Building Design Approaches and Performance Under Predicted Climate Conditions

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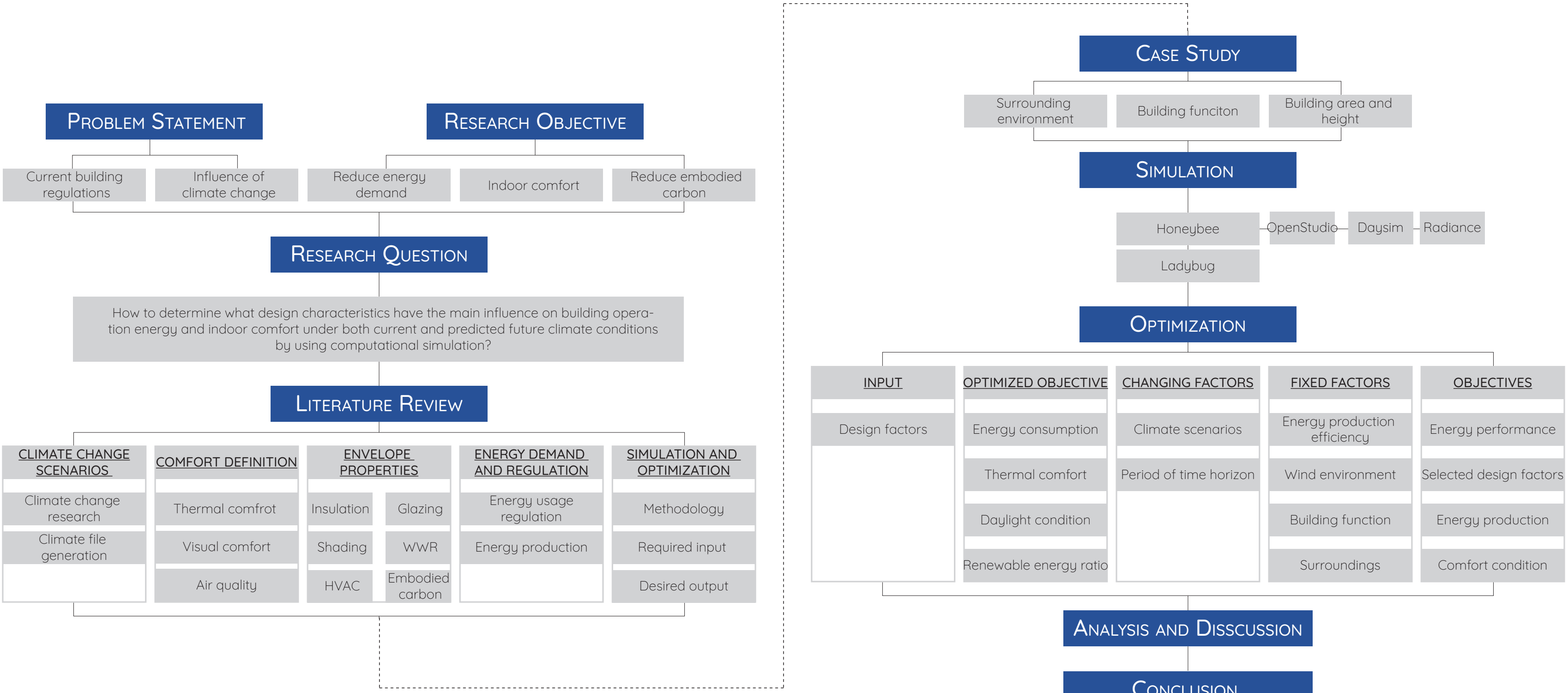
INTRODUCTION

RESEARCH FRAMEWORK



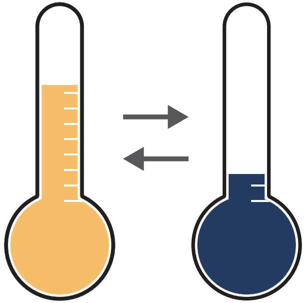
BACKGROUND

Problem

Building environment consumes 40% of primary energy & emits 24% of greenhouse gas globally.

Analysis

Building performance simulation and optimization in design and production phases.

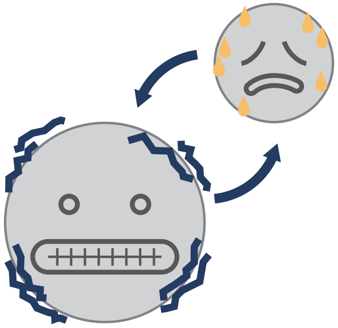


Solution

Minimizing operation energy & optimizing indoor comfort with smart energy strategies.

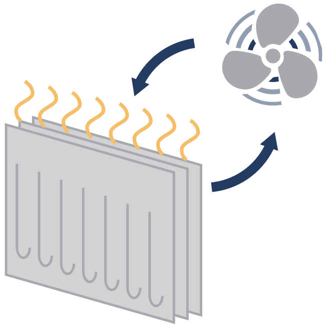
BACKGROUND

- Current and common approaches -



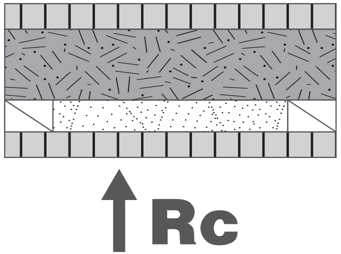
Comfort

Providing a comfortable indoor environment is essential. The main challenge in the Netherlands is the cold winter.



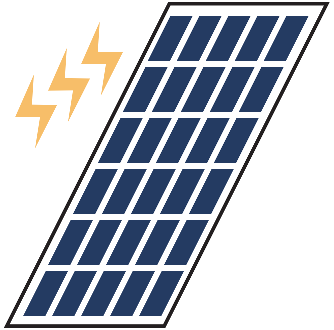
Heating and cooling

Insuring the indoor comfort, the installations combine with infrastructure to use heat energy more effeciently.



Insulation

The higher Rc-value for the building envelope is promoted in the Dutch regulation to reserve heat inside.

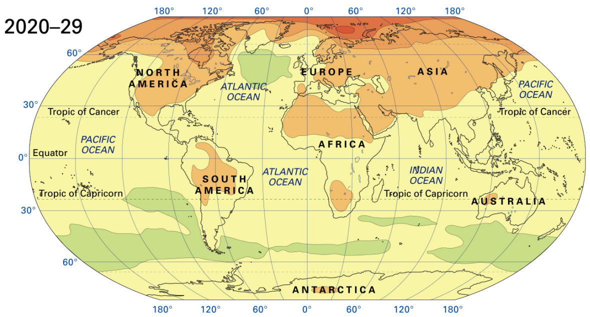


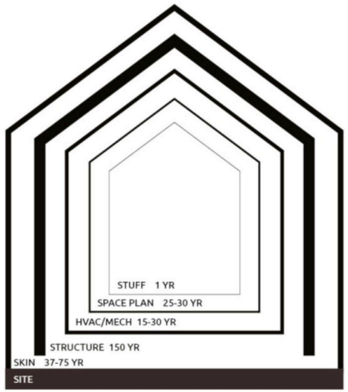
Renewable energy

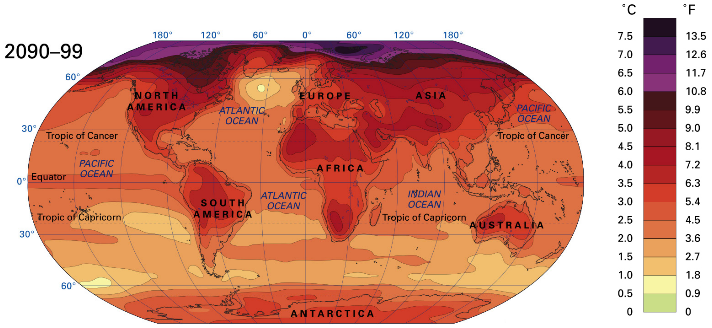
Renewable energy reduces the carbon emission caused by operation energy usage.

PROBLEM STATEMENT

- Suitable design vs. climate change -







Current climate condition

Climate information collected during 1980-2001.

Building lifespan

Projects are designing and constructing right now.

Future climate condition

Climate change, a warming environment.

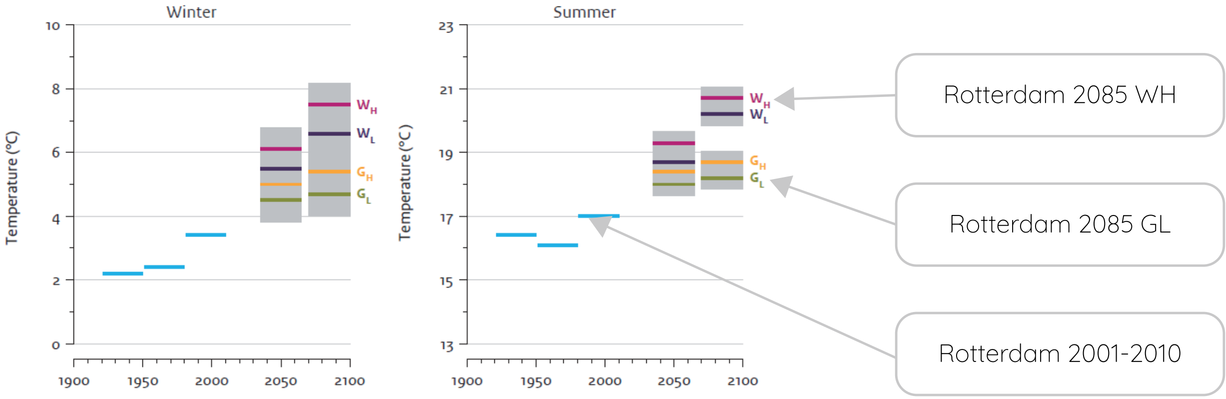
RESEARCH QUESTIONS

How to determine what design characteristics have the main influence on building operation energy and indoor comfort under both current and predicted future climate conditions by using computational simulation?

1. What climate conditions will be within the lifespan of the building(s) we are designing and building now?
2. How to minimize the operation energy demand throughout building lifespan under climate change conditions?
3. How to optimize the comfort hours by changing the envelope component?
4. What design decisions and design factors have a higher influence on energy consumption and indoor comfort?
5. How to evaluate the building performance through the building lifespan?
6. What is the methodology for simulation and optimization of the energy performance with different design decisions and for climate change conditions?

CLIMATE CHANGE

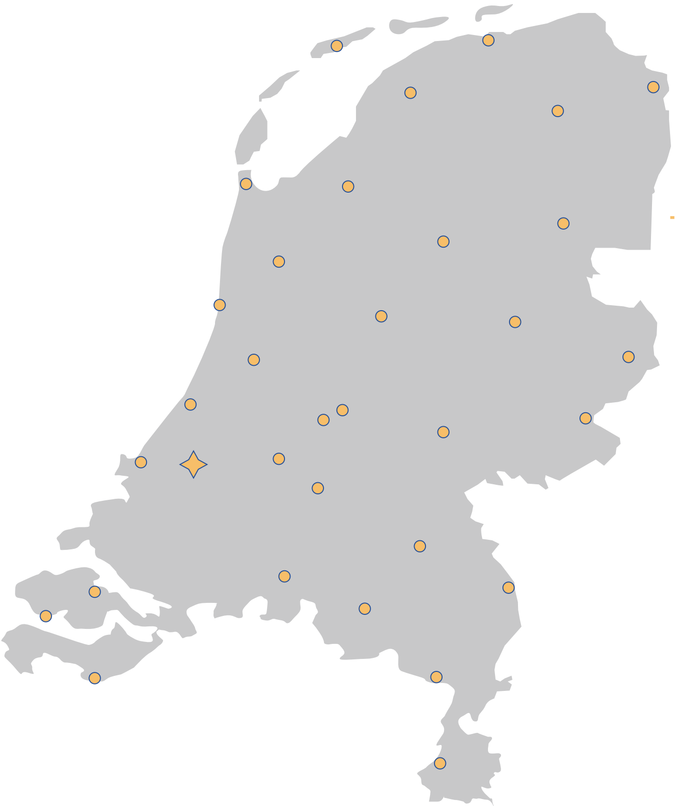
KNMI'14 CLIMATE INFORMATION



	GL	GH	WL	WH
Global temperature rise	+1.5°C	+1.5°C	+3.5°C	+3.5°C
Winter average temperature	+1.8°C	+2.3°C	+3.6°C	+4.6°C
Coldest winter day temperature	+2.1°C	+2.9°C	+4.2°C	+5.8°C
Summer average temperature	+1.7°C	+2.8°C	+3.4°C	+5.6°C
Warmest summer day temperature	+2.1°C	+3.8°C	+4.2°C	+7.6°C

*Reference from KNMI'14

33 WEATHER STATIONS IN KNMI'14



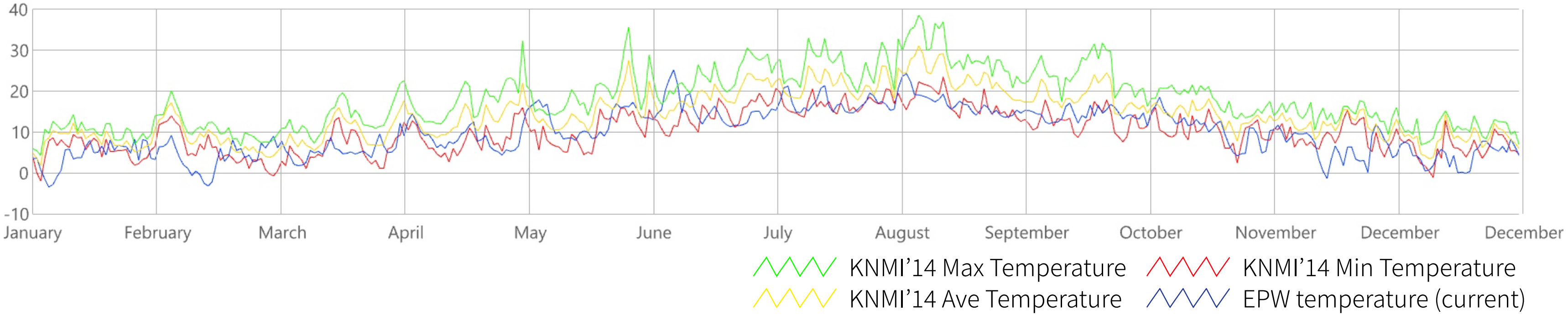
Daily climate data

Max temperature
Min temperature
Average temperature
Evaporation
Global radiation
Precipitation

X

Climate data for simulation

COMPARISON OF TEMPERATURE INFORMATION KNMI'14 AND EPW



METHOD OF GENERATING WEATHER DATA SET

KNMI 2001-2010 (hourly):

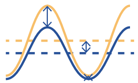
Temperature (in 0.1 Celsius)
Dew temperature (in 0.1 Celsius)
Global horizontal radiation (in J/cm2)
Wind speed (in 0.1 m/s)
Wind direction
Relative humidity (%)
Visibility
Atmosphere pressure (in 0.1 hPa)
Sky coverage (%)
Weather code (00-99)
Duration of sunshine (in 0.1 hour)
Duration of precipitation (in 0.1 hour)

KNMI’14 (daily):

Max temperature
Min temperature
Average temperature

Morph data

Hourly temperature



Dew point temperature

Dry bulb temperature
Relative humidity

KNMI’14 (daily):

Global horizontal radiation

NEN5060

Direct normal radiation
Diffuse horizontal radiation

NBS TECHNICAL NOTE 1148

Global horizontal illuminance
Direct normal illuminance
Diffuse horizontal illuminance

Other climate data

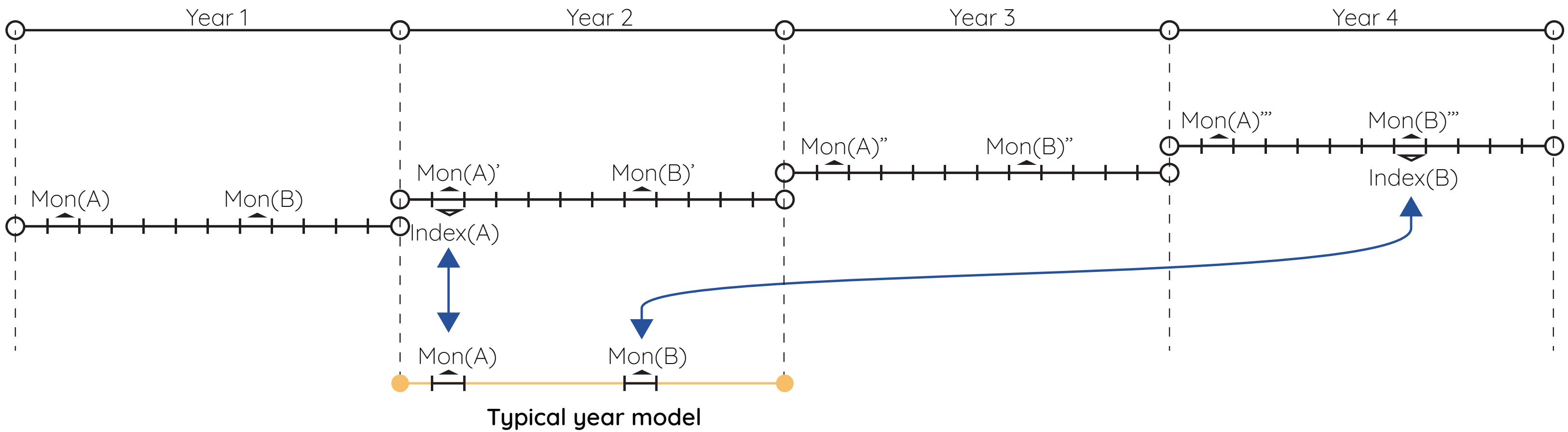
KNMI’14 (hourly):

Dry bulb temperature
Dew point temperature
Global horizontal radiation
Direct normal radiation
Diffuse horizontal radiation
Global horizontal illuminance
Direct normal illuminance
Diffuse horizontal illuminance
Wind speed
Wind direction
Relative humidity
Atmosphere pressure
Sky coverage
Visibility

EPW file

Climate data
+
Location, YYYYMMDD

TYPICAL YEAR MODEL WITH KNMI CLIMATE DATA

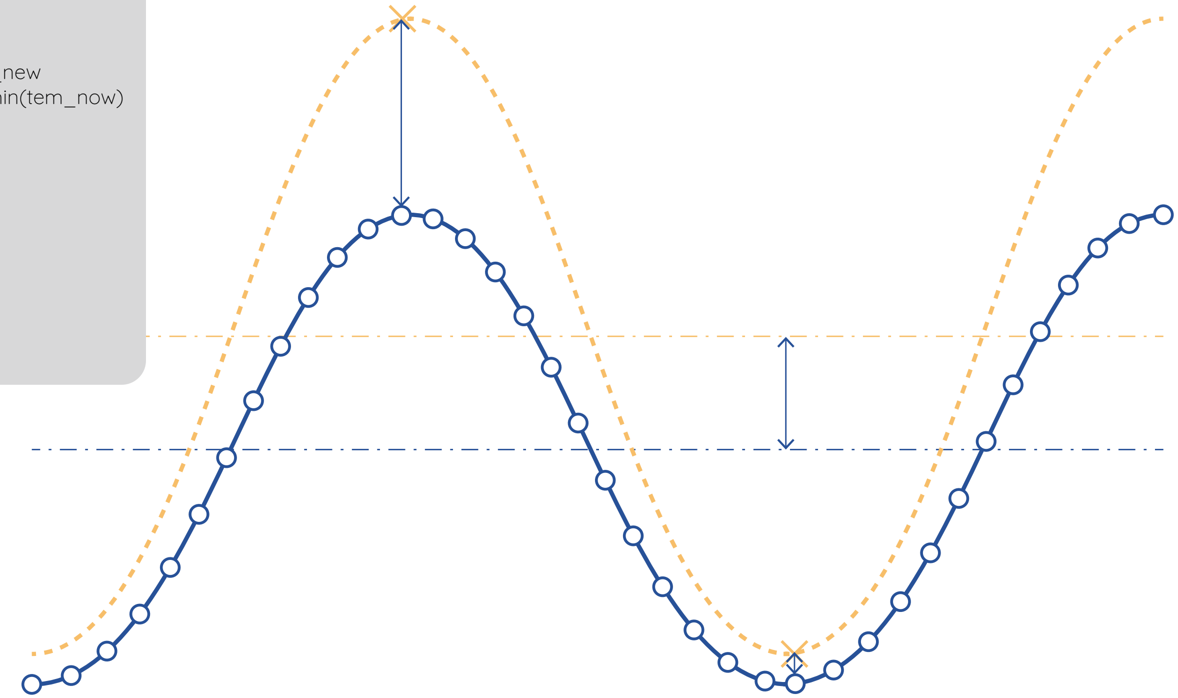


MORPHING CLIMATE DATA

Morphing

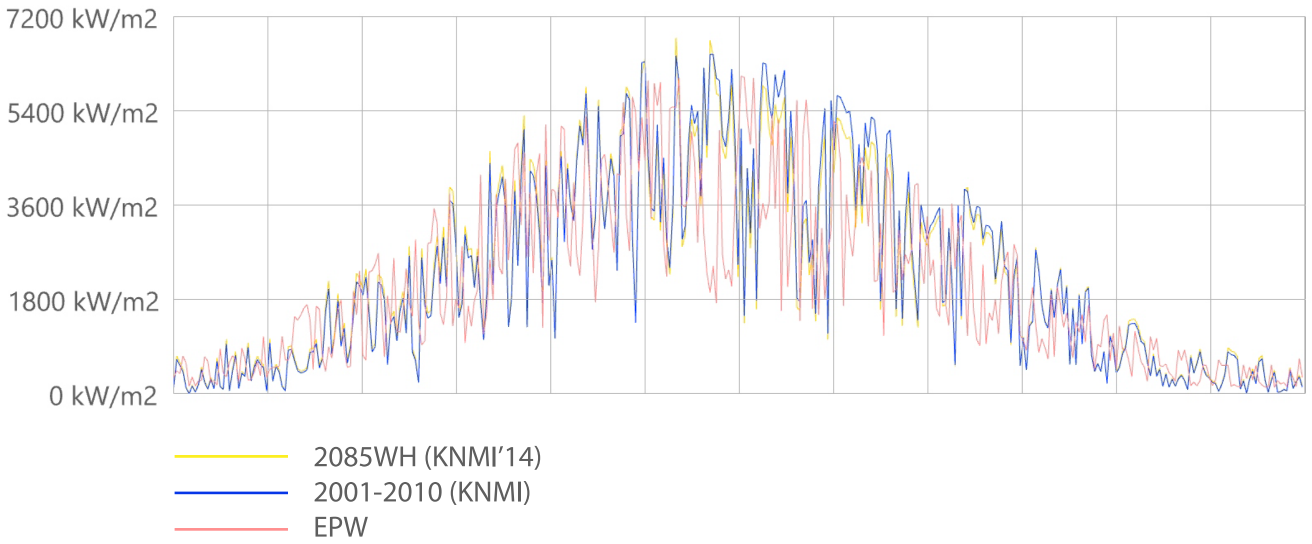
```
"""Scale the temperature value"""
New_diviation = ave_new * list_len - max_new - min_new
Now_diviation = sum(tem_now) - max(tem_now) - min(tem_now)
Scale_factor = New_diviation / Now_diviation
sub_list = [ i *Scale_factor for i in tem_now]

  for v in sub_list:
      if v == ori_max:
         final_sub_list.append(max_new[i])
      elif v == ori_min:
         final_sub_list.append(min_new[i])
      else:
         final_sub_list.append(v)
```

- Current data point
- Current data trend
- Known predicted data
- Morphed data trend
- Average data
- Difference



