CHANGING PHASE

Design of a Shading and Latent Heat Energy Storage System
for Lightweight Dwellings

Oskar Frick

Master thesis P5 presentation

Introduction

Background

Research

Design

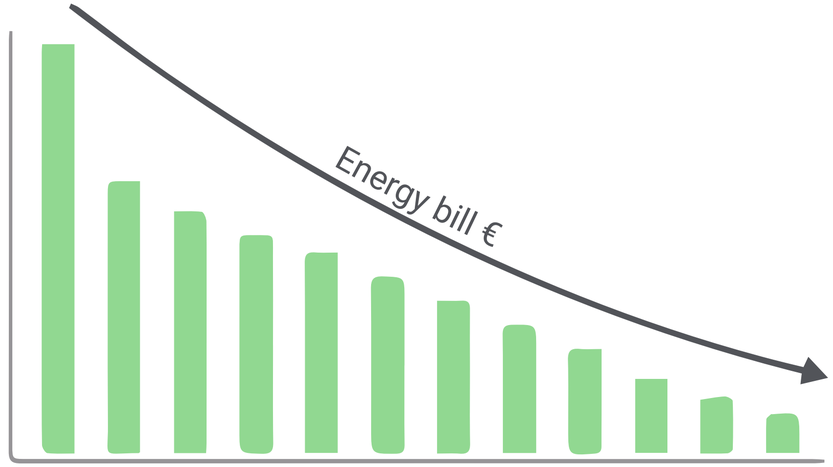
Conclusion & reflection

Source: https://www.clearwaycommunitysolar.com/p-content/uploads/2019/05/iStock-177131518-1024x826.jpg

Background

Phase change material

Dutch dwellings



Source: Google street view
https://www.rubitherm.eu/media/products/images/_de-
tailImage/Rubitherm-RT-400x240.jpg

Background: energy price

Background: Dutch building stock

Building envelope U-Value (W/m² a)

Timeline

	1920	1945	1960	1980	1990	2000	2010	2020
Single-dwelling								
Wall	1.21	1.20	1.09	0.78	0.41	0.27	0.22	0.20
Roof	1.02	1.02	0.83	0.53	0.35	0.21	0.17	0.15
Floor	1.65	1.65	1.51	1.38	0.51	0.22	0.13	0.13
Window	2.18	2.21	2.23	2.20	2.21	2.04	1.81	1.43

Roughly **48%** of Dutch residential buildings was constructed before 1970.

U - value = heat transfer rate through a material.

Source: modified from van den Brom et al., 2018

Background: Dutch building stock

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Roughly **48%** of Dutch residential buildings was constructed before 1970.

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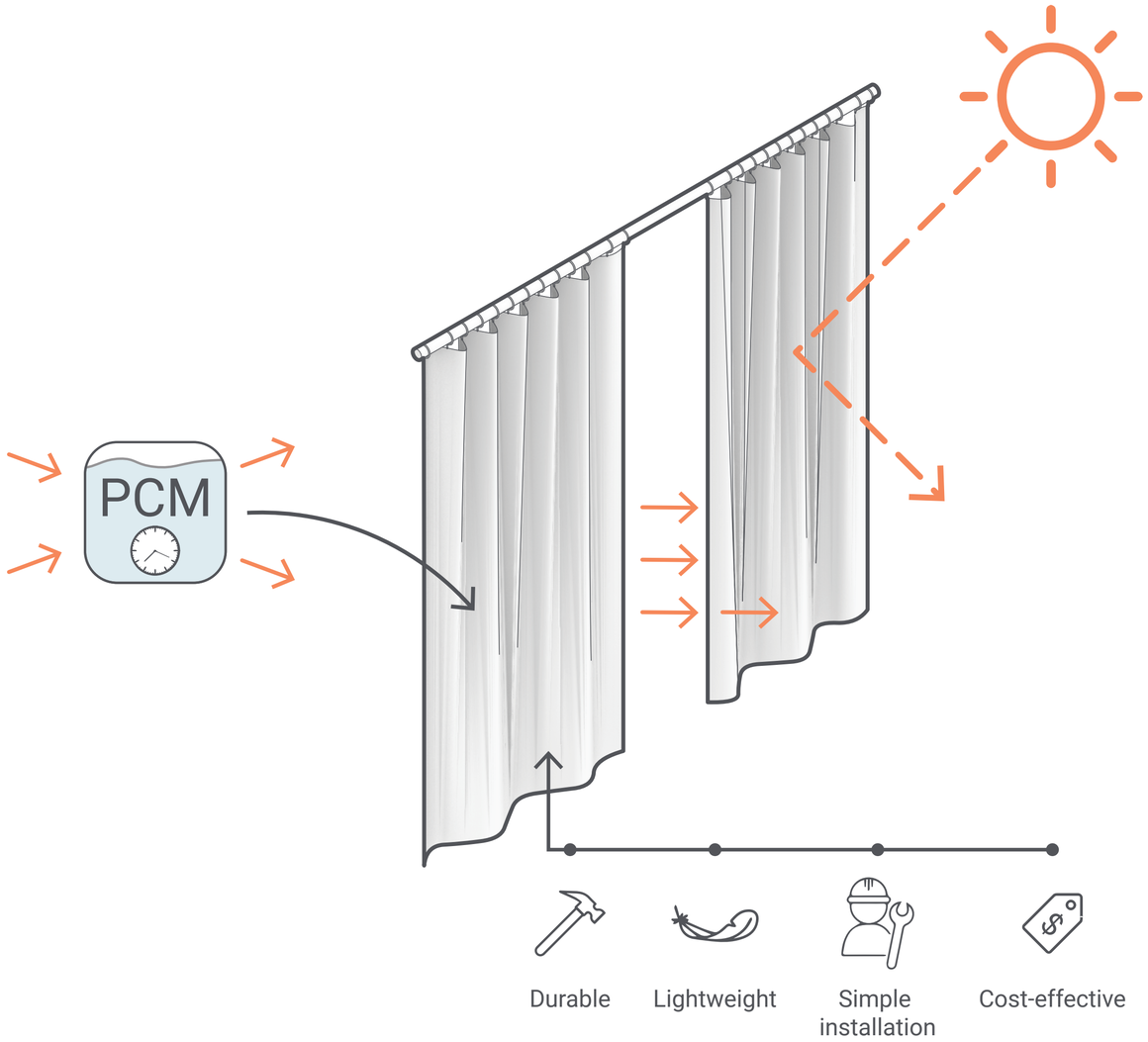
Background: research question

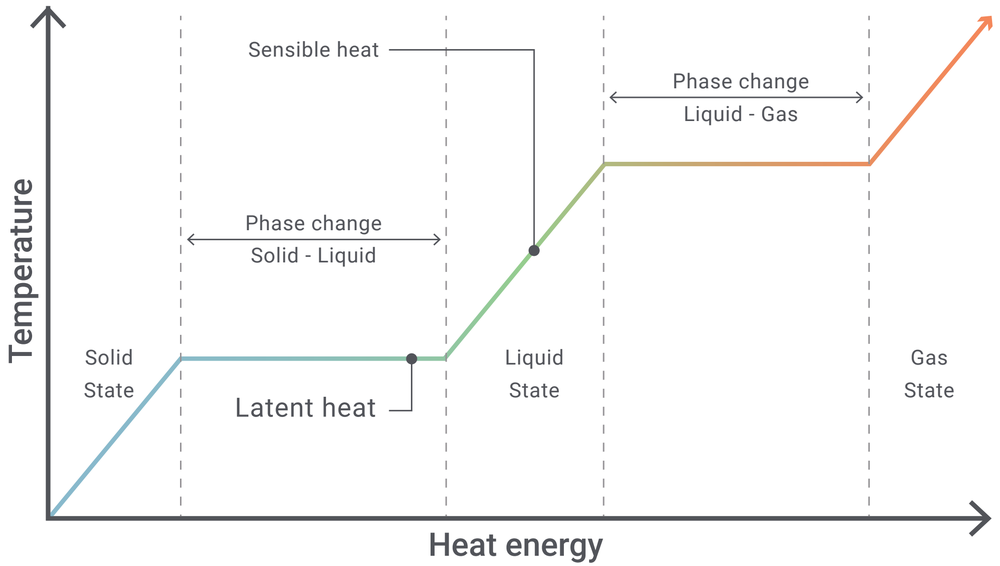
How can **phase change material** be incorporated into a **cost-effective product** to increase the thermal inertia of **lightweight dwellings** in a Cfb climate to enhance passive cooling and heating throughout the year?

