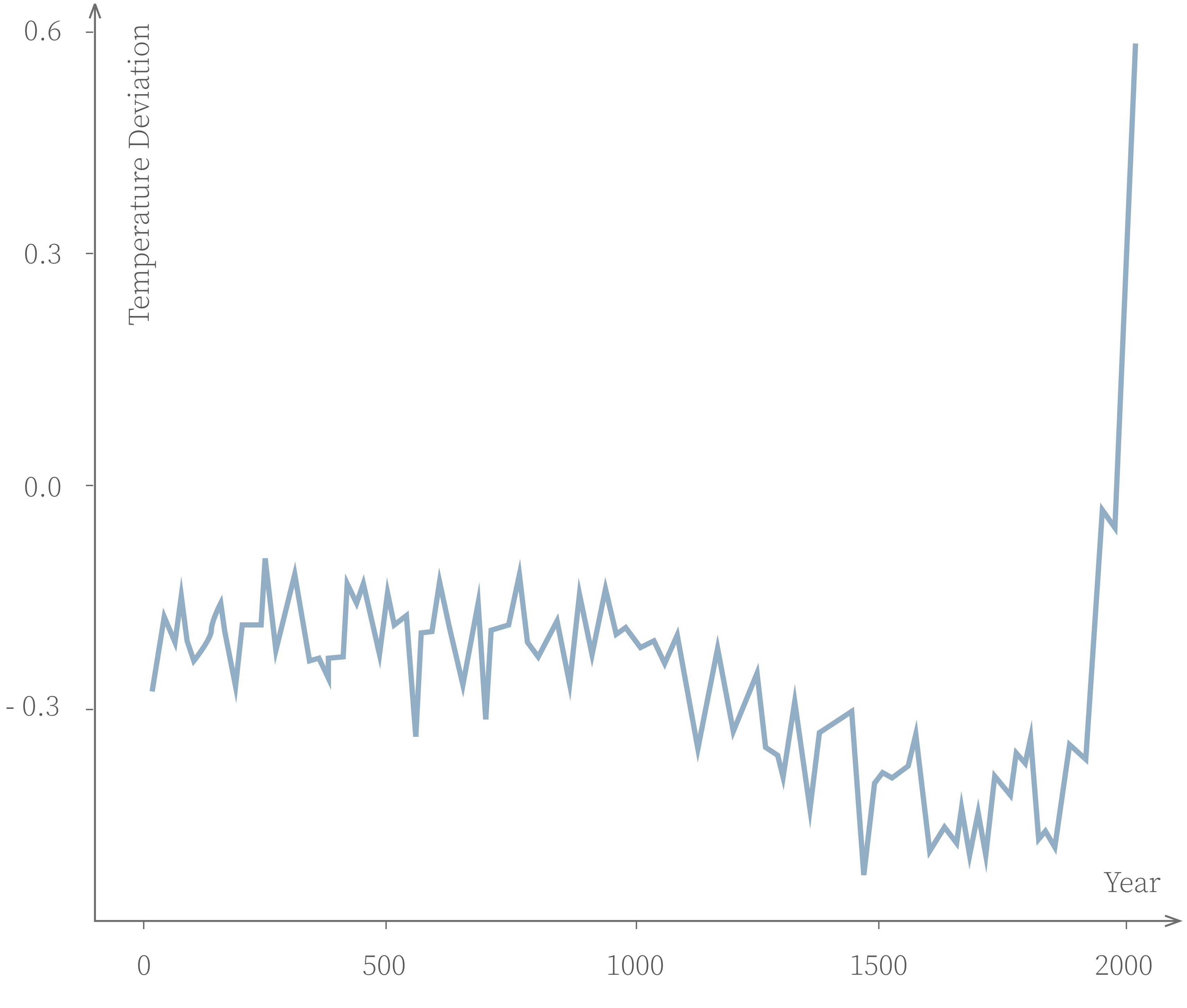
Master of Science Architecture, Urbanism & Building Sciences
Building Technology
Year 2022 - 2023

Phase Change Materials Trombe Wall

Exploring the potential application of PCMs in a modular design for thermal and daylight comfort

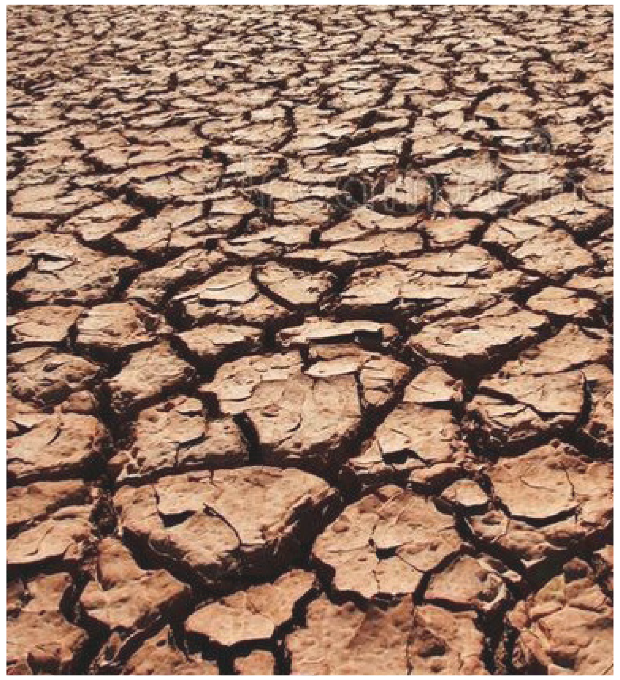
Graduation Studio
Gabriella Consoli | 5611784



Ghosh, 2021

DeVries, 2020

Santiago, n.d.



Andrushko, 2019

Weekly Wire News, 2022

”Housing and tertiary buildings are responsible for the consumption of approximately 46% of all energies and approximately 19% of the total CO_2 emission”

(Kuznik et al., 2011: 380)

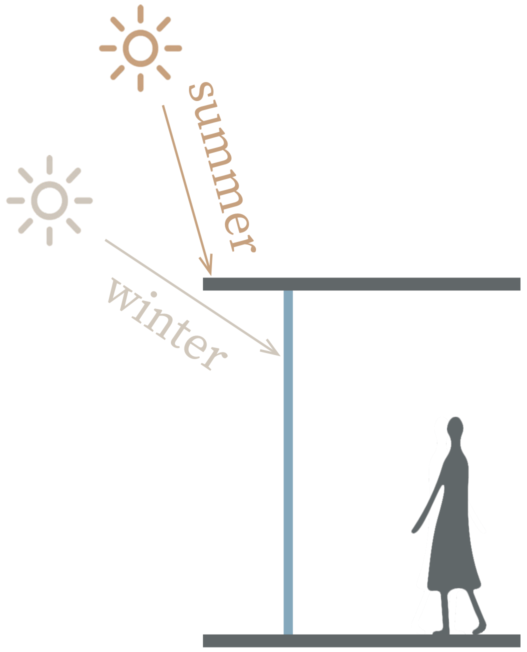
Weessies, 2022

Passive design strategies

They maximize the building's thermal performance by taking advantage of the **climatic conditions** to reduce the reliance on mechanical systems for heating, cooling, and lighting.

Weessies, 2022

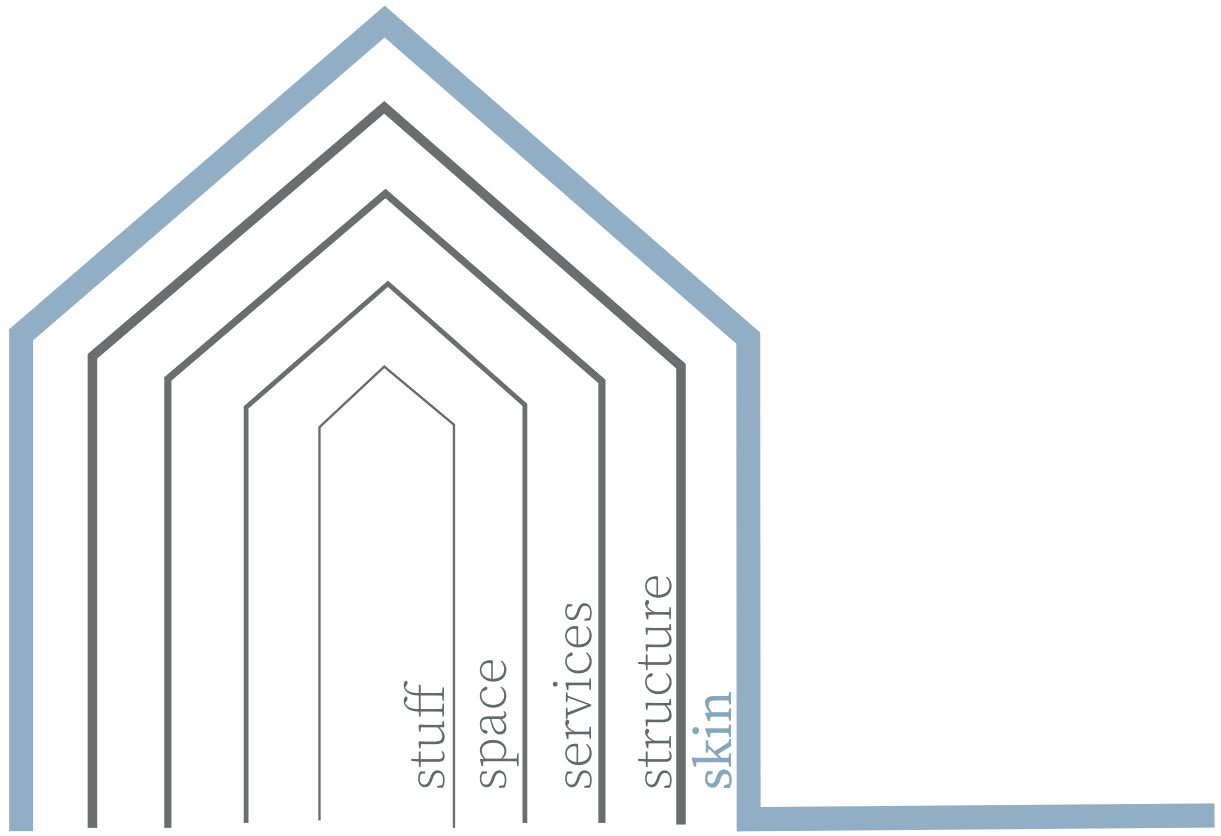
Passive design strategies



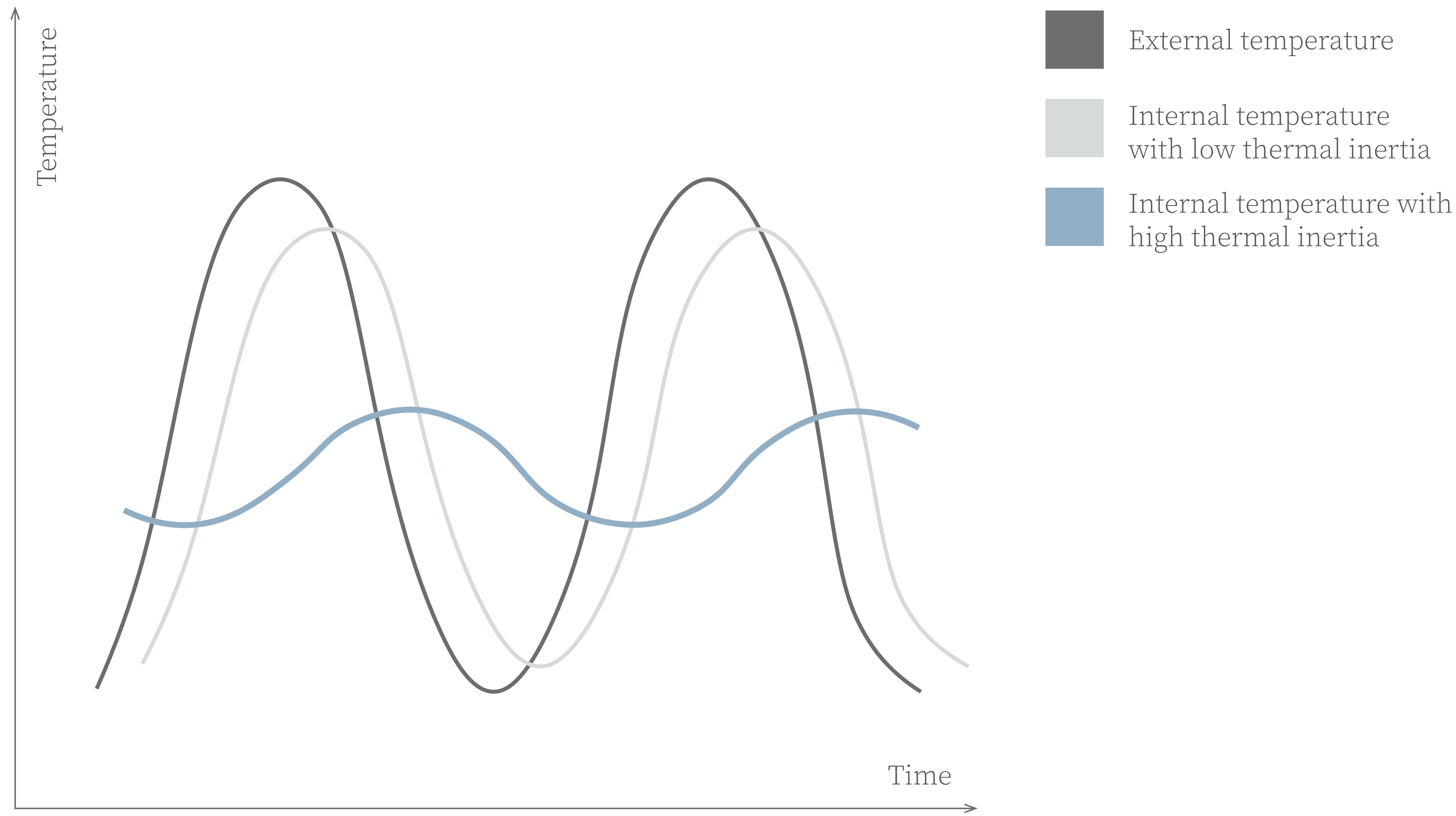
Sun-shading system

Weessies, 2022

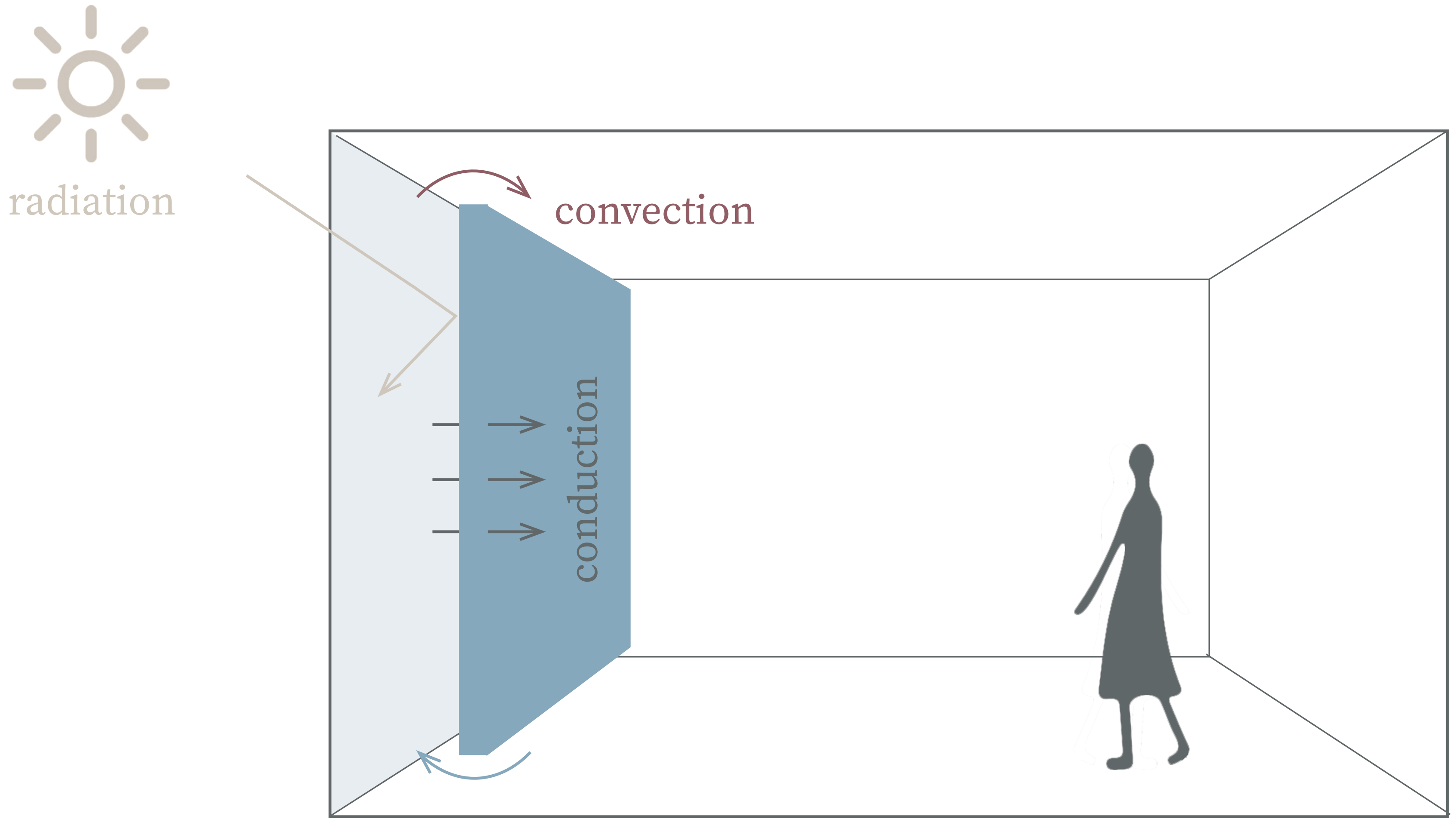
Passive design strategies: thermal inertia



