

# 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



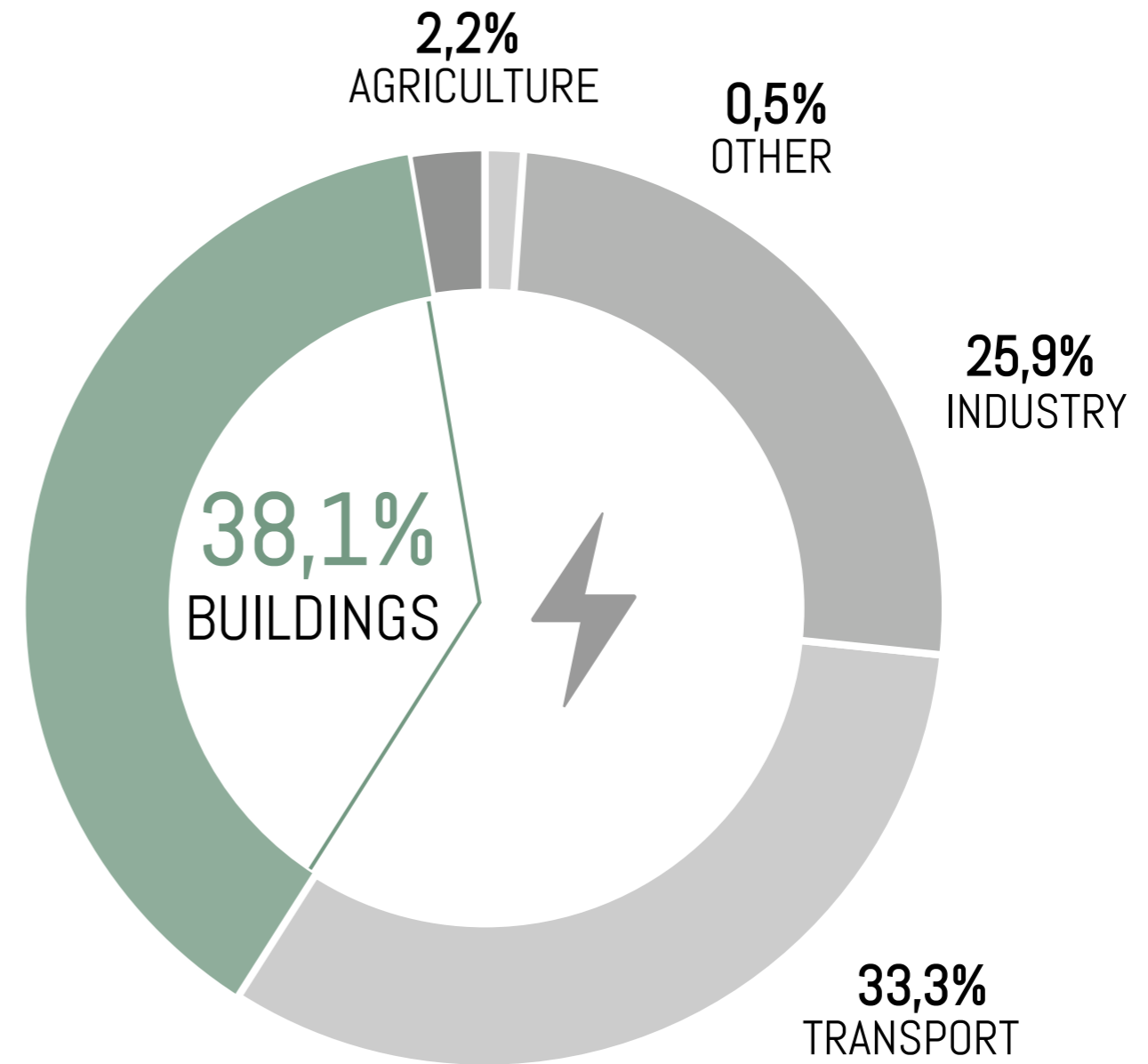
**1** INTRO

**METHODOLOGY**

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# PROBLEM

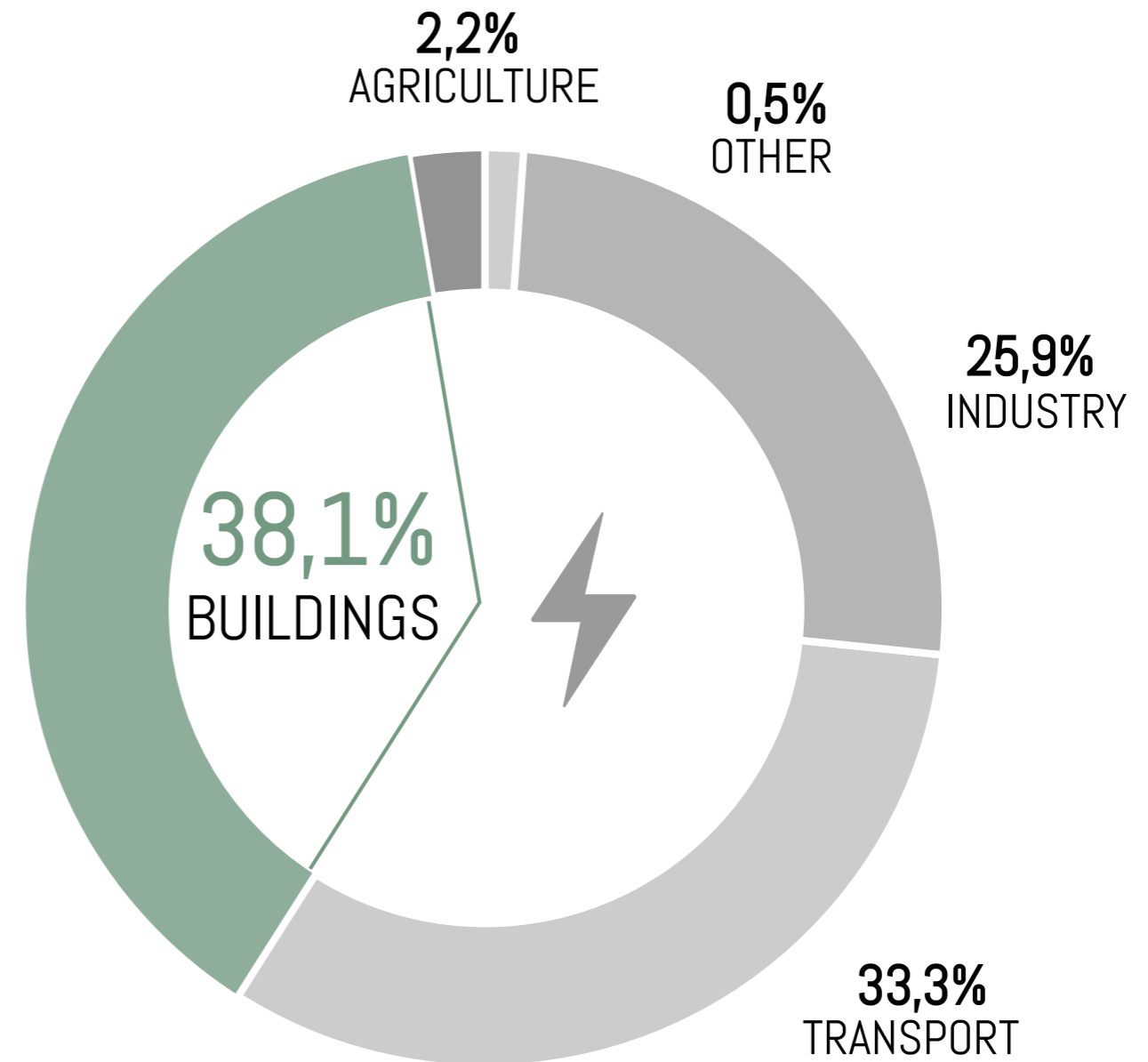
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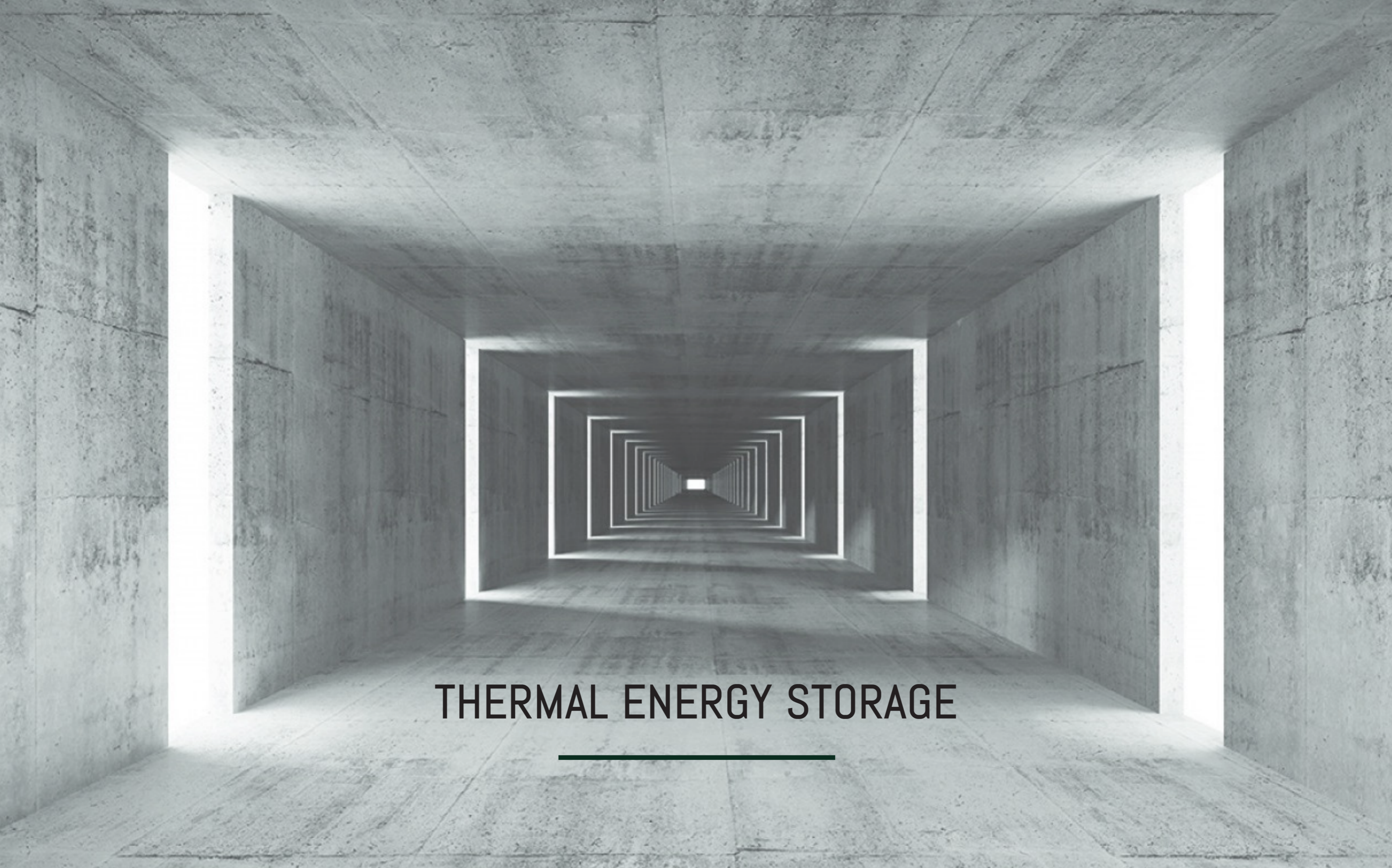
# PROBLEM



-32,5%



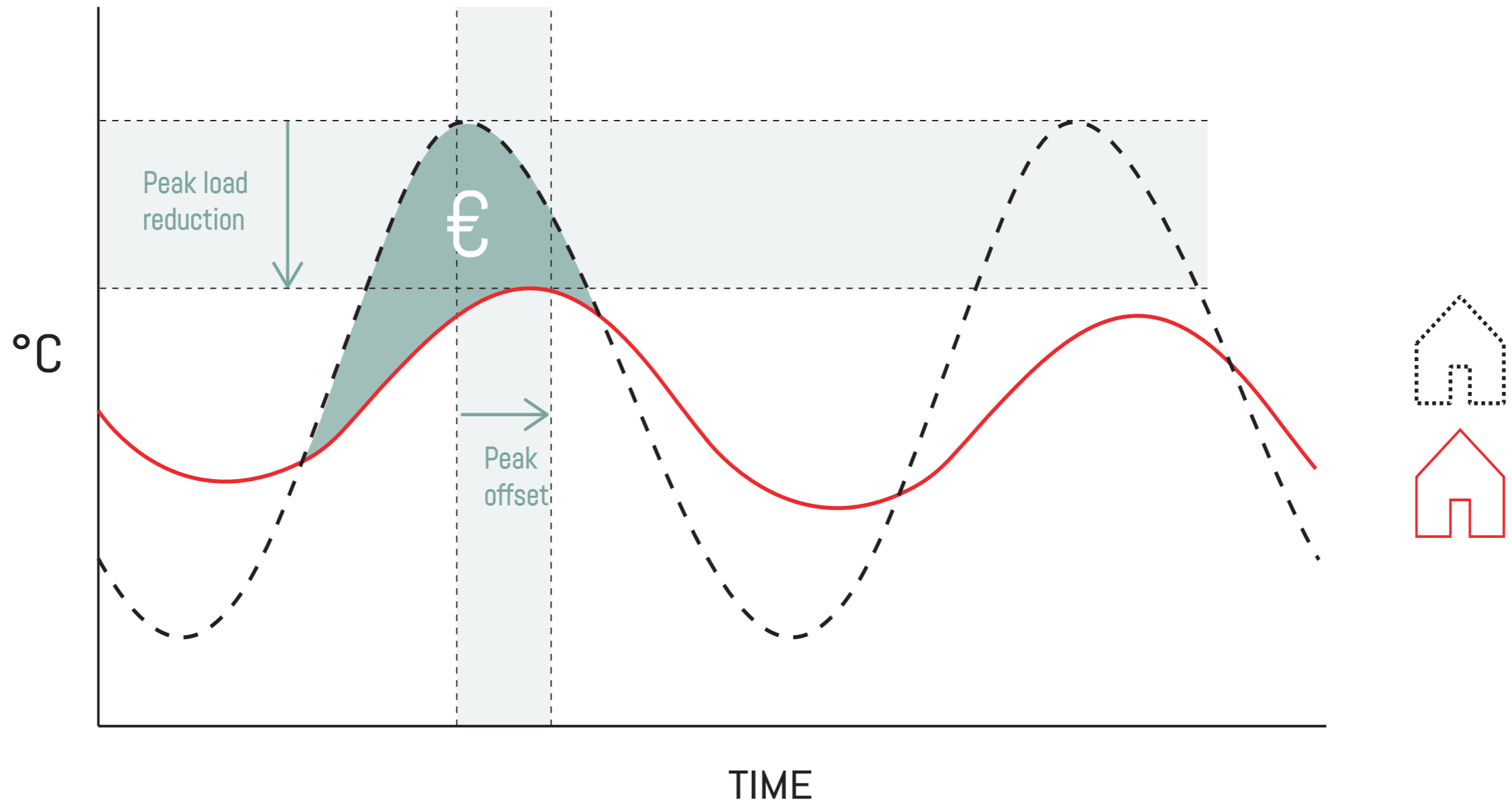




# THERMAL ENERGY STORAGE

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# THERMAL ENERGY STORAGE





# PROBLEM

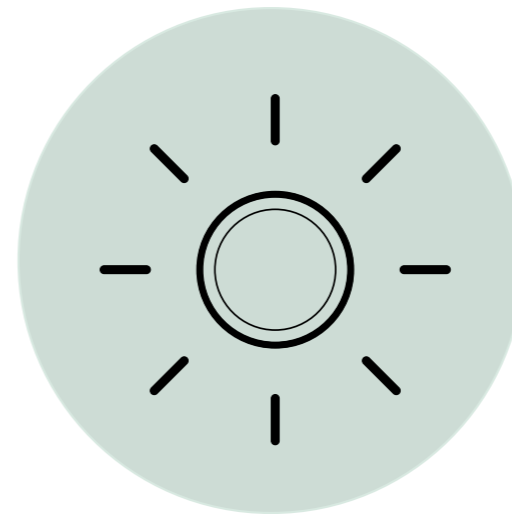
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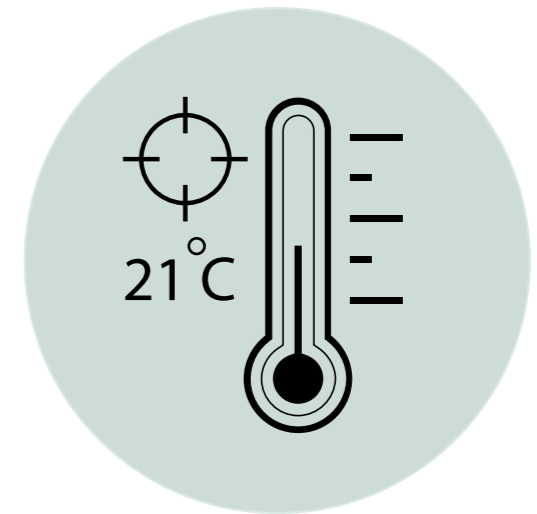
HIGH  
DENSITY