Cfb = climate zone in the Netherlands

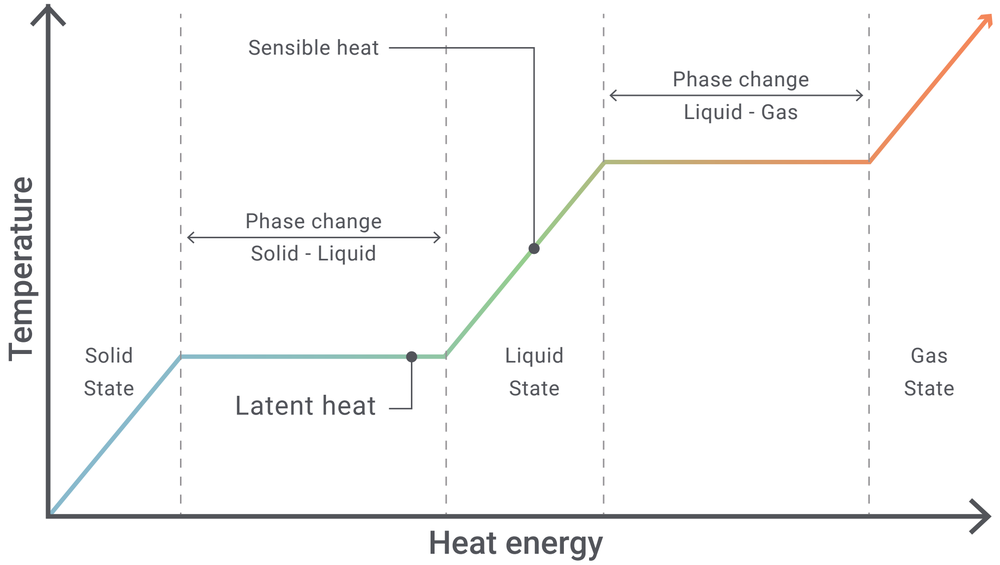
Background: objective

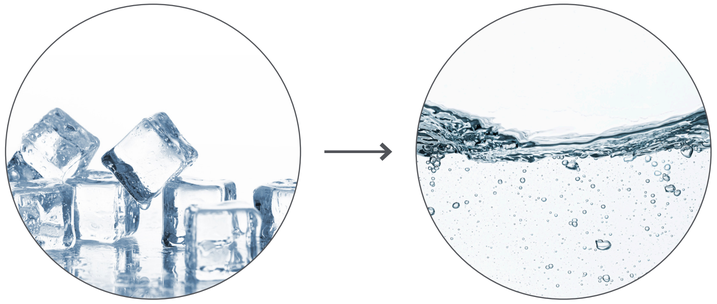


Research: PCM



Research: PCM



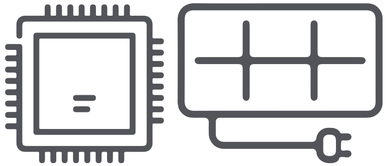


Source: freepik.com

Research: PCM applications

Packaging & transportation

military & space application



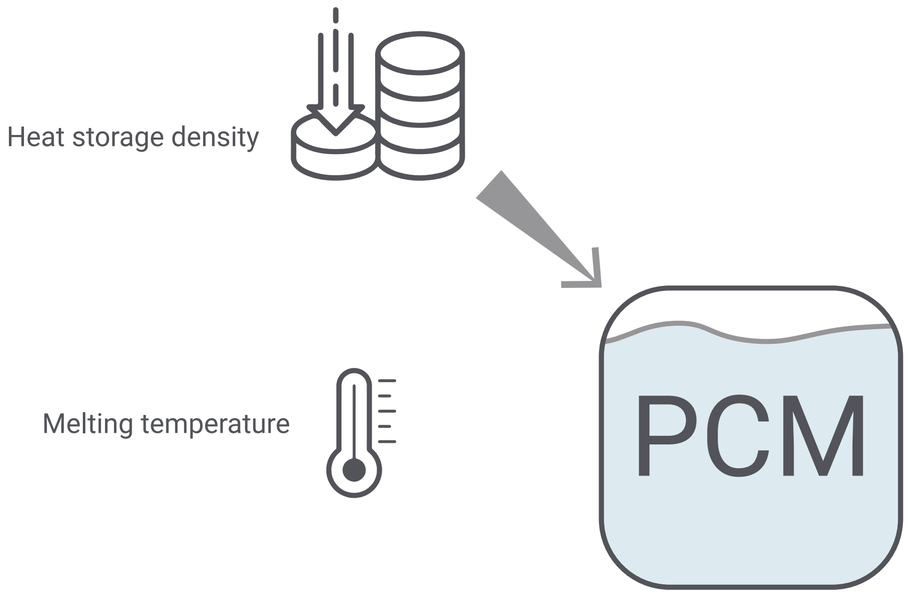
microelectronics & PV panels

Buildings
23 - 26 °C

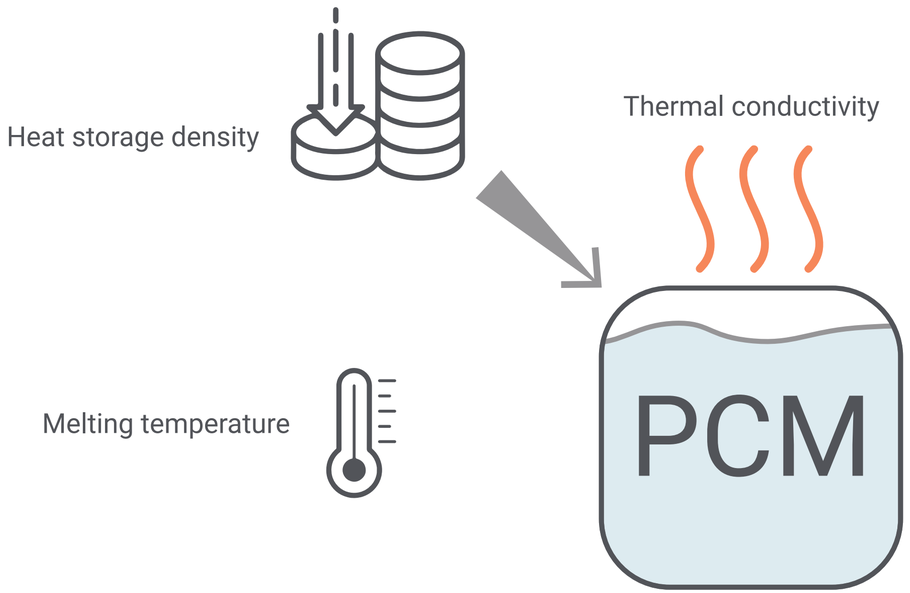
Research: PCM properties

Melting temperature

Research: PCM properties



Research: PCM properties



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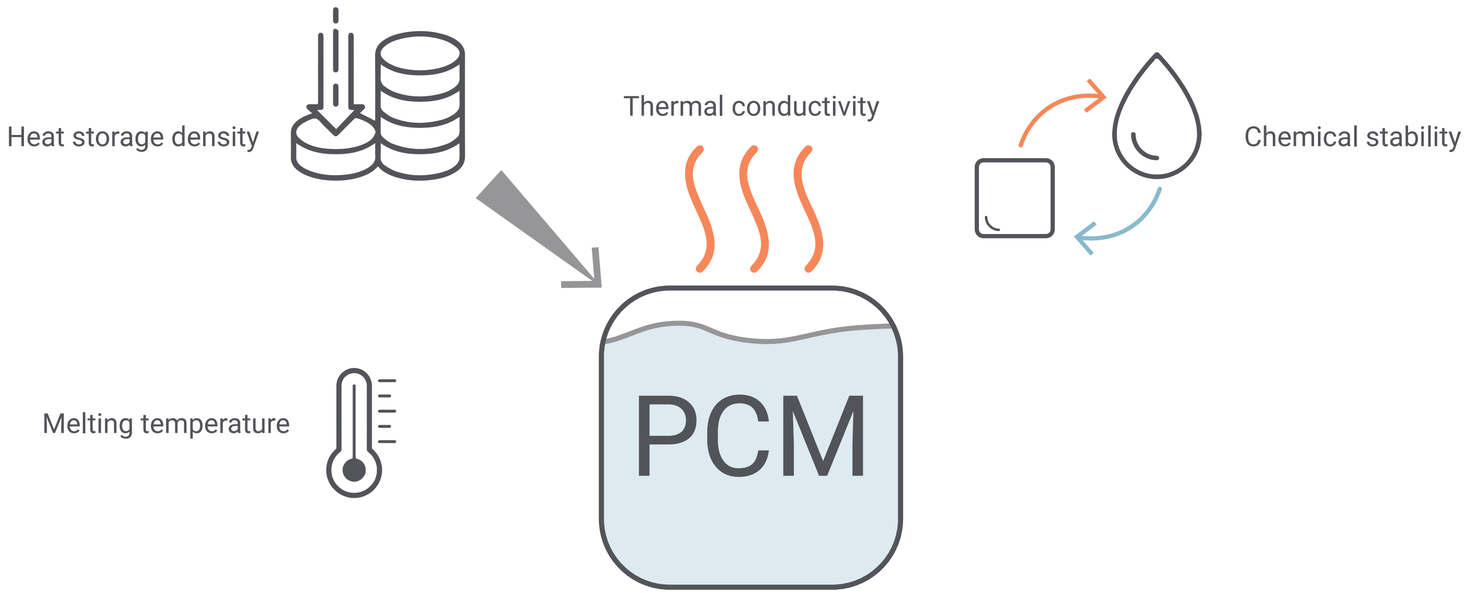
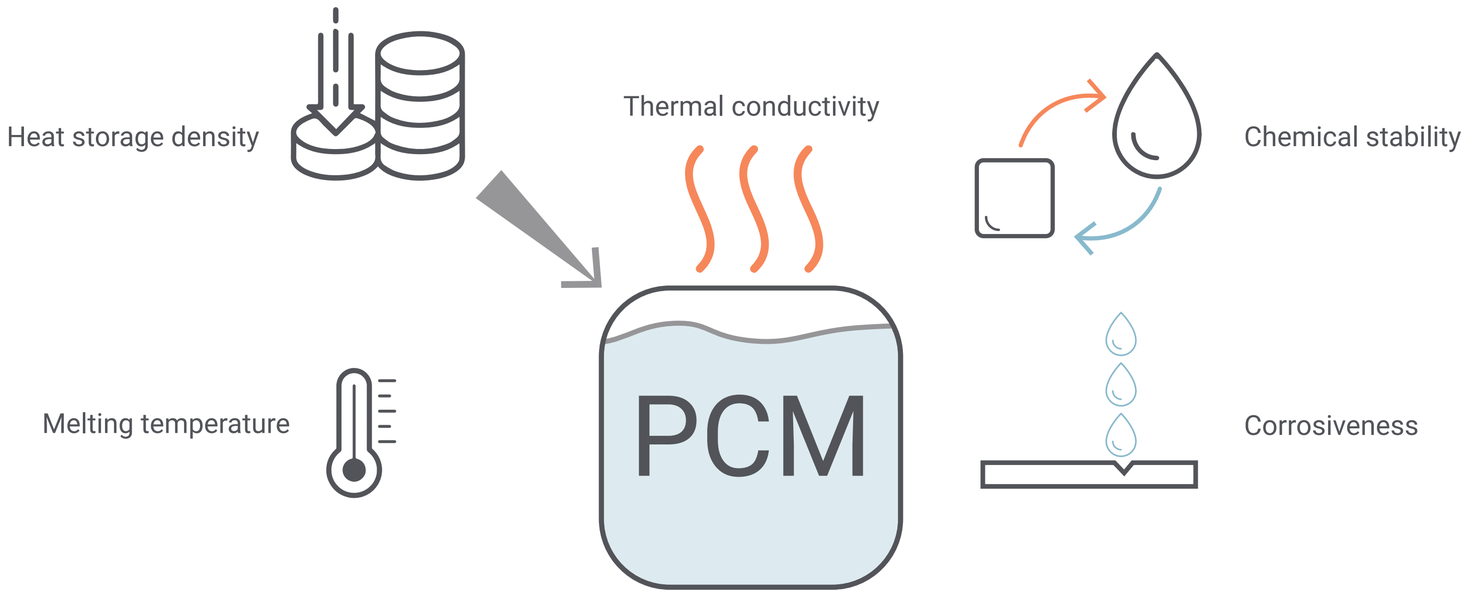