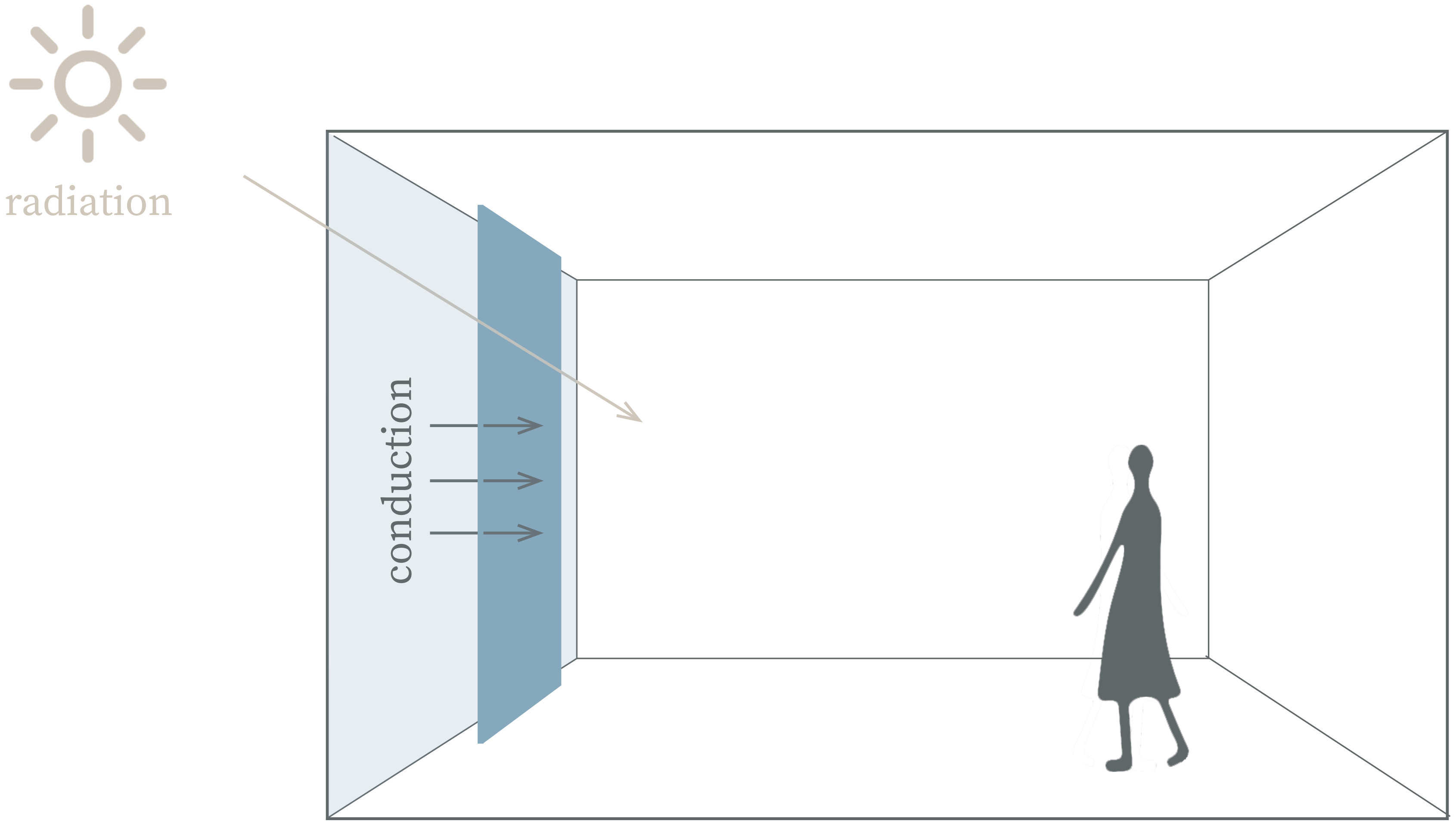
Passive design strategies: thermal inertia



Trombe wall

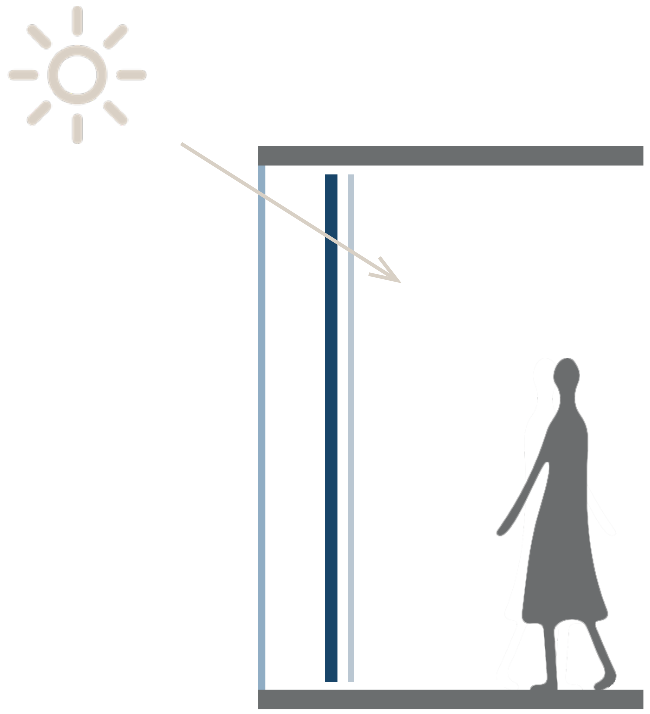


Trombe wall

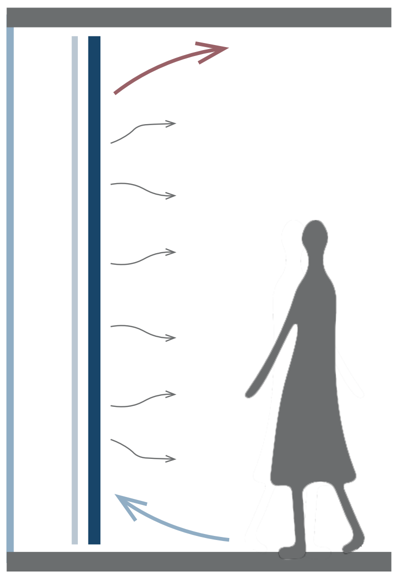


PCMs trombe wall

PASSIVE HEATING



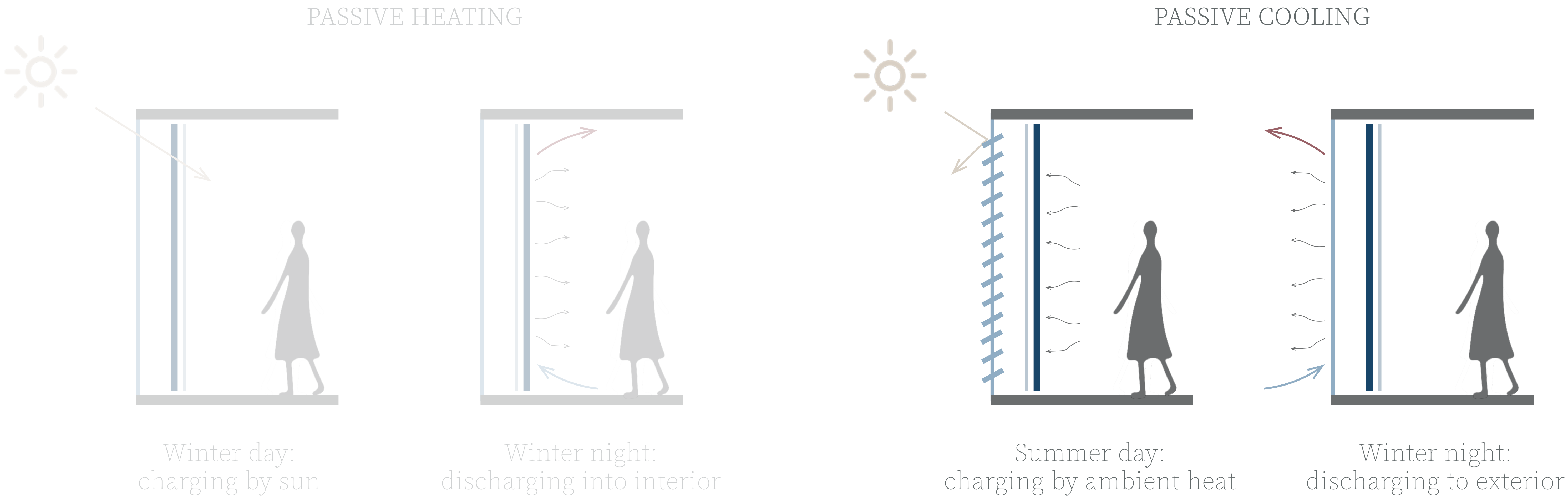
Winter day:
charging by sun



Winter night:
discharging into interior

Edited from Tenpierik et al., 2018

PCMs trombe wall

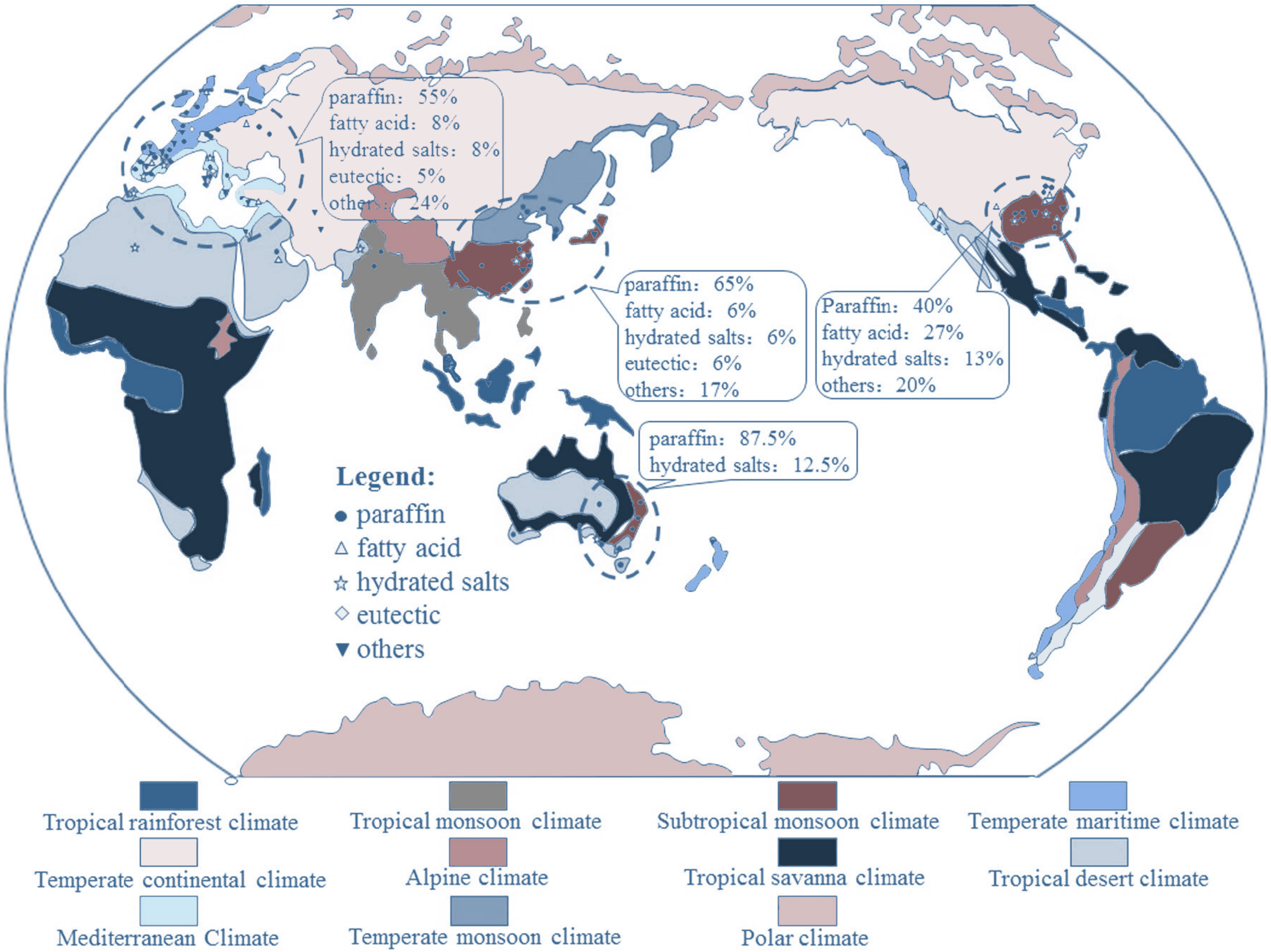


Edited from Tenpierik et al., 2018

Phase Change Materials

PCMs are materials that can **store** a lot of **energy** during their **phase transition** to heat or cool an indoor space.

Phase Change Materials



Cui et al., 2017

Danish Academy, 2018

PARAFFINS

PROS

- Large temperature range
- Congruent melting
- No segregation
- Freeze without much supercooling
- Recyclable
- High heat of fusion
- Chemically stable
- Safe and non-reactive

CONS

- Low thermal conductivity
- Low volumetric latent heat storage capacity
- Flammable
- Translucent only when liquid

Infobuild, 2018

SALT HYDRATES

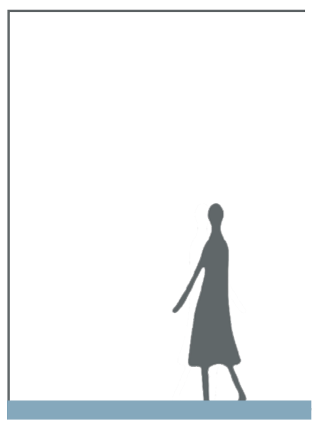
PROS

- High thermal conductivity
- High volumetric latent heat storage capacity
- Non-flammable
- Sharp phase change
- Low cost
- Easy availability
- Safe
- Translucent when solid and liquid

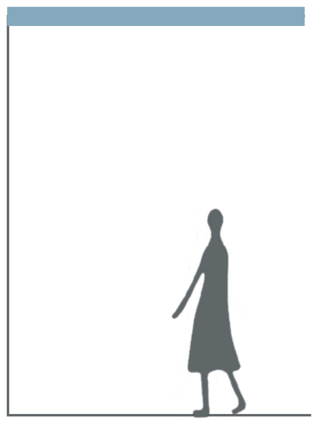
CONS

- Incongruent melting
- Supercooling
- Large volume change
- Corrosion
- Uncertain long term reliability

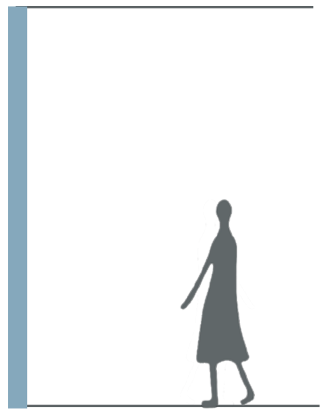
PCMs building applications



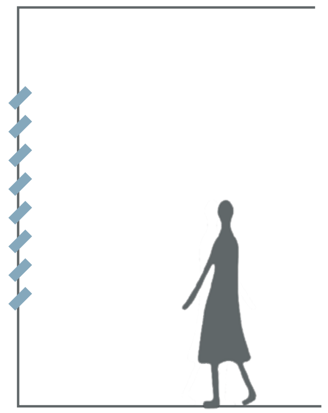
Floor heating



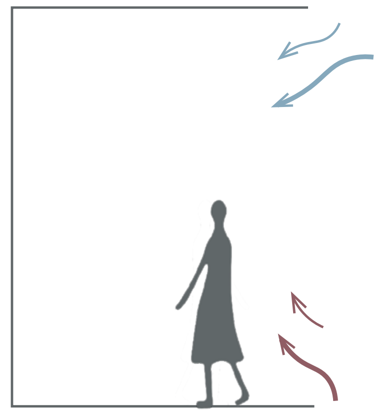
Cooling ceiling



Wall



Shutters



Energy storage system

PROBLEM

Climate change

↓

Building energy demand

SOLUTION

Passive design strategies

↓

Trombe walls

↓

PCMs trombe walls

PROBLEM

Climate change

↓

Building energy demand

SOLUTION

Passive design strategies

↓

Trombe walls

↓

PCMs trombe walls

↓

PCMs products are not expanded

Aim

The research envisions the development of strategies for expanding the use of PCMs trombe walls in the built environment

Research question

How can a **modular** and **translucent PCMs trombe wall** be integrated as a passive strategy in **existing** and **energy optimized** buildings to work as **heating** during winter and **cooling** in summer?

