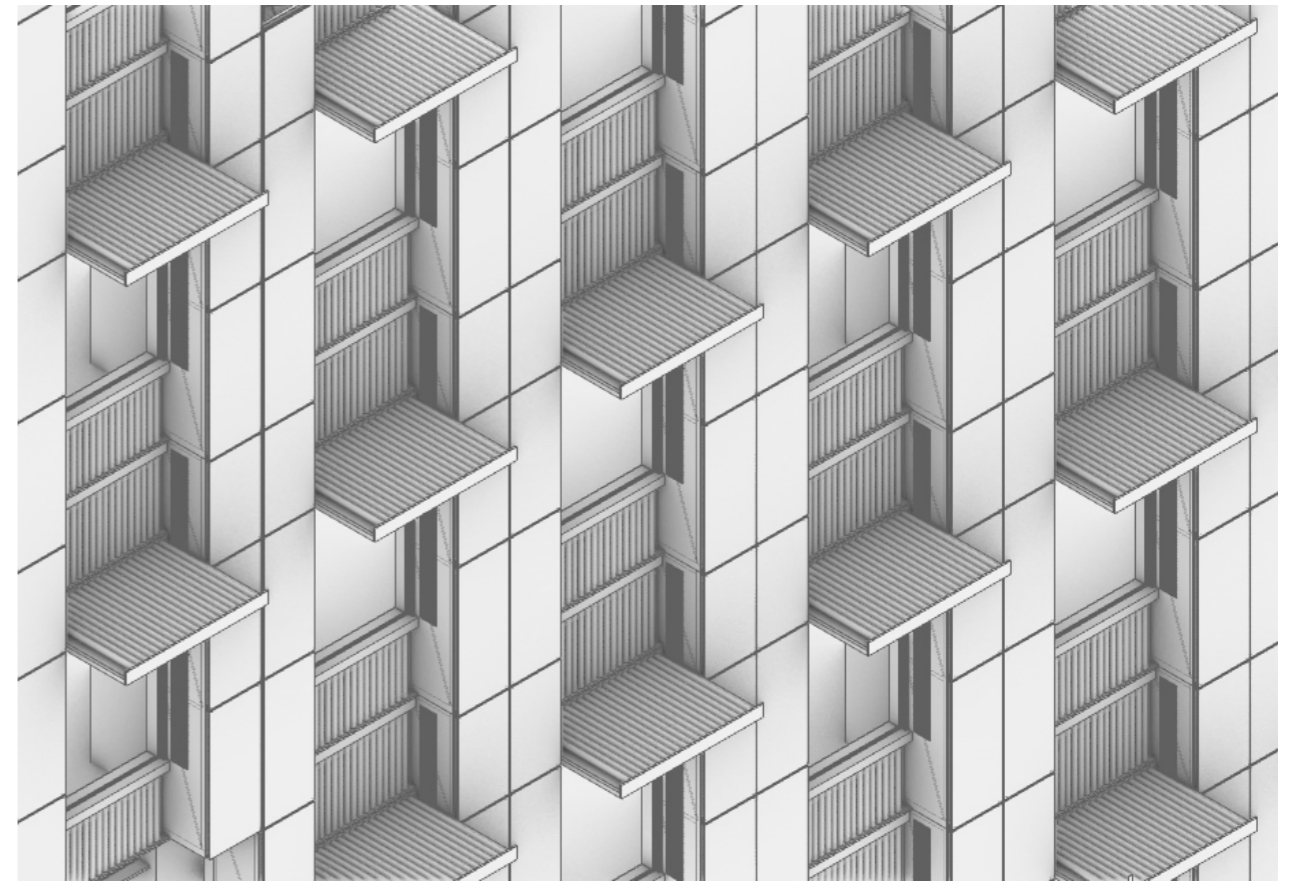
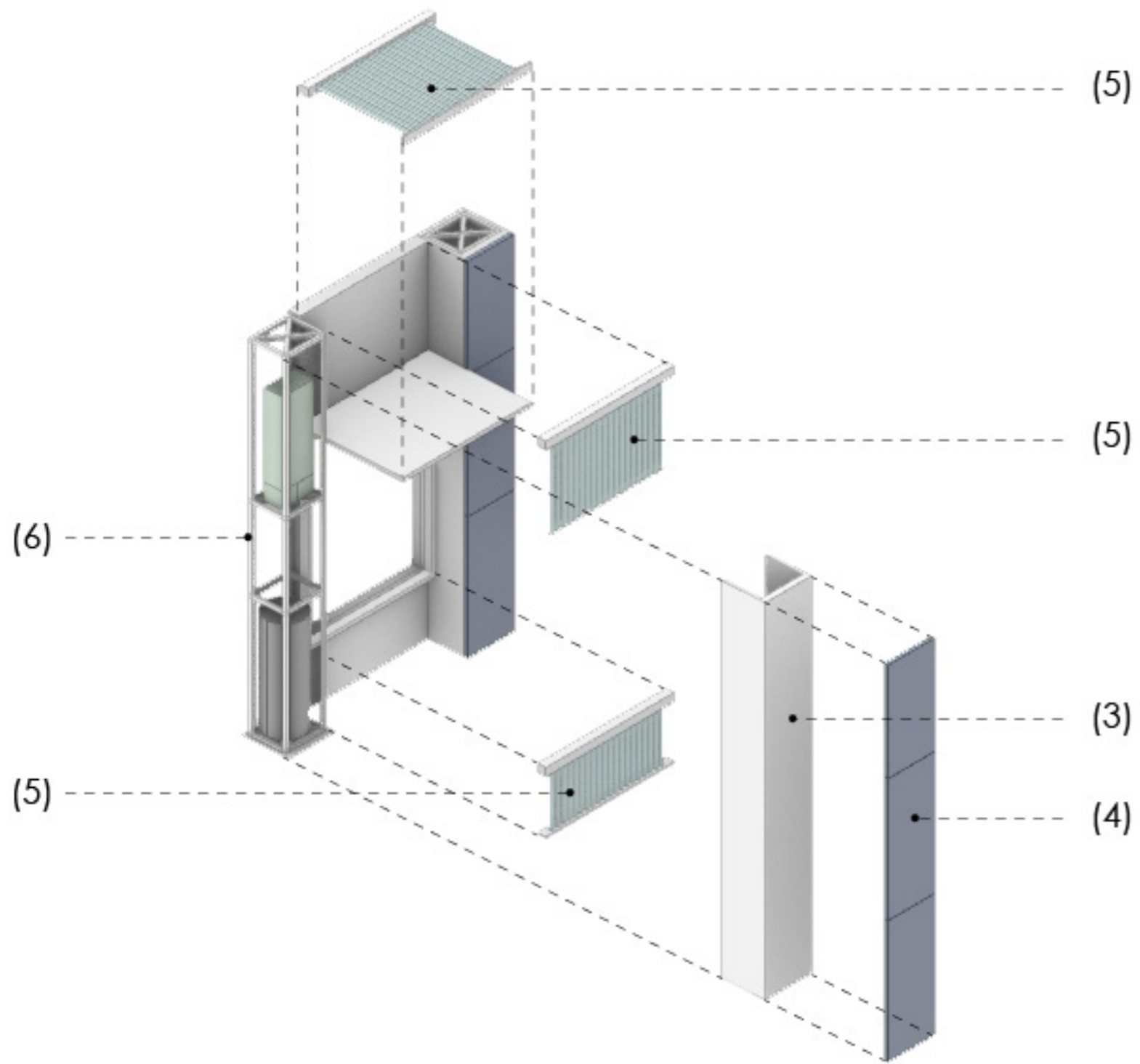
“ In hot-humid climate, how can the design application of solar cooling integrated facades minimize the