Research: PCM properties



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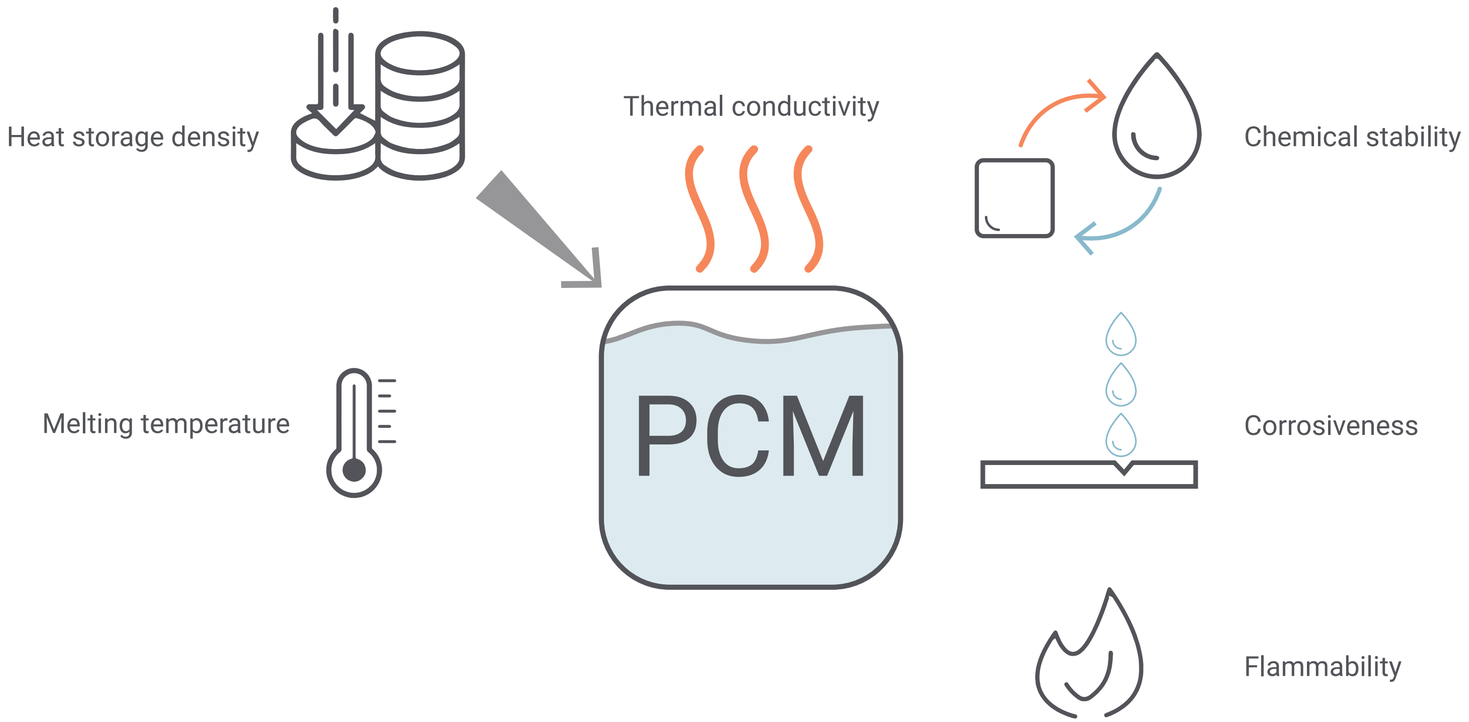

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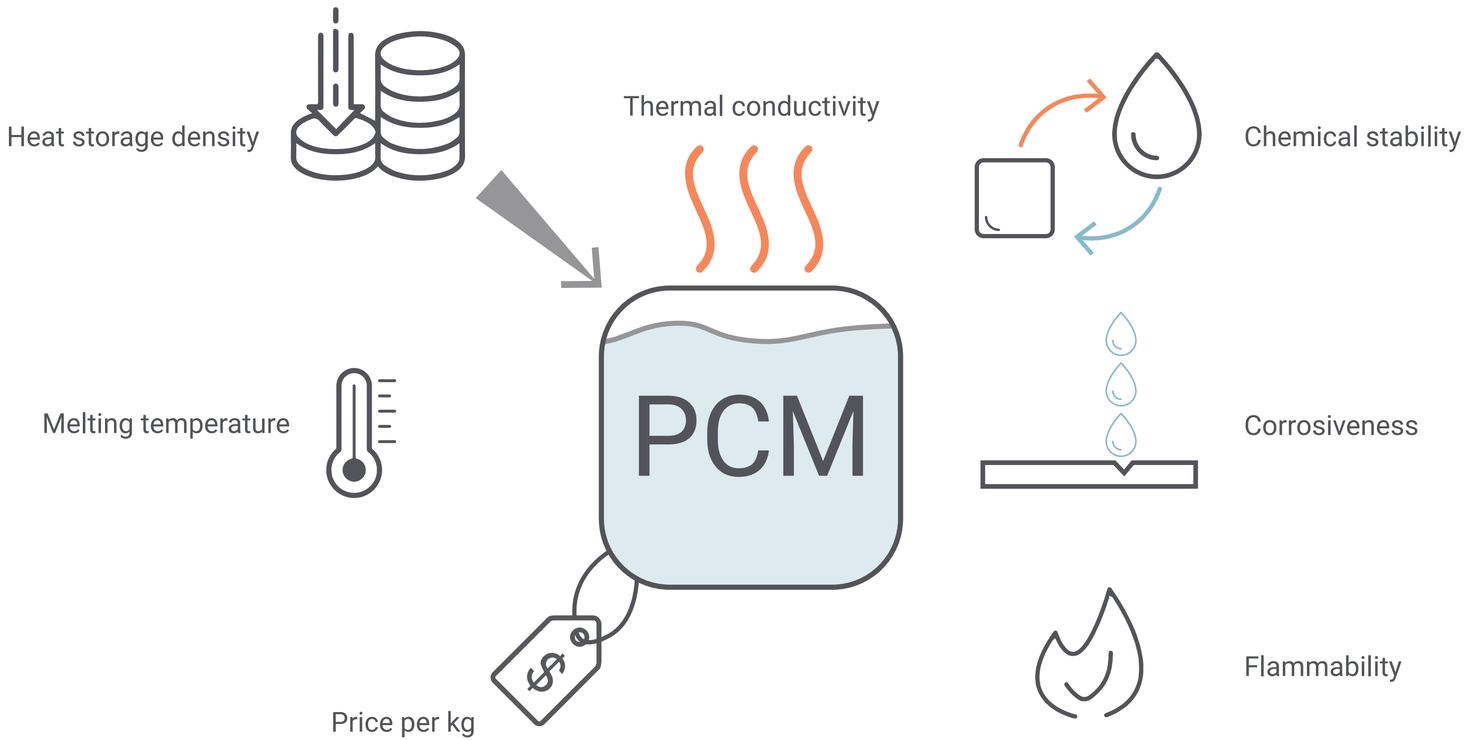

Research: PCM type

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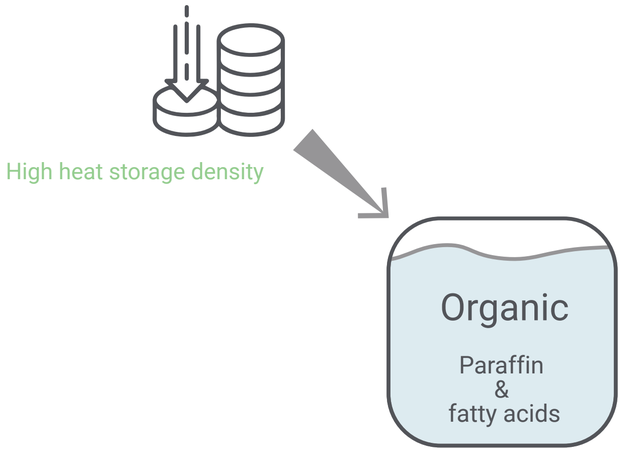

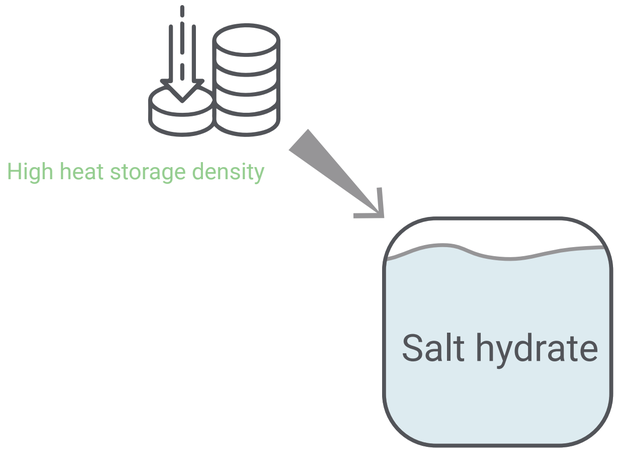

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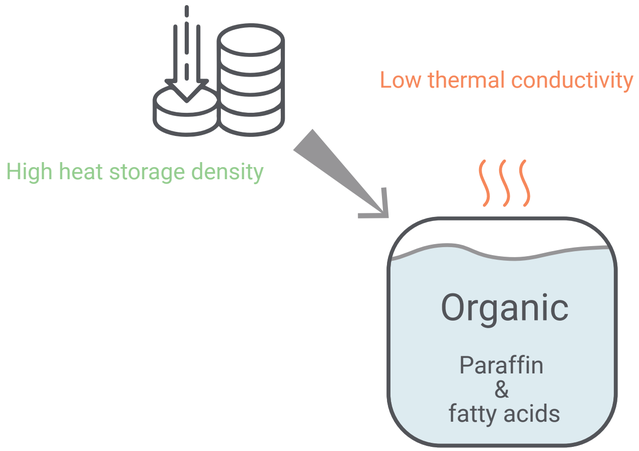

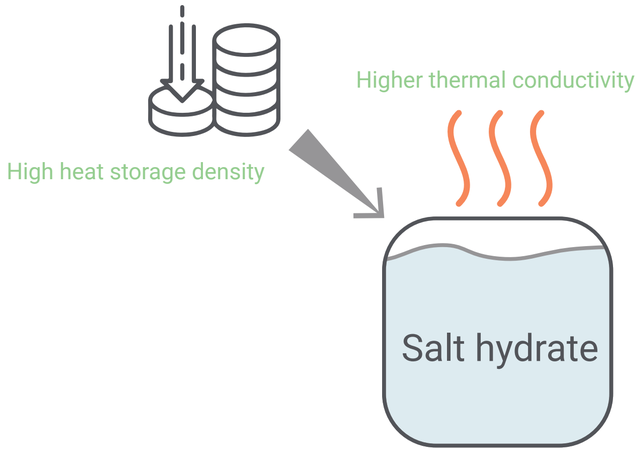

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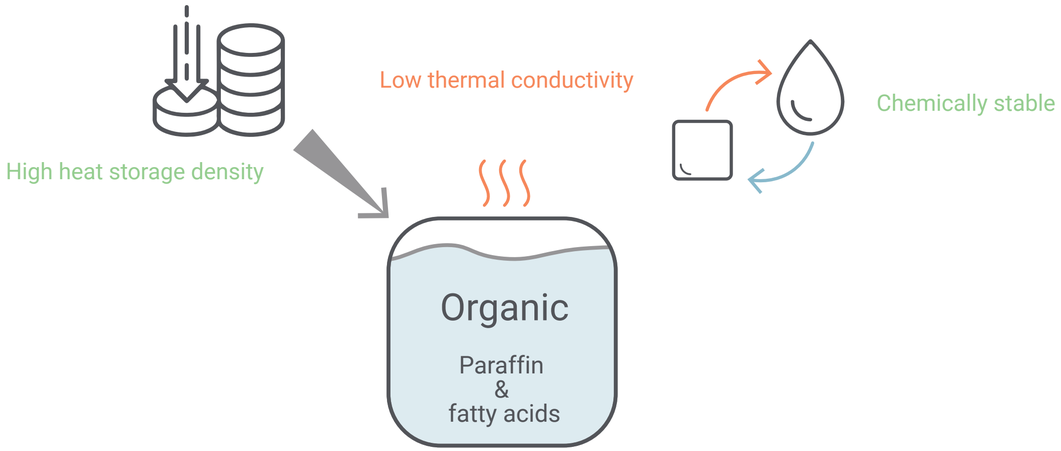

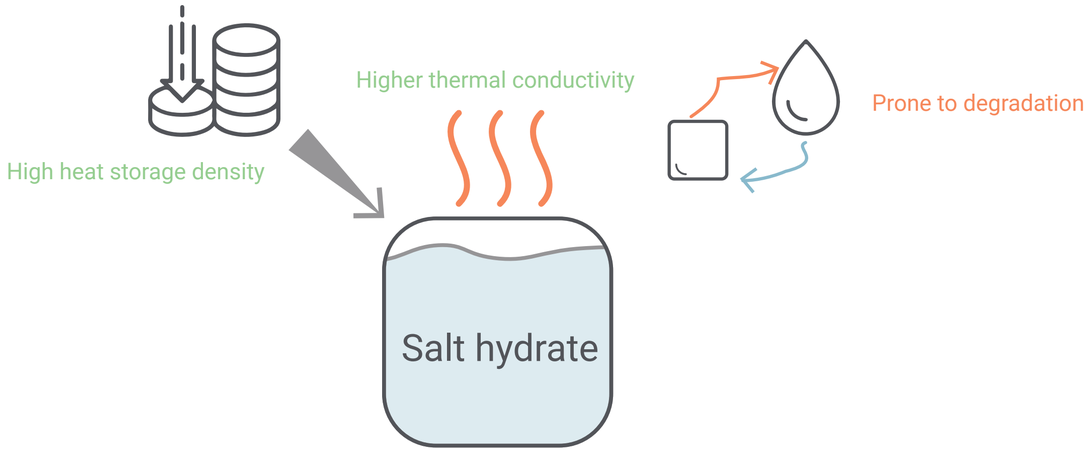

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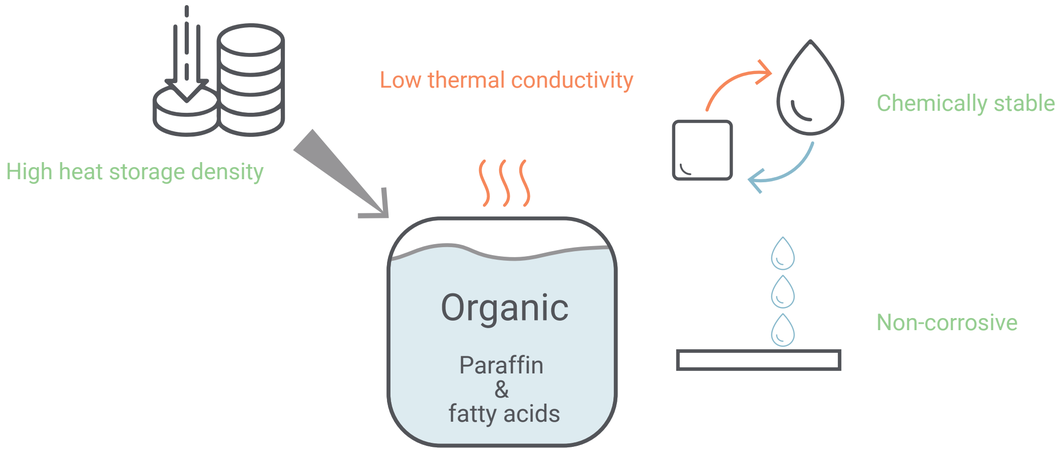

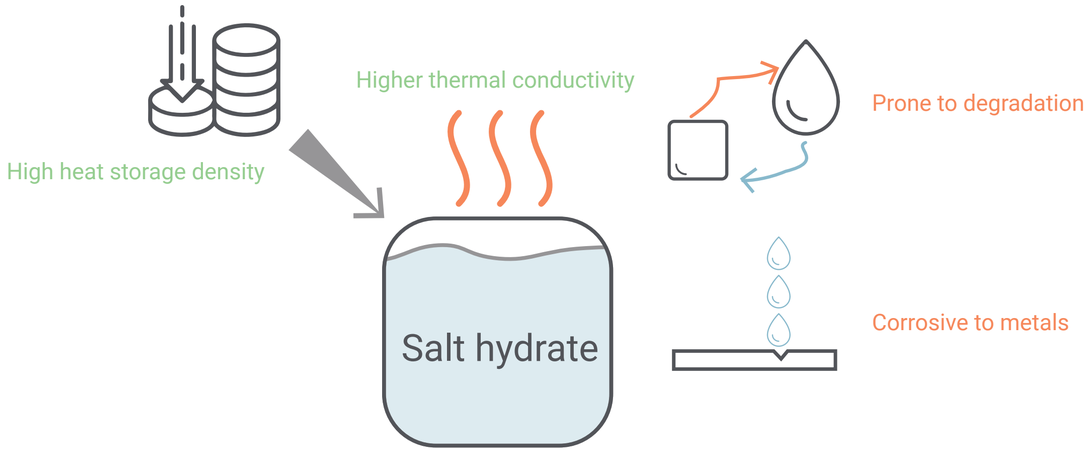

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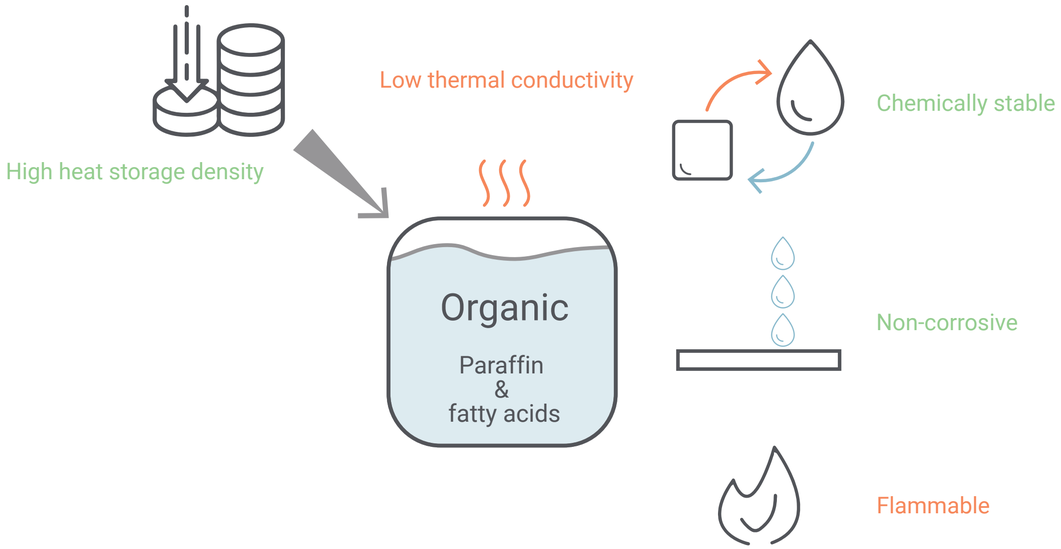

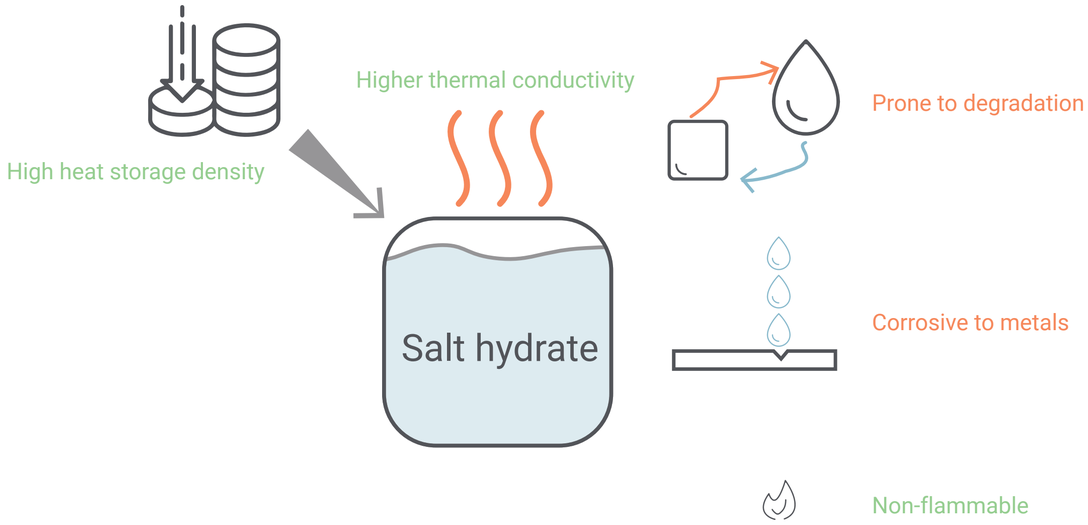

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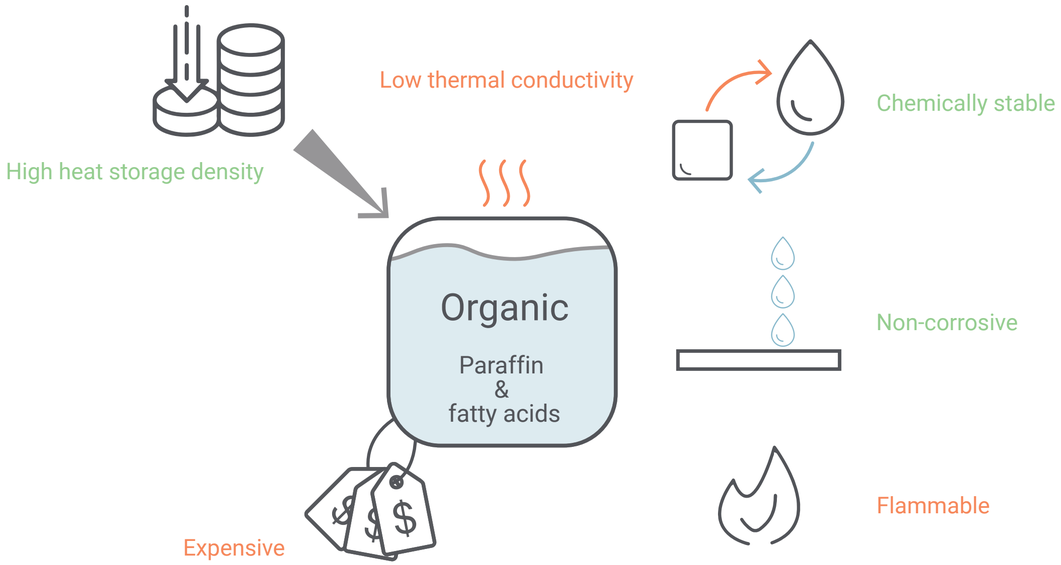
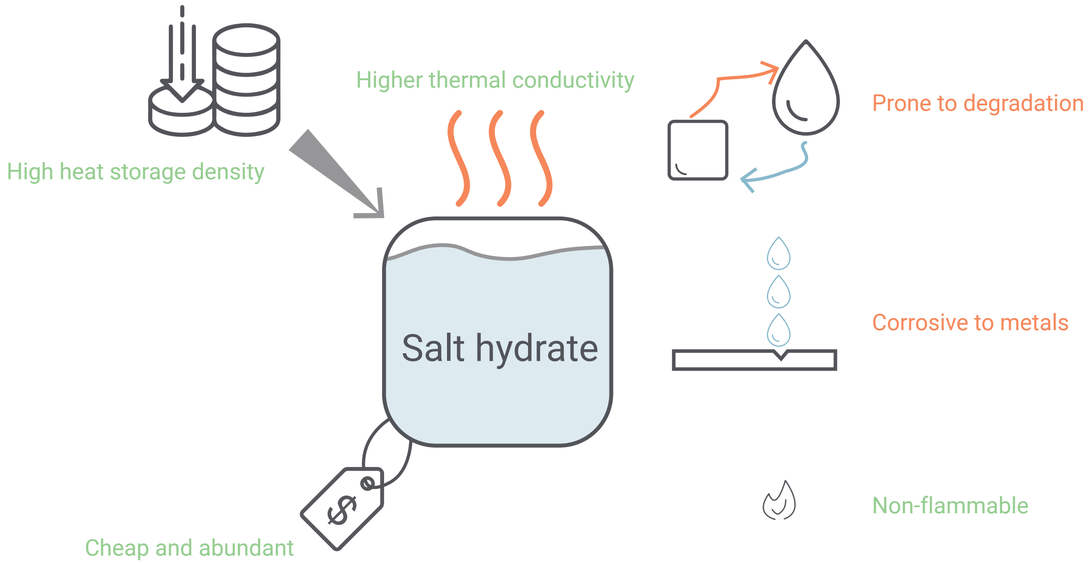
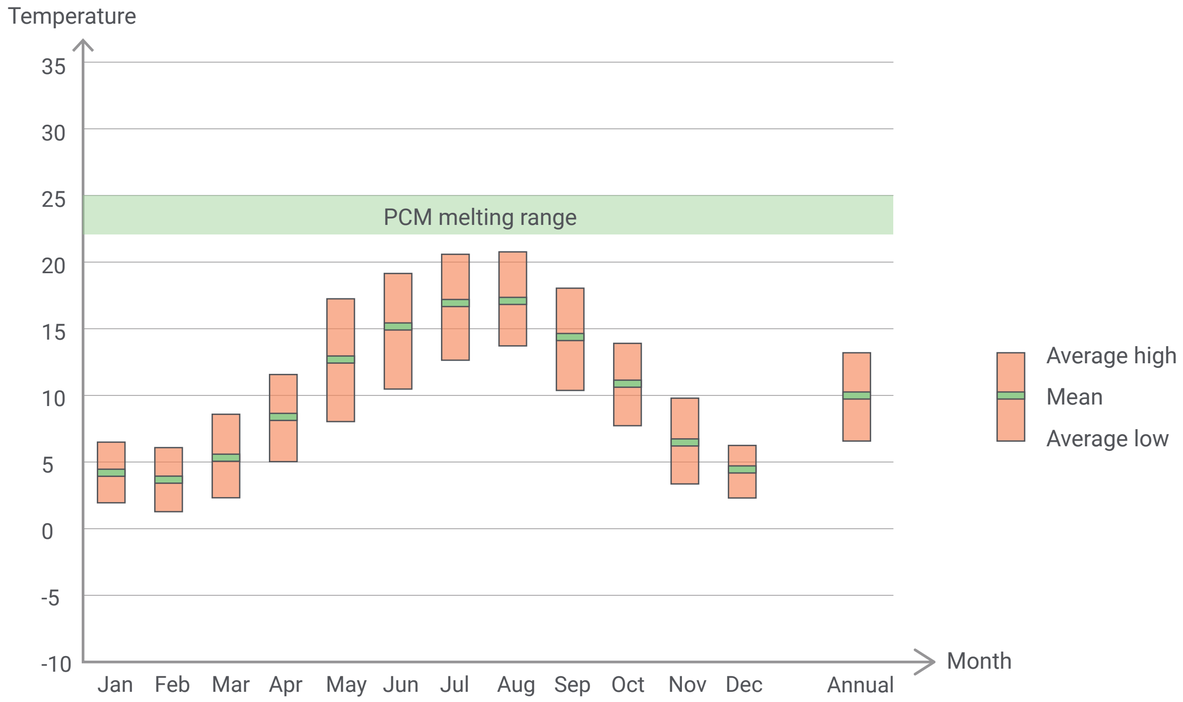




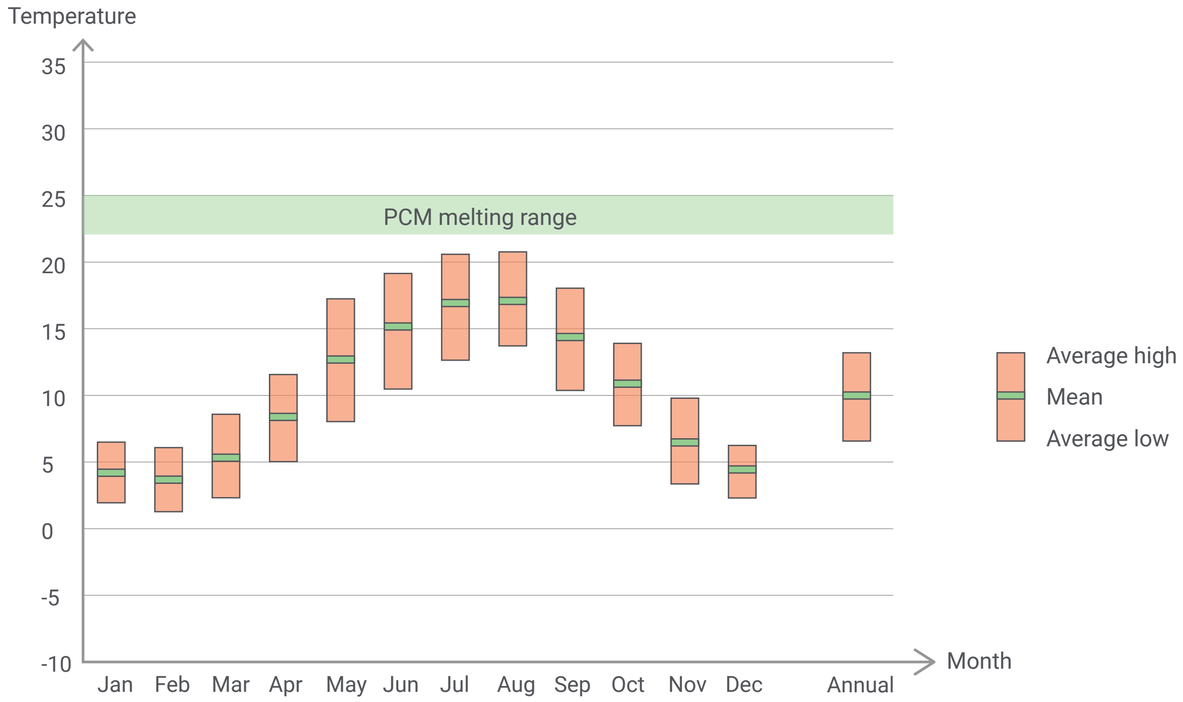
Research: climate



Temperature range the Netherlands (°C)

Source: climate consultant

Research: climate



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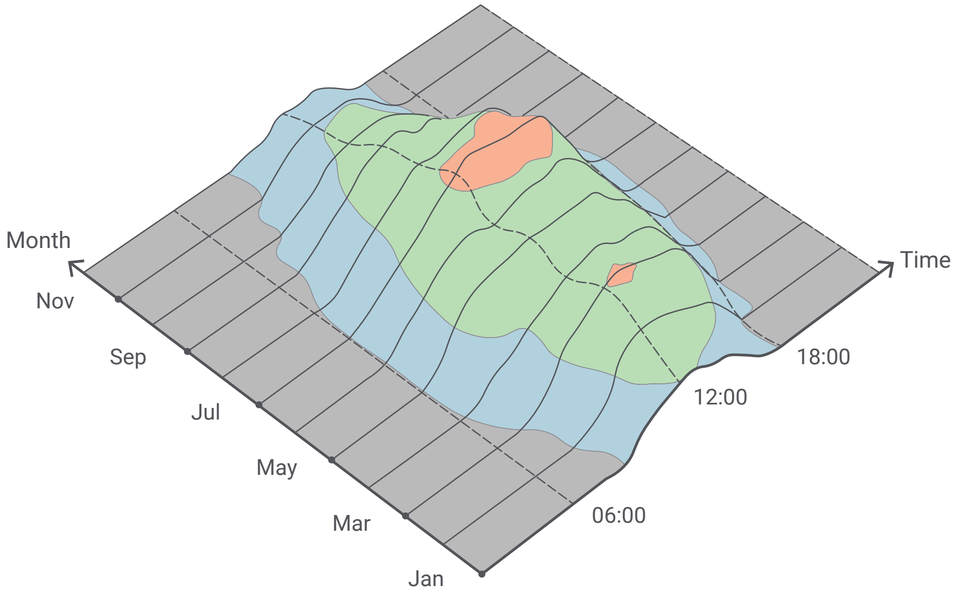
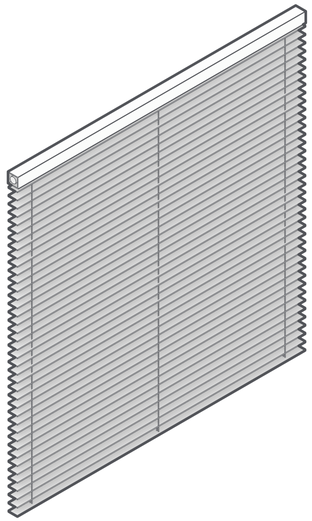


Direct normal solar radiation (Wh/m²)

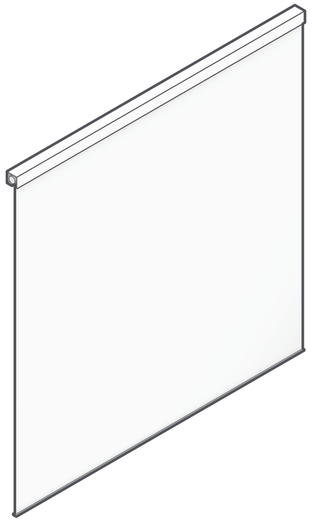
54%	0 - 4
22%	4 - 158
22%	158 - 316
2%	316 - 474

Source: climate consultant

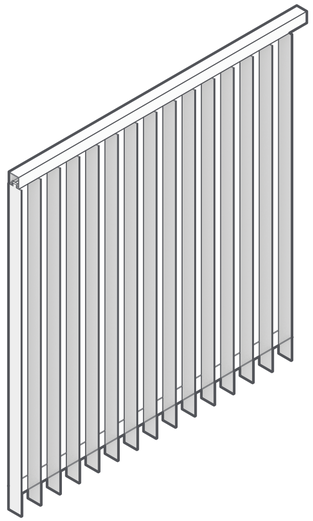
Research: shading type



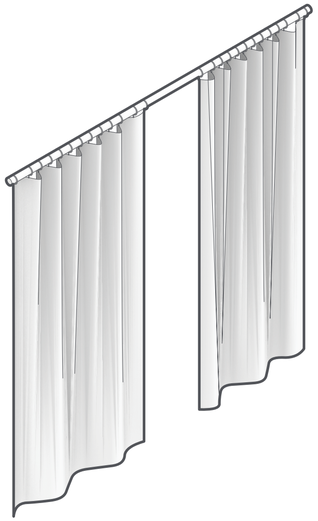
Venetian



Roller



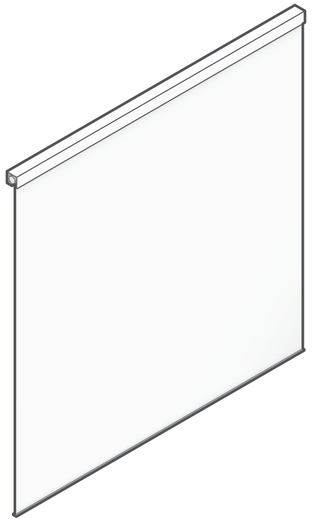
Vertical



Curtain

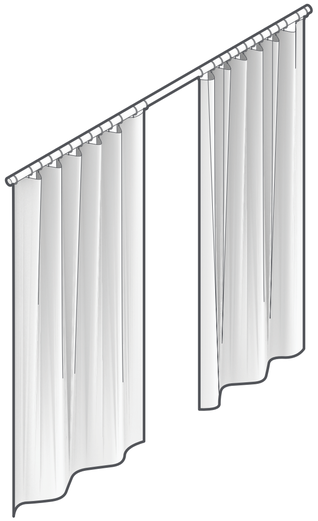
Research: shading type

Venetian



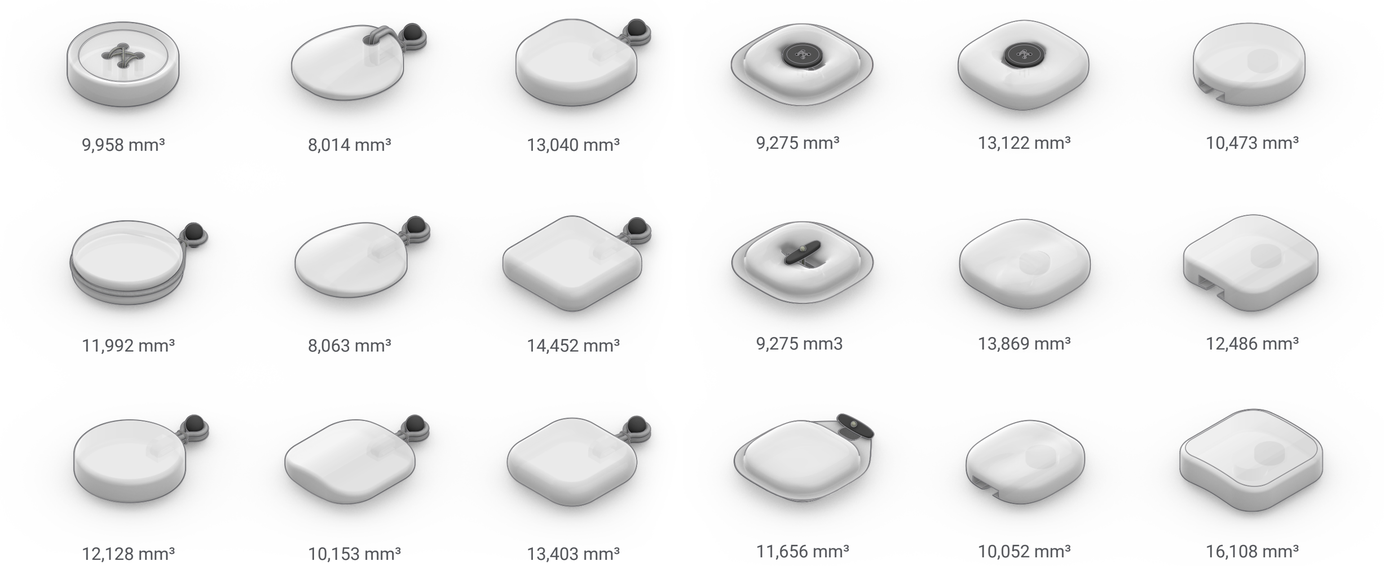
Roller

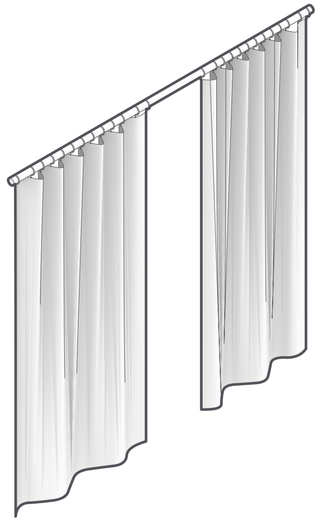
Vertical



Curtain

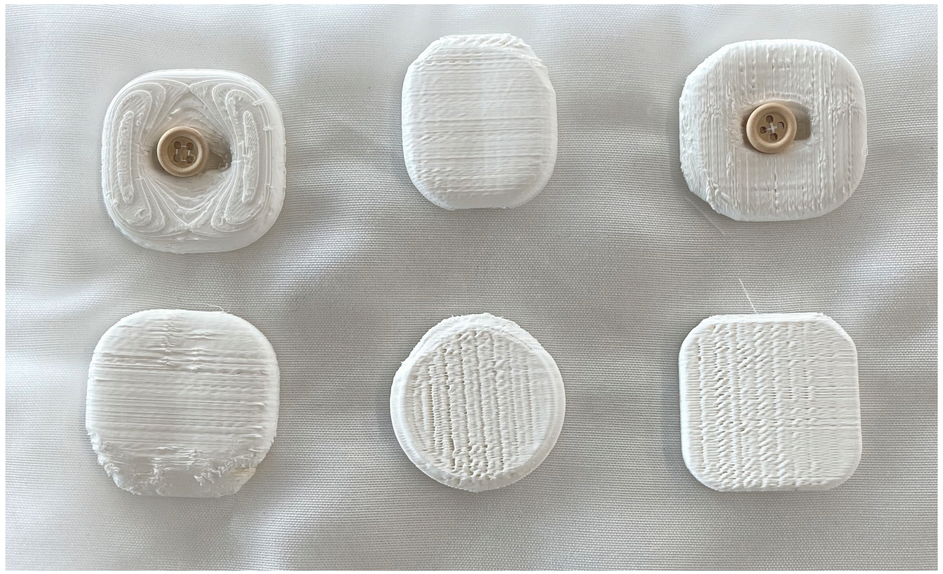
Design: encapsulation

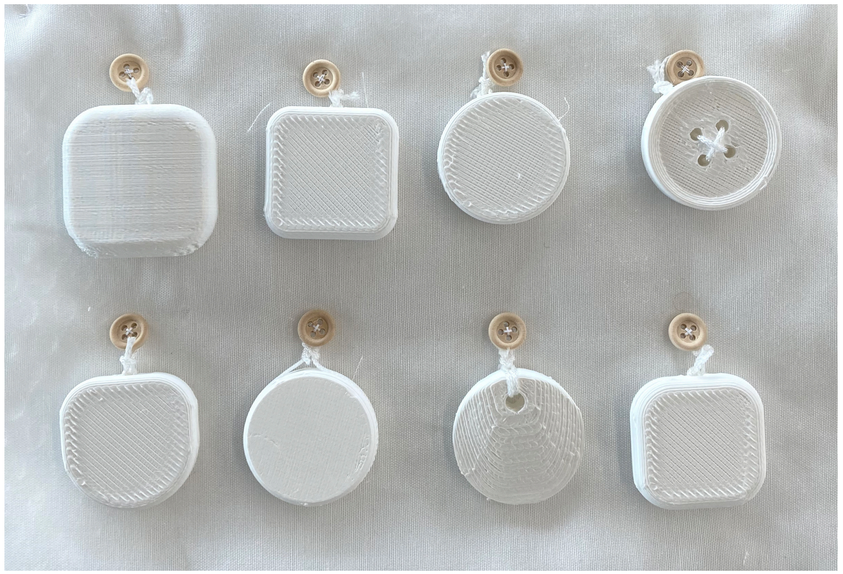




Curtain

Design: encapsulation





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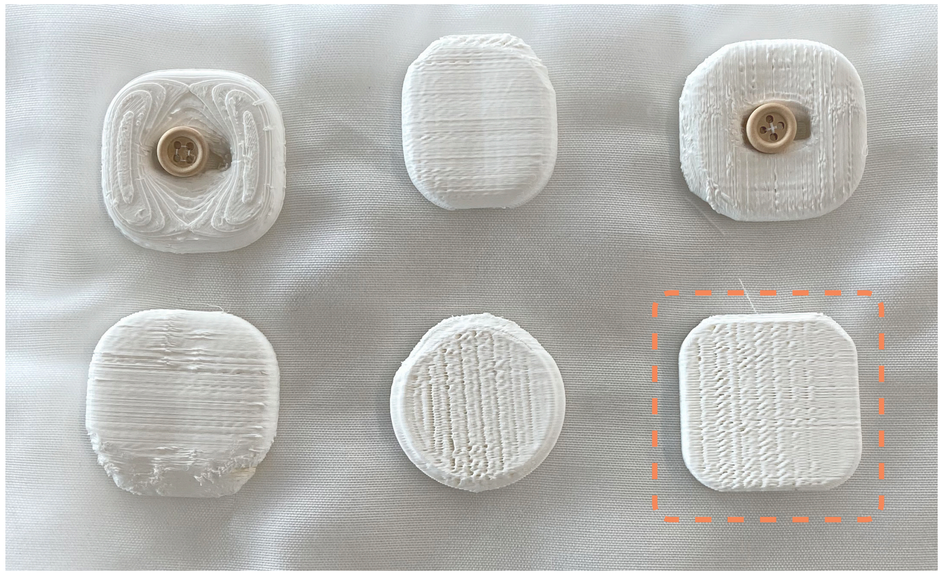
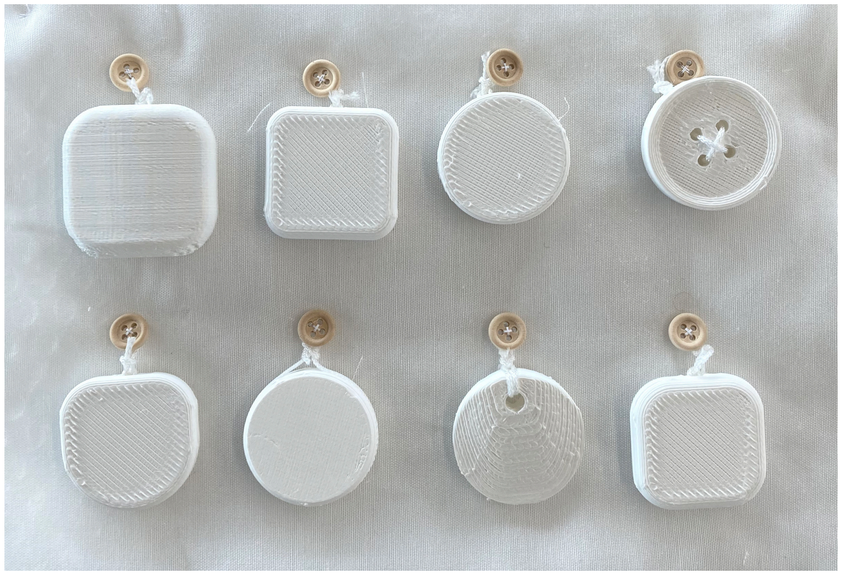
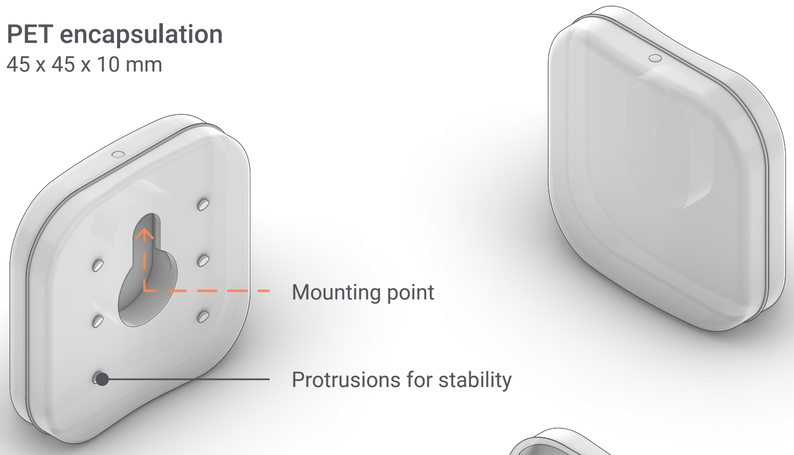


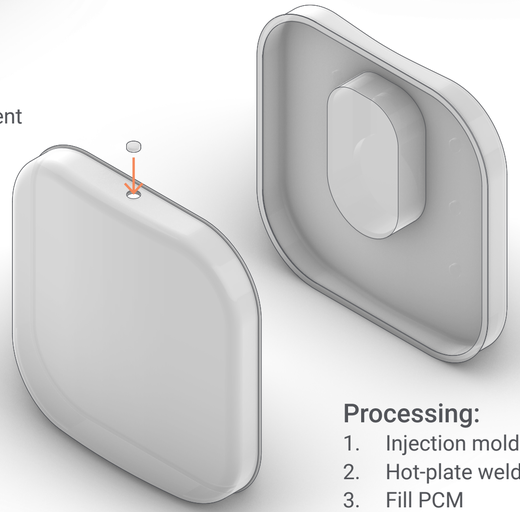


Design: encapsulation

PET encapsulation
45 x 45 x 10 mm

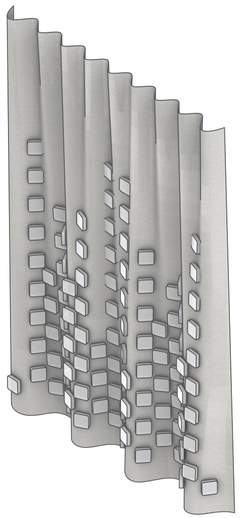


Additives:
Spectrally selective pigment
UV stabilizer

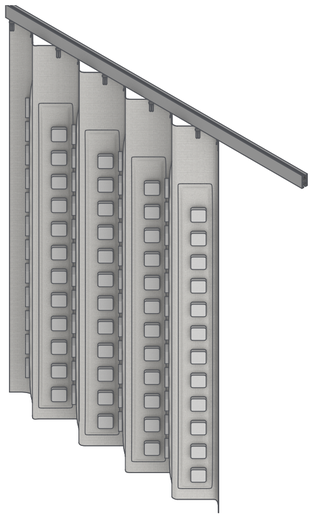


Processing:
1. Injection molding
2. Hot-plate welding
3. Fill PCM
4. Heat sealing

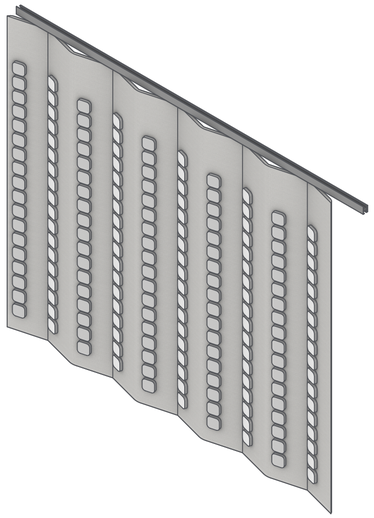
Design: PCM distribution



40 x 40 x 10 mm
Volume: 1.78 liter/m2
Coverage: 13.5 %

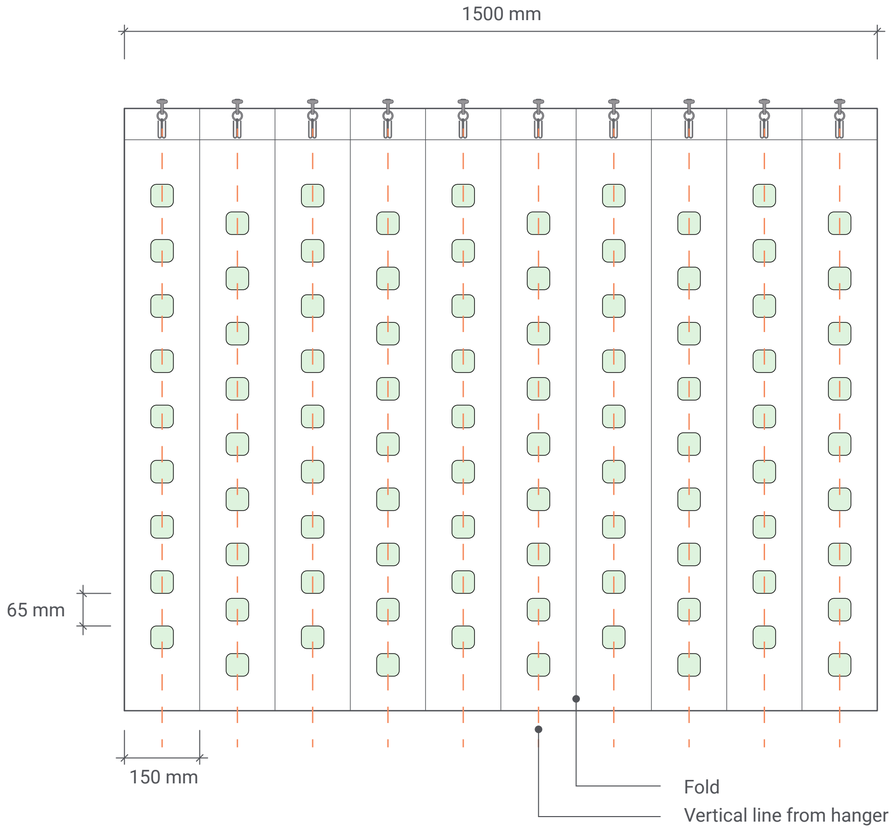


40 x 40 x 10 mm
Volume: 1.52 liter/m²
Coverage: 11.7 %

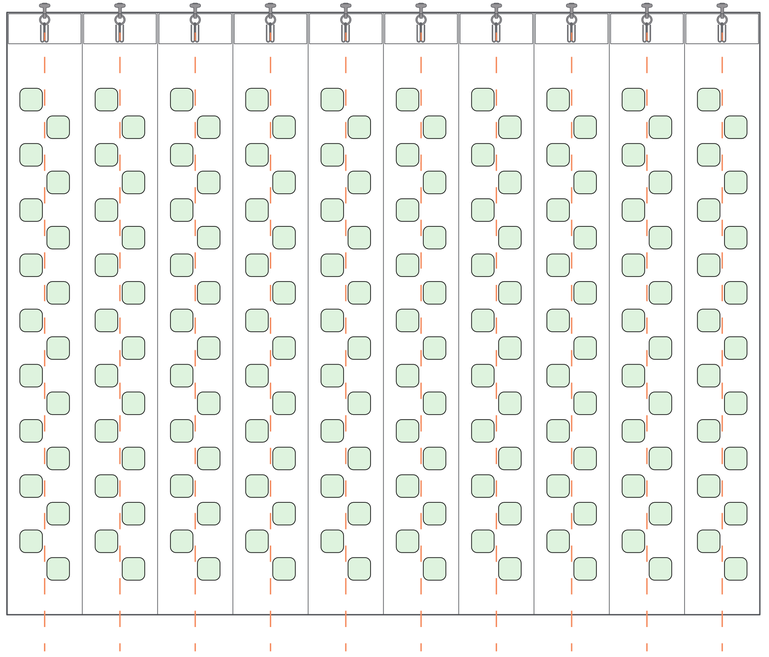


45 x 45 x 10 mm
Volume: 2.55 liter/m²
Coverage: 19.2 %

Design: PCM distribution



63 encapsulation / m²
0.97 liter/m2



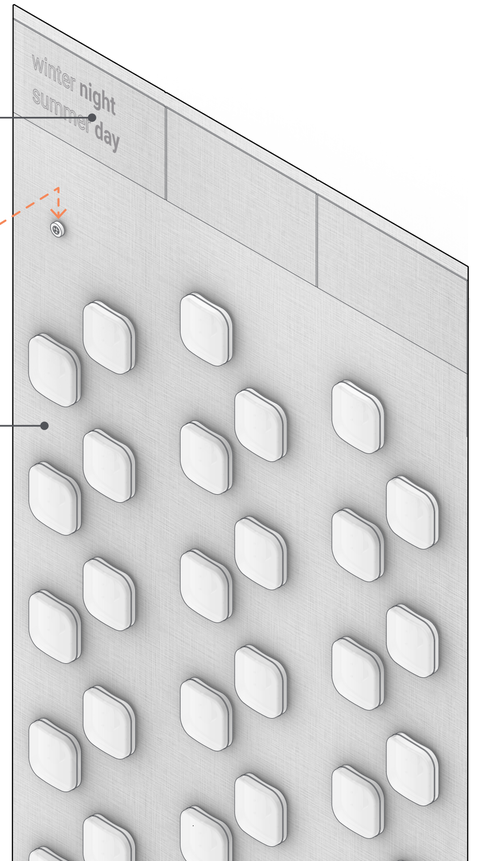
126 encapsulation / m²
1.95 liter / m²

Design: overview

Hard PET plates
Structural support
Even folding
145 mm wide
Embroidered description

Encapsulation

Sