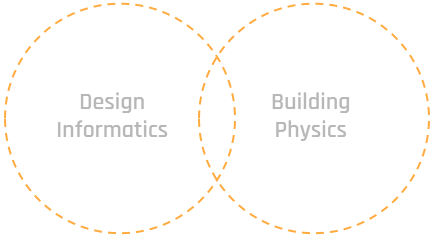
A computational method to guide sustainable energy upgrading of school buildings in Greece



P5 presentation 31.01.2020 | Anna Tsagkalou | Mentors: Dr. Michela Turrin, Dr. R.M.J. Bokel

TU Delft
Delft University of Technology

(0) Starting point.

(BACKGROUND)

⅓ of the day in schools → **Impact** of school spaces on both **mental & physical health**

Sustainable school design → Improved indoor conditions → Enhancement of learning ability

15.000 school buildings in Greece

1.600.000 students

40% older than 40 years old

Absence of insulation
Absence of any passive measures

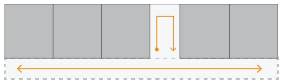
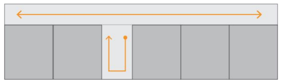
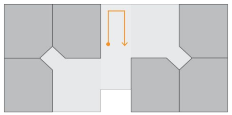
Inadequate maintenance & control

Increased energy consumption

Poor interior **Thermal comfort**

Poor **daylight** conditions and **glare** issues

Insufficient or uncontrolled **ventilation**

School type	Construction period	Schematic plan
Old stone building	Before 1960	
Open corridor linear layout	1960-1980	
Closed corridor linear layout	After 1960	
"Athena" type	After 1980	

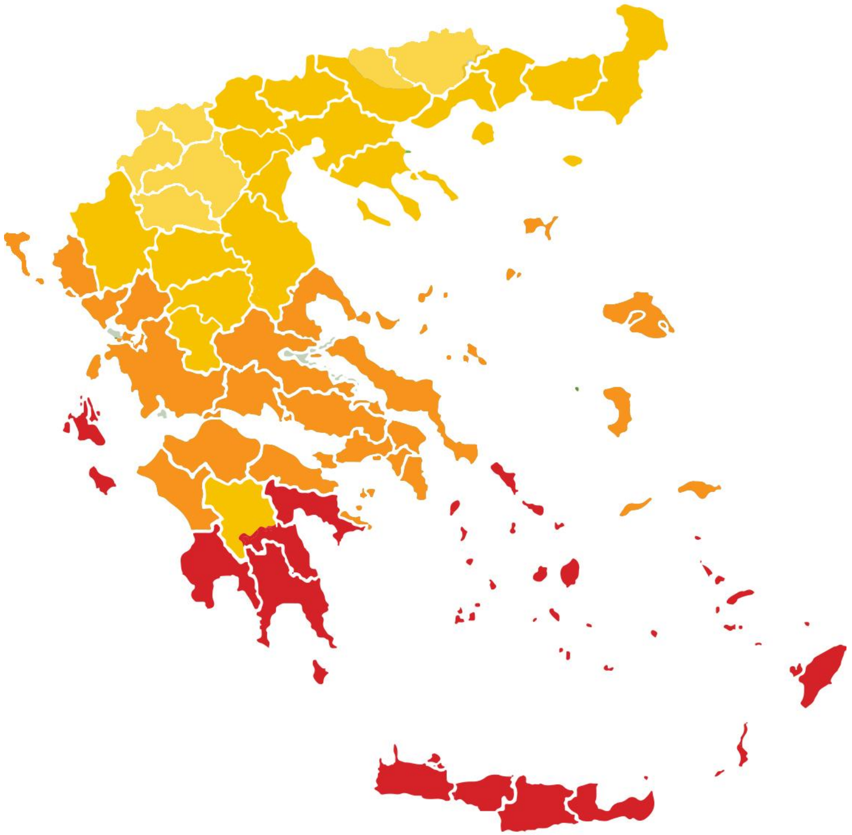
Period of interest

1960

School Building Organization of Greece is established

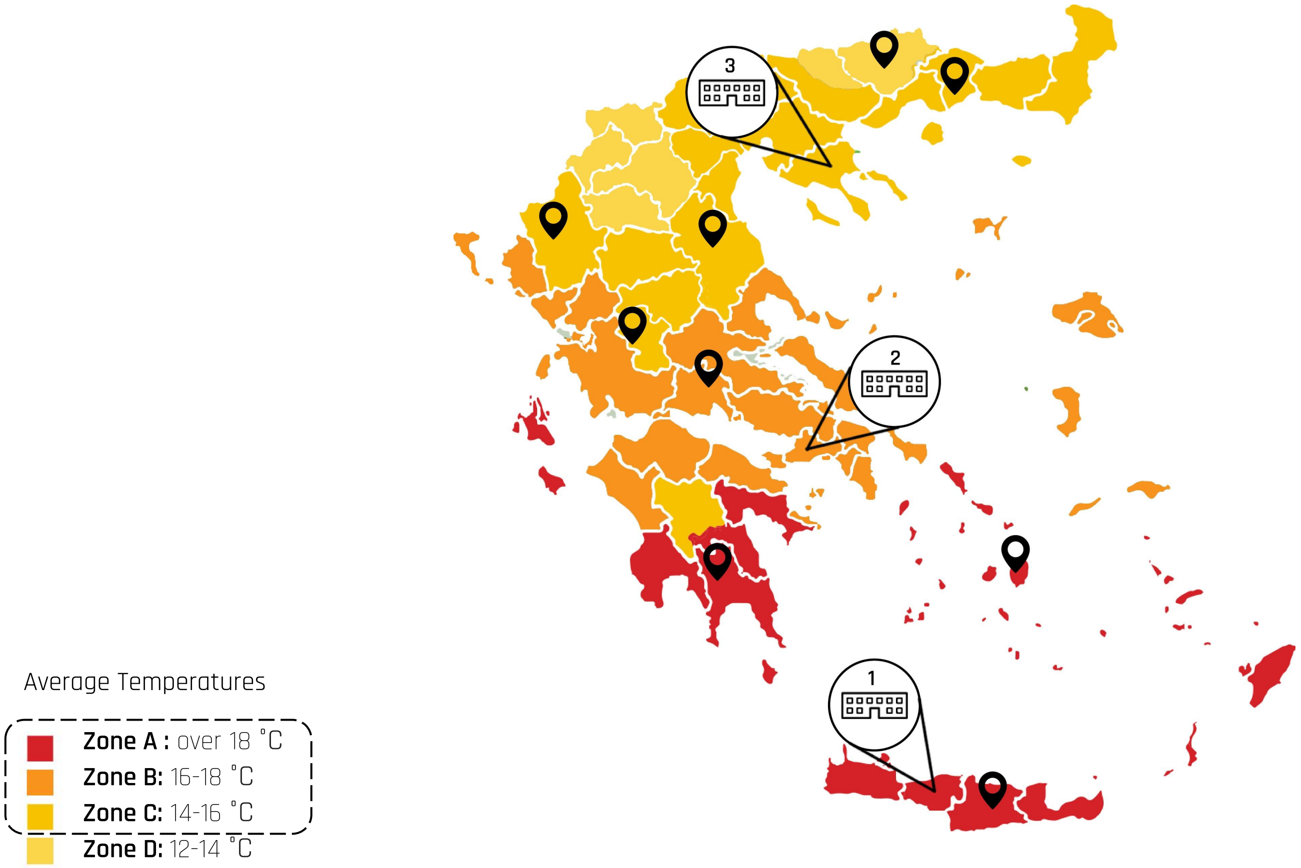
1980

Building Insulation Regulation



Average Temperatures

Zone A : over 18 ˚C
Zone B: 16-18 ˚C
Zone C: 14-16 ˚C
Zone D: 12-14 ˚C


3
2
1
Average Temperatures
Zone A : over 18 ˚C
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Zone C: 14-16 ˚C
Zone D: 12-14 ˚C

FACT

- Large number of underperforming school buildings
- Identical typology
- Spread across the country

NEED

for upgrade

FACT

- Large number of underperforming school buildings
- Identical typology
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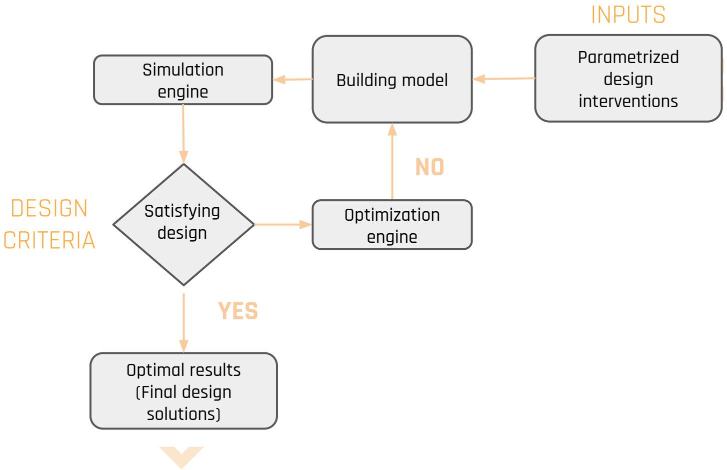
NEED

for upgrade

HOW?

*"A **computational** method to guide sustainable energy upgrading of school buildings in Greece"*

The BESO method



Advantages

- Exploration of numerous building variables and combinations
- Identification of the most promising building variants on the basis of diverse and potentially contrasting needs
- Time, cost and effort efficiency

(1) Research Framework.