LOW HEAT  
CAPACITY



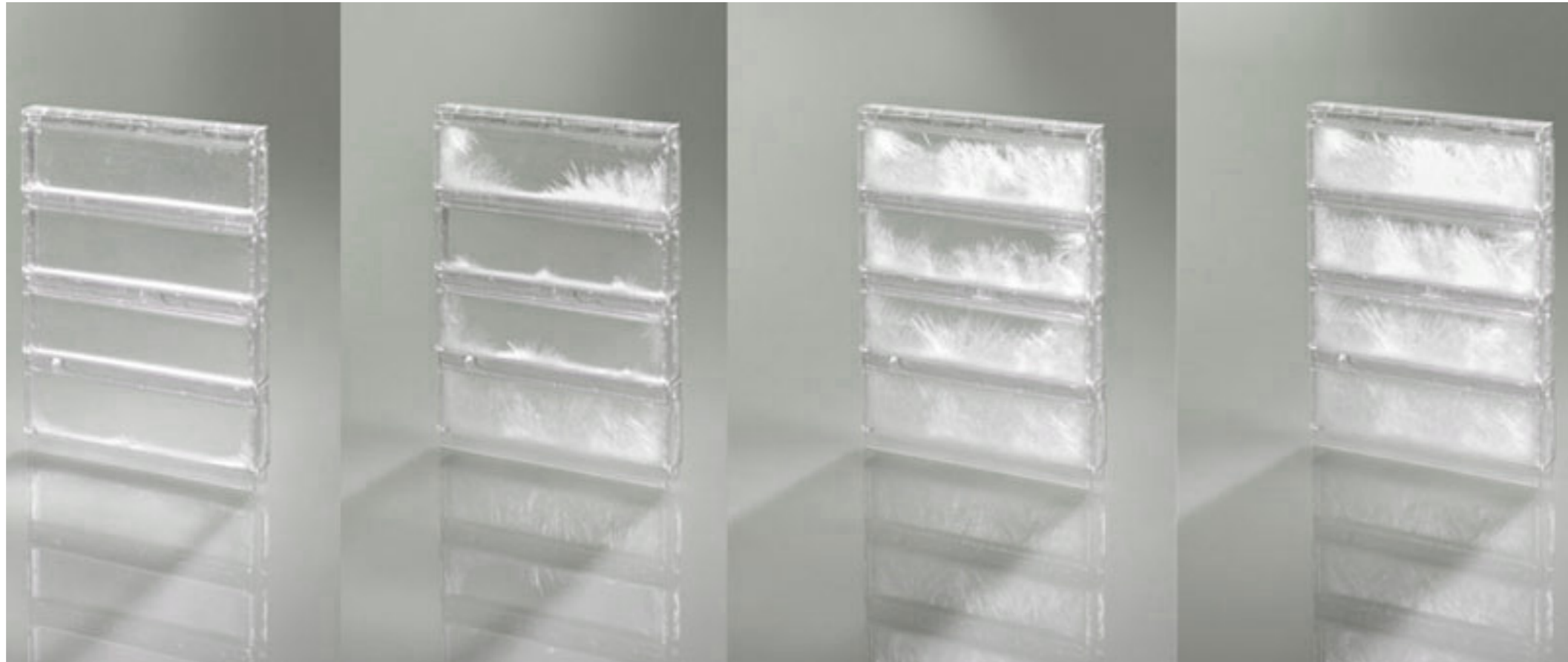
NO  
DAYLIGHT



NO TARGET  
TEMPERATURE

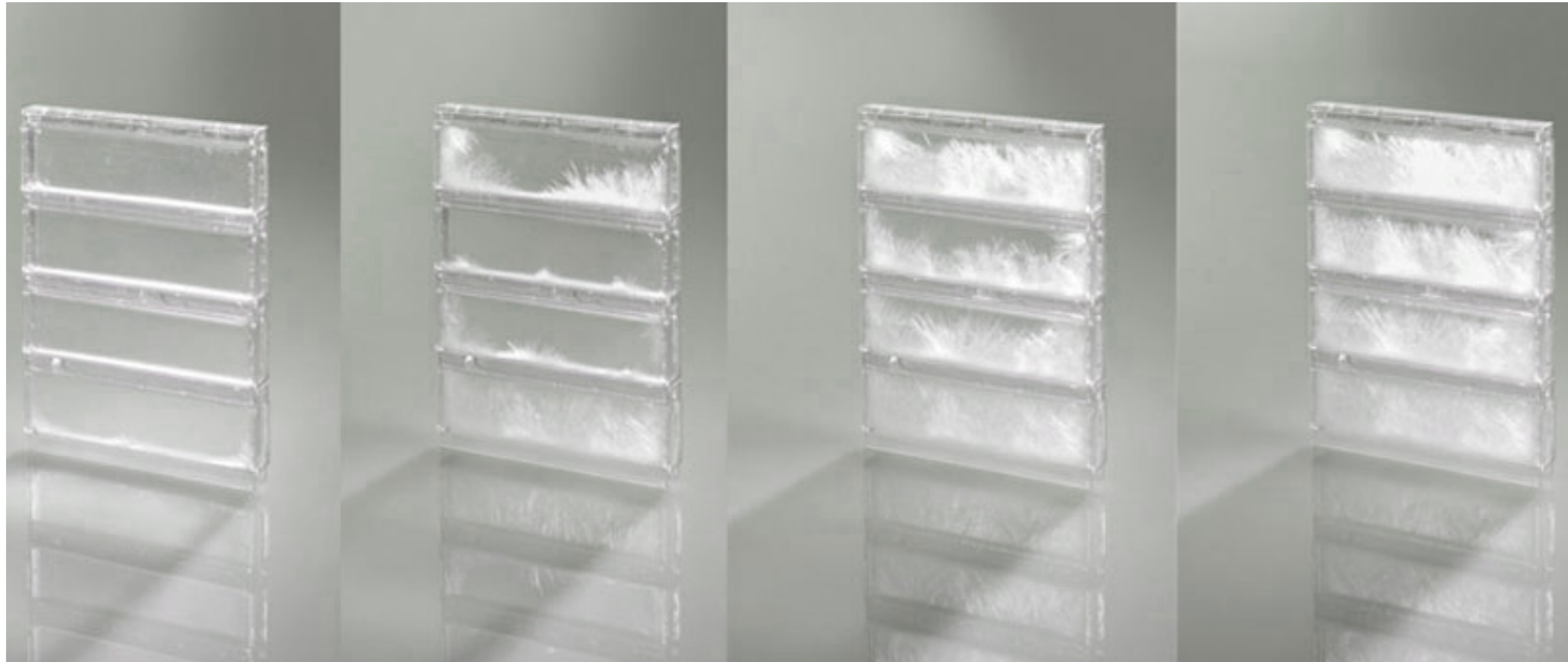
# PHASE CHANGE MATERIAL

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# PHASE CHANGE MATERIAL

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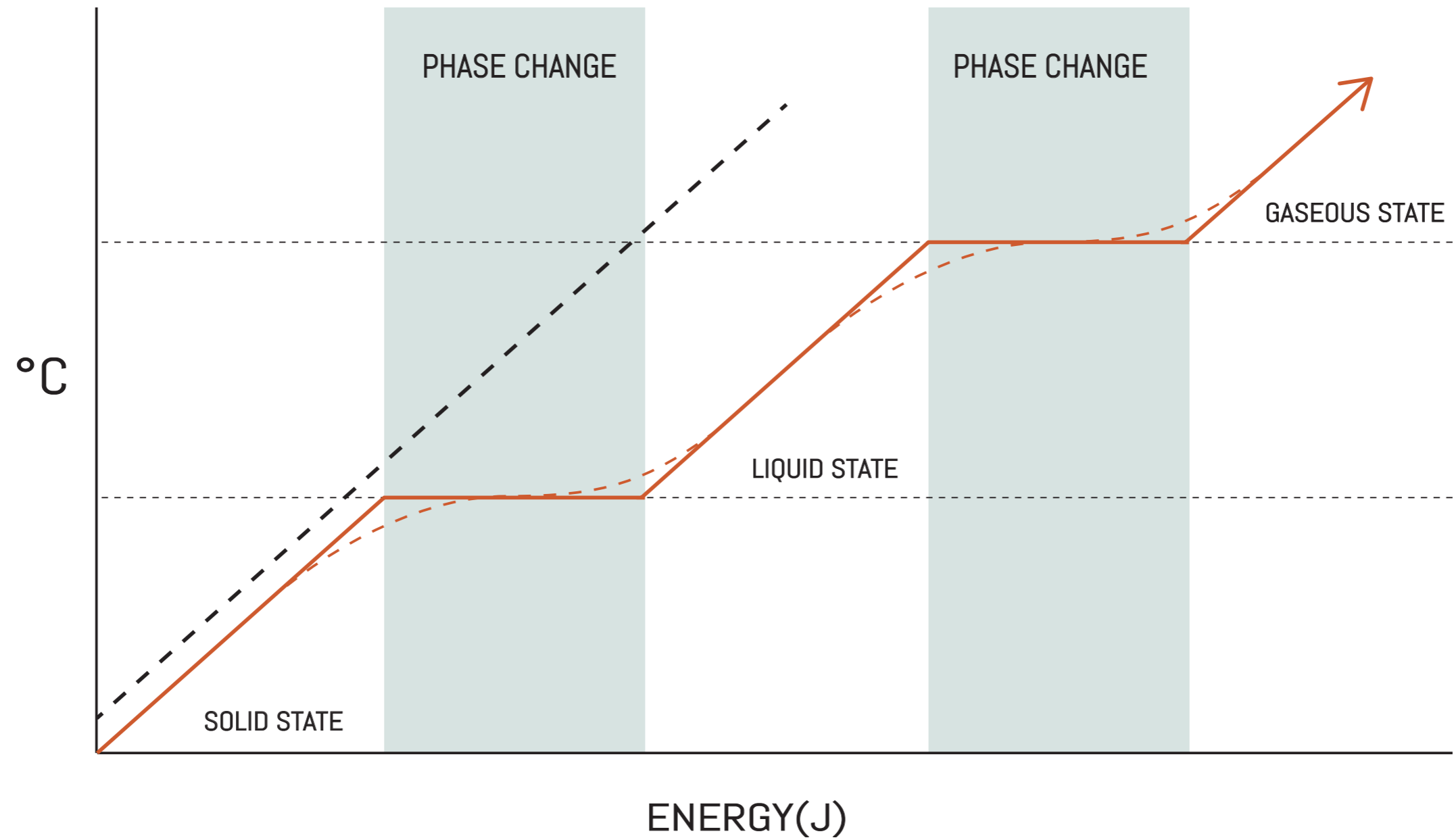


Liquid

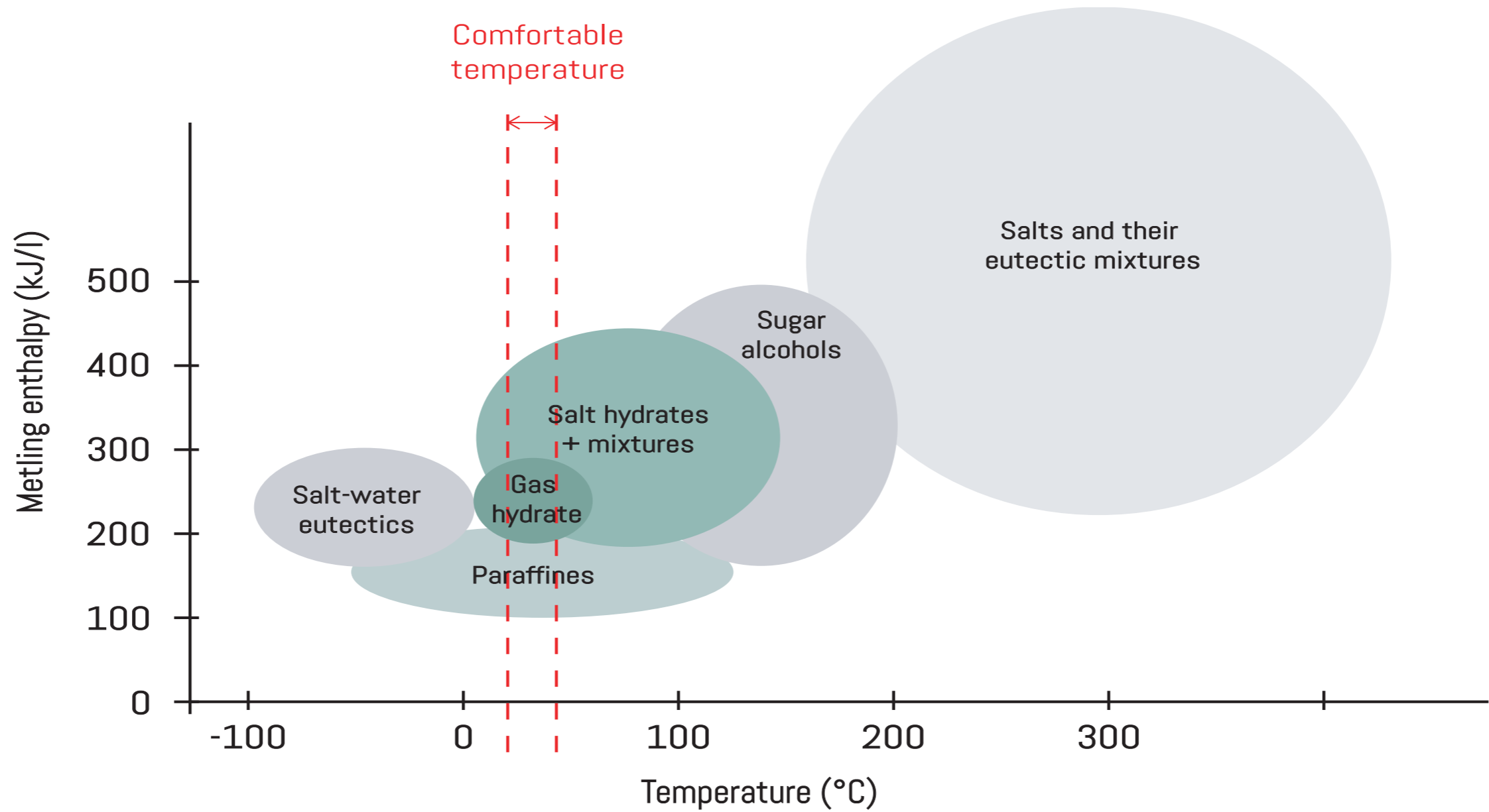


Solid

# PHASE CHANGE MATERIAL



# PHASE CHANGE MATERIAL





**1** CONTEXT

CLIMATE  
TYPOLOGY  
ELEMENT

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# CLIMATE

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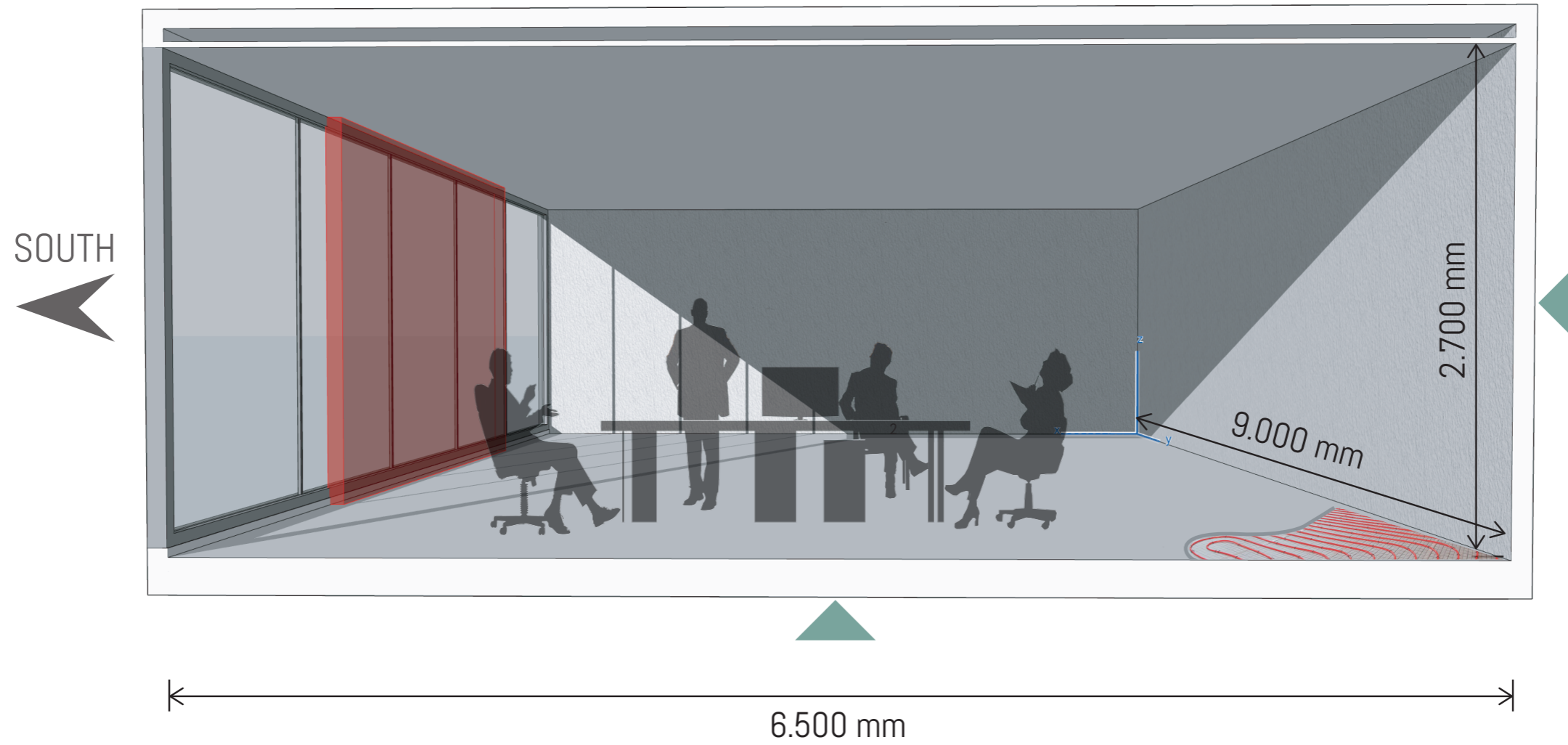
Amsterdam

*Temperate climate*



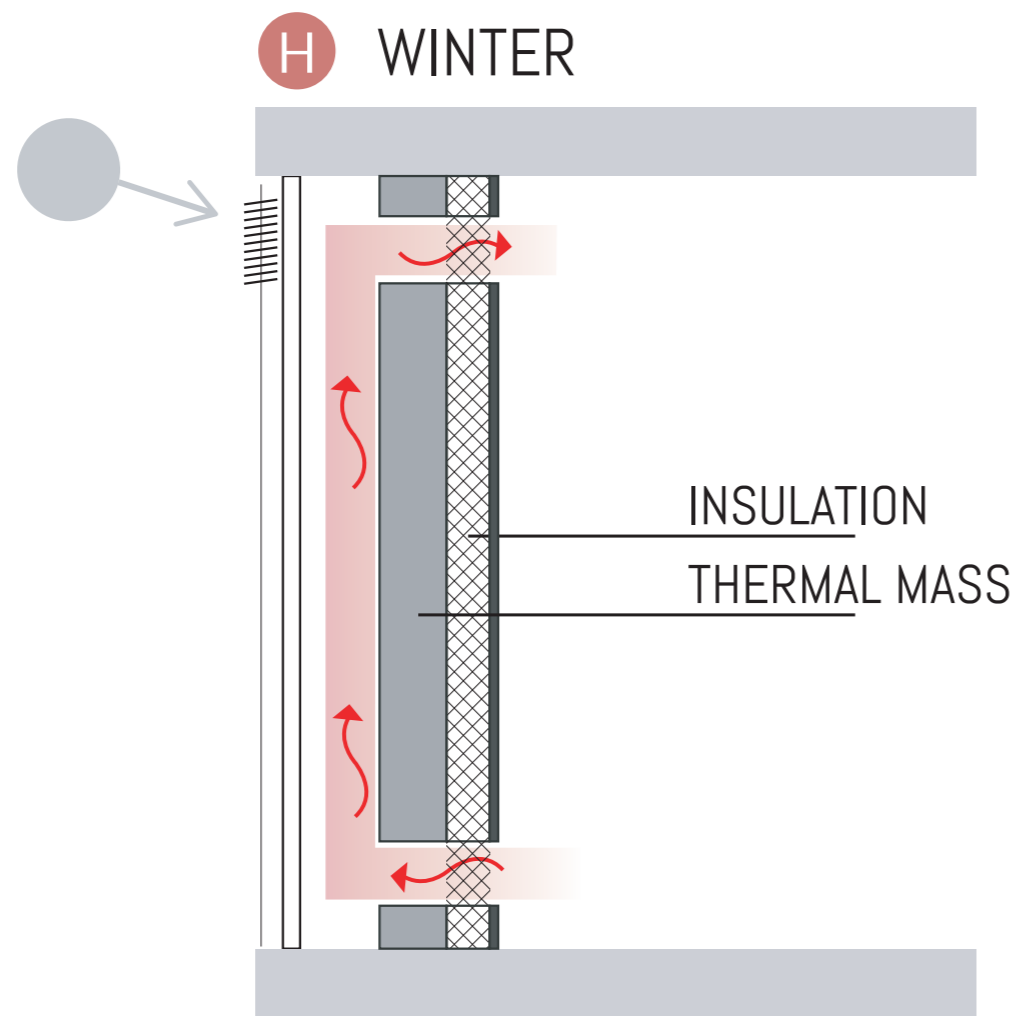
# TYOLOGY

ADIABATIC

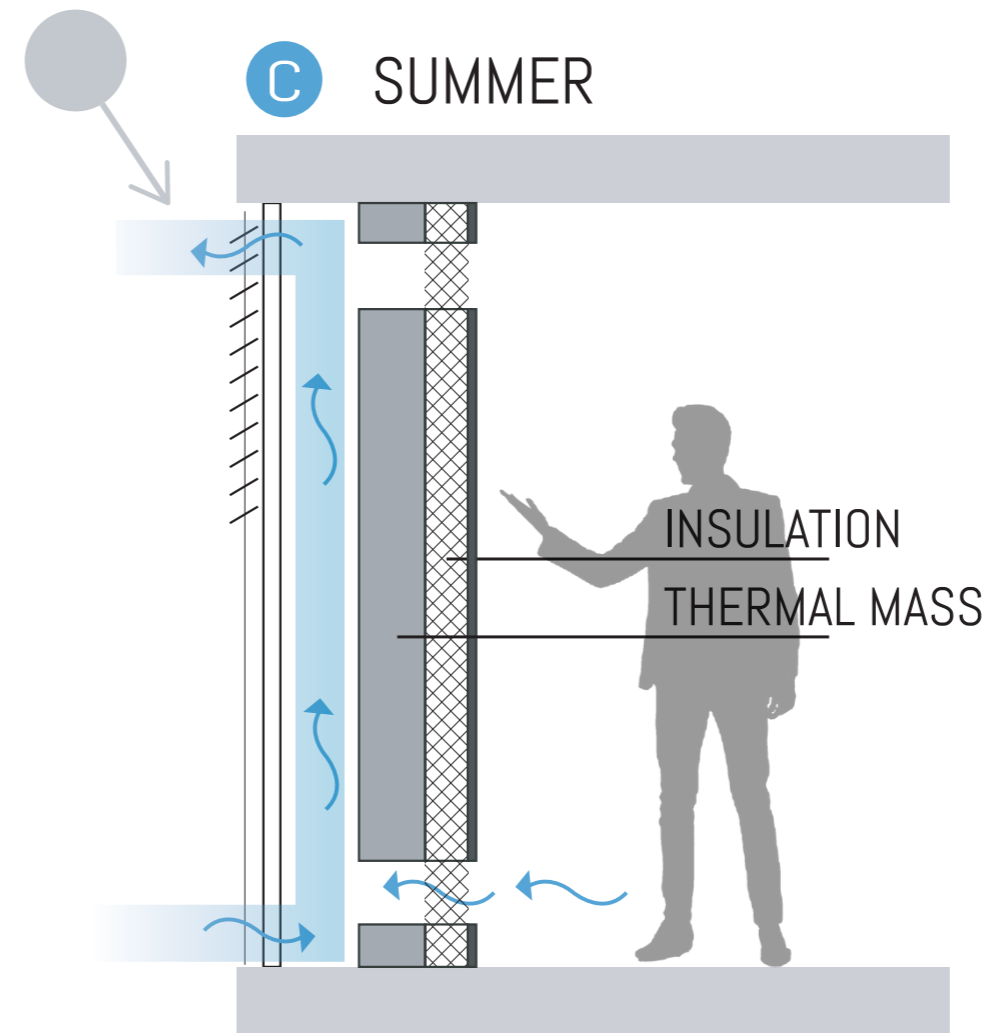




# TROMBE WALL



Air circulation +  
Heating strategy



Solar absorption +  
Ventilation strategy

# RESEARCH QUESTION

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“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

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“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



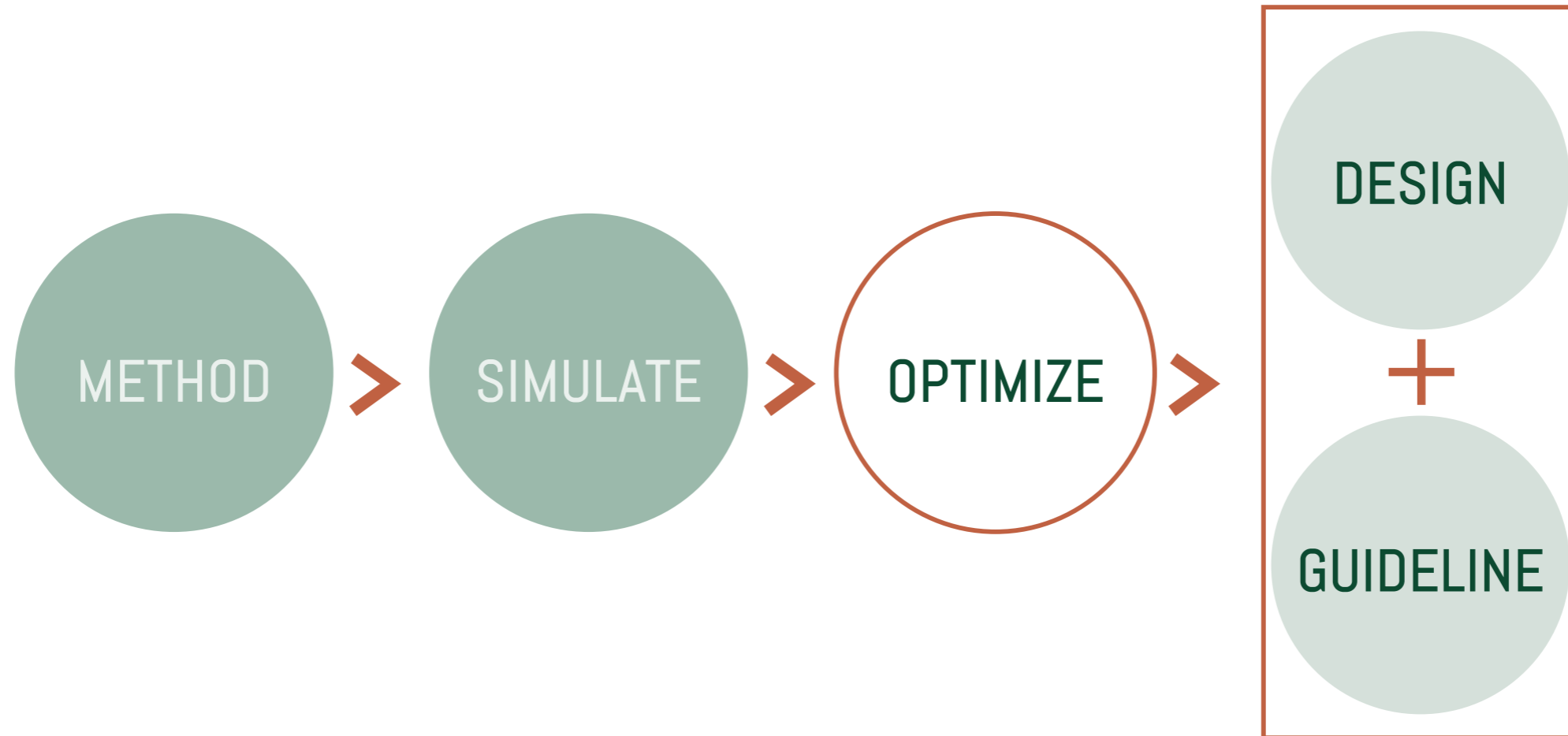
**2** RESEARCH

**METHODOLOGY**

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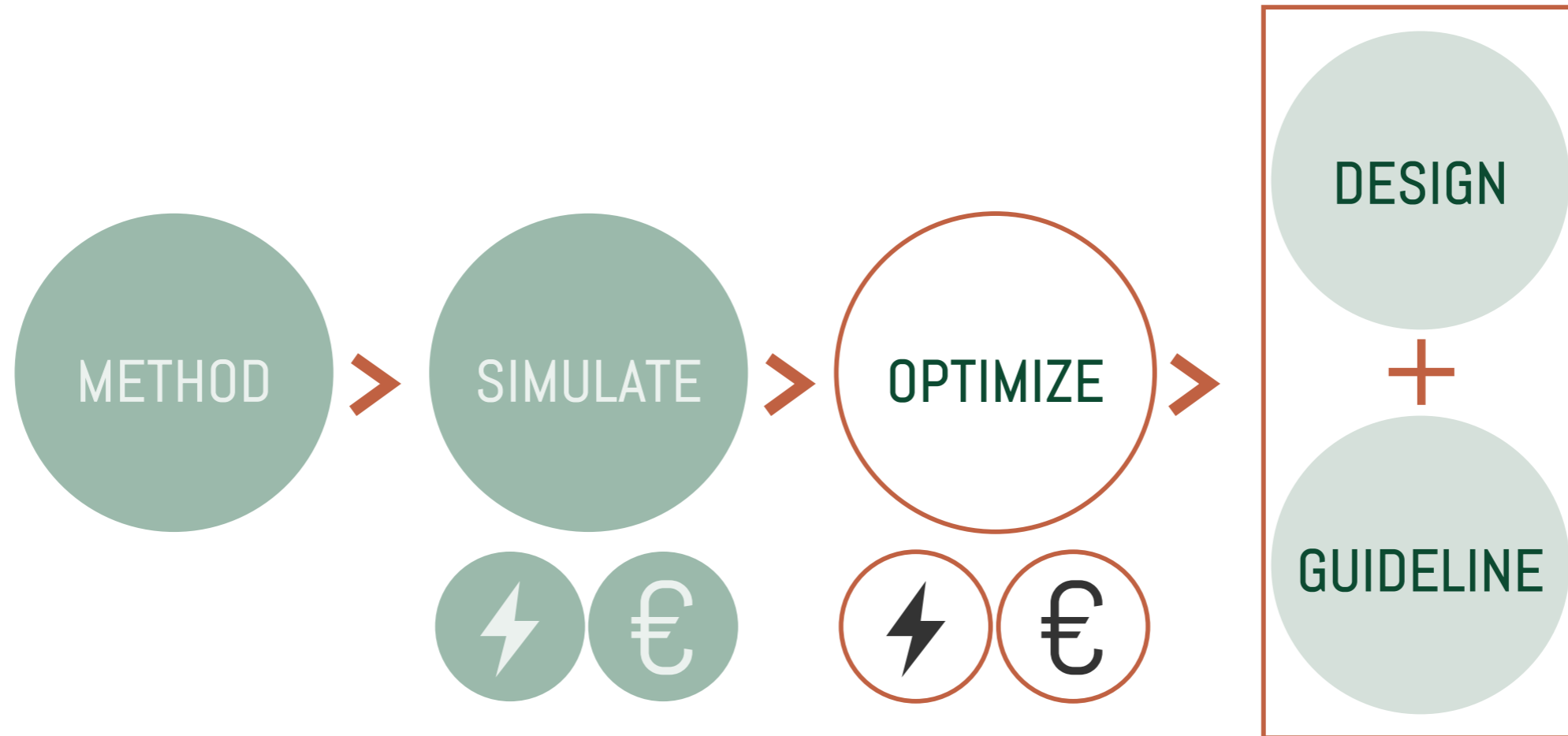
# PROCESS

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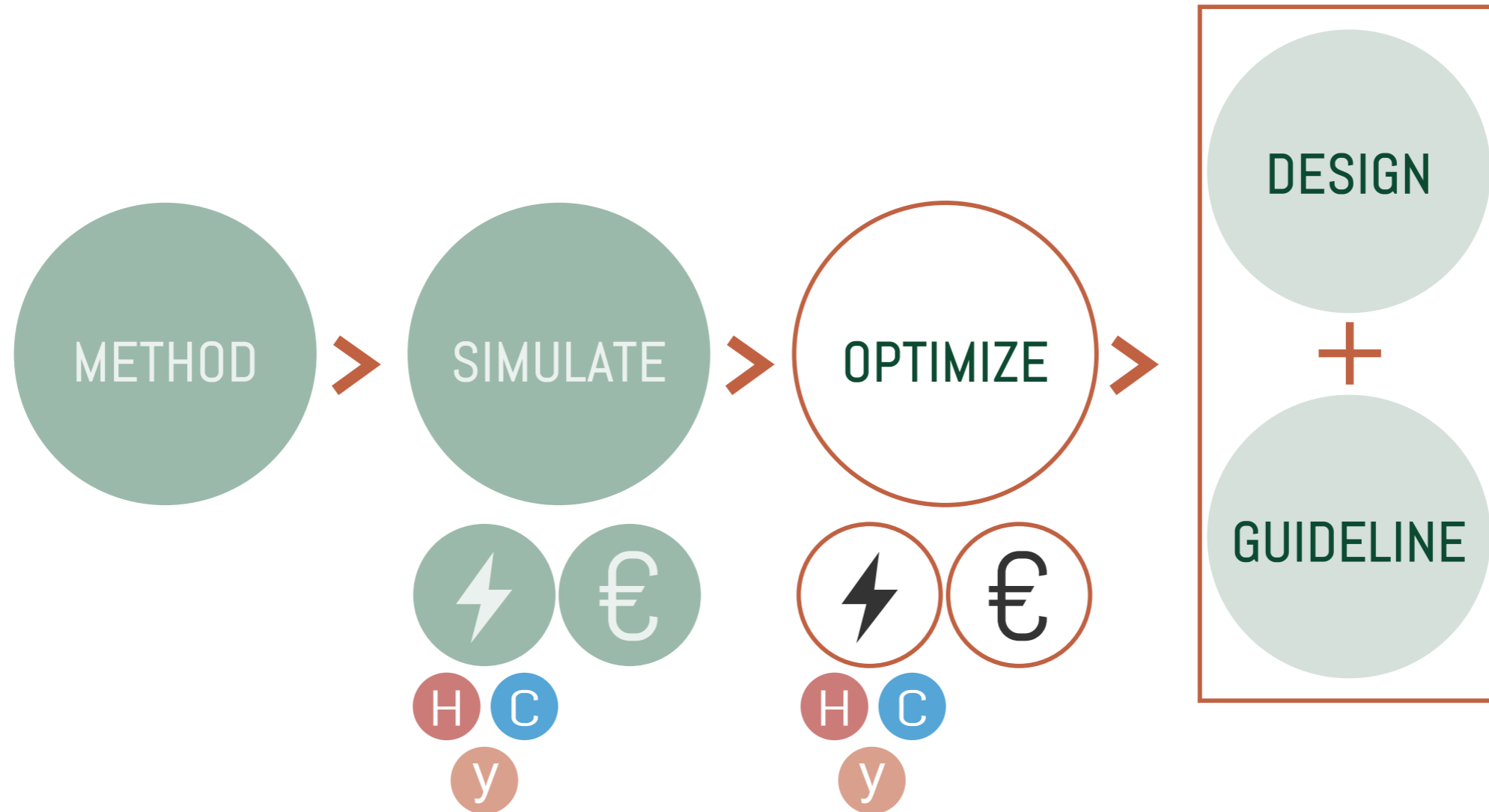
# PROCESS

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# PROCESS

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# PLATFORM

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INITIAL  
MODEL

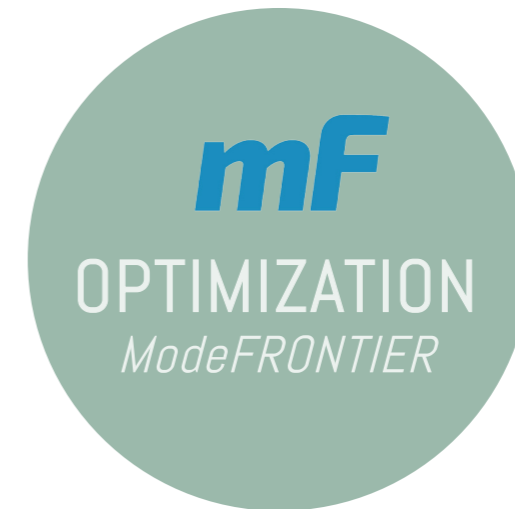




# PLATFORM

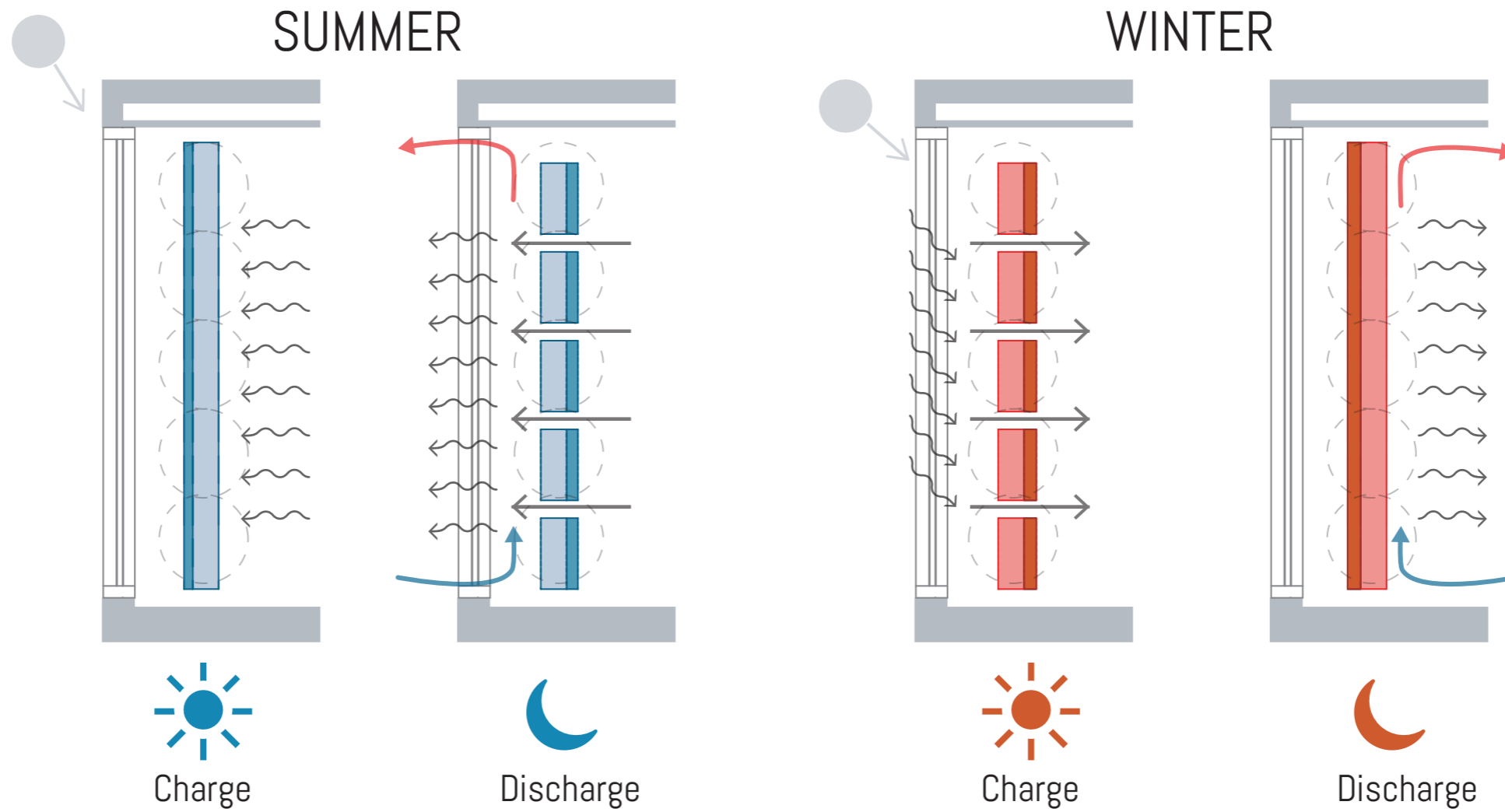
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INITIAL  
MODEL



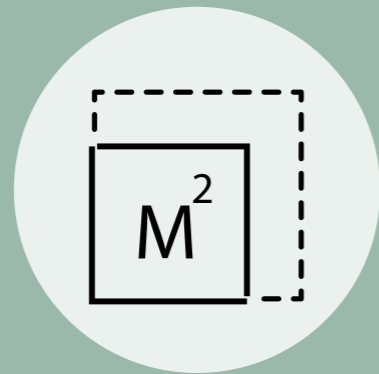
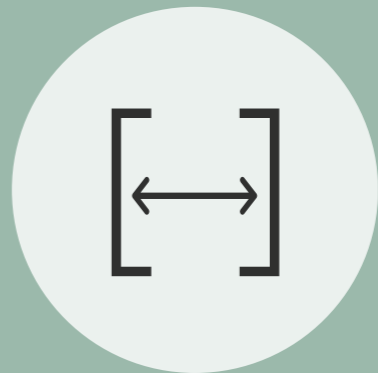
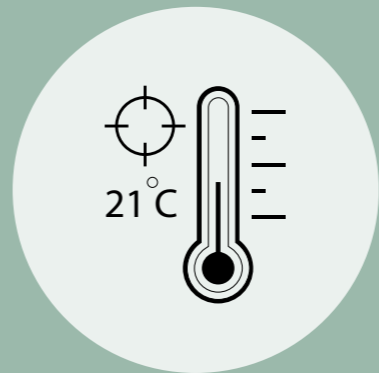
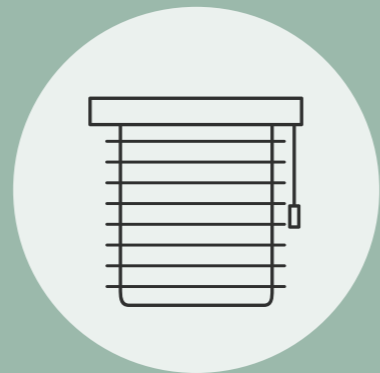
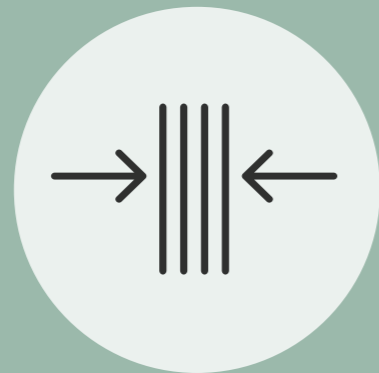
# STRATEGIES

