A CHANGE OF STATE

A thermodynamic and cost-effective optimized trombe wall based on latent heat storage

P5 Presentation

K.J. HENDRIKS (4655397)

02-07-2019

1

INTRO

2

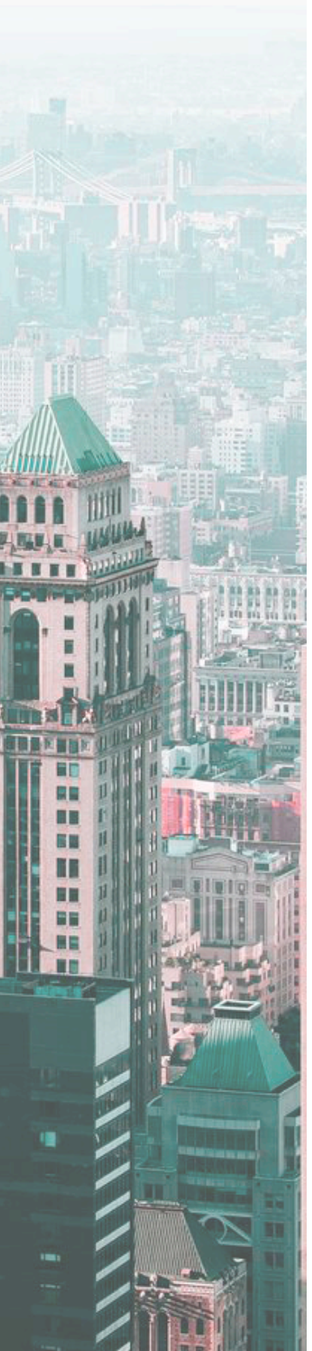
RESEARCH

3

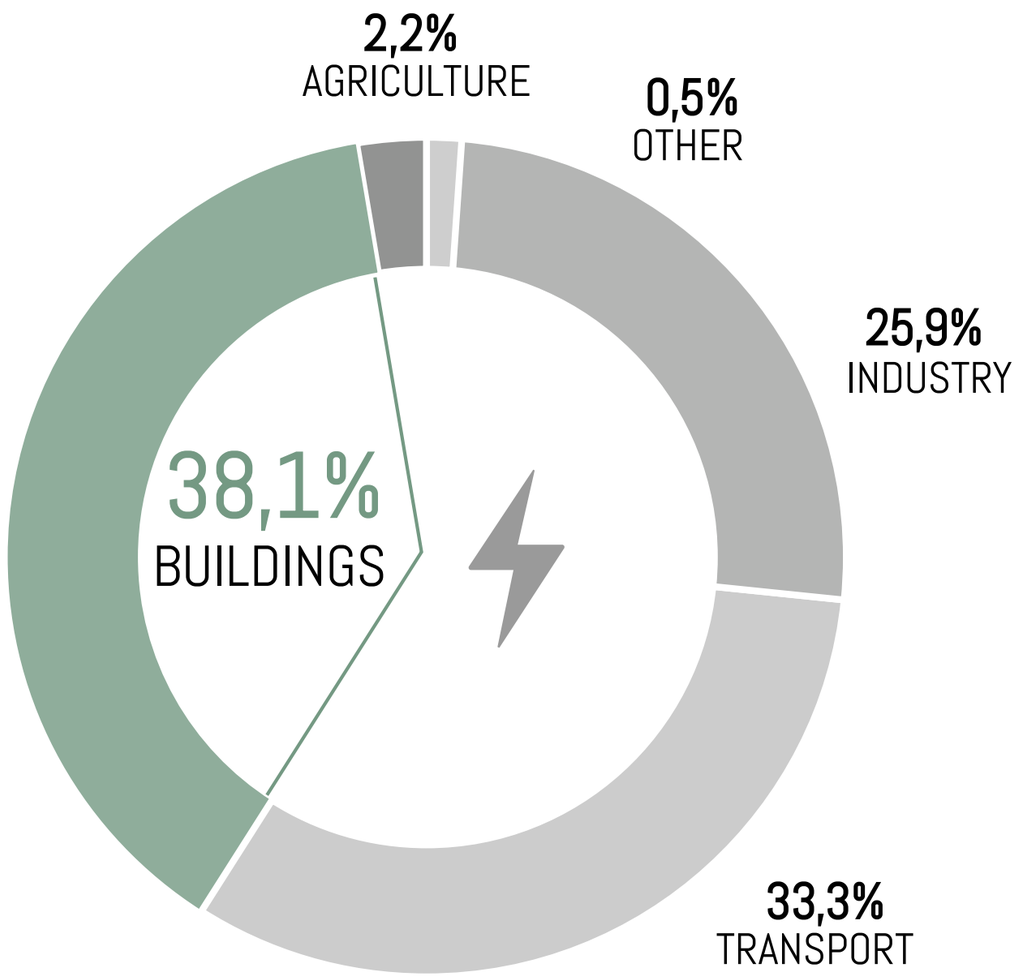
DESIGN

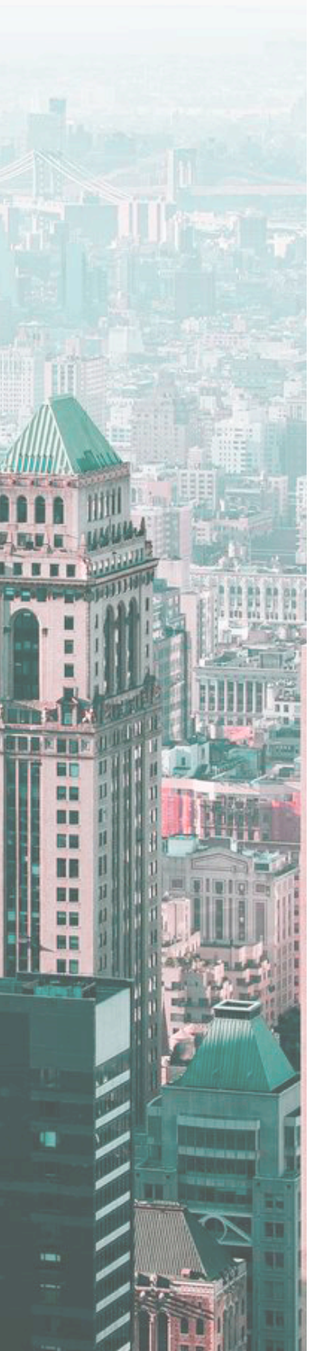
1 INTRO

METHODOLOGY

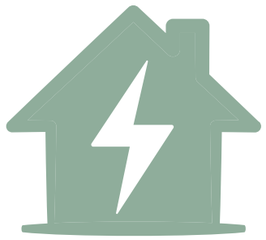


PROBLEM


2,2%
AGRICULTURE
0,5%
OTHER
25,9%
INDUSTRY
38,1%
BUILDINGS
33,3%
TRANSPORT



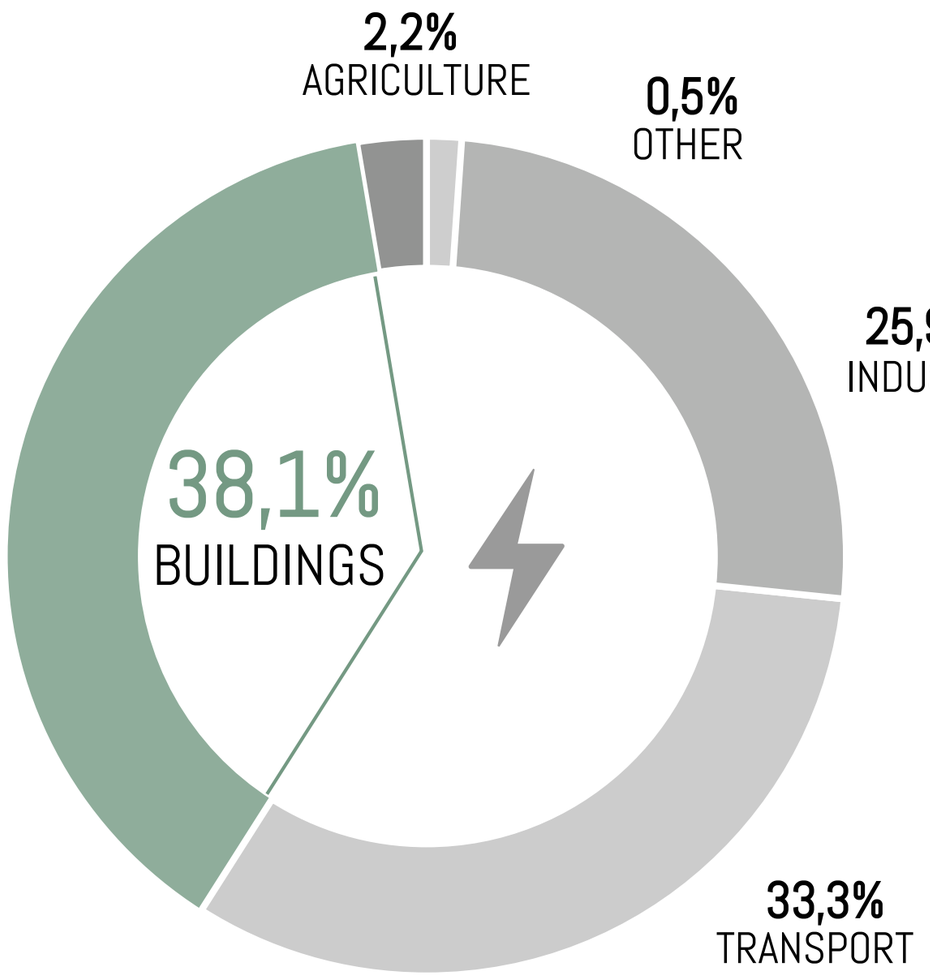
PROBLEM



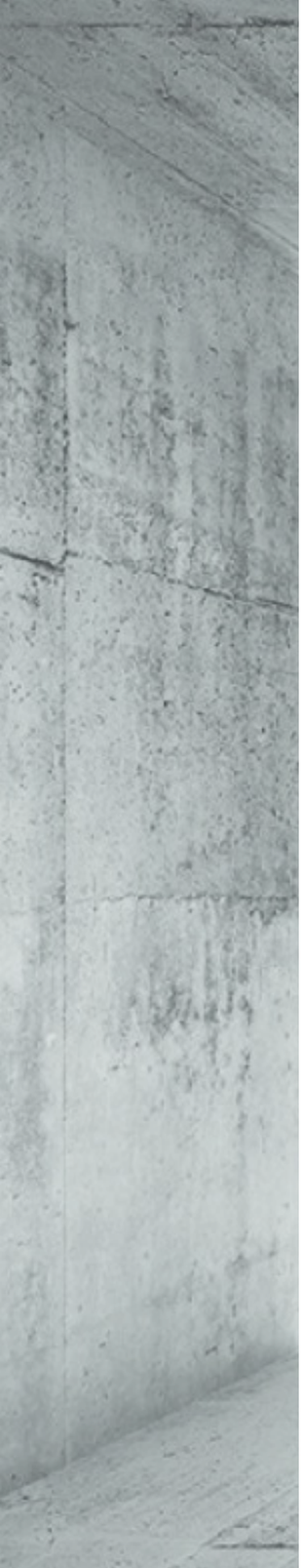
-32,5%

European Commission

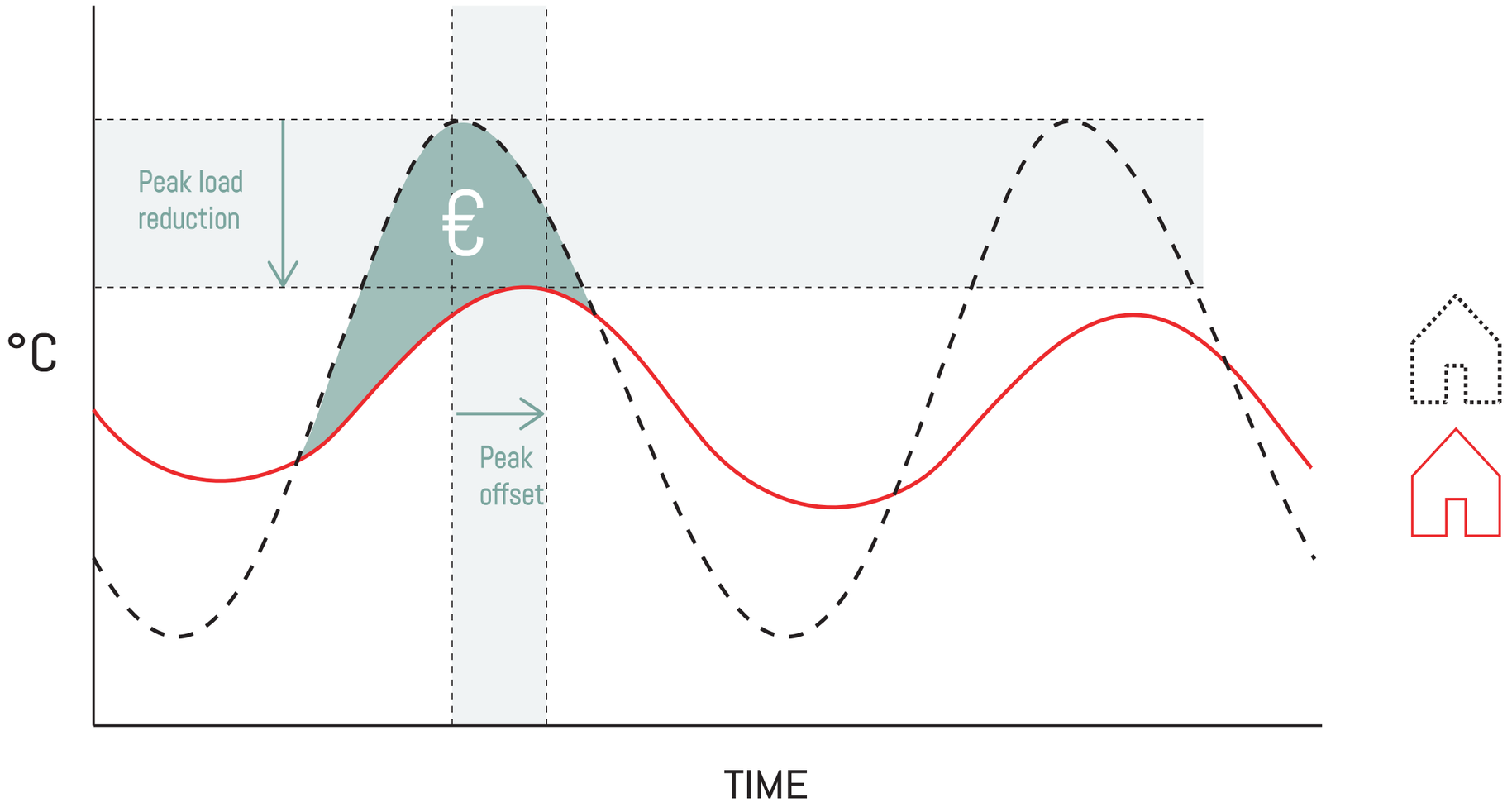
2030

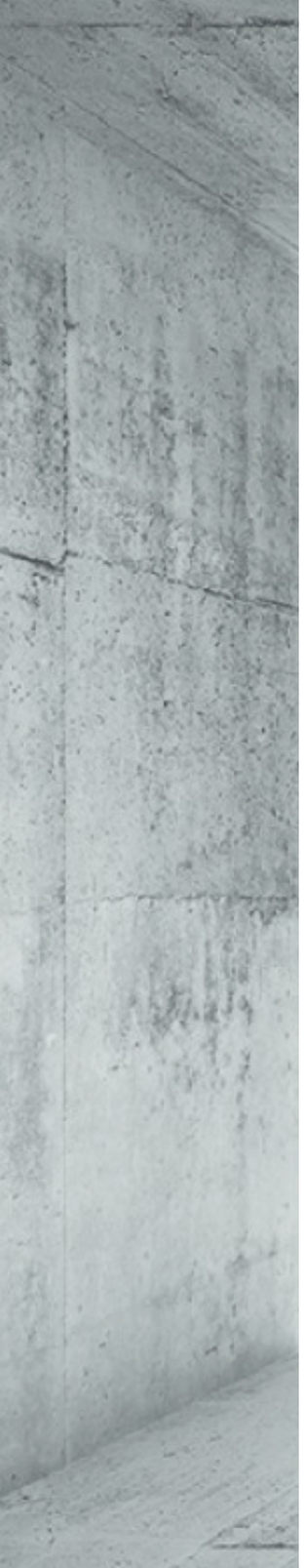


THERMAL ENERGY STORAGE



THERMAL ENERGY STORAGE

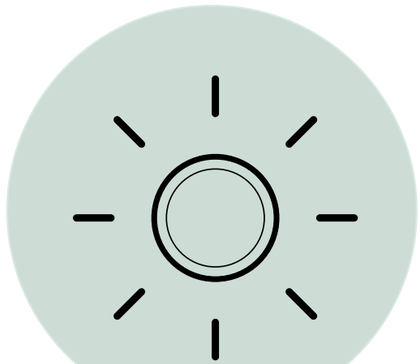




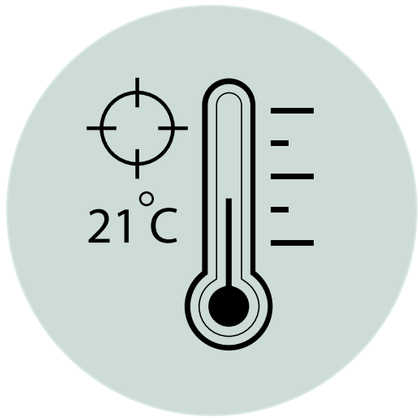
PROBLEM

HIGH
DENSITY

LOW HEAT
CAPACITY

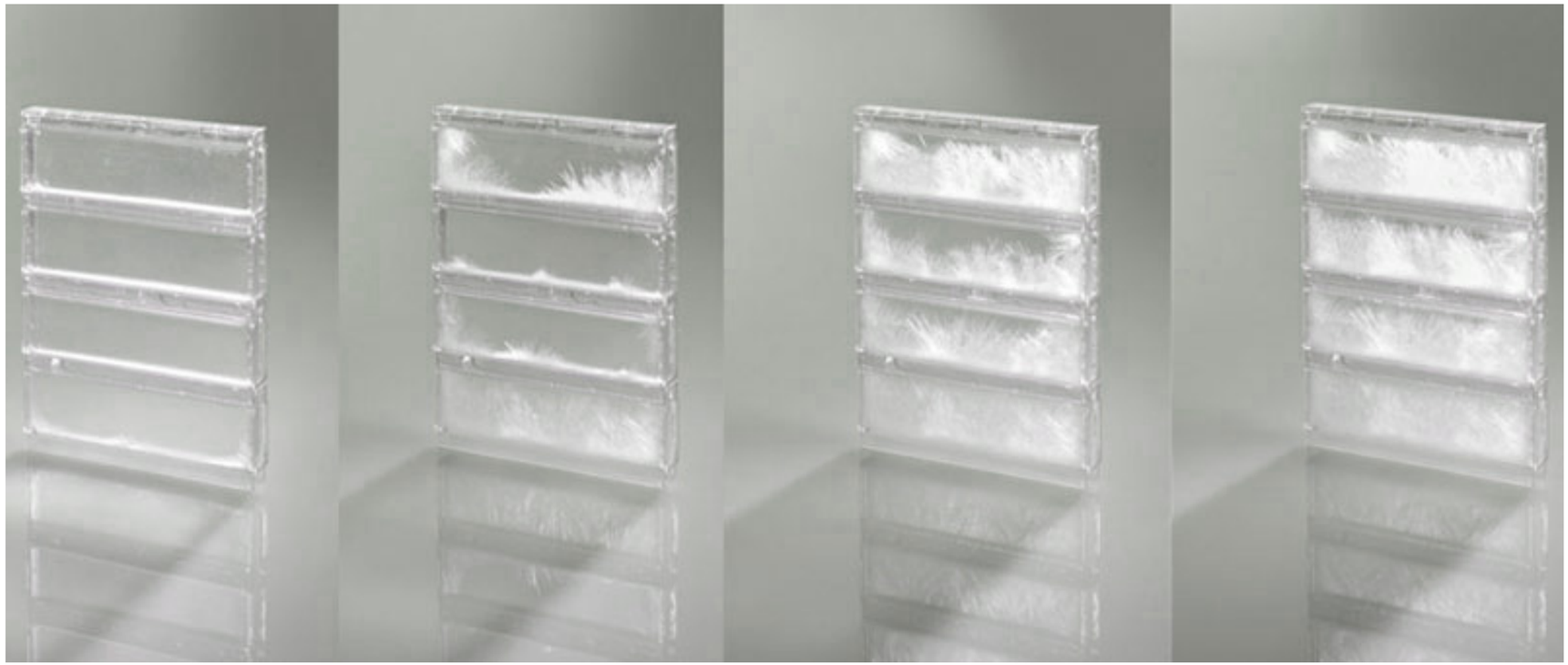


NO
DAYLIGHT

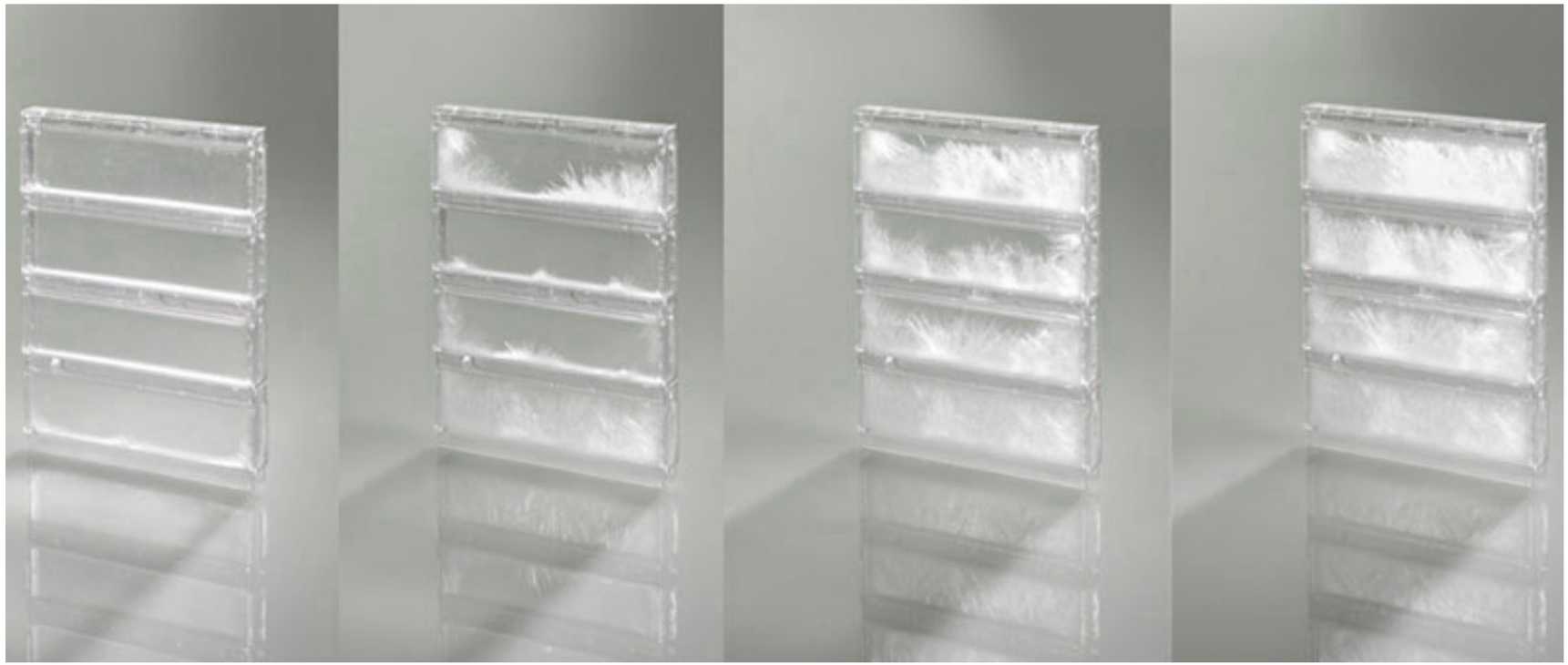


NO TARGET
TEMPERATURE

PHASE CHANGE MATERIAL

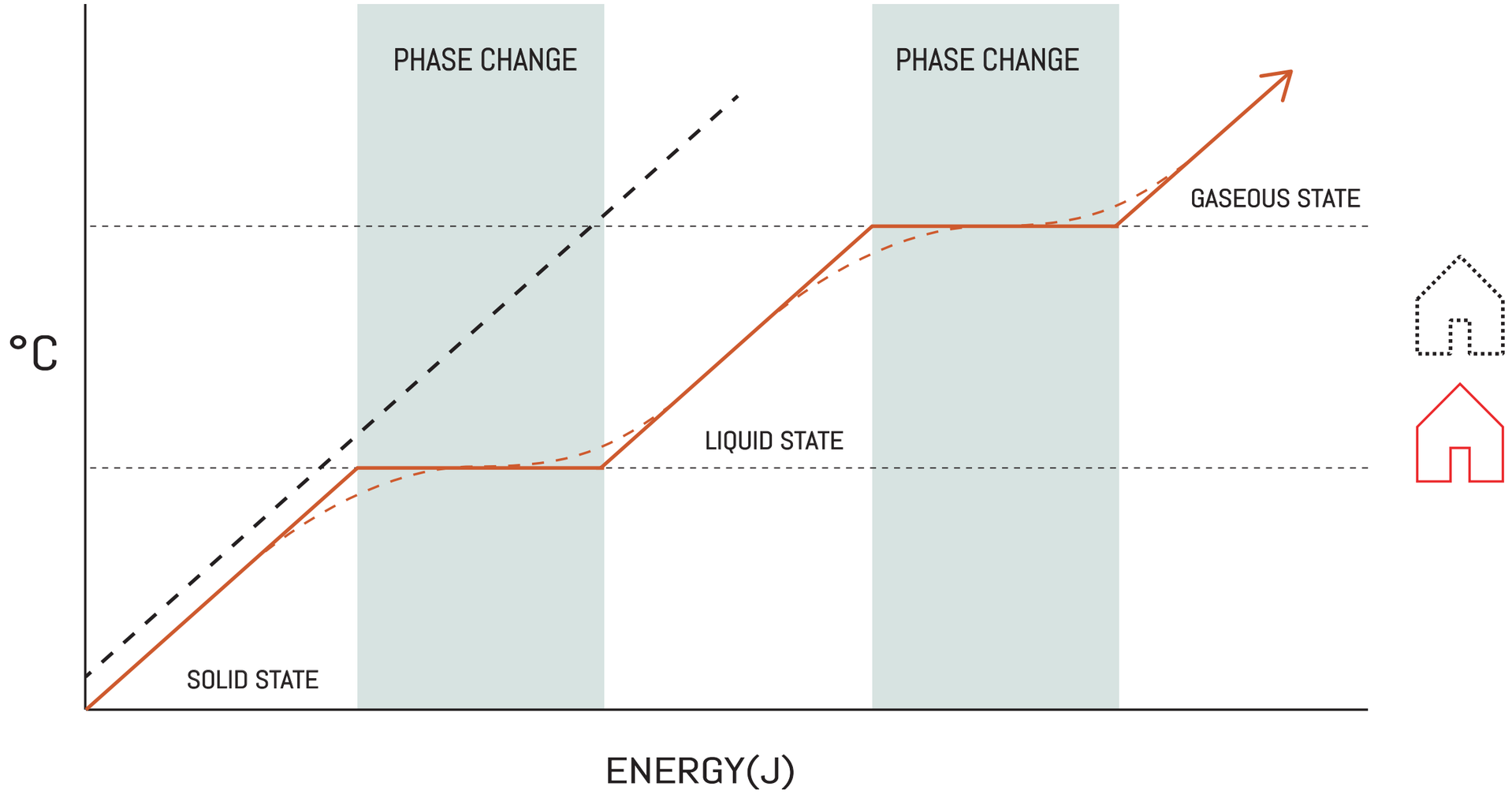


PHASE CHANGE MATERIAL

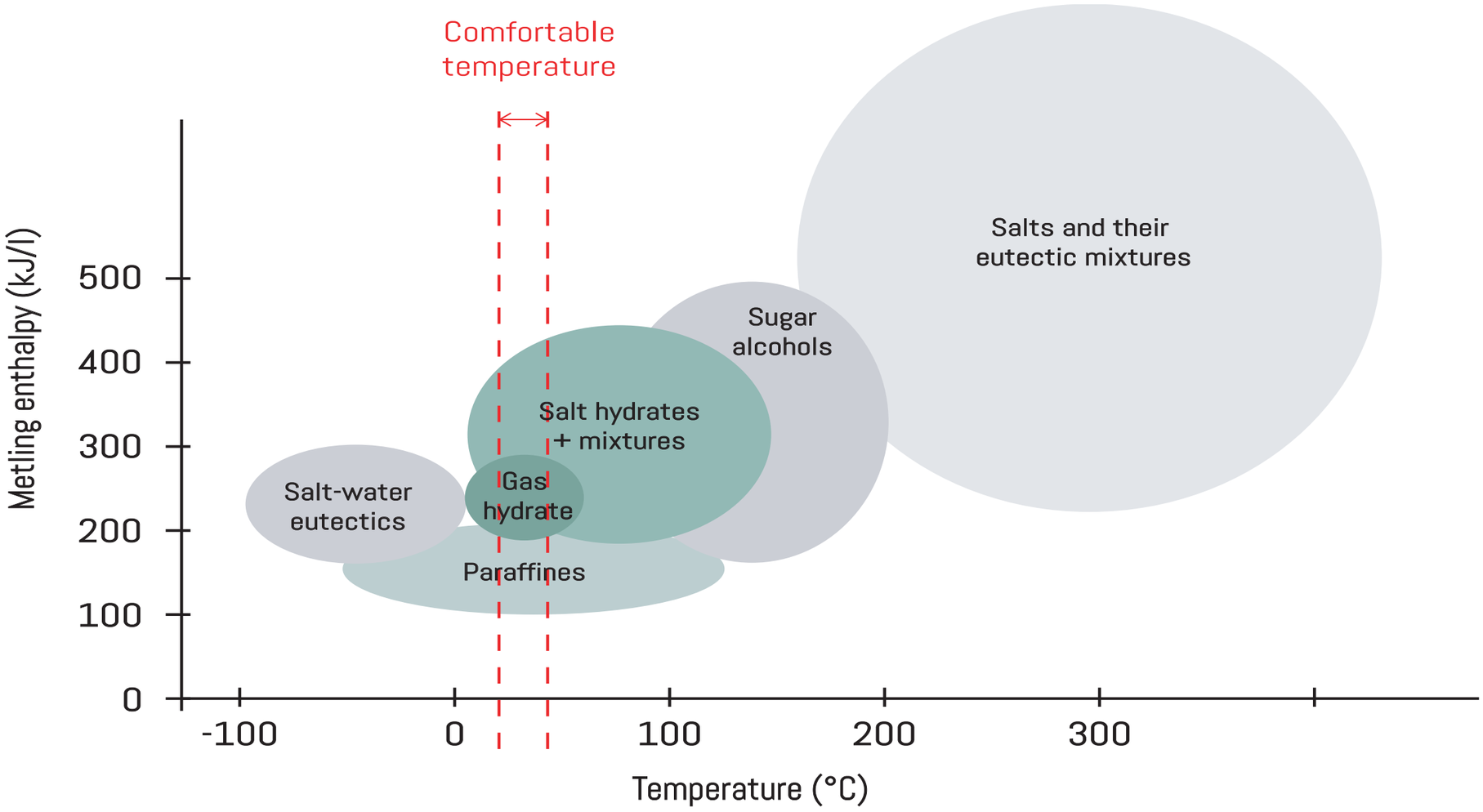


Liquid → Solid

PHASE CHANGE MATERIAL



PHASE CHANGE MATERIAL



1 CONTEXT

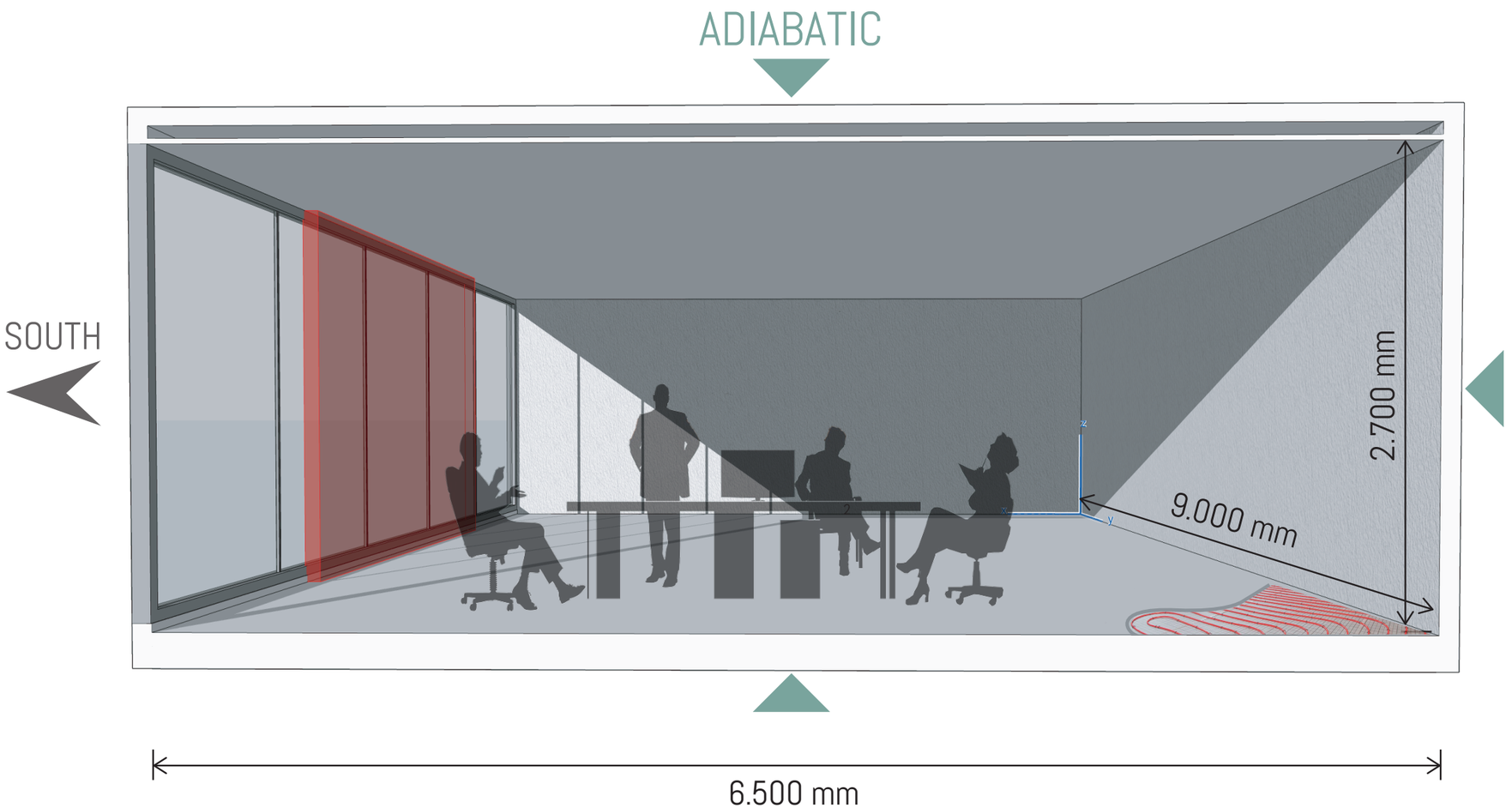
CLIMATE
TYPOLOGY
ELEMENT

CLIMATE

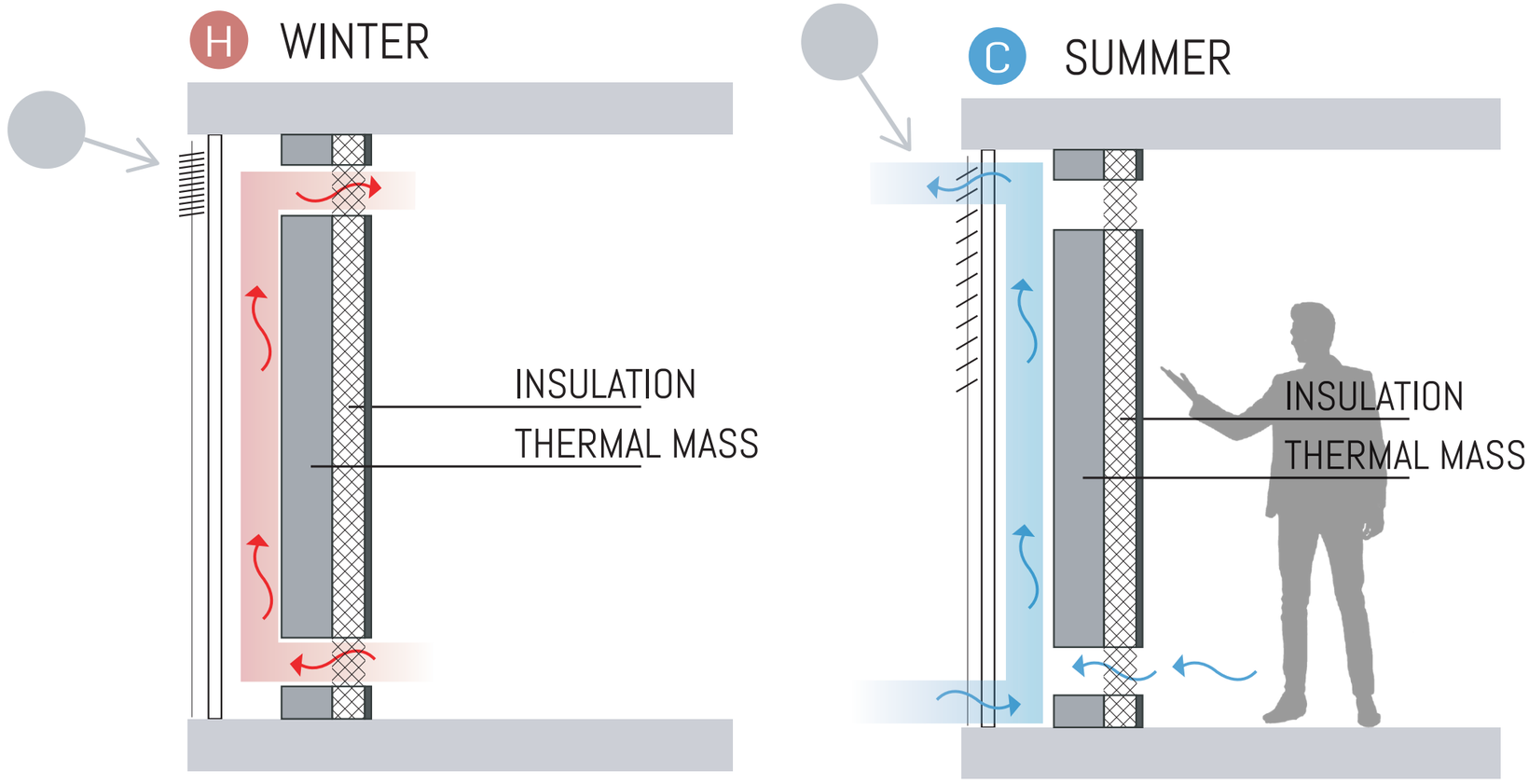
Amsterdam

Temperate climate

TYPOLOGY



TROMBE WALL



Air circulation +
Heating strategy

Solar absorption +
Ventilation strategy

RESEARCH QUESTION

"What is the most **cost-effective** and **thermodynamic** optimized design for a **passive trombe wall** based on latent heat storage for **year round** application in an office building in Amsterdam, the Netherlands?"

RESEARCH QUESTION

"What is the most **cost-effective** and **thermodynamic** optimized design for a **passive trombe wall** based on latent heat storage for **year round** application in an office building in Amsterdam, the Netherlands?"

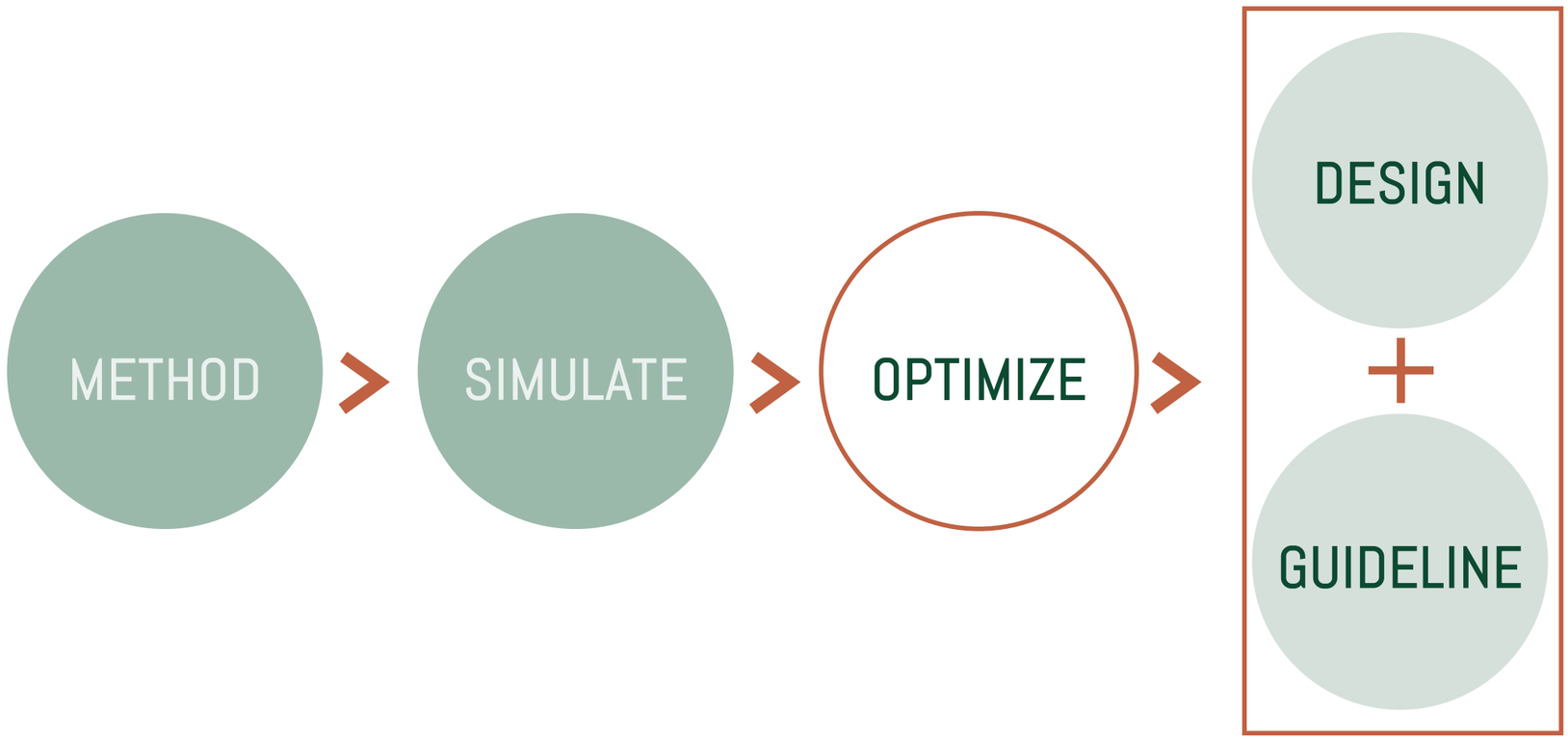
1 Thermodynamic optimization

2 Cost-effective optimization

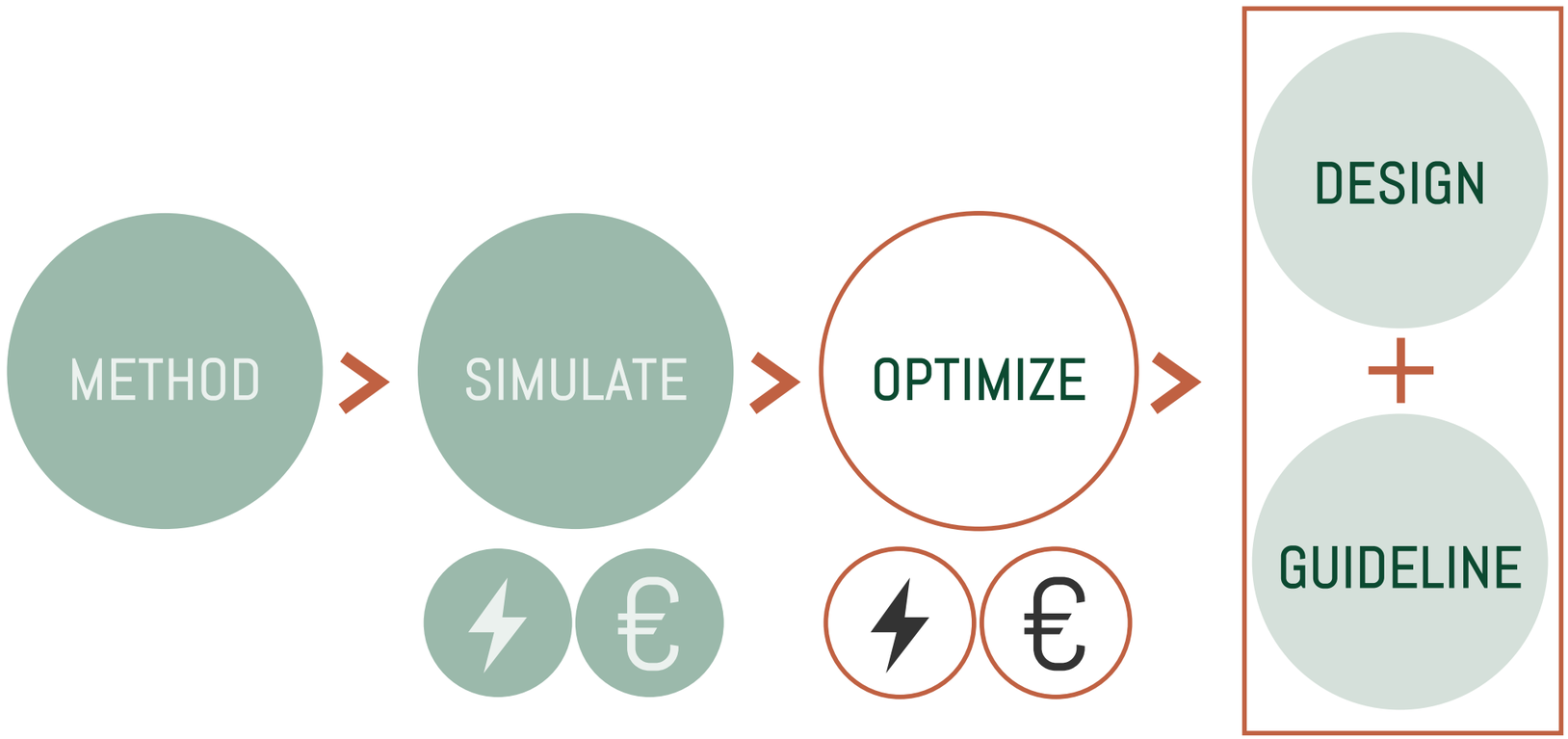
2 RESEARCH

METHODOLOGY

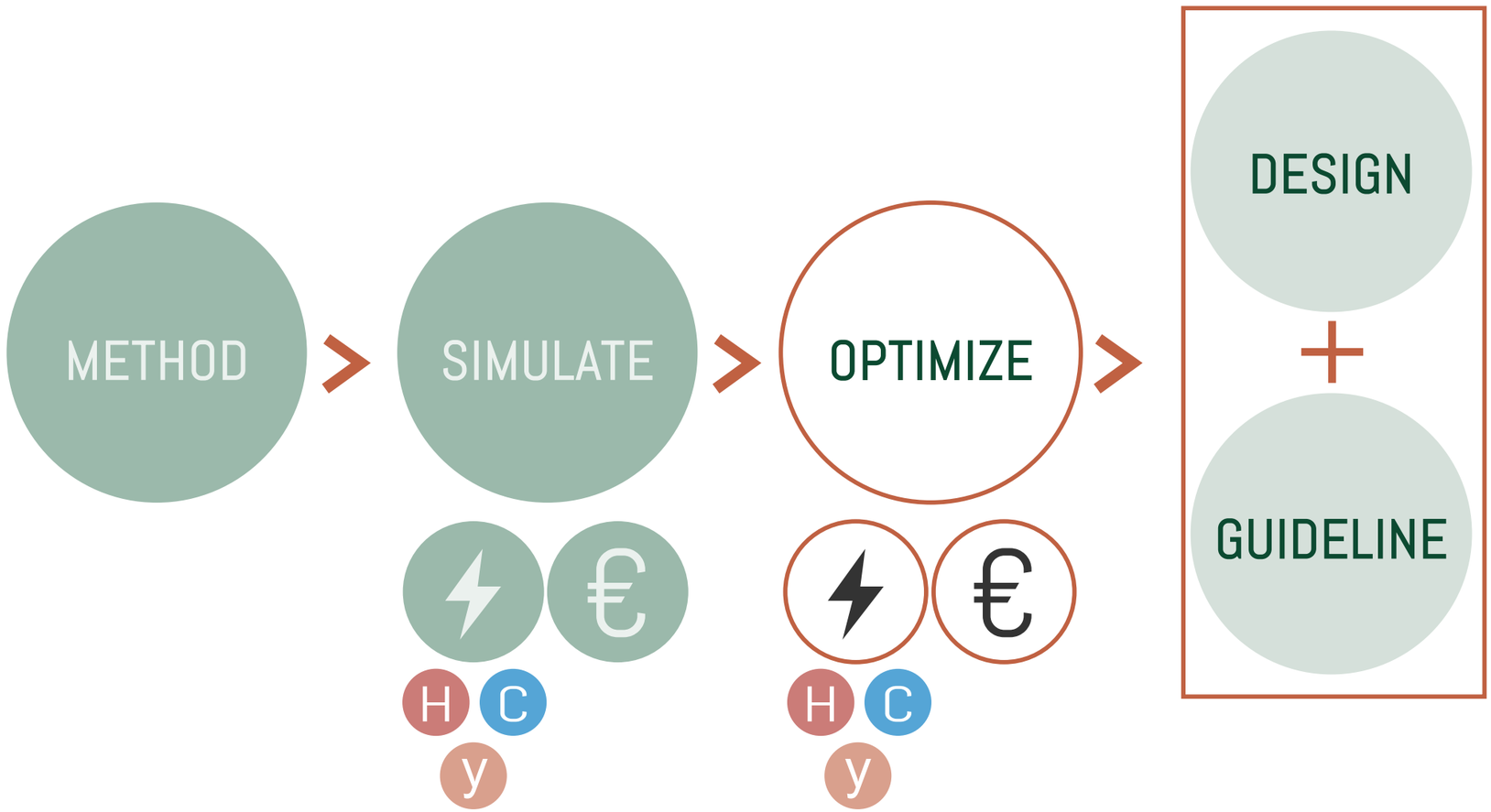
PROCESS



PROCESS



PROCESS



PLATFORM

INITIAL MODEL

SIMULATION

MATLAB + Simulink

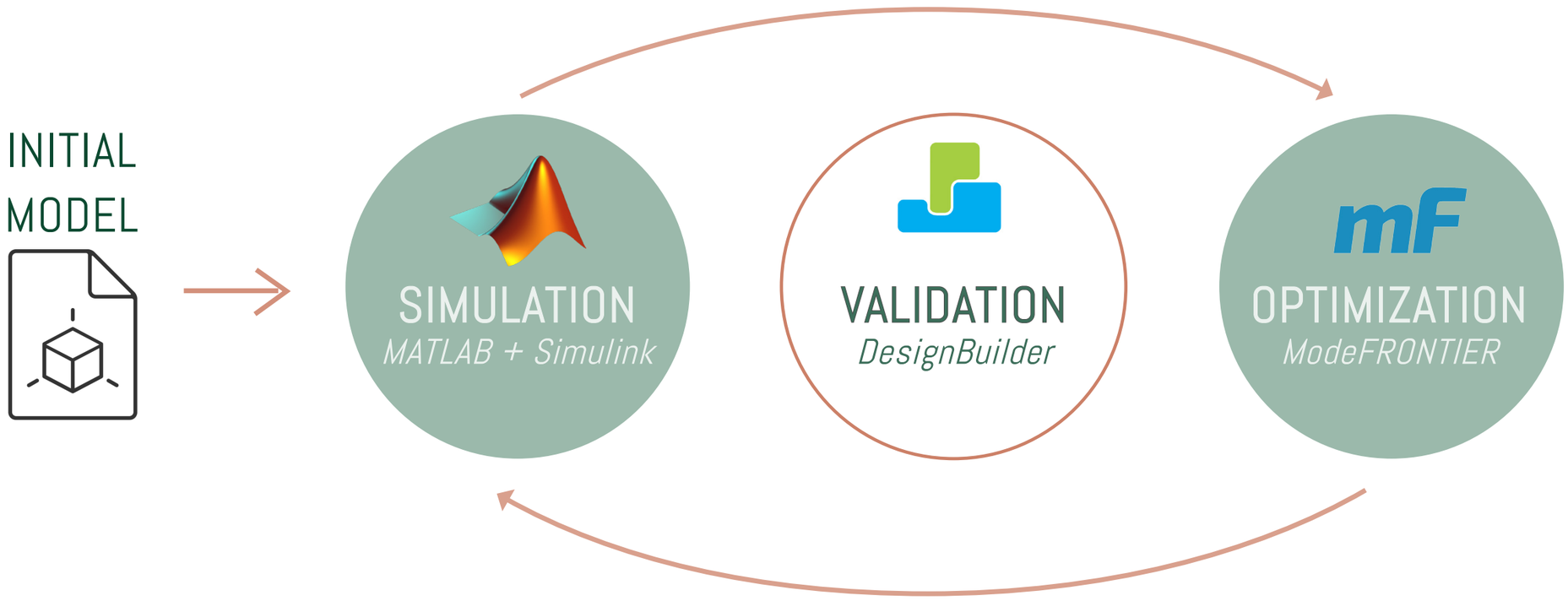
VALIDATION

DesignBuilder

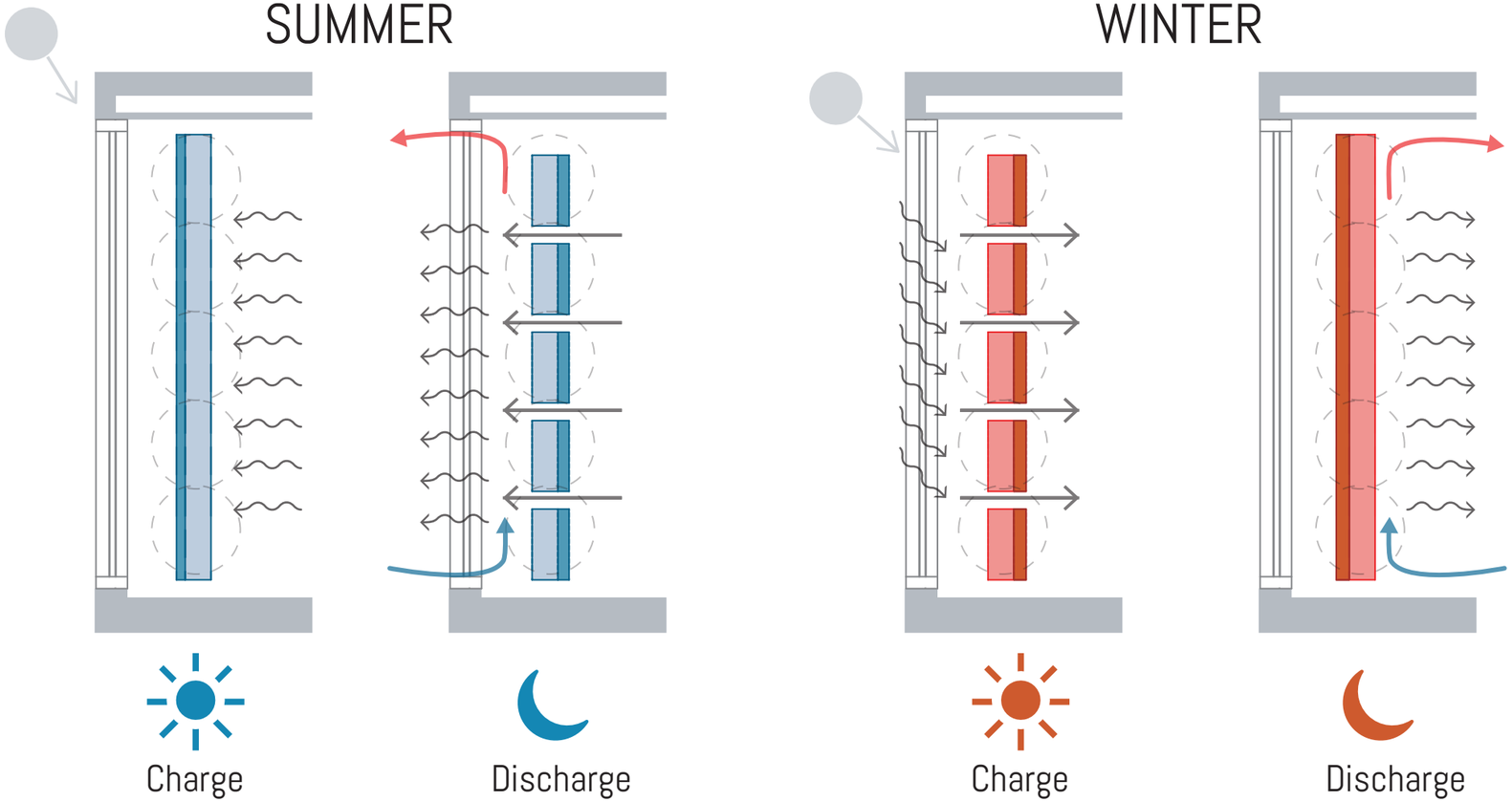
OPTIMIZATION

ModeFRONTIER

PLATFORM


INITIAL
MODEL
SIMULATION
MATLAB + Simulink
VALIDATION
DesignBuilder
mF
OPTIMIZATION
ModeFRONTIER

STRATEGIES



STRATEGIES

STRATEGIES

160	180	200	220	240
160	180	200	220	240

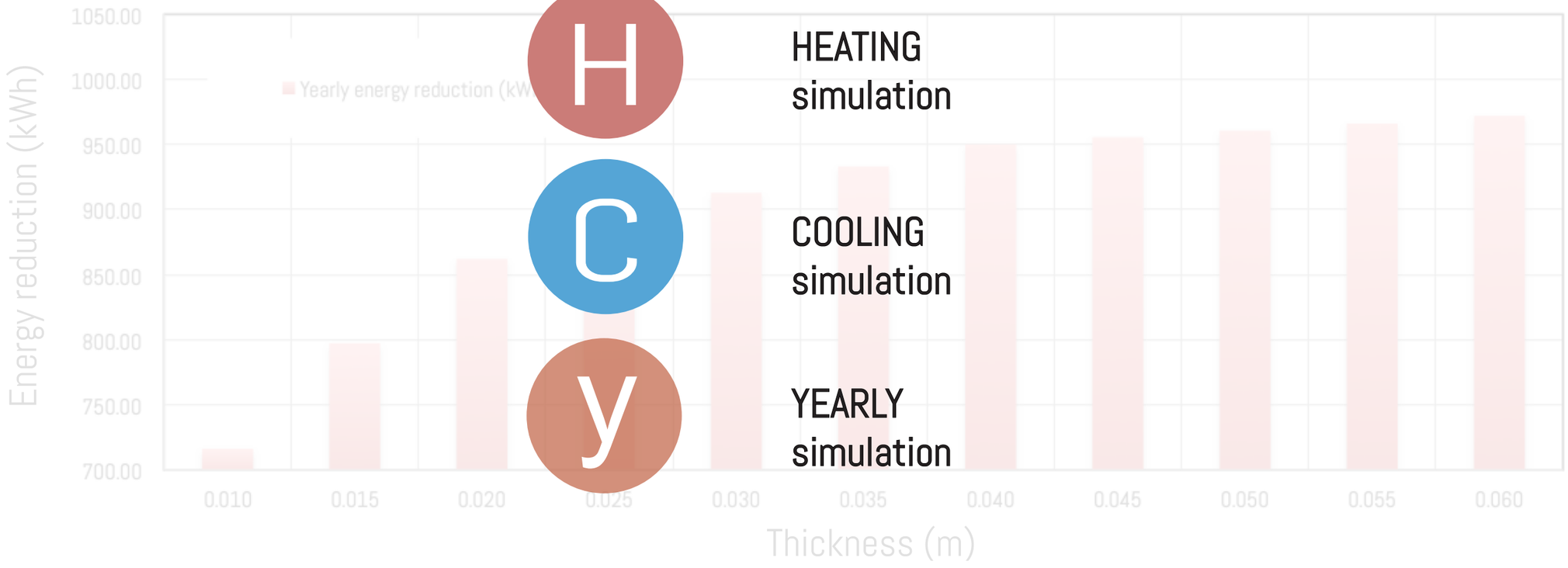
2 ENERGY

SIMULATION AND OPTIMIZATION

SIMULATION: Energy

1 PCM layer thickness (mm)

10 20 30 40 50 60



H HEATING simulation

C COOLING simulation

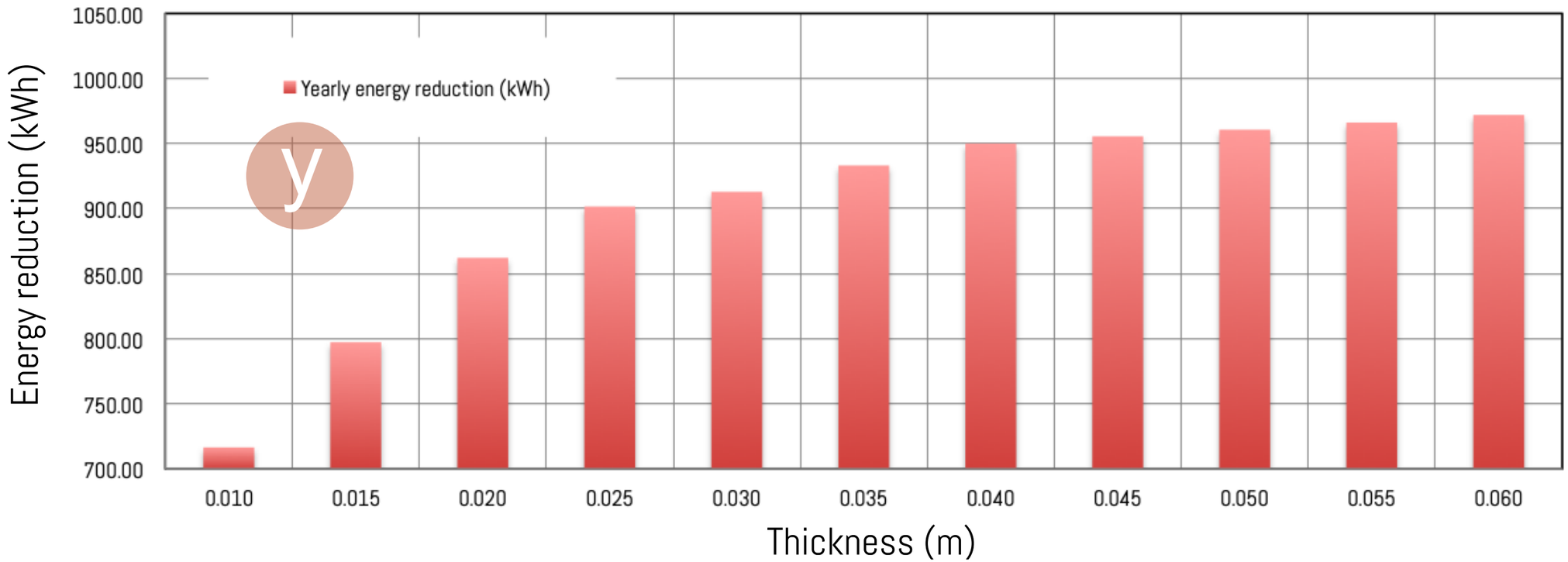
y YEARLY simulation

SIMULATION: Energy

1 PCM layer thickness (mm)

10 | 20 | 30 | 40 | 50 | 60

PANEL THICKNESS



SIMULATION: Energy

8 Convective heat transfer (W/m^2K)

2,00 | **2,50** | 3,00 | 3,50 | 4,00 | **4,50**

CONVECTIVE HEAT TRANSFER

ID (#)	Simulation value	Cooling energy usage (kWh)	Heating energy usage (kWh)	Cooling reduction (%)	Heating reduction (%)	Cooling reduction (kWh)	Heating reductionn (kWh)	Yearly energy reduction (kWh)
55	2.00	495.67	78.70	56.21	76.09	636.33	250.40	886.74
56	2.50	486.00	101.94	57.07	69.02	646.00	227.16	873.16
57	3.00	455.50	122.16	59.76	62.88	676.50	206.94	883.44
58	3.50	438.34	158.56	61.28	51.82	693.66	170.54	864.20
59	4.00	420.78	181.13	62.83	44.96	711.22	147.97	859.19
60	4.50	418.51	207.80	63.03	36.86	713.49	121.30	834.79

C H y

SIMULATION: Energy

C

H

TROMBE WALL RATIO

MELTING TEMPERATURE

COVERING TEMPERATURE

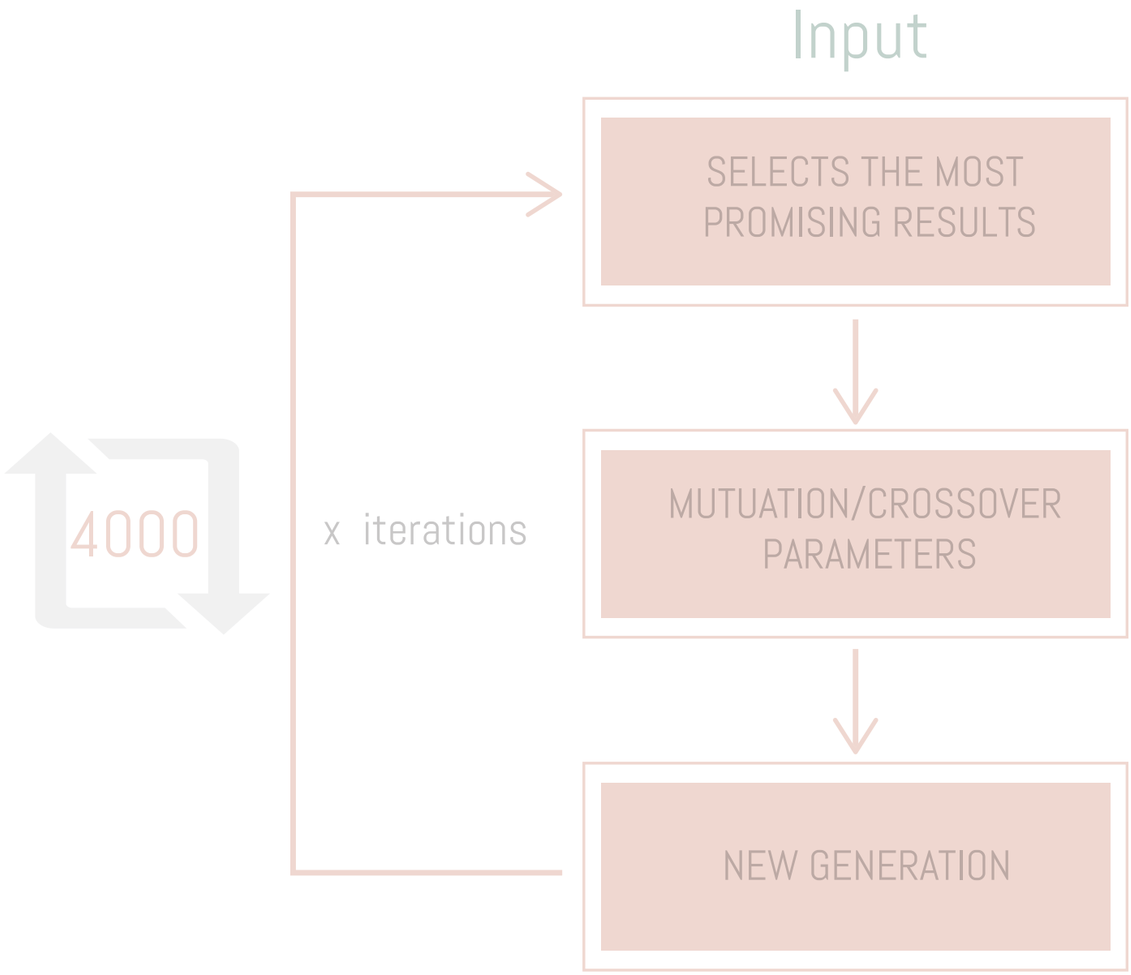
SIMULATION: Energy

Summarized overview

Energy performance

		INPUT		RESULTS				SIMULATION RESULT VALUES				
		ID (#)	Simulation value	Cooling reduction (%)	Heating reduction (%)	Cooling reduction (kWh)	Heating reductionn (kWh)	Cooling energy usage (kWh)	Heating energy usage (kWh)	Total panel volume (m^3)	Latent storage capacity (kJ)	Panel surface area (m^2)
1.1	Panel thickness (m)	1.1	0.010	48.53	50.82	549.35	167.26	582.65	161.84	0.21	5.39E+07	20.65
		1.2	0.015	53.01	59.95	600.12	197.31	531.88	131.79	0.31	8.09E+07	20.65
		2.1	0.020	57.51	64.17	651.06	211.18	480.94	117.92	0.41	1.08E+08	20.65
		2.2	0.025	58.84	71.58	666.05	235.58	465.95	93.52	0.52	1.35E+08	20.65
		3.1	0.030	59.76	71.86	676.45	236.49	455.55	92.61	0.62	1.62E+08	20.65
		3.2	0.035	60.71	74.73	687.26	245.93	444.74	83.17	0.72	1.89E+08	20.65
		4.1	0.040	61.51	77.09	696.35	253.72	435.65	75.38	0.83	2.16E+08	20.65
		4.2	0.045	61.76	77.93	699.10	256.46	432.90	72.64	0.93	2.43E+08	20.65
		5.1	0.050	61.64	79.89	697.74	262.92	434.26	66.18	1.03	2.70E+08	20.65
		5.2	0.055	62.66	78.02	709.36	256.76	422.64	72.34	1.14	2.97E+08	20.65
		6	0.060	62.50	80.37	707.51	264.49	424.49	64.61	1.24	3.23E+08	20.65
2.1	Blind covering (°C)	7	20.00	60.50	50.19	684.88	165.19	447.12	163.91	0.52	1.35E+08	20.65
		8	21.00	60.68	60.66	686.94	199.64	445.06	129.46	0.52	1.35E+08	20.65
		9	22.00	58.84	71.58	666.05	235.58	465.95	93.52	0.52	1.35E+08	20.65
		10	23.00	48.74	75.01	551.76	246.86	580.24	82.24	0.52	1.35E+08	20.65
		11	24.00	-	75.99	-	250.08	829.40	79.02	0.52	1.35E+08	20.65
		12	25.00	-	77.16	-	253.95	3029.17	75.15	0.52	1.35E+08	20.65
		13	26.00	-	77.85	-	256.20	3328.89	72.90	0.52	1.35E+08	20.65
3.1	Latent heat storage: organic (J/kg)	14	1.60E+05	52.47	57.72	593.92	189.96	538.08	139.14	0.52	7.02E+07	20.65
		15	1.80E+05	52.37	58.90	592.86	193.83	539.14	135.27	0.52	7.90E+07	20.65
		16	2.00E+05	52.94	63.58	599.32	209.24	532.68	119.86	0.52	8.78E+07	20.65
		17	2.20E+05	52.69	69.10	596.42	227.40	535.58	101.70	0.52	9.66E+07	20.65
		18	2.40E+05	53.02	68.58	600.15	225.69	531.85	103.41	0.52	1.05E+08	20.65
4.1	Latent heat storage: inorganic (J/kg)	19	1.60E+05	58.25	67.30	659.38	221.48	472.62	107.62	0.52	1.20E+08	20.65
		20	1.80E+05	58.84	71.58	666.05	235.58	465.95	93.52	0.52	1.35E+08	20.65
		21	2.00E+05	58.92	74.02	666.92	243.62	465.08	85.48	0.52	1.50E+08	20.65
		22	2.20E+05	59.45	78.67	673.01	258.90	458.99	70.20	0.52	1.65E+08	20.65
		23	2.40E+05	60.64	76.81	686.40	252.79	445.60	76.31	0.52	1.80E+08	20.65
5.1	Melting temperature (°C)	24	20.00	41.88	58.85	474.10	193.67	657.90	135.43	0.52	1.35E+08	20.65
		25	21.00	43.52	66.90	492.70	220.18	639.30	108.92	0.52	1.35E+08	20.65
		26	22.00	46.48	71.83	526.12	236.39	605.88	92.71	0.52	1.35E+08	20.65
		27	23.00	49.95	72.82	565.45	239.64	566.55	89.46	0.52	1.35E+08	20.65
		28	24.00	54.27	71.84	614.34	236.43	517.66	92.67	0.52	1.35E+08	20.65
		29	25.00	58.84	71.58	666.05	235.58	465.95	93.52	0.52	1.35E+08	20.65
		30	26.00	60.74	64.45	687.54	212.12	444.46	116.98	0.52	1.35E+08	20.65
6.1	Trombe wall ratio 1 (%)	31	0.40	60.07	-44.25	680.01	-145.62	451.99	474.72	0.23	5.99E+07	9.18
		32	0.50	59.98	-20.59	678.95	-67.77	453.05	396.87	0.29	7.49E+07	11.47
		33	0.60	59.24	9.09	670.56	29.90	461.44	299.20	0.34	8.98E+07	13.77
		34	0.70	59.94	17.81	678.50	58.62	453.50	270.48	0.40	1.05E+08	16.06
		35	0.80	60.08	36.49	680.10	120.10	451.90	209.00	0.46	1.20E+08	18.36
		36	0.90	60.23	52.45	681.80	172.60	450.20	156.50	0.52	1.35E+08	20.65
7.1	Trombe wall ratio 2 (%)	37	0.40	69.66	-132.44	788.58	-435.87	343.42	764.97	0.52	1.35E+08	20.65
		38	0.50	67.91	-85.35	768.70	-280.90	363.30	610.00	0.52	1.35E+08	20.65
		39	0.60	66.64	-44.18	754.38	-145.38	377.62	474.48	0.52	1.35E+08	20.65
		40	0.70	66.10	-4.36	748.26	-14.36	383.74	343.46	0.52	1.35E+08	20.65
		41	0.80	63.32	28.95	716.73	95.29	415.27	233.81	0.52	1.35E+08	20.65
		42	0.90	60.08	52.45	680.10	172.60	451.90	156.50	0.52	1.35E+08	20.65
8.1	System layers degrees (no.)	43.1	1.00	58.84	71.58	666.05	235.58	465.95	93.52	0.52	1.35E+08	20.65
		44.1	2.00	58.31	65.42	660.10	215.30	471.90	113.80	0.52	1.35E+08	20.65
		45.1	3.00	59.43	64.62	672.80	212.68	459.20	116.42	0.52	1.35E+08	20.65
		46.1	1.00	58.44	54.83	661.53	180.45	470.47	148.65	0.52	1.35E+08	20.65
		47.1	2.00	57.00	57.86	645.28	190.41	486.72	138.69	0.52	1.35E+08	20.65
		48.1	3.00	57.44	49.68	650.19	163.50	481.81	165.60	0.52	1.35E+08	20.65
9.1	System layers +degree (no.)	43.2	1.00	43.62	67.54	493.73	222.29	638.27	106.81	0.52	1.35E+08	20.65
		44.2	2.00	56.32	64.79	637.57	213.23	494.43	115.87	0.52	1.35E+08	20.65
		45.2	3.00	56.92	66.81	644.37	219.87	487.63	109.23	0.52	1.35E+08	20.65
		46.2	1.00	54.97	71.88	622.22	236.55	509.78	92.55	0.52	1.35E+08	20.65
		47.2	2.00	56.66	55.45	641.51	182.49	490.49	146.61	0.52	1.35E+08	20.65
		48.2	3.00	59.77	54.66	676.57	179.90	455.43	149.20	0.52	1.35E+08	20.65
10.1	Panel area ratio (%)	49	1.05	57.95	67.85	656.00	223.30	476.00	105.80	0.52	1.35E+08	21.69
		50	1.10	58.42	65.36	661.30	215.10	470.70	114.00	0.52	1.35E+08	22.72
		51	1.15	58.60	65.54	663.40	215.70	468.60	113.40	0.52	1.35E+08	23.75
		52	1.20	59.06	65.66	668.60	216.10	463.40	113.00	0.52	1.35E+08	24.79
		53	1.25	59.47	67.79	673.20	223.10	458.80	106.00	0.52	1.35E+08	25.82
		54	1.30	59.90	64.87	678.10	213.50	453.90	115.60	0.52	1.35E+08	26.85
11.1	Convective heat transfer (W/m2K)	55	2.00	56.21	76.09	636.33	250.40	495.67	78.70	0.52	1.35E+08	20.65
		56	2.50	57.07	69.02	646.00	227.16	486.00	101.94	0.52	1.35E+08	20.65
		57	3.00	59.76	62.88	676.50	206.94	455.50	122.16	0.52	1.35E+08	20.65
		58	3.50	61.28	51.82	693.66	170.54	438.34	158.56	0.52	1.35E+08	20.65
		59	4.00	62.83	44.96	711.22	147.97	420.78	181.13	0.52	1.35E+08	20.65
		60	4.50	63.03	36.86	713.49	121.30	418.51	207.80	0.52	1.35E+08	20.65
12.1	Cavity width (m)	61	0.01 m	57.39	67.79	649.70	223.10	482.30	106.00	0.52	1.35E+08	20.65
		62	0.04 m	57.38	67.79	649.50	223.10	482.50	106.00	0.52	1.35E+08	20.65
		63	0.07 m	57.45	65.36	650.30	215.10	481.70	114.00	0.52	1.35E+08	20.65
		64	0.10 m	57.75	65.03	653.70	214.00	478.30	115.10	0.52	1.35E+08	20.65
		65	0.13 m	57.60	67.55	652.00	222.30	480.00	106.80	0.52	1.35E+08	20.65
		66	0.16 m	57.74	67.15	653.60	221.00	478.40	108.10	0.52	1.35E+08	20.65
13.1	Thermal conduction (W/m.K) + density	67	0.30	57.75	63.59	653.70	209.30	478.30	119.80	0.52	1.35E+08	20.65
		68	0.50	59.07	68.00	668.70	223.80	463.30	105.30	0.52	1.35E+08	20.65
		69	0.70	60.13	73.15	680.60	240.72	451.40	88.38	0.52	1.35E+08	20.65
		70	0.90	60.70	78.53	687.10	258.43	444.90	70.67	0.52	1.35E+08	20.65
		71	1.10	61.24	81.68	693.30	268.81	438.70	60.29	0.52	1.35E+08	20.65
		72	1.30	61.51	85.91	696.30	282.71	435.70	46.39	0.52	1.35E+08	20.65
13.2	Thermal conduction (W/m.K)	67	0.30	57.09	67.82	646.30	223.20	485.70	105.90	0.52	1.35E+08	20.65
		68	0.50	57.31	67.15	648.70	221.00	483.30	108.10	0.52	1.35E+08	20.65
		69	0.70	57.49	67.61	650.80	222.50	481.20	106.60	0.52	1.35E+08	20.65
		70	0.90	57.95	66.82	656.00	219.90	476.00	109.20	0.52	1.35E+08	20.65
		71	1.10	58.33	67.55	660.30	222.30	471.70	106.80	0.52	1.35E+08	20.65
		72	1.30	58.23	63.66	659.20	209.50	472.80	119.60	0.52	1.35E+08	20.65

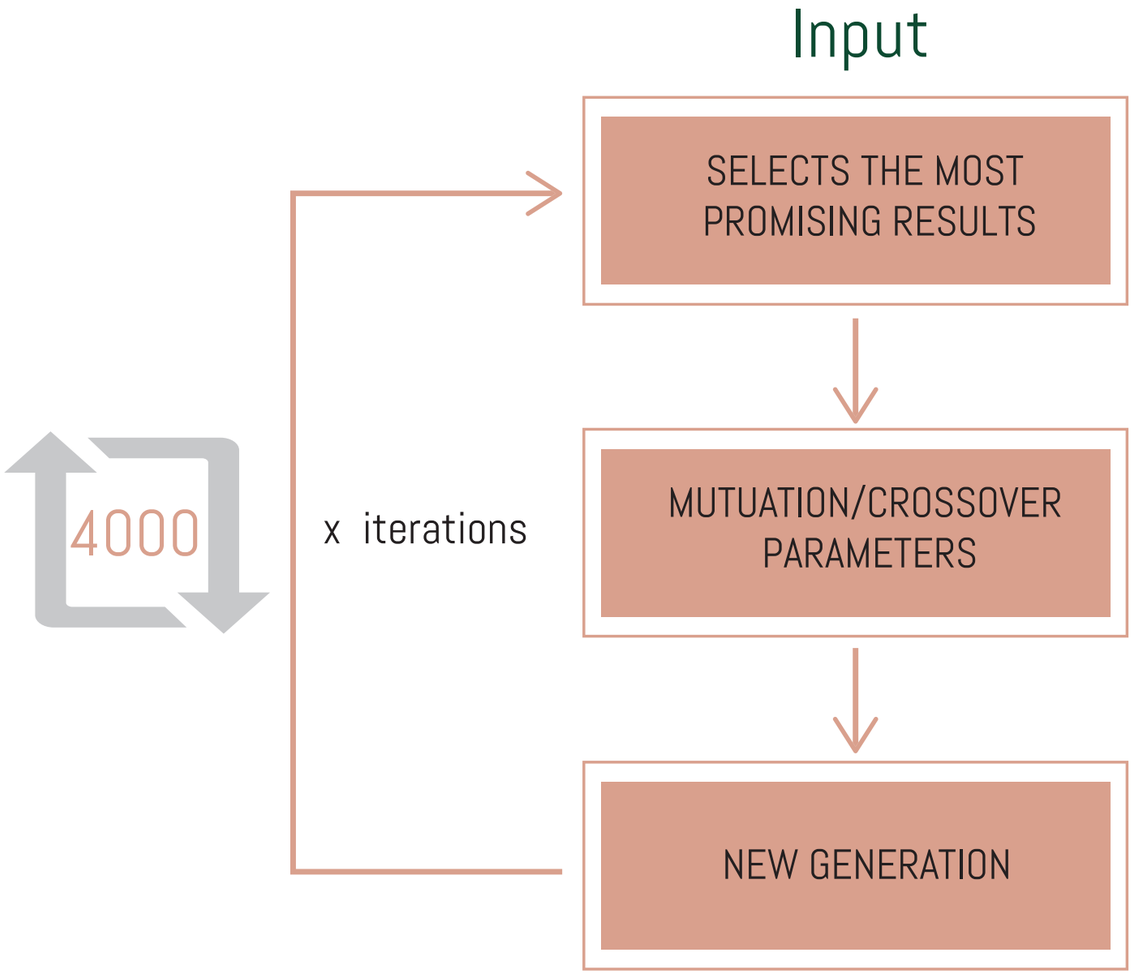
OPTIMIZATION: Genetic algorithm

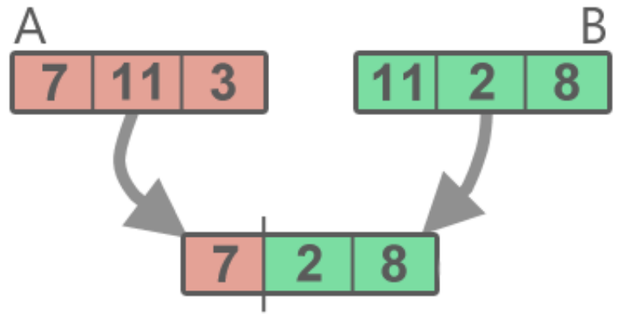


objective

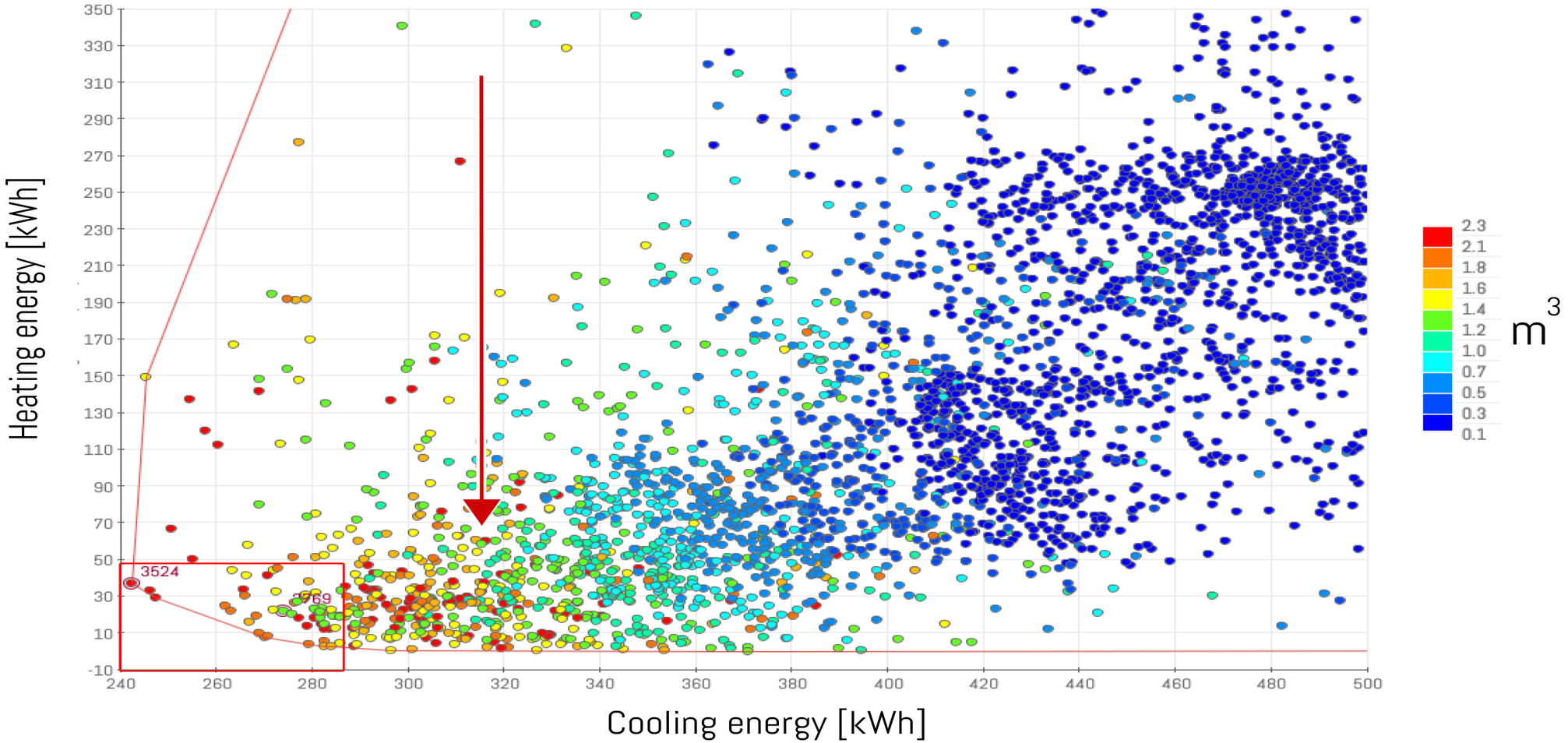
ENERGY DEMAND

OPTIMIZATION: Genetic algorithm

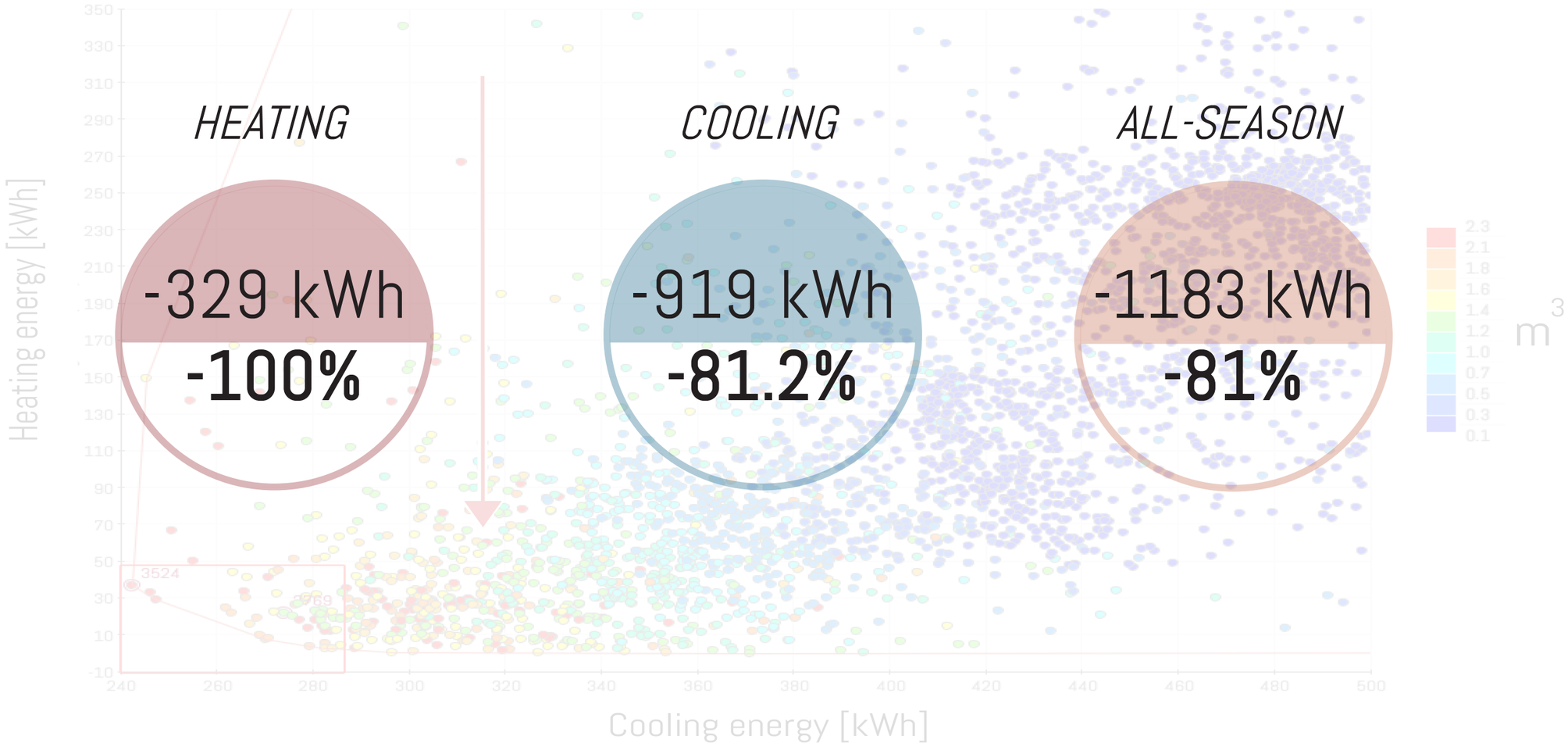




OPTIMIZATION: All-season



OPTIMIZATION: Energy



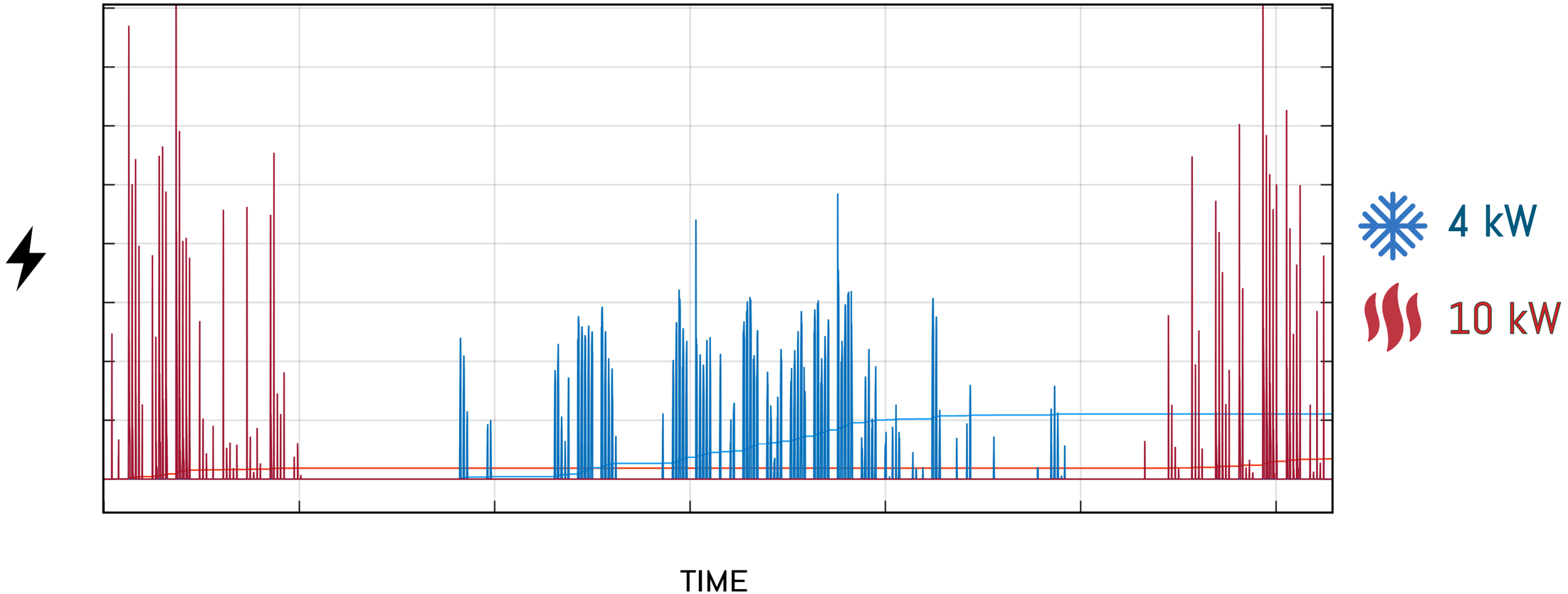
2 COSTS

SIMULATION AND OPTIMIZATION

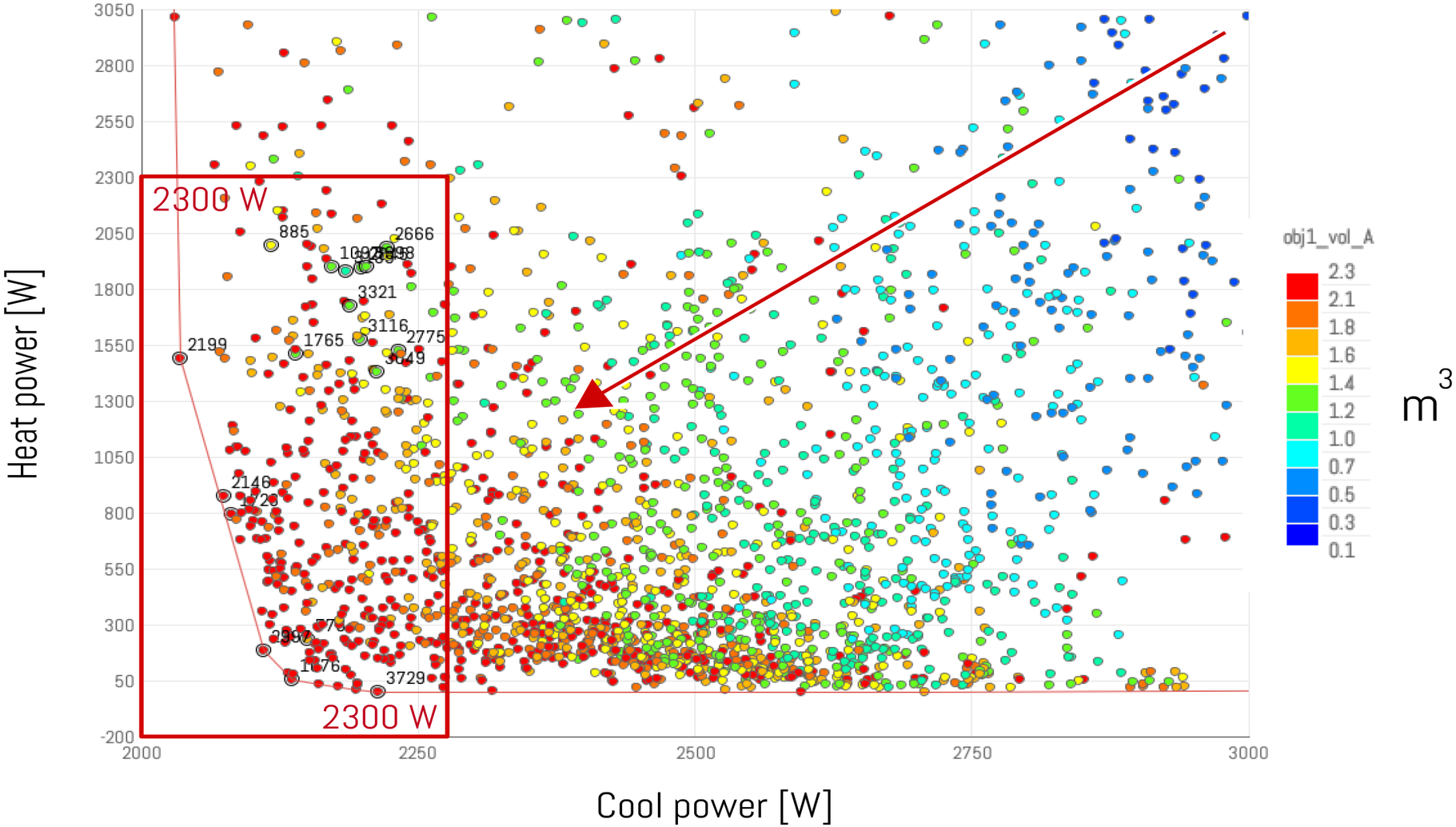
OPTIMIZATION: Objectives

REDUCTION IN COSTS

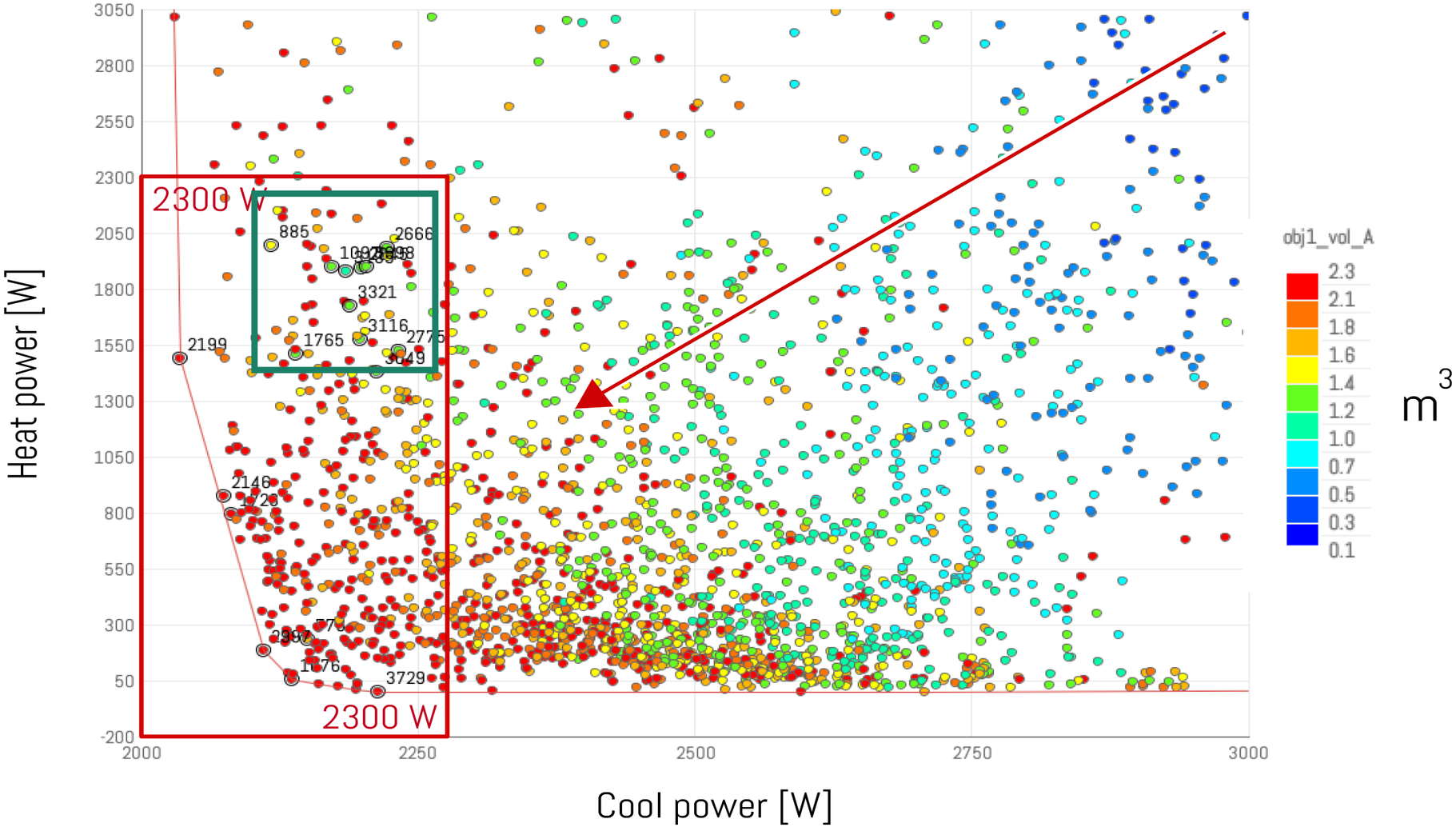
CALCULATION: Peak-loads



OPTIMIZATION: Costs

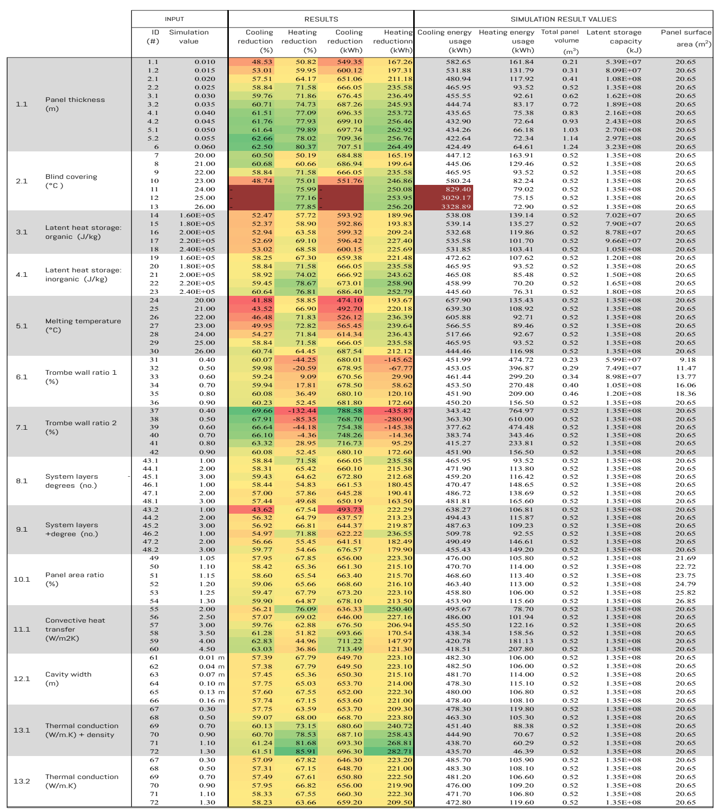


OPTIMIZATION: Costs

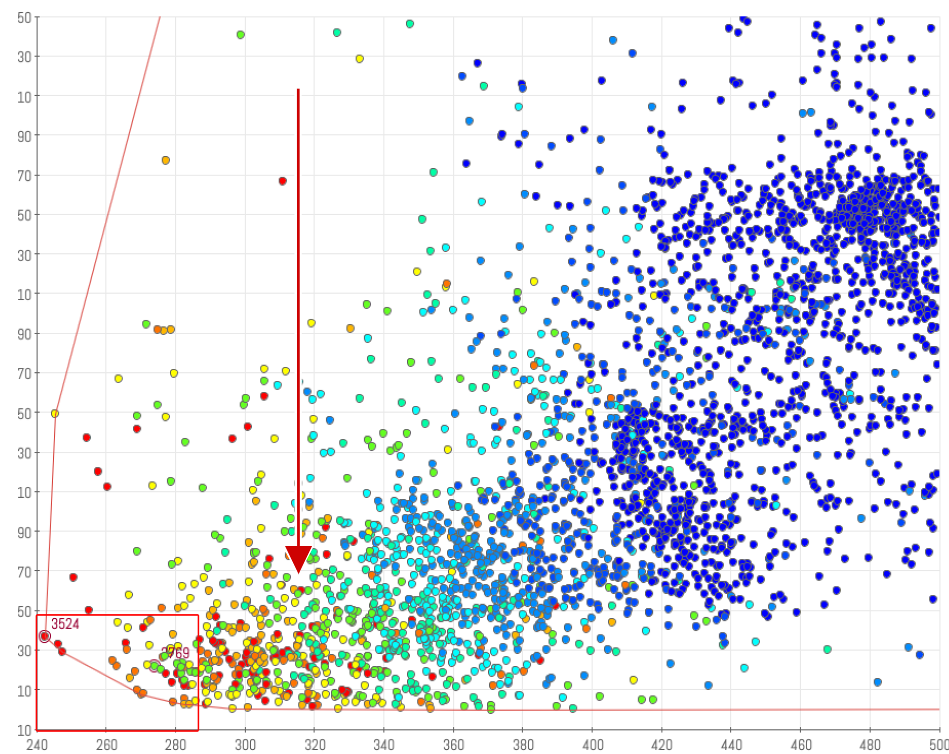


DESIGN REQUIREMENTS

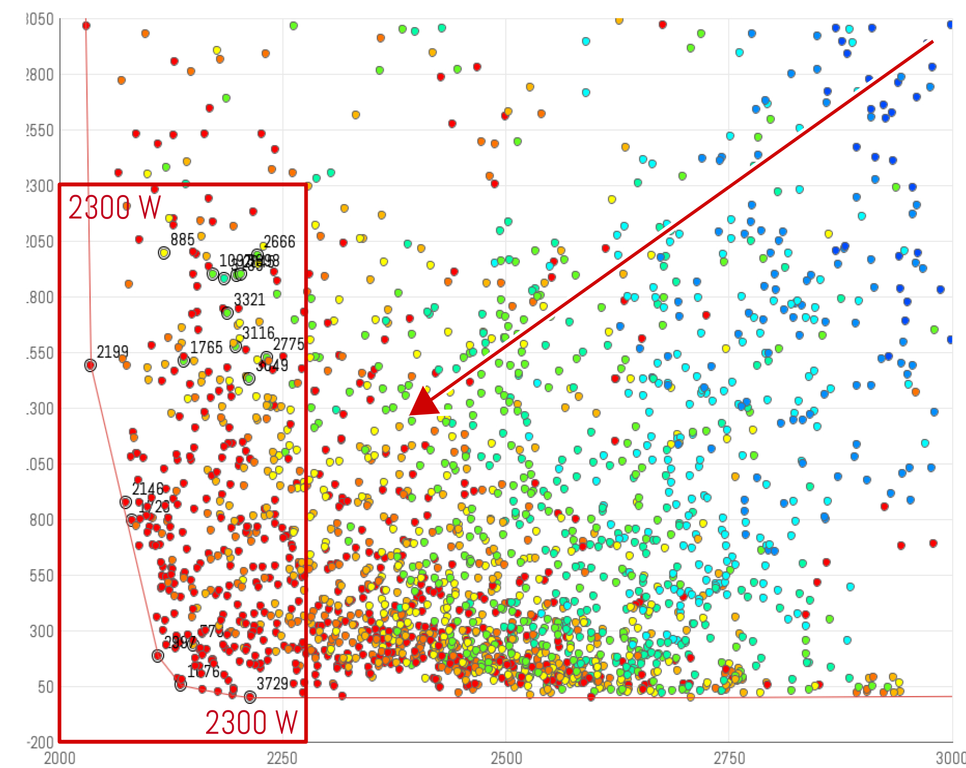
Simulations



Optimizations energy



Optimization costs



DESIGN REQUIREMENTS

TROMBE WALL PROPERTIES

6 cm	180 kJ/kg		25°C	
Panel thickness	PCM heat capacity	Various Trombe wall ratios	Melting temperature	Increased surface area
1 layered		0.1 W/m.K		22°C
Panel layering	Small cavity width	Thermal conductivity	Varying convective heat transfer	Covering temperature

GUIDELINE SUMMARY

CATEGORIES

1 Heating energy reduction

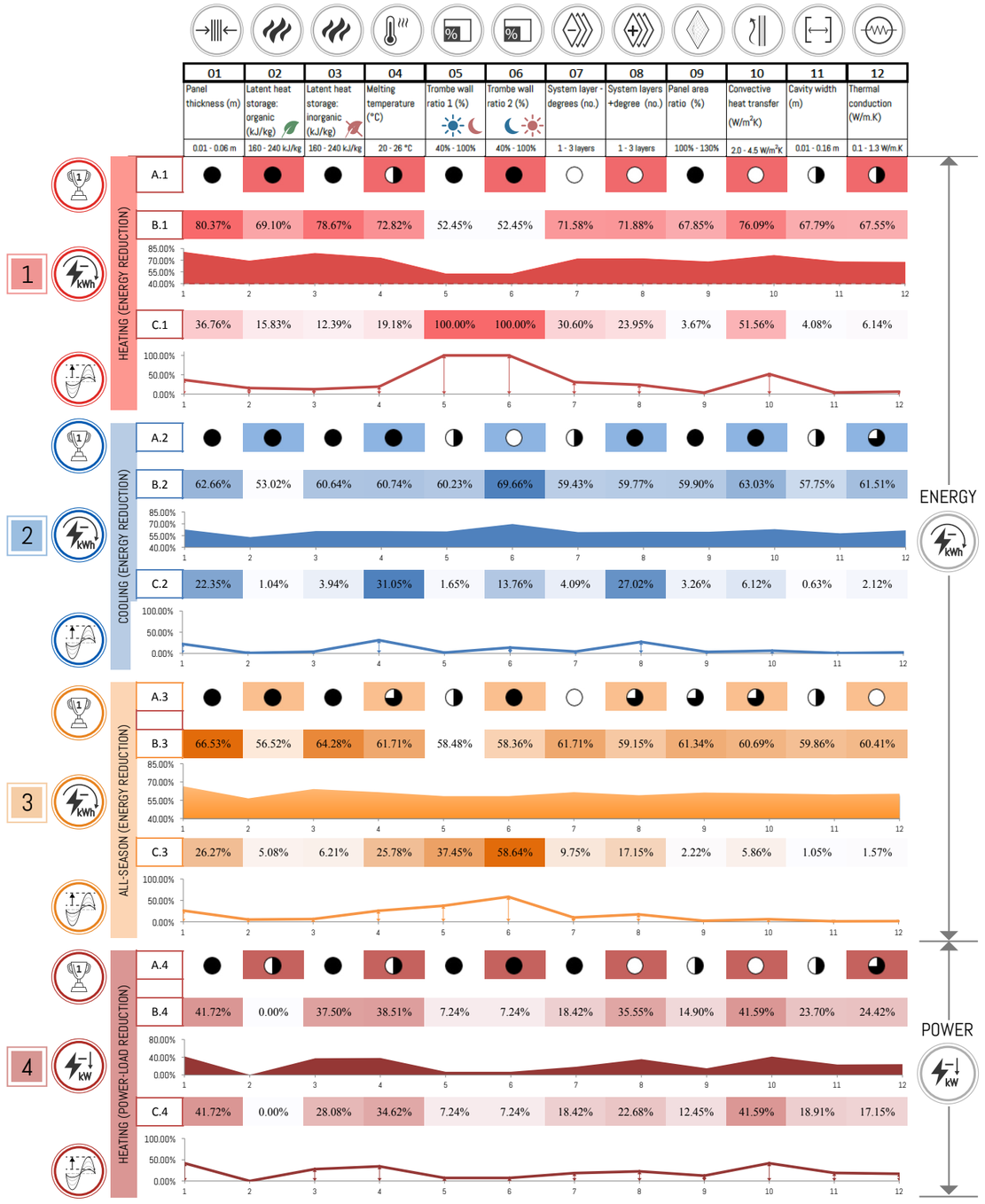
2 Cooling energy reduction

3 All-season energy reduction

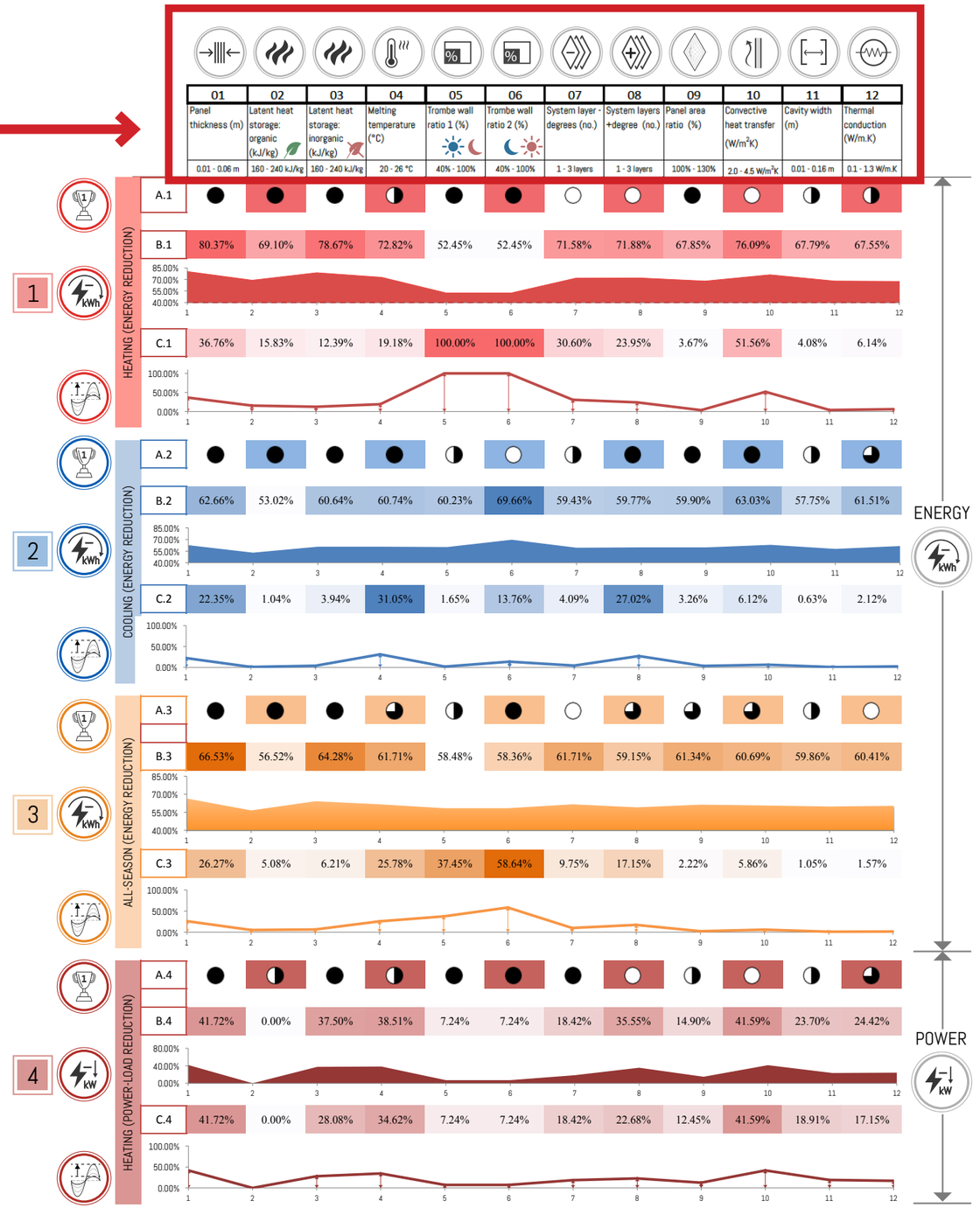
4 Heating power reduction

energy

power



INPUT PARAMETERS

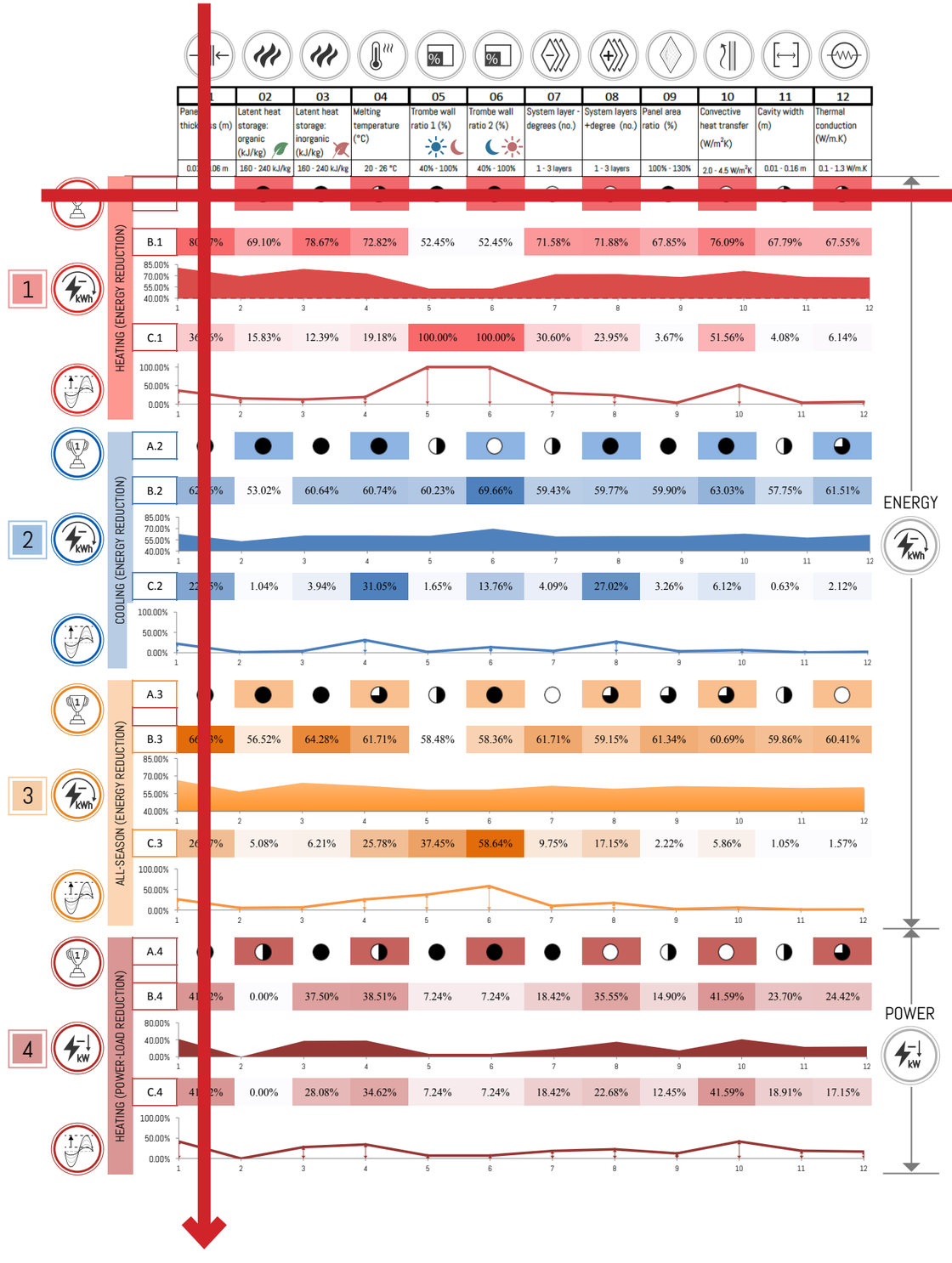


COMPARISON

A — *Best performing parameter value*

B — *Energy reduction performance*

C — *Range of dataset*



3 DESIGN

CONCLUSION

3 CONCLUSION

"What is the most **cost-effective** and **thermodynamic** optimized design for a **passive trombe wall** based on latent heat storage for **year round** application in an office building in Amsterdam, the Netherlands?"

ADAPTIVE DESIGN

difference in required performance for seasonal application

HEAT CAPACITY

peak loads are highly affected by panel thickness

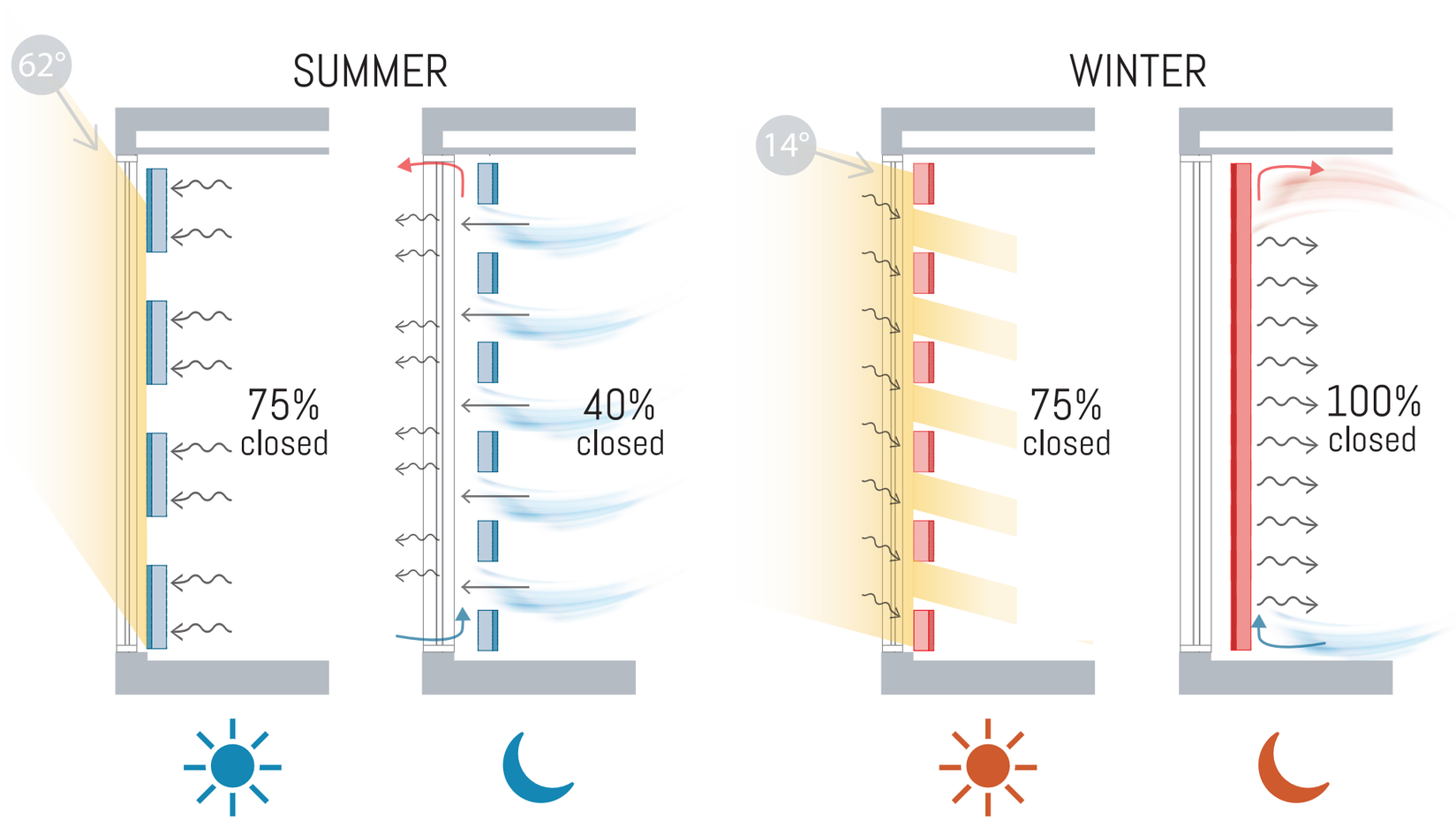
HEAT TRANSFER

difference in performance for energy and power-load

INSULATION

a higher insulation factor reduces the heat losses to the exterior

DESIGN REQUIREMENTS

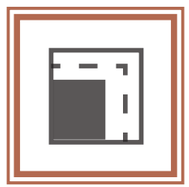


DESIGN REQUIREMENTS

TROMBE WALL PROPERTIES

Panel thickness

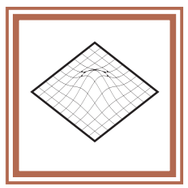
Latent heat of fusion



Various Trombe wall ratios

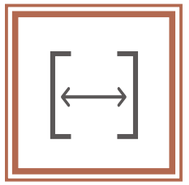
Melting temperature

Varying convective heat transfer



Increased surface area

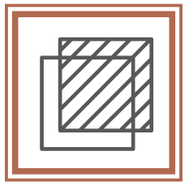
Panel layering



Small cavity width

Thermal conductivity

Cascading strategy

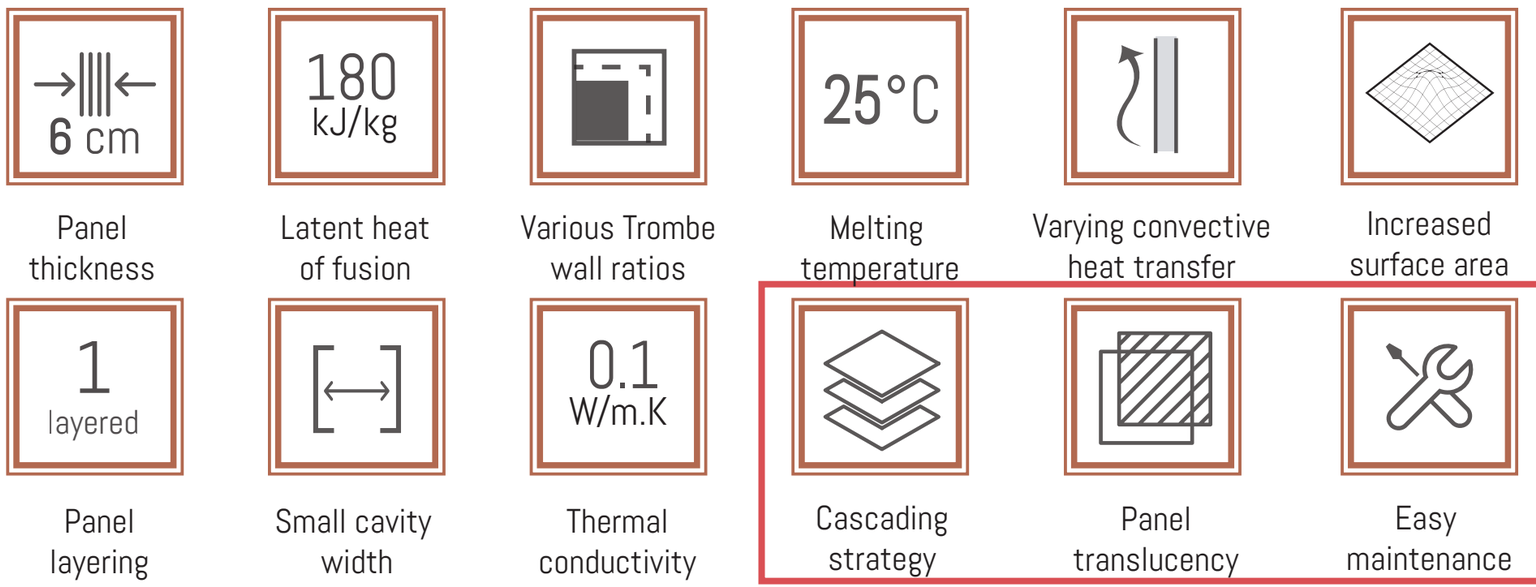


Panel translucency

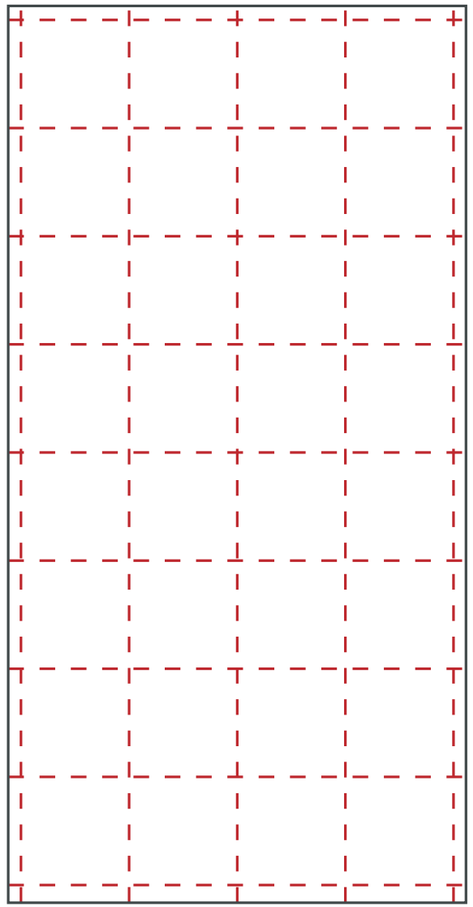
Easy maintenance

DESIGN REQUIREMENTS

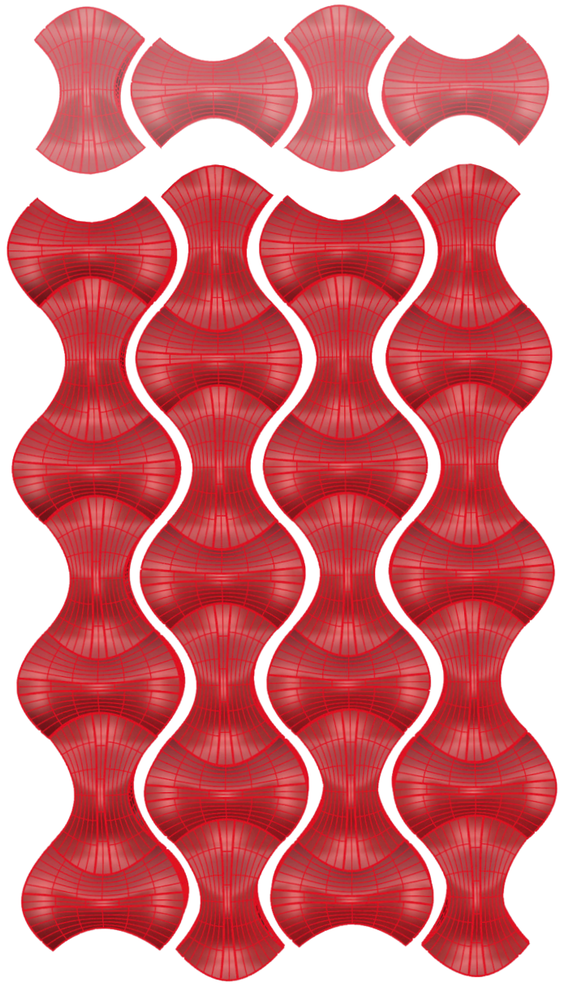
TROMBE WALL PROPERTIES



DESIGN TYPOLOGY

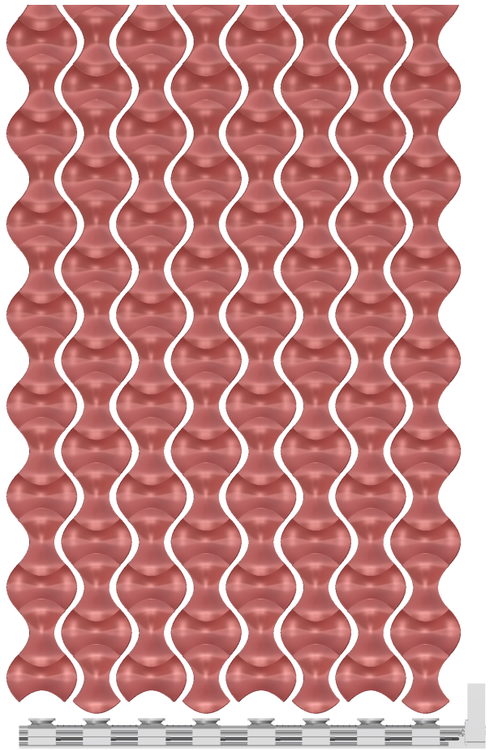


1 Small segment division

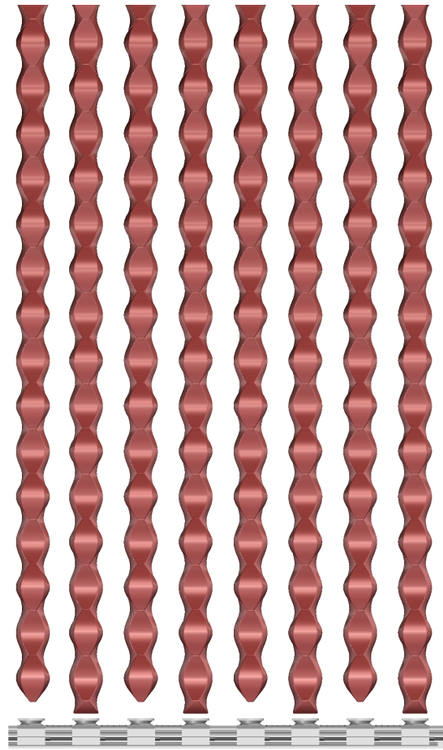


2 Vertical elements

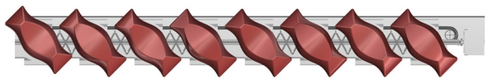
DESIGN TYPOLOGY



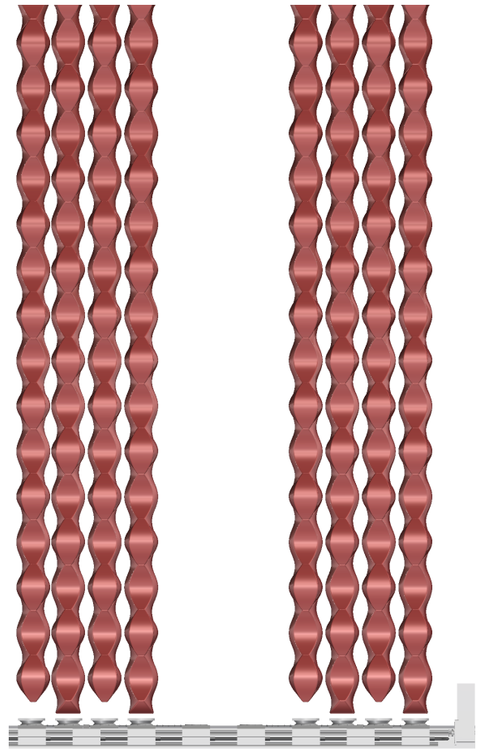
Position 1: 100%



Position 2: 40-50%

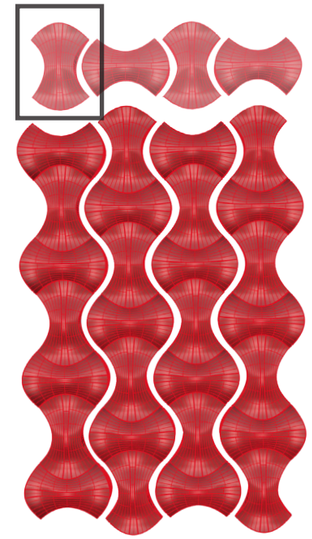


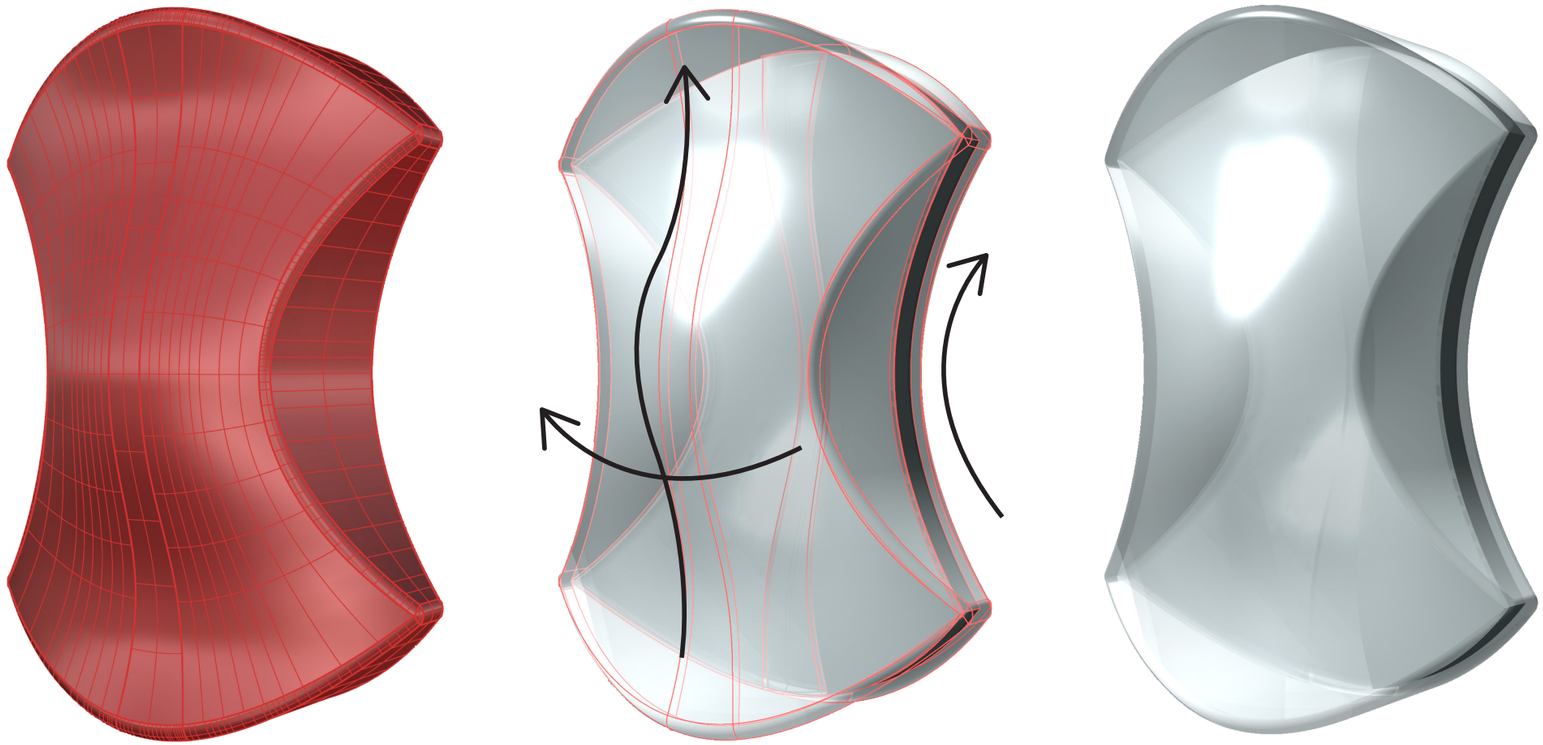
Position 3: 75-85%



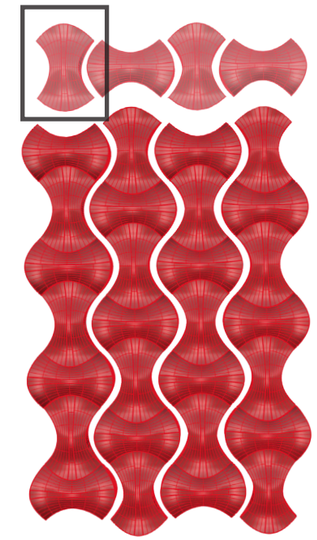
Position 4: 40-50%

DESIGN TYPOLOGY

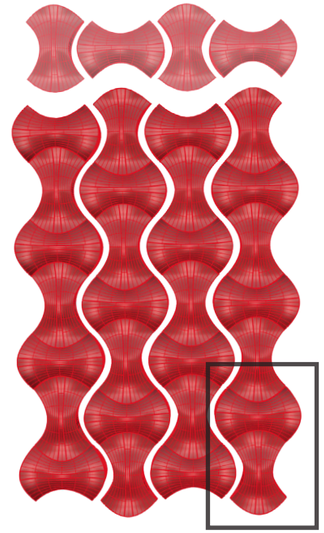


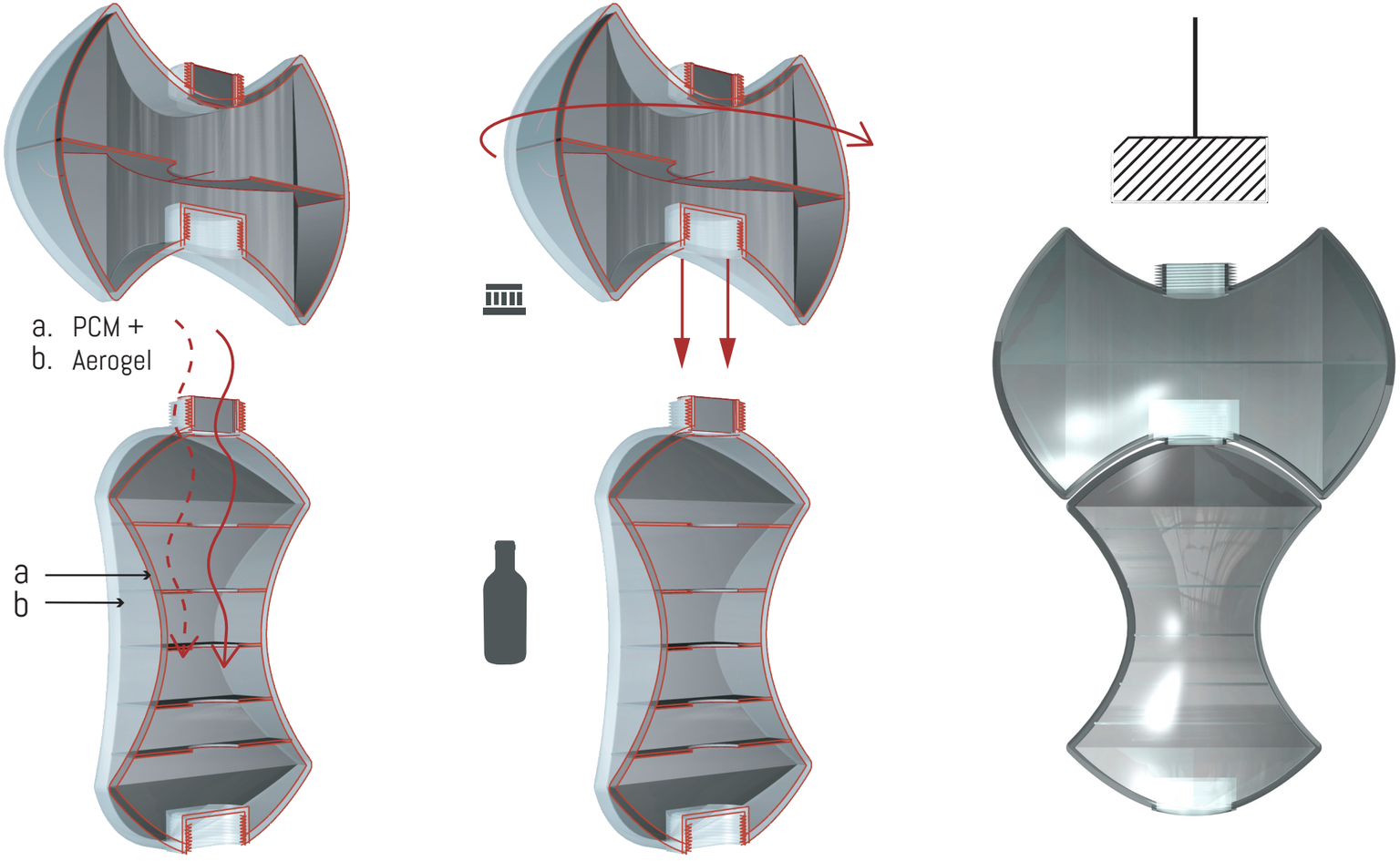


DESIGN TYPOLOGY



DESIGN ASSEMBLY





DESIGN COSTS

	Capital costs	Operation costs	Energy investment allowance (EIA)	Investment after EIA
PCM	€9,143.00	€21.33 /year	€3,585.00	€5,558.00
Heatpump	€10,390.00	€86.30 /year	€1,750.00	€8,640.00

	Energy reduction	50 years payback	20 years payback	EIA
PCM	75.30%			

DESIGN COSTS

	Capital costs	Operation costs	Energy investment allowance (EIA)	Investment after EIA
PCM	€9,143.00	€21.33 /year	€3,585.00	€5,558.00
Heatpump	€10,390.00	€86.30 /year	€1,750.00	€8,640.00

	Energy reduction
PCM	75.30%

50 years payback

20 years payback

EIA

3 REFLECTION

- Results based on one, high performing, installation principle;
- Reliability of a passive system in comparison to temperature exceeding days
- Large scale production, economics according to 350 m^2 office;
- Design element integrated within the office makes people aware of their usage.