Thermal performance

Daylight admittance

Thermal performance ⟷ Daylight admittance

PCMs trombe wall

1 design

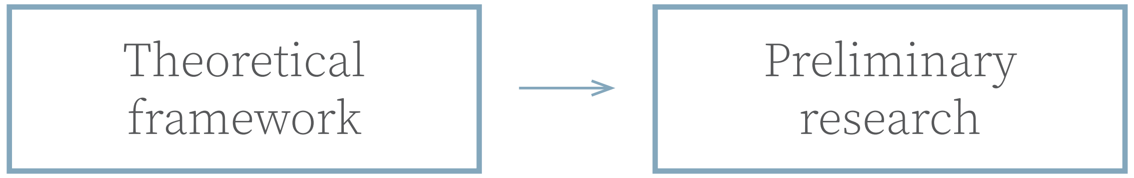
PCMs trombe wall

1 design → Multiple room configurations

Research method

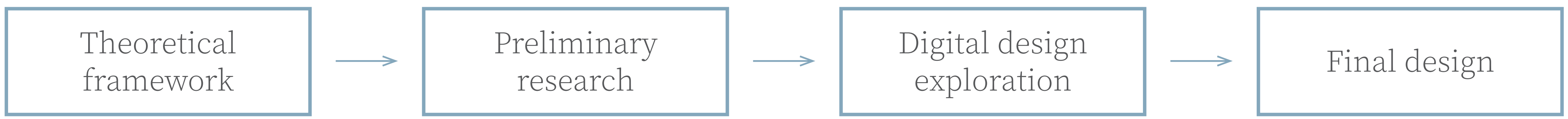
Theoretical framework

Research method



Research method

Research method



Research method → Theoretical framework

Research method

→ Theoretical framework

→ Preliminary research

Habitat Royale

Mecanoo, 2022

INFO

Project: Habitat Royale

Architects: Mecanoo, ARUP, BOOM Landscape

Location: Amsterdam

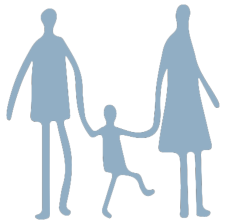
Climate zone: Temperate

Function: Residential, public

Year: 2024

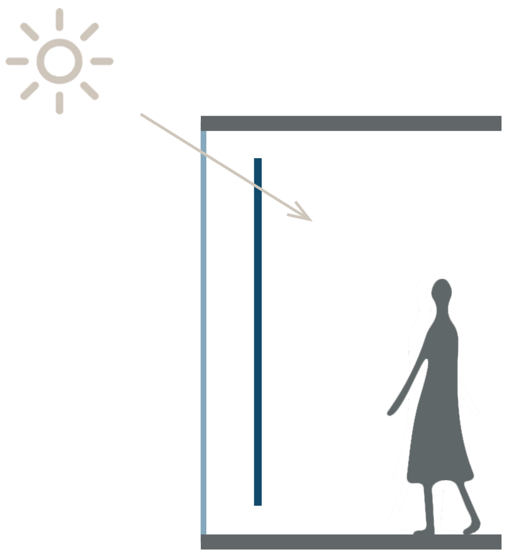
Building requirements

Temperate climate zone



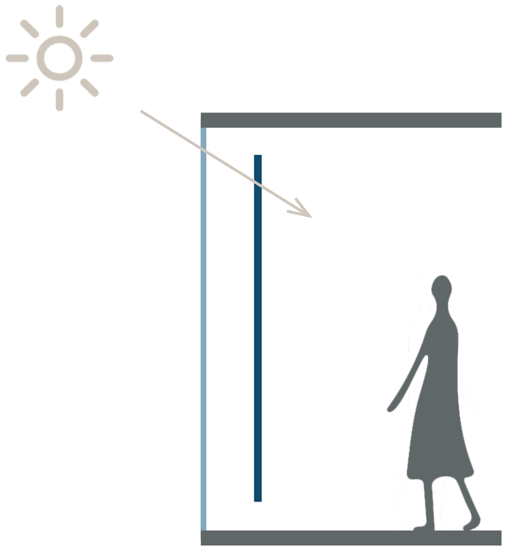
Residential function

Design guidelines: macro scale

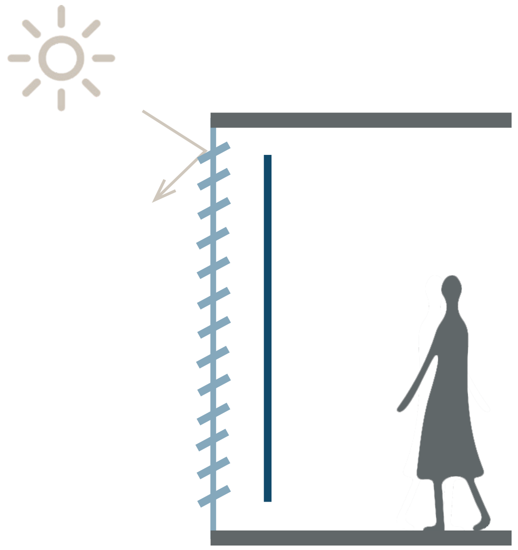


Daylight

Design guidelines: macro scale

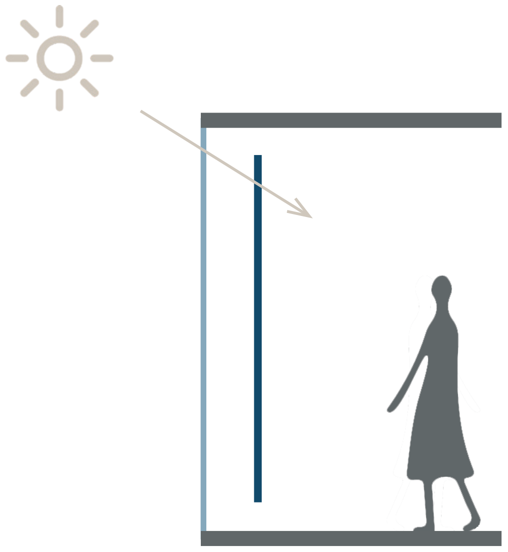


Daylight

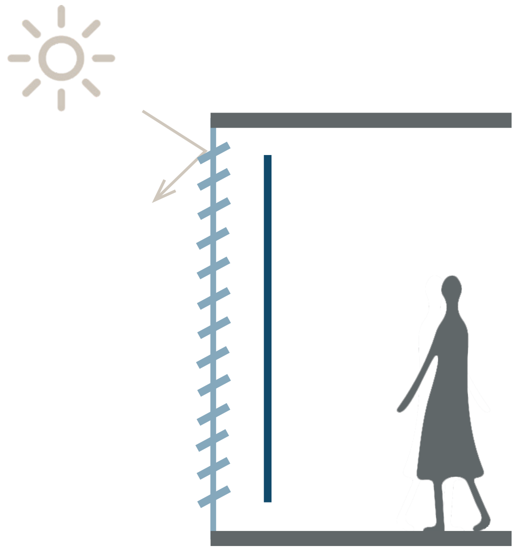


Shading system

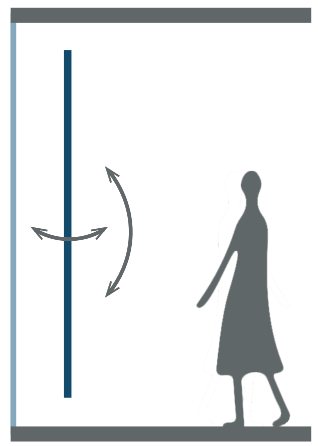
Design guidelines: macro scale



Daylight

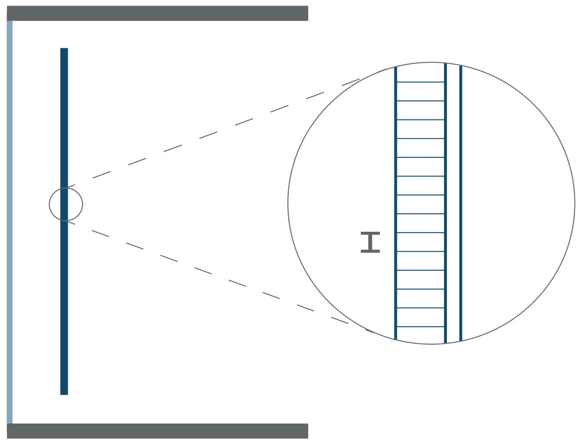


Shading system



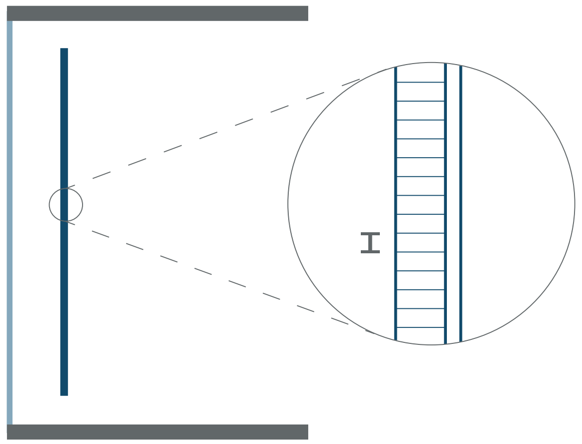
Adjustability

Design guidelines: micro scale

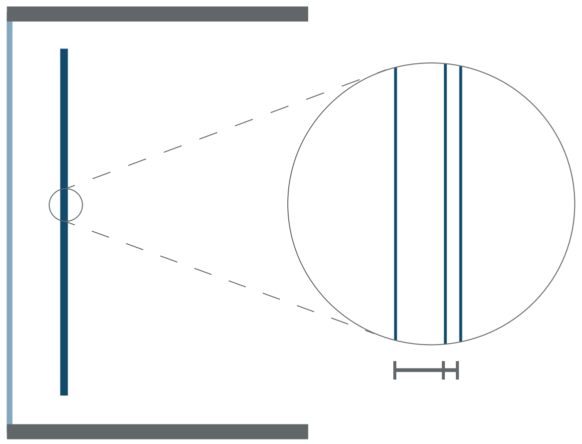


Internal subdivision

Design guidelines: micro scale

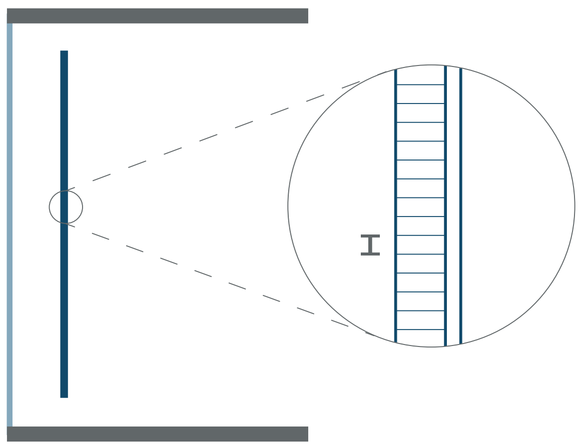


Internal subdivision

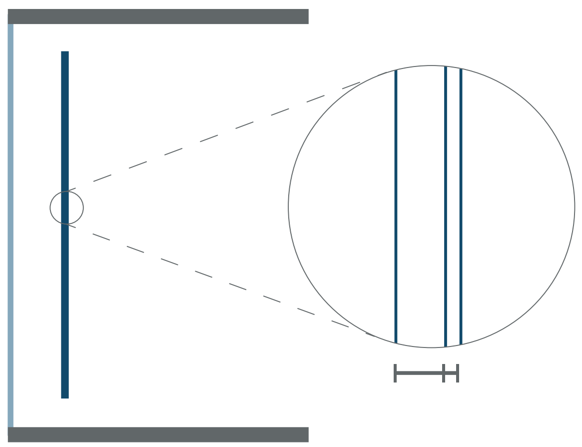


Thickness

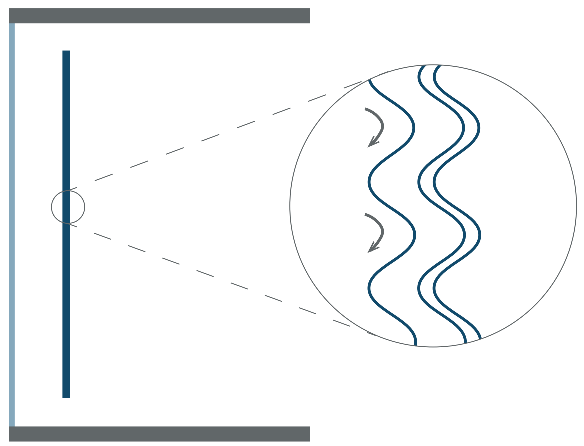
Design guidelines: micro scale



Internal subdivision



Thickness



Heat transfer coefficient

Materials choice

Salt hydrates
Rubitherm - SP25E2

Aerogel
Lumira aerogel LA1000

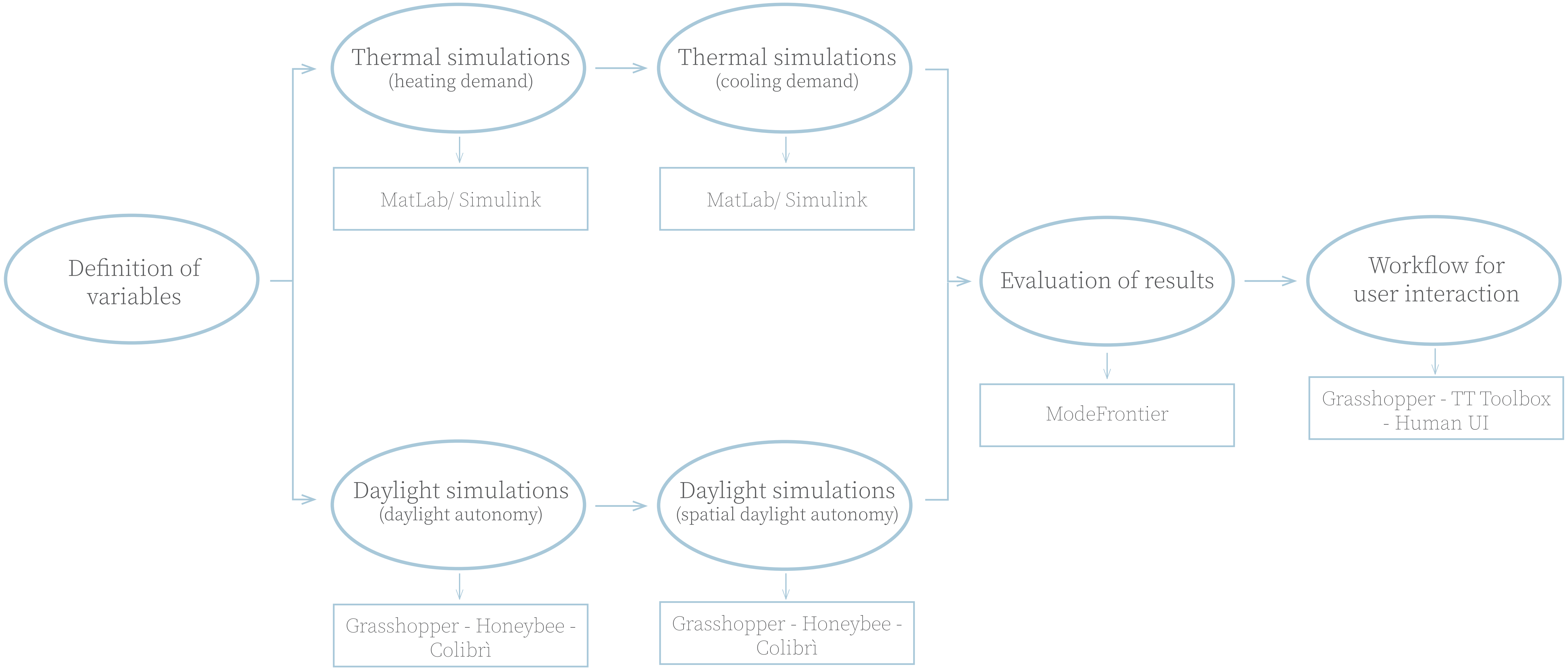
Research method

→ Theoretical framework

→ Preliminary research

→ Digital design exploration

Methodology



Assumptions

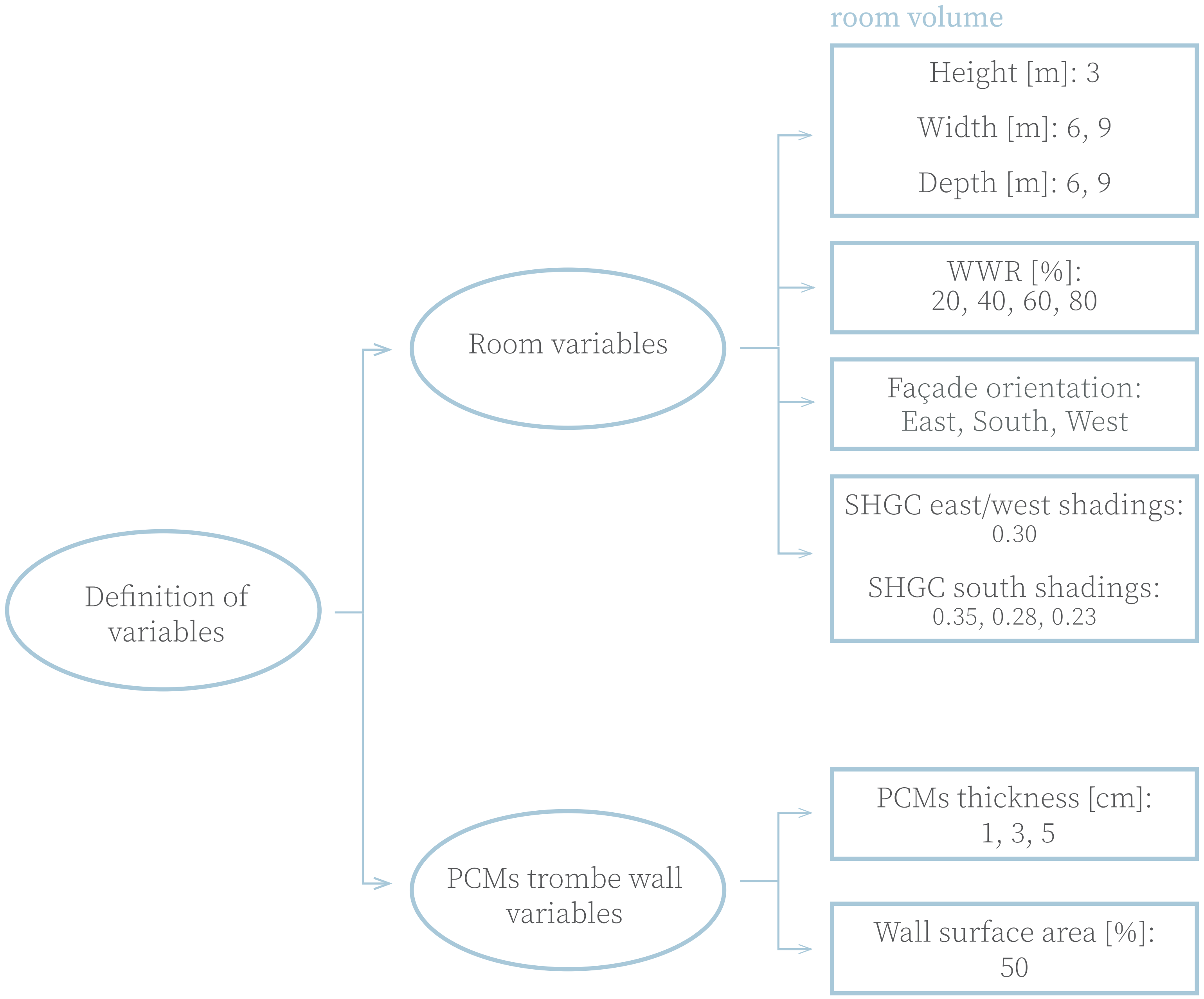
Flat façade

PCMs flat trombe wall

No obstructions

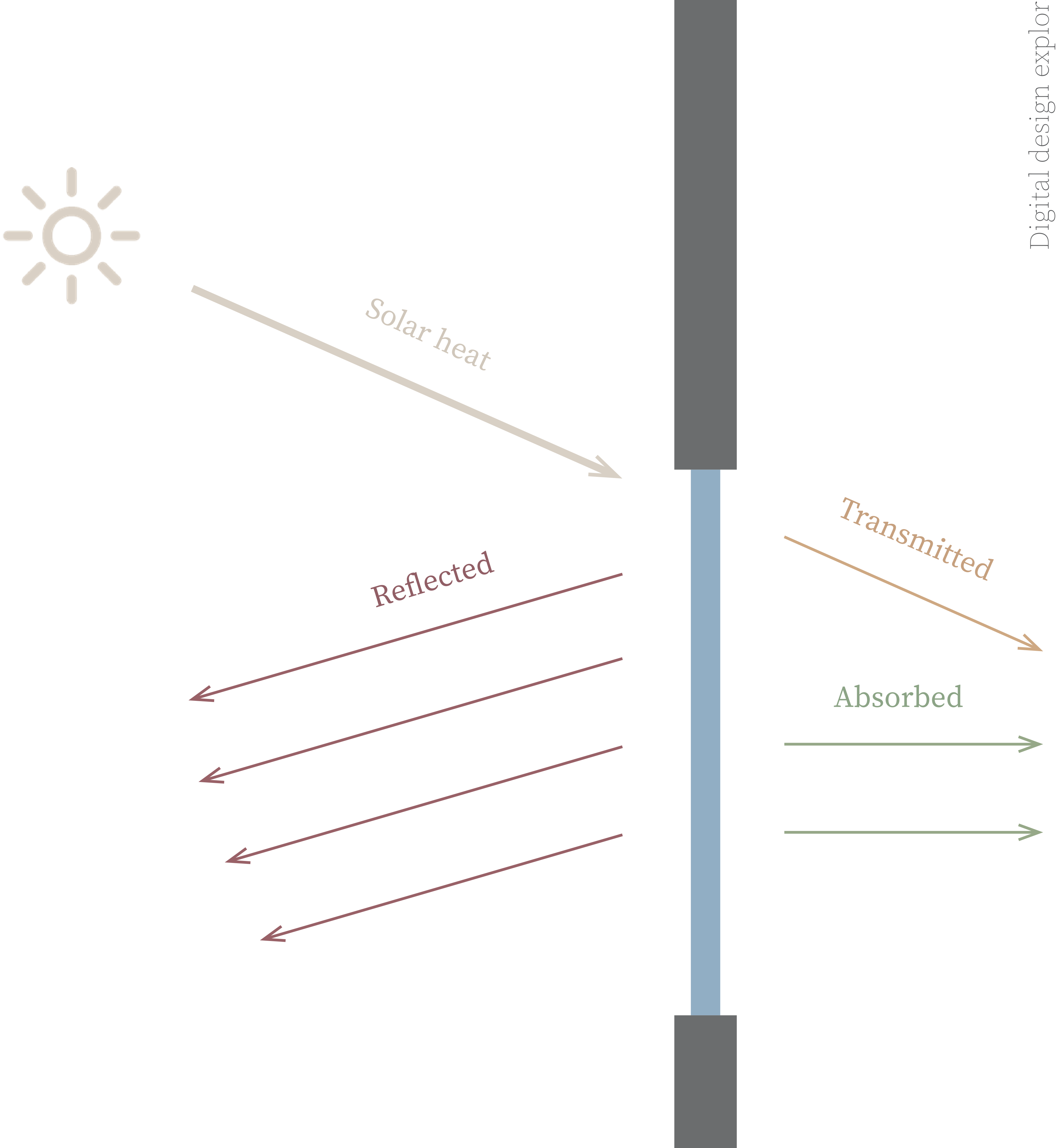
PCMs translucency is the average of solid and liquid value

Variables

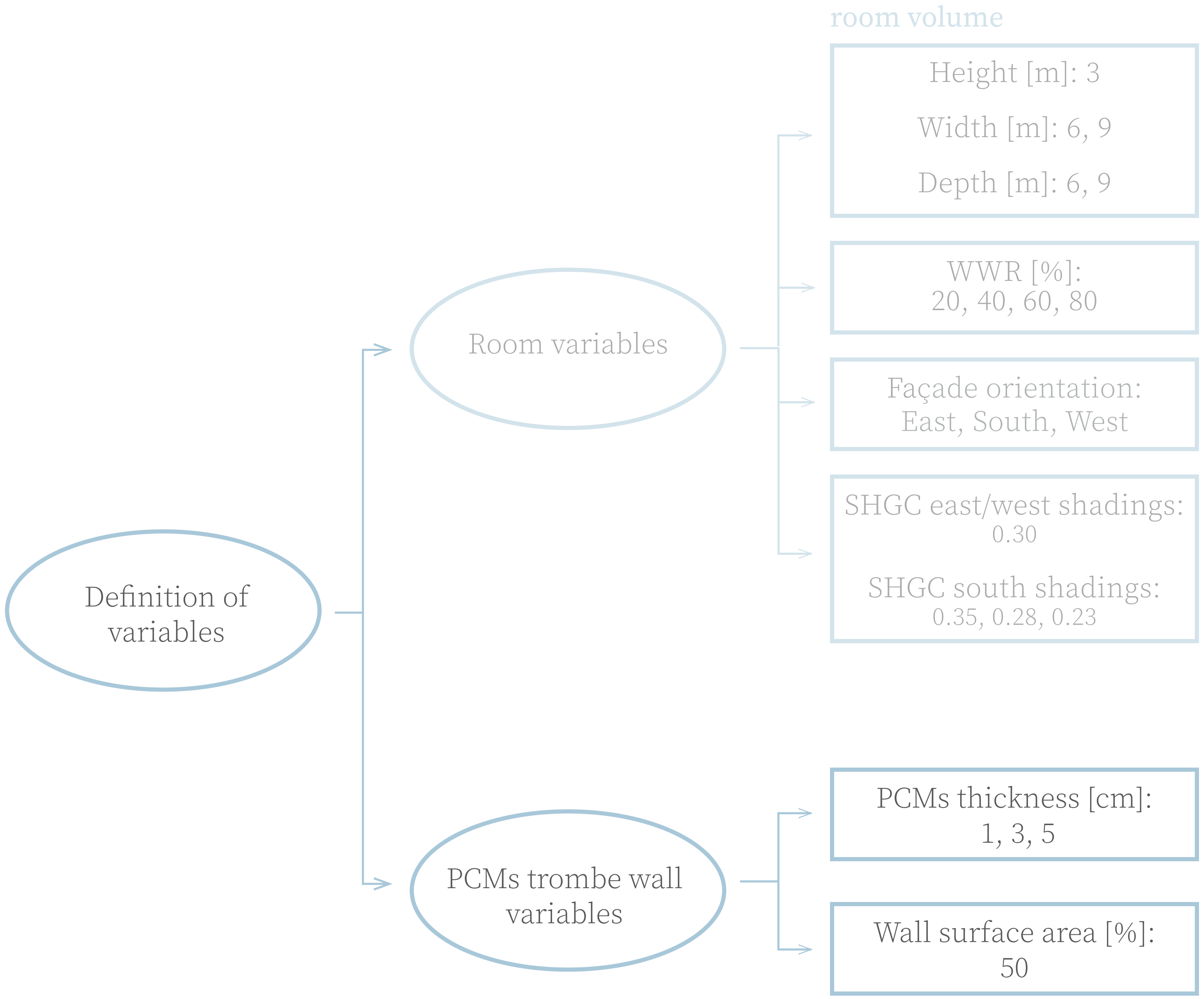

room volume
Height [m]: 3
Width [m]: 6, 9
Depth [m]: 6, 9
WWR [%]:
20, 40, 60, 80
Façade orientation:
East, South, West
SHGC east/west shadings:
0.30
SHGC south shadings:
0.35, 0.28, 0.23
Room variables
Definition of
variables
PCMs trombe wall
variables
PCMs thickness [cm]:
1, 3, 5
Wall surface area [%]:
50

Solar Heat Gain Coefficient

The SHGC is the solar energy admitted through the window



Variables


room volume
Height [m]: 3
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WWR [%]:
20, 40, 60, 80
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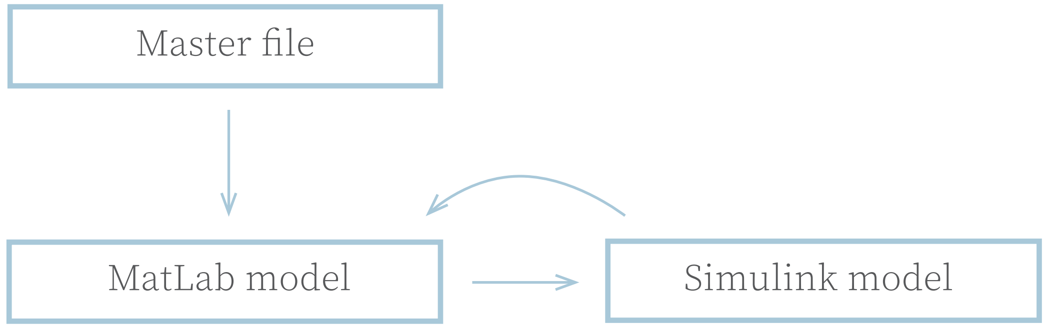
East, South, West
SHGC east/west shadings:
0.30
SHGC south shadings:
0.35, 0.28, 0.23
Room variables
Definition of variables
PCMs trombe wall variables
PCMs thickness [cm]:
1, 3, 5
Wall surface area [%]:
50

Thermal simulations
MatLab/ Simulink



Thermal simulations
MatLab/ Simulink

MASTER FILE

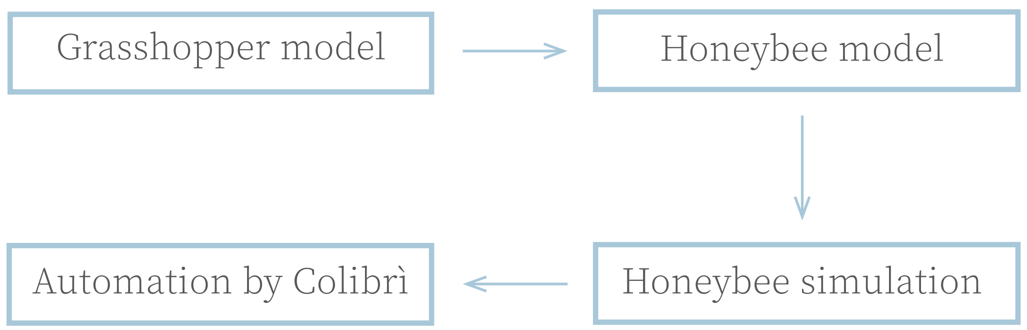
```
%Y variables
A_matrix = [6;9];
B_matrix = [6;9];
C_matrix = [3];
D_matrix = [1; 2; 3; 4];
E_matrix = [5];
F_matrix  = [90; 180; 270];
G_matrix = [5];
H_matrix= [1];
I_matrix  = [1;2;3];

% X variables
M_matrix= [1;2;3];
N_matrix = [1]
```

Thermal simulations
MatLab/ Simulink

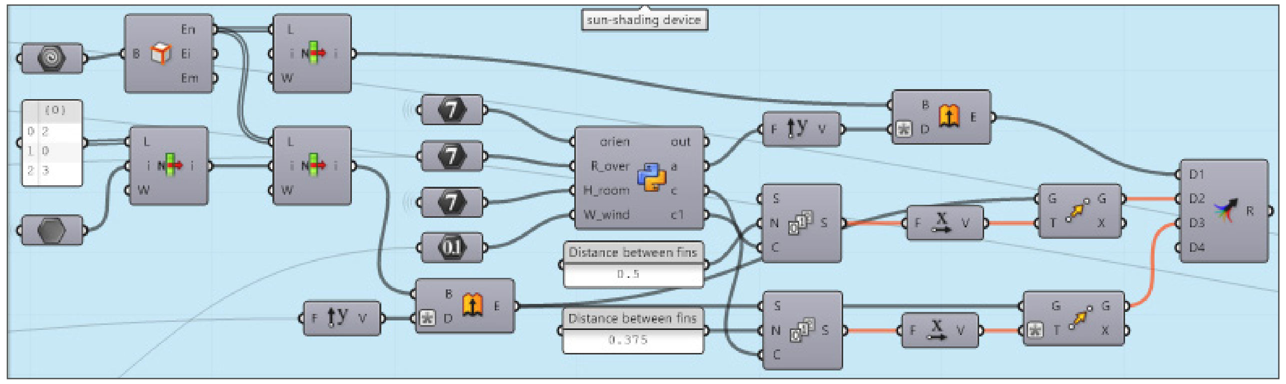
RESULTS

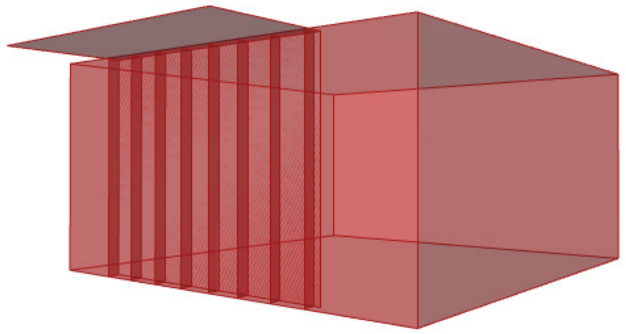
	1	2
1	$a_1 * b_1 * c_1$	$a_1 * b_1 * c_2$
2	$a_2 * b_1 * c_1$	$a_2 * b_1 * c_2$
3	$a_1 * b_2 * c_1$	$a_1 * b_2 * c_2$
4	$a_2 * b_2 * c_1$	$a_2 * b_2 * c_2$

Daylight simulations
Grasshopper



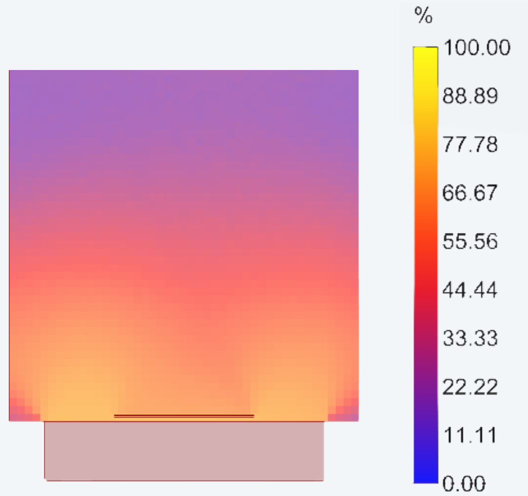
Daylight simulations
Grasshopper





Daylight simulations
Grasshopper

RESULTS



	1
1	$a_1 * b_1 * c_1$
2	$a_2 * b_1 * c_1$
3	$a_1 * b_2 * c_1$
4	$a_2 * b_2 * c_1$
5	$a_1 * b_1 * c_2$
6	$a_2 * b_1 * c_2$
7	$a_1 * b_2 * c_2$
8	$a_2 * b_2 * c_2$

Research method

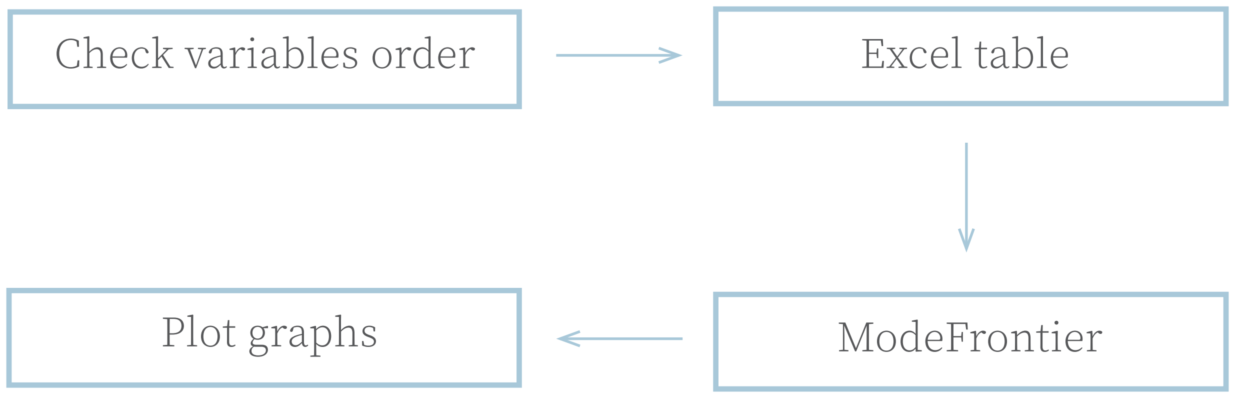
→ Theoretical framework

→ Preliminary research

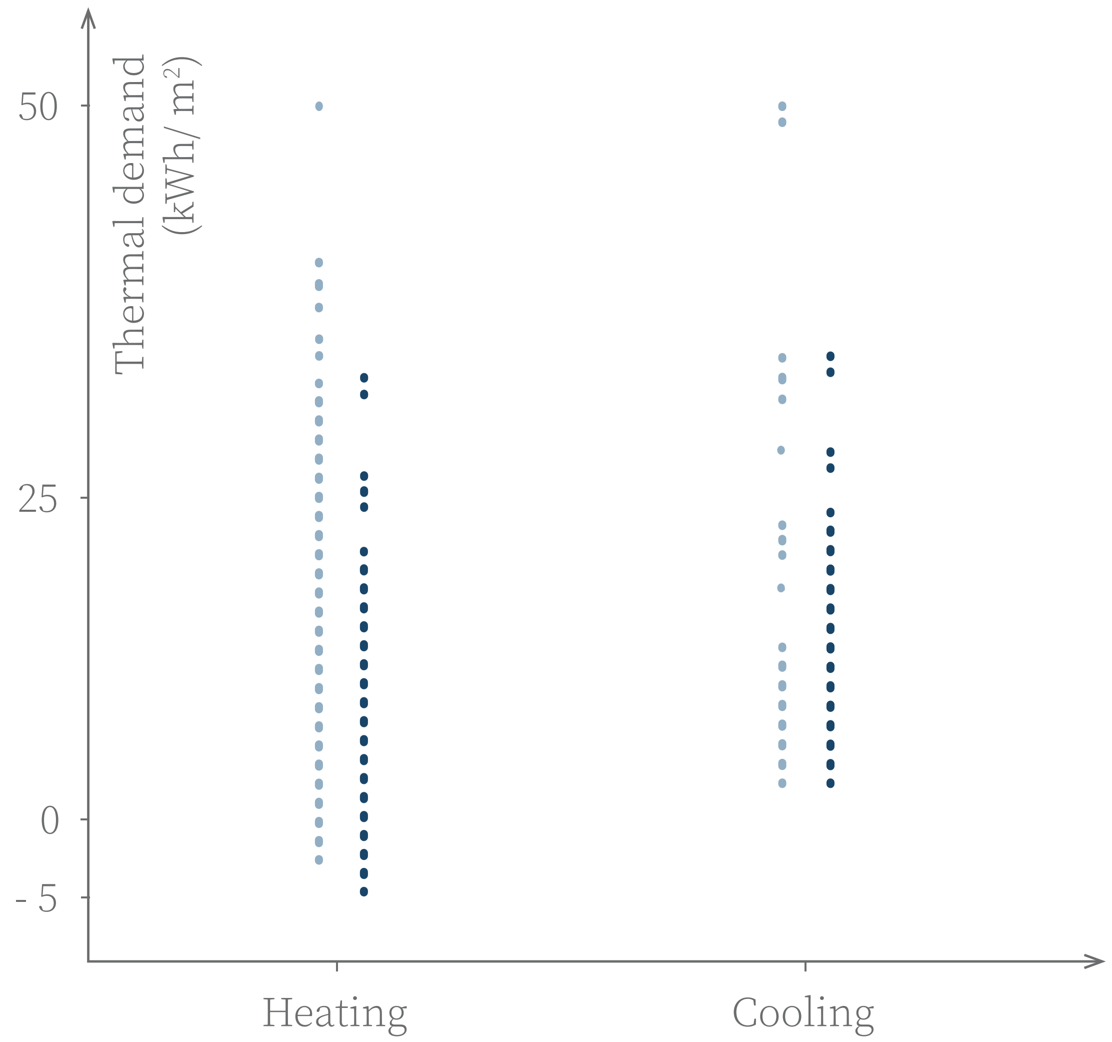
→ Digital design exploration

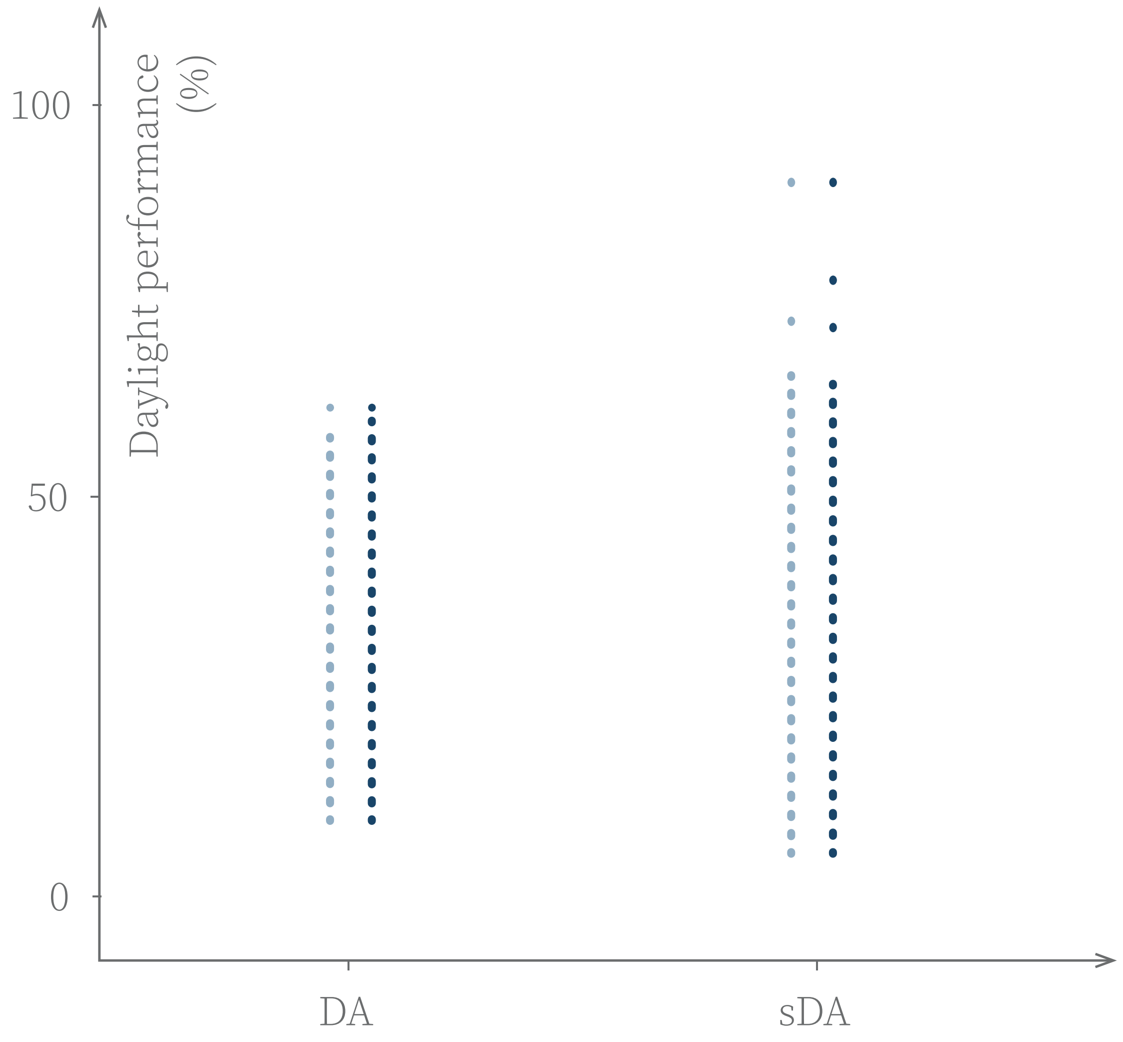
→ Final design

Results

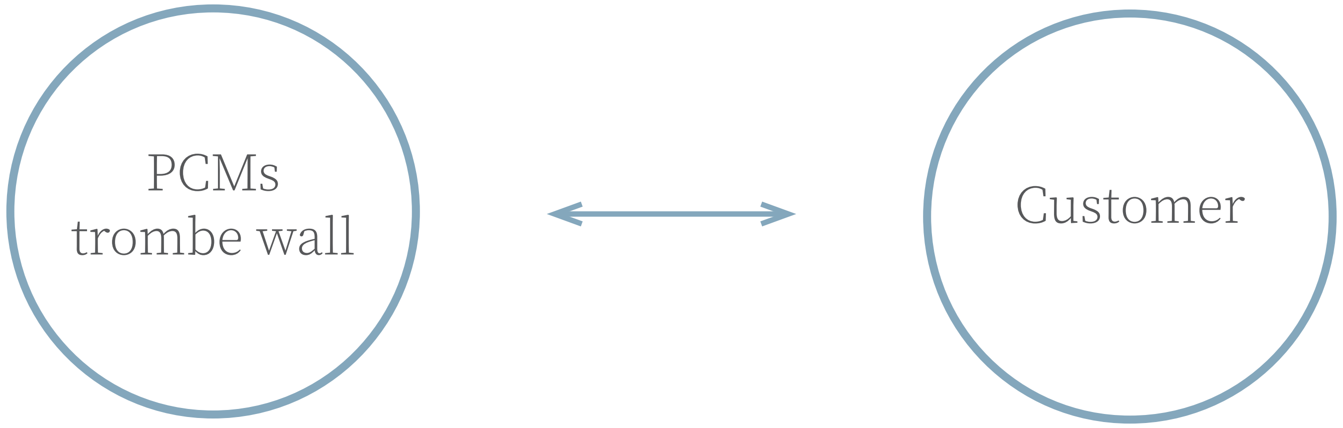

Check variables order
Excel table
ModeFrontier
Plot graphs

Results

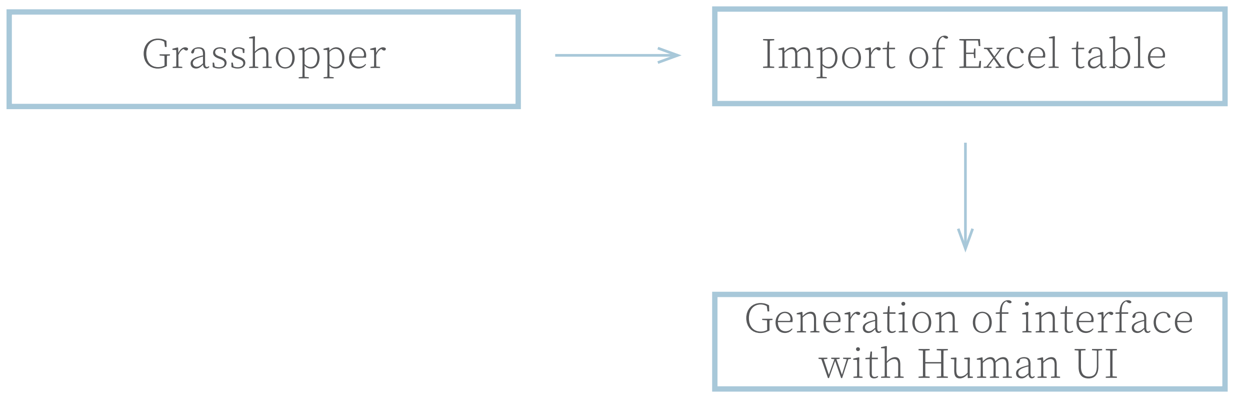

Thermal demand (kWh/ m²)
50
25
0
- 5
Heating
Cooling


Daylight performance (%)
100
50
0
DA
sDA

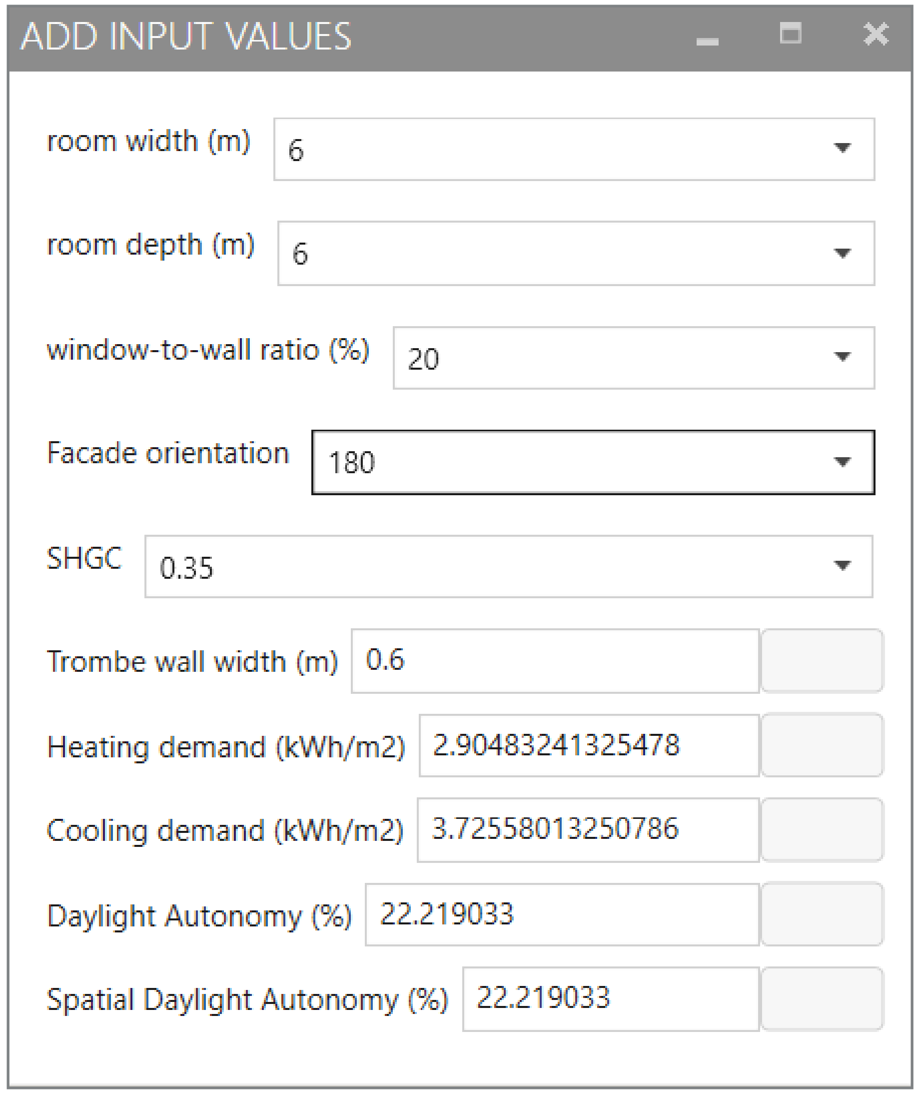

PCMs
trombe wall
Customer


PCMs
trombe wall
Customer

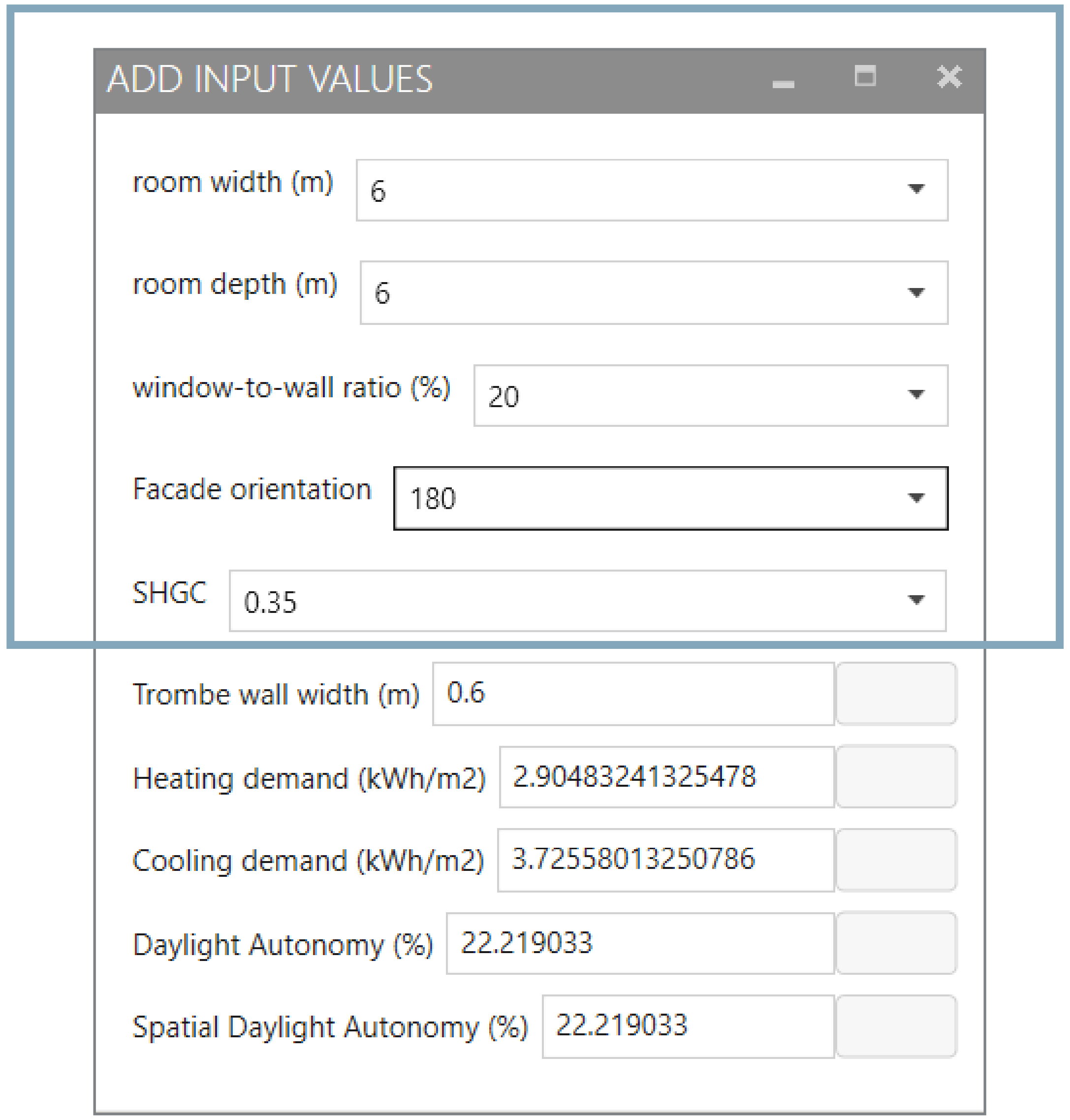
Workflow for user interaction



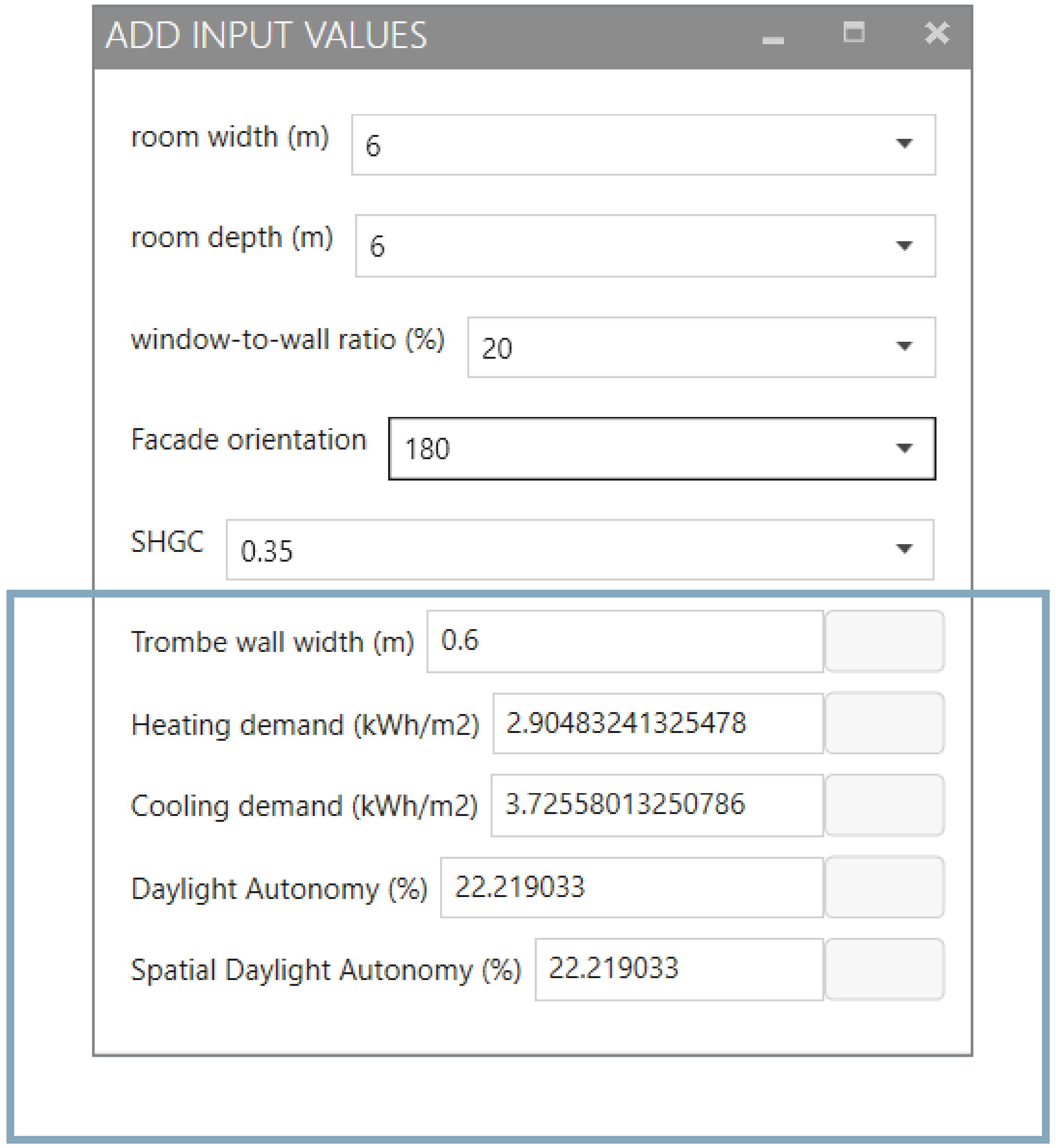
Workflow for user interaction



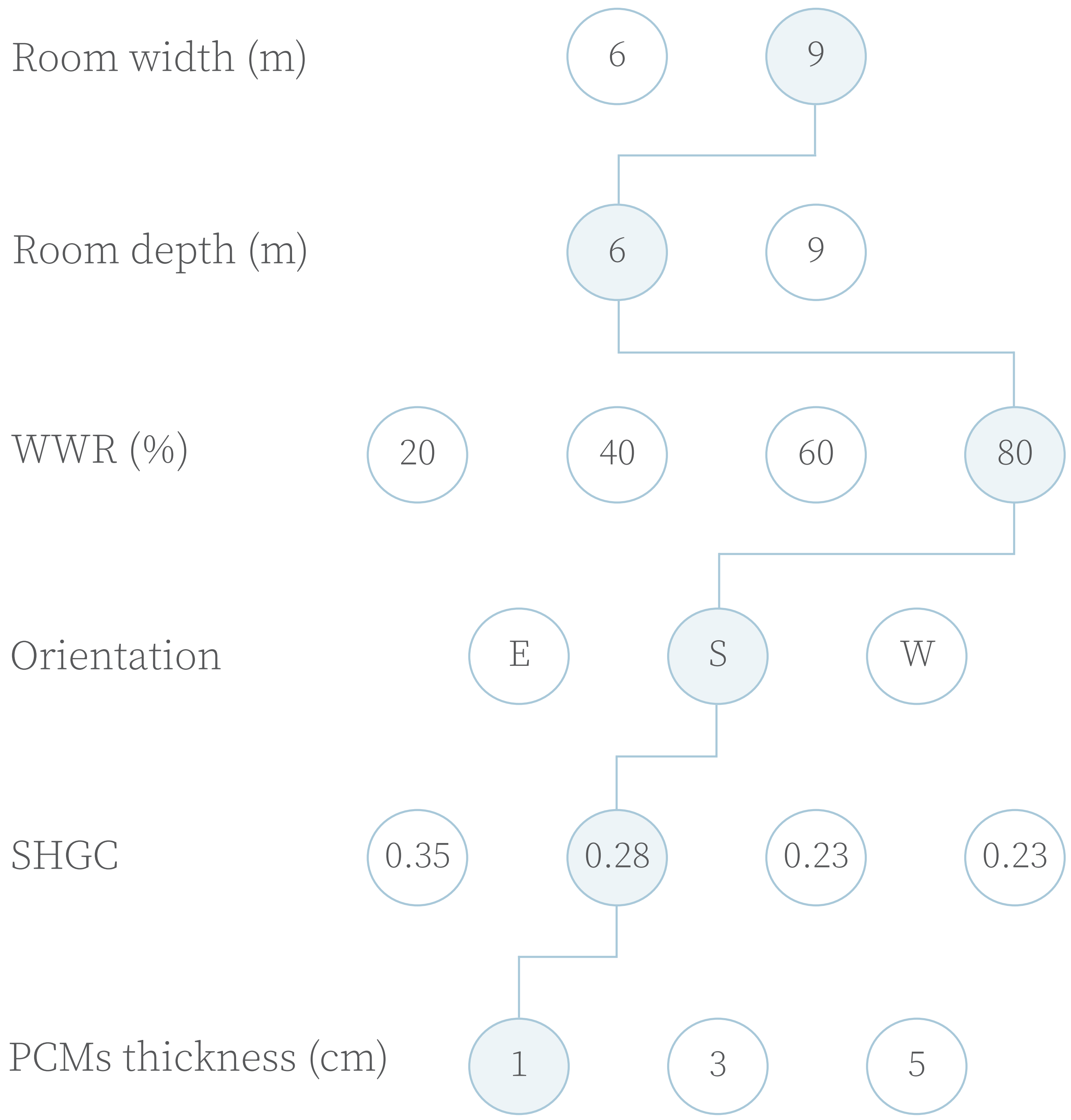
Workflow for user interaction



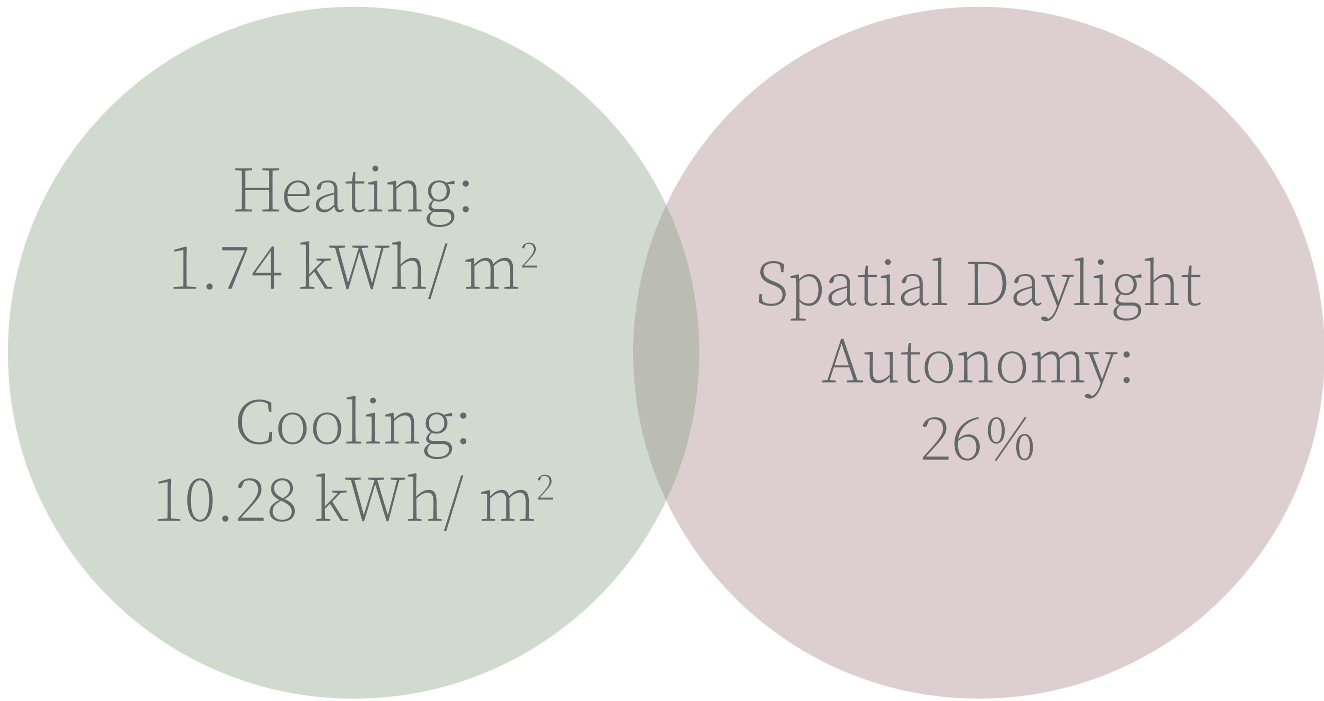
Workflow for user interaction



Selected configuration

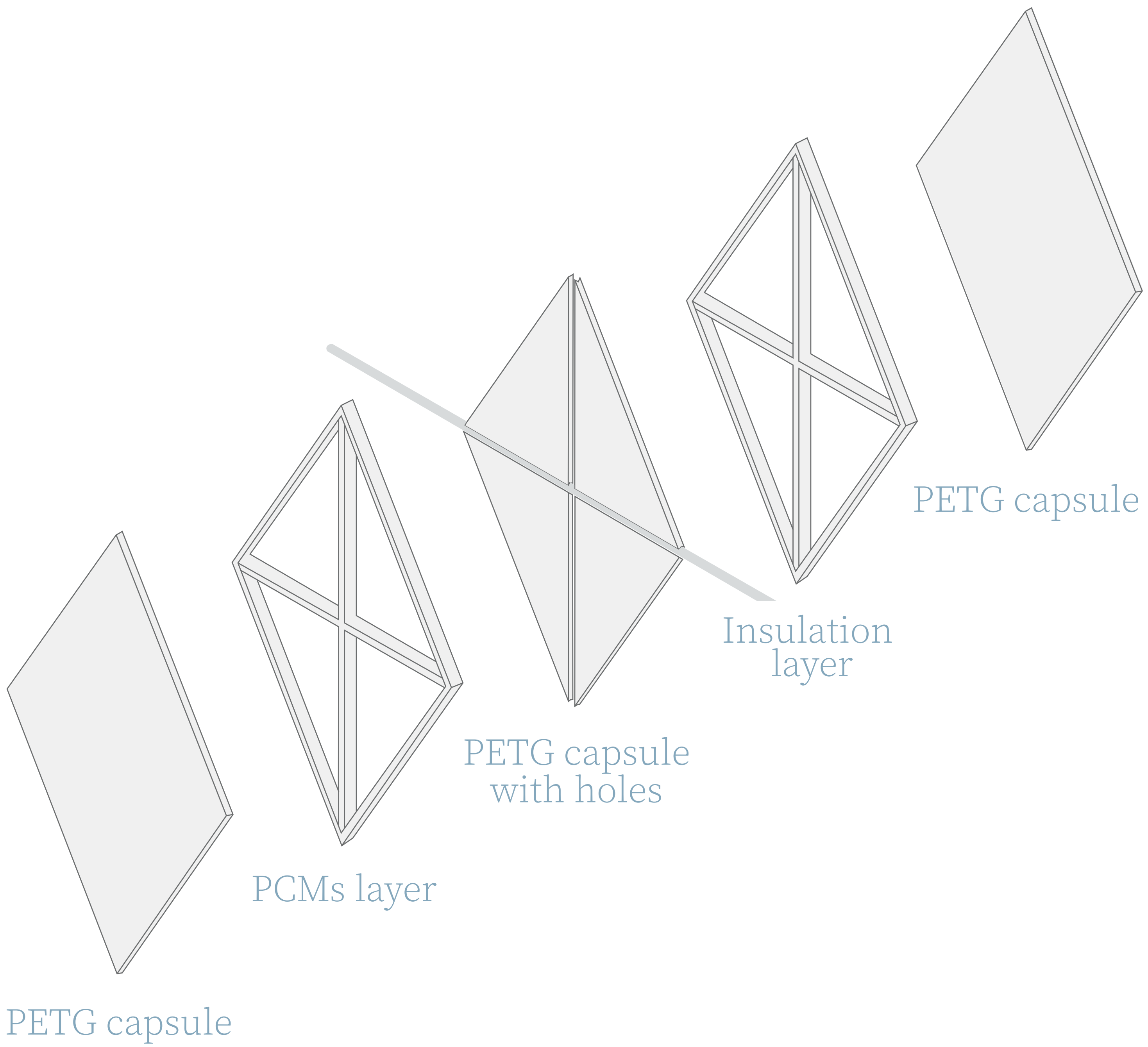


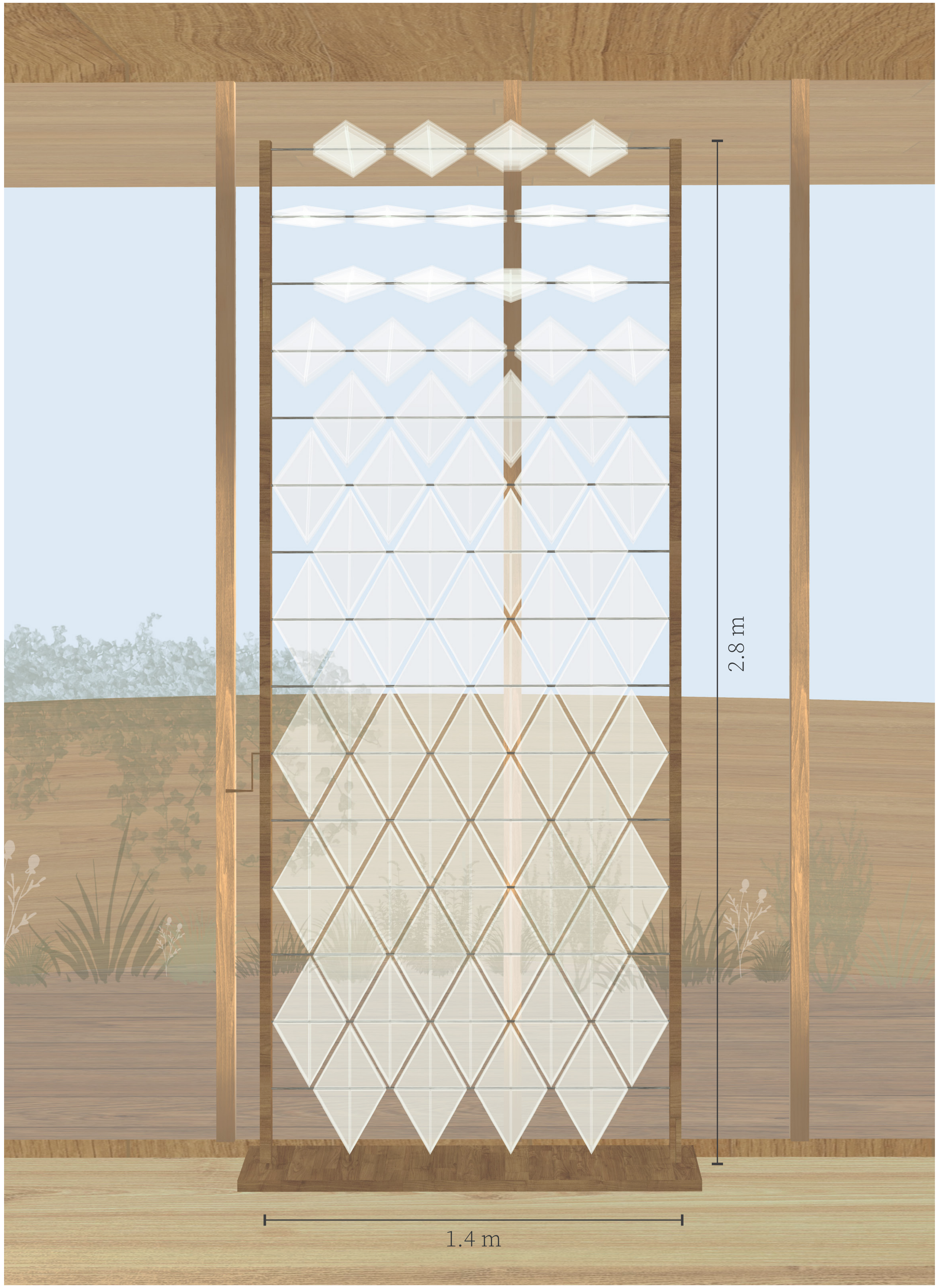
Reduction

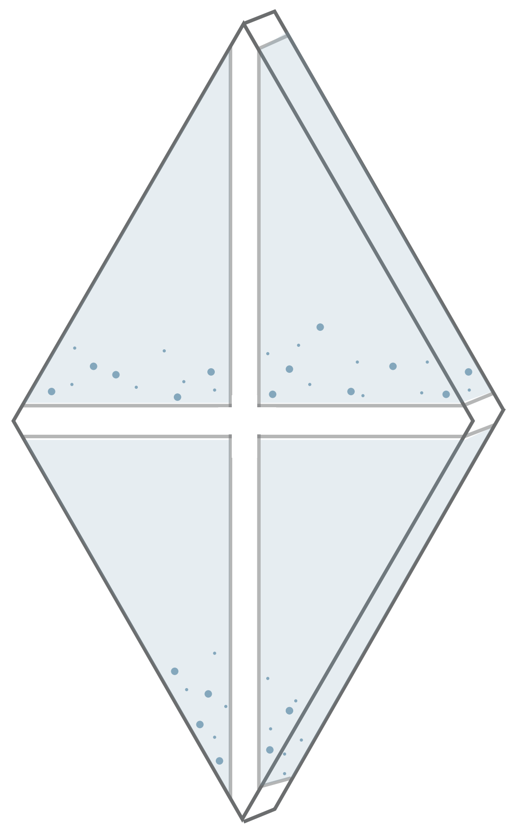

Heating:
1.74 kWh/ m²
Cooling:
10.28 kWh/ m²
Spatial Daylight
Autonomy:
26%

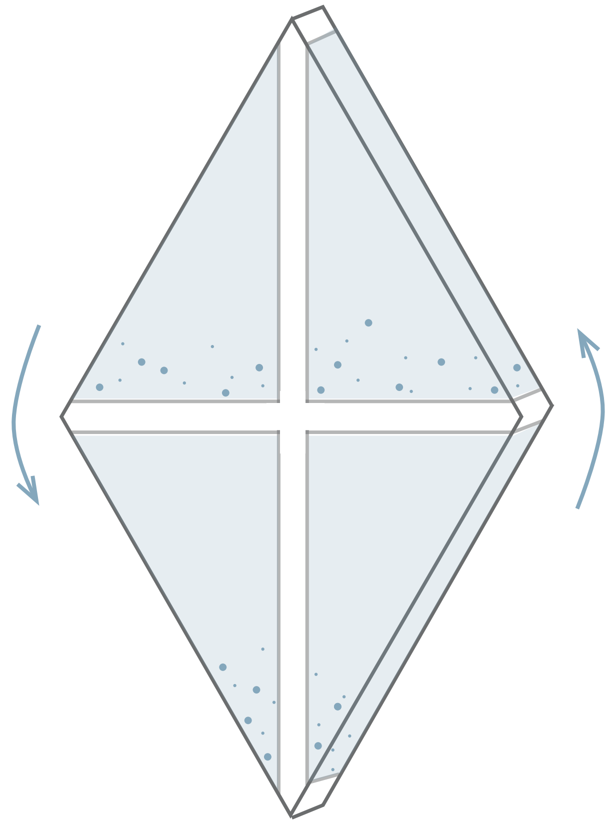
Design criteria

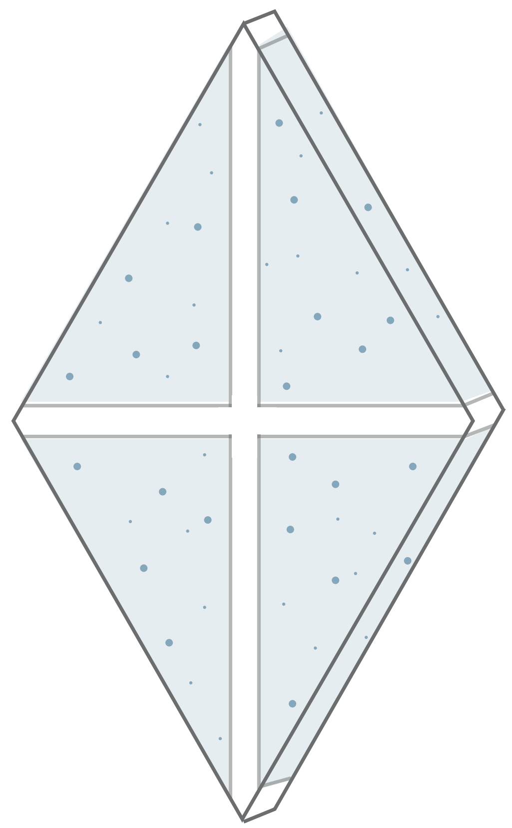
Final design




2.8 m
1.4 m

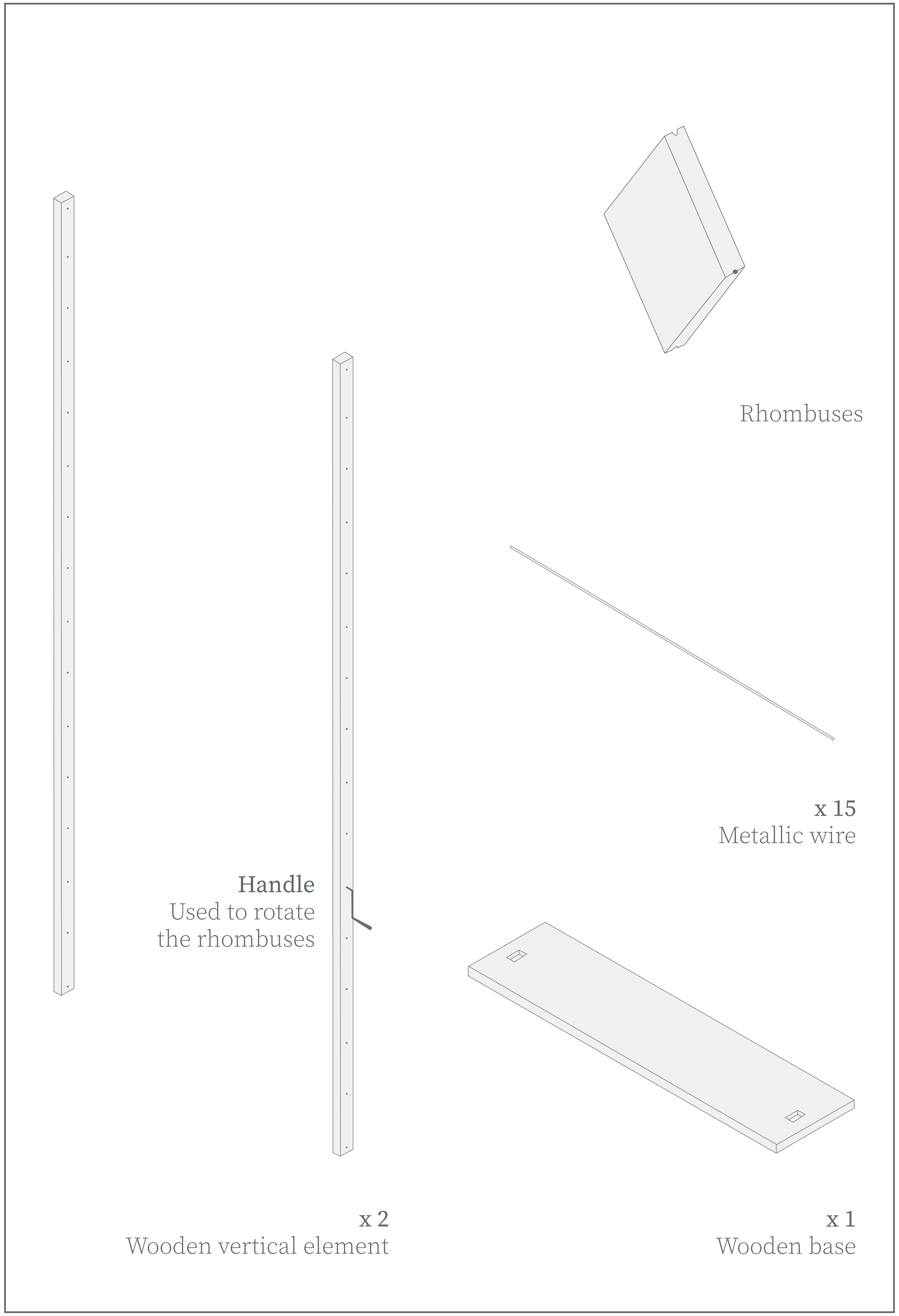




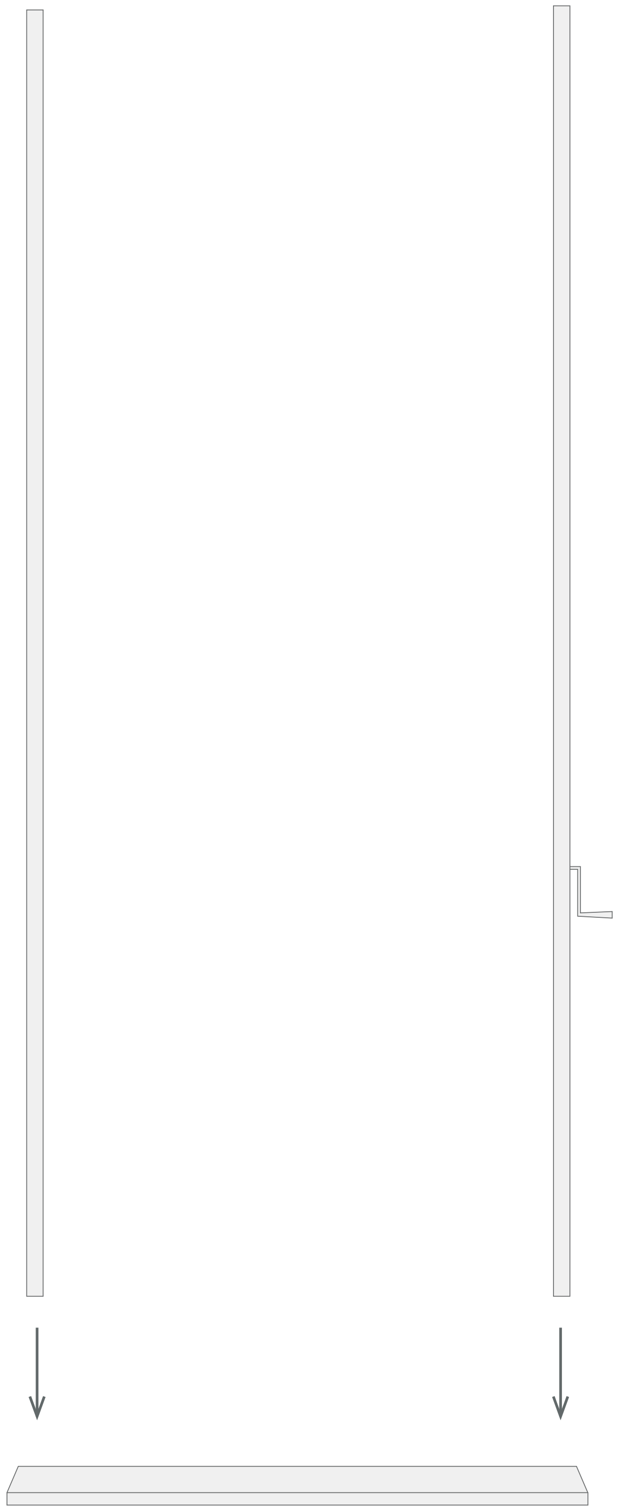


32 mm

Design guidelines

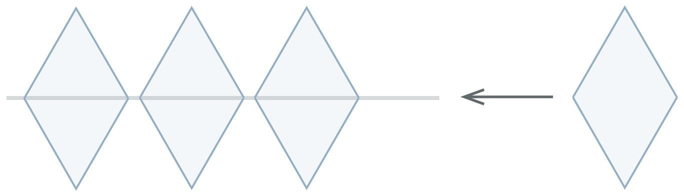

Rhombuses
x 15
Metallic wire
Handle
Used to rotate
the rhombuses
x 2
Wooden vertical element
x 1
Wooden base

1.



Attach the vertical wooden elements to the base

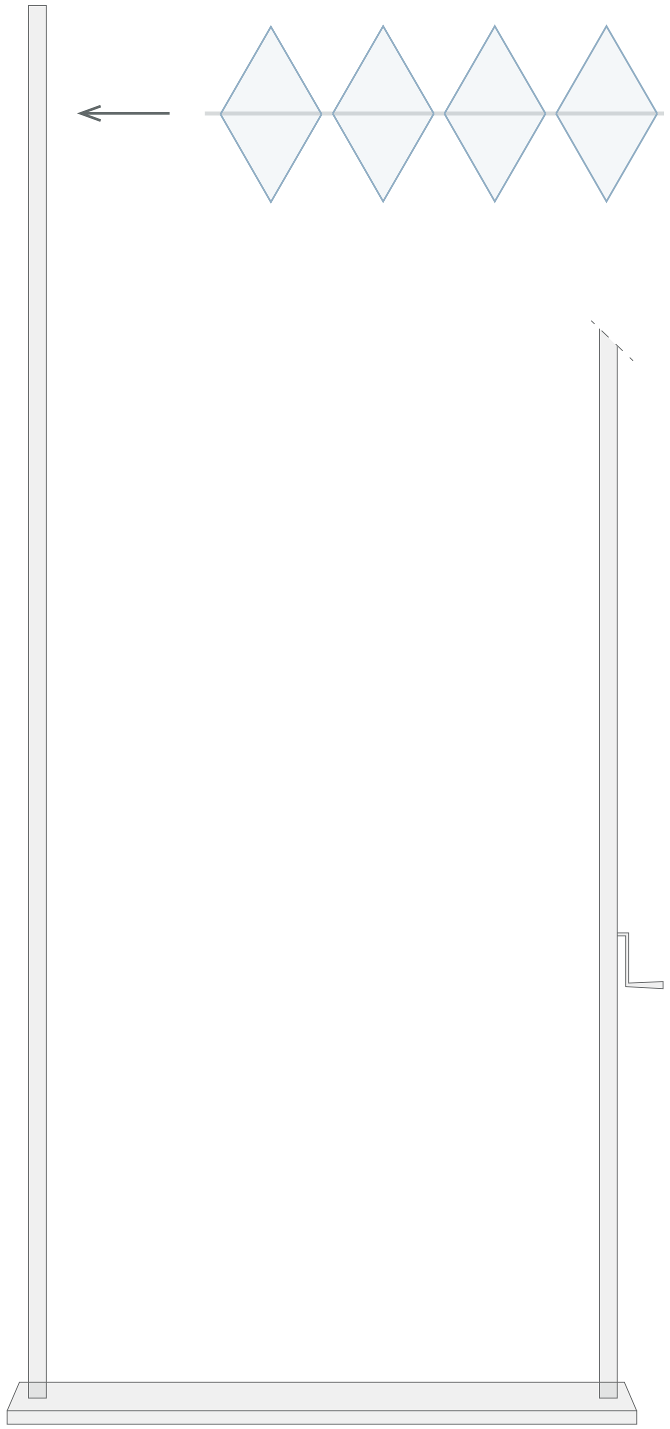
2.



Put the rhombuses in the metallic wire

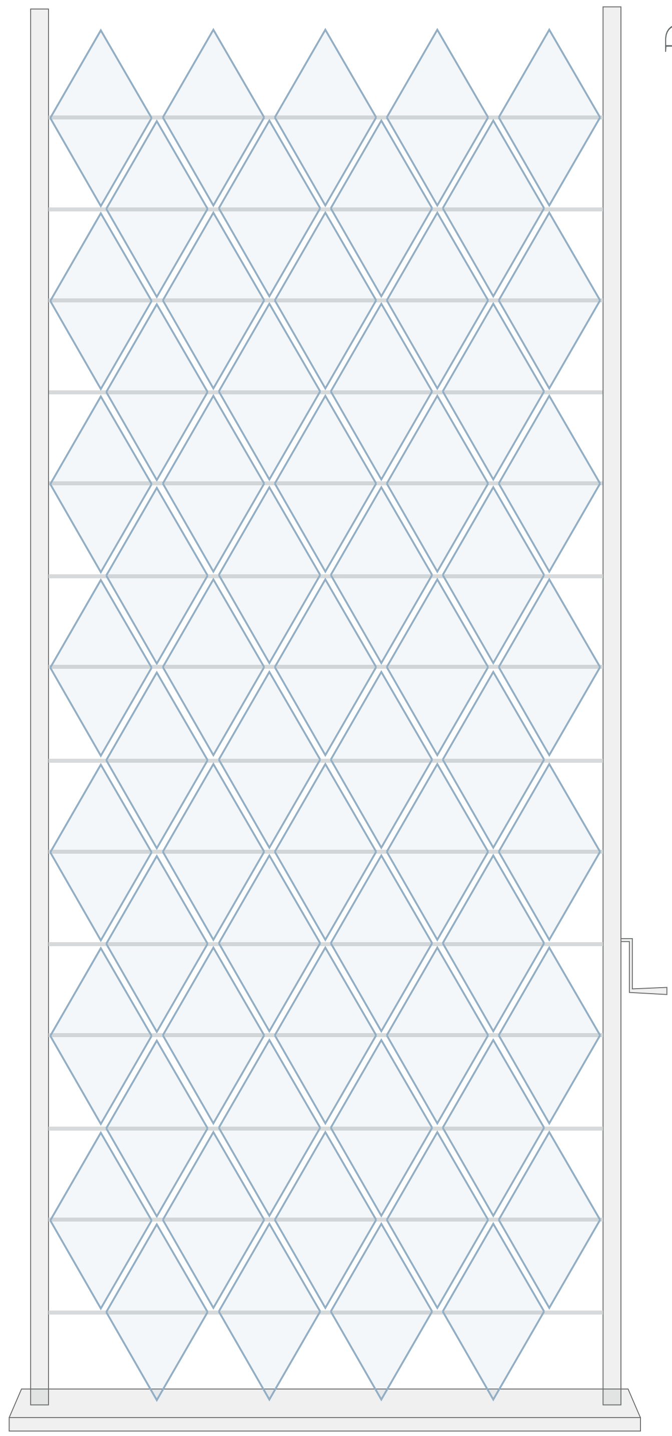
! Make sure that the PCMs layer of each rhombus faces the same side

3.

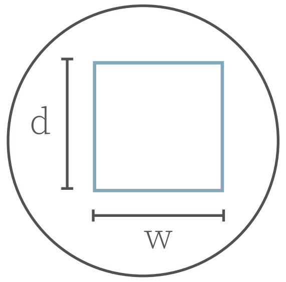


Attach the wires in the holes of the two vertical elements

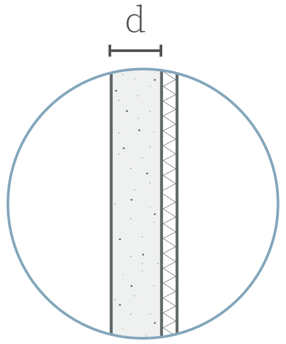
4.



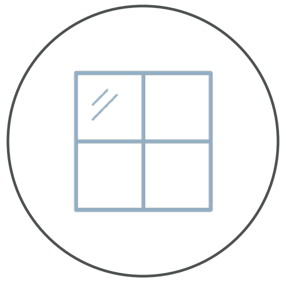
The PCMs trombe wall is ready to be used



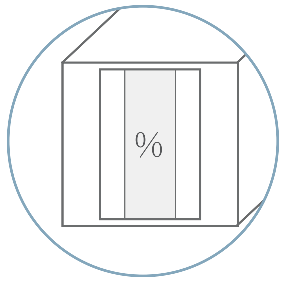
Room area:
1:1 or 3:2
(width : depth)



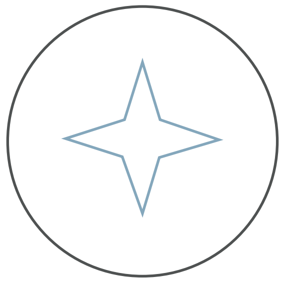
PCMs thickness:
1 cm



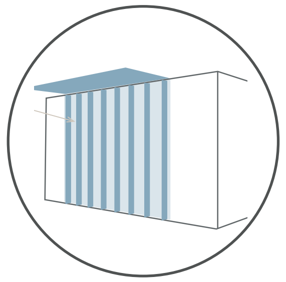
Window-to-wall ratio:
80 or 60%



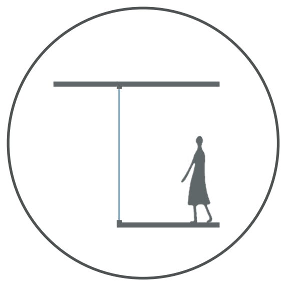
Area of trombe wall
≤ 50%



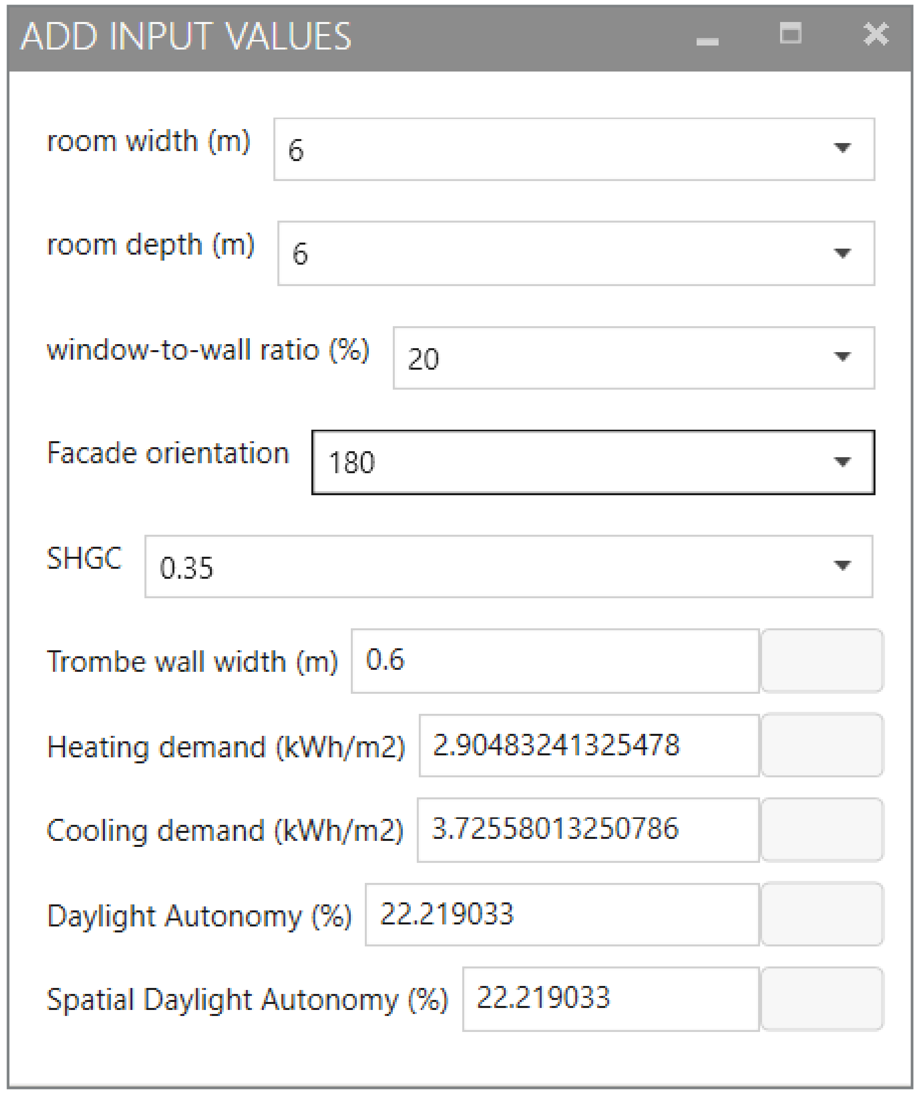
Orientation:
east, south, or west



East and west:
external fixed
shading system



Overhang on the south:
1:2, 1:1, and 3:2
(overhang length : room height)


ADD INPUT VALUES
room width (m)
6
room depth (m)
6
window-to-wall ratio (%)
20
Facade orientation
180
SHGC
0.35
Trombe wall width (m)
0.6
Heating demand (kWh/m2)
2.90483241325478
Cooling demand (kWh/m2)
3.72558013250786
Daylight Autonomy (%)
22.219033
Spatial Daylight Autonomy (%)
22.219033

Conclusion

Development of strategies to expand the use of PCMs

AIM

Conclusion

Development of strategies to expand the use of PCMs

AIM

Integration of a PCMs trombe wall in existing and energy-optimized buildings

FOCUS

Conclusion

Development of strategies to expand the use of PCMs

AIM

Integration of a PCMs trombe wall in existing and energy-optimized buildings

FOCUS

PCMs trombe wall acts as intermediary element to reach a balance between thermal and daylight demands

POTENTIAL

Further work

- Increase of sDA of room with PCMs trombe wall

Further work

- Increase of sDA of room with PCMs trombe wall
- Research on other properties that differ in rooms

Further work

- Increase of sDA of room with PCMs trombe wall
- Research on other properties that differ in rooms
- Analysis on the micro scale of the PCMs trombe wall

Further work

- Increase of sDA of room with PCMs trombe wall
- Research on other properties that differ in rooms
- Analysis on the micro scale of the PCMs trombe wall
- Real life measurements

Reflection

Modular and
translucent PCMs
trombe wall

GRADUATION
PROJECT

Reflection

Potential of PCMs
(thermal energy storage system)

Modular and
translucent PCMs
trombe wall

GRADUATION
PROJECT

Reflection

Potential of PCMs
(thermal energy storage system)

Modular and
translucent PCMs
trombe wall

GRADUATION
PROJECT

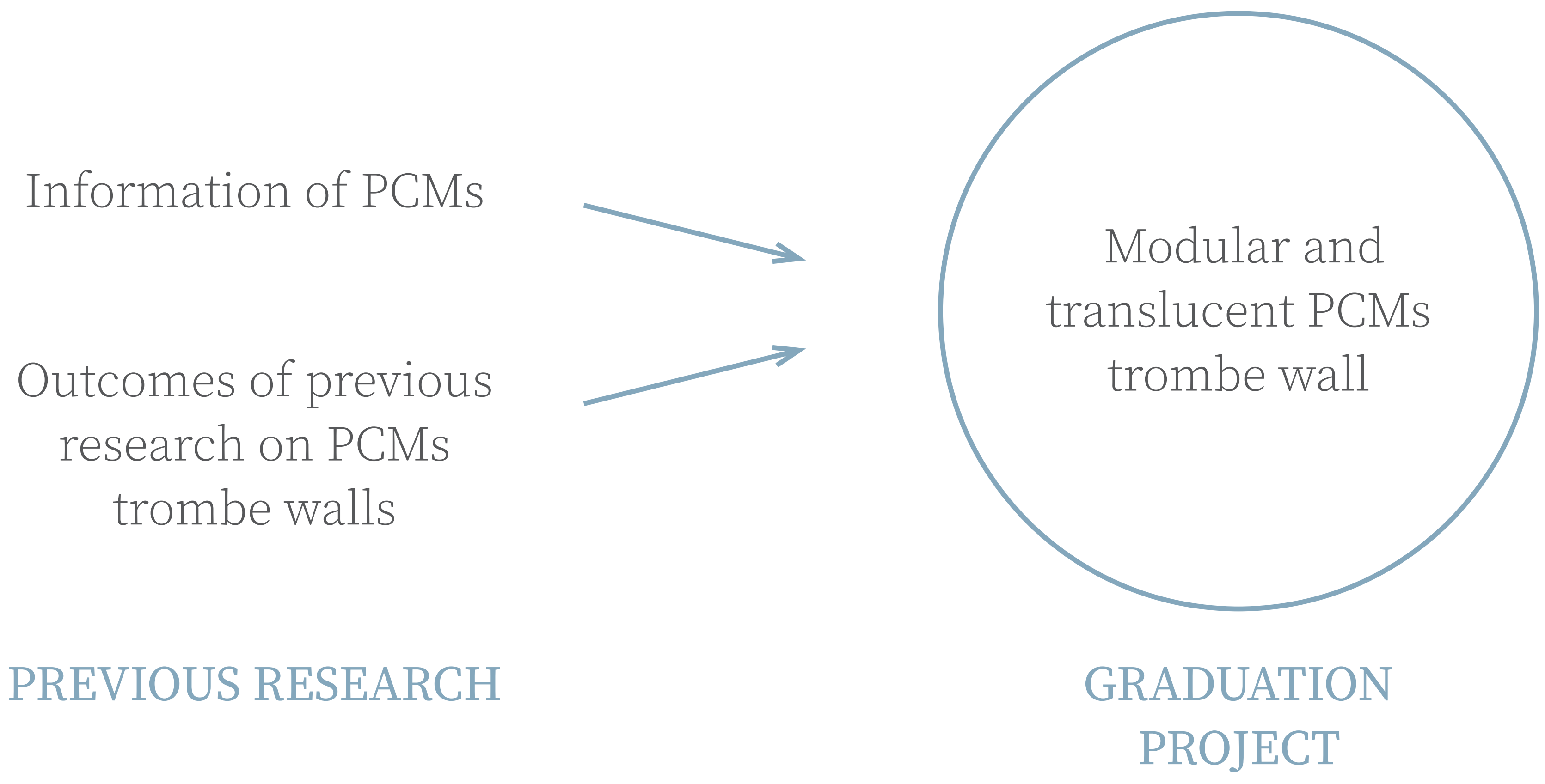
Advantage of PCMs trombe wall
(improves thermal inertia +
transmits daylight)

Reflection

Modular and
translucent PCMs
trombe wall

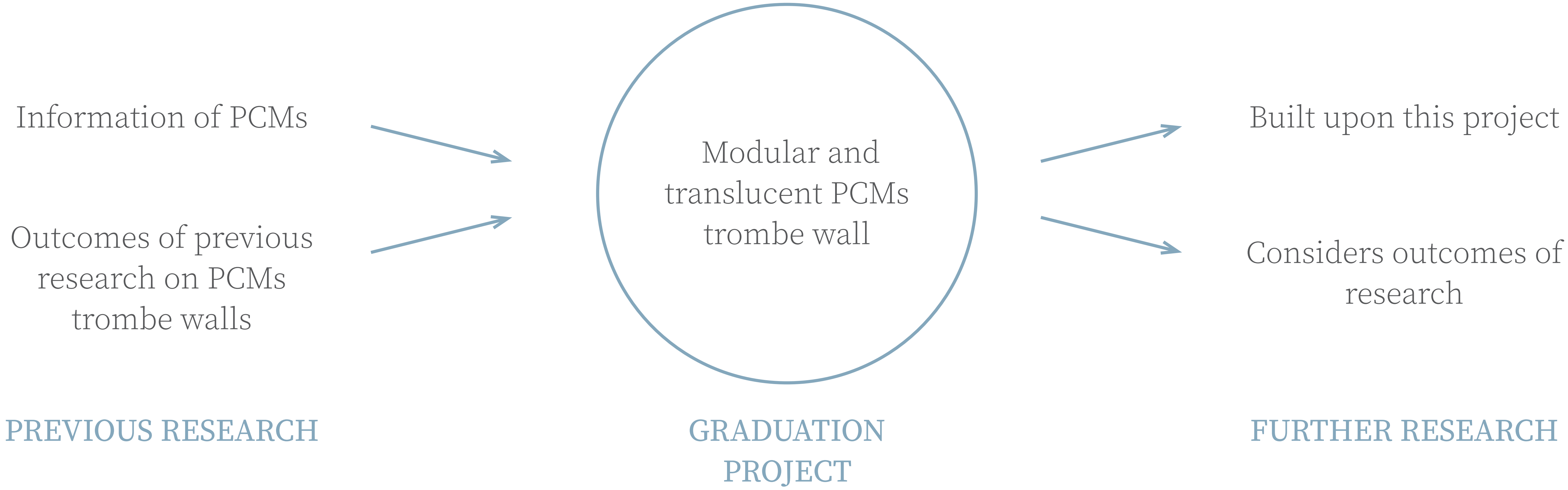
GRADUATION
PROJECT

Reflection



Information of PCMs
Outcomes of previous research on PCMs trombe walls
Modular and translucent PCMs trombe wall
PREVIOUS RESEARCH
GRADUATION PROJECT

Reflection


Information of PCMs
Outcomes of previous research on PCMs trombe walls
PREVIOUS RESEARCH
Modular and translucent PCMs trombe wall
GRADUATION PROJECT
Built upon this project
Considers outcomes of research
FURTHER RESEARCH

Reflection

UNIQUE AND
CUSTOMIZED

MODULAR AND
STANDARDIZED

Thank you!

Sub research questions

- Which **passive design strategies** are applied in energy-optimized buildings and **how** do they **affect** their thermal inertia?

- Which **room variables** are considered to achieve a PCMs trombe wall that could **adapt** to various buildings?

- How are the **thermal performance** and **daylight admittance** affected by the room variables and the PCMs trombe wall?

- What is the **final appearance** of the room and trombe wall if it is researched a **balance** between the **best results** of thermal and daylight simulations?

- Which **strategies** could in the future be developed to bridge the **gap** between a **customized** and **unique** PCMs product and a **standardized** and **modular** component?