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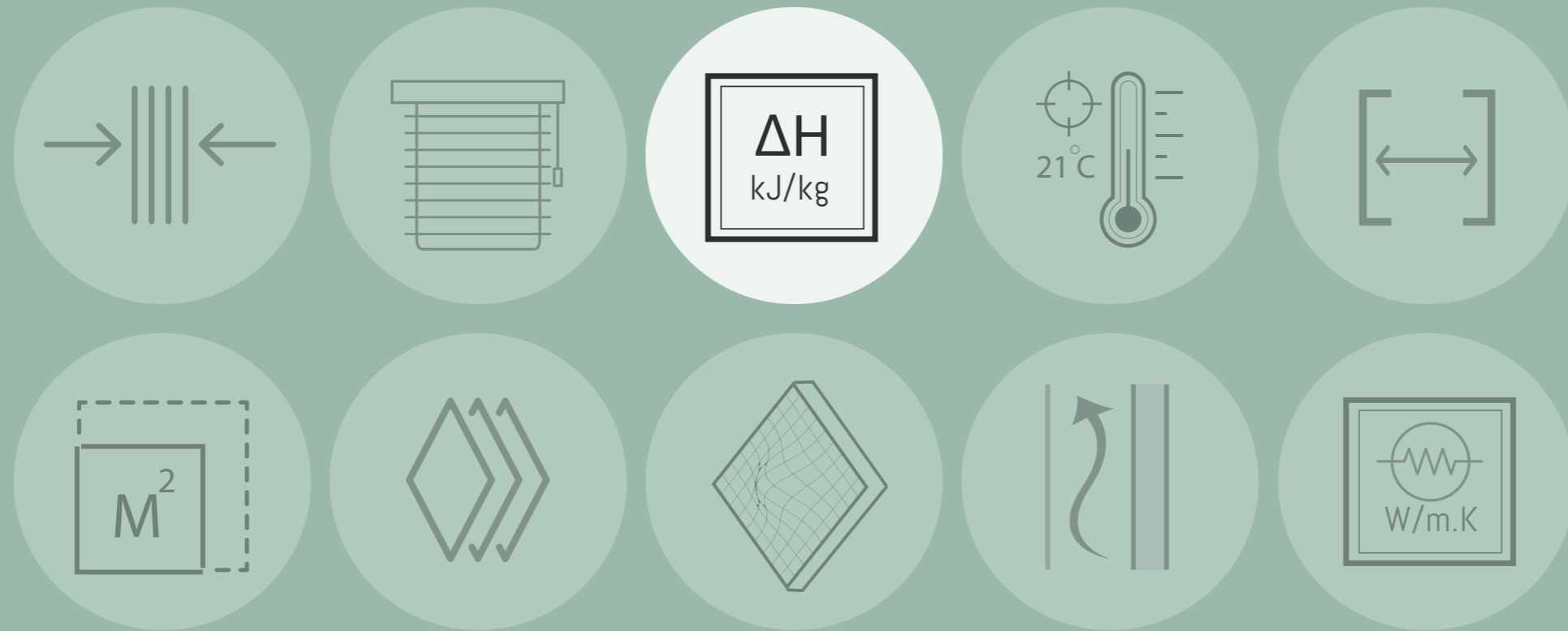
# STRATEGIES

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# STRATEGIES

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160	180	200	220	240
160	180	200	220	240



# 2 ENERGY

## SIMULATION AND OPTIMIZATION

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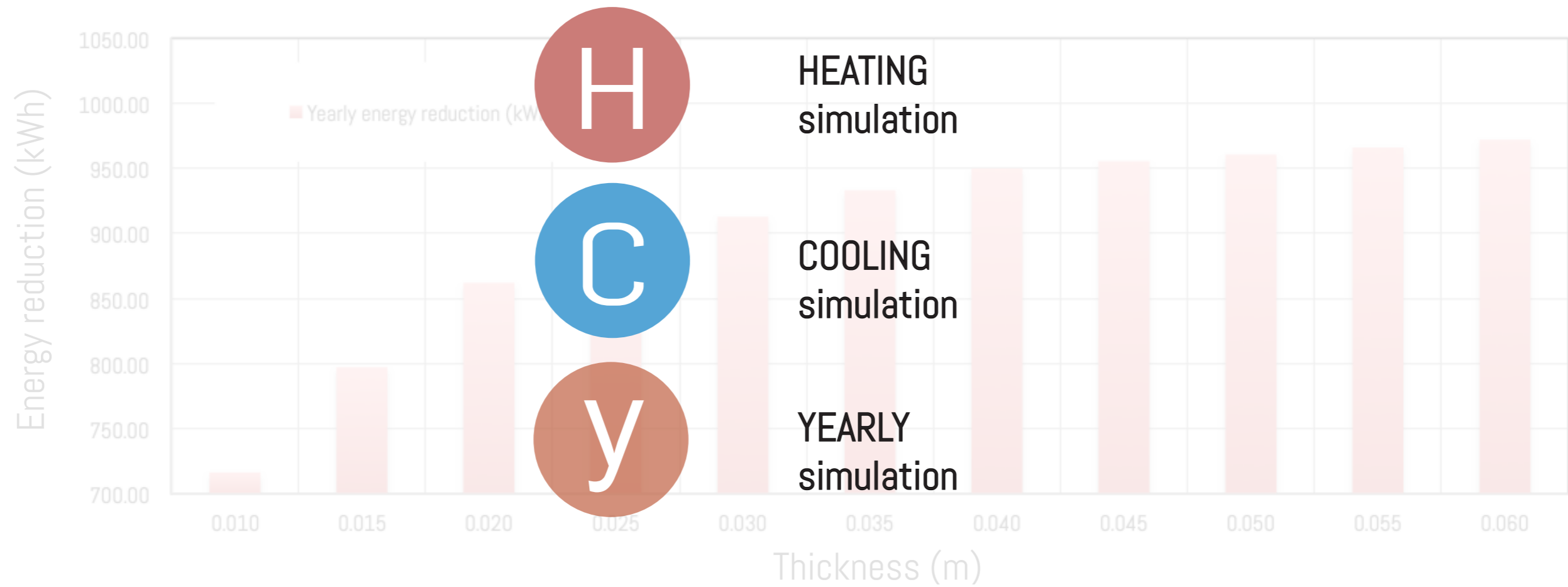




# SIMULATION: Energy

1 PCM layer thickness (mm)

10 20 30 40 50 60



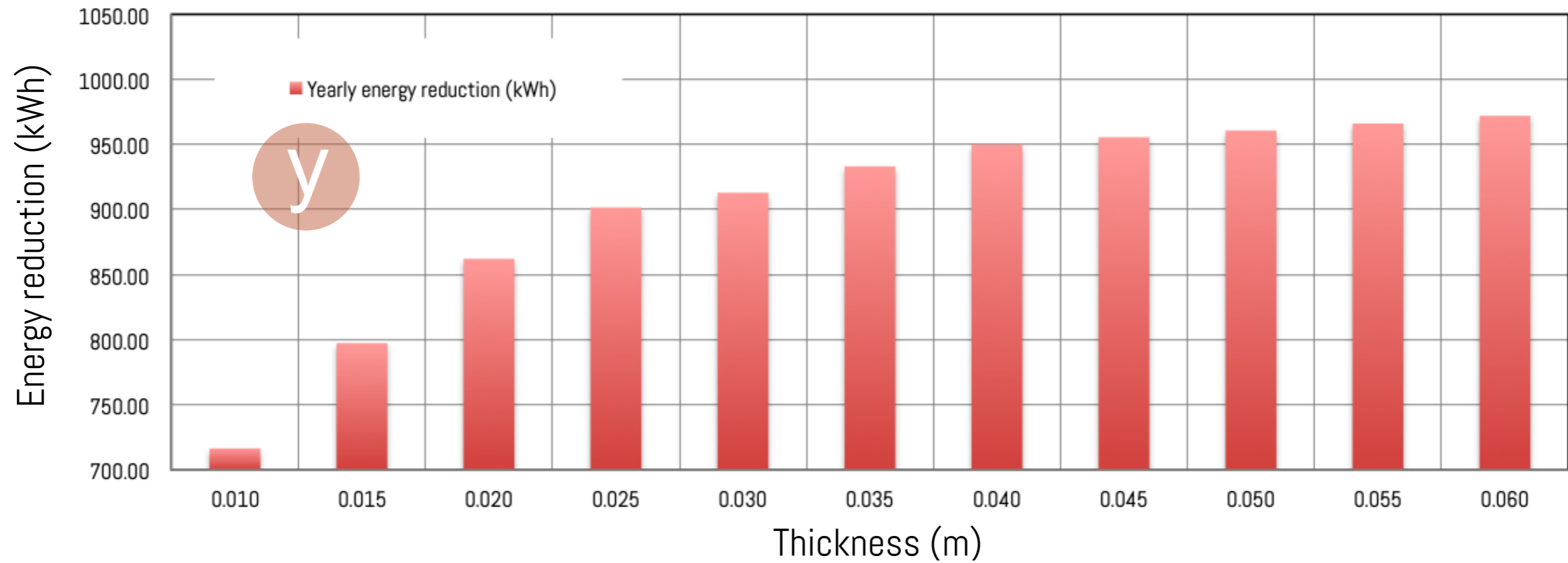


# SIMULATION: Energy

1 PCM layer thickness (mm)

10 20 30 40 50 60

## PANEL THICKNESS





# SIMULATION: Energy

8 Convective heat transfer (W/m<sup>2</sup>K)

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 reduction (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

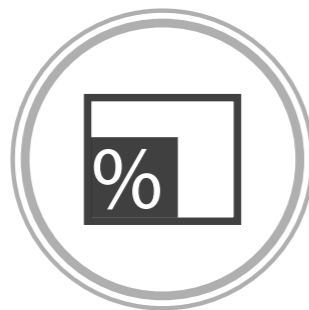




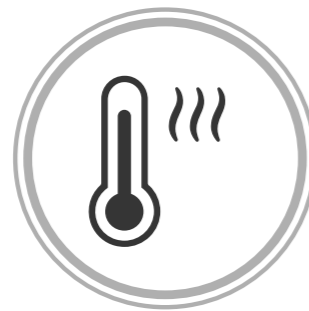


# SIMULATION: Energy

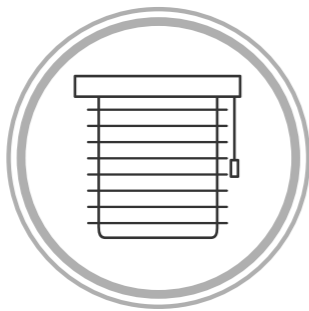
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*TROMBE WALL RATIO*



*MELTING TEMPERATURE*



*COVERING TEMPERATURE*





# SIMULATION: Energy

## Summarized overview

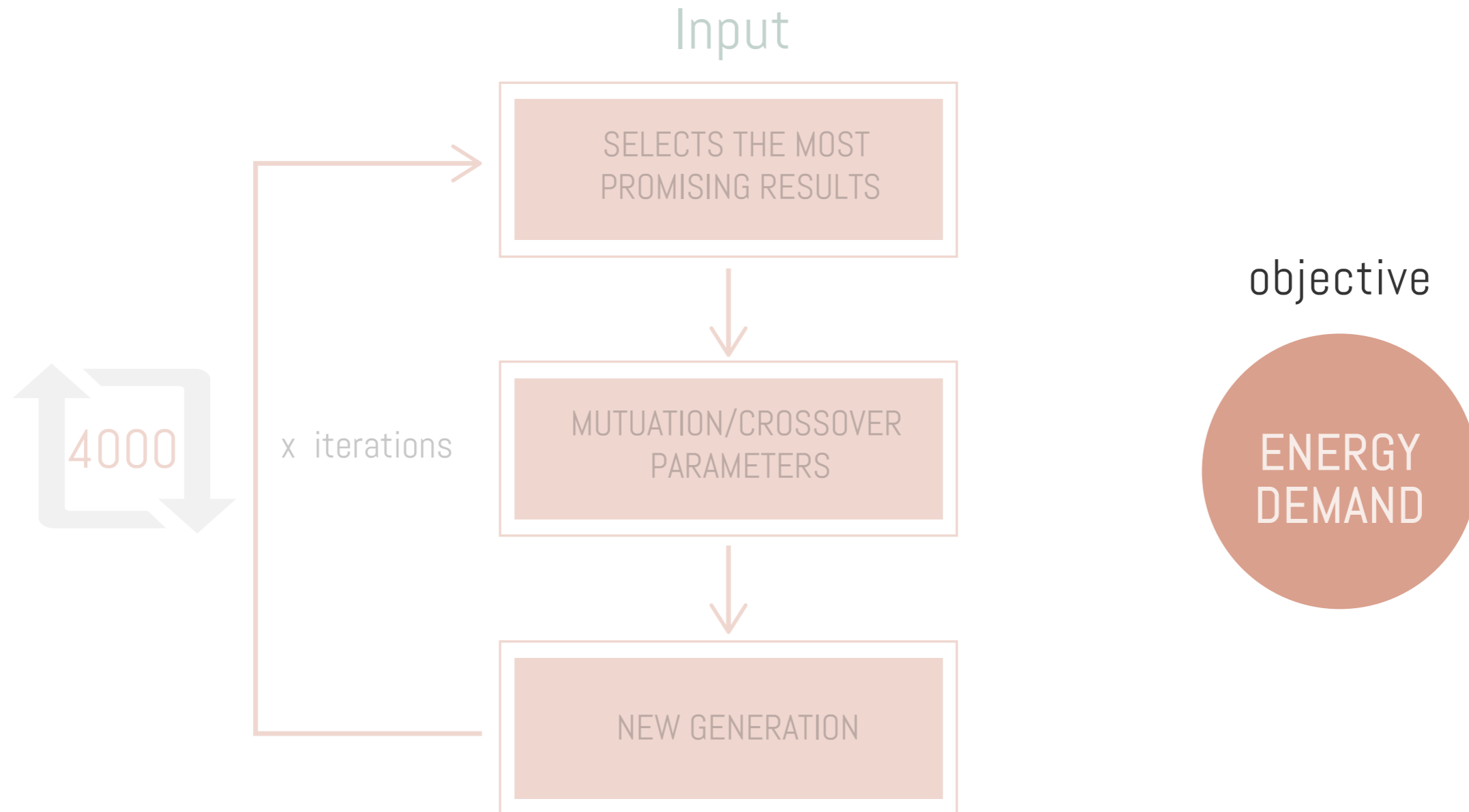
### Energy performance

	INPUT		RESULTS				SIMULATION RESULT VALUES				
	ID (#)	Simulation value	Cooling reduction (%)	Heating reduction (%)	Cooling reduction (kWh)	Heating reduction (kWh)	Cooling energy usage (kWh)	Heating energy usage (kWh)	Total panel volume (m³)	Latent storage capacity (kJ)	Panel surface area (m²)
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
2.1 Blind covering (°C)	6	0.060	62.50	80.37	707.51	264.49	424.49	64.61	1.24	3.23E+08	20.65
	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
3.1 Latent heat storage: organic (J/kg)	13	26.00	77.85	-	256.20	3328.89	72.90	0.52	1.35E+08	20.65	
	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
	19	1.60E+05	58.25	67.30	659.38	221.48	472.62	107.62	0.52	1.20E+08	20.65
4.1 Latent heat storage: inorganic (J/kg)	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
	37	0.40	69.66	-132.44	788.58	-435.87	343.42	764.97	0.52	1.35E+08	20.65
7.1 Trombe wall ratio 2 (%)	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	-234.36	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
	43.1	1.00	58.84	71.58	666.05	235.58	465.95	93.52	0.52	1.35E+08	20.65
8.1 System layers degrees (no.)	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
	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
9.1 System layers +degree (no.)	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
	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
10.1 Panel area ratio (%)	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
	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
11.1 Convective heat transfer (W/m2K)	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
	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
12.1 Cavity width (m)	66	0.16 m	57.74	67.15	653.60	221.00	478.40	108.10	0.52	1.35E+08	20.65
	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
13.1 Thermal conduction (W/m.K) + density	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
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	



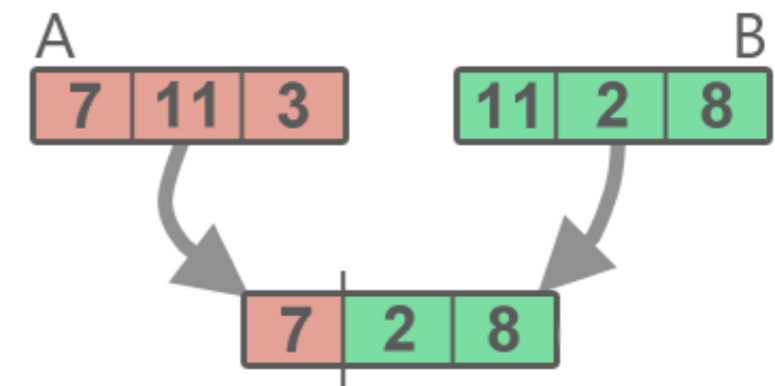
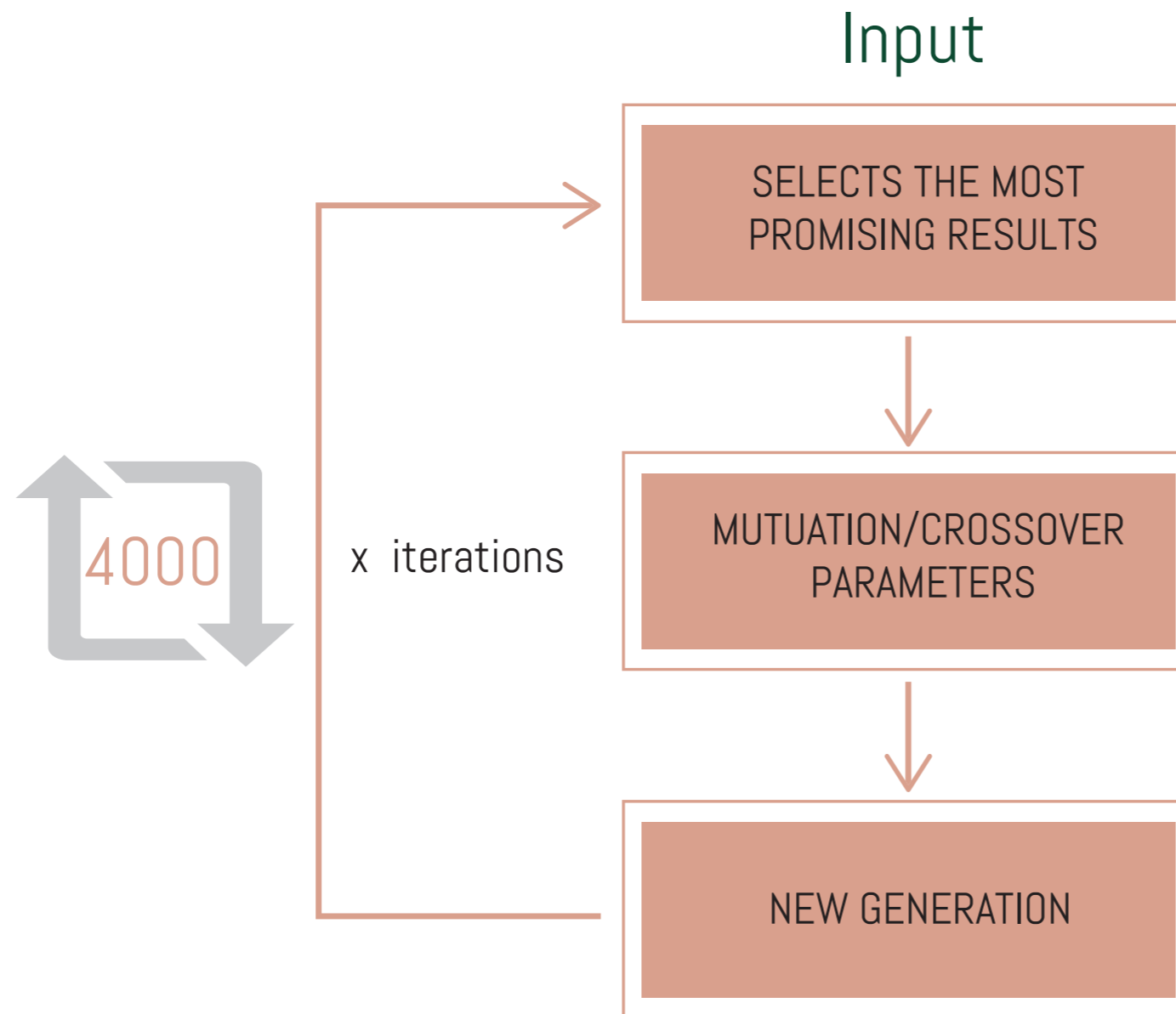
# OPTIMIZATION: Genetic algorithm

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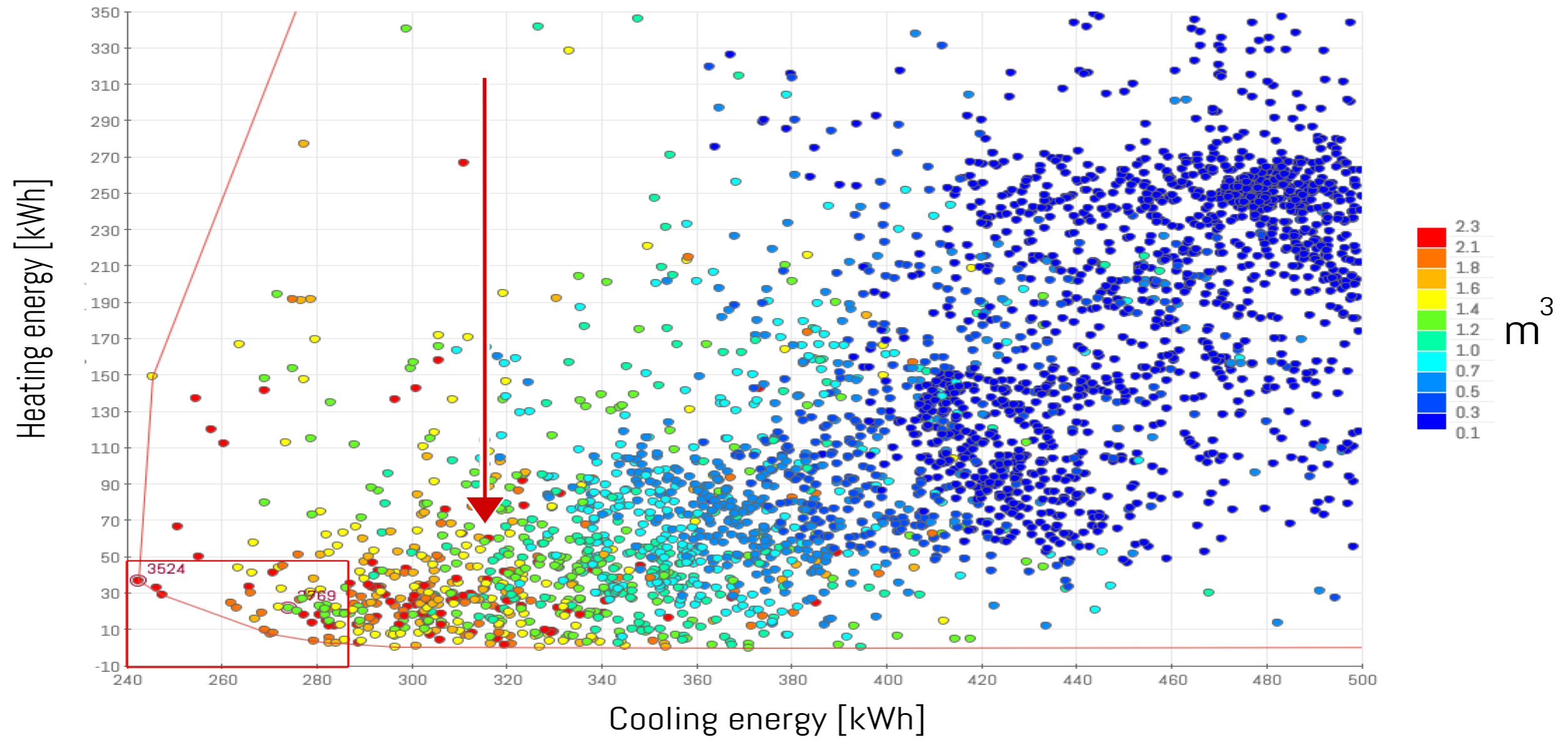
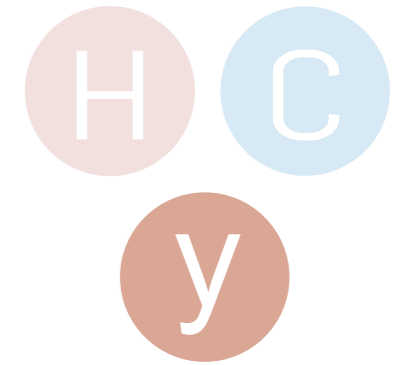


# OPTIMIZATION: Genetic algorithm



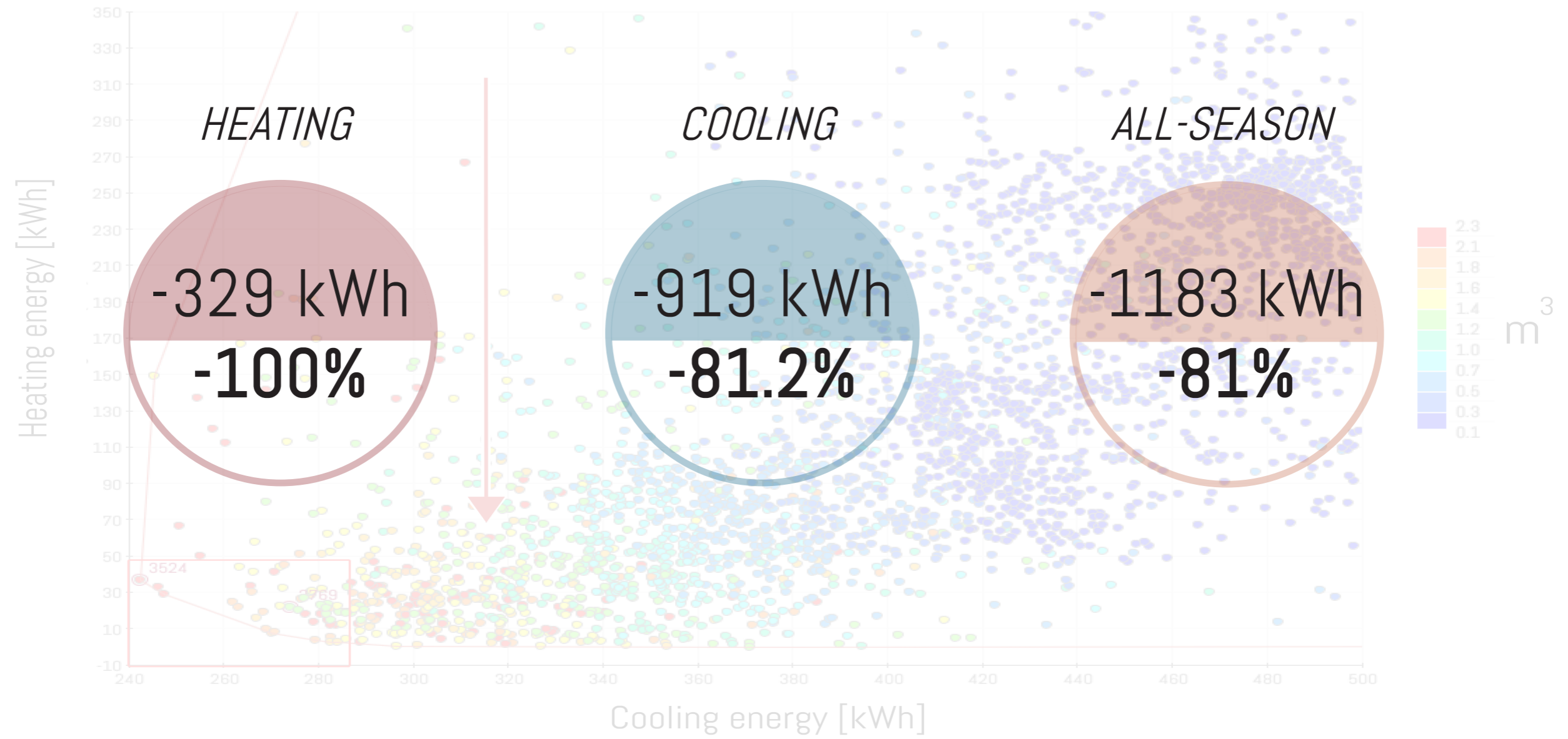


# OPTIMIZATION: All-season





# OPTIMIZATION: Energy



2 COSTS

## SIMULATION AND OPTIMIZATION

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## OPTIMIZATION: Objectives

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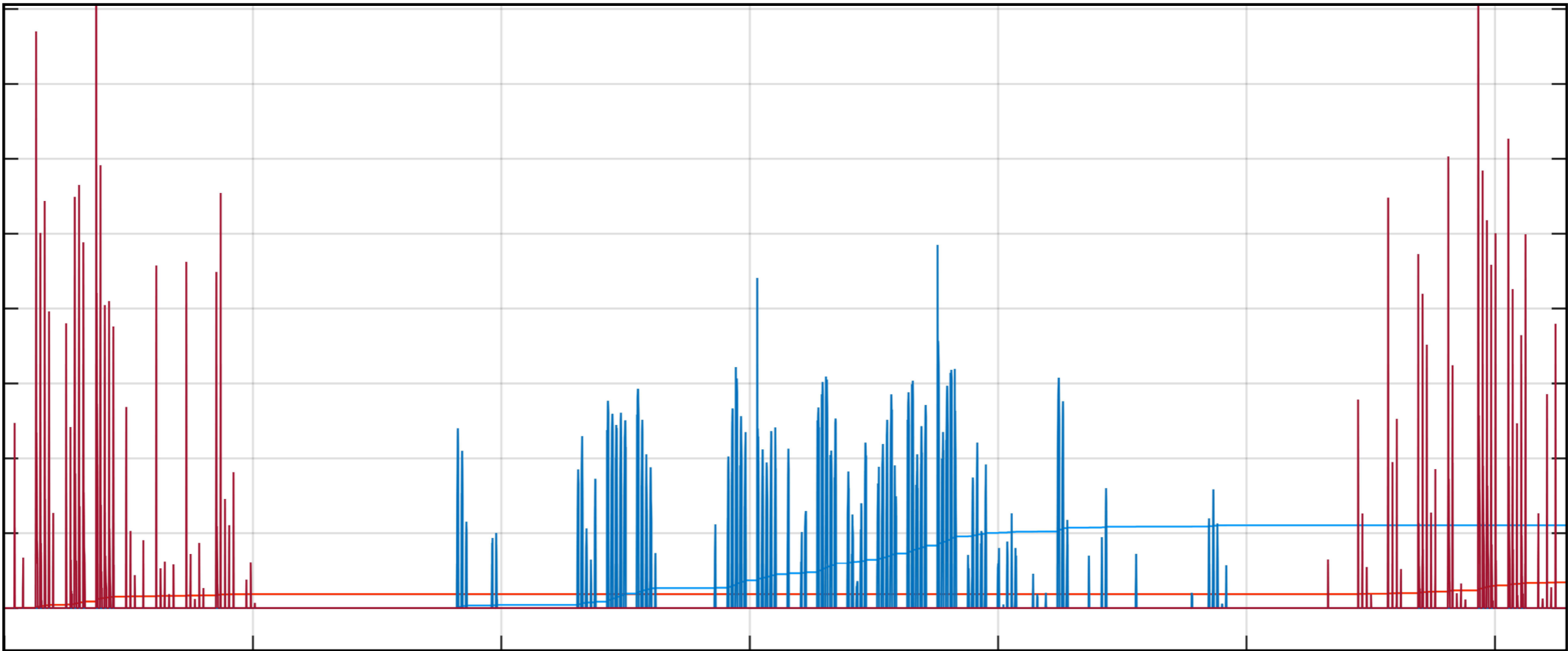
*REDUCTION IN COSTS*







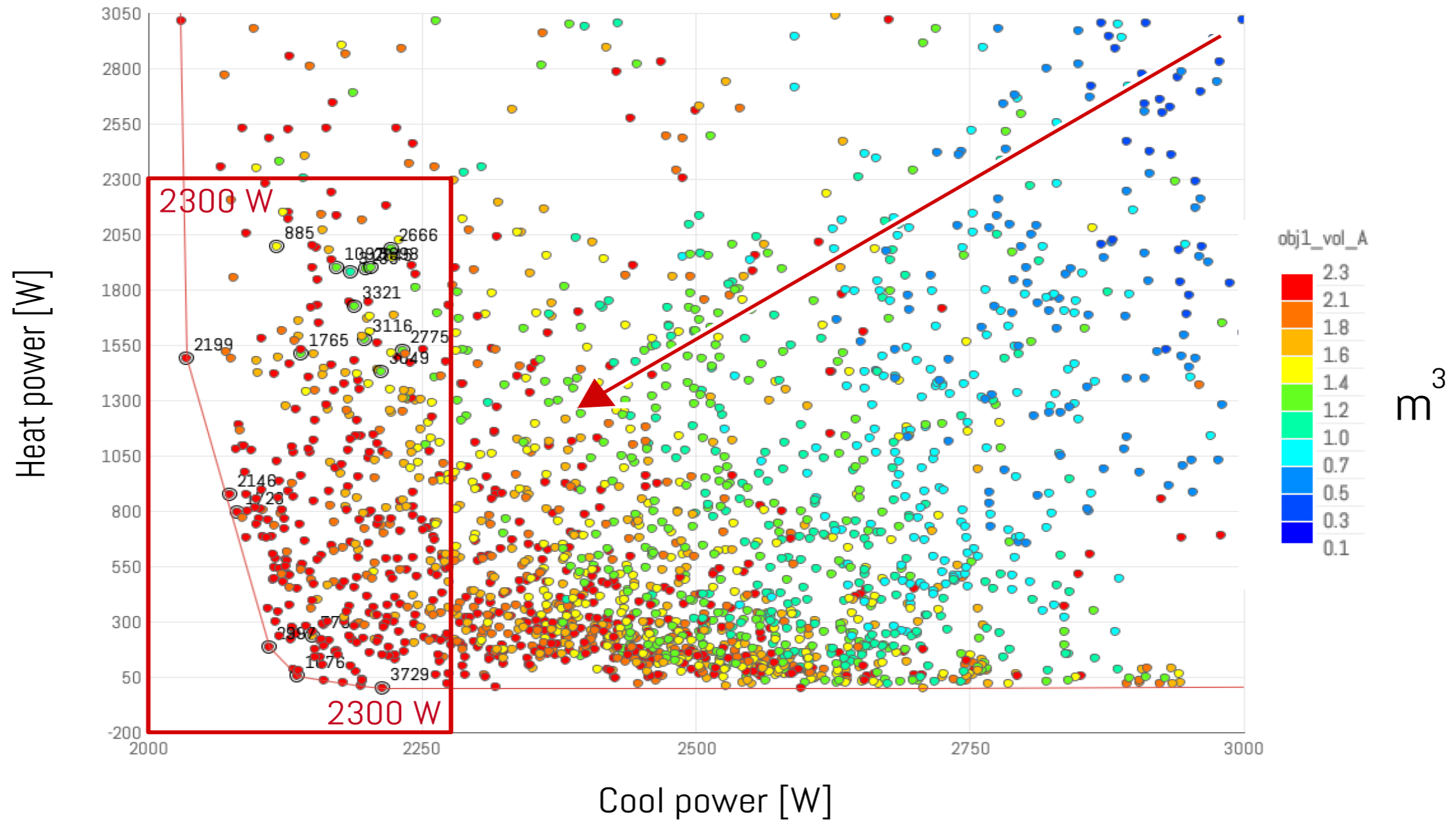
# CALCULATION: Peak-loads



 4 kW  
 10 kW

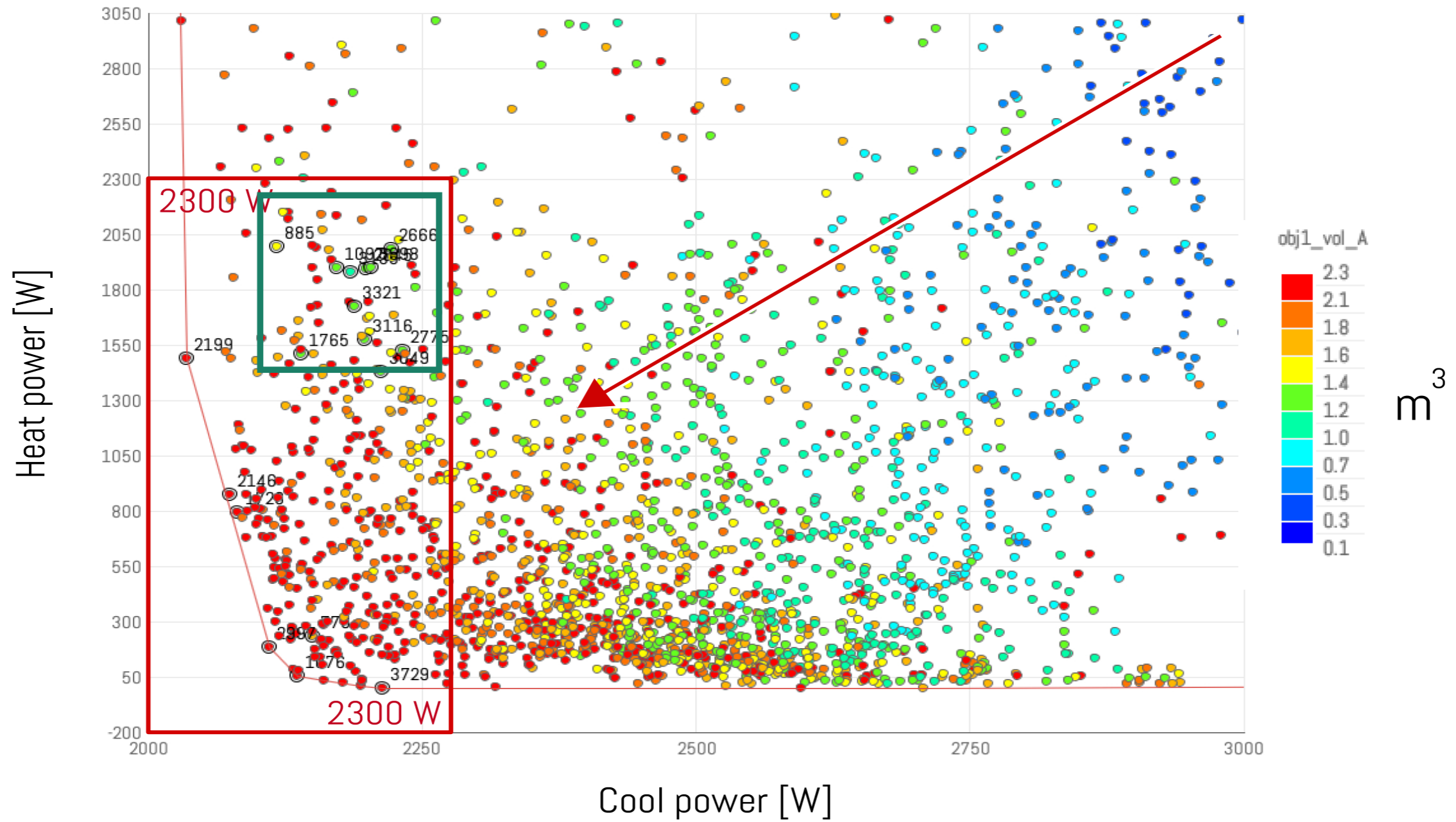


# OPTIMIZATION: Costs





# OPTIMIZATION: Costs



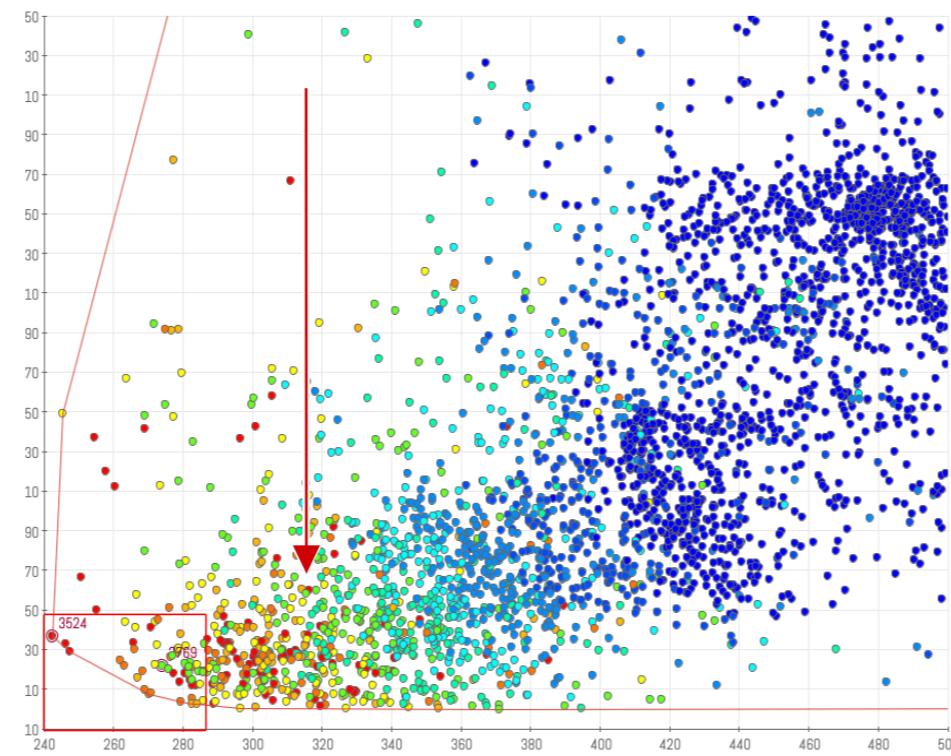


# DESIGN REQUIREMENTS

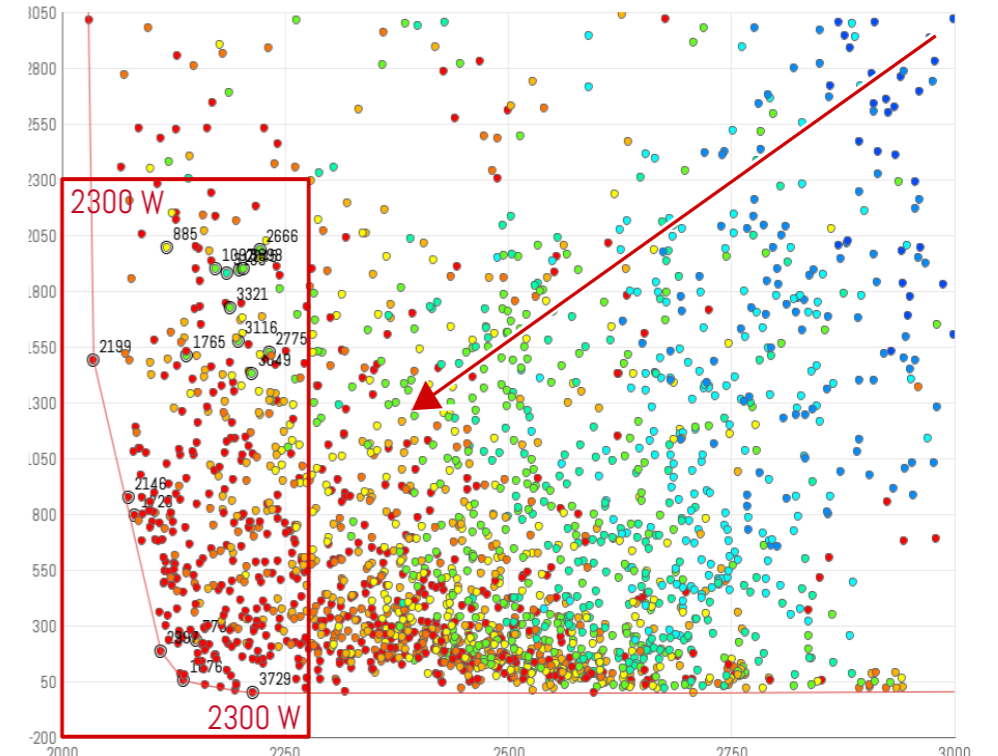
## Simulations

ID	Simulation value	RESULTS				SIMULATION RESULT VALUES				Panel surface area (m <sup>2</sup> )	
		Cooling reduction (%)	Heating reduction (%)	Cooling reduction (kWh)	Heating reduction (kWh)	Cooling energy usage (kWh)	Heating energy usage (kWh)	Total panel volume (m <sup>3</sup> )	Latent storage capacity (kJ)		
1.1	0.010	48.43	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	609.12	197.31	633.88	174.79	0.21	8.09E+07	20.65	
2.1	0.020	57.51	64.17	651.06	211.14	680.94	177.92	0.41	1.03E+08	20.65	
2.2	0.025	58.84	71.38	666.05	235.58	665.95	93.52	0.52	1.35E+08	20.65	
3.1	0.030	59.76	71.86	676.45	236.49	655.55	92.61	0.62	1.62E+08	20.65	
3.2	0.035	60.71	74.75	687.26	245.93	644.74	83.17	0.72	1.89E+08	20.65	
4.1	0.040	61.51	77.09	696.35	253.72	635.65	75.38	0.83	2.16E+08	20.65	
4.2	0.045	61.76	77.95	699.10	256.68	632.90	72.64	0.93	2.43E+08	20.65	
5.1	0.050	61.64	79.80	697.74	262.92	624.46	66.18	1.03	2.70E+08	20.65	
5.2	0.055	62.68	78.02	709.36	258.70	622.64	72.34	1.14	2.97E+08	20.65	
6	0.060	62.56	80.37	707.31	268.44	624.49	64.61	1.24	3.23E+08	20.65	
7	20.00	60.59	80.10	684.88	165.19	645.06	447.12	163.91	0.52	1.35E+08	20.65
8	21.00	60.66	80.66	686.94	159.64	645.06	178.60	0.52	1.35E+08	20.65	
9	22.00	58.84	71.58	666.05	235.58	665.95	93.52	0.52	1.35E+08	20.65	
10	23.00	58.74	75.03	652.76	246.86	680.24	82.24	0.52	1.35E+08	20.65	
11	24.00	57.90	73.90	650.08	250.08	670.40	79.02	0.52	1.35E+08	20.65	
12	25.00	57.64	77.64	653.95	255.95	670.40	75.15	0.52	1.35E+08	20.65	
13	26.00	57.83	77.83	656.20	256.20	670.40	72.90	0.52	1.35E+08	20.65	
14	1.60E+05	52.47	67.72	593.02	189.96	639.54	139.54	0.52	9.02E+07	20.65	
15	1.80E+05	52.37	58.90	592.86	193.83	639.14	135.27	0.52	7.90E+07	20.65	
16	2.00E+05	52.54	61.58	599.23	209.24	632.68	119.86	0.52	8.79E+07	20.65	
17	2.20E+05	52.69	69.10	596.42	227.40	633.58	101.70	0.52	9.66E+07	20.65	
18	2.40E+05	53.02	68.58	606.15	225.69	631.85	103.41	0.52	1.05E+08	20.65	
19	1.60E+05	58.25	67.30	659.38	221.44	672.62	107.62	0.52	1.29E+08	20.65	
4.1	1.80E+05	58.84	71.58	666.05	235.58	665.95	93.52	0.52	1.35E+08	20.65	
2.1	2.00E+05	58.82	68.62	666.92	243.62	665.08	85.48	0.52	1.50E+08	20.65	
2.2	2.00E+05	59.45	78.67	673.01	238.90	658.99	70.20	0.52	1.65E+08	20.65	
2.3	2.00E+05	60.64	76.81	686.49	237.79	645.60	76.31	0.52	1.80E+08	20.65	
24	20.00	41.88	58.85	474.10	193.67	657.90	135.43	0.52	1.35E+08	20.65	
25	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	665.95	93.52	0.52	1.35E+08	20.65	
30	26.00	60.74	64.45	687.54	212.12	644.46	116.98	0.52	1.35E+08	20.65	
31	0.40	60.07	48.25	688.03	149.62	611.99	474.72	0.23	5.99E+07	9.18	
32	0.50	59.98	-20.50	678.95	-67.77	453.05	396.87	0.29	7.49E+07	11.47	
33	0.60	59.24	9.09	676.86	29.99	461.44	299.20	0.34	8.99E+07	13.77	
34	0.70	59.04	17.81	676.50	58.62	453.50	270.48	0.40	1.03E+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	680.80	172.60	450.20	156.90	0.52	1.35E+08	20.65	
37	0.40	69.66	-132.44	788.38	-435.87	343.42	764.97	0.52	1.35E+08	20.65	
38	0.50	67.91	-61.51	768.78	-284.96	363.30	616.00	0.52	1.35E+08	20.65	
39	0.60	66.68	-44.18	754.38	-145.38	377.62	474.48	0.52	1.35E+08	20.65	
40	0.70	66.58	-24.84	748.26	-14.84	383.74	343.46	0.52	1.35E+08	20.65	
41	0.80	63.32	28.95	736.73	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	156.90	0.52	1.35E+08	20.65	
43.1	1.00	58.84	71.58	666.05	235.58	665.95	93.52	0.52	1.35E+08	20.65	
44.1	2.00	58.31	65.42	666.10	215.36	671.90	113.80	0.52	1.35E+08	20.65	
45.1	3.00	59.43	64.62	672.80	212.68	659.20	116.42	0.52	1.35E+08	20.65	
46.1	1.00	58.44	58.83	651.53	180.45	670.47	146.65	0.52	1.35E+08	20.65	
47.1	2.00	57.60	57.86	645.28	190.41	646.72	138.69	0.52	1.35E+08	20.65	
48.1	1.00	57.44	49.68	655.19	165.50	641.81	165.60	0.52	1.35E+08	20.65	
43.2	1.00	63.62	67.54	693.73	222.29	638.27	106.81	0.52	1.35E+08	20.65	
44.2	2.00	56.32	69.79	657.57	213.23	694.43	115.87	0.52	1.35E+08	20.65	
45.2	3.00	56.92	66.81	644.37	219.87	687.63	109.23	0.52	1.35E+08	20.65	
46.2	1.00	54.97	73.98	622.22	236.55	599.78	92.55	0.52	1.35E+08	20.65	
47.2	2.00	56.66	55.45	641.51	182.49	696.49	146.61	0.52	1.35E+08	20.65	
48.2	3.00	59.77	54.66	676.57	179.95	649.20	169.20	0.52	1.35E+08	20.65	
49	1.05	57.95	67.83	656.00	223.30	676.00	105.80	0.52	1.35E+08	21.69	
50	1.10	58.42	65.36	661.30	215.10	670.70	114.00	0.52	1.35E+08	22.72	
51	1.15	58.60	63.54	663.40	215.70	668.60	113.80	0.52	1.35E+08	23.75	
52	1.20	59.66	63.66	666.60	216.10	663.40	113.00	0.52	1.35E+08	24.79	
53	1.25	59.47	67.79	673.20	221.10	658.80	106.00	0.52	1.35E+08	25.82	
54	1.30	59.69	58.47	676.10	221.30	653.90	115.60	0.52	1.35E+08	26.85	
55	2.00	56.21	56.00	636.33	200.80	695.67	115.40	0.52	1.35E+08	28.88	
56	2.50	57.67	69.02	686.00	227.10	686.00	103.94	0.52	1.35E+08	30.91	
57	3.00	59.76	62.83	676.50	206.94	655.50	122.16	0.52	1.35E+08	32.94	
58	3.50	61.28	69.66	696.66	179.48	638.54	138.36	0.52	1.35E+08	34.97	
59	4.00	62.83	44.90	711.22	147.97	620.78	181.13	0.52	1.35E+08	37.00	
60	4.50	63.63	36.86	713.49	121.30	618.51	207.80	0.52	1.35E+08	39.03	
61	0.01 m	57.59	67.79	649.70	221.10	682.30	106.00	0.52	1.35E+08	20.65	
62	0.04 m	57.38	67.79	649.50	221.10	680.00	106.00	0.52	1.35E+08	20.65	
63	0.07 m	57.45	65.36	650.30	215.10	681.70	114.00	0.52	1.35E+08	20.65	
64	0.10 m	57.75	65.03	653.70	214.00	678.30	115.10	0.52	1.35E+08	20.65	
65	0.15 m	57.65	65.65	656.30	215.10	680.00	116.00	0.52	1.35E+08	20.65	
66	0.16 m	57.74	67.15	653.60	221.00	678.40	108.10	0.52	1.35E+08	20.65	
67	0.20 m	57.70	65.50	651.70	209.50	678.30	119.80	0.52	1.35E+08	20.65	
68	0.50	59.07	65.00	668.70	223.80	663.30	105.30	0.52	1.35E+08	20.65	
69	0.70	60.70	61.82	680.80	228.40	665.40	98.18	0.52	1.35E+08	20.65	
70	0.90	60.70	78.53	687.10	238.43	644.90	70.67	0.52	1.35E+08	20.65	
71	1.10	60.30	61.68	689.30	248.63	602.29	60.29	0.52	1.35E+08	20.65	
72	1.30	61.21	38.93	696.30	280.73	635.70	46.39	0.52	1.35E+08	20.65	
73	0.50	57.69	67.82	648.39	223.28	645.70	105.10	0.52	1.35E+08	20.65	
74	0.50	57.31	67.13	648.70	221.00	643.30	108.10	0.52	1.35E+08	20.65	
75	0.70	57.49	67.61	650.80	222.20	641.20	106.60	0.52	1.35E+08	20.65	
76	0.70	60.65	68.20	652.30	228.63	619.20	109.20	0.52	1.35E+08	20.65	
77	1.10	58.33	67.55	660.30	222.30	671.70	106.80	0.52	1.35E+08	20.65	
78	1.30	58.23	63.66	656.20	209.26	672.80	119.60	0.52	1.35E+08	20.65	

## Optimizations energy



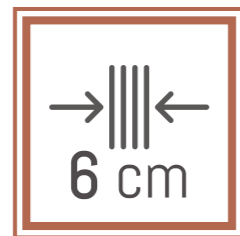
## Optimization costs





# DESIGN REQUIREMENTS

## TROMBE WALL PROPERTIES



Panel thickness



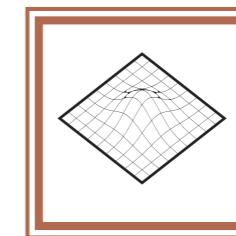
PCM heat capacity



Various Trombe wall ratios



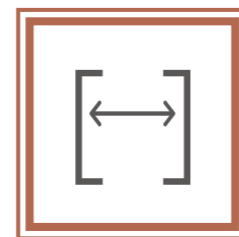
Melting temperature



Increased surface area



Panel layering



Small cavity width



Thermal conductivity

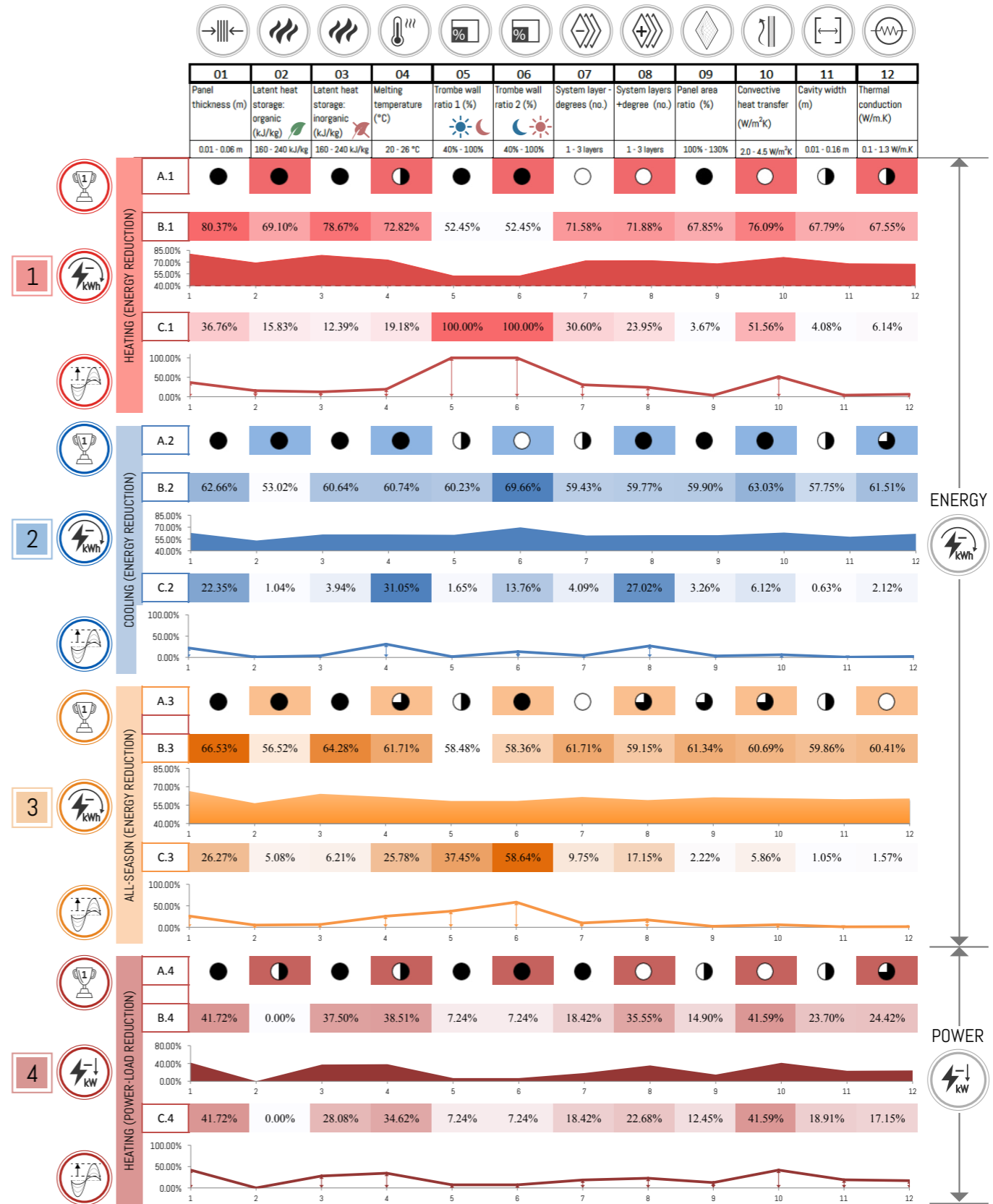


Varying convective heat transfer



Covering temperature

# GUIDELINE SUMMARY



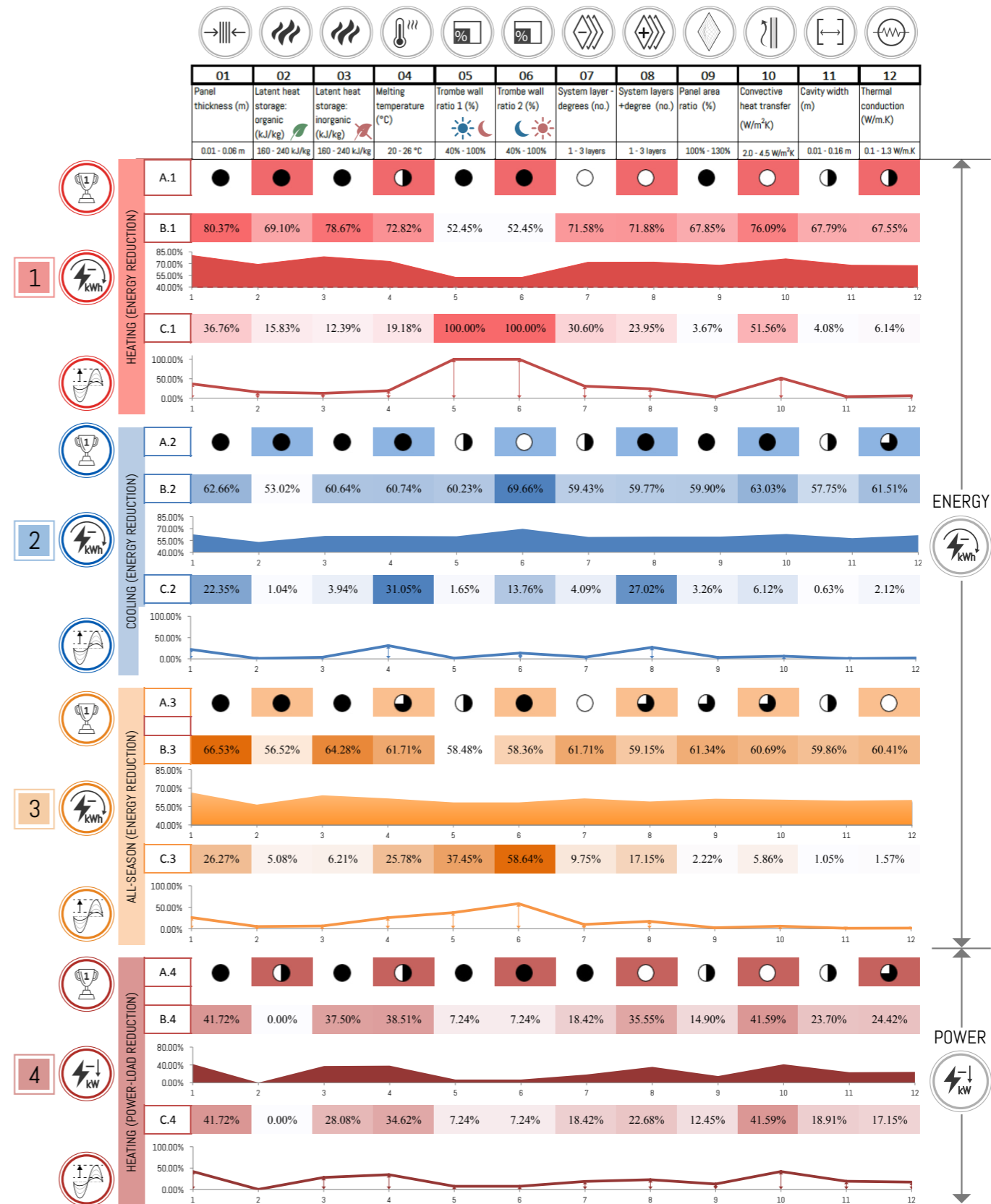
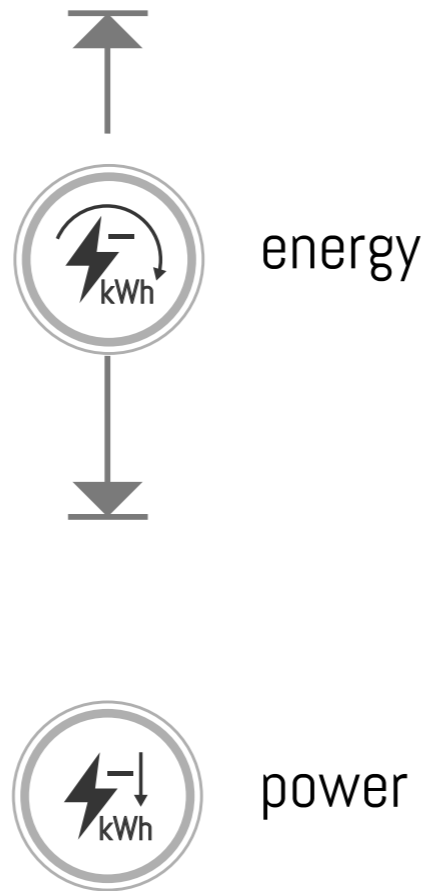
# CATEGORIES

1 Heating energy reduction

2 Cooling energy reduction

3 All-season energy reduction

4 Heating power reduction



# INPUT PARAMETERS



	01	02	03	04	05	06	07	08	09	10	11	12
Panel thickness (m)	0.01 - 0.06 m	Latent heat storage: organic (kJ/kg)	Latent heat storage: inorganic (kJ/kg)	Melting temperature (°C)	Trombe wall ratio 1 (%)	Trombe wall ratio 2 (%)	System layer degrees (no.)	System layers +degree (no.)	Panel area ratio (%)	Convective heat transfer (W/m²K)	Cavity width (m)	Thermal conduction (W/m.K)
	0.01 - 0.06 m	180 - 240 kJ/kg	180 - 240 kJ/kg	20 - 26 °C	40% - 100%	40% - 100%	1 - 3 layers	1 - 3 layers	100% - 130%	2.0 - 4.5 W/m²K	0.01 - 0.16 m	0.1 - 1.3 W/m.K





# COMPARISON

A



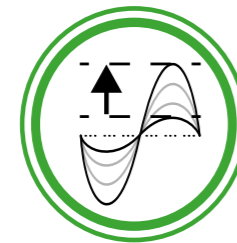
Best performing parameter value

B

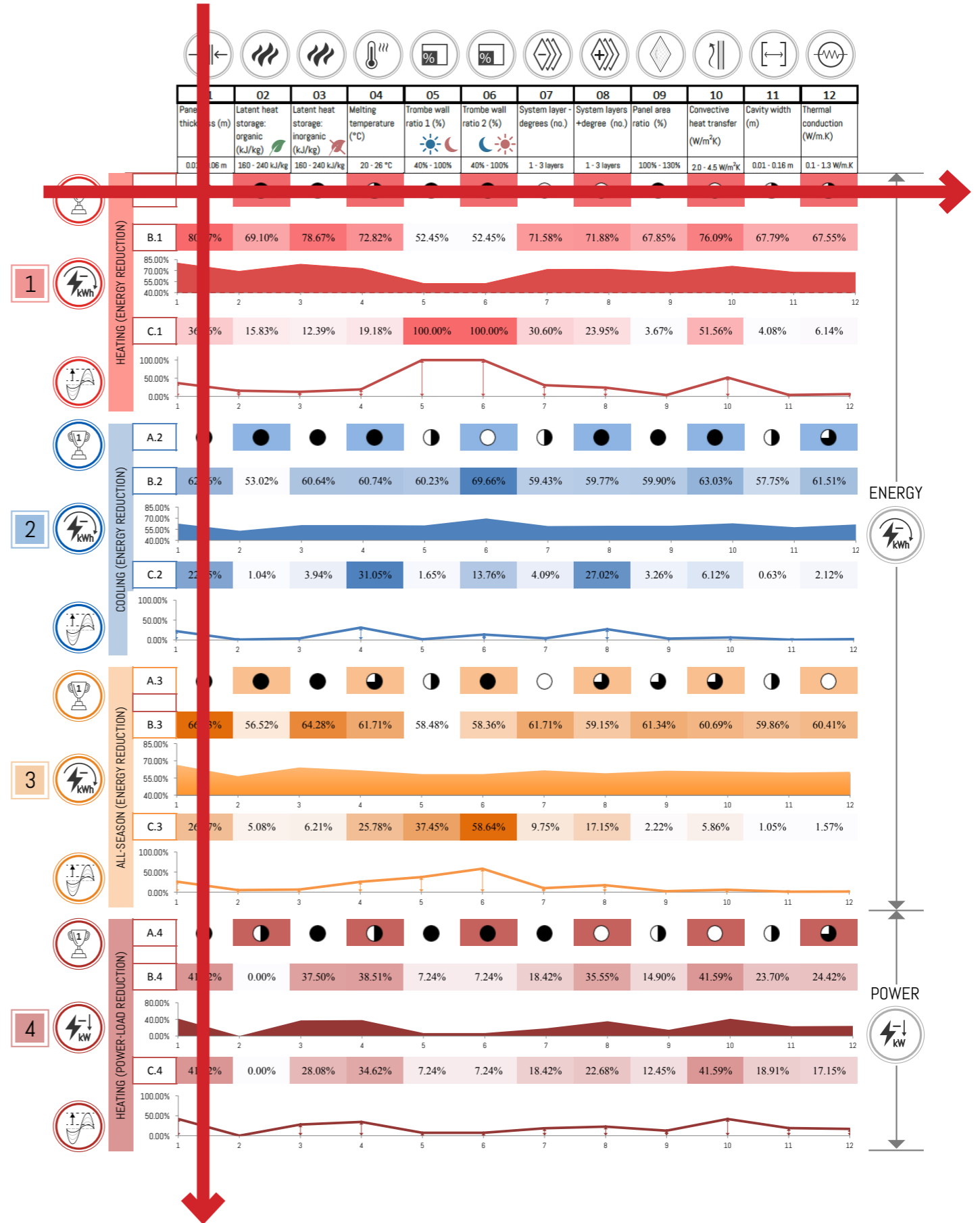


Energy reduction performance

C



Range of dataset





**3** DESIGN

CONCLUSION

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# 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

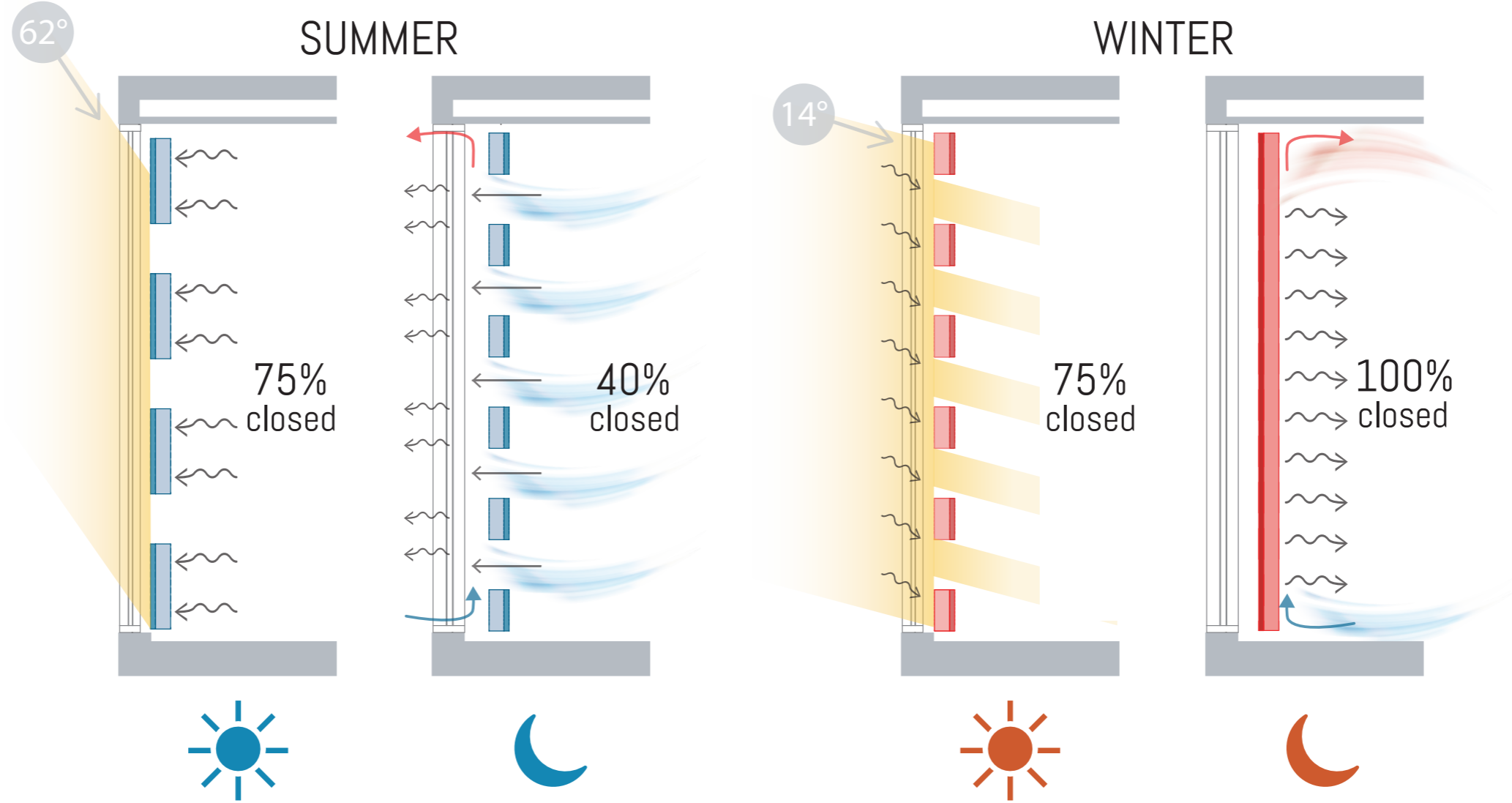
## **HEAT TRANSFER**

difference in performance for energy and power-load

## **INSULATION**

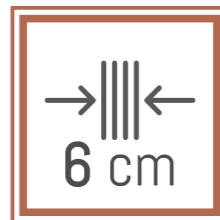
a higher insulation factor reduces the heat losses to the exterior

# DESIGN REQUIREMENTS

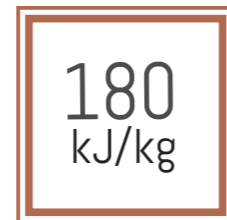


# DESIGN REQUIREMENTS

## TROMBE WALL PROPERTIES



Panel thickness



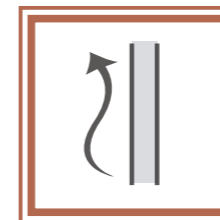
Latent heat of fusion



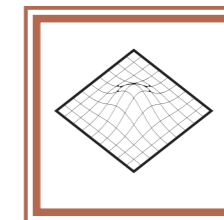
Various Trombe wall ratios



Melting temperature



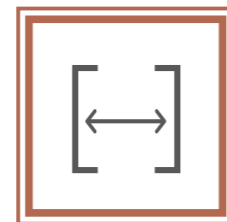
Varying convective heat transfer



Increased surface area



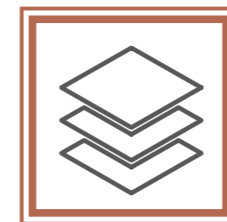
Panel layering



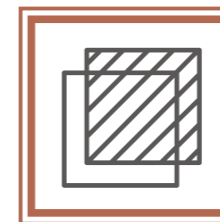
Small cavity width



Thermal conductivity



Cascading strategy



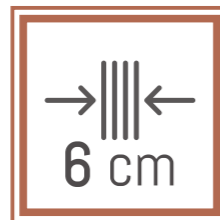
Panel translucency



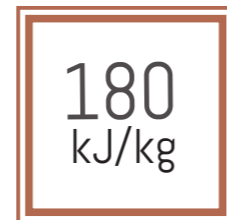
Easy maintenance

# DESIGN REQUIREMENTS

## TROMBE WALL PROPERTIES



Panel thickness



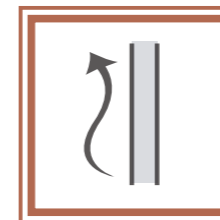
Latent heat of fusion



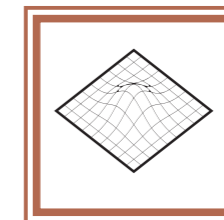
Various Trombe wall ratios



Melting temperature



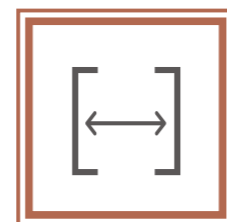
Varying convective heat transfer



Increased surface area



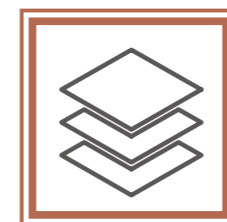
Panel layering



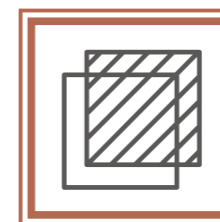
Small cavity width



Thermal conductivity



Cascading strategy



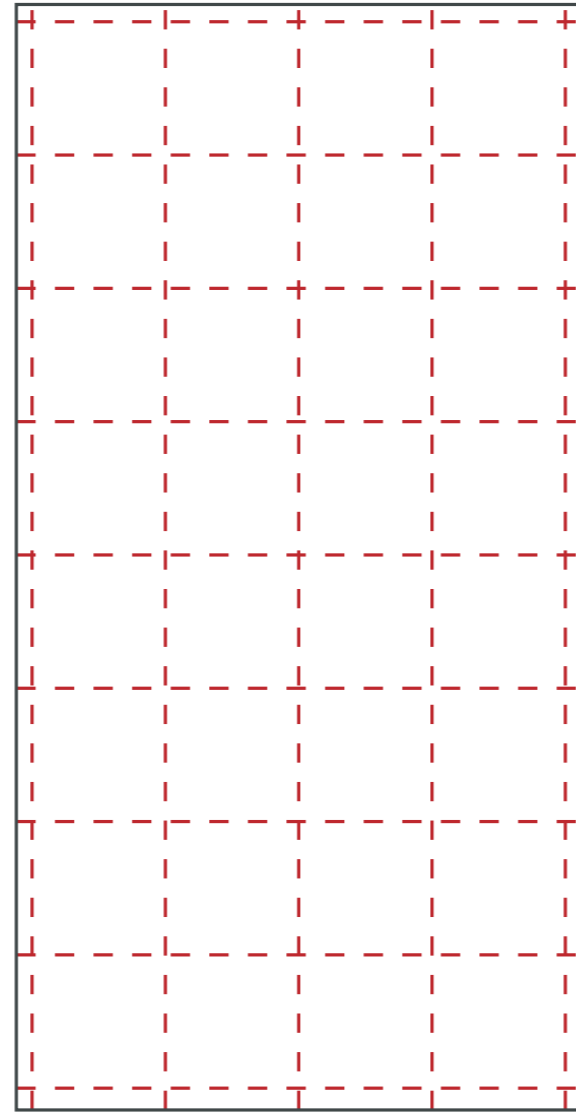
Panel translucency



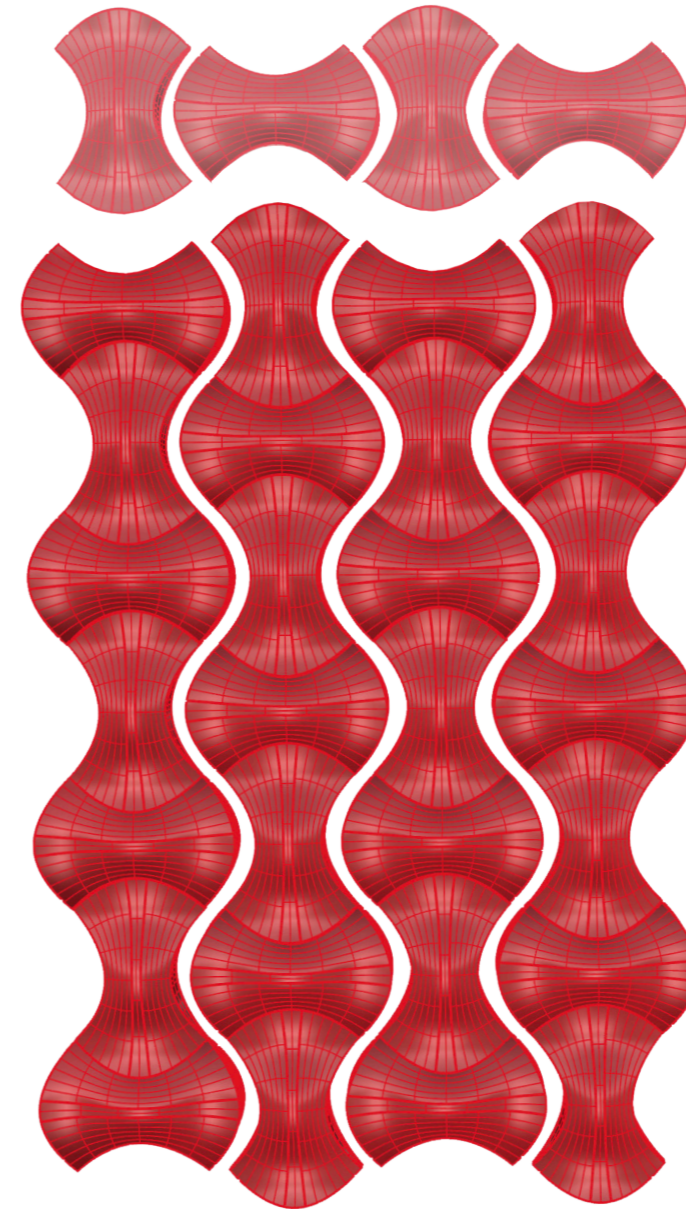
Easy maintenance

# DESIGN TYPOLOGY

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1 Small segment division



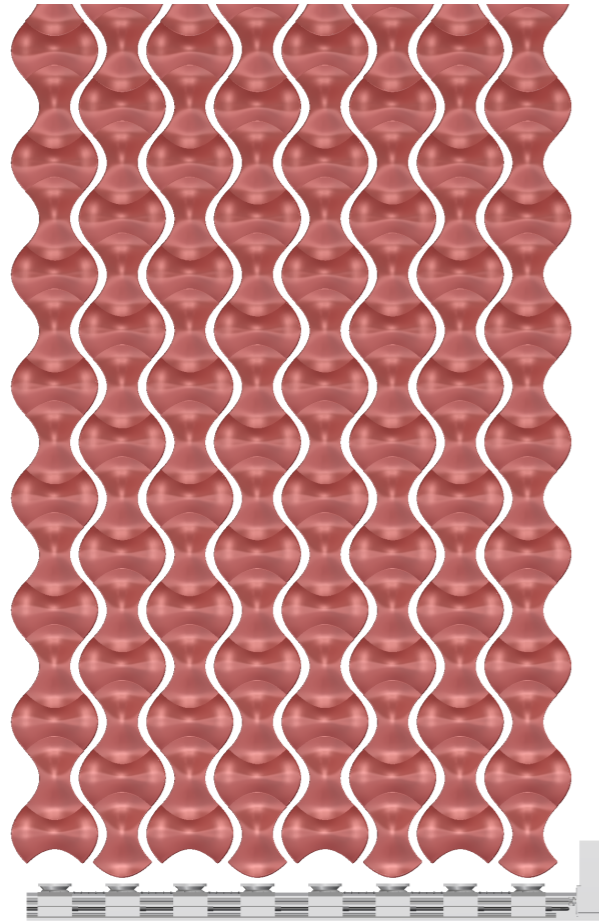
2 Vertical elements



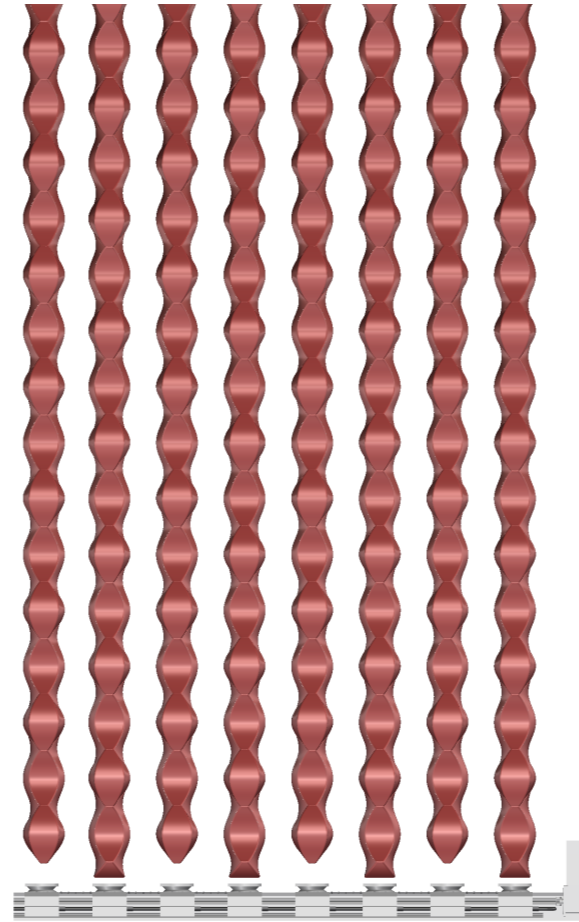


# DESIGN TYPOLOGY

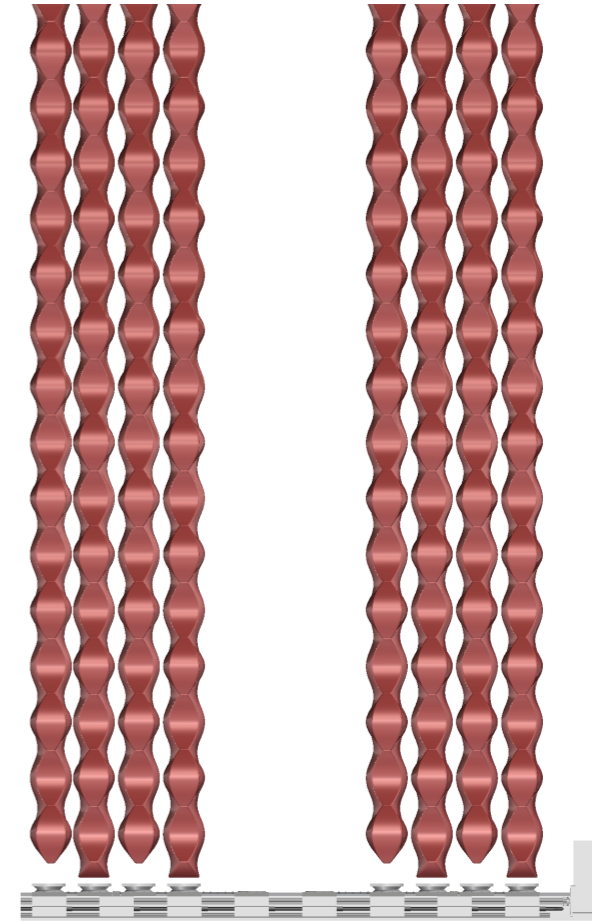
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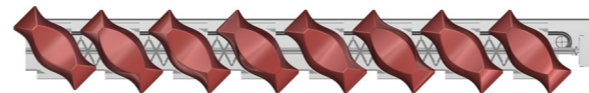
Position 1: 100%



Position 2: 40-50%



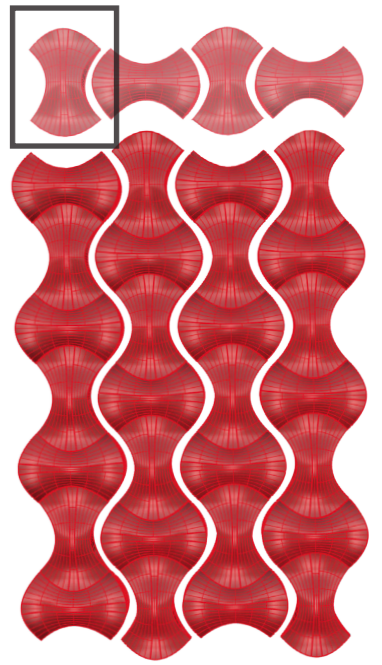
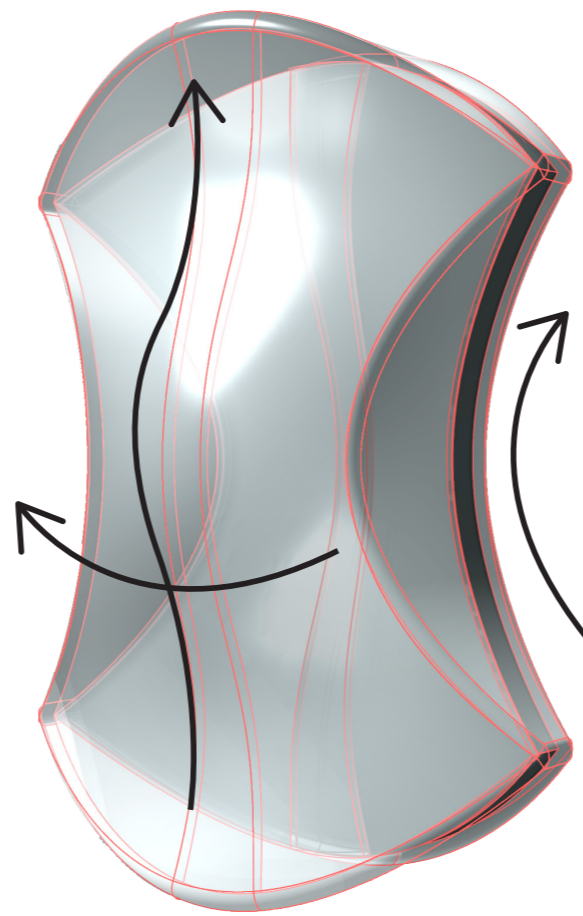
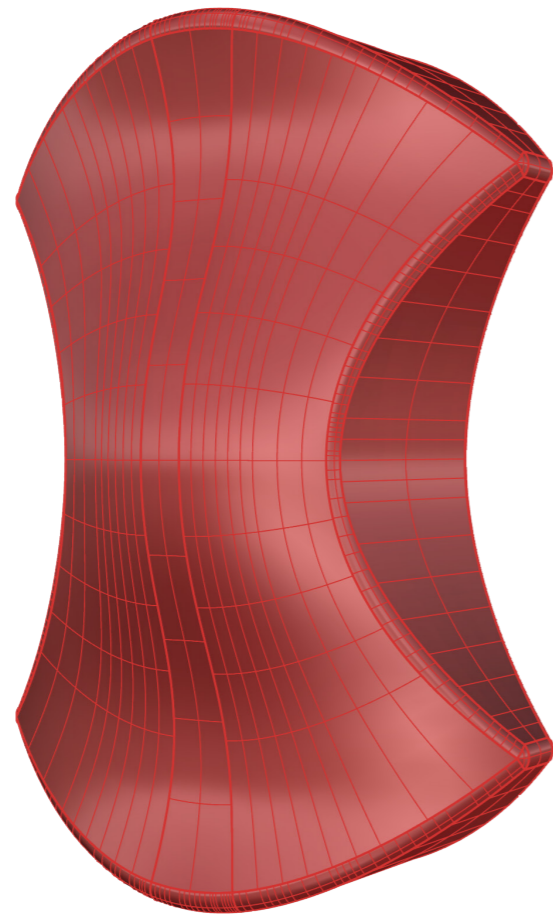
Position 4: 40-50%



Position 3: 75-85%

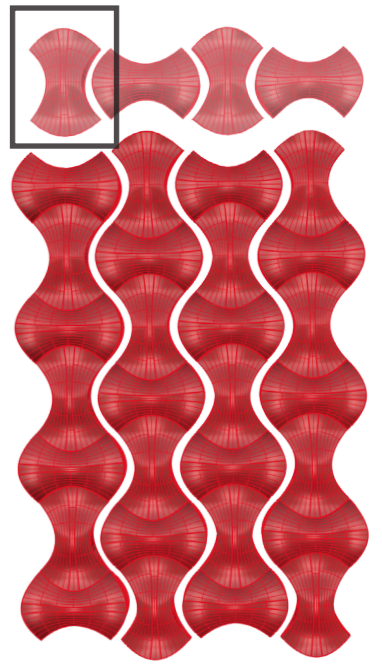
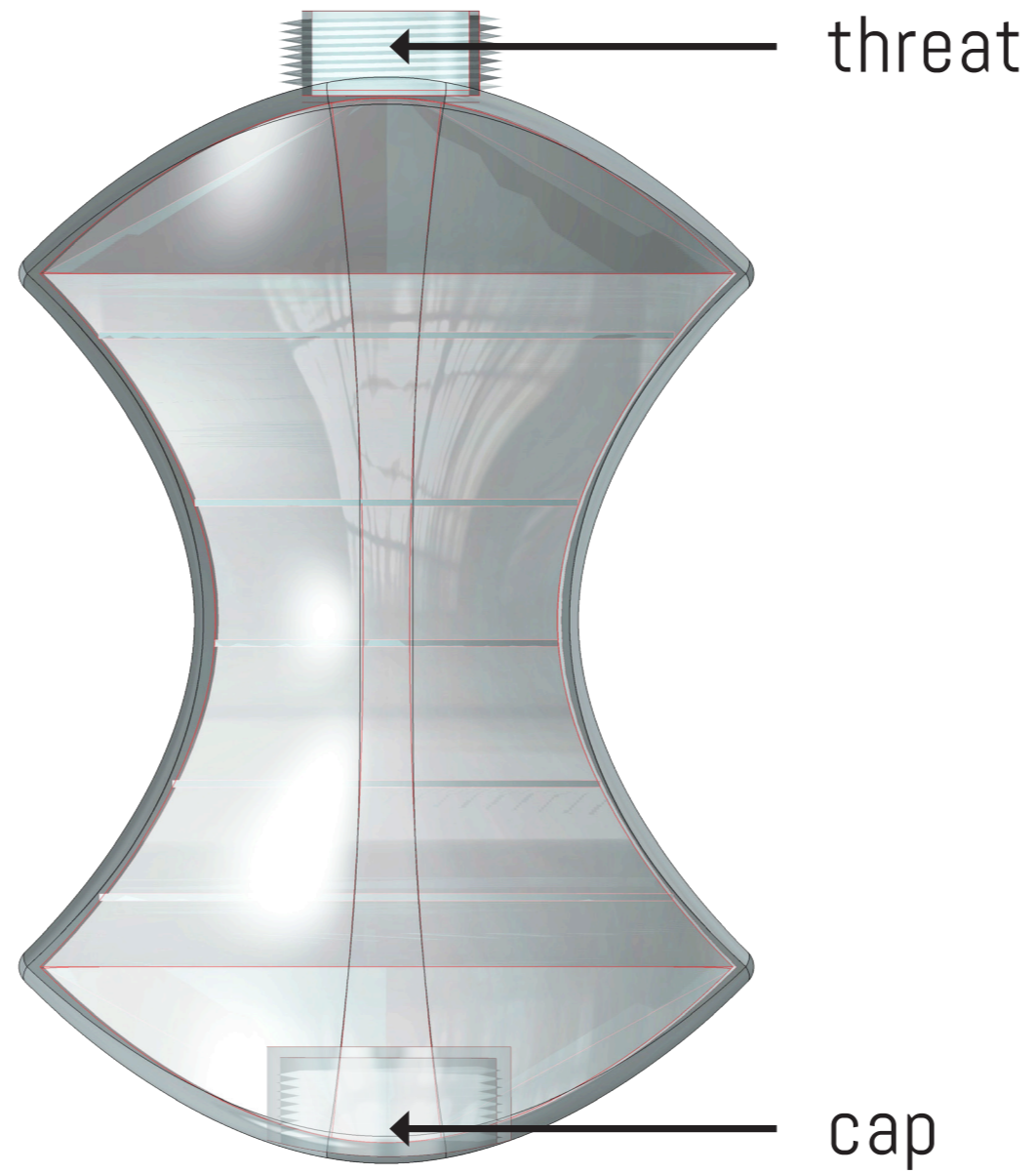
# DESIGN TYPOLOGY

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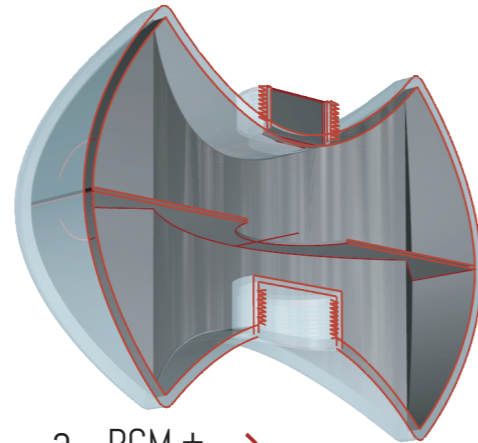
# DESIGN TYPOLOGY

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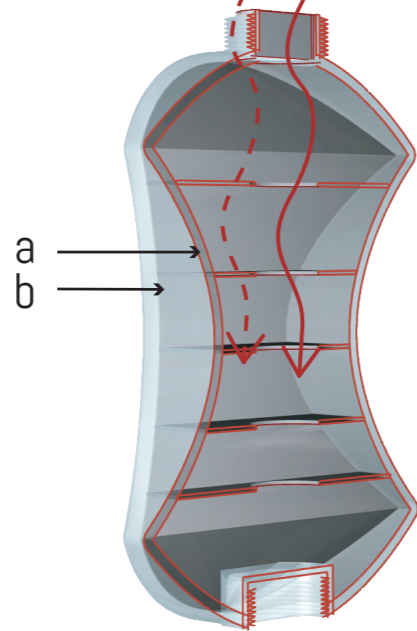


# DESIGN ASSEMBLY

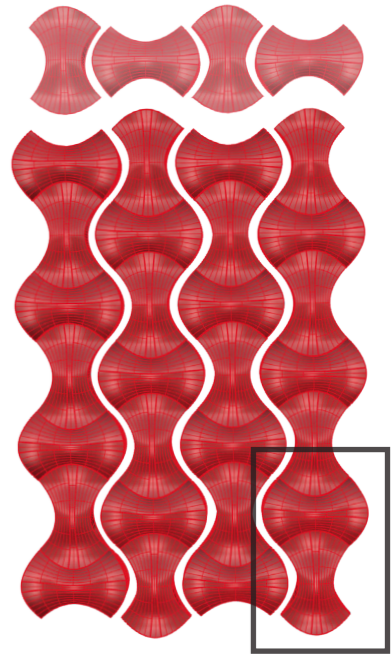
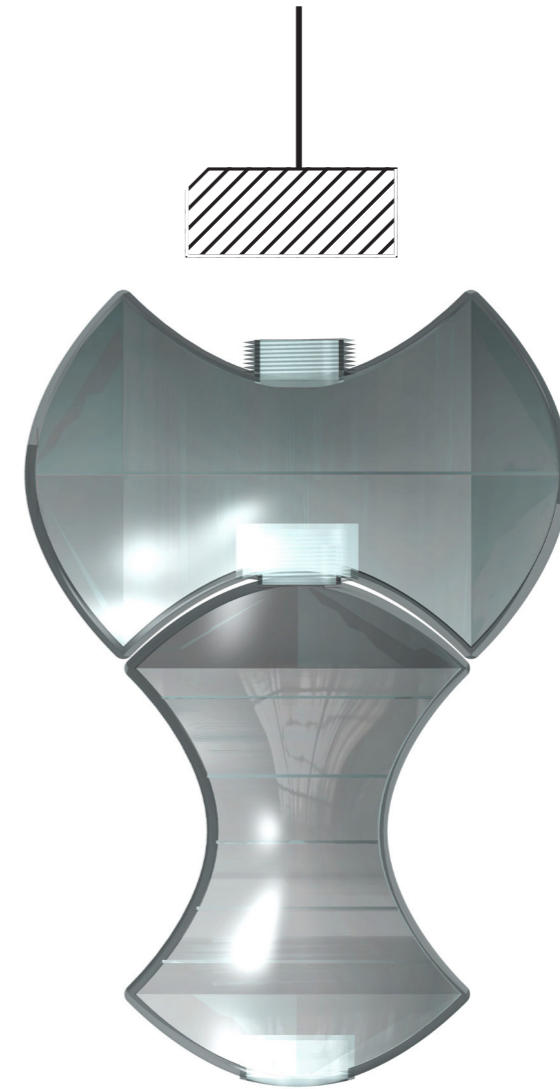
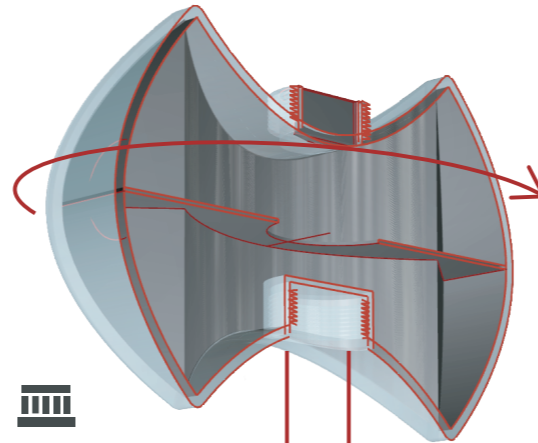
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a. PCM +  
b. Aerogel



a  
b



# 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

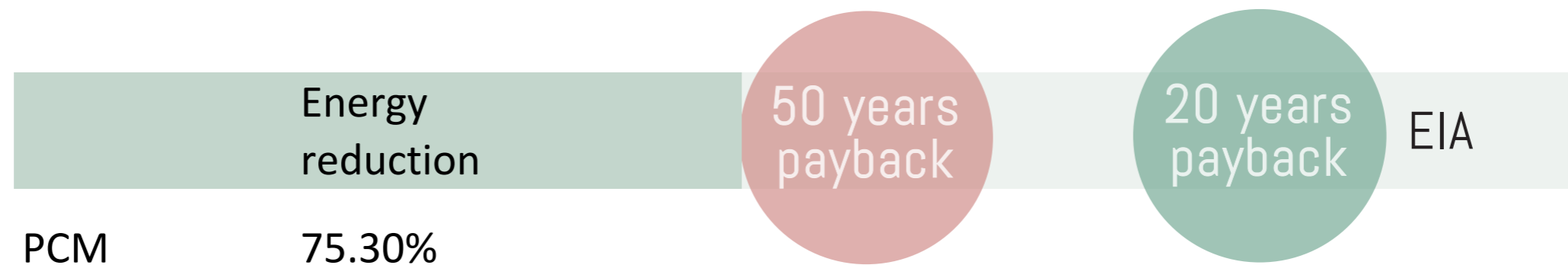


	Energy reduction	50 years payback	20 years payback	EIA
PCM	75.30%			

# 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





# 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<sup>2</sup> office;
- Design element integrated within the office makes people aware of their usage.