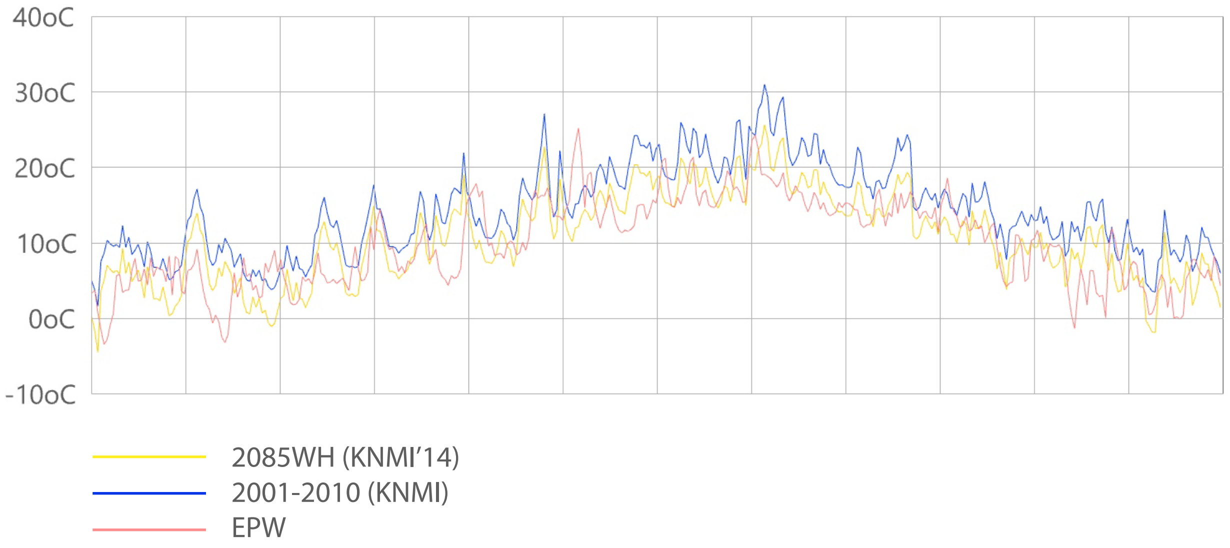
COMPARISON OF RESULT AND EPW

- Global horizontal radiation -

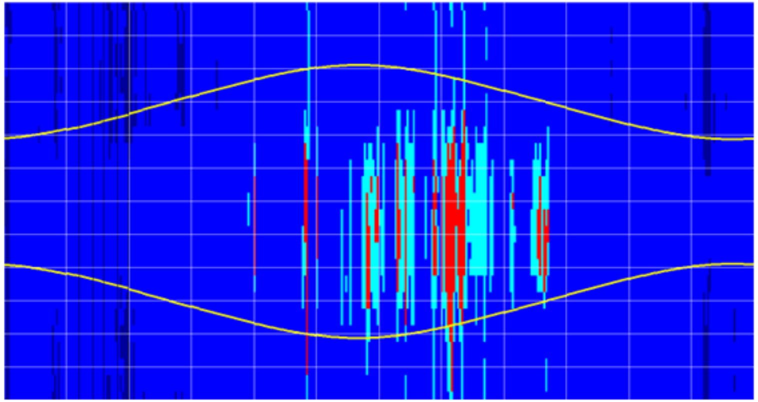


COMPARISON OF RESULT AND EPW

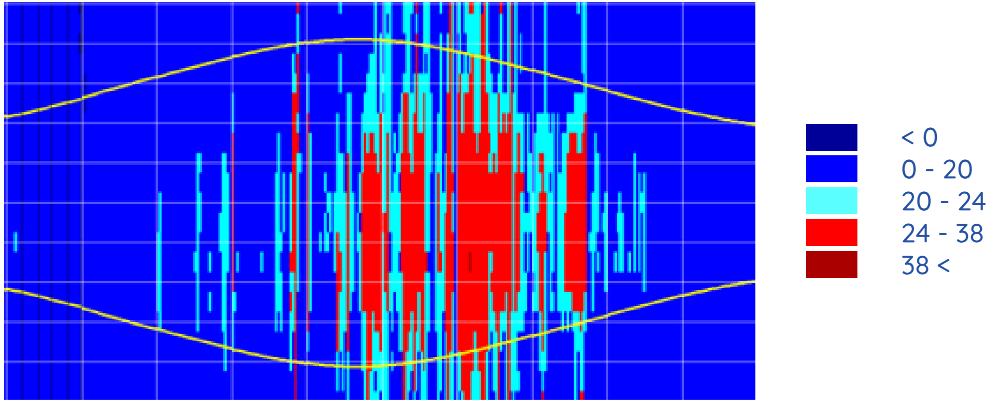
- dry bulb Temperature -



MORPHING RESULT



Current climate model

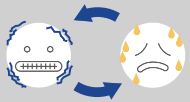


KNMI'14 climate model

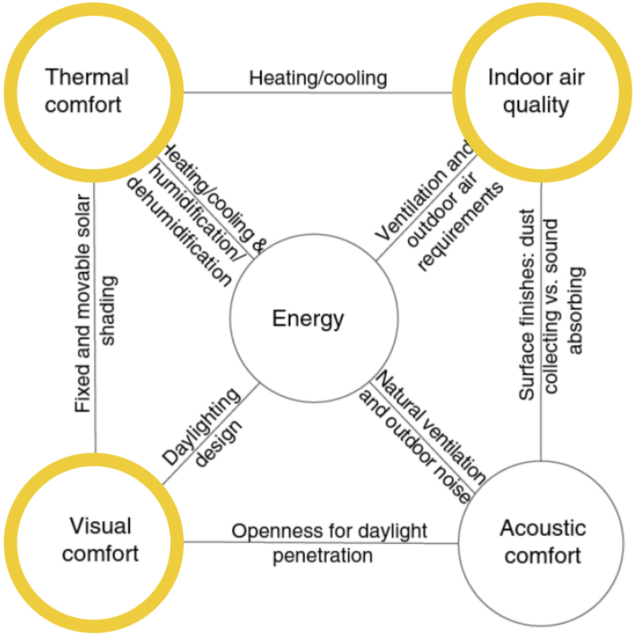
COMFORT DEFINITION

INDOOR COMFORT

Thermal comfort



Daylight performance



THERMAL COMFORT

PPD-PMV

Category	Thermal state of the body as a whole	
	PPD %	PMV
I	<6%	-0.2<PMV<0.2
II	<10%	-0.5<PMV<0.5
III	<15%	-0.7<PMV<0.7
IV	>15%	-0.7>PMV, or PMV>0.7

* Reference from NEN-EN 15251

Summer period

Metabolic rate: 1.3

Clothing factor: 0.5

Winter period

Metabolic rate: 1.3

Clothing factor: 1

Passed

No pass

Result

X % of the occupied period is comfortable

AIR QUALITY

Category	Occupancy [m2/person]	Ventilation rate [dm3/s]	Ventilation rate [dm3/s m2 person]
Bedroom	18	7	0.5
Kitchen	15	40	2.7
Bathroom	10	15	1.5
Living room	5	7	0.8
Workspace	17	6.5	0.4
Laundry	9	10	1.1

X

People in rooms * average of using time

||

Average ventilation rate per floor [m3/s m2]

Lowest air changes rate = 0.35/hour >> *floor height /3600

*Reference from Fumagalli, 2020, ASHRAE 62.1

VISUAL COMFORT

Spatial Daylight Autonomy (sDA300/50%)

At least 300lux with 50% of occupied time

sDA for regularly occupied floor area	Point	Result
sDa< 55%	0	1~54
55%<= sDa < 75%	2	55~74
75% <= sDA	3	75~100

Annual Sunlight Exposure (ASE1000,250)

At least 1000 lux for at least 250 occupied hours per year

sDA for regularly occupied floor area	Result
ASE <= 10%	True
10% < ASE	Fault

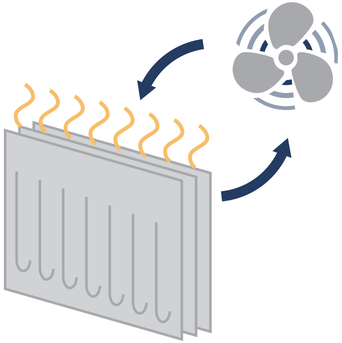
Result
Daylight Condition

* Reference from LEED v4.

ENERGY PERFORMANCE

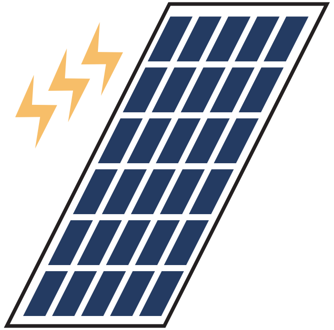
ENERGY PERFORMANCE

BENG1



Energy consumption
(kWh/m2.year)

BENG3



Percentage of renewable
energy usage
(%)

ENERGY CONSUMPTION AND REGULATION

Energy consumption for heating and cooling

Energy consumption for heating, cooling

* Als= Heat loss area
  Ag = Usable area

Same area and efficiency of energy productivity of PV panel

Energy Consumption (BENG1) [kWh/m2.yr]

Function	Condition	Requirement
Residential	Als/Ag <= 1.83	BENG1 <= 65
	1.83<Als/Ag<= 3.0	BENG1 <= 55+30*(Als/Ag -1.5)
	3.0< Als/Ag	BENG1<= 100+50*(Als/Ag -1,5)
Office	Als/Ag <= 1.8	BENG1 <= 90
	1.8<Als/Ag	BENG1 <= 90+30*(Als/Ag -1.8)

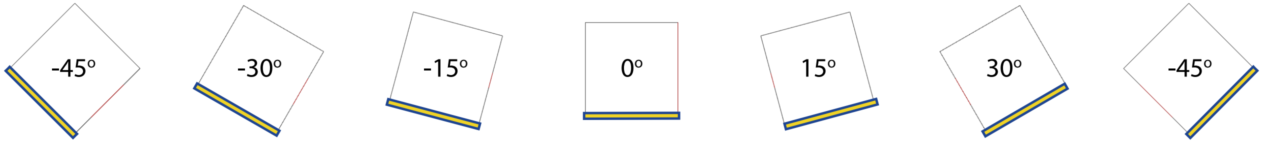
Percentage of Renewable Energy [%]

Function	Requirement
Residential	40% <=
Office	30 %<=

* Reference from NTA 8800

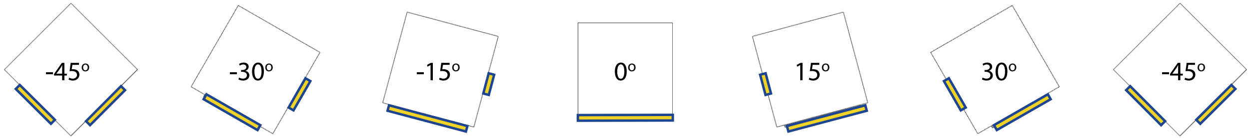
EFFICIENCY OF PV PANELS WITH DIFFERENT APPROACHES

On Single surface



997 kWh/yr	1184 kWh/yr	1676 kWh/yr	2400 kWh/yr	1652 kWh/yr	1161 kWh/yr	997 kWh/yr
41%	49%	70%	100%	69%	48%	41%

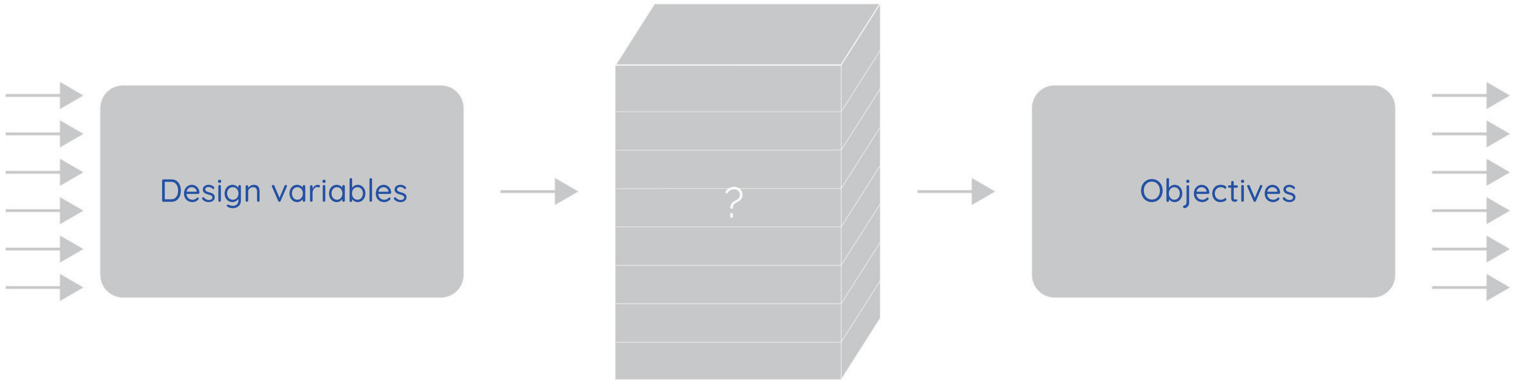
On one to two surfaces



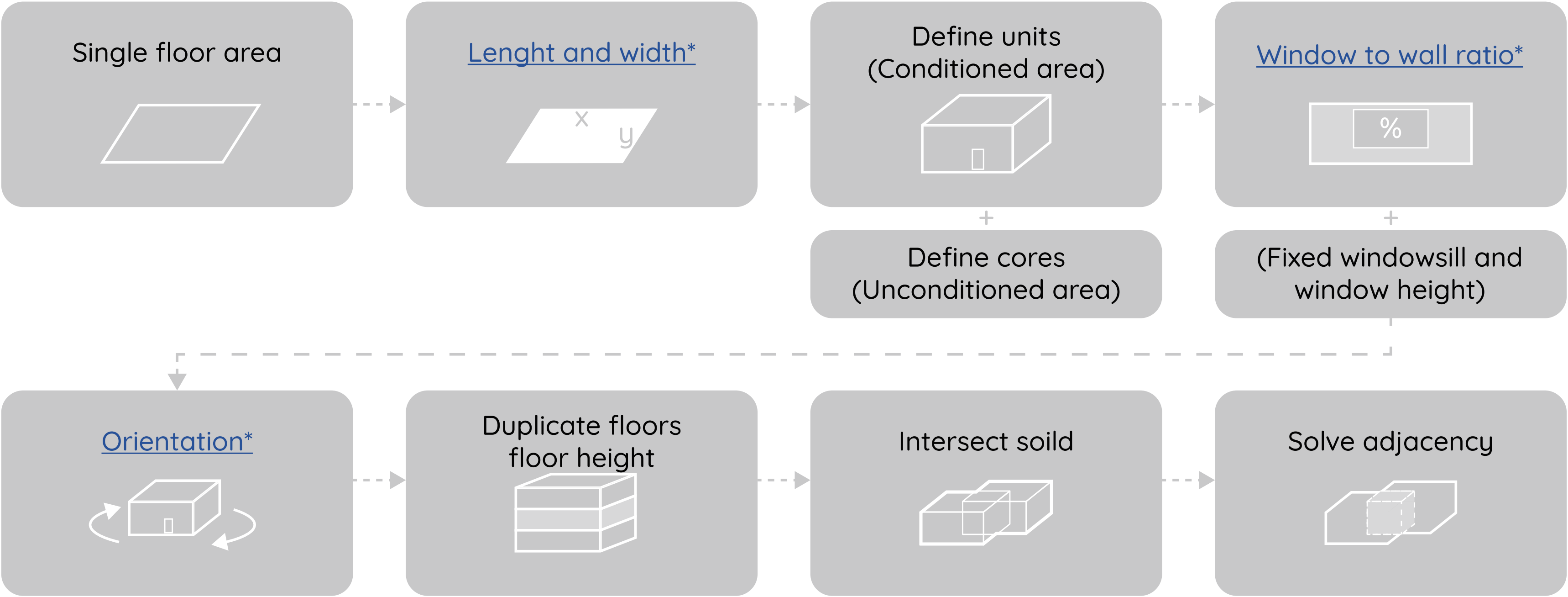
2149 kWh/yr	2301 kWh/yr	2385 kWh/yr	2400 kWh/yr	2346 kWh/yr	2224 kWh/yr	2054 kWh/yr
89%	96%	99%	100%	97%	92%	86%

SIMULATION AND OPTIMIZATION

APPROACH IN EARLY DESIGN PHASE



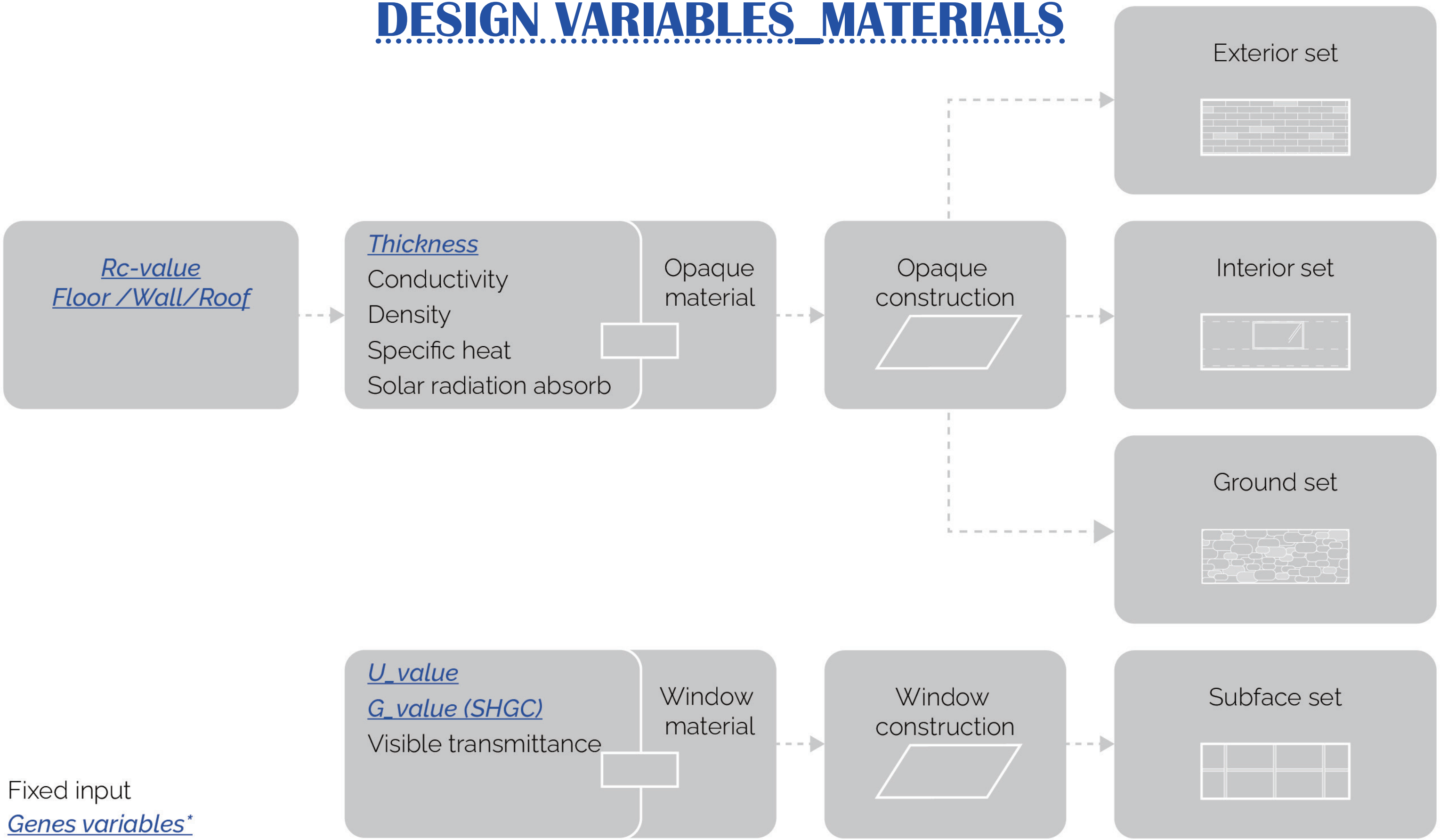
DESIGN VARIABLES_GEOMETRY



Fixed input

Genes variables*

DESIGN VARIABLES_MATERIALS



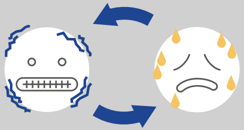
Fixed input
*Genes variables**

OBJECTIVES IN MULTI-OBJECTIVE OPTIMIZATION

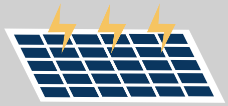
Energy consumption

Daylight performance

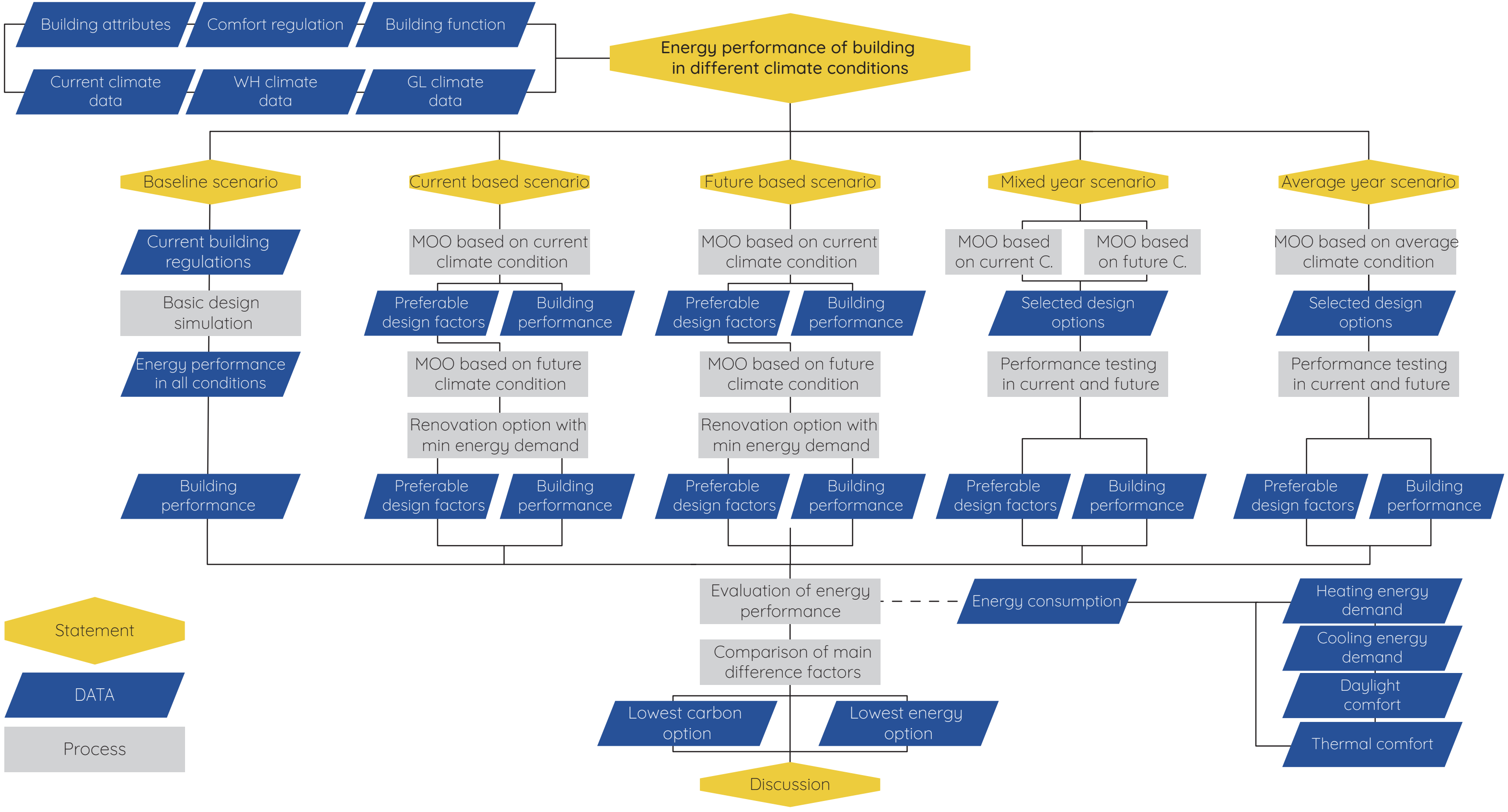
Thermal comfort



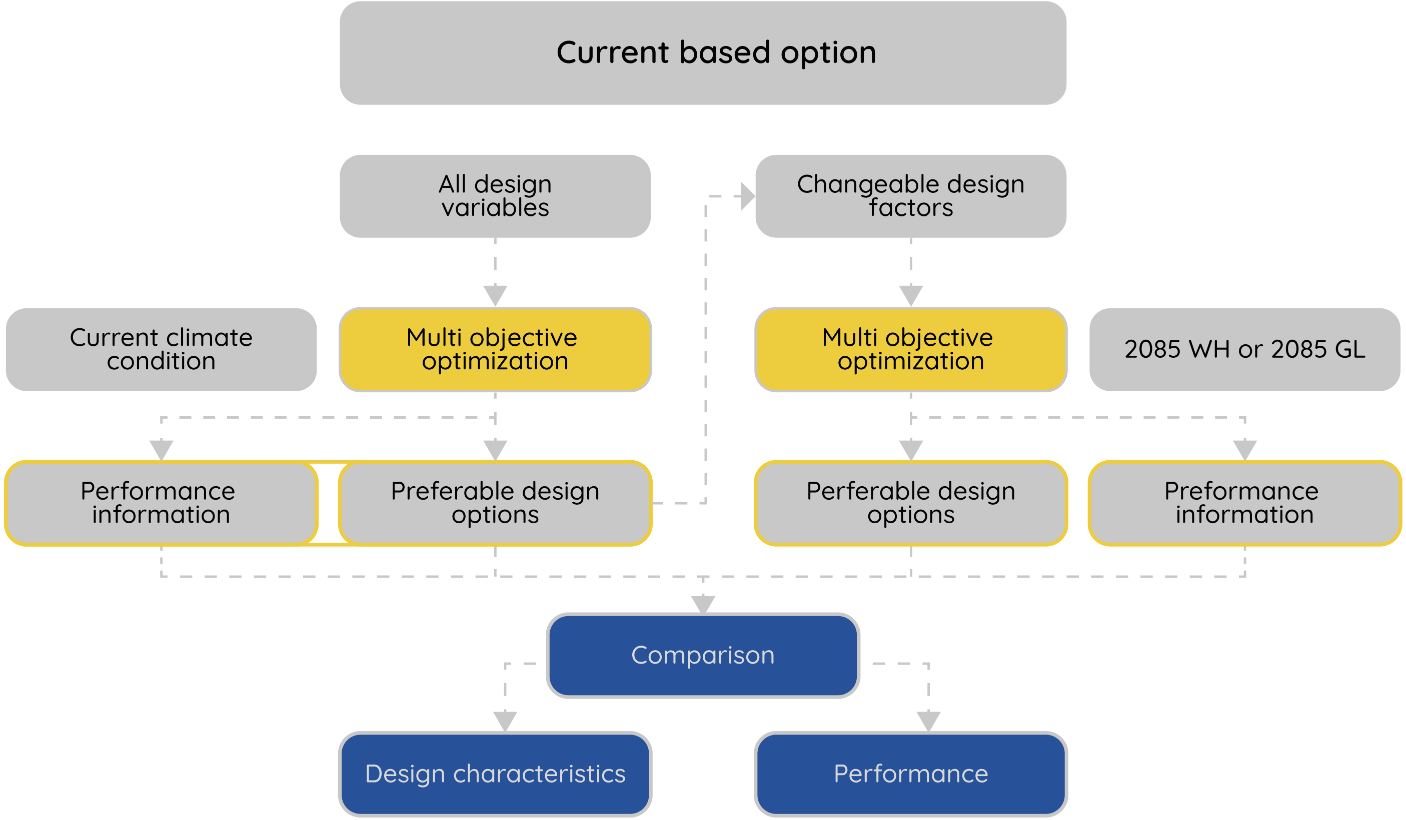
Percentage of renewable energy



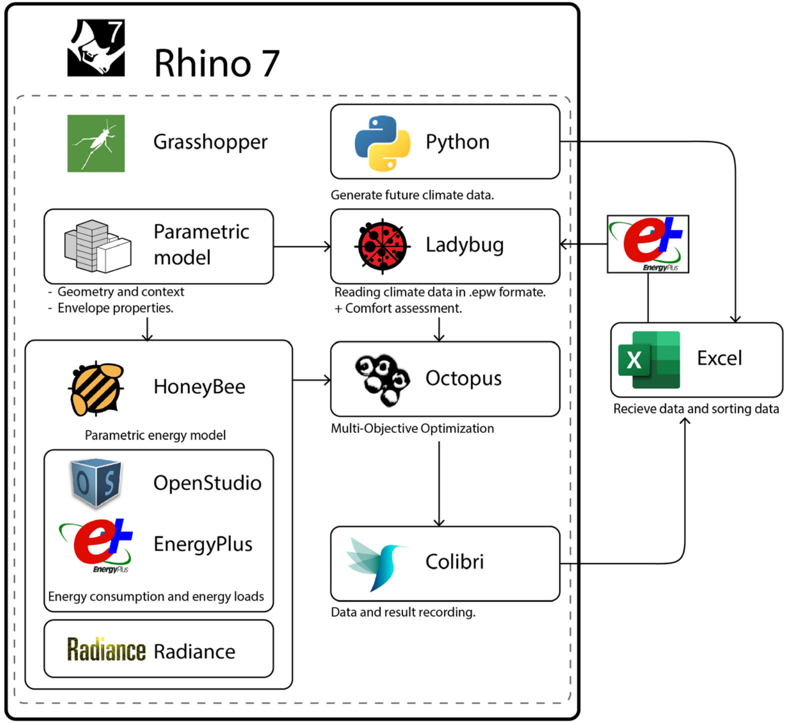
APPROACHES AND SCENARIOS



SAMPLE OF THE CURRENT BASED SCENARIO



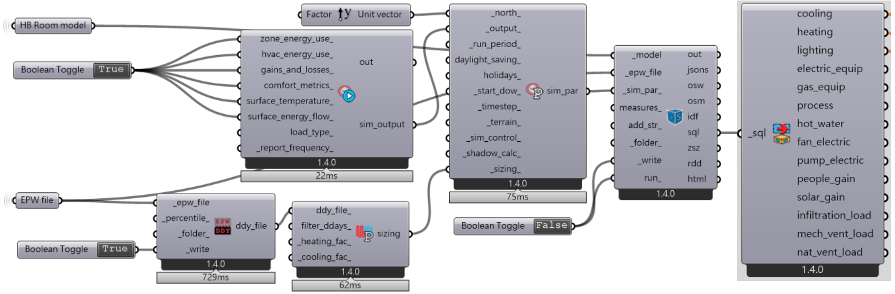
SOFTWARE


Rhino 7
Grasshopper
Python
Generate future climate data.
Parametric model
- Geometry and context
- Envelope properties.
Ladybug
Reading climate data in .epw formate.
+ Comfort assessment.
EnergyPlus
Excel
Recieve data and sorting data
HoneyBee
Parametric energy model
Octopus
Multi-Objective Optimization
OpenStudio
EnergyPlus
Energy consumption and energy loads
Colibri
Data and result recording.
Radiance Radiance

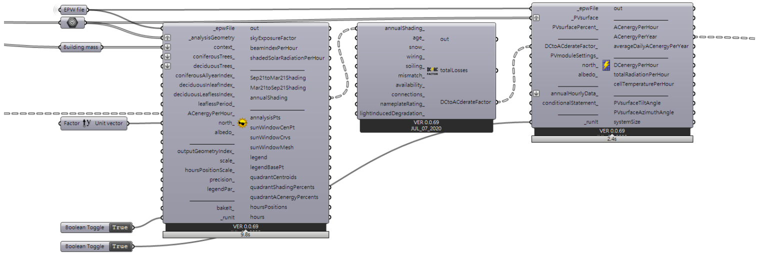
EXECUTION OF SIMULATION

Design model

EPW



Energy consumption

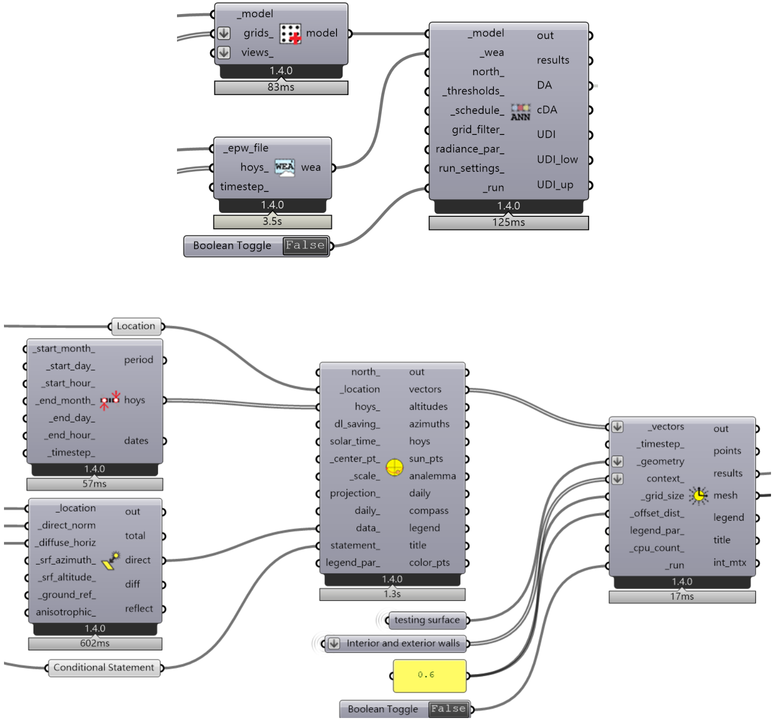


Generated energy

EXECUTION OF SIMULATION

Design model

EPW

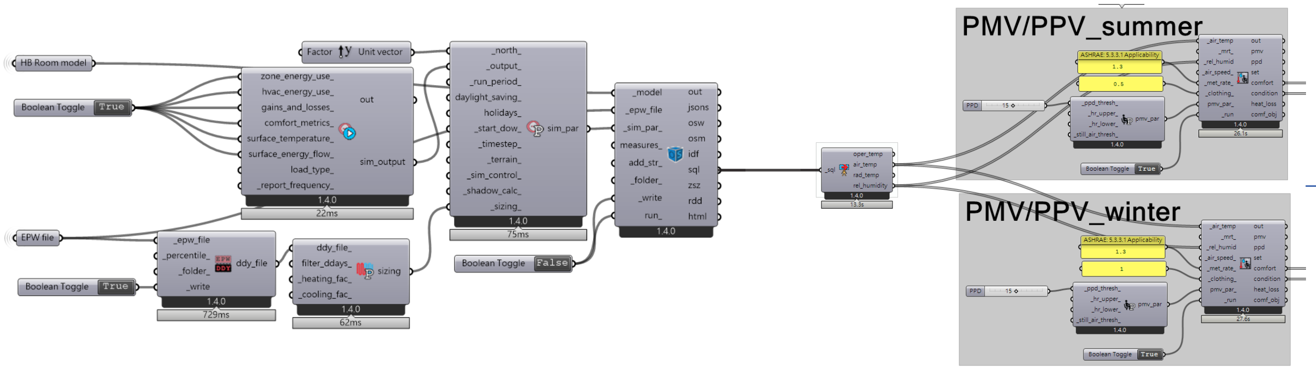


Spatial daylight autonomy

Visual comfort

Annual sunlight exposure

EXECUTION OF SIMULATION



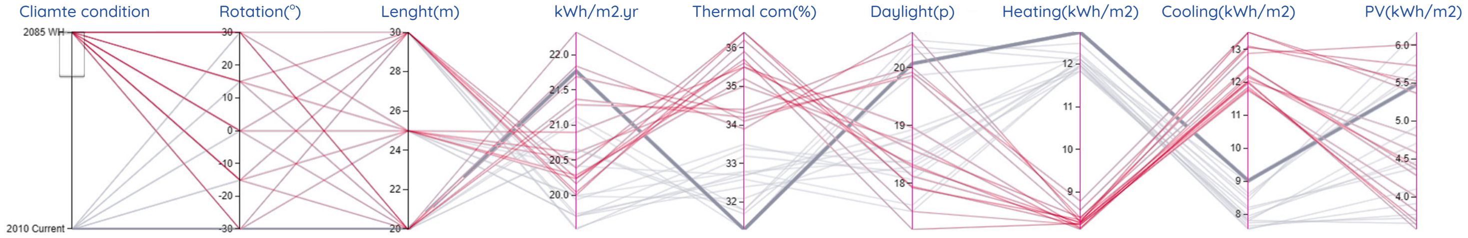
Thermal comfort

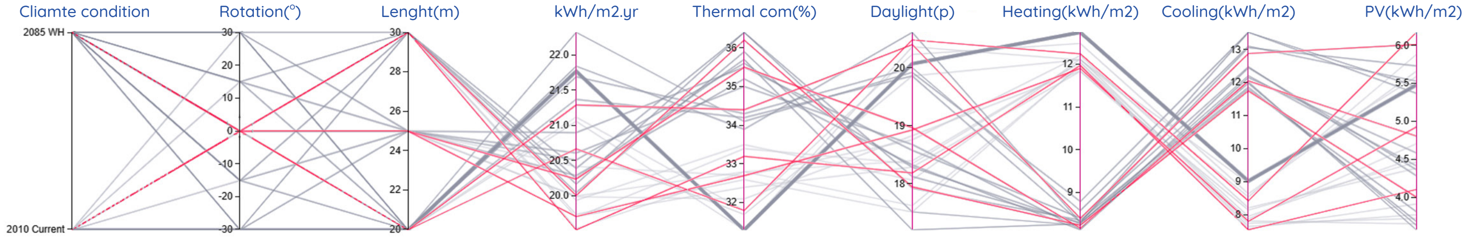
SENSITIVITY ANALYSIS

Climate and geometry

Climate: Shifting the performance quality but a minor impact on daylight.

Geometry: The combination of length and rotation has a significant influence.

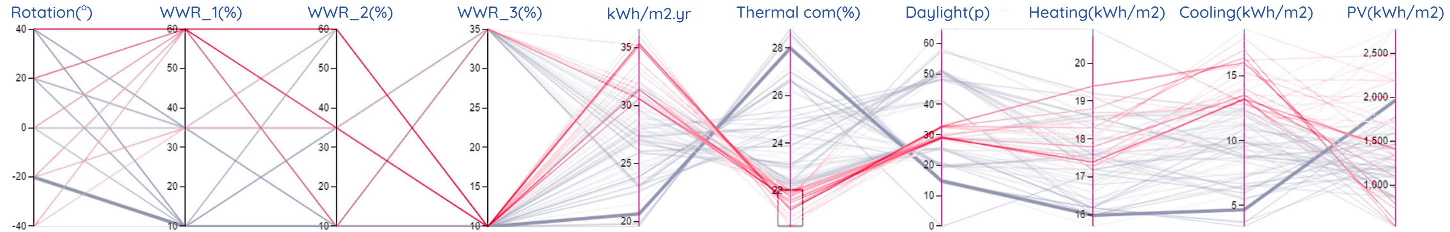


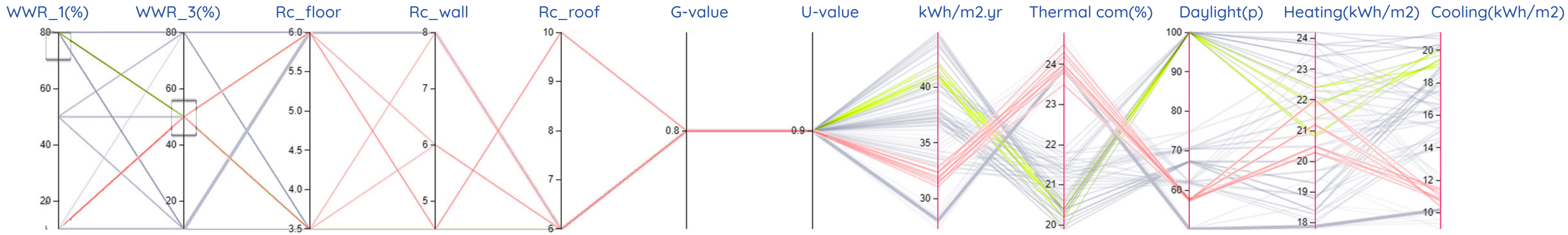


SENSITIVITY ANALYSIS

WWR and Rc-value

WWR: The orientation of facade determine the best ratio.
Rc-value The influence of Rc-value is smaller than WWR.

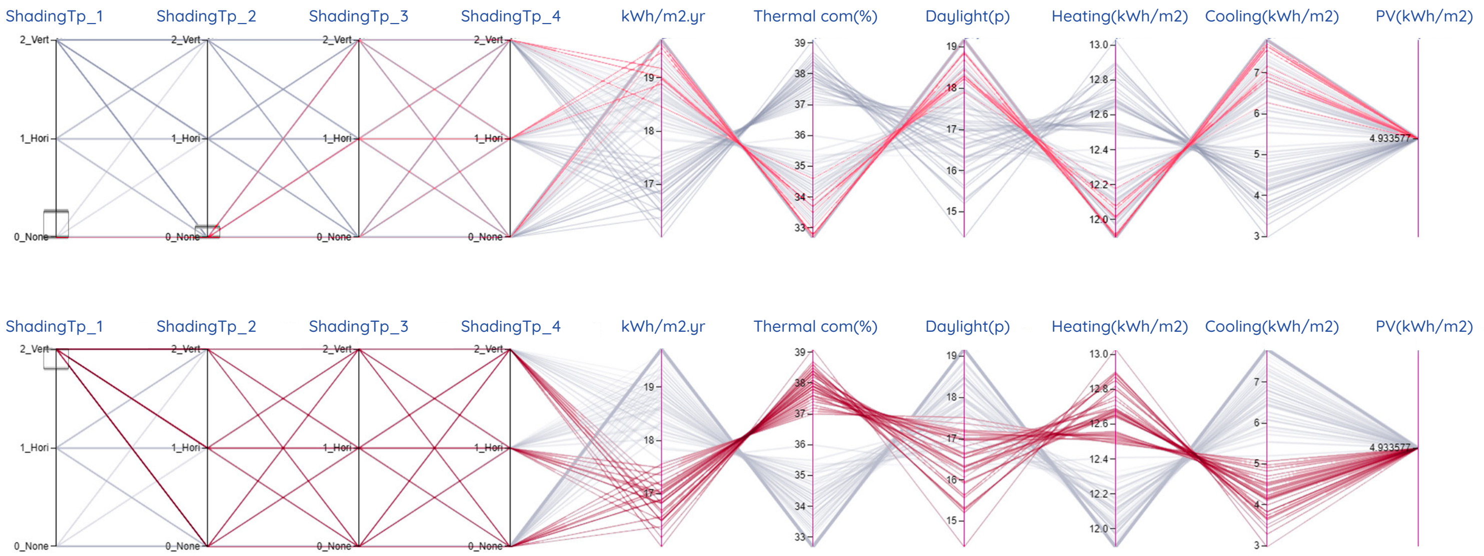




SENSITIVITY ANALYSIS

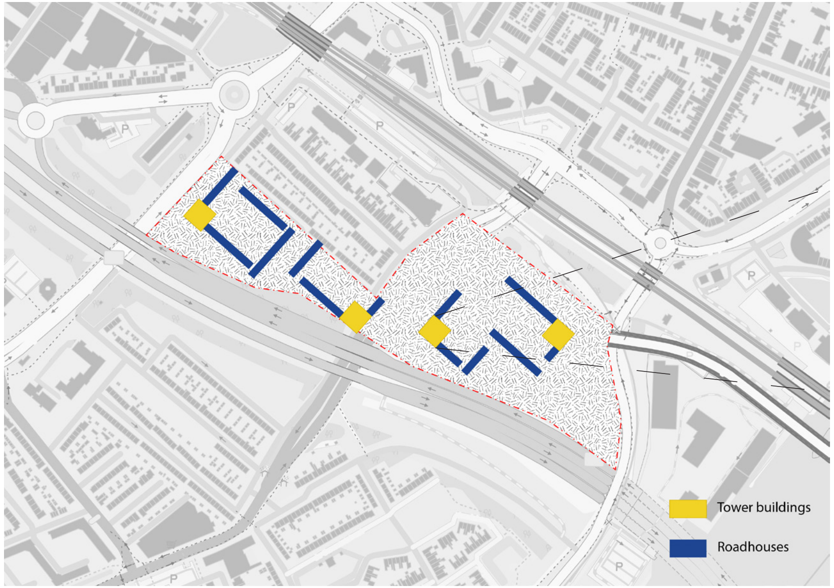
Shading and orientation

Shading: Efficient shading system and facade orientation have a linear relationship.

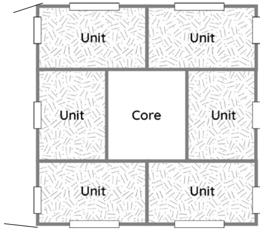


CASE STUDY

CASE STUDY PROJECT

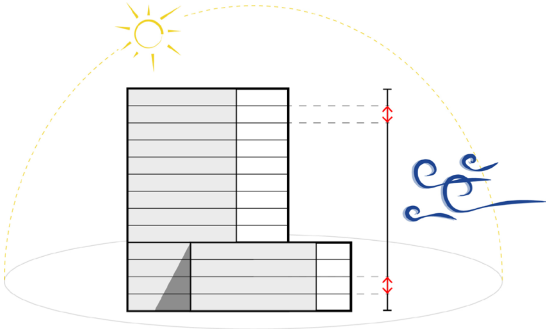


Project site and location

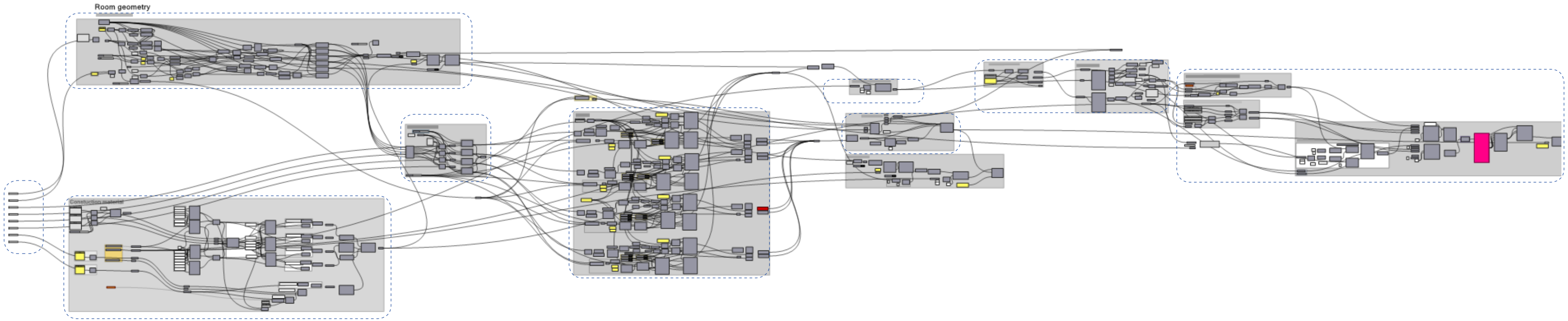


Standard layout

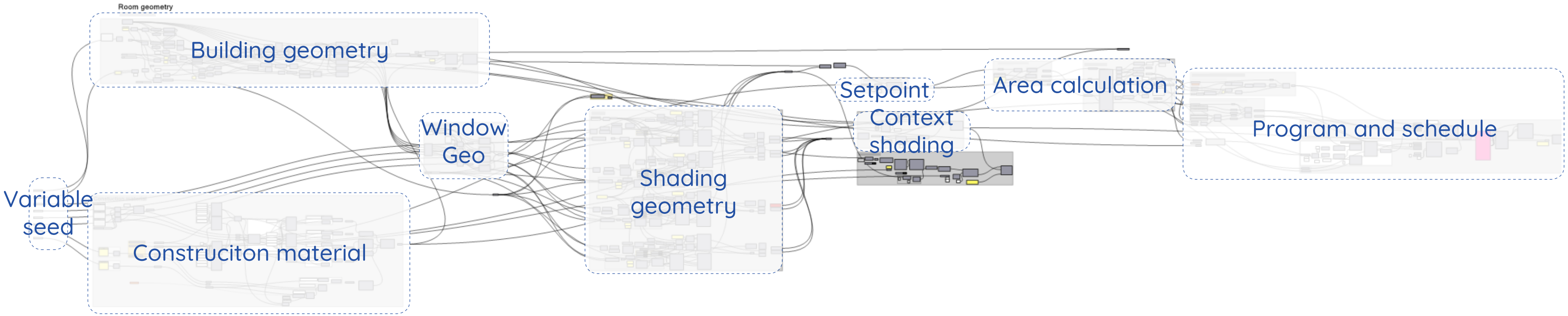
Location: Zwijndrecht
Funciton: Residential
Design phase: Early design phase
Area: 53,784 m2/576m2
Floors: 13
Floor height: 3 m



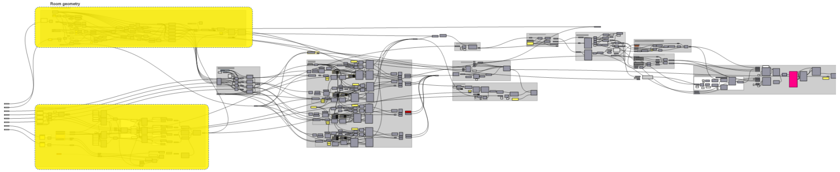
GRASSHOPPER SCREENSHOT



GRASSHOPPER SCREENSHOT



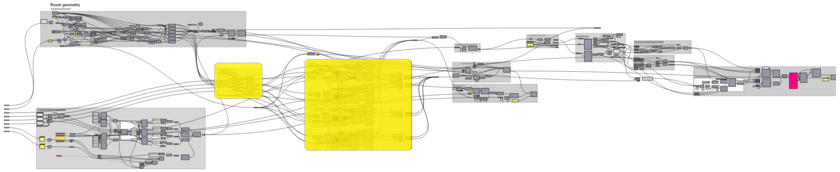
BUILDING GEOMETRY AND CONSTRUCTION MATERIALS

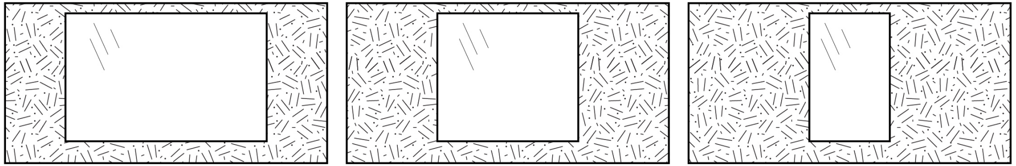


Items	Range				
Length	20	24	28	-	-
Rotation	-30˚	-15˚	0˚	+15˚	+30˚
WWR (wall 1)	20%	35%	50%	-	-
WWR (wall 2)	20%	35%	50%	-	-
WWR (wall 3)	20%	35%	50%	-	-
WWR (wall 4)	20%	35%	50%	-	-

Thermal insulation	Quality level		
	Basic	Good	Excellent
Opaque part	$Rc_{Floor} \geqq 3.5\ m^2K/W$ $Rc_{Facade} \geqq 4.5\ m^2K/W$ $Rc_{Roof} \geqq 6.0\ m^2K/W$	$Rc_{Floor} \geqq 4.5\ m^2K/W$ $Rc_{Facade} \geqq 6.5\ m^2K/W$ $Rc_{Roof} \geqq 8.0\ m^2K/W$	$Rc_{Floor} \geqq 5.5\ m^2K/W$ $Rc_{Facade} \geqq 8.5\ m^2K/W$ $Rc_{Roof} \geqq 10.0\ m^2K/W$

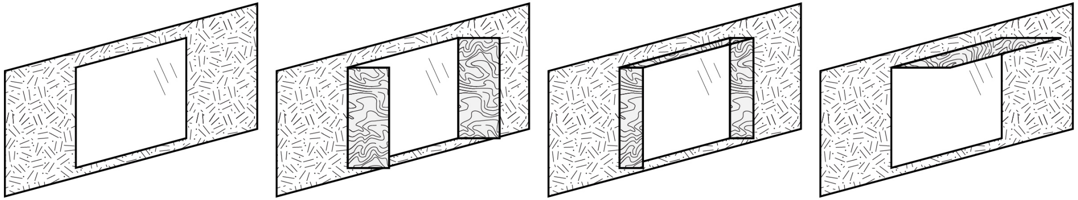
WINDOW GEOMETRY AND SHADING





50% WWR 35% WWR 20% WWR

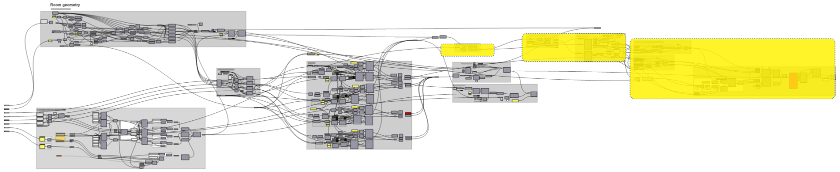
Window to wall ratio



North facade West and East facade Between South the East and West South facade

Shading system

BUILDING GEOMETRY AND CONSTRUCTION MATERIAL



$$\frac{A_{g,zi}}{N_{Woon;zi}} \le 30m^2: N_{P;woon;zi} = 1$$

$$30\,m^2 < \frac{A_{g,zi}}{N_{Woon;zi}} \le 100m^2: N_{P;woon;zi} = 2.28 - \frac{1.28}{70} * \left(100 - \frac{A_{g,zi}}{N_{Woon;zi}}\right)$$

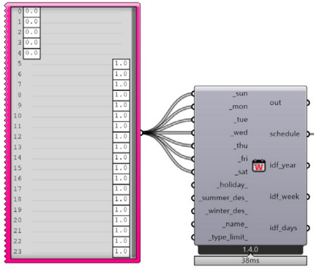
$$100\,m^2 < \frac{A_{g,zi}}{N_{Woon;zi}}: N_{P;woon;zi} = 1.28 + 0.01 * \frac{A_{g,zi}}{N_{Woon;zi}}$$

People per floor area

x

Internal heat gain	1.3 met_rate
Ventilation requirement	0.7 dm^3/m^2
Heating and cooling setpoint	20°C / 26°C
Equipement and lighting	-

x



Occupancy schedule

OPIMIZATION VARIAVABLES AND OBJECITVES

Input variables

- Orientation*
- Lenght and width*
- Window to wall ratio* x 4 facades
- Rc-value Floor /Wall/Roof
- U-value Window
- G-value Window

Multi-Objective Optimization

Objectives

- Energy consumption
- Thermal comfort
- Daylight performance
- Percentage of renewable energy

RESULTS AND ANALYSIS

SCENARIOS AND RESULTS

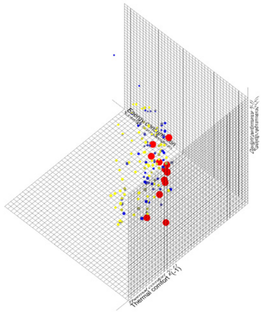
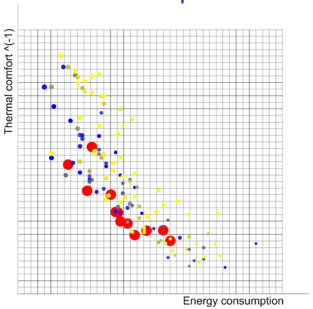
1. Baseline scenario
2. The current based scenario
3. The future based scenario
4. Mixed year scenario
5. Average year scenario

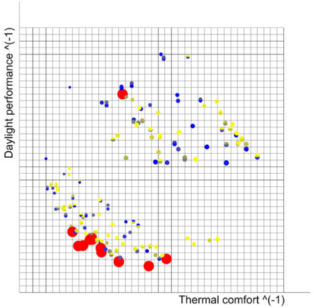
x

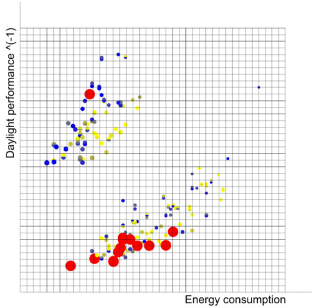
0. Building geometry
1. Energy consumption
2. Heating demand
3. Cooling demand
4. Thermal comfort
5. Warm hours
6. Cool hours
7. Overheating Hours
8. Daylight performance
9. Ratio of renewable energy usage

SELECTION FROM PARETO FRONT

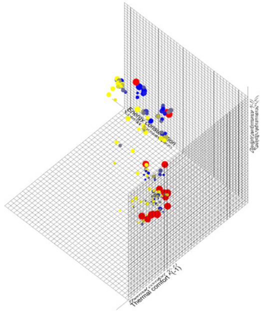
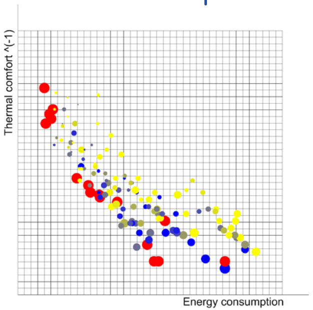
Results from MOO
-First step in The current based scenairo-

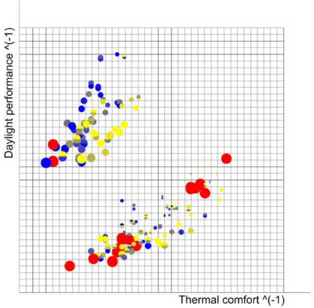



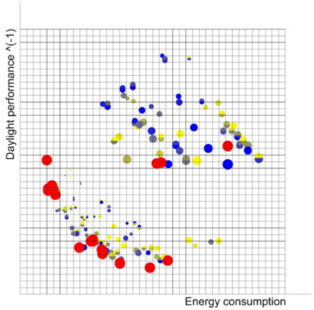




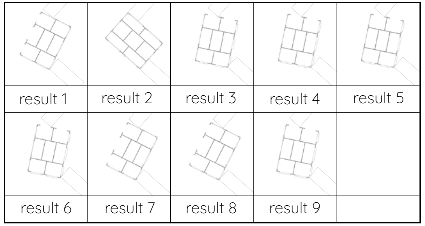
Results from MOO
-Second step in The current based scenairo-