cooling energy consumption for office buildings and optimize the indoor thermal comfort? ”



Experimental design guide

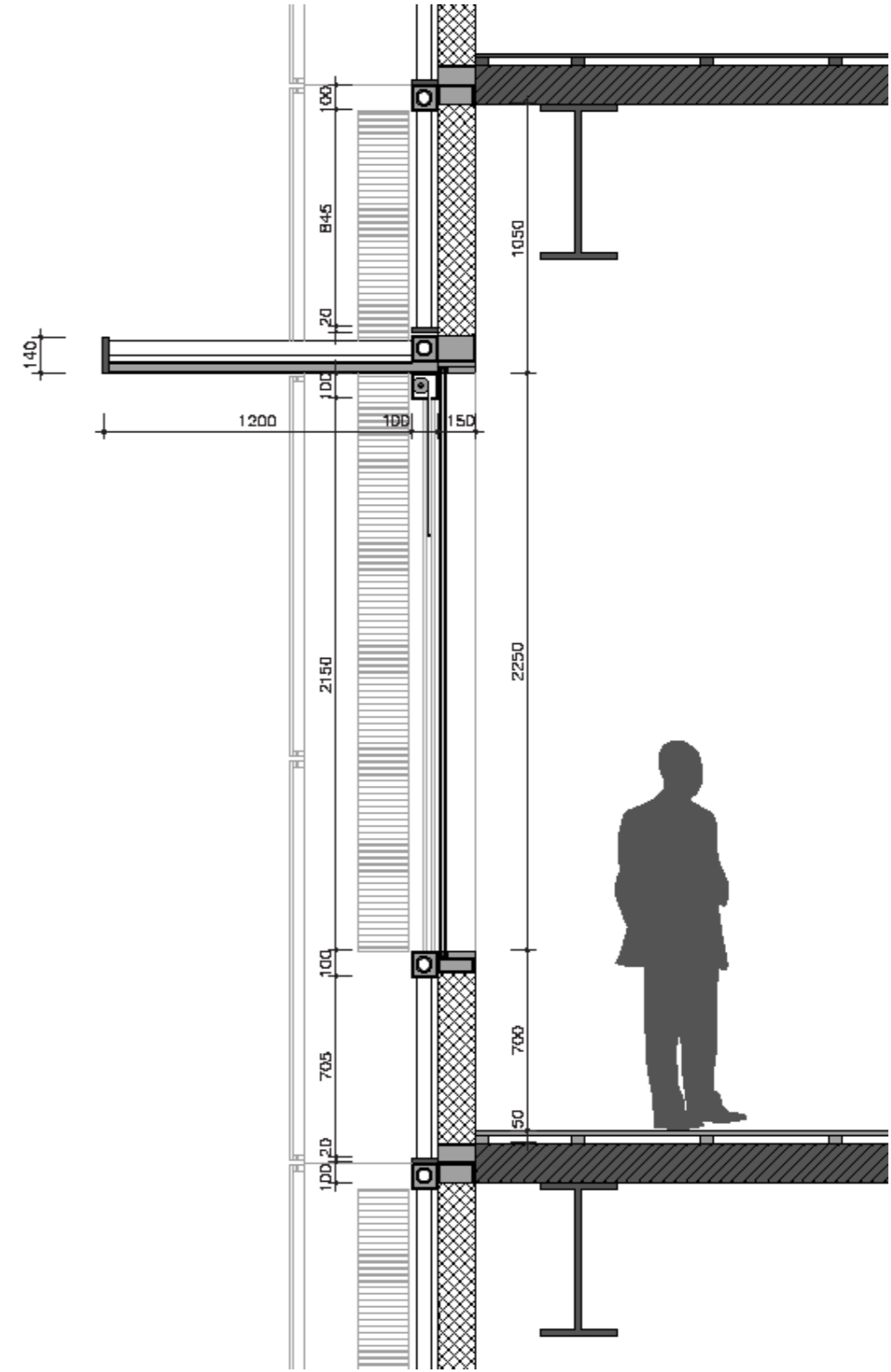
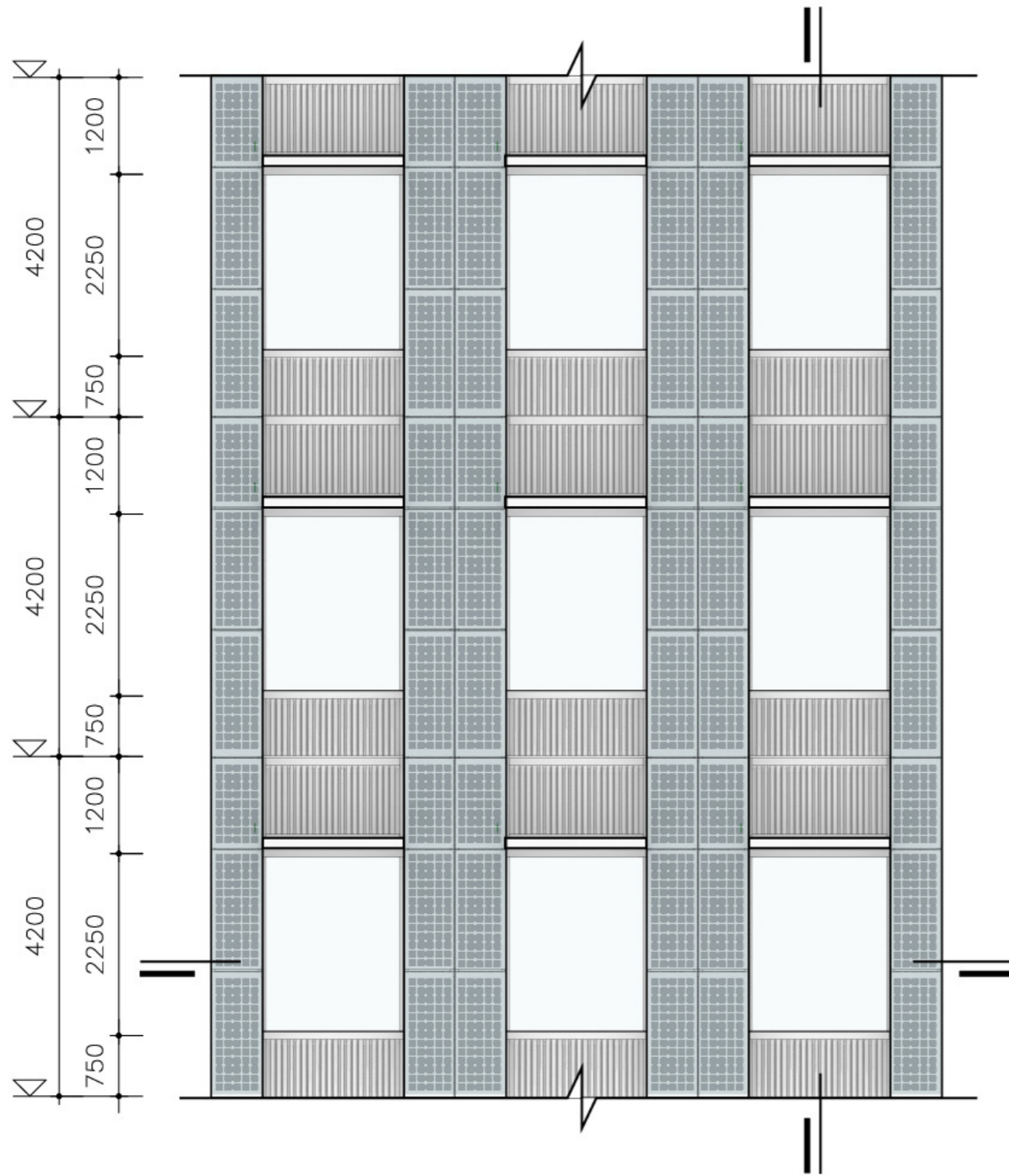


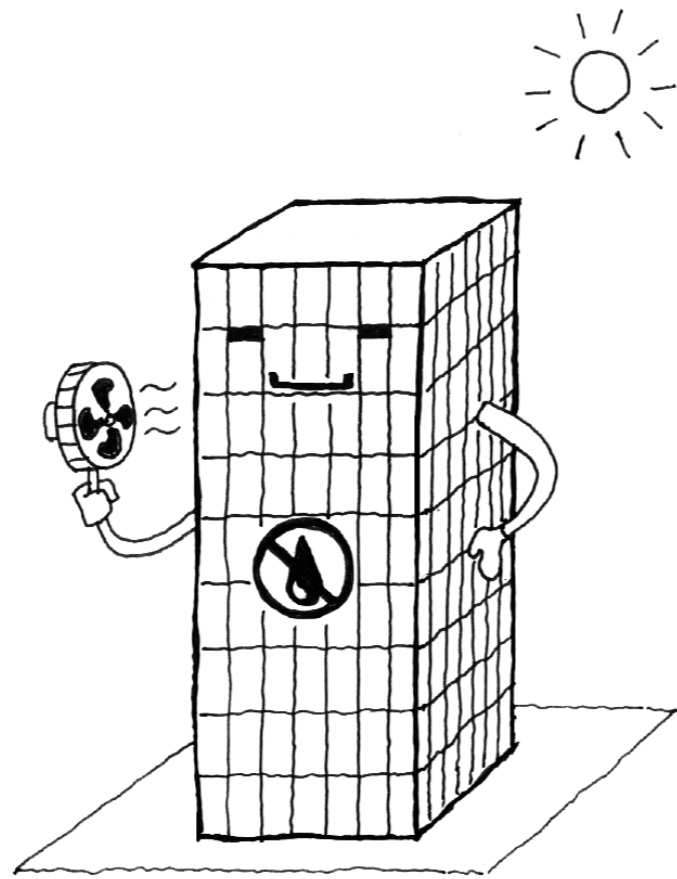
- Step 1** Check the background conditions
- Step 2** Define cooling strategy
- Step 3** Design the core systems
- Step 4** Define design scenarios (optional)
- Step 5** Assess the performance of the design proposal
- Step 6** Evaluate the simulated results
- Step 7** Finalize the design proposal











Thanks