Energy Space Layout

Designing space layout with optimised energy performance

Delft University of Technology

M.Sc. Building Technology

P5 - Sustainable Design Graduation Studio | AR3B025

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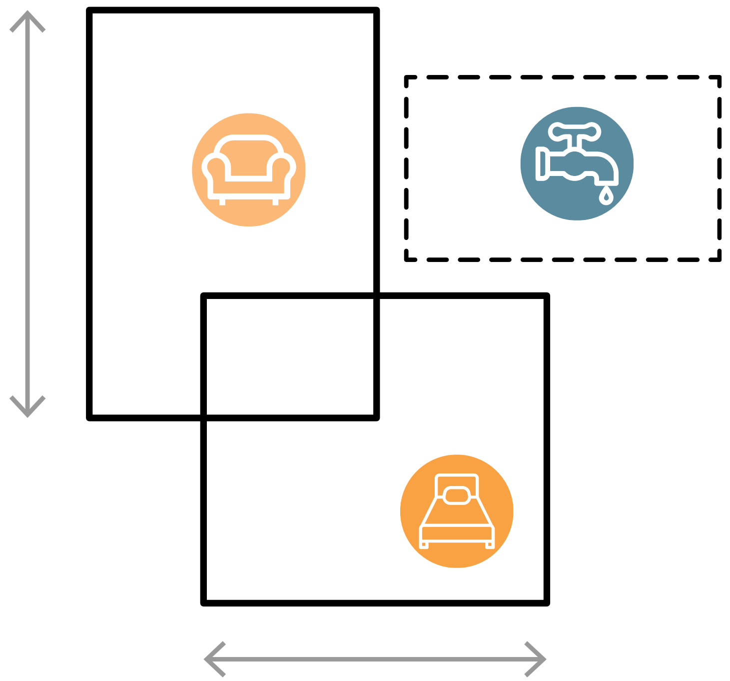
Supervisor: PhD. T.Du

Student: Andrea Fumagalli | 4736974

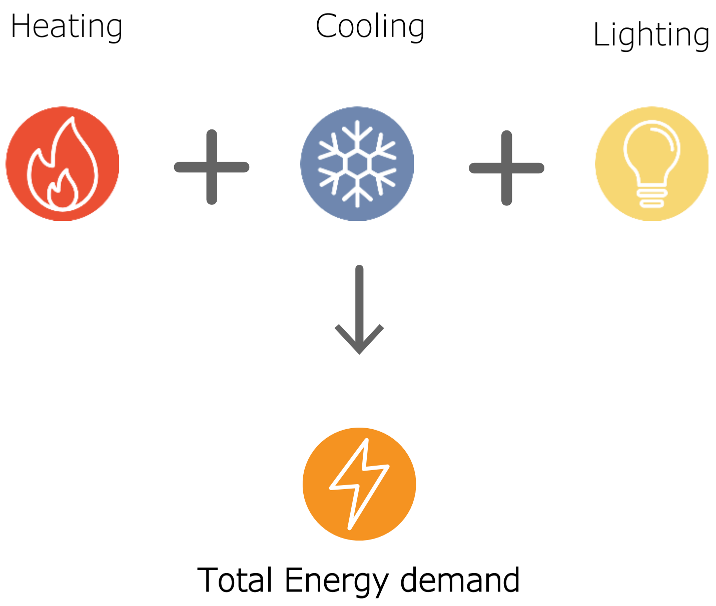
BACKGROUND

- **Space layout** is the spatial definition of the functions.



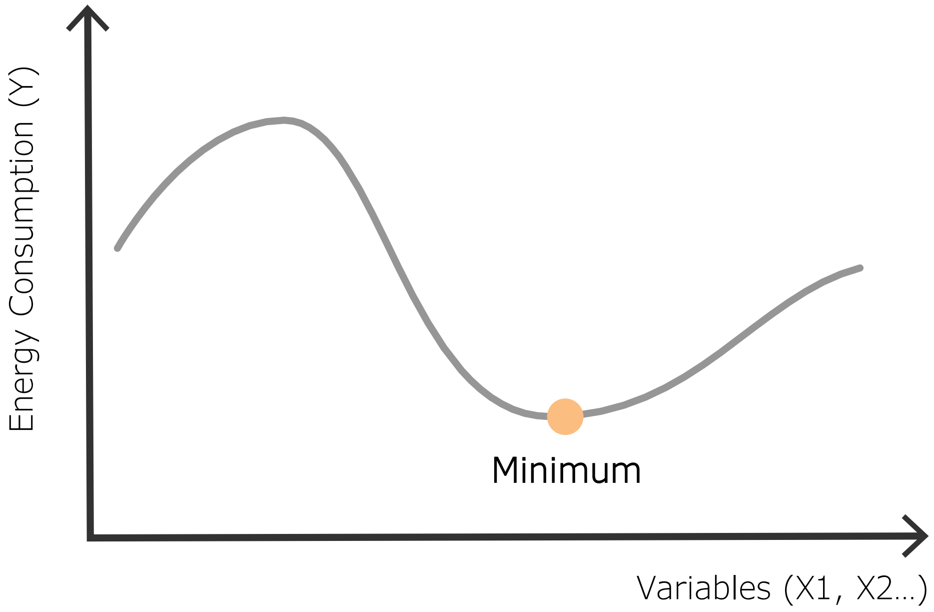
BACKGROUND

- **Space layout** is the spatial definition of the functions.
- **Energy Performance** identifies the building consumption for heating, cooling and lighting.



BACKGROUND

- **Space layout** is the spatial definition of the functions.
- **Energy Performance** identifies the building consumption for heating, cooling and lighting.
- **Optimisation** finds the best solution.



REASON \ Why?

Housing crisis for young people.

Need for energy-efficient buildings.

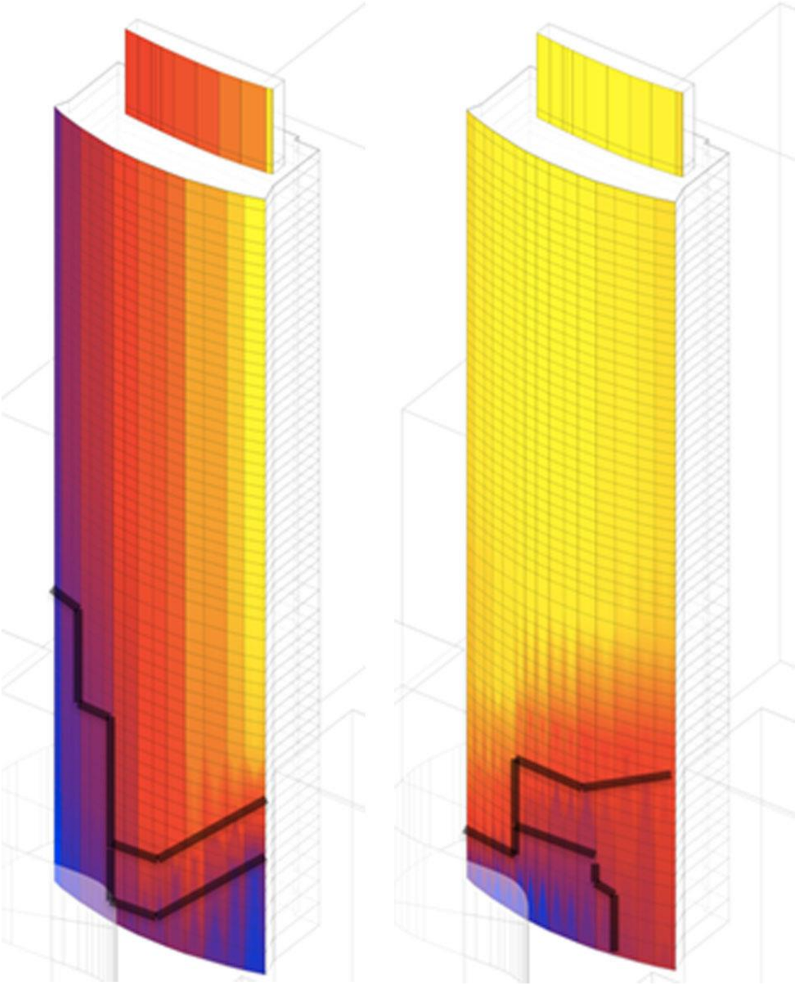
→ **Residence** for young professionals

FRAMEWORK \ How?

- **Performative Computational Architecture** (PCA) is a computational methodology that integrates the building performances into the design process. *(Sariyildiz, 2012)*

→ It effectively improves the final results.

→ **Gap** between space layout and energy optimisation.



(*Source:* glumac.com)

To what extent does space layout affect the energy demand of a co-living residence for young professionals in the Netherlands, with a computational method that makes the knowledge explicit and available for further projects?

Where should we locate the functions (bathroom, kitchen..)?

How deep should the rooms be?

Which dimensions should the windows have?

PROCESS

Problem Statement

PROCESS

Problem Statement

Digital workflow

PROCESS

Problem Statement

Digital workflow

Data Analysis

PROCESS

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Digital workflow

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Design Proposal

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Conclusions

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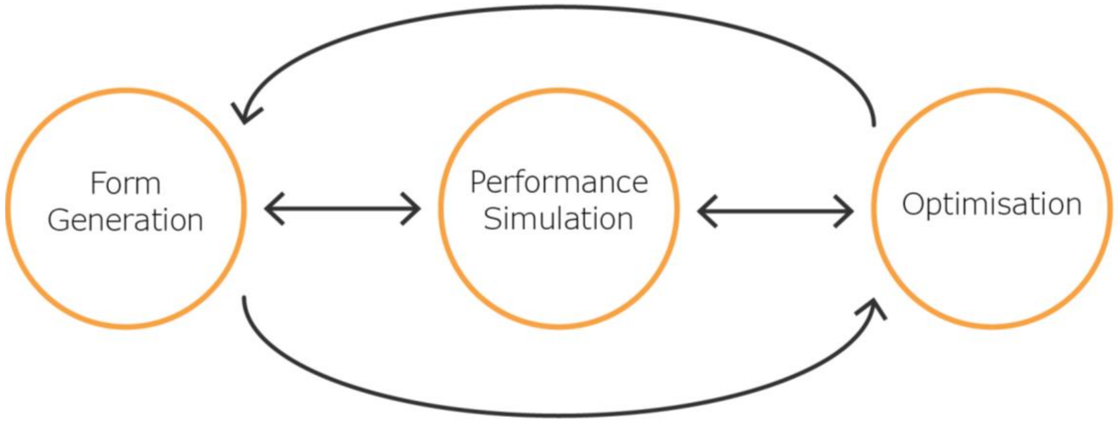
Setting the **process** for the optimisation

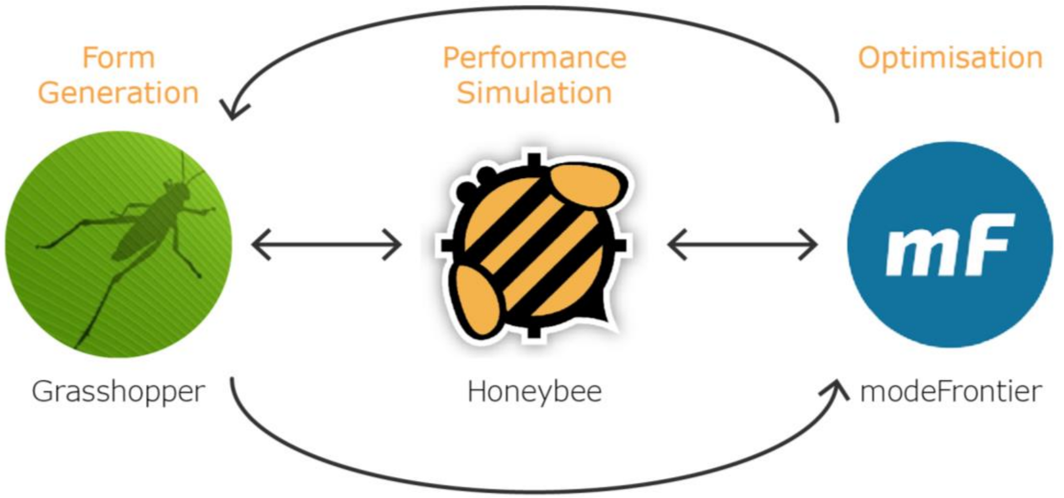
PCA FRAMEWORK

- 3 iterative steps



PCA FRAMEWORK

- 3 iterative steps
- 3 different programs

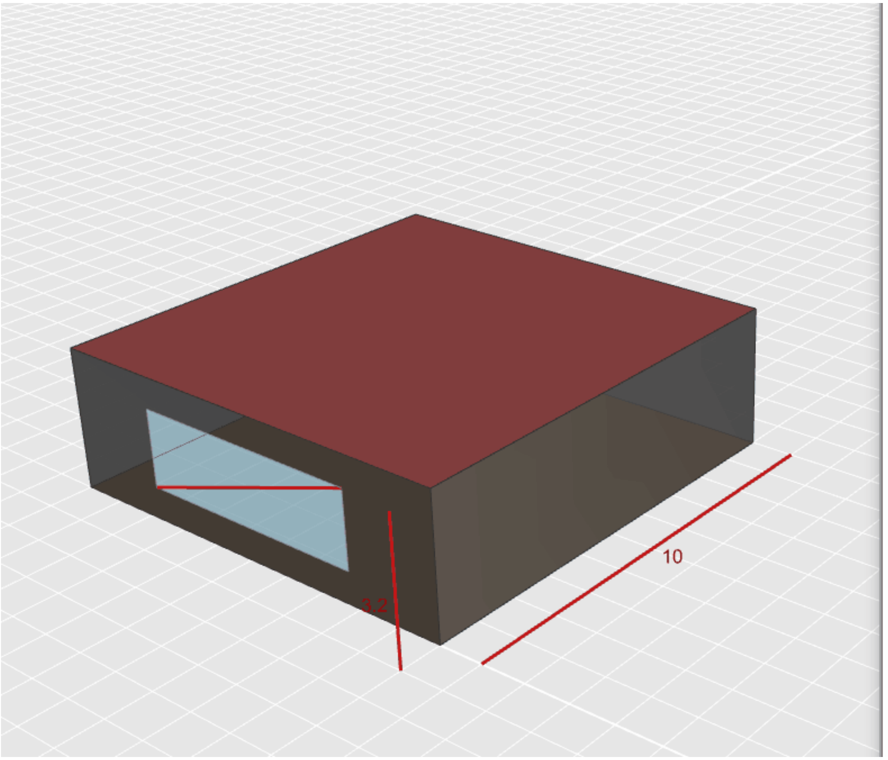


PCA FRAMEWORK

- 3 iterative steps
- 3 different programs
- It is based on a **digital model** with design variables

↓

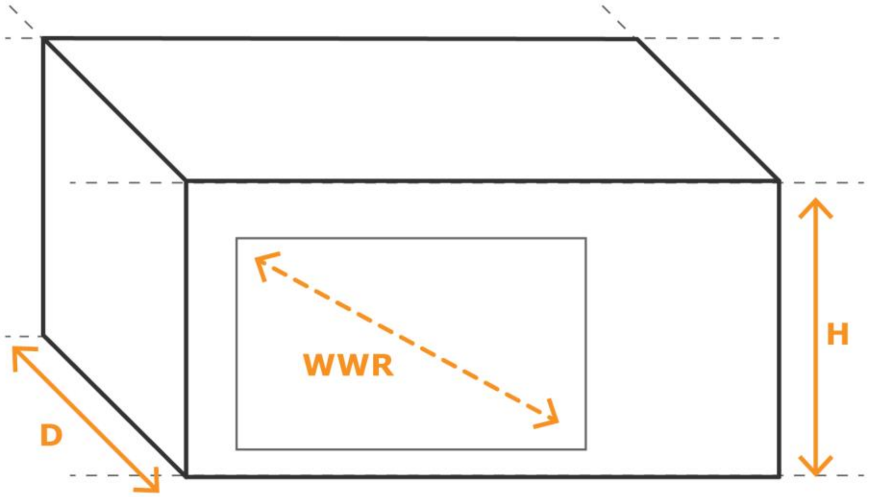
Define all possible solutions



VARIABLES

- **Spatial Parameters**

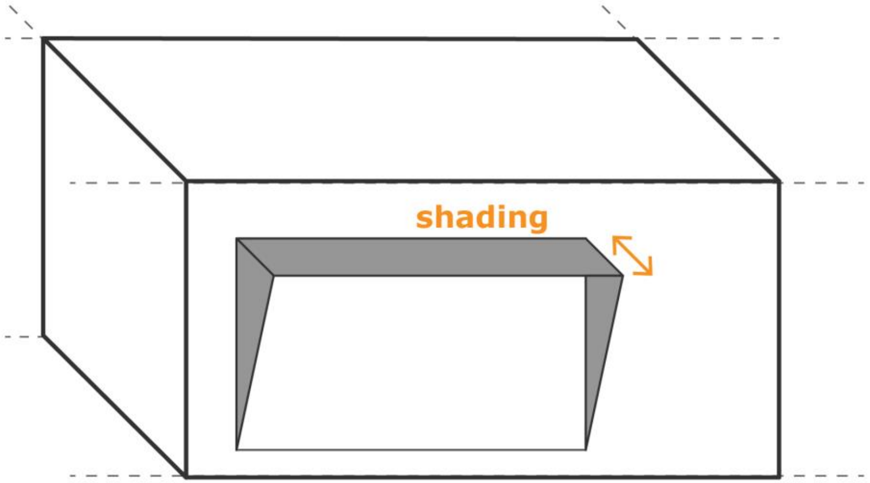
Height (3-4.5m) / Depth (6-8m) / WWR (20-60%)



VARIABLES

- Spatial Parameters
- **Shading**

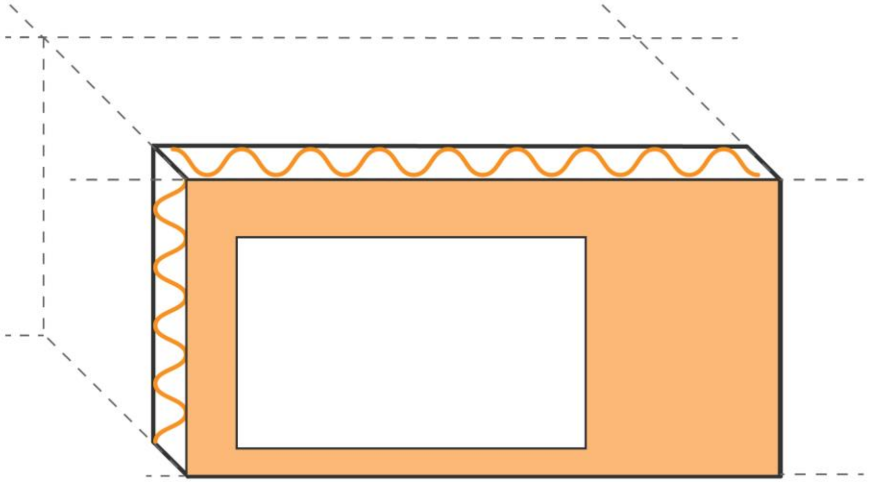
Overhang (0-2m)



VARIABLES

- Spatial Parameters
- Shading
- **Façade insulation**

POOR / BASIC / EXCELLENT (*Bouwbesluit, 2012)*

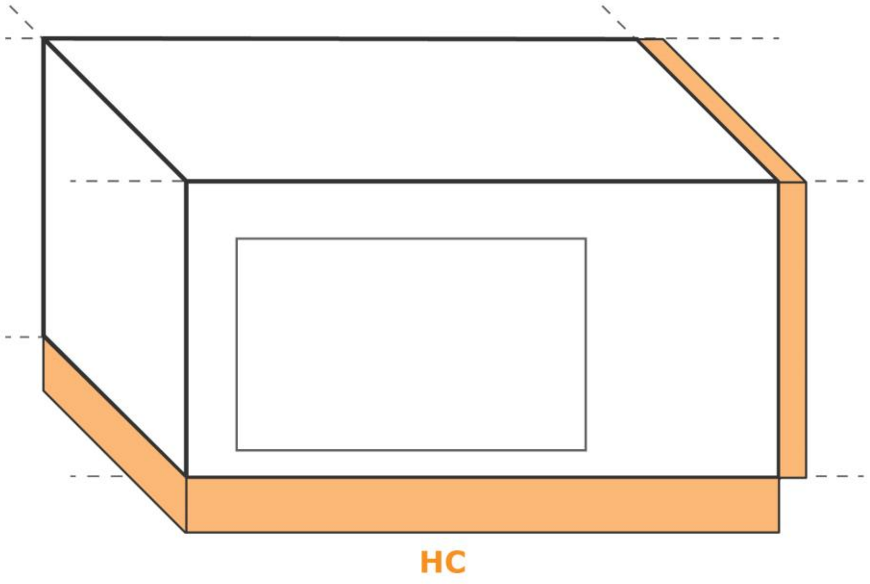


The better ⇧ ⇩ The less heat

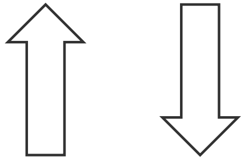
VARIABLES \ Properties of the model controlled by a parameter

- Spatial Parameters
- Shading
- Façade insulation
- **Thermal mass**

LIGHT / MEDIUM / HIGH



The heavier



The slower

VARIABLES

- Spatial Parameters
- Shading
- Façade insulation
- Thermal mass
- **Functions**

Bedrooms

Corridor

Living room

Bathroom

Kitchen

Indoor Gardens

Workspace

Laundry

VARIABLES

- Spatial Parameters
- Shading
- Façade insulation
- Thermal mass
- **Functions**

Bedrooms

Corridor

Living room

Bathroom

Kitchen

Indoor Gardens

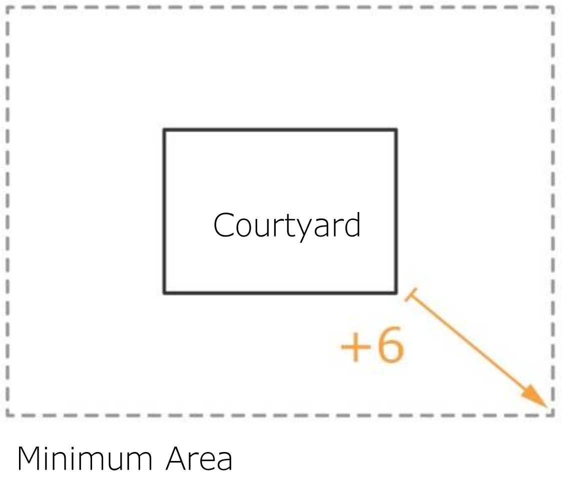
Workspace

Laundry

Indoor Gardens improve the quality of living and the thermal comfort with passive strategies.

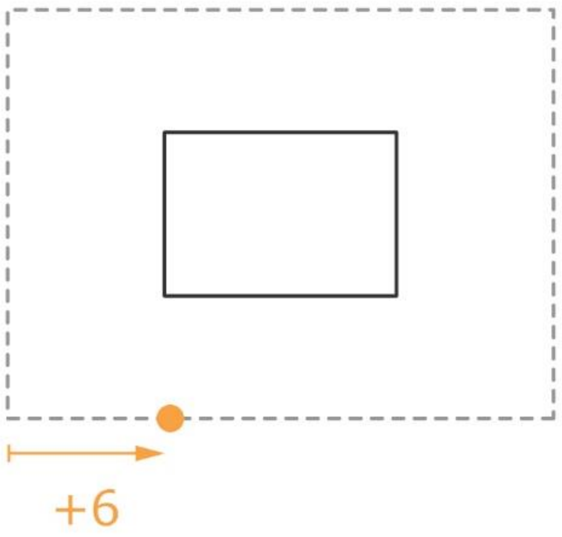
FORM GENERATION \ *How do we place the functions?*

1. Define the **courtyard** and **minimum area** (as reference)



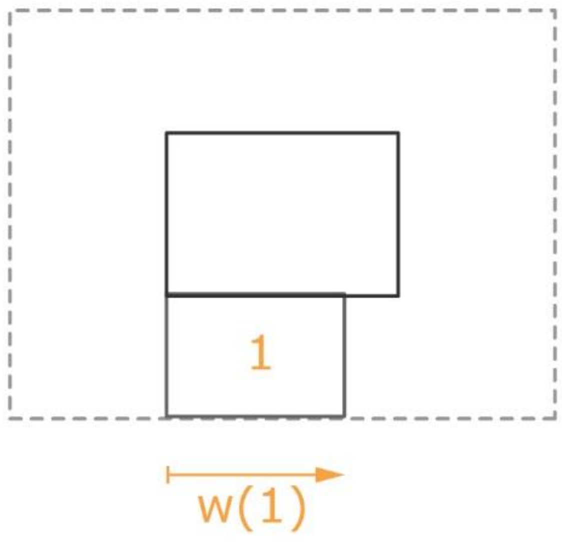
FORM GENERATION \ *How do we place the functions?*

1. Define the **courtyard** and **minimum area** (as reference)
2. The starting point



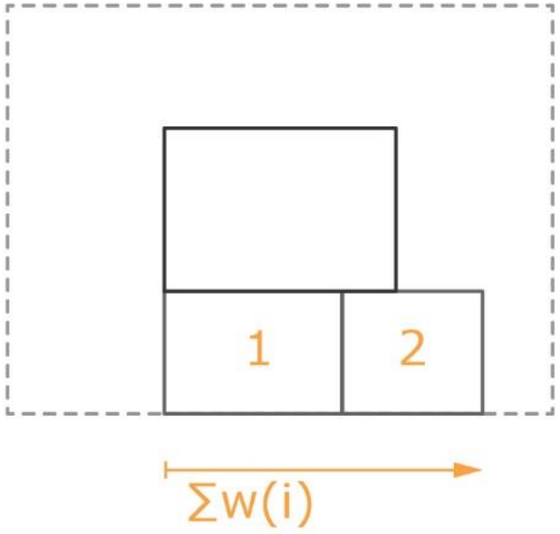
FORM GENERATION \ *How do we place the functions?*

1. Define the **courtyard** and **minimum area** (as reference)
2. The starting point
3. Locate the first function



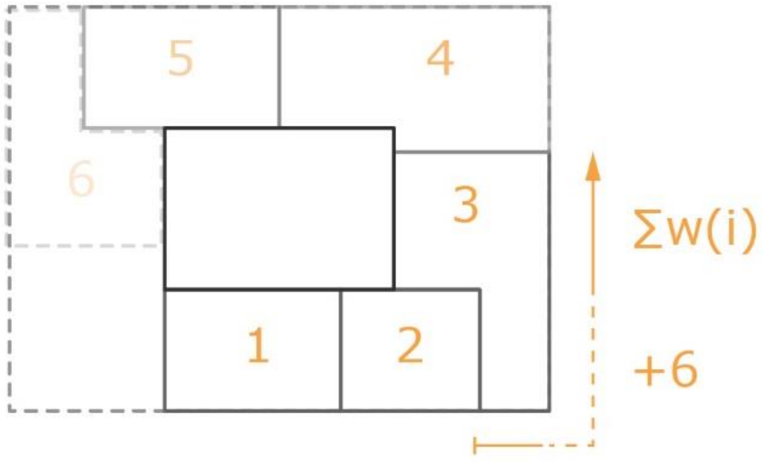
FORM GENERATION \ *How do we place the functions?*

1. Define the **courtyard** and **minimum area** (as reference)
2. The starting point
3. Locate the first function
4. Locate the second function successively



FORM GENERATION \ *How do we place the functions?*

1. Define the **courtyard** and **minimum area** (as reference)
2. The starting point
3. Locate the first function
4. Locate the second function successively
5. At each corner, jump to the next 6 meters



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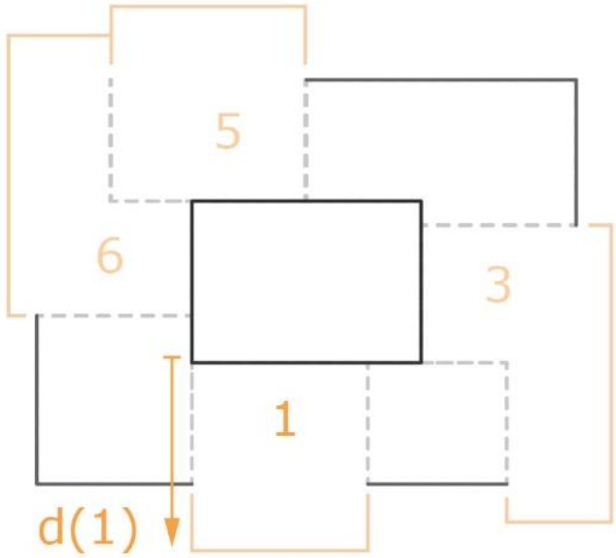
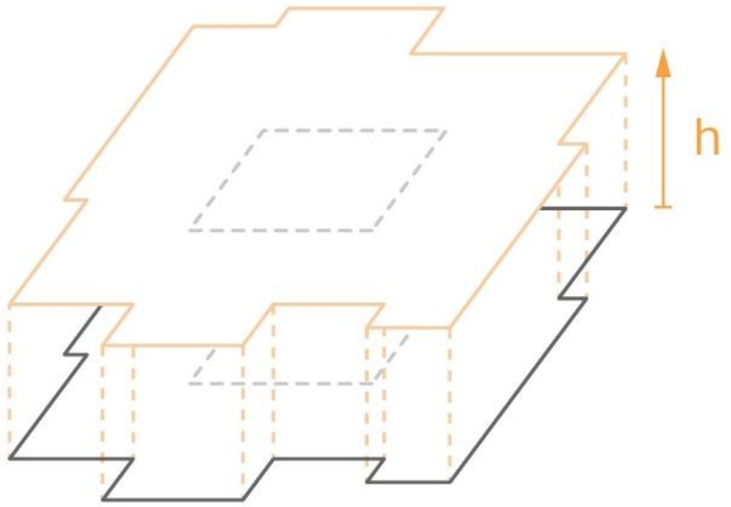
6. Extend the **depth** of each room (6-8 meters)



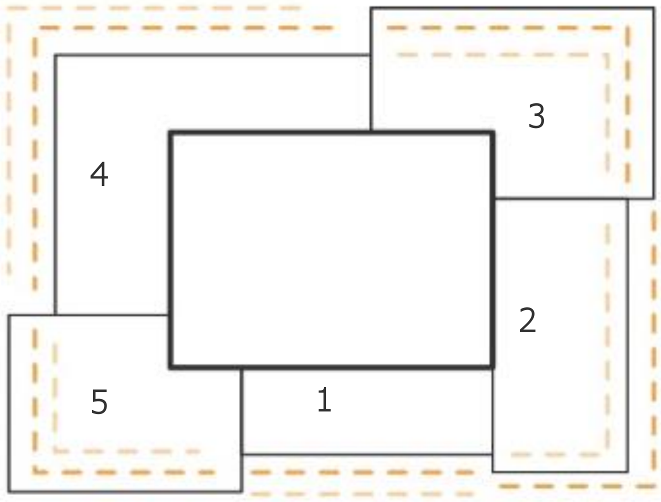
FORM GENERATION \ *How do we place the functions?*

1. Define the **courtyard** and **minimum area** (as reference)
2. The starting point
3. Locate the first function
4. Locate the second function successively
5. At each corner, jump to the next 6 meters
6. Extend the **depth** of each room (6-8 meters)
7. Extrude all surfaces to the **height** of the floor



FORM GENERATION

- The **courtyard** is constant to avoid its influence.
- **Depth** of each function is variable
- The function can change the **position** as a variable



ENERGY SIMULATION

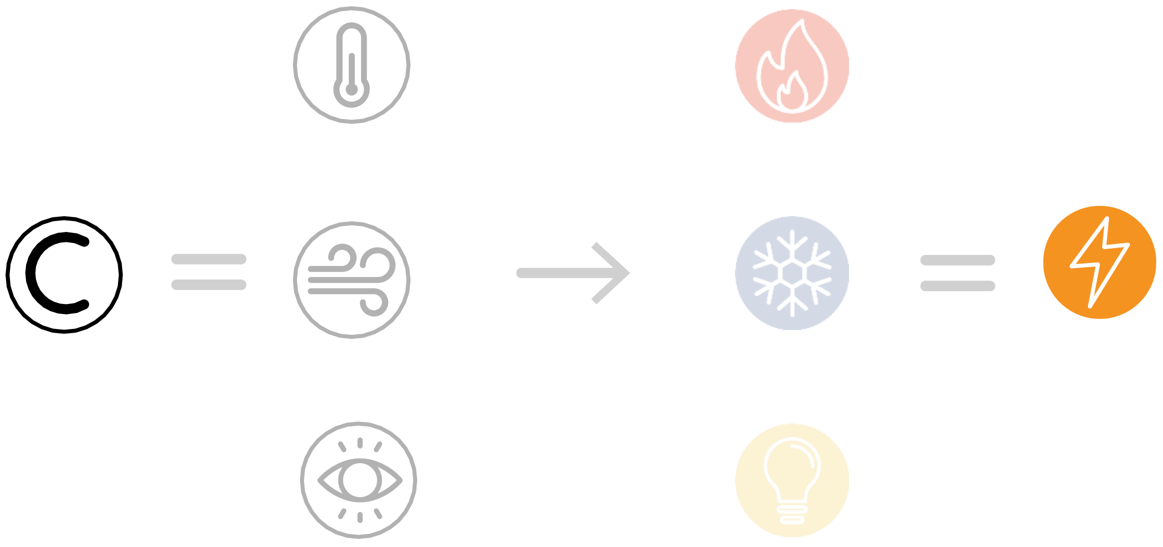
- Define the **comfort values** for each room:

  → temperature, air and light

- Simulate the building consumption for **heating, cooling** and **lighting**

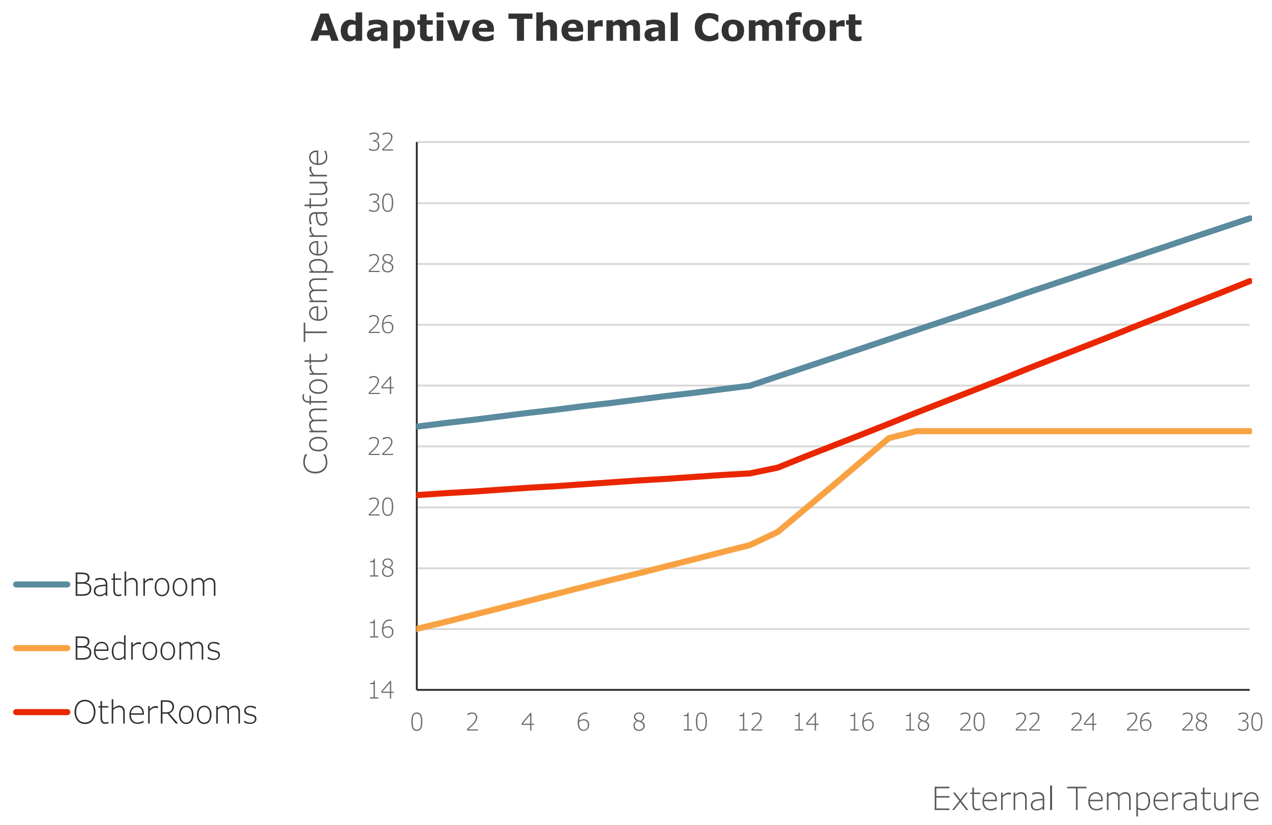
  → total energy demand

Comfort = Energy



ENERGY SIMULATION

- The **workspace** (500 lux) requires more light than the others.
- The **bedrooms** prefer cooler temperatures.
- The **bathroom** needs warmer temperatures.



OPTIMISATION

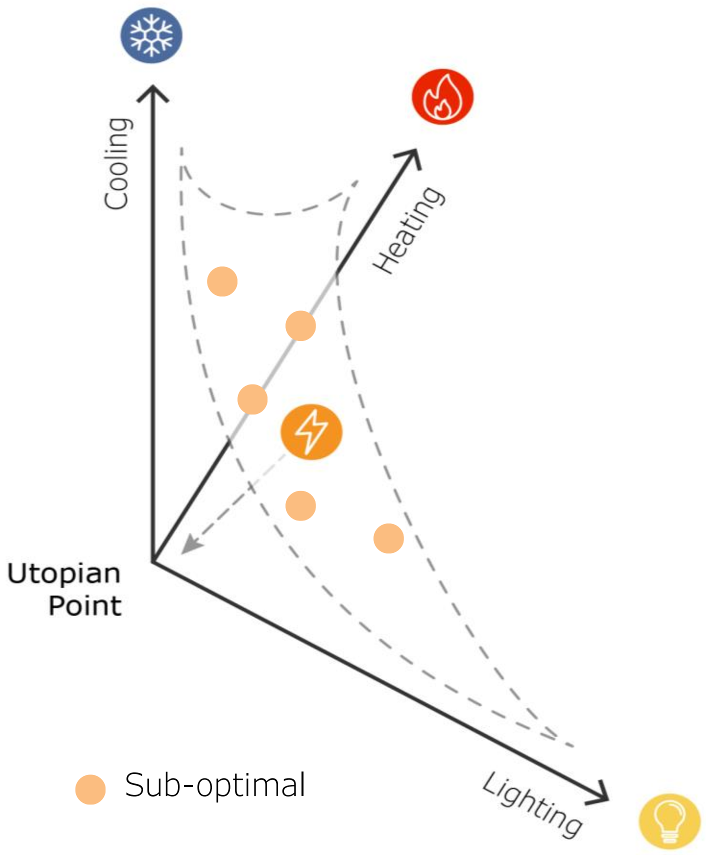
- Make use of an **algorithm** to find the best solutions for each objective:

  → Heating, Cooling and Lighting contemporary

- Interesting to find the **sub-optimal** solutions:

  → to understand the principles

  → to help the architect in making decisions



OPTIMISATION \ *It is not just pressing a button!*

It is similar to picking blueberries in the forest:

- Explore the forest in different spots
- Taste
- Go back

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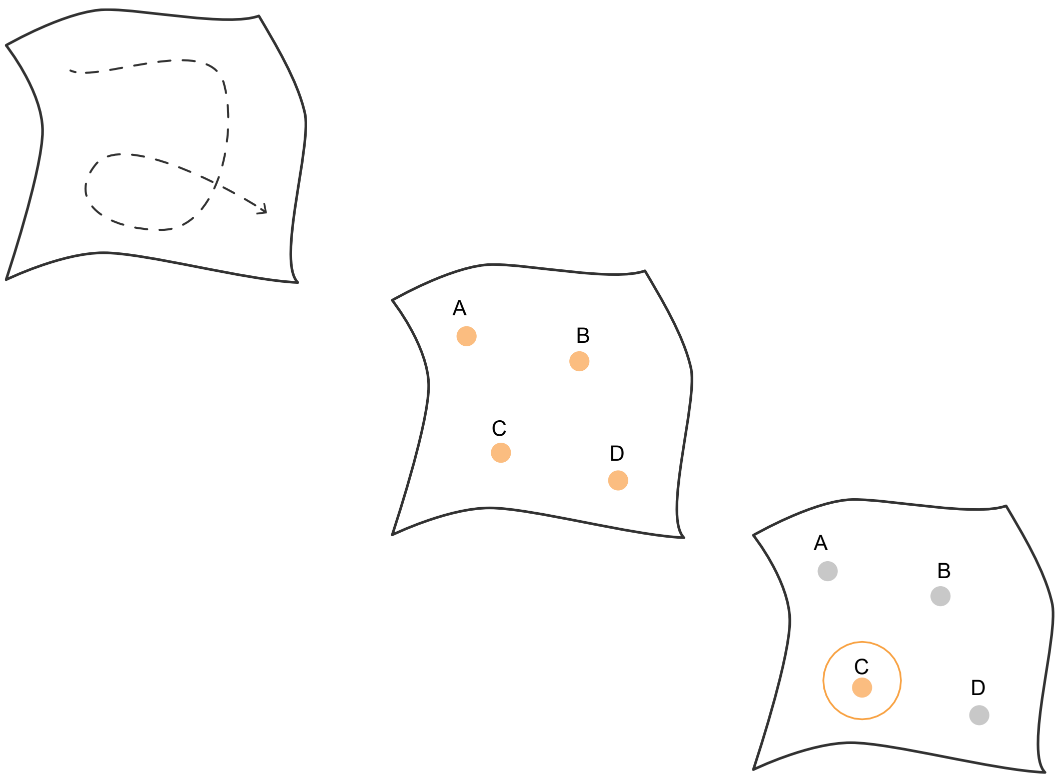


- **Train** the algorithm to explore the *solution space*
- **Analyse** the samples → draw generic insights
- **Refine** the algorithm to focus specifically