Main Research Question

"To what extent can state-of-the-art Building Energy Simulation and Optimization (BESO) methods guide the renovation process of school buildings in Greece, through passive design interventions, with regards to energy efficiency, daylight and thermal comfort? "

Sub questions

- *What are the most determining passive design parameters to the energy demand and thermal comfort for each zone?*
- *What are the most optimal design solutions for each climate zone?*
- *How could such a method evolve to a tool that can be used in practise for the upgrading process of school buildings in Greece*

Main Research Question

"To what extent can state-of-the-art Building Energy Simulation and Optimization (BESO) methods guide the renovation process of existing school buildings in Greece, through passive design interventions, with regards to energy efficiency, daylight and thermal comfort? "

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1 RESEARCH FRAMEWORK

2 LITERATURE REVIEW

3 BUILDING ENERGY SIMULATION & OPTIMIZATION

4 RESULTS DISCUSSION

1 x case study
3 x locations

(2) Case study.

Geometry

Classroom area: 58m²
Corridor area: 24m²
Free height: 3.9m

Materials

Ext. walls: Double brick walls (no insulation)
U=1.752 W/m² K

Int. walls: Single brick walls
U=2.135 W/m² K

Floors/ceil.: Concrete & PVC
U=5.900 W/m² K

Windows: Single glazing
U=5.84 W/m² K

Shadings

Interior curtains

Internal loads

Occupancy: Classroom: 0.39 people/m²
Corridor: 0.11 people/m²

Schedules

Occupancy: Monday-Friday 08:00-16:00
Closed July-August

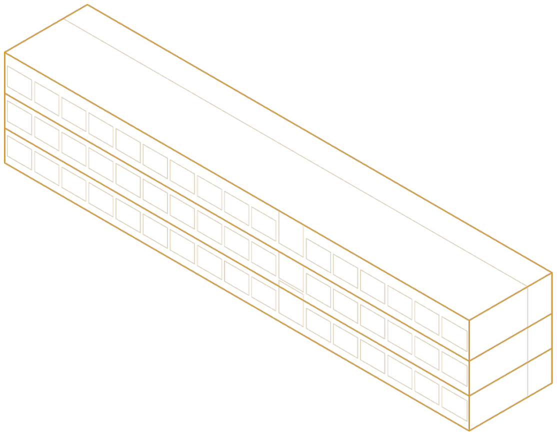
Heating:: Available Nov. to Feb.
Central heating
Heating setpoint: 18°C

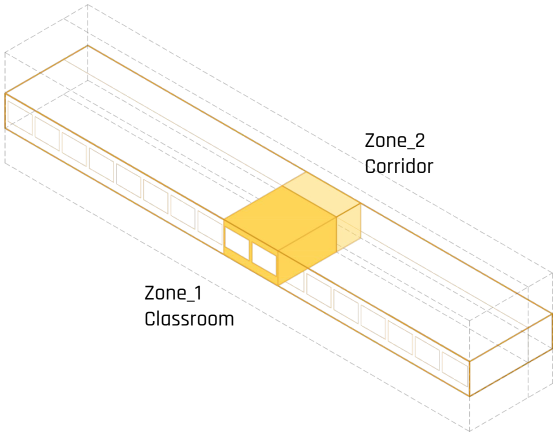
Required comfort values (OSK,2008)

Temperatures:
Classroom: 18-25°C
Corridor:16-28°C

Lighting:
Classroom: 300 lux
Corridor: 150 lux

Ventilation:
5 ACH




Zone_2
Corridor
Zone_1
Classroom

(3) Method.

1. PRE PROCESSING

Outputs definition
Simulation set-up
Preliminary analysis
Workflow validation

Simulation variables exploration

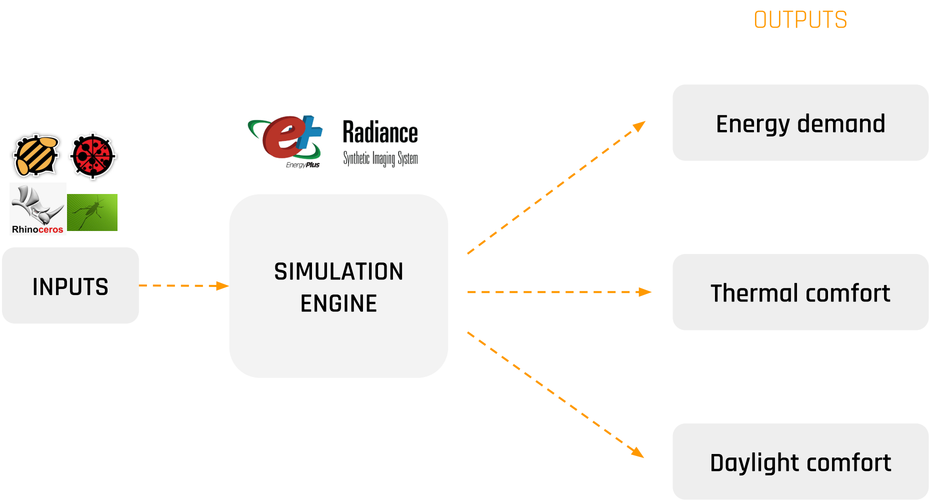
2.OPTIMIZATION

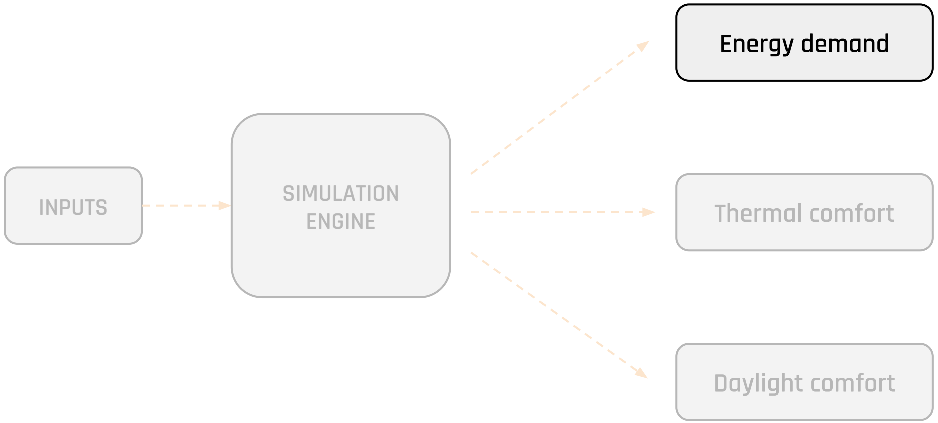
Variables
Objectives
Algorithm selection
Number of evaluations

3.RESULTS ANALYSIS

Variables correlation
Pareto front solutions

(3a) Preprocessing.


OUTPUTS
Radiance
Synthetic Imaging System
EnergyPlus
Rhinoceros
INPUTS
SIMULATION ENGINE
Energy demand
Thermal comfort
Daylight comfort

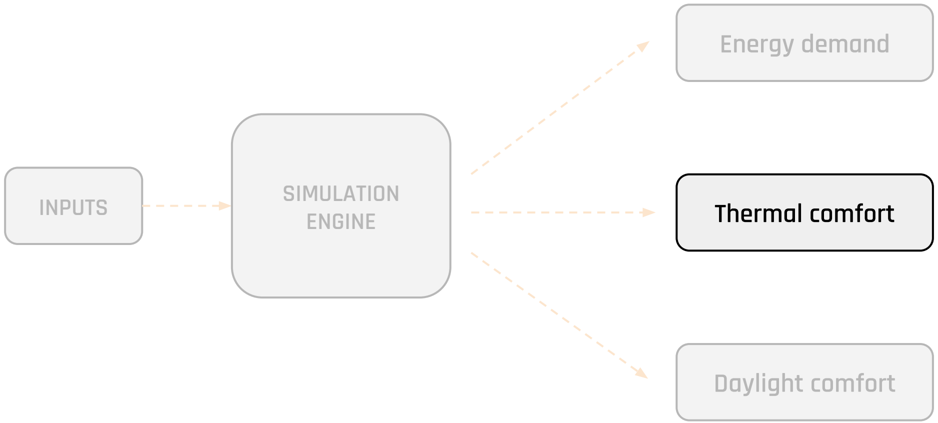


Annual energy analysis:

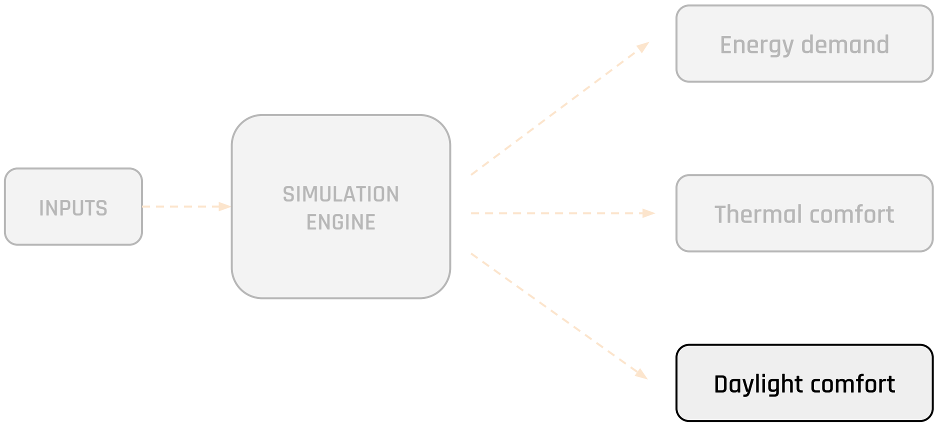
Total energy demand

(kWh/m²)=

Heating + Lighting + Electric fan demand

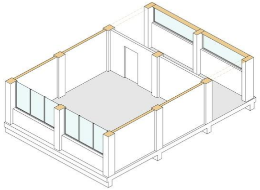


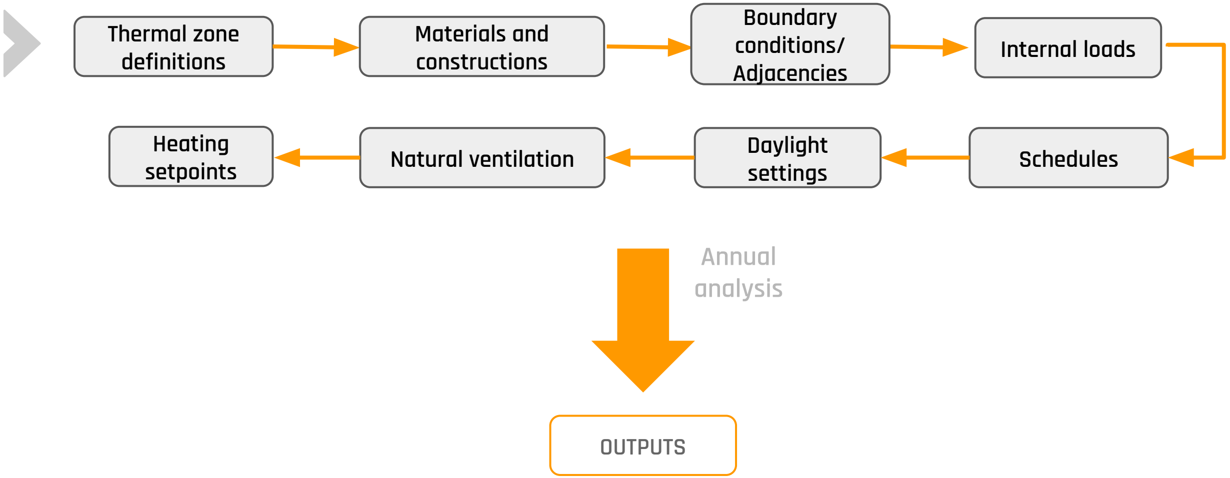
% of occupancy hours when
18°C < classroom temp<25°C



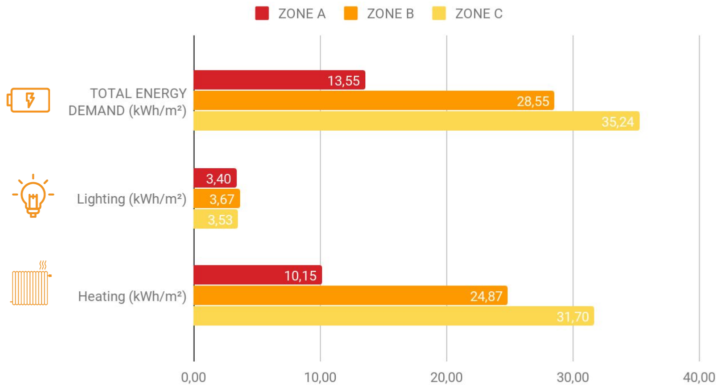
Daylight Autonomy (DLA) Avg **=**
% of occupancy hours when
Avg illuminance> 300 lux

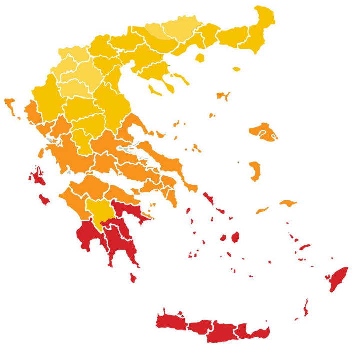
INPUT
GEOMETRY

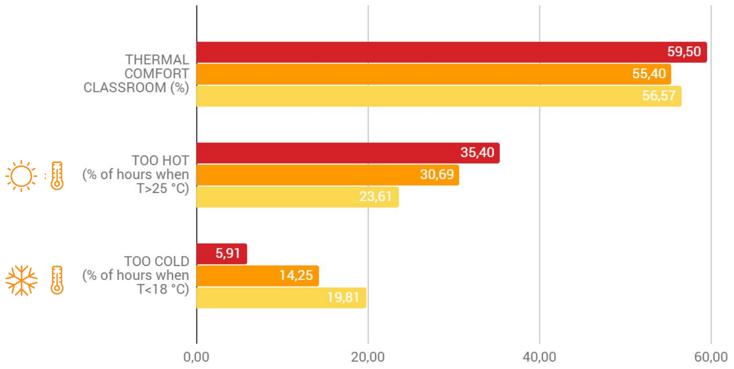


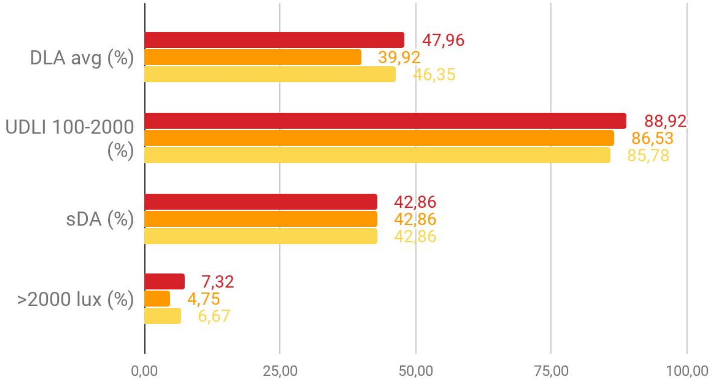


Preliminary analysis.


ZONE A
ZONE B
ZONE C
TOTAL ENERGY DEMAND (kWh/m²)
13,55
28,55
35,24
Lighting (kWh/m²)
3,40
3,67
3,53
Heating (kWh/m²)
10,15
24,87
31,70
0,00
10,00
20,00
30,00
40,00

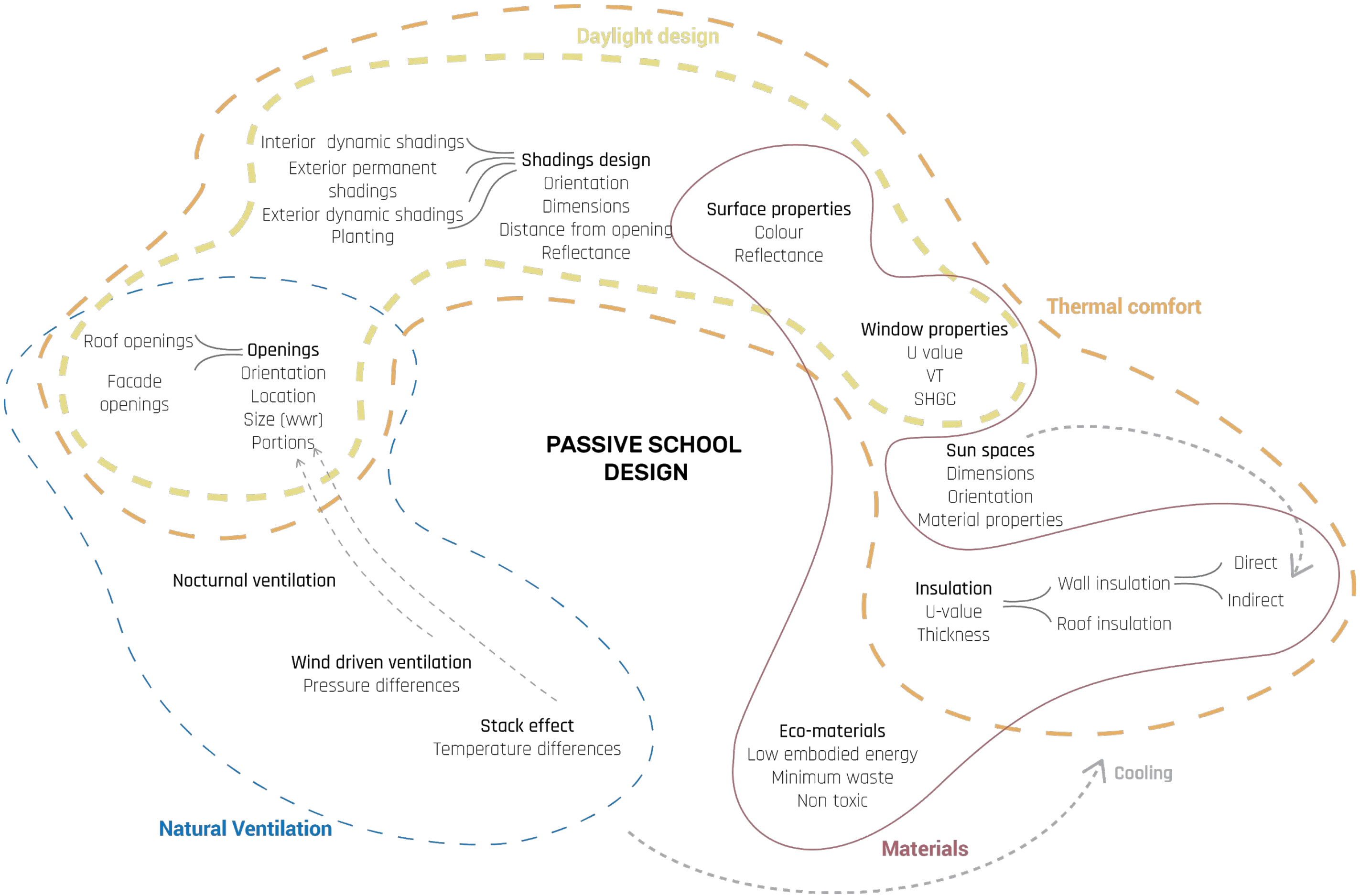



THERMAL COMFORT CLASSROOM (%)
59,50
55,40
56,57
TOO HOT (% of hours when T>25 °C)
35,40
30,69
23,61
TOO COLD (% of hours when T<18 °C)
5,91
14,25
19,81
0,00
20,00
40,00
60,00


DLA avg (%)
47,96
39,92
46,35
UDLI 100-2000 (%)
88,92
86,53
85,78
sDA (%)
42,86
42,86
42,86
>2000 lux (%)
7,32
4,75
6,67
0,00
25,00
50,00
75,00
100,00

Variables exploration.

LITERATURE
REVIEW FINDINGS.
(Guidelines
provided by OSK)


Daylight design
Interior dynamic shadings
Exterior permanent shadings
Exterior dynamic shadings
Planting
Shadings design
Orientation
Dimensions
Distance from opening
Reflectance
Surface properties
Colour
Reflectance
Thermal comfort
Window properties
U value
VT
SHGC
Roof openings
Facade openings
Openings
Orientation
Location
Size (wwr)
Portions
PASSIVE SCHOOL DESIGN
Sun spaces
Dimensions
Orientation
Material properties
Direct
Indirect
Wall insulation
Roof insulation
Insulation
U-value
Thickness
Nocturnal ventilation
Wind driven ventilation
Pressure differences
Stack effect
Temperature differences
Cooling
Eco-materials
Low embodied energy
Minimum waste
Non toxic
Natural Ventilation
Materials

VARIABLES EXPLORATION

Constants

U-value of exterior walls

U-glazing

Ventilation strategy

Reflectance/colour

Variants

Wwr

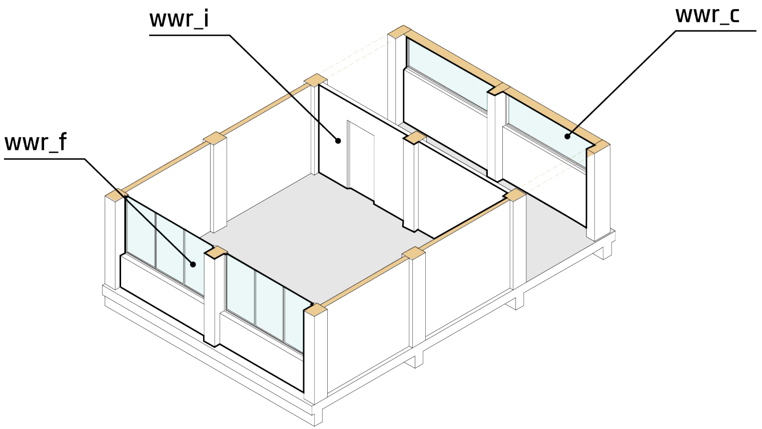
SHGC
VT

SHADINGS

R_int_wall.

Window-to-wall ratios

1. wwr_f: 0.3/0.4/0.5/0.6/0.7/0.8
2. wwr_c: open corridor/0.3/0.6.0/9
3. wwr_i: 0.2/0.4/0.6/0.8

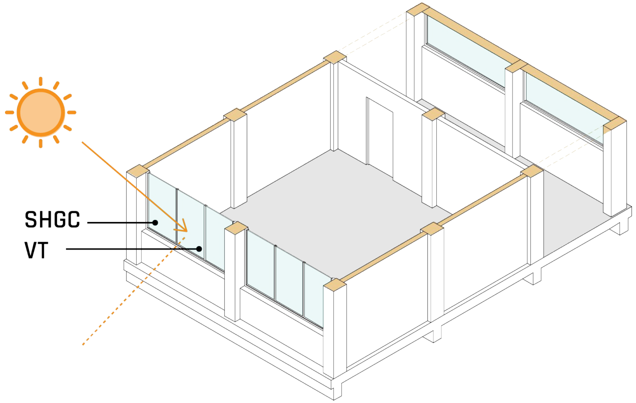


Cross ventilation enabled when all wwr>0.2

Glazing properties

4. SHGC (Solar heat gain coefficient): 0.2/0.3/0.4/0.5/0.6/0.7

5. VT (Visible transmittance): 0.4/0.5/0.6/0.7



Thermal transmittance (U): constant

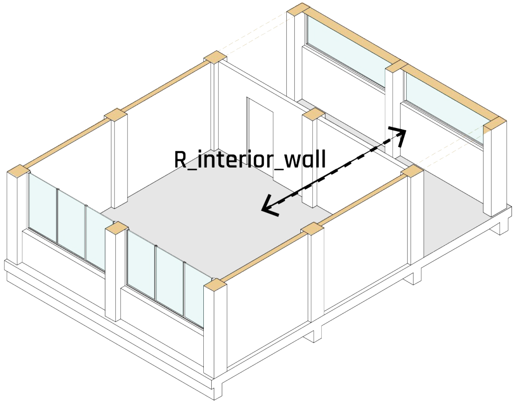
U_window_A=2.2 W/m² K

U_window_B=2.0 W/m² K

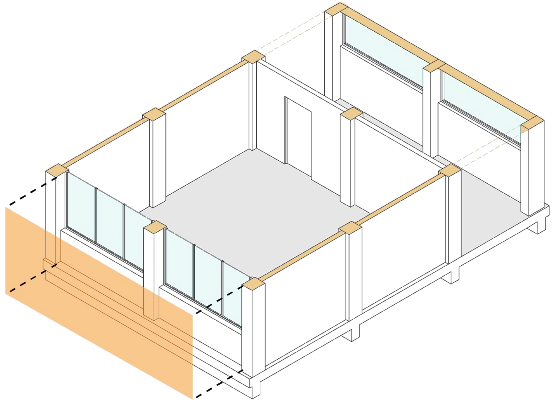
U_window_C=1.8 W/m² K

6. Thermal resistance of interior wall

0.5/ 1.0/ 1.5 (m^2K/W)

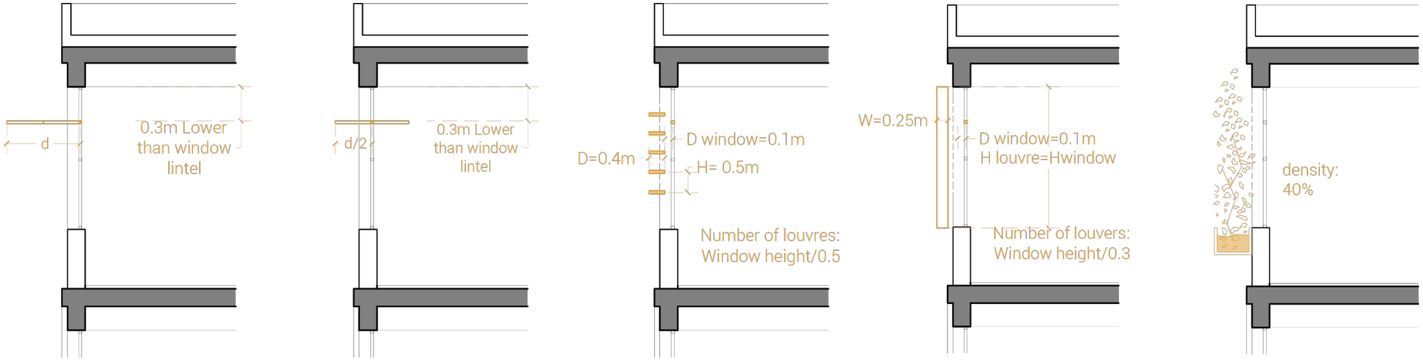


Shadings



7. Shading type

8. Light shelf depth: 0.6/0.9/1.2/1.5 m



Shading type 0
Exterior light shelf

Shading type 1
Interior/exterior light shelf

Shading type 2
Horizontal louvres

Shading type 3
Vertical louvres

Shading type 4
Vegetation

414720 possible combinations (!)

	OPTIMIZATION VARIABLES							
	Category	Variable	Abbreviation	Optimization Range	Step	Type	Simulation range	Units
1	**Envelope**	WWR facade	wwr_f	[0,5]	1	Discrete	[0.3/0.4/0.5/0.6/0.7/0.8]	-
2	**Envelope**	WWR corridor	wwr_c	[0,3]	1	Discrete	[0/0.3/0.6/0.9]	-
3	**Interior wall**	WWR interior wall	wwr_i	[1,4]	1	Discrete	[0.2/0.4/0.6/0.8]	-
4	**Exterior glazing**	Visible transmittance	VT	[4,7]	1	Discrete	[0.4/0.5/0.6/0.7]	-
5		SHGC	SHGC	[2,7]	1	Discrete	[0.2/0.3/0.4/0.5/0.6/0.7]	-
6	**Shadings**	Shading type	Shading	[0,4]	1	Discrete		
7		Light shelf Depth	lightShelfDepth	[6,15]	3	Discrete	[0.6/0.9/1.2/1.5]	m
8	**Orientation**	Classroom Orientation	Or	[0,2]	1	Discrete	0: South/1:SE/2:SW	-
9	**Interior wall material**	R Interior Wall	R_int_wall	[1,3]	1	Discrete	x 0.5	K m²/W

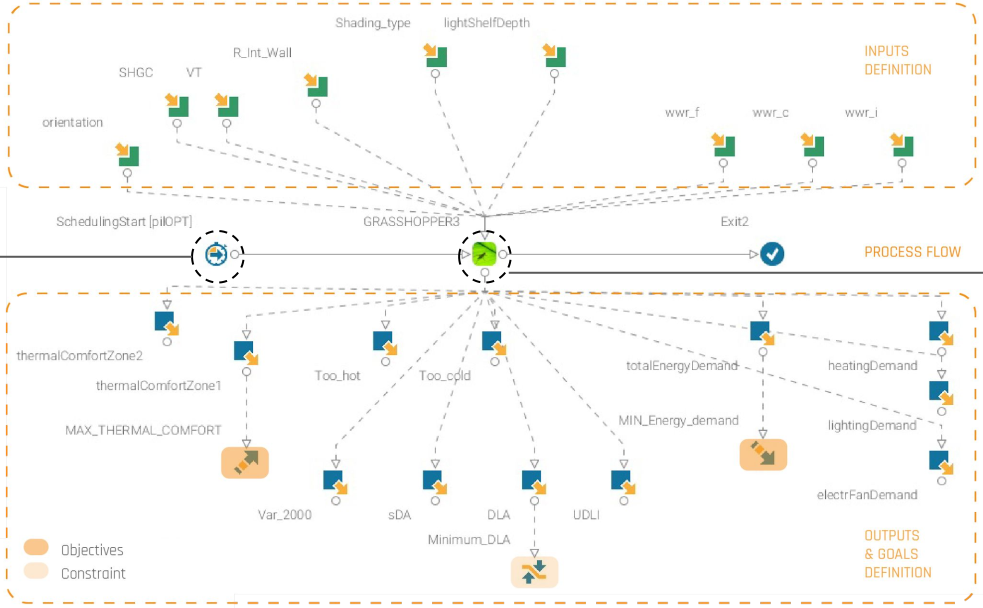
(3b) Optimization.


Optimization **1**
ZONE A


Optimization **2**
ZONE B


Optimization **3**
ZONE C

PilOPT
600 design iterations



Grasshopper
Connection node

Objectives
Maximize the thermal comfort of the classroom
Minimize the total energy demand (heating, lighting, electric fan)

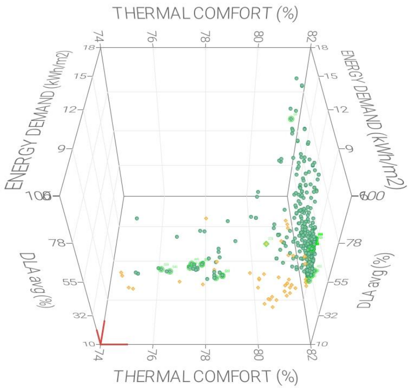
Constraint
DLA avg > 50%

(3c) Results Analysis.

A

29 hours duration

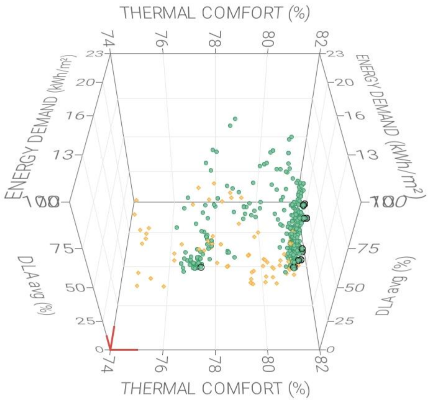
544 feasible solutions



B

30 hours duration

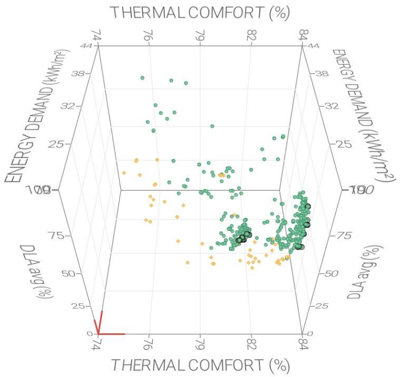
516 feasible solutions



C

28 hours duration

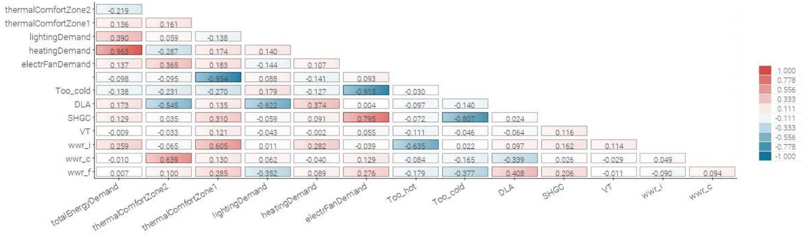
542 feasible solutions



Correlation between variables and objectives

Algorithm **convergence / evolution**

Pareto front solutions

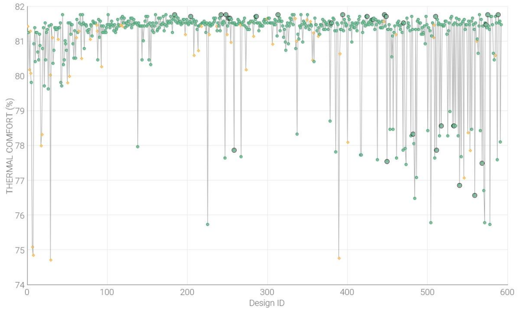


Correlation between variables and objective

Algorithm **convergence / evolution**

Pareto front solutions

Degree of correlations (-1 to 1) between variables and objectives that were (maybe) not obvious before.

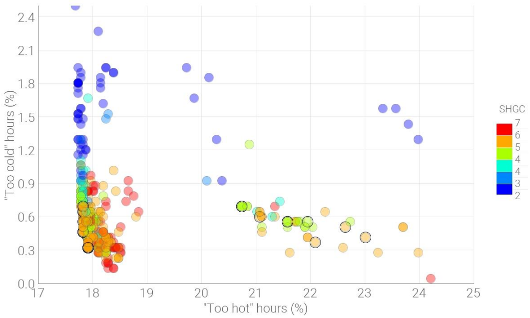


Correlation between variables and objective

Algorithm **convergence / evolution**

Pareto front solutions

This term describes how well the algorithm converged into finding designs that satisfied our objectives.

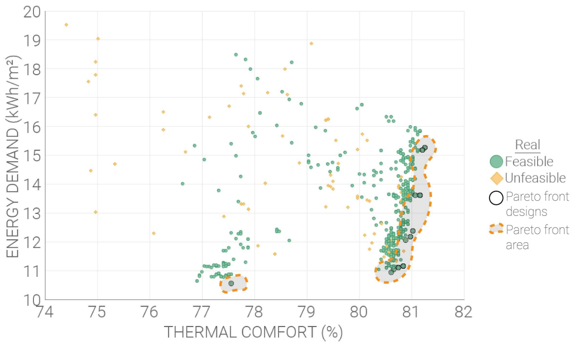


Correlation between variables and objective

Algorithm **convergence / evolution**

Pareto front solutions

Indications regarding preferred values for each variable



Algorithm **convergence/ evolution**

Correlation between variables and objective

Pareto front solutions

Set of resulting solutions that are considered optimal, that is that no variable change from that point would satisfy more one objective without sacrificing the others.

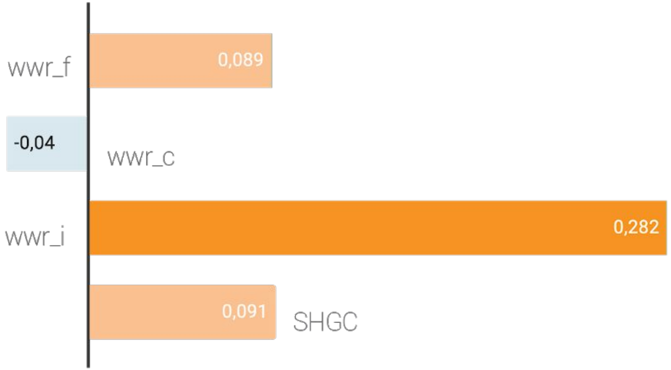
(4) Results discussion.

What are the most determining passive design parameters to the energy demand and thermal comfort for each zone?

What are the most determining passive design parameters to the energy demand and thermal comfort for each zone?

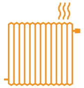
Energy demand

- **Heating demand**
- El. fan demand
- Lighting demand

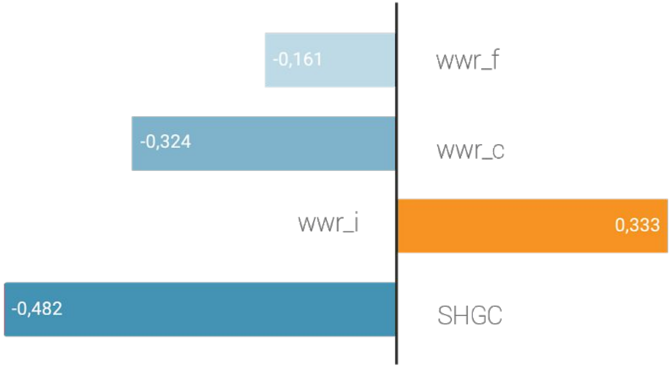


What are the most determining passive design parameters to the energy demand and thermal comfort for each zone?

Energy demand



Heating demand | El. fan demand | Lighting demand



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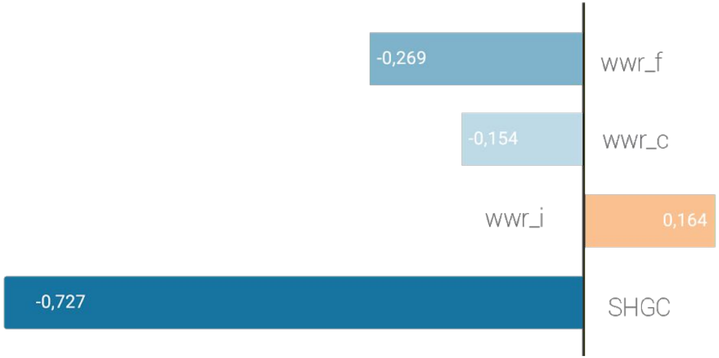


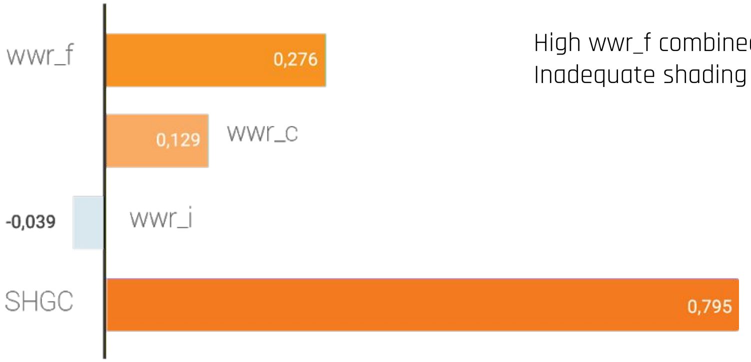
\+ Shading type

Higher wwr_f values combined with narrow light shelves ↓

What are the most determining passive design parameters to the energy demand and thermal comfort for each zone?

Energy demand

Heating demand | **El. fan demand** | Lighting demand



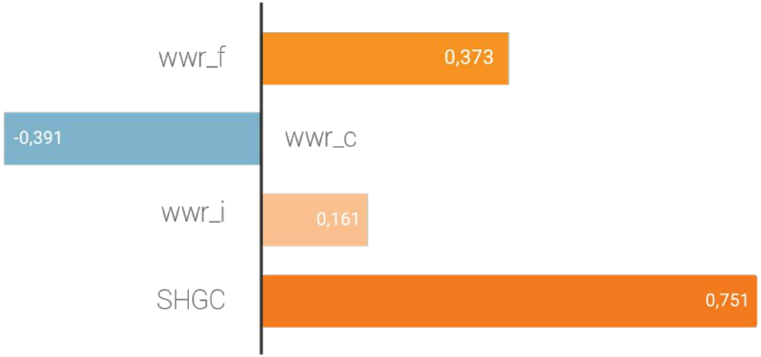
High wwr_f combined with Inadequate shading ↑

What are the most determining passive design parameters to the energy demand and thermal comfort for each zone?

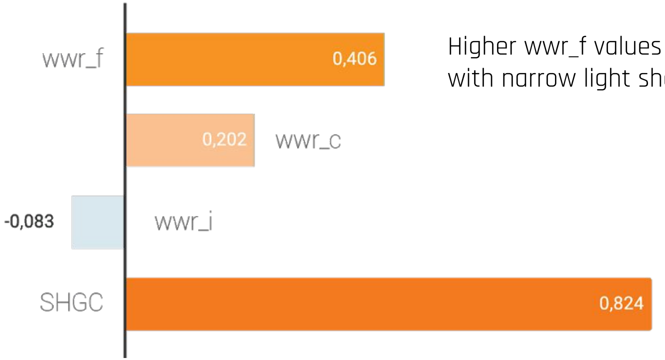
Energy demand

Heating demand | **El. fan demand** | Lighting demand

ZONE B



ZONE C



Higher wwr_f values combined with narrow light shelves ↑

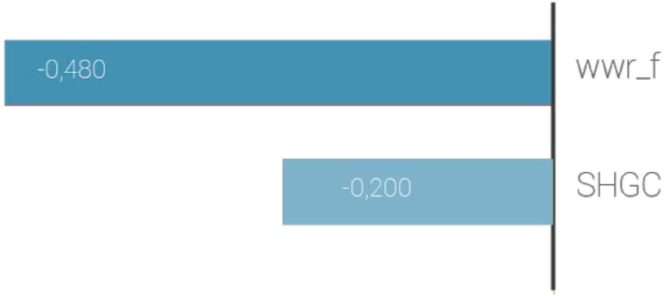
What are the most determining passive design parameters to the energy demand and thermal comfort for each zone?

Energy demand

Heating demand

El. fan demand

Lighting demand

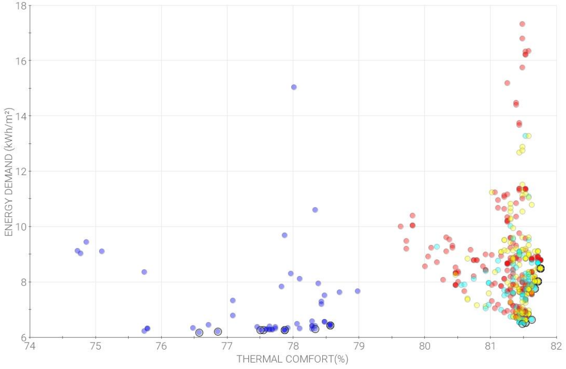


\+ Shading type

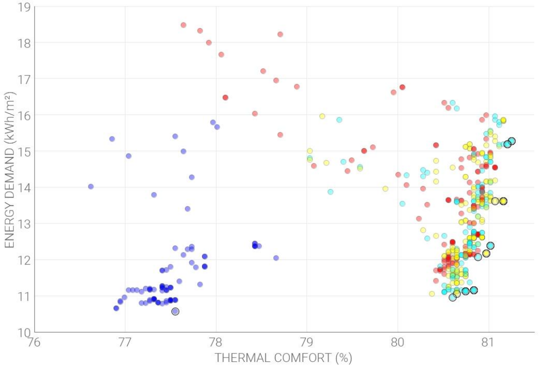
What are the most determining passive design parameters to the energy demand and thermal comfort for each zone?

THERMAL COMFORT

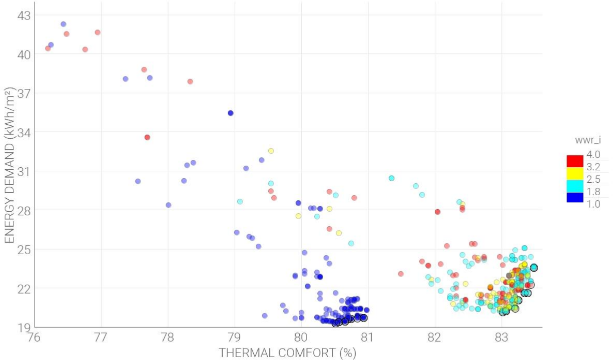
wwr_i



Zone A



Zone B

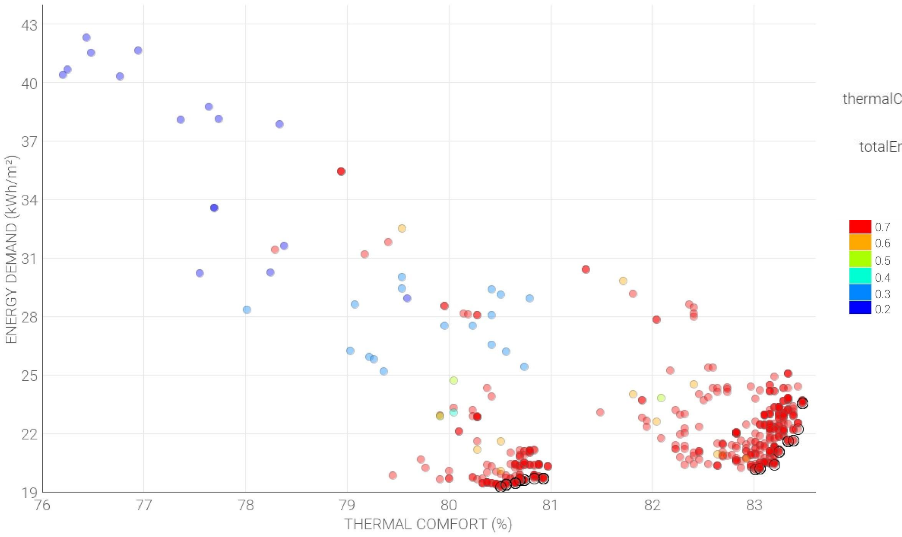


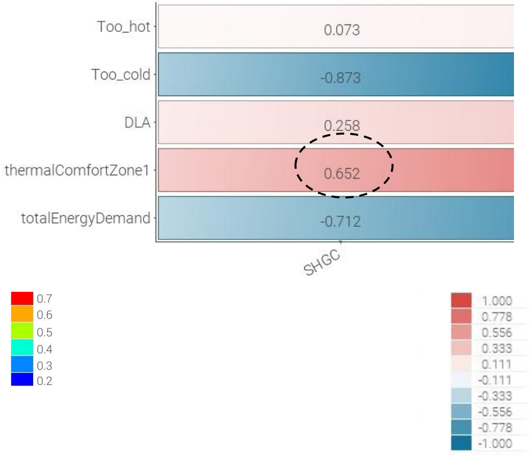
Zone C

What are the most determining passive design parameters to the energy demand and thermal comfort for each zone?

THERMAL COMFORT

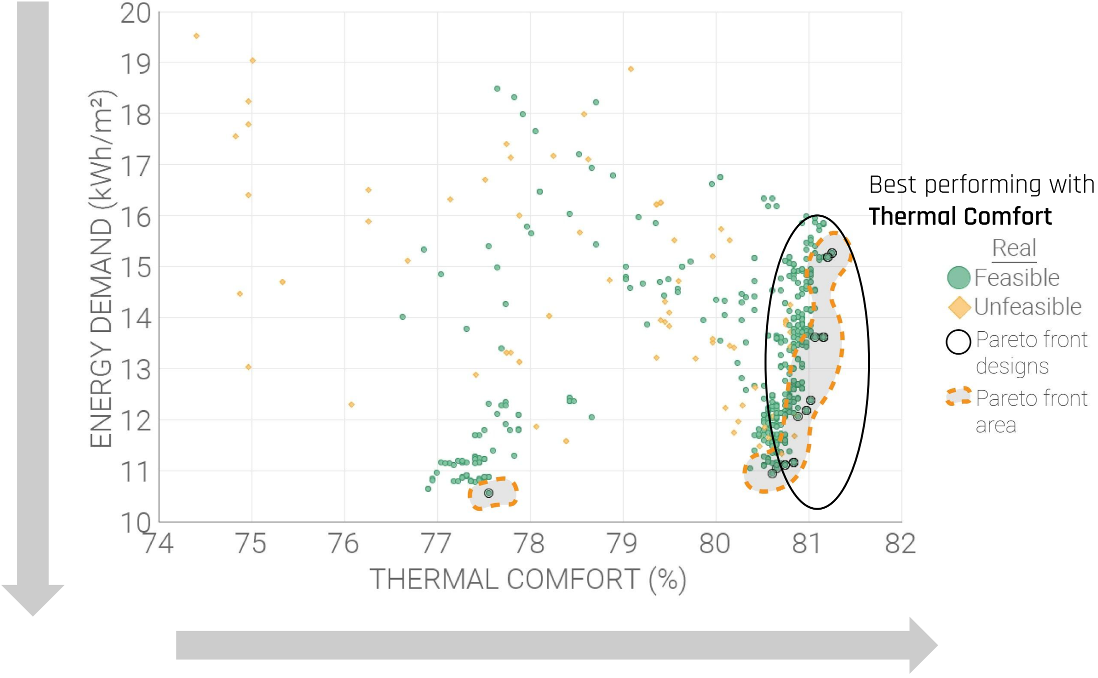
SHGC





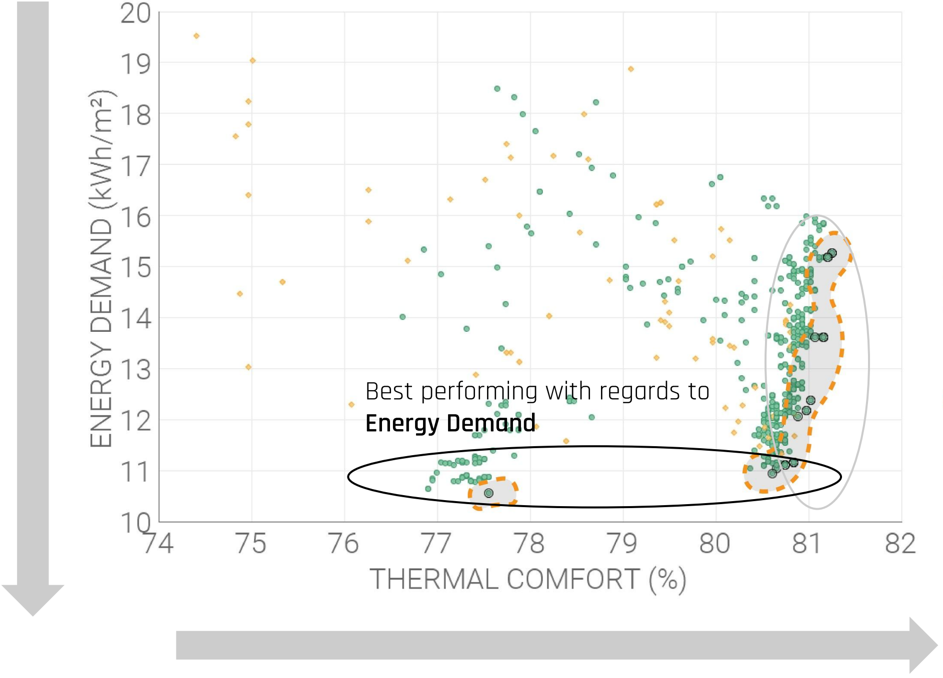
What are the most optimal design solutions for each climate zone?

What are the most optimal design solutions for each climate zone?

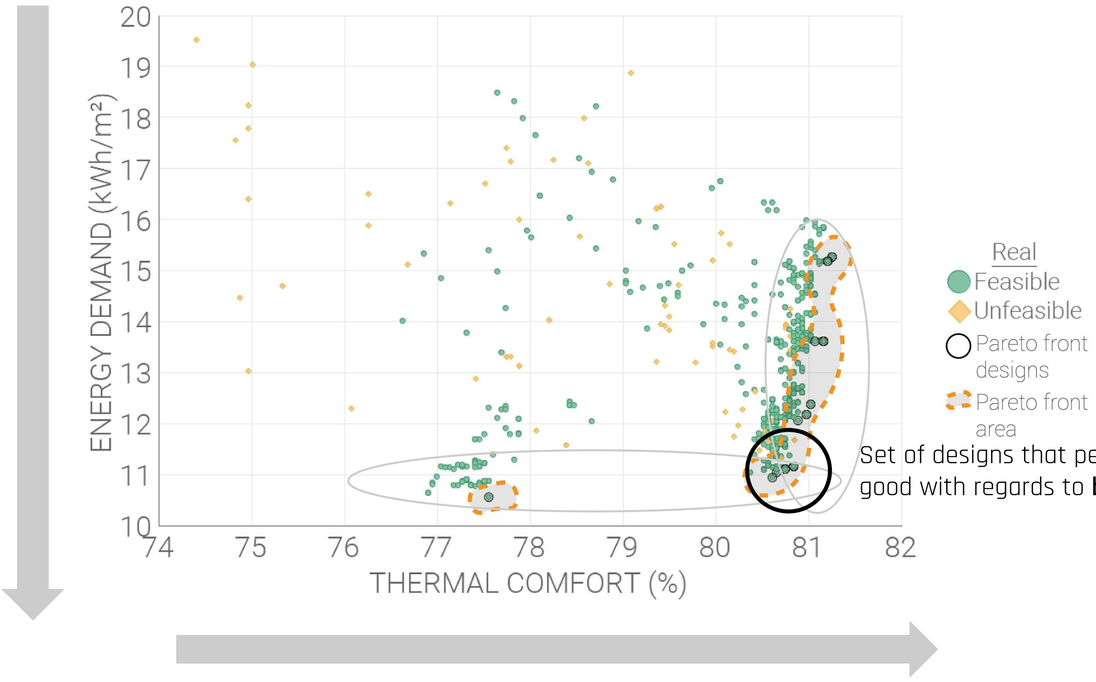


Best performing with regards to **Thermal Comfort**

What are the most optimal design solutions for each climate zone?



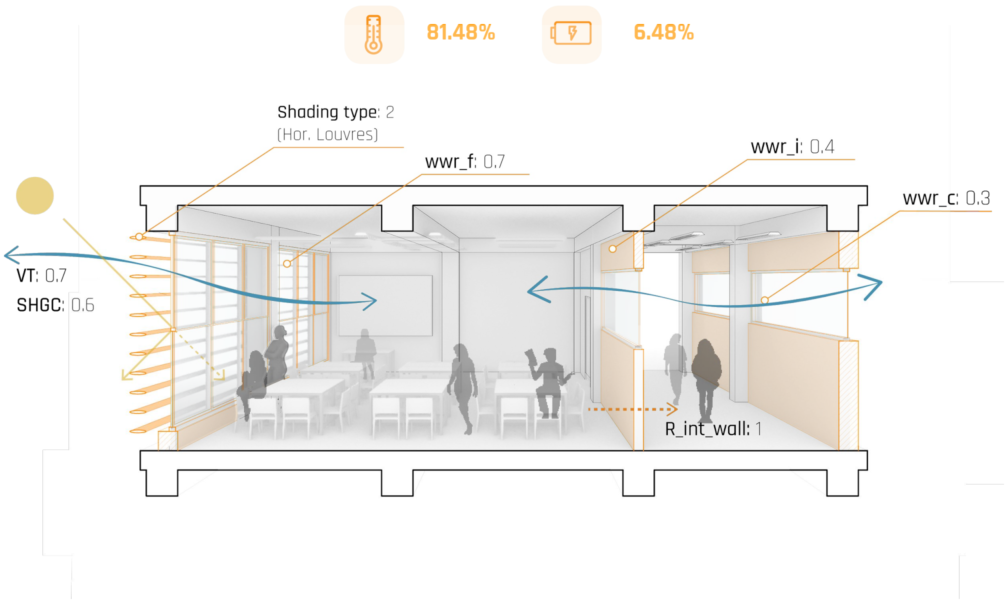
What are the most optimal design solutions for each climate zone?



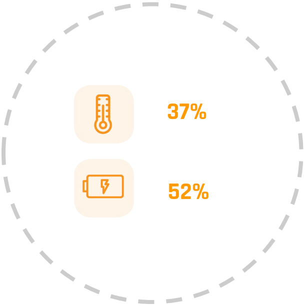
Set of designs that perform adequately good with regards to **both objectives**

What are the most optimal design solutions for each climate zone?

ZONE A



% of improvement in relation to the existing situation

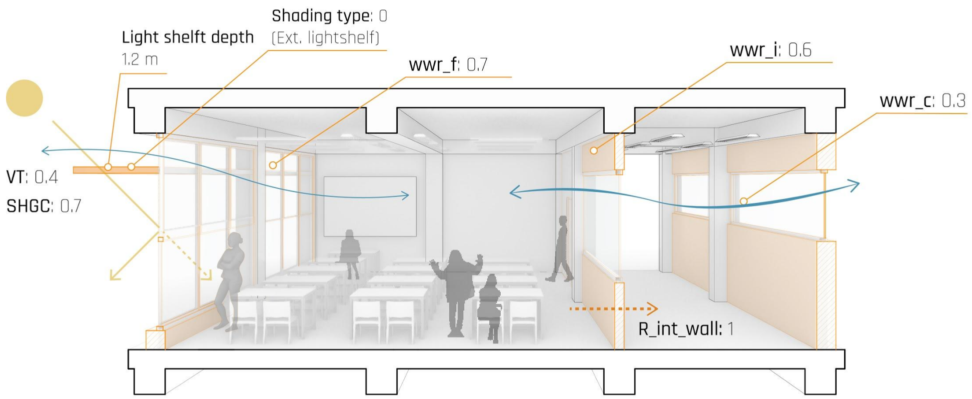


Best performing results with regards to **both objectives**

What are the most optimal design solutions for each climate zone?

ZONE B

80.60% 10.96%



% of improvement in relation to the existing situation

47%

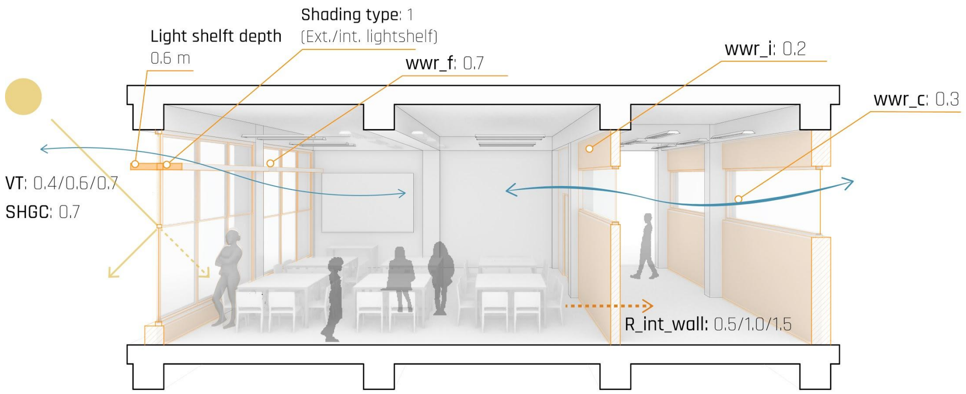
62%

Best performing results with regards to **both objectives**

What are the most optimal design solutions for each climate zone?