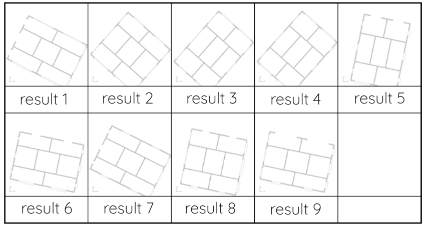




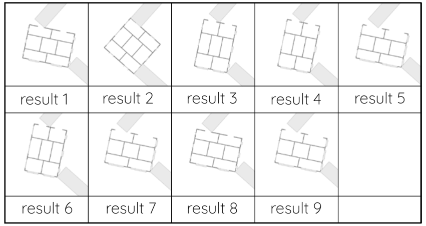
GEOMETRY FROM MIXED BASED SCENARIO



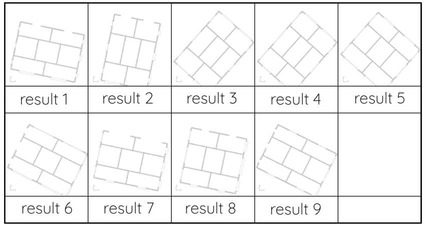
Current_lower floors



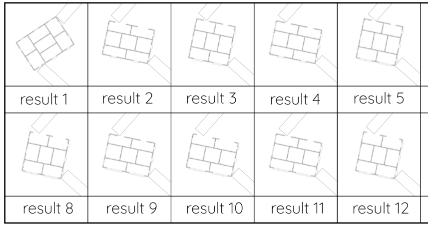
Current_higher floors



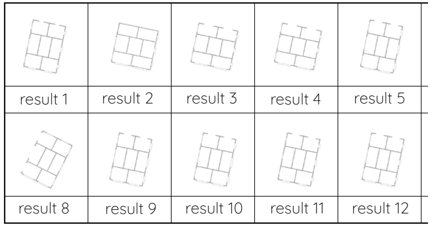
Future_lower floors



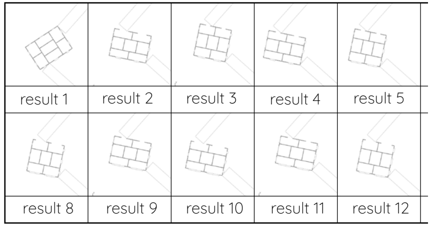
Future_higher floors



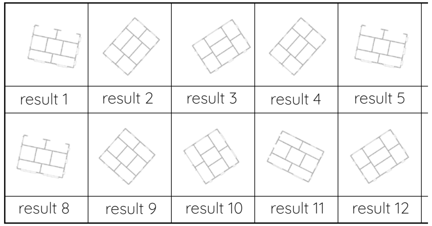
Mixed_lower floors



Mixed_higher floors

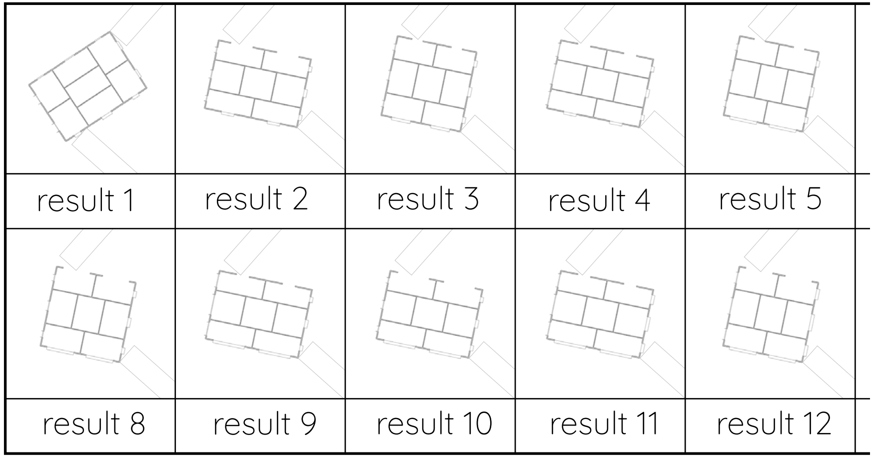


Average_lower floors

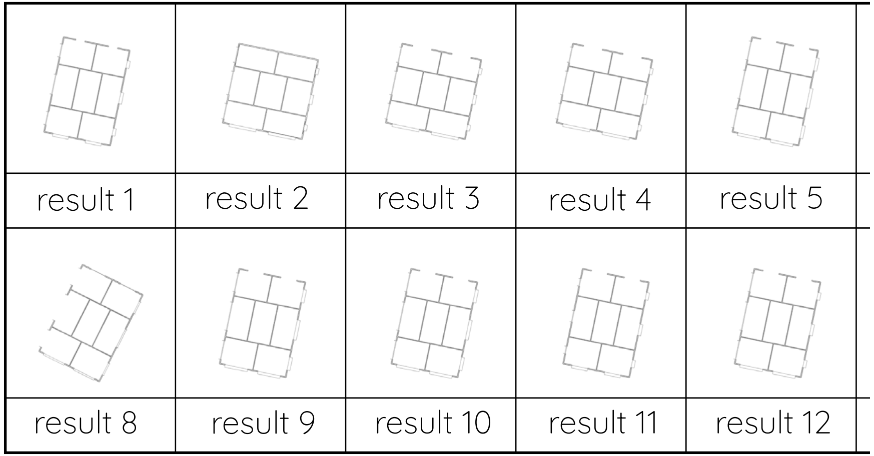


Average_higher floors

GEOMETRY FROM MIXED YEAR SCENARIO

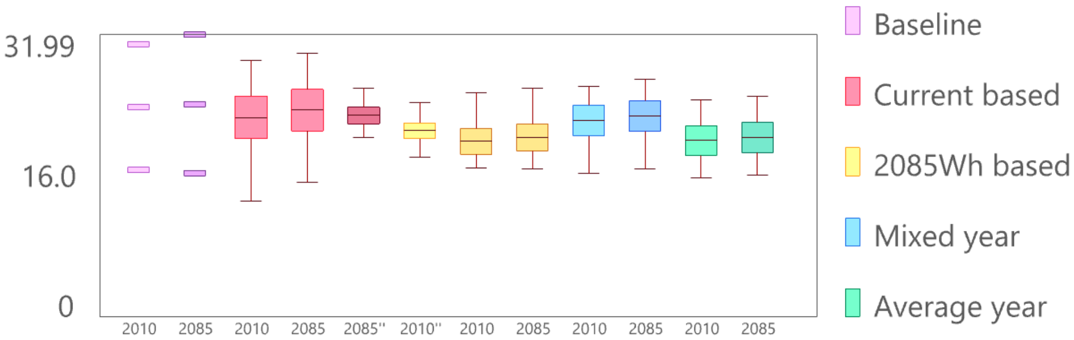


Lower floors

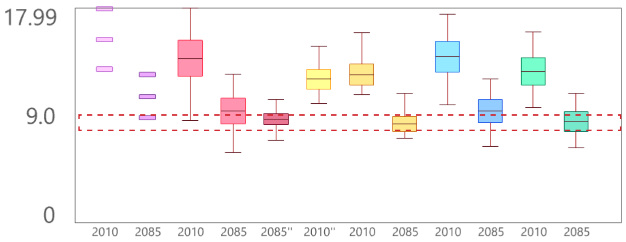


Higher floors

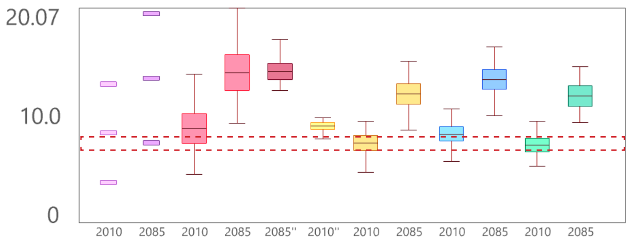
ENERGY CONSUMPTION



Energy Consumption(kWh/m2.year)

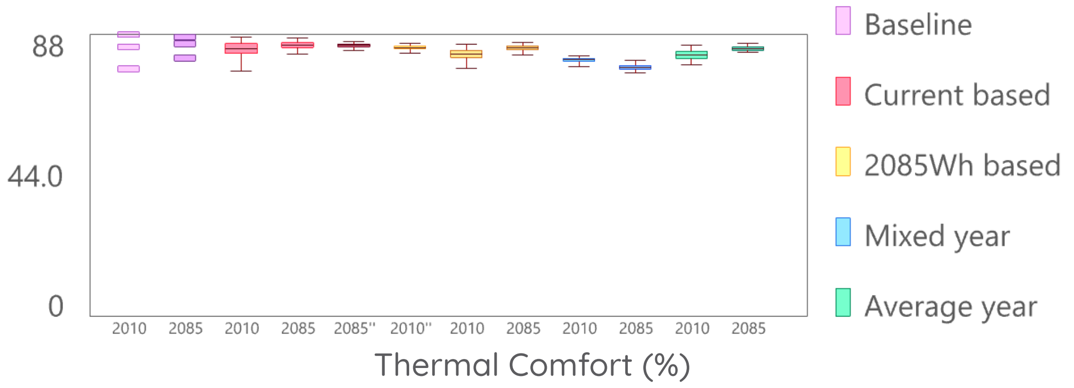


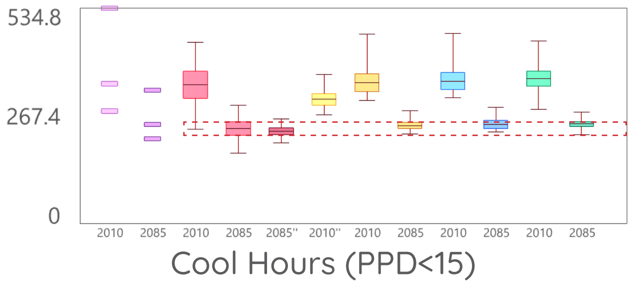
Heating Demand (kWh/m2.year)

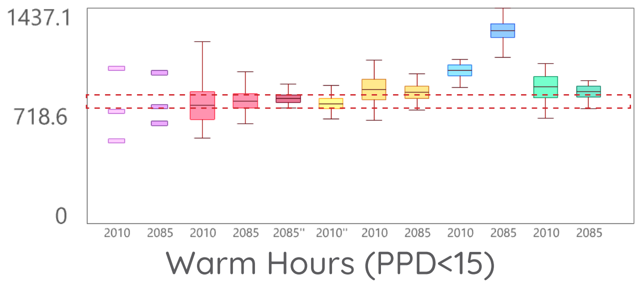


Cooling Demand (kWh/m2.year)

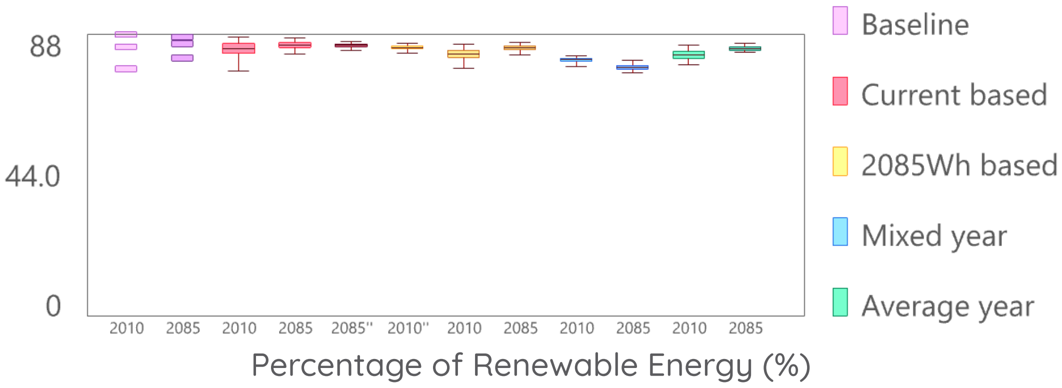
THERMAL COMFORT

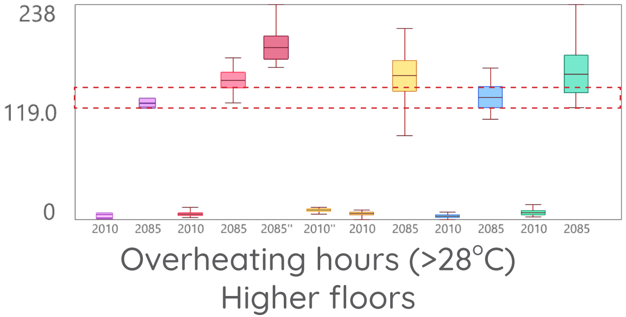


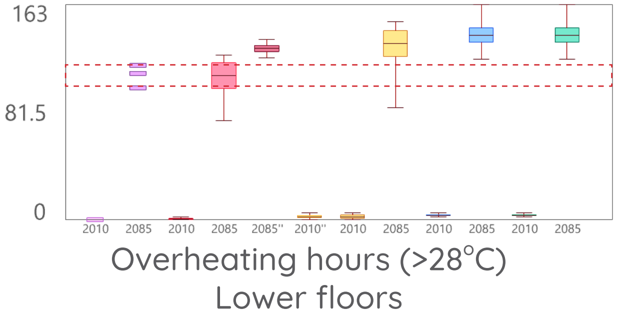




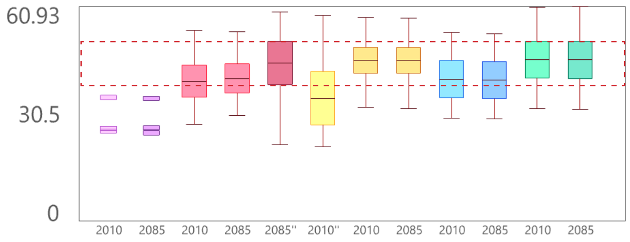
THERMAL COMFORT



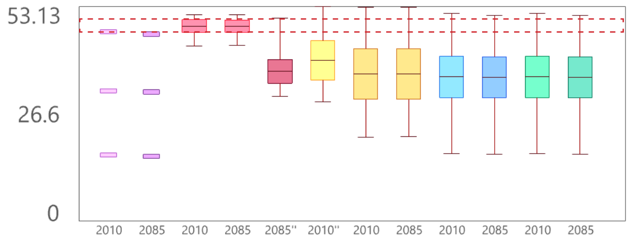




DAYLIGHT PERFORMANCE

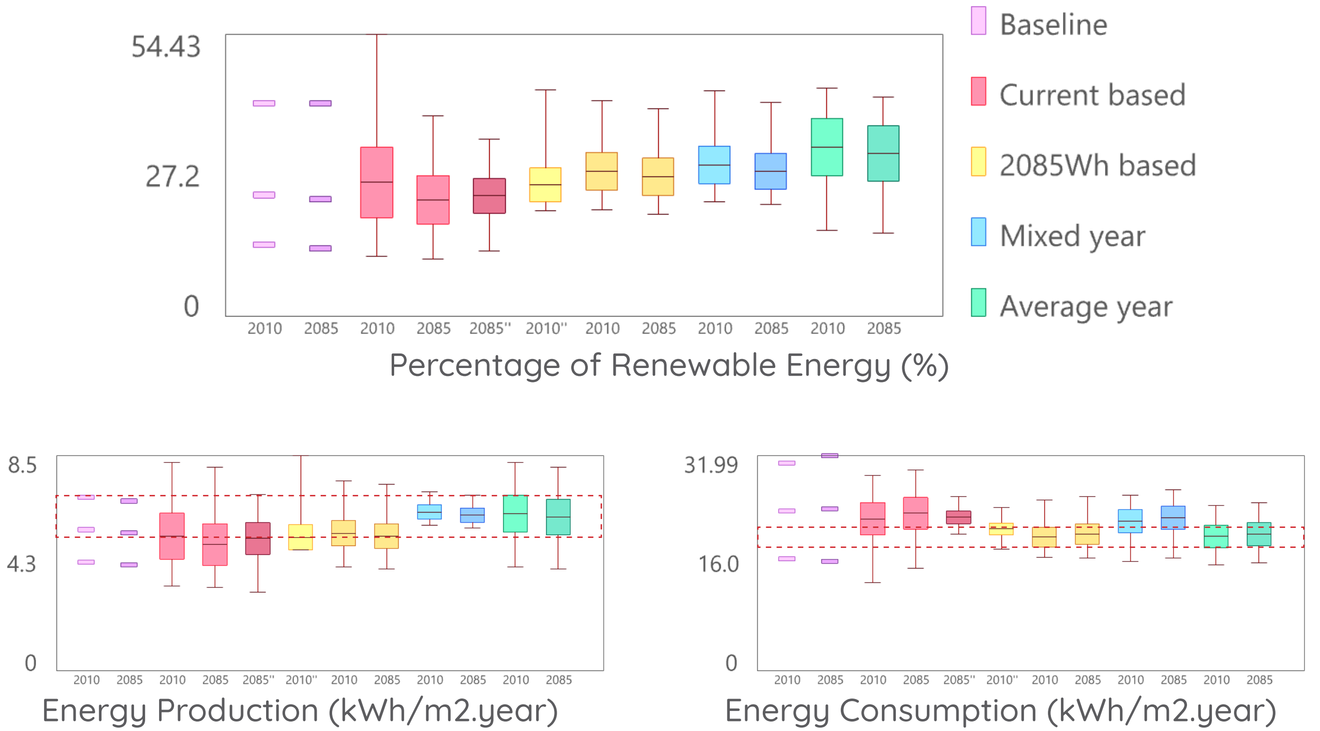


Daylight performance (%)
Higher floors



Daylight performance (%)
Lower floors

RATIO OF RENEWABLE ENERGY USAGE



CONCLUSION AND REFLECTION

CONCLUSION

1. Climate selection influences the performance throughout the building's lifespan.
2. Building geometry and orientation have a major impact on the performance overall.
3. The total comfort hours and the total building operation energy do not have a great variation in this study.
4. Smart renovation can reduce the usage of building operation energy and discomfort caused by climate change but it is limited.
5. The challenge for indoor comfort brought by climate change is the overheating hours.
6. The rising cooling demand and the declining heating demand in the living environment are expected in a near future.

REFLECTION

1. The study of building performance in **future climate conditions** should be used as a **reference in the design phases.**
2. To improve this research the **following steps** can be finer define the building design, **shading, and partition walls for example.**
3. With sufficient weather data, this research can be built as a **climate generator tool.**
4. The **uncertainty** of future weather conditions and the combination of different climate files make the workload very heavy and **computationally expensive.**

THANK YOU