Problem Statement

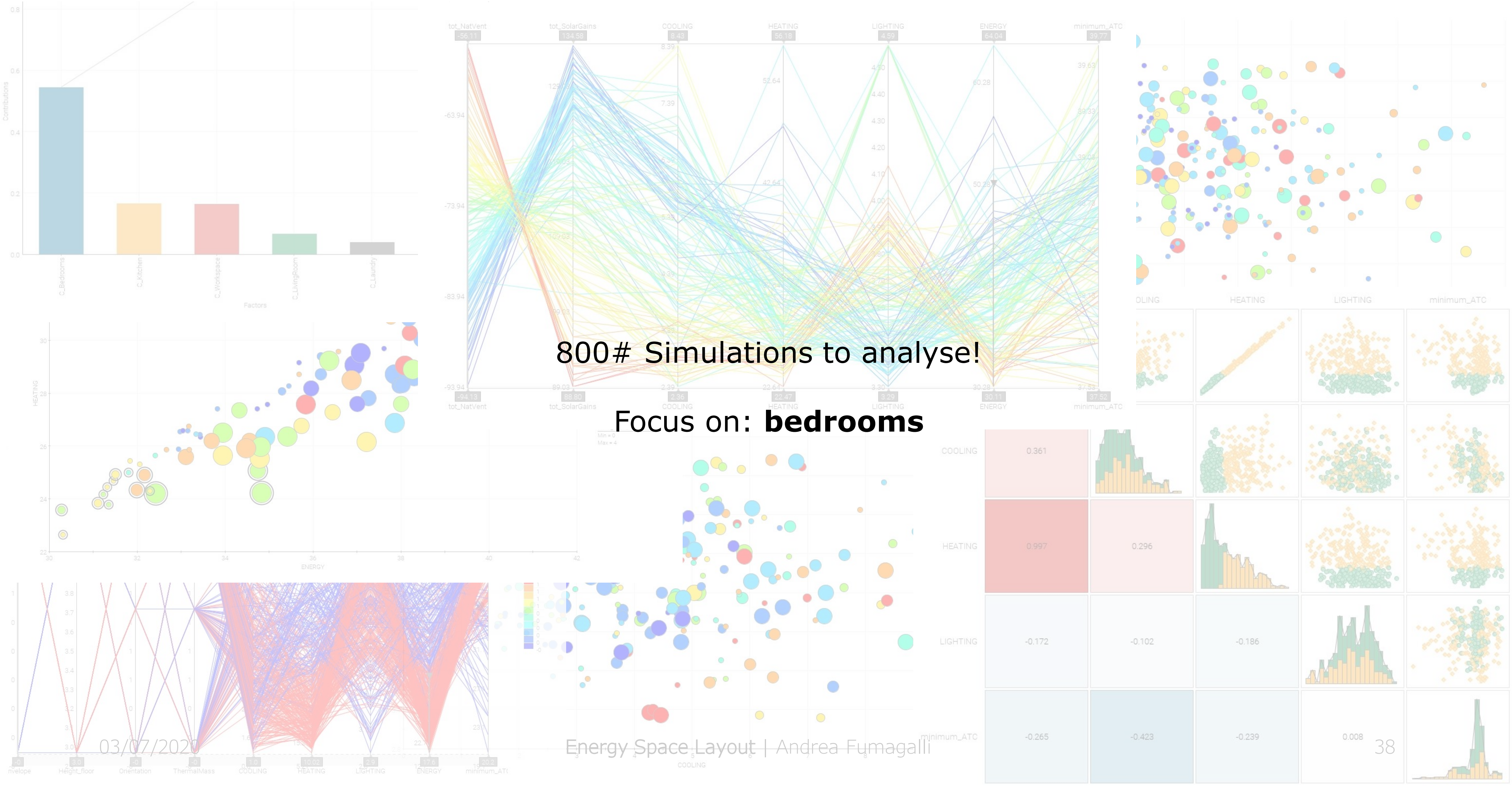
Digital Workflow

Data Analysis

Design Proposal

Conclusions

Understanding
the **trends** and
the **principles**



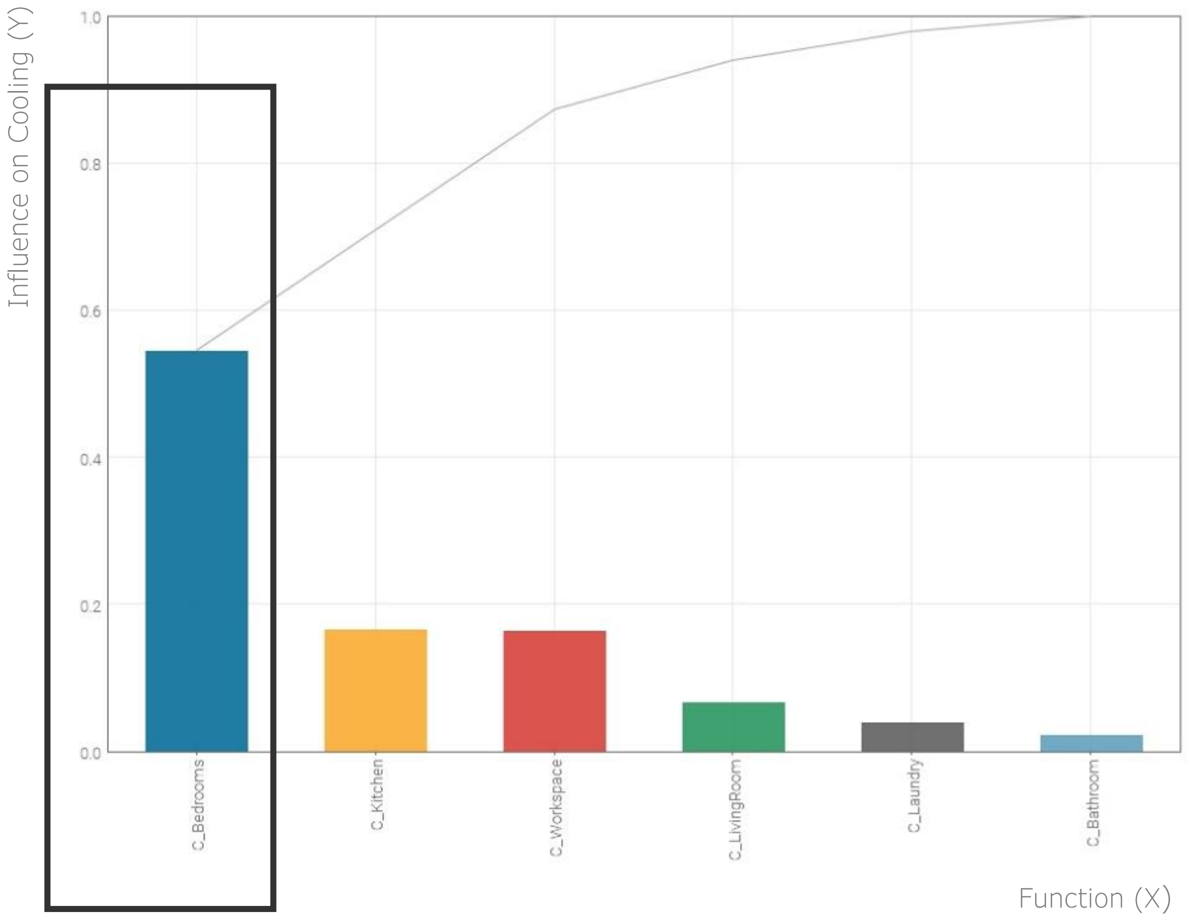
800# Simulations to analyse!