ZONE C

80.56%   19.39%



% of improvement in relation to the existing situation

49%

44%

Best performing results with regards to **both objectives**

(5) Conclusion.

"To what extent can state-of-the-art Building Energy Simulation and Optimization (BESO) methods guide the renovation process of existing school buildings in Greece, through passive design interventions, with regards to energy efficiency, daylight and thermal comfort? "

Valuable indications regarding the importance of certain passive design variables among others. (Guidelines)

Better understanding of the complexity of the problem and the various parameters that are involved in it.

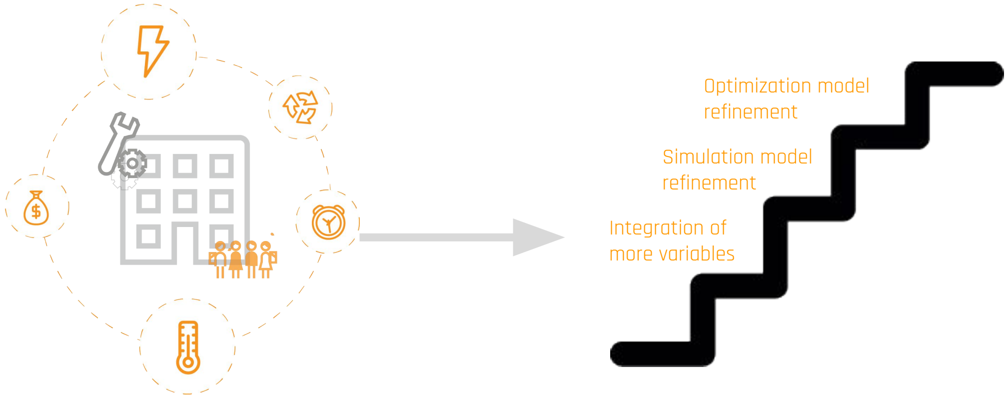
Despite limitations, **Promising tool** in the hands of the designers of school buildings in Greece.

(6) Vision.

"A school building designer, with access to a database of conducted BESO studies and their results, who is able to address his design decision guided by the knowledge and guidelines the collected data can offer him, based on his/her specific case study and its constants."

We are here

- Establishing the foundation for consequent BESO studies
- Justifying its importance by highlighting the relevance of its results
- Constituting an example of proposed guidelines, under its specific context


Optimization model refinement
Simulation model refinement
Integration of more variables

Thank you for your attention!

And thanks to:
Michela, Regina, Odysseas,
Luca, Despoina, Christina,
Aurelie, Okan, Dimitris,Margarita,
Aytac, Miktha, Tiantian,
Michalis, Iasonas, Kim,
Vasilis, Klairi, Giannis,
Kyriaki,
....

"To what extent can state-of-the-art Building Energy Simulation and Optimization (BESO) methods guide the renovation process of existing school buildings in Greece, through passive design interventions, with regards to energy efficiency, daylight and thermal comfort? "

Degree of improvement in relation to the existing situation.

ZONE A

37%

52%

ZONE B

47%

62%

ZONE C

49%

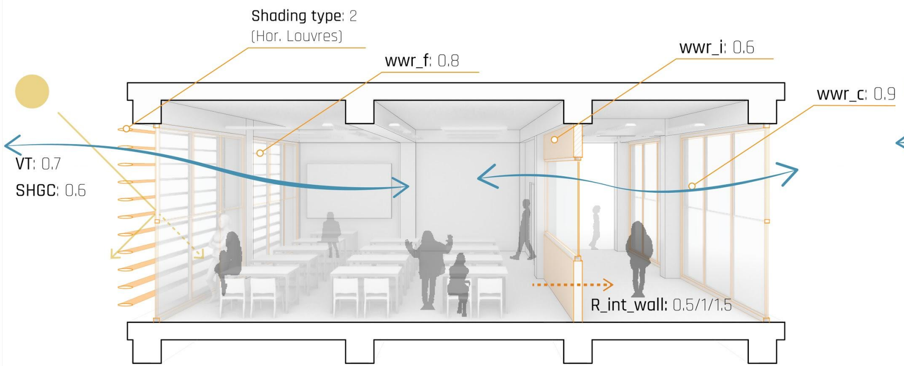
44%

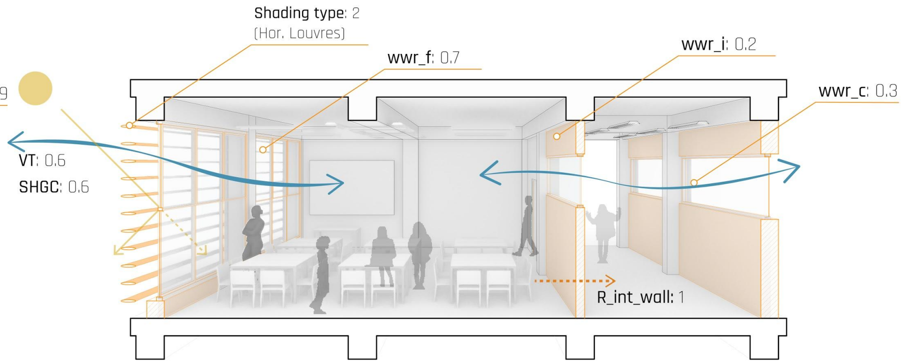
What are the most optimal design solutions for each climate zone?

ZONE A

81.76%

6.17%





Best performing results with regards to **Thermal Comfort**

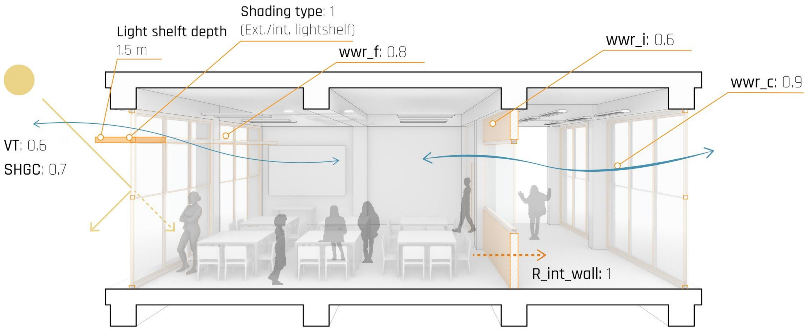
Best performing results with regards to **Energy Demand**

What are the most optimal design solutions for each climate zone?

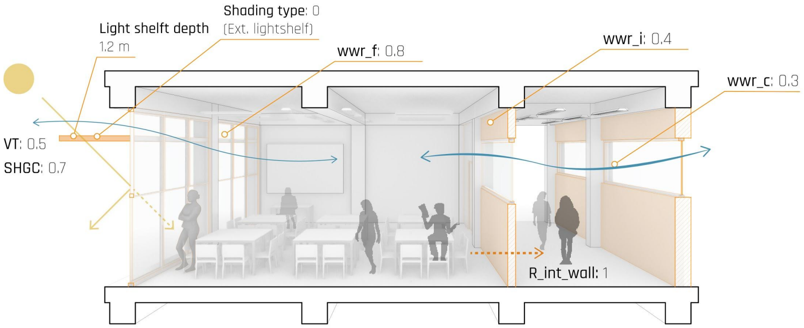
ZONE B

81.25%

10.58%



Best performing results with regards to **Thermal Comfort**



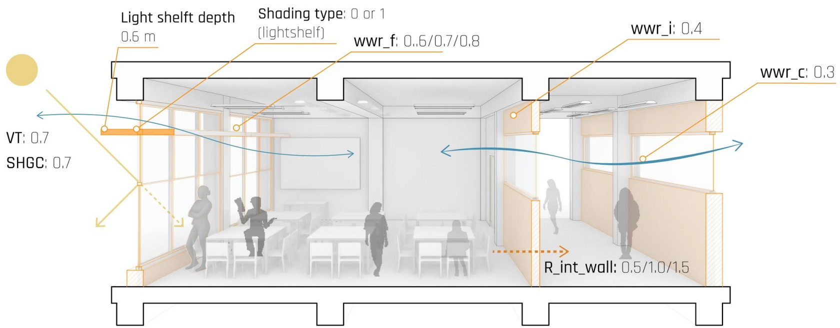
Best performing results with regards to **Energy Demand**

What are the most optimal design solutions for each climate zone?

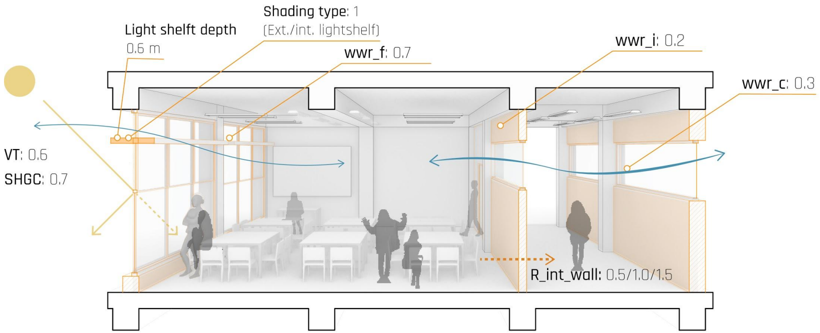
ZONE C

83.47%

19.46%



Best performing results with regards to **Thermal Comfort**



Best performing results with regards to **Energy Demand**