Focus on: **bedrooms**

BEDROOMS

Major impact on cooling

→They require cooler temperatures

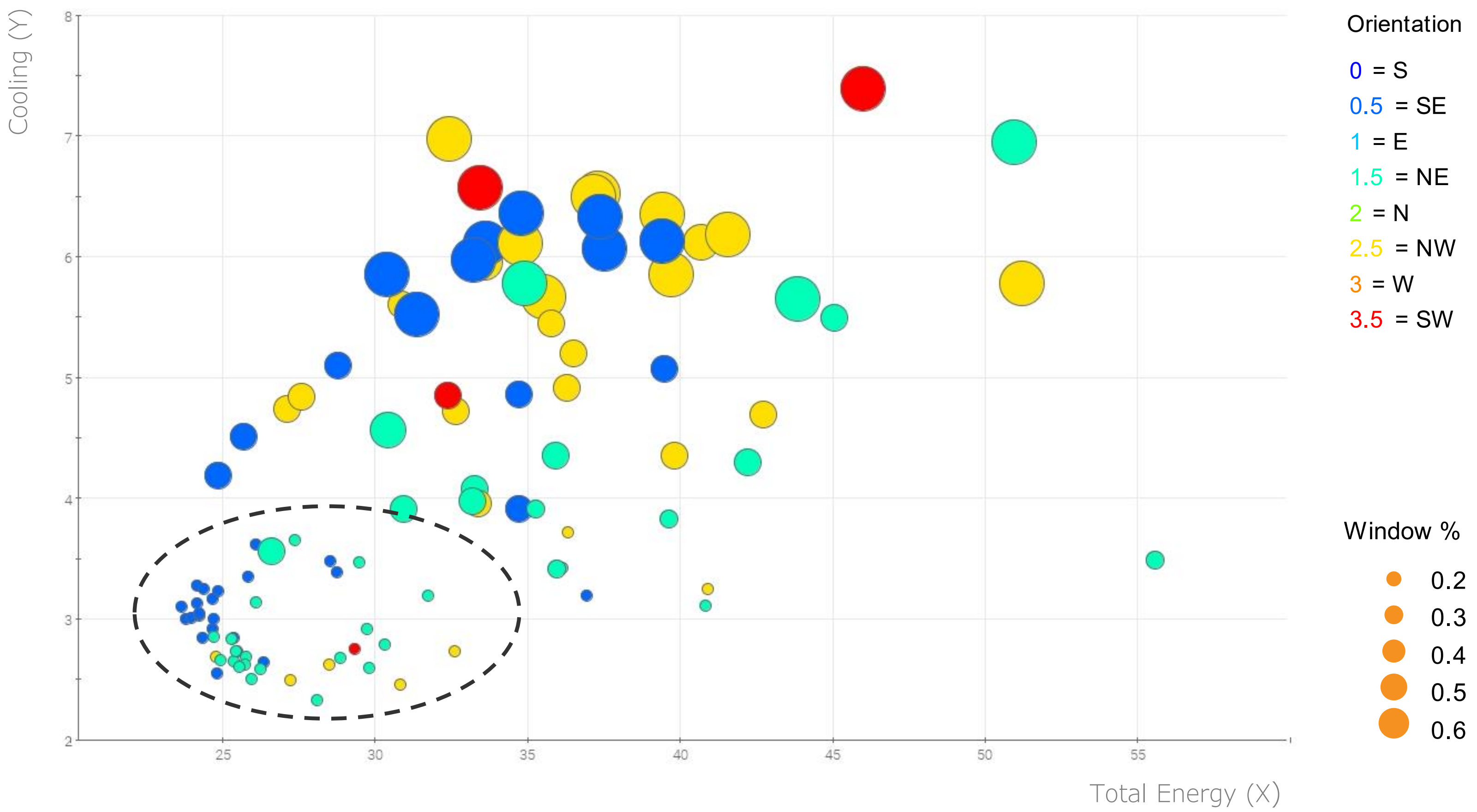


BEDROOMS

Major impact on cooling

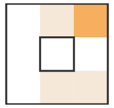
To avoid overheating

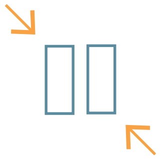
To reduce solar radiation



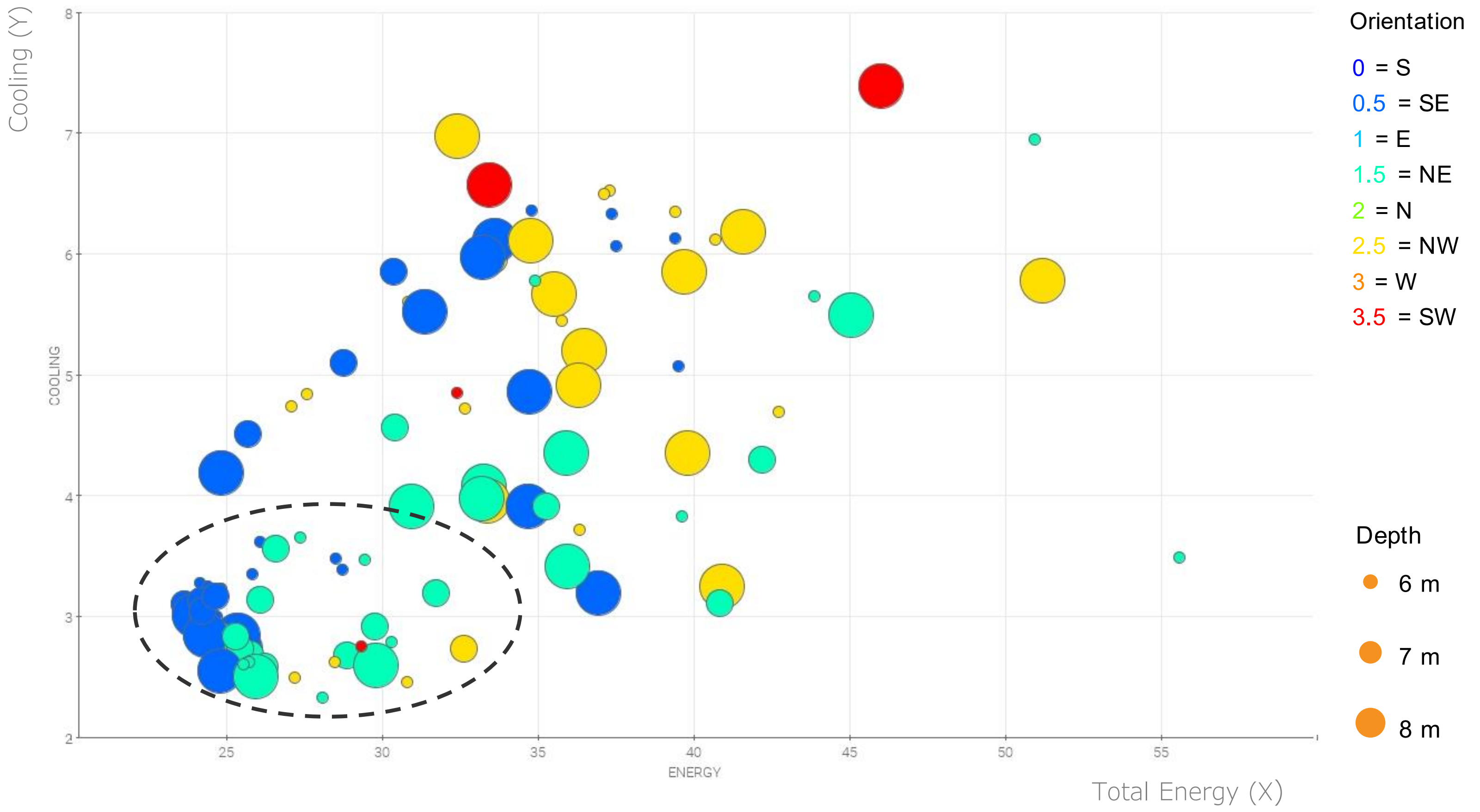
BEDROOMS

Major impact on cooling





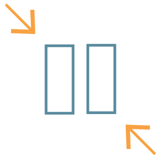
To reduce the area exposed



GUIDELINES \ Cooling

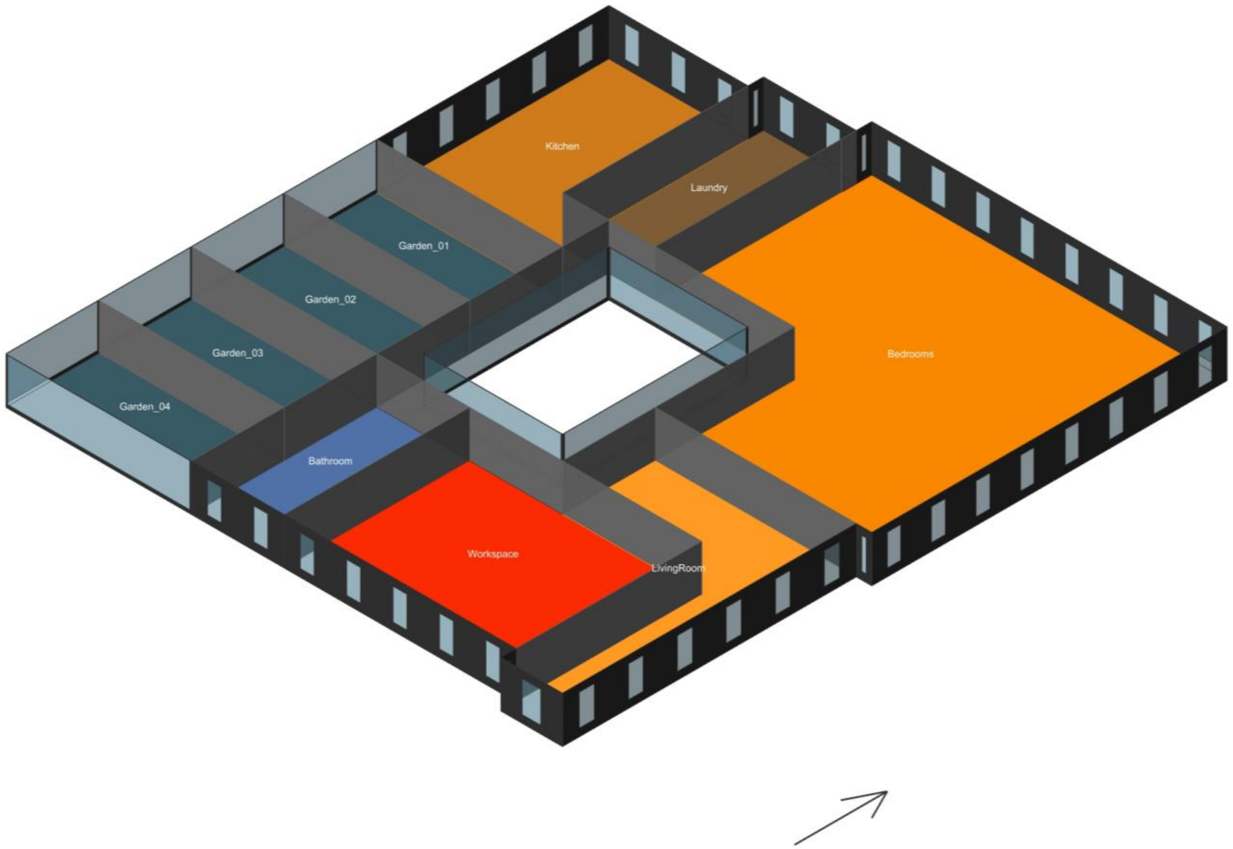
Aim Avoid overeating

Depths 

Windows 

Sensitive Function  NE

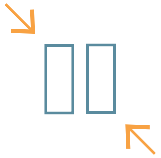
Energy Savings **-52%**



GUIDELINES \ Heating

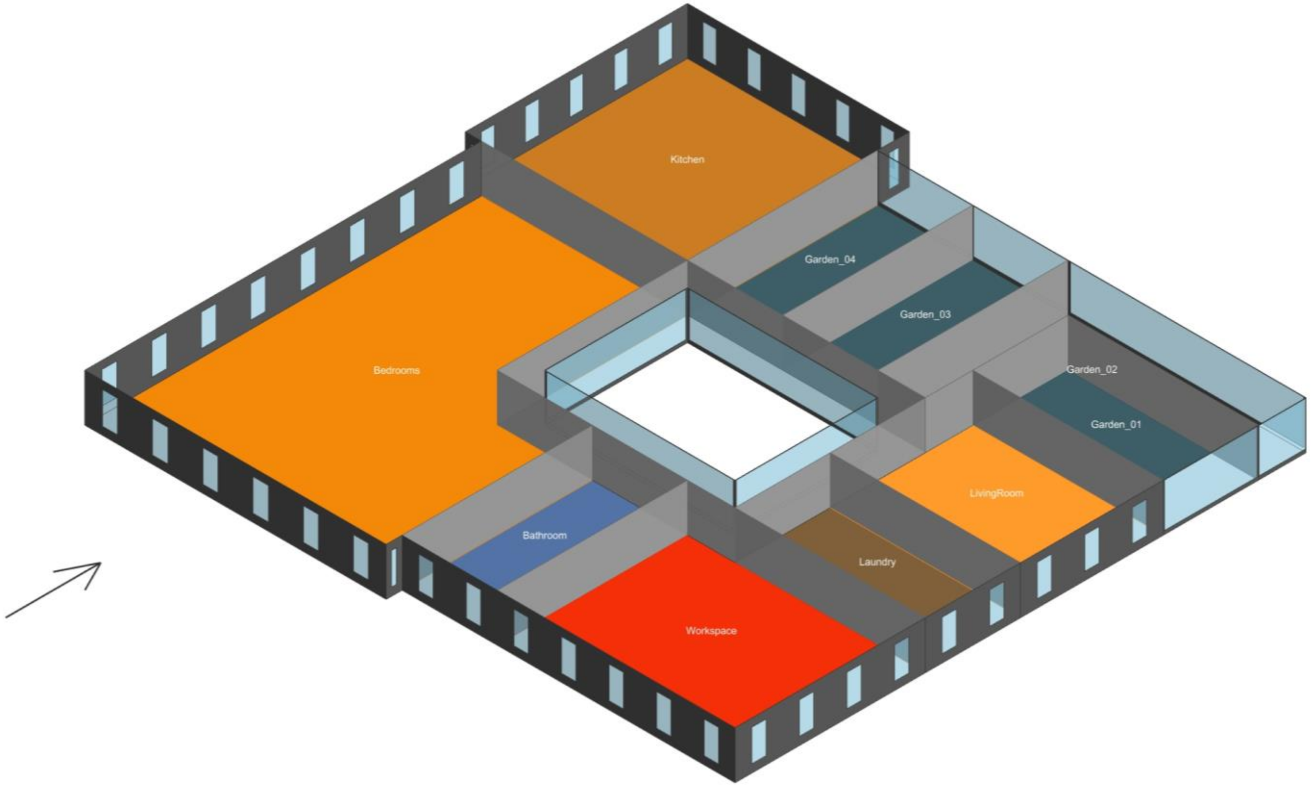
Aim Keep warm inside

Depths 

Windows 

Sensitive Function  S

Energy Savings **-55%**

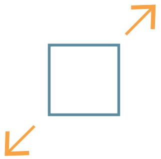


GUIDELINES \ Lighting

Aim Improve daylight

Depths

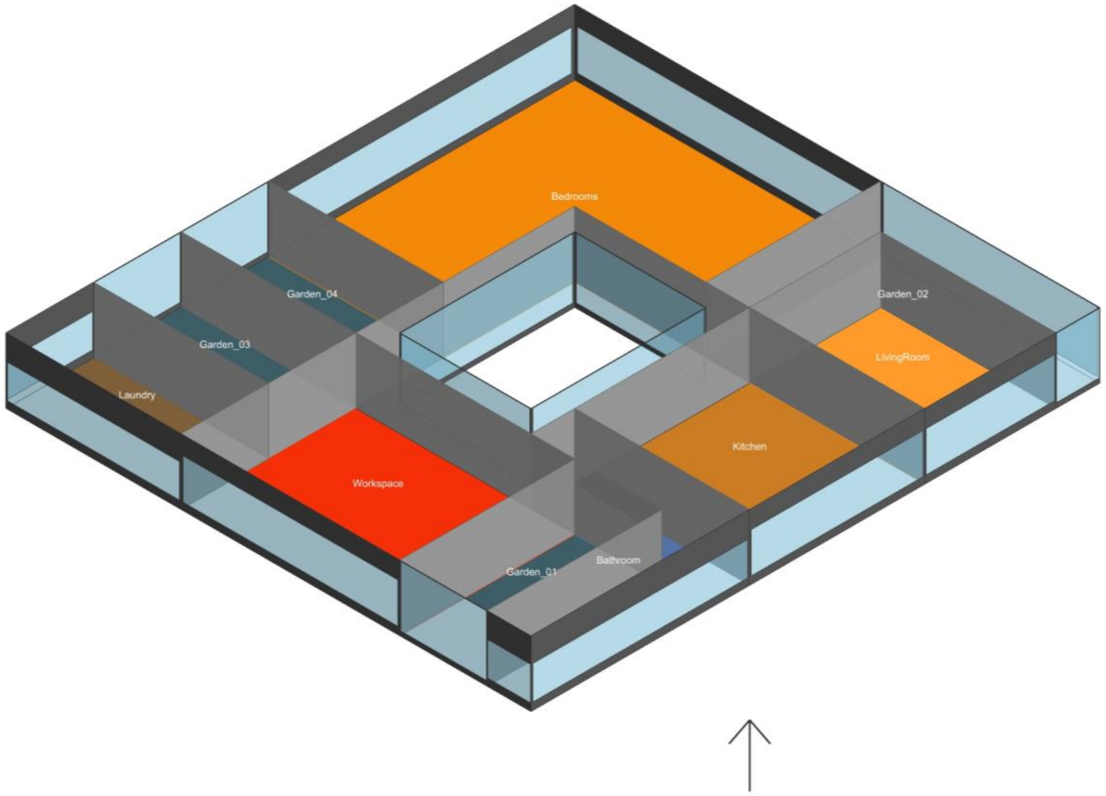
Windows



Sensitive Function

SW

Energy Savings **-37%**



Problem Statement

Digital Workflow

Data Analysis

Design Proposal

Conclusions

Evaluating the guidelines and the workflow

CASE STUDY

- **Building case study**: *Solids 11,* Amsterdam

  →it fits the building typology

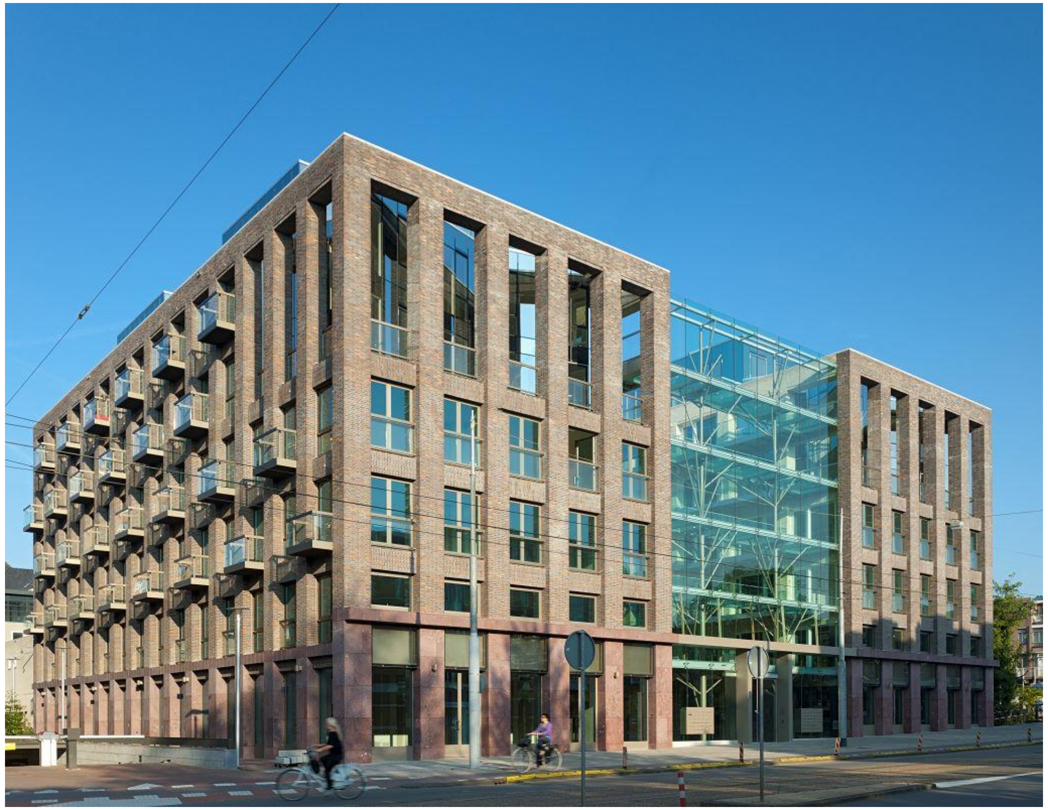
- Add **design criteria**

  → visual quality

  → proximity

  → functionalism

- Select **3rd Floor**

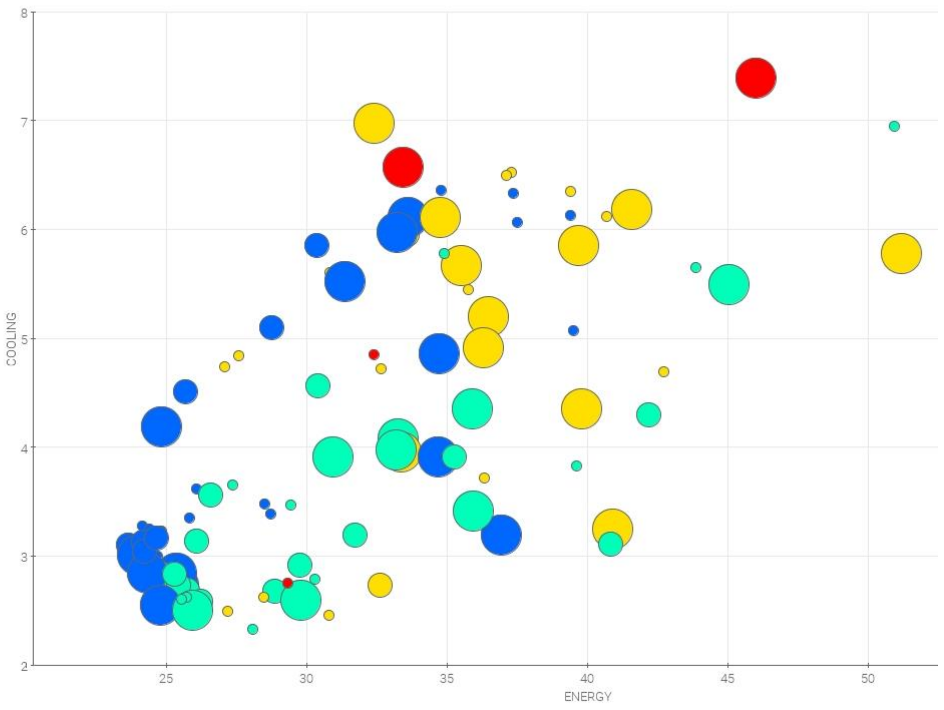


(Source: www.archdaily.com/)

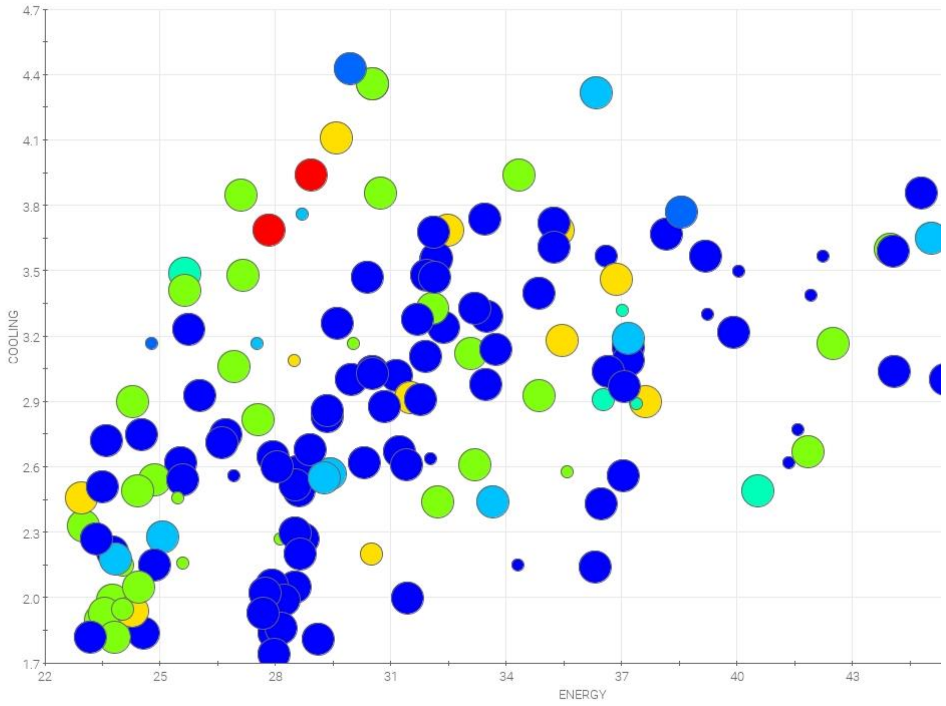
OPTIMISATION

\ The orientation are different

Generic model



Case study



Orientation

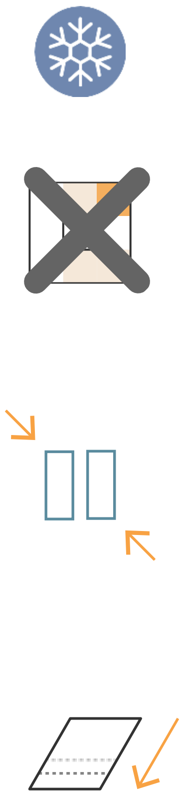
- 0 = S
- 0.5 = SE
- 1 = E
- 1.5 = NE
- 2 = N
- 2.5 = NW
- 3 = W
- 3.5 = SW

Depth

- 6 m
- 7 m
- 8 m

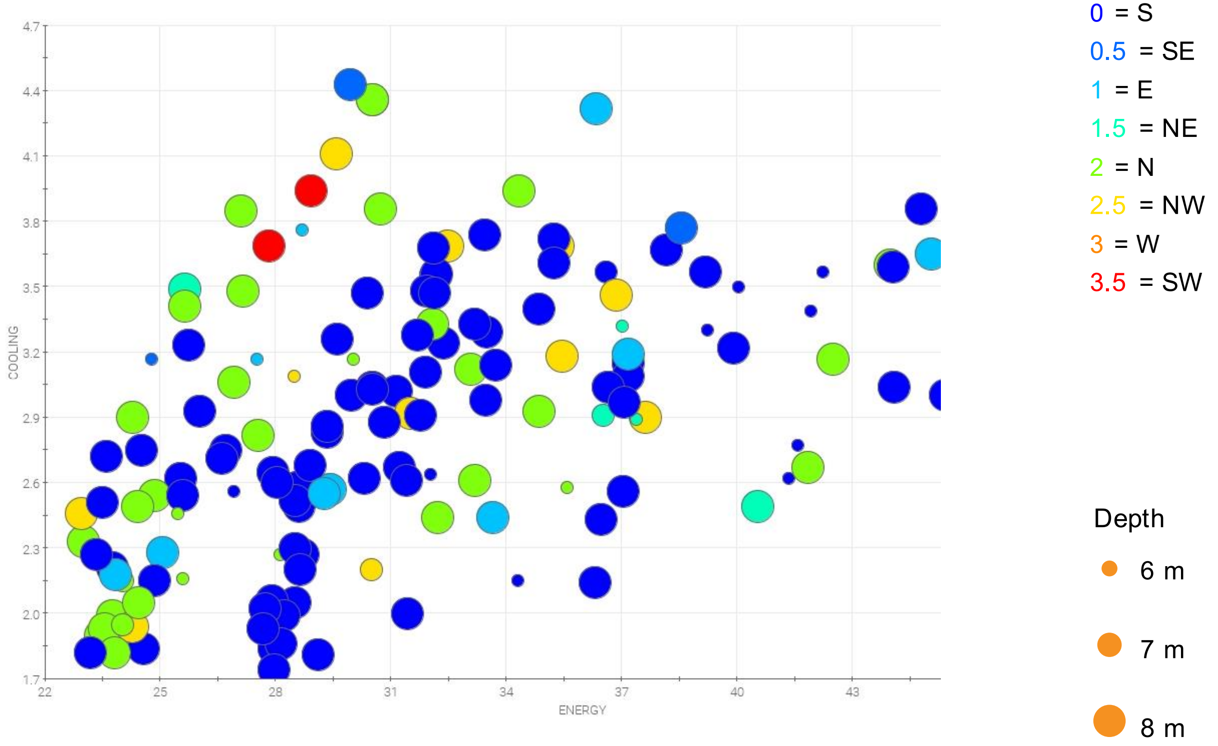
Additional criteria to include

OPTIMISATION



- **Results** are not directly applicable
- The **energy-efficient principles** are valid
- The **model** is flexible to adapt

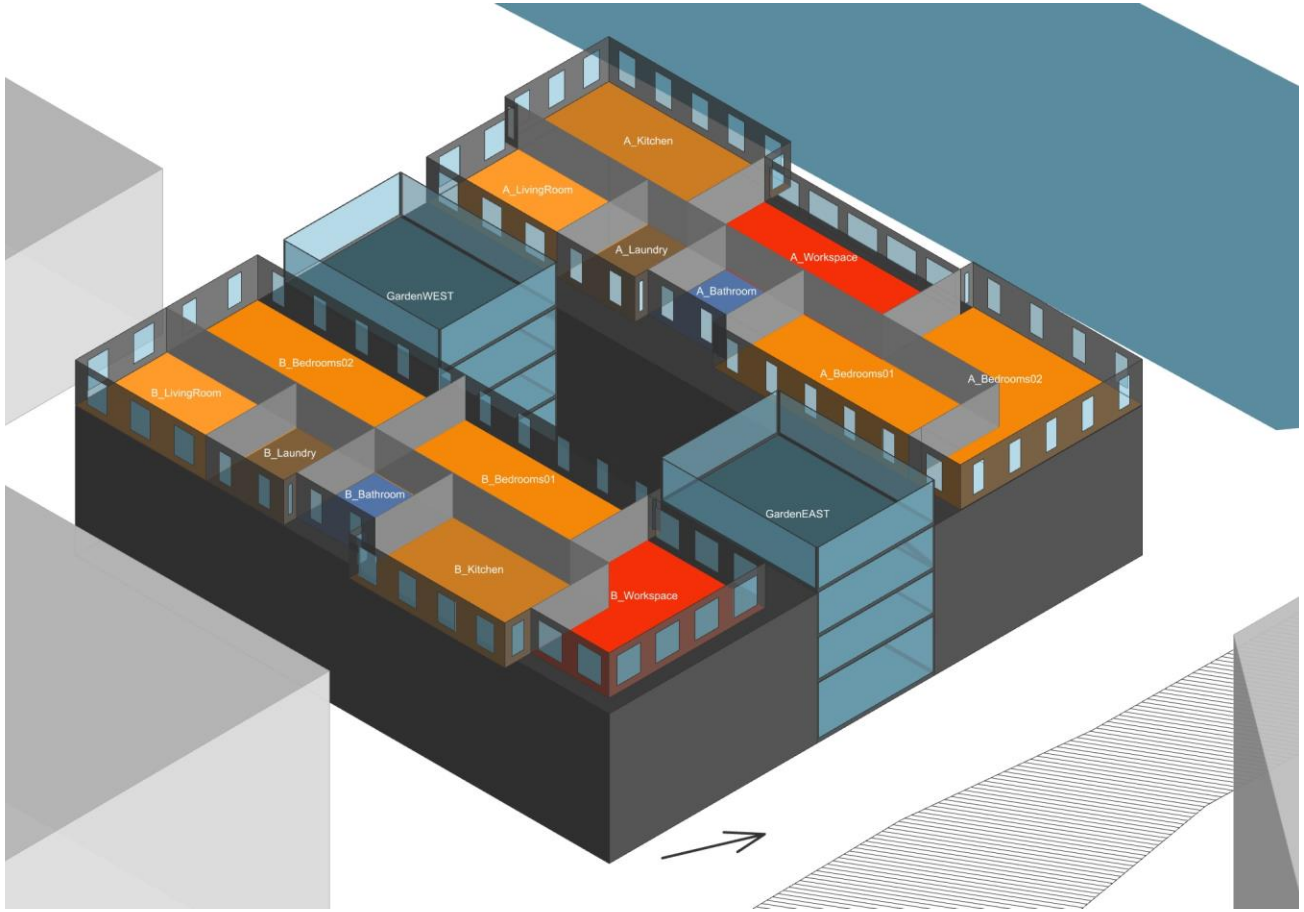
Case study



PROPOSAL

Schematic layout to meet both design and energy criteria:

- Gardens
- Workspaces
- Bedrooms
- Low energy demand



PROPOSAL

Schematic layout to meet both design and energy criteria:

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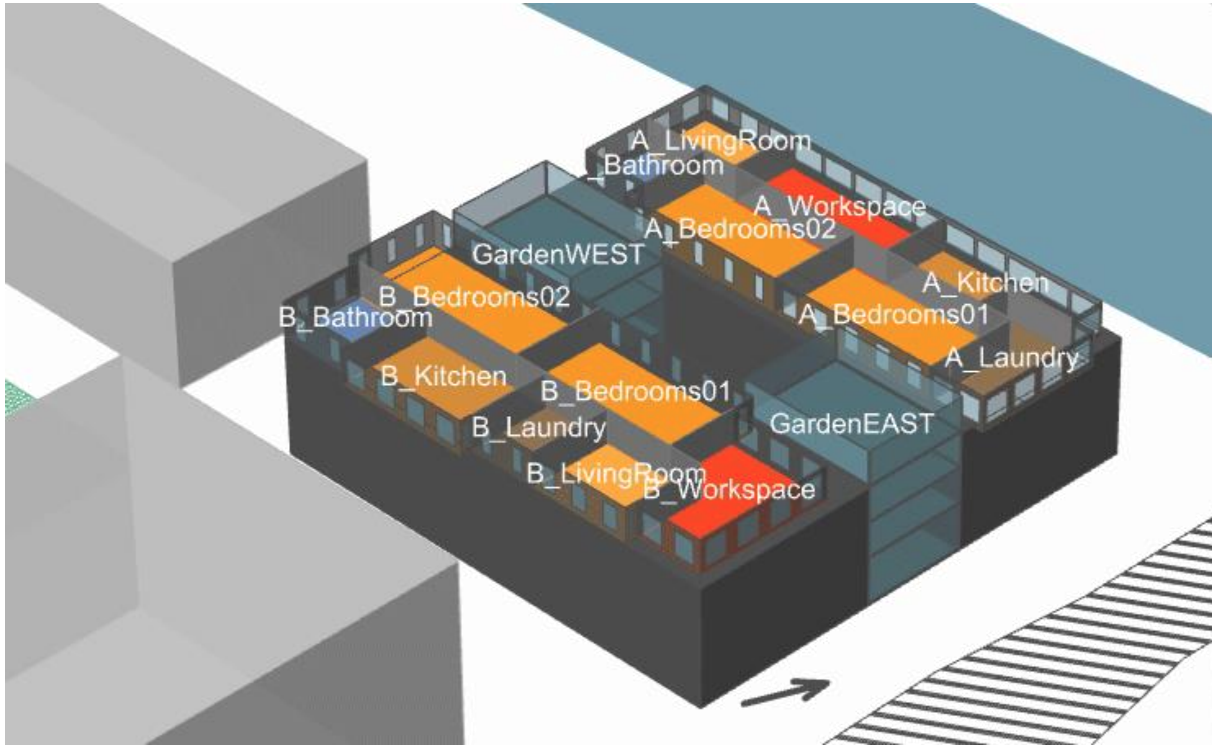
Sub-optimal solutions help in making decisions



PROPOSAL

External view of the 3rd floor

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" To what extent does space layout design affect the energy demand of a co-living residence for young professionals in the Netherlands, within a computational method that makes the knowledge explicit and available for further projects? "

- Different functions play **the leading role** for different objectives.

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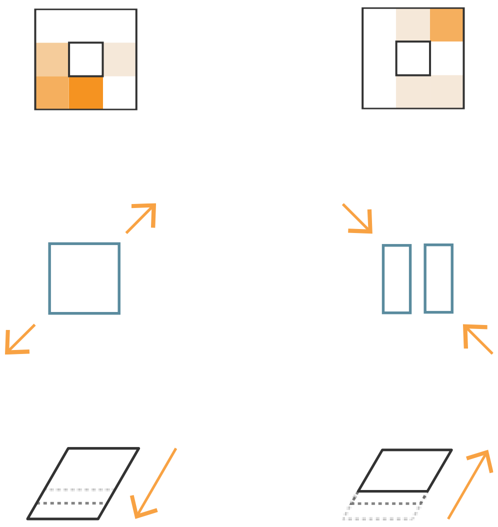
- Windows and depths of the functions should be planed to meet the **energy and comfort requirements.**



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- Different functions play **the leading role** for different objectives.
- Windows and depths of the functions should be planed to meet the **energy and comfort requirements.**
- In shallow buildings, energy-optimised configurations are effective in **saving energy**.

-52% **-55%** **-37%**

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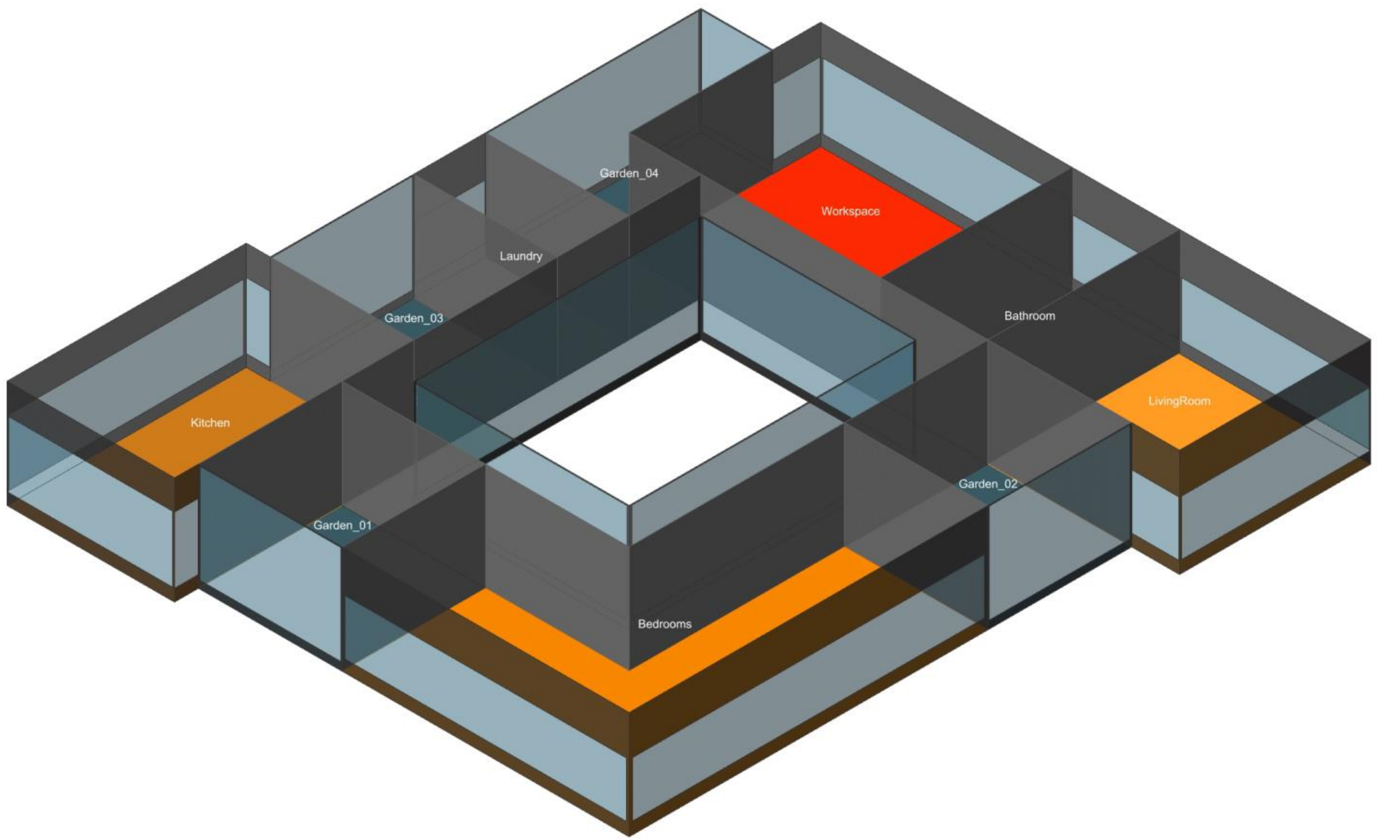
- Different functions play **the leading role** for different objectives.
- Windows and depths of the functions should be planed to meet the **energy and comfort requirements.**
- In shallow buildings, energy-optimised configurations are effective in **saving energy**.
- The designer needs to translate the principles into **guidelines** or to develop a **site-specific optimisation**.


Garden_04
Workspace
Laundry
Garden_03
Bathroom
Kitchen
LivingRoom
Garden_02
Garden_01
Bedrooms

Master BT

Torneino

Michela

Amaldi

Martin

Delft

Zii

Tiantian

Mamma

Milano

Chiara

Thank you.

Papà

Stüttgart

Ale

Nonni

Nazza

Cugini

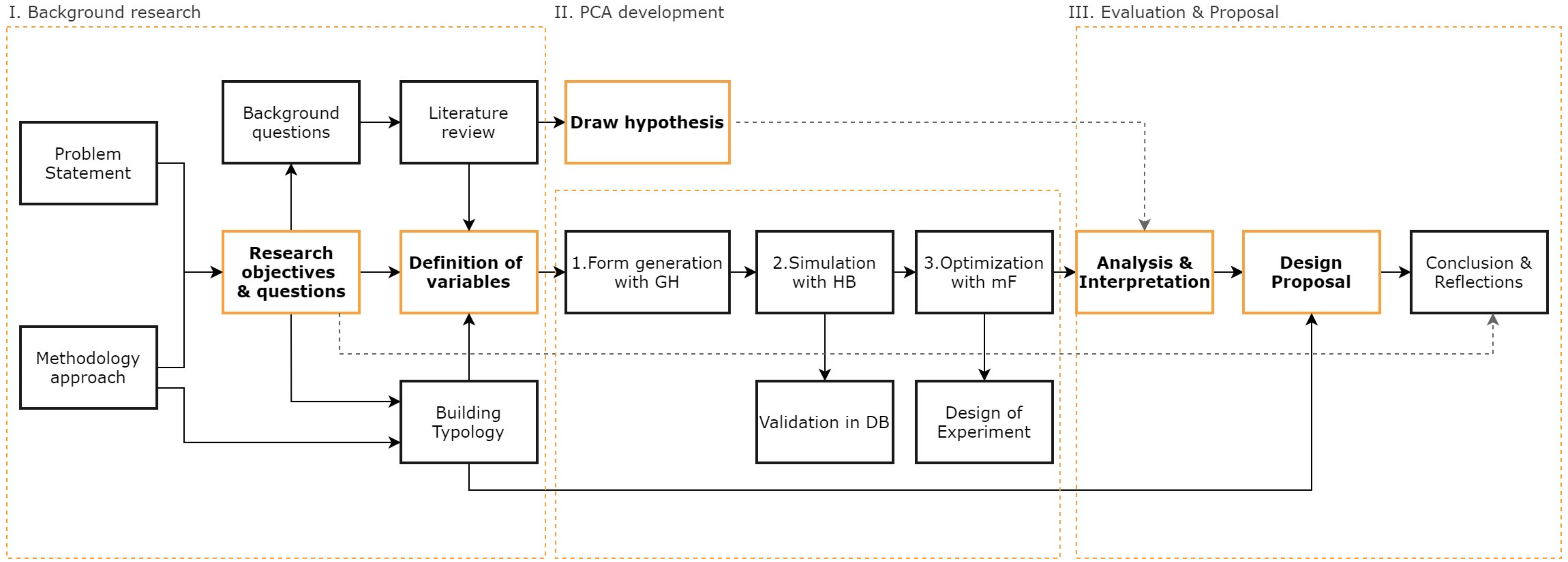
Zürich

Slopend

Bergamo

Earthy

METHODOLOGY



Performative Computational Architecture to set the process.

- support the design and extract the knowledge
- parametrisation process / exploration of solutions

Energy and comfort regulations to define the target values

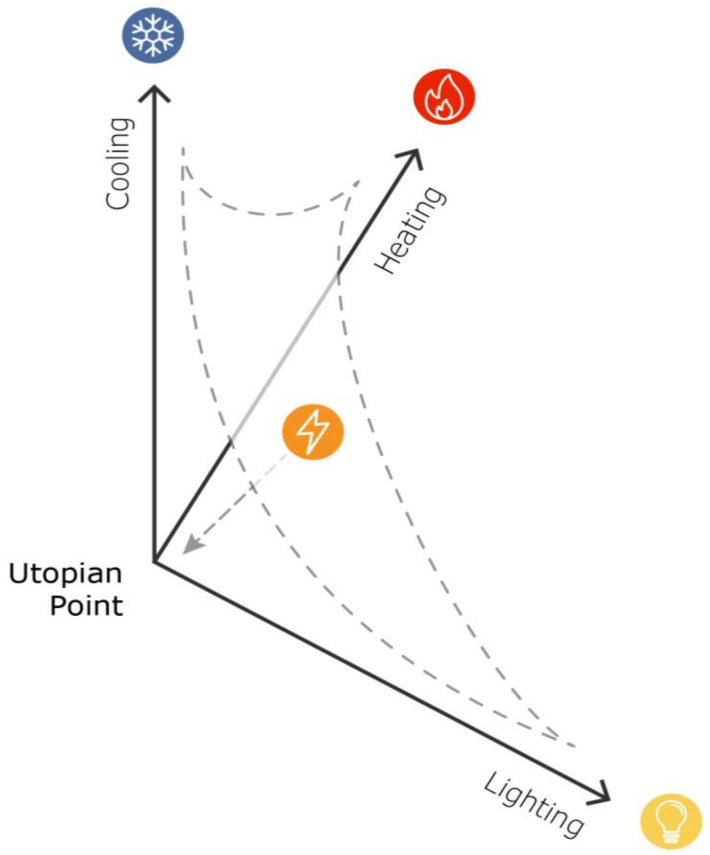
- Adaptive thermal comfort model
- Illuminance rate
- Ventilation rate

Energy-efficient strategies for the variables and hypotheses.

- Orientation and WWR are influencing parameters
- Lighting strategies are conflicting with thermal strategies

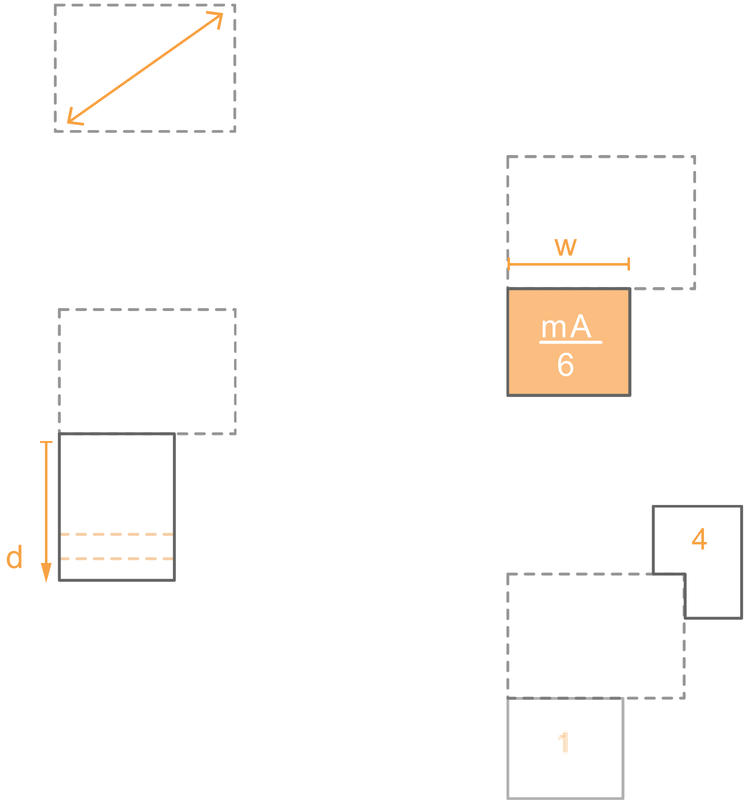
OBJECTIVES

- The model considers a **mixed-mode building** → suitable and promising for the Dutch housing situation.
- **Heating, cooling and lighting** activate on the basis of the comfort model → minimisation of energy implies the optimisation of comfort.
- **Three-objectives** optimisation allows to neglect HVAC efficiency → final energy demand is the common ground



Hierarchical Relations between the geometric attributes:

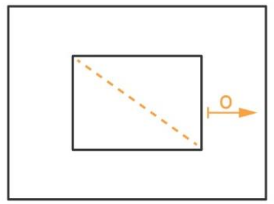
- Perimeter of courtyard (Pc) is constant to avoid its influence.
- Widths (w) of each function are constants, depending on minimum areas and depths.
- Depths (d) of each function are variable, but relate to an increase of area
- Positions of each function are variable



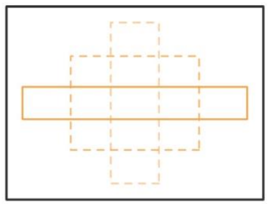
→ Importance to the positions, than to the areas

→ No extra constraints

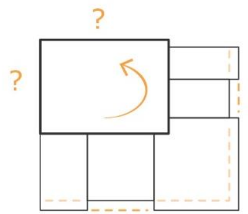
MODEL OPTIONS



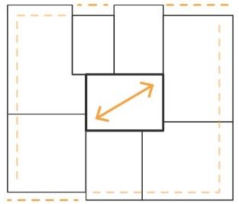
1. Model 1 fixes the façade and changes the internal perimeter as variable
→ It might end with shallow and long courtyards from east to west to increase the space facing south.



2. Model 2 sets a general depth from the courtyard and, then, it moves the partition walls independently to size functions.
→ it expects to extend the depth in order to increase the overall compactness.

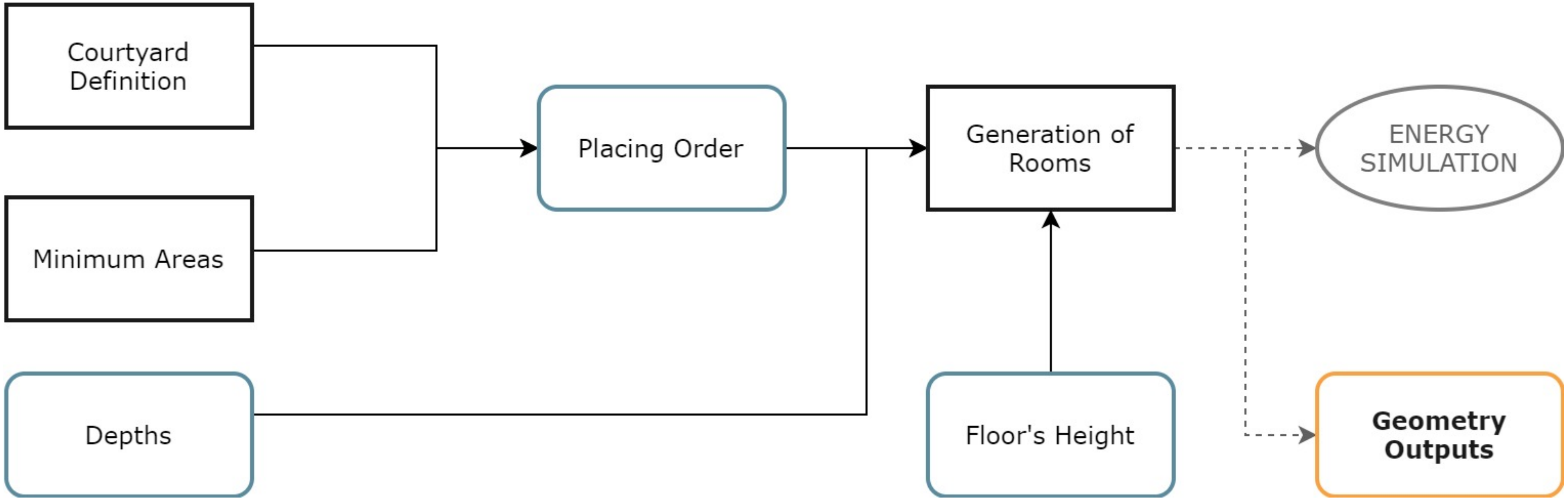


3b. The width of each function (*w(i)*) derives from the respective depth (*d(i)*), area and position of the function, whereas the courtyard is constant.
→ The rooms would start collecting counter-clockwise from the south, leaving the remaining sides (west and north) empty.

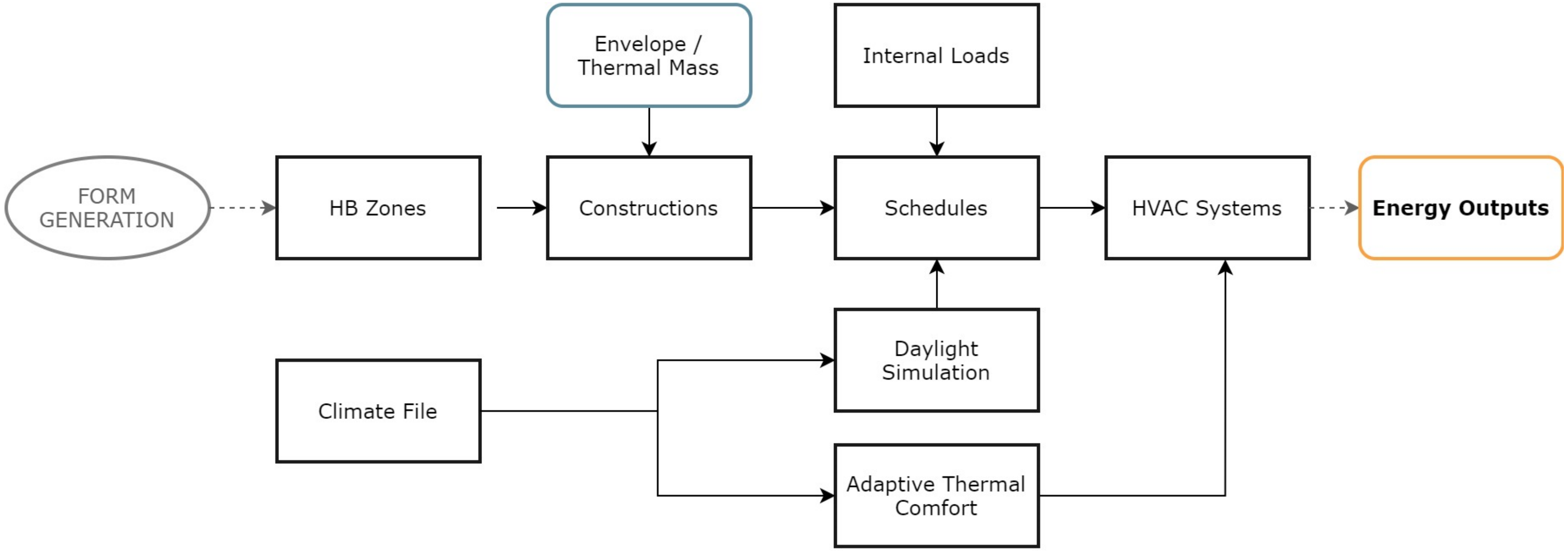


3c. The width of each function (*w(i)*) derives from the respective depth (*d(i)*), but the courtyard changes its perimeter time by time to accommodate all rooms around.
→ the functions might extend their depth to increase the compactness, resulting in small widths.

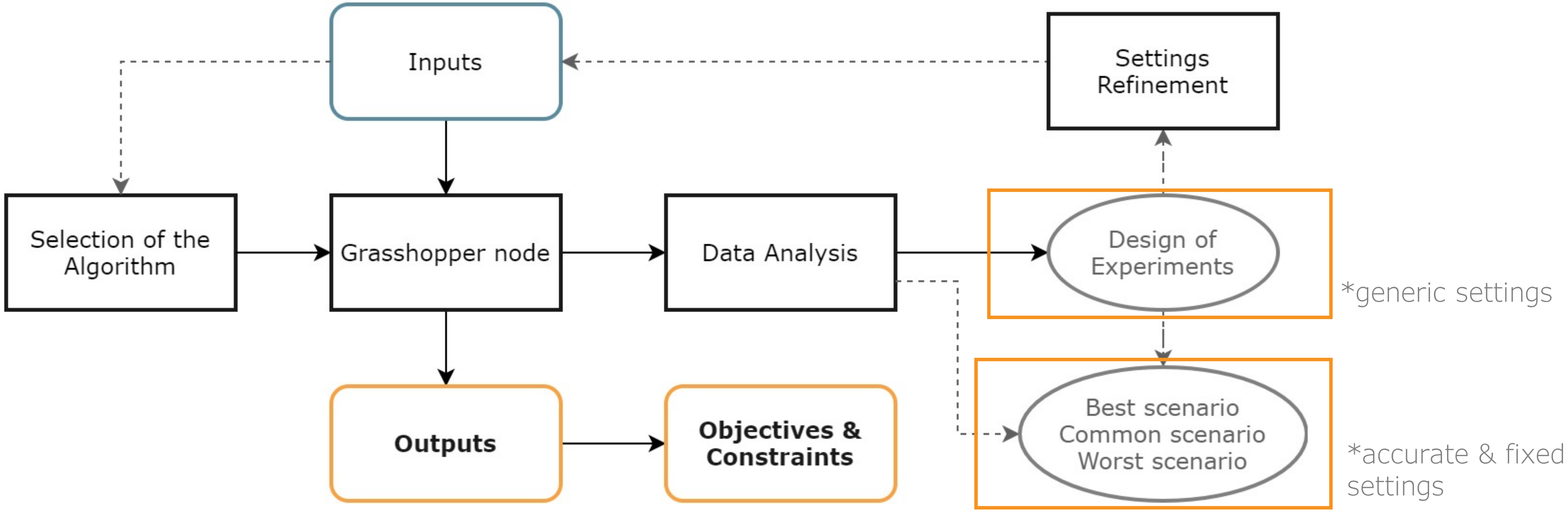
FORM GENERATION



ENERGY SIMULATION



OPTIMISATION



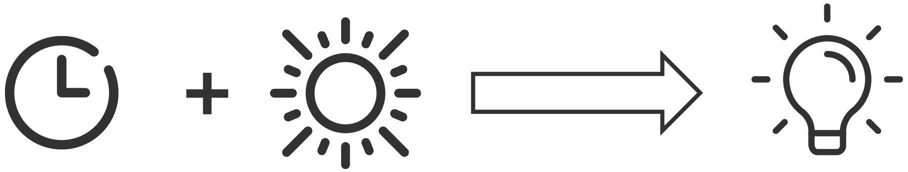
Name	Envelope	Height Floor	Thermal Mass	Orientation	Shading	Depth	Position	WWR
BEST	Excellent	3 m	Heavy	90°	OFF	6m	variable	variable
COMMON	Basic	3 m	Medium	0°	OFF	6m	variable	variable
WORST	Basic	4.5 m	Light	45°	OFF	6m	variable	variable

LIGHTING SCHEDULE

To include smaller time steps:

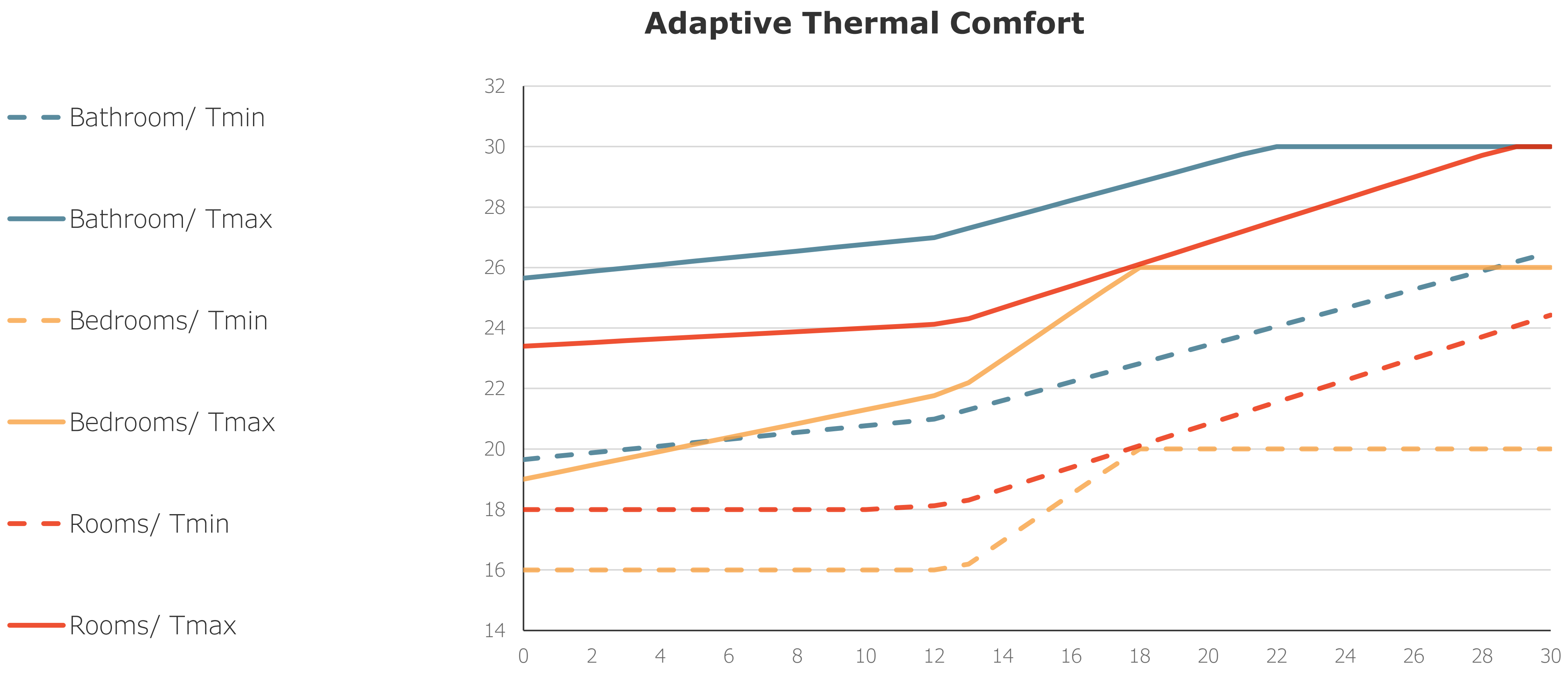
- The **daylight simulation** estimates the rate of artificial light needed to provide the illuminance rate every hour of the year.
- The **lighting usage**, as manual schedule, indicates how long the light is switch on in the room in every hour.

→ It considers both smaller time steps and dimming.



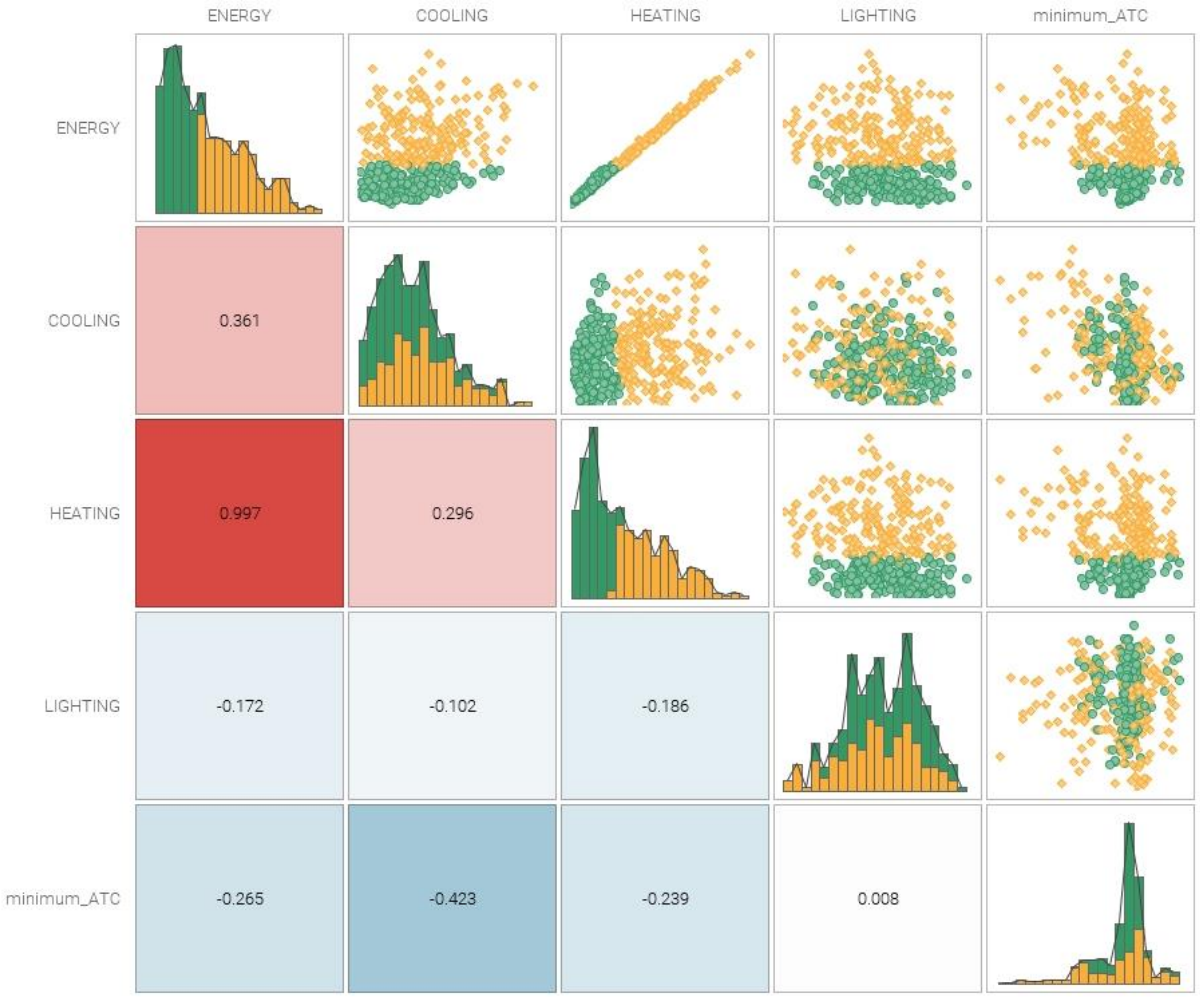
h	*0*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*
Usage	0	0	0	0	0	0	0.5	1	1	0.5	0	0	0.2	0.2	0	0	0	0.2	0.5	0.5	0.2	0.2	0	0
Daylight	1	1	1	1	1	1	0.9	0.8	0.7	0.5	0.2	0	0	0	0.1	0.2	0.5	0.7	0.8	0.9	1	1	1	1
Lighting	0	0	0	0	0	0	0.45	0.8	0.7	0.25	0	0	0	0	0	0	0	0.14	0.4	0.45	0.2	0.2	0	0

ENERGY SIMULATION



**Peeters, Dear, Hensen, & D'haeseleer, (2009)* On the total energy demand:

- <u>Heating</u> is the most influencing factor with a **strong and linear correlation** → cold climate
- <u>Cooling</u> has a medium positive correlation
- <u>Lighting</u> has a low negative correlation, determining a Pareto-Front.



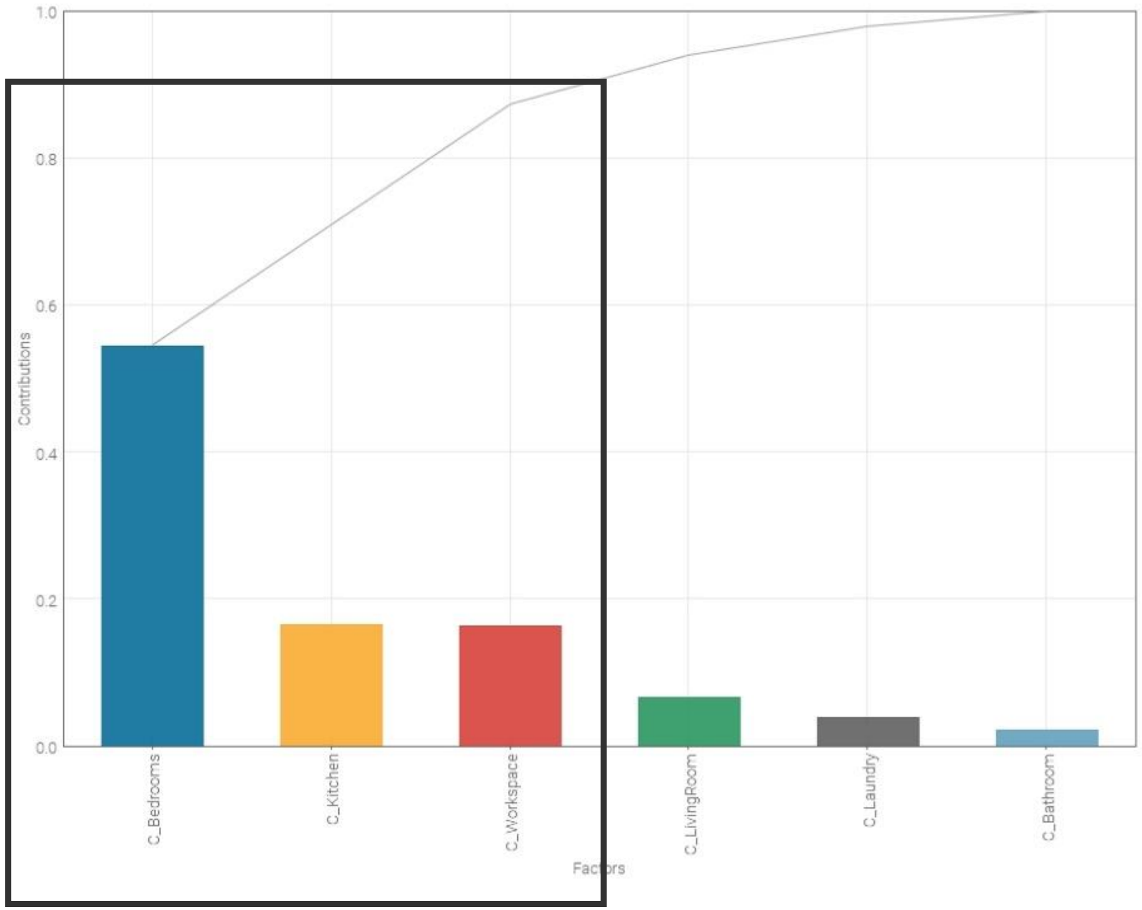
Principle: Larger savings derive from minimising the heating than the other two objectives

Influences of the functions on the demands:

- On cooling, the bedrooms induce a medium impact, kitchen and workspace a mild one:

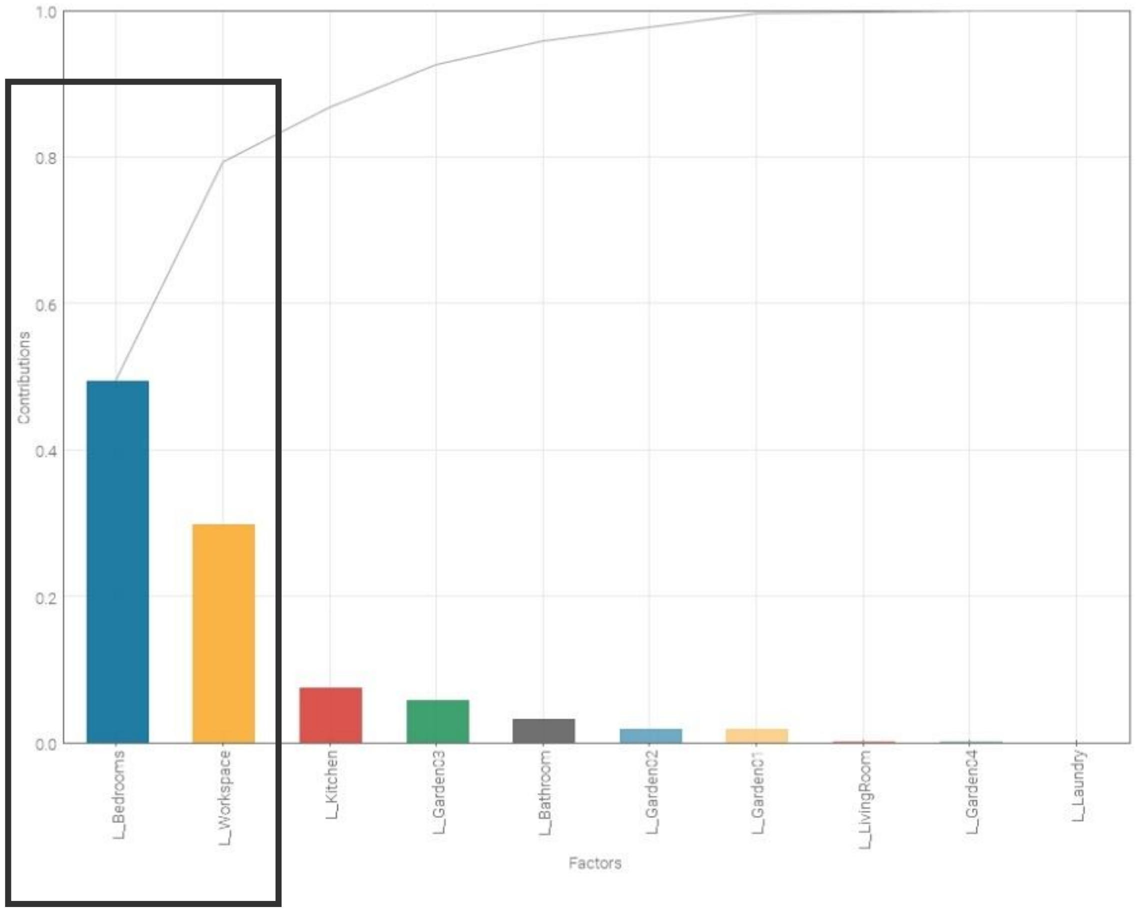
→ low temperature requirements

→ high internal gains



Influences of the functions on the demands:

- On lighting, the bedrooms and the workspace have medium influences:
    - → large dimensions
    - → high illuminance level

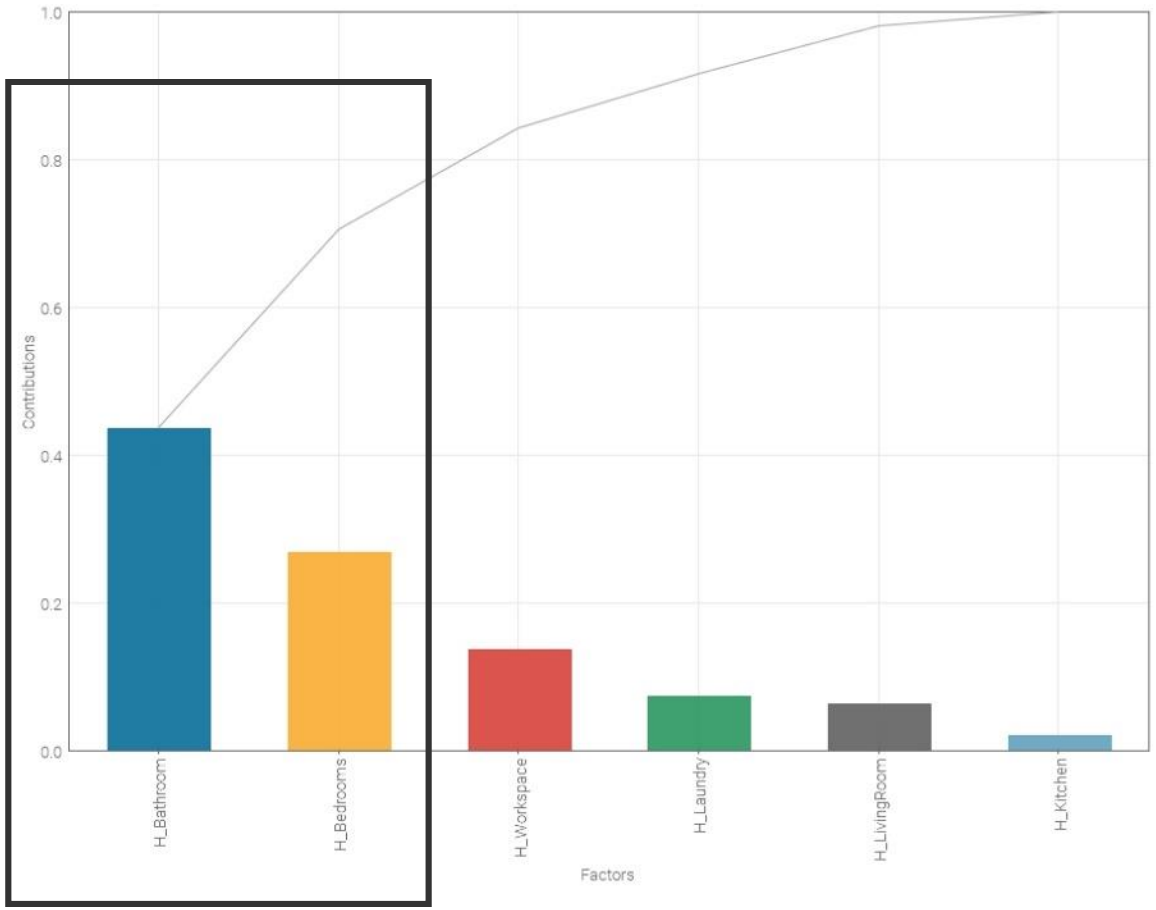


Influences of the functions on the demands:

- <u>On heating</u>, the bathroom and the bedrooms play noticeable roles:

  → high temperature requirements

  → large dimensions

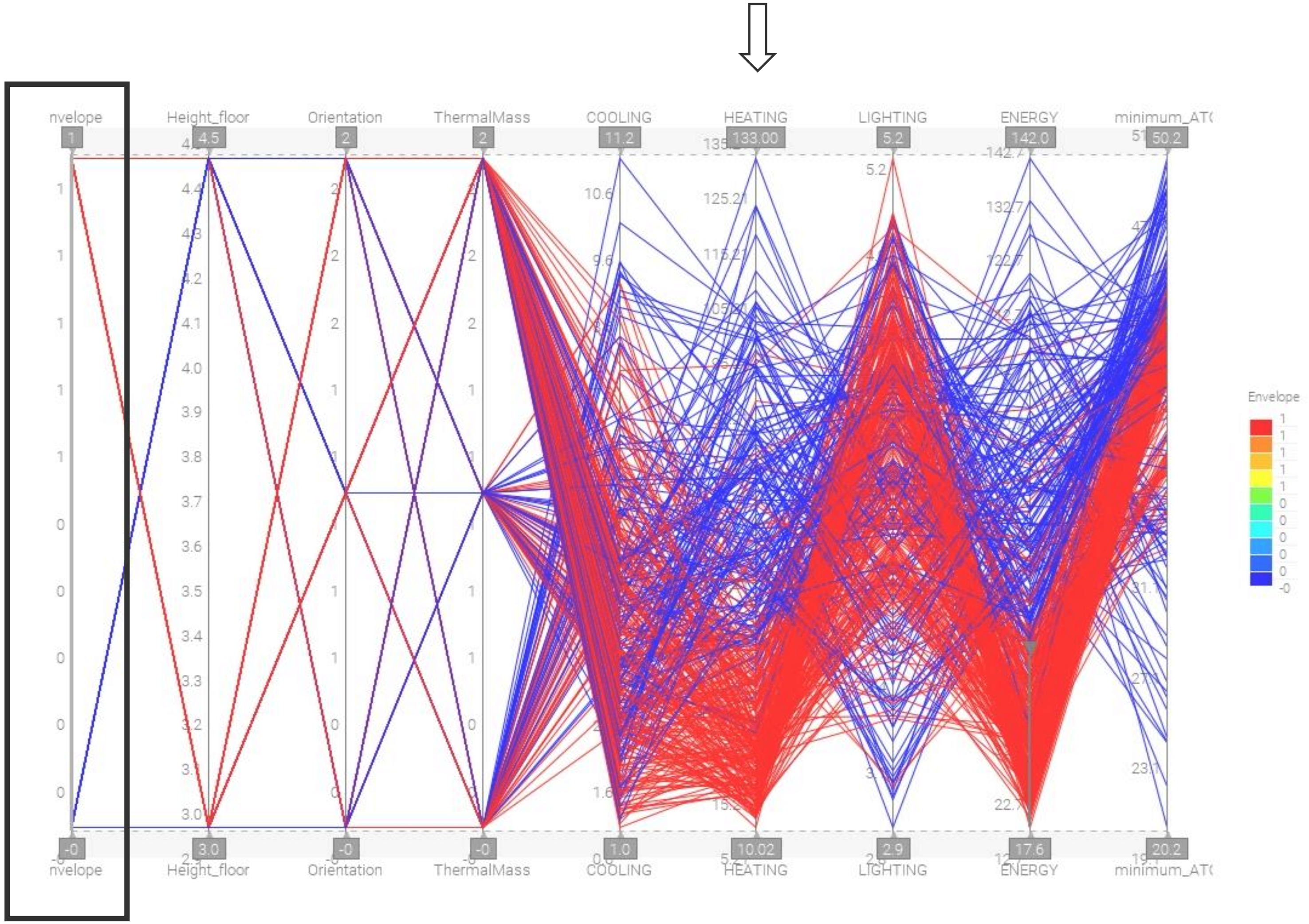


Principle: Planning the functions to meet their energy and comfort requirements.

DESIGN OF EXPERIMENTS

- **Excellent envelope** performs better, especially on the heating demand.

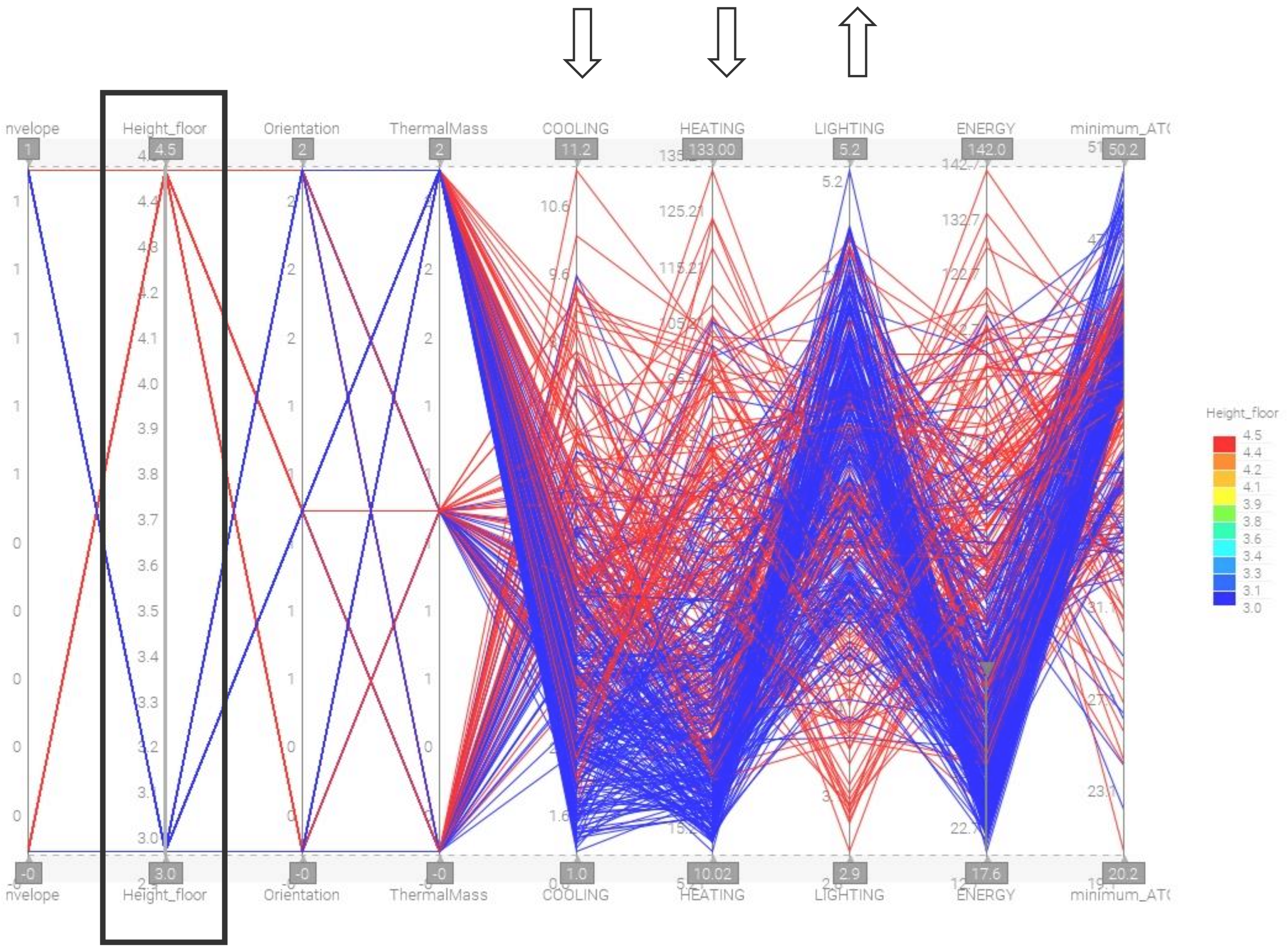
→ Reducing heat losses



DESIGN OF EXPERIMENTS

- **Low floor's height** minimises cooling and heating, but it increases lighting.

→ Less air volume and less façade surface

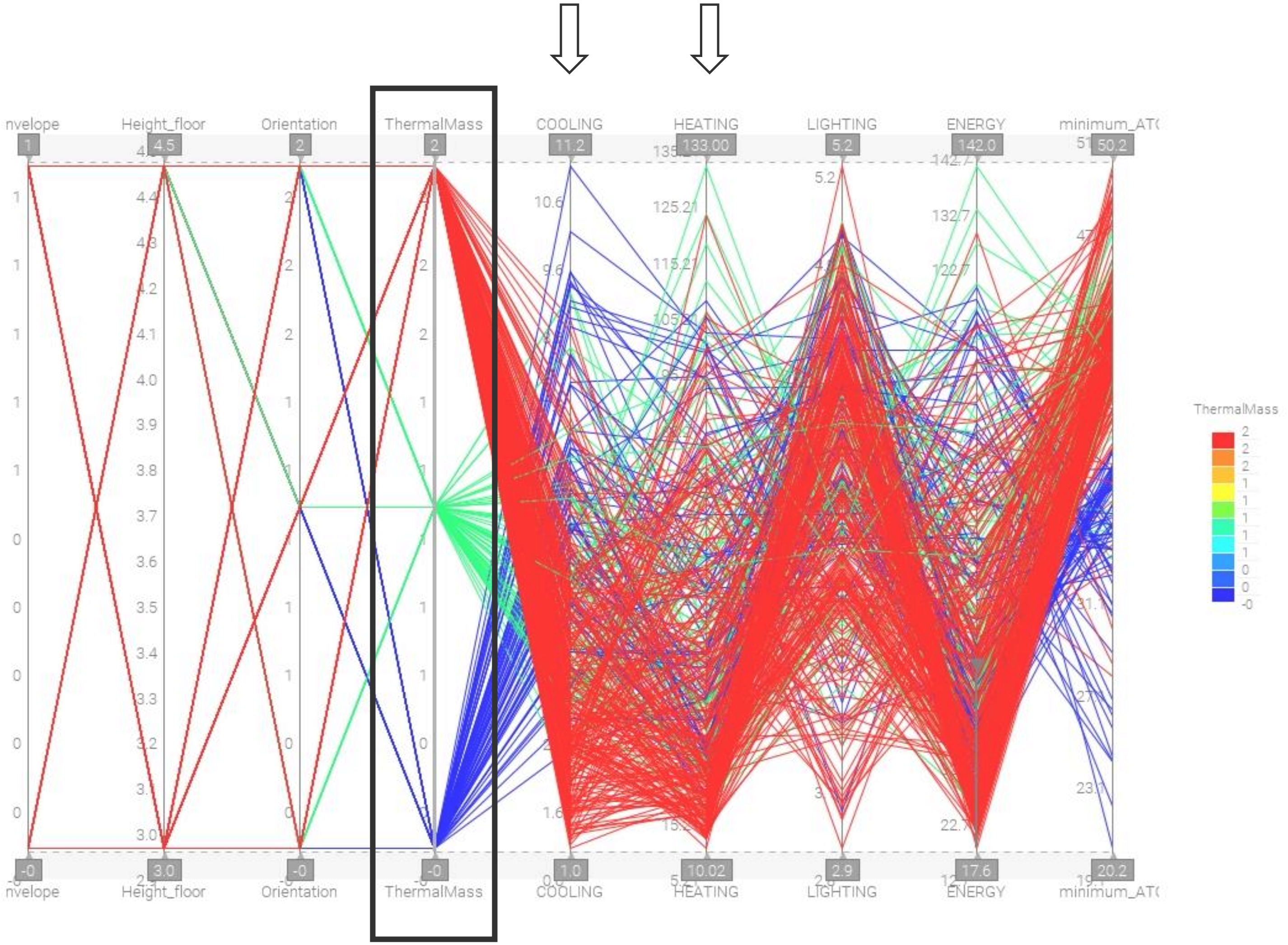


DESIGN OF EXPERIMENTS

- **High thermal mass** optimises cooling, heating and comfort.

→ Accumulate the solar gains

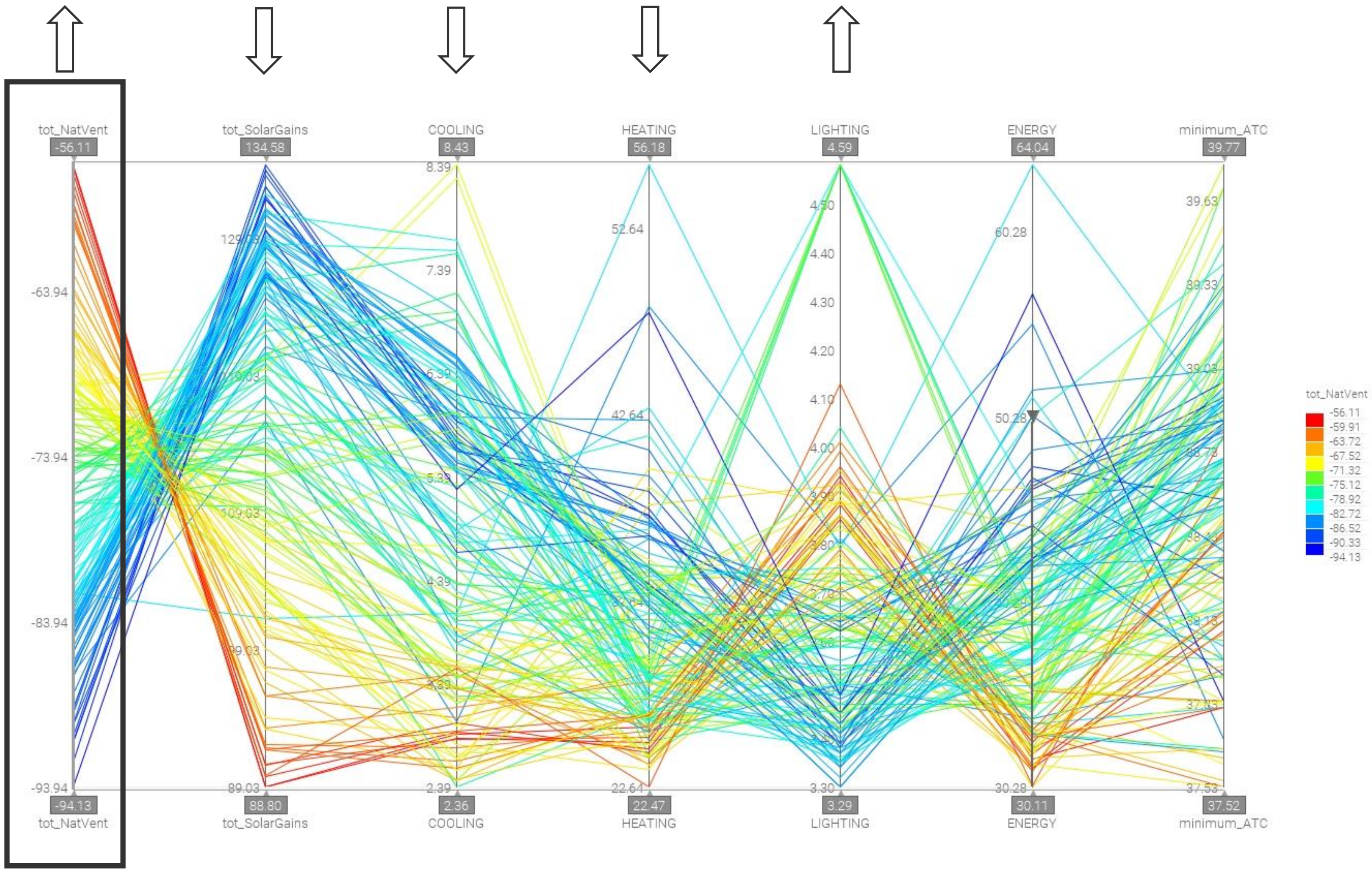
Principle: high thermal properties of the envelope are necessary.



COMMON SCENARIO

Connection between **Windows / Natural ventilation / Solar gains:**

- small windows reduce heat losses via natural ventilation, resulting less heating.



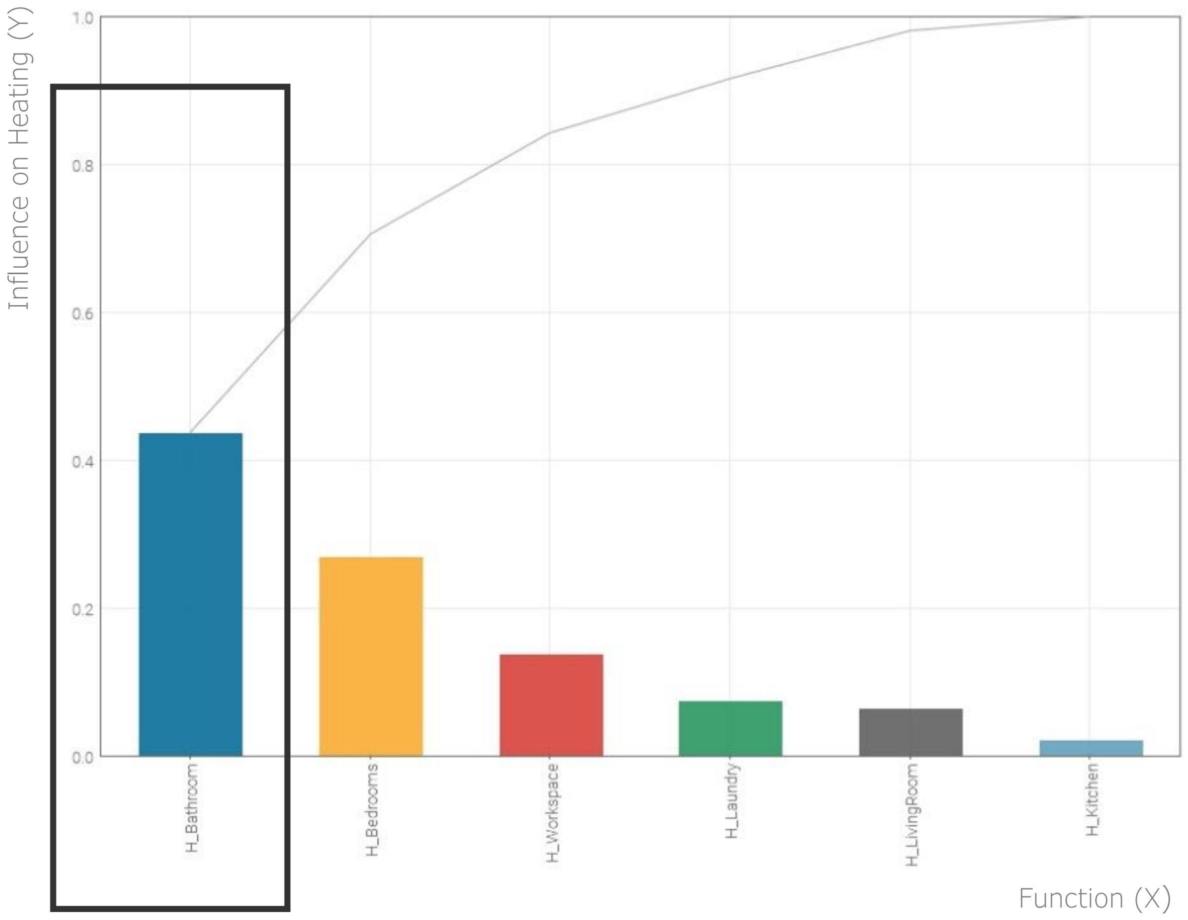
Principle: high window-to-wall ratio does not lead always to less heating

Principle: natural ventilation is critical to plan.

BATHROOM

relevant impact on heating

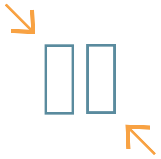
→it requires warmer temperatures



BATHROOM

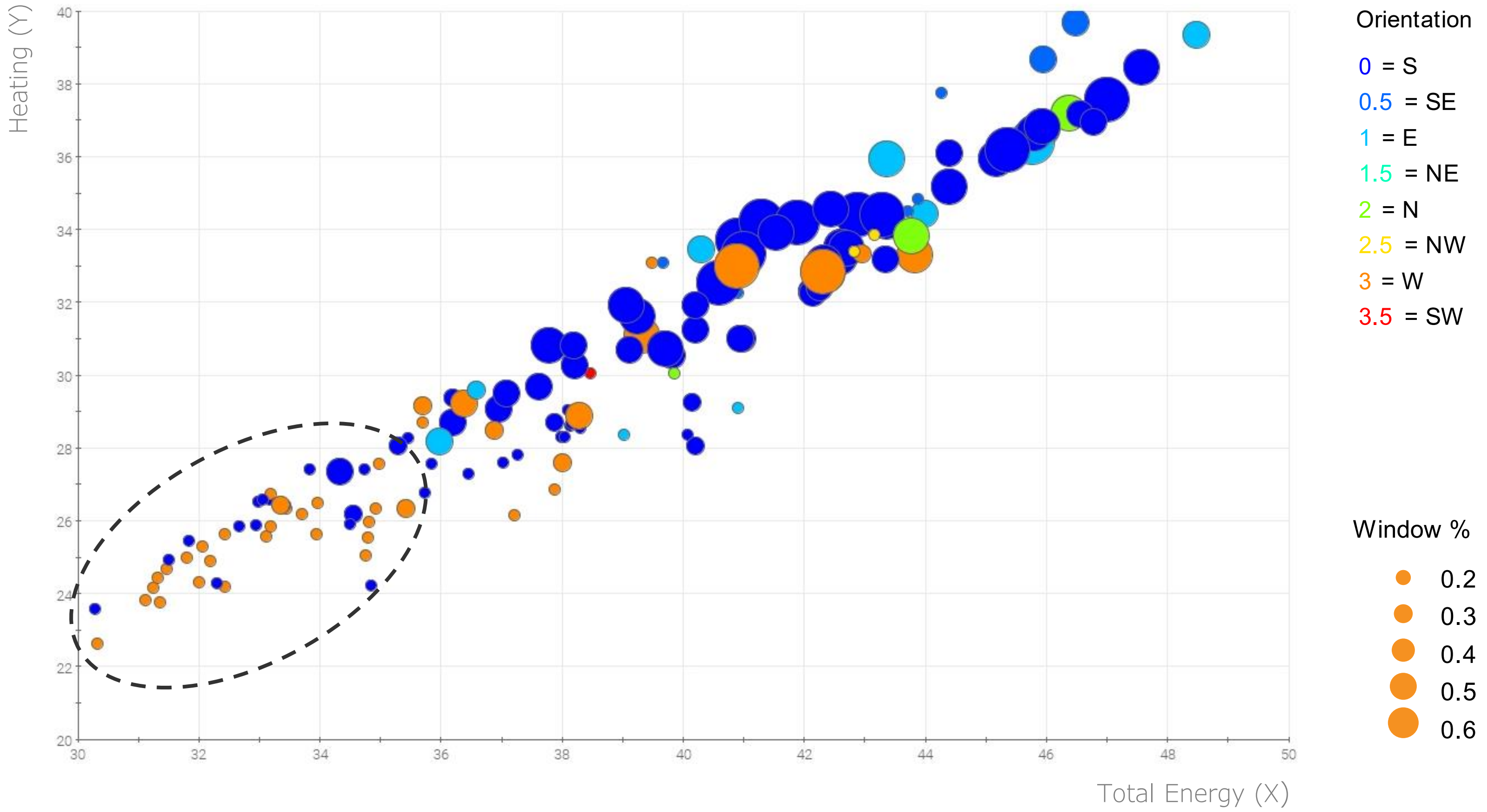
relevant impact on heating

To increase solar radiation



To reduce ventilation losses

To maximise solar gains



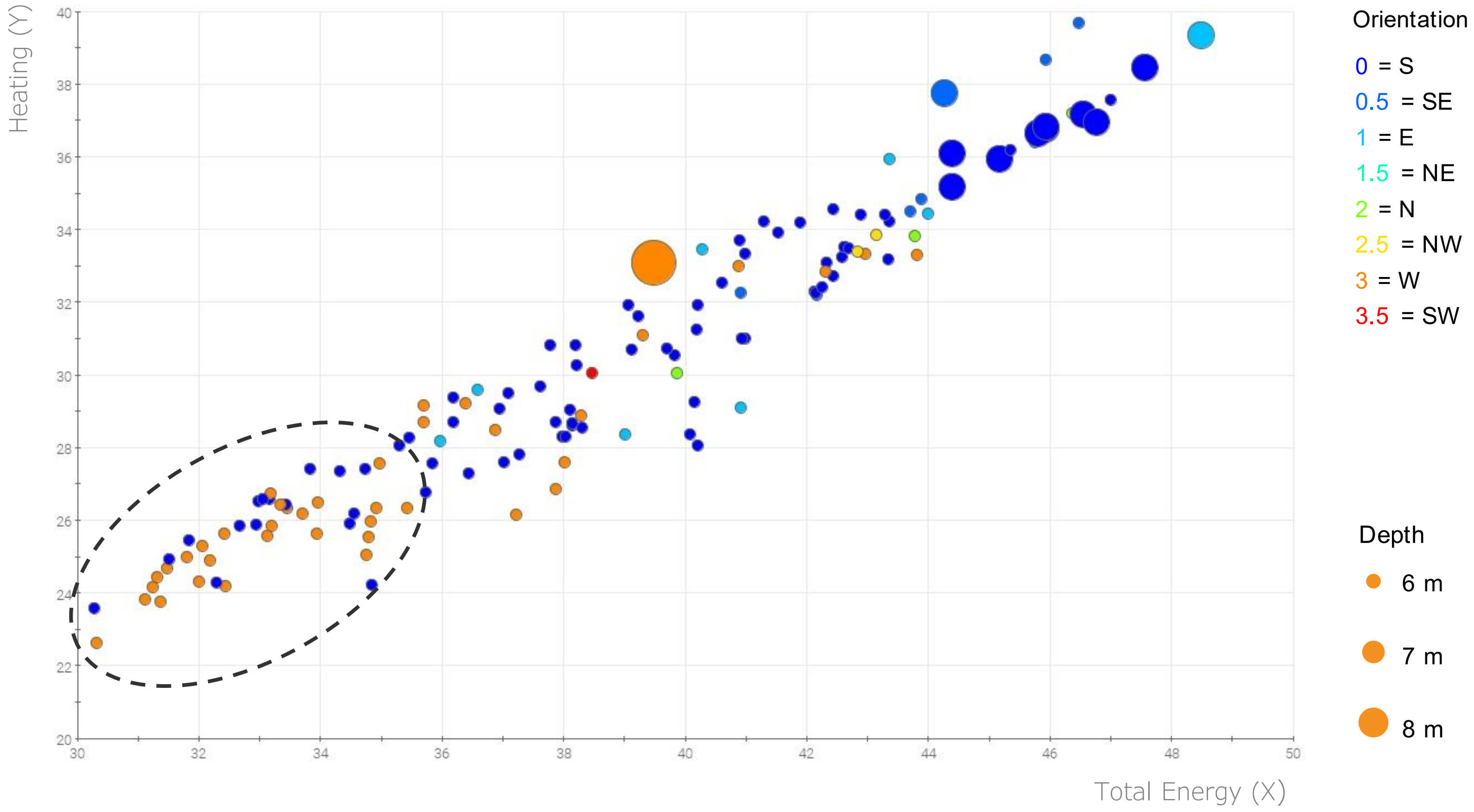
BATHROOM

relevant impact on heating

To increase solar exposure

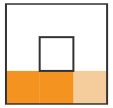
To reduce ventilation losses

To maximise solar gains

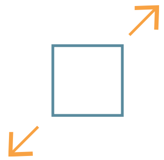


WORKSPACE

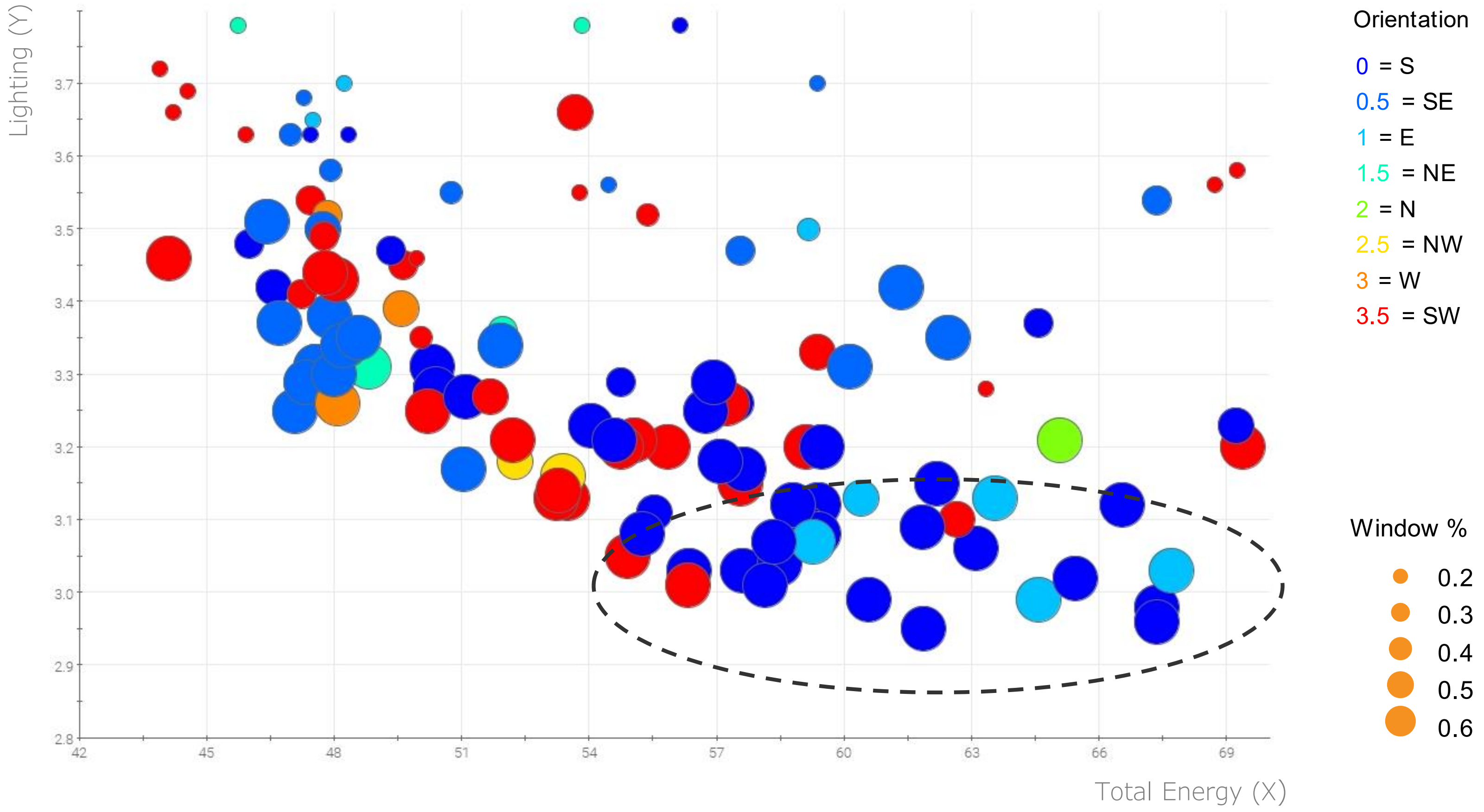
It affects lighting



To benefit from daylight

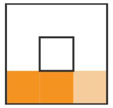


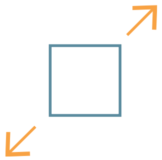
To increase light



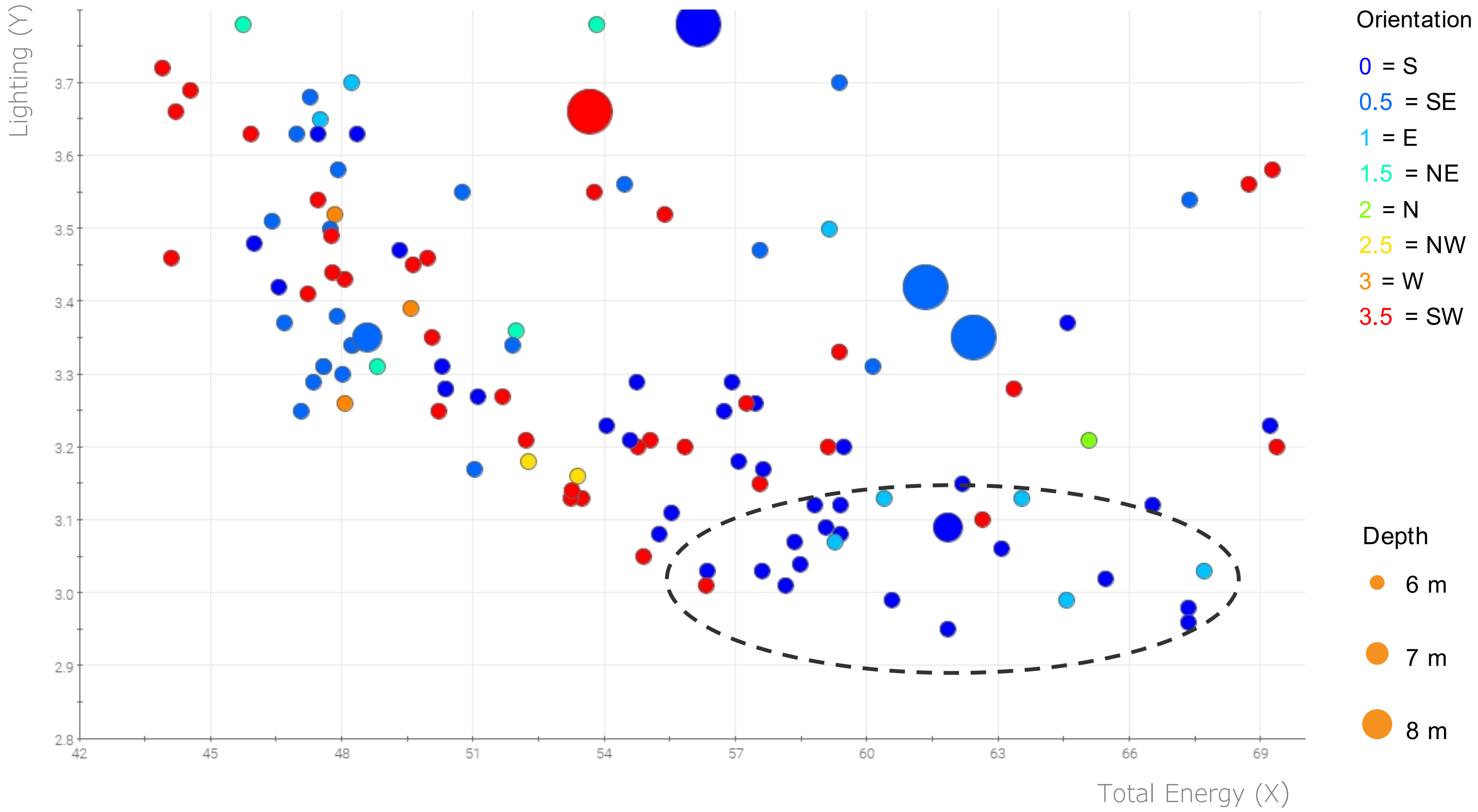
WORKSPACE

It affects lighting

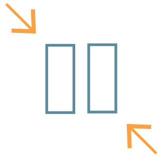
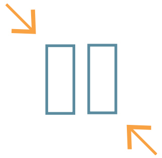
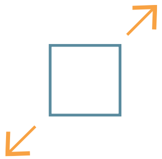




To maximise
solar radiation



GUIDELINES

	Aim	Depth	Windows	Sensitive Function	Energy Savings
COOLING	Avoid overheating				**-52%**
HEATING	Keep heat inside				**-55%**
LIGHTING	Improve daylight				**-37%**

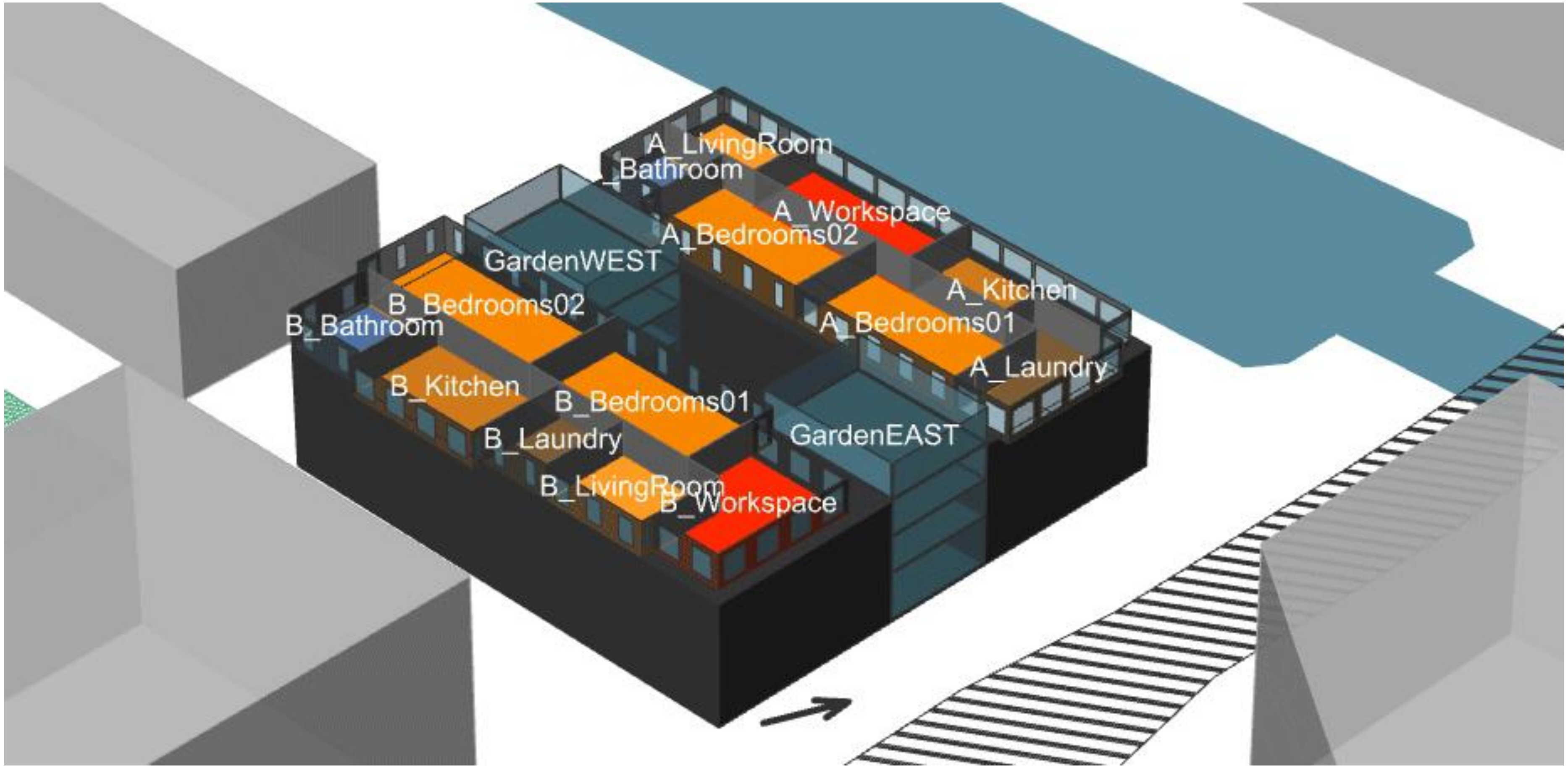
SUMMARY

Scenario	Strategy	Cooling	Heating	Lighting	Energy	Cooling	Heating	Lighting	Energy	Energy
		Demand - kWh/m²				*Improvement - kWh/m²*				*%*
Best	*Poorest*	7.05	45.51	3.42	55.98					
	Cooling	**2.24**	19.58	3.98	25.8	4.8	25.9	-0.6	30.2	53.9
	Heating	2.84	**18.13**	3.89	**24.86**	4.2	27.4	-0.5	31.1	55.6
	Lighting	7.78	22.51	**3.27**	33.56	-0.7	23.0	0.2	22.4	40.1
Common	*Poorest*	6.40	56.79	3.43	66.62					
	Cooling	**2.39**	26.74	4.04	33.17	3.9	31.3	-0.5	34.8	52.2
	Heating	3.54	**22.64**	4.13	**30.31**	2.9	34.2	-0.7	36.3	54.5
	Lighting	6.55	32.28	**3.3**	42.13	-0.1	24.5	0.1	24.5	36.8
Worst	*Poorest*	10.4	93.85	3.1	107.35					
	Cooling	**4.13**	39.46	3.68	47.27	6.3	54.4	-0.6	60.1	56.0
	Heating	6.15	**34.48**	3.46	**44.09**	4.3	59.4	-0.4	63.3	58.9
	Lighting	12.02	46.88	**2.95**	61.85	-1.6	47.0	0.2	45.5	42.4

SUMMARY

- The lighting strategy contradicts the cooling and partly the heating strategy, determining a pareto-front in between. In the Dutch climate, higher savings derive from minimising the heating than the others.
- It is possible to meet BENG 1 requirement. However, it is necessary first to ensure high thermal properties of the envelope and then to optimise the space layout.
- High window-to-wall ratios do not lead always to lower heating demand.
- Functions are the driving factors of the envelope, more than its shape.
- The most influencing functions are the bathroom and the bedrooms, followed by the workspace. They change their variables to meet their requirements.
- Planning natural ventilation is challenging and essential.
- High dependency on schedules.

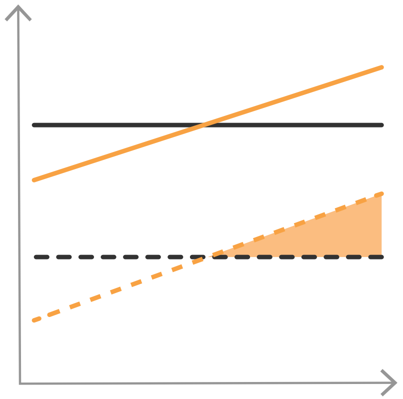
PROPOSAL


A_LivingRoom
_Bathroom
A_Workspace
A_Bedrooms02
GardenWEST
A_Kitchen
B_Bedrooms02
B_Bathroom
A_Bedrooms01
A_Laundry
B_Kitchen
B_Bedrooms01
GardenEAST
B_Laundry
B_LivingRoom
B_Workspace

FURTHER IMPROVEMENTS

- Difference with **steady-state thermal comfort**

→ to evaluate pros and cons



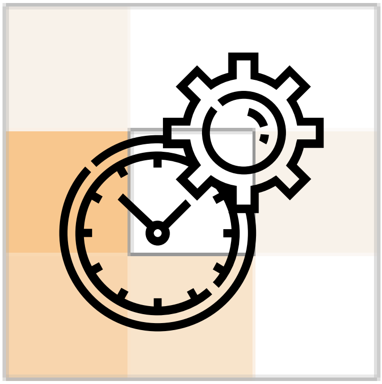
FURTHER IMPROVEMENTS

- Difference with **steady-state thermal comfort**

→ to evaluate pros and cons

- Include the efficiency of the **building systems**

→ to evaluate the compromises with different HAVCs



FURTHER IMPROVEMENTS

- Difference with **steady-state thermal comfort**

→ to evaluate pros and cons

- Include the efficiency of the **building systems**

→ to evaluate the compromises with different HAVCs

- Consider the current needs of professional practice

→ **new Pareto-Front** between electricity and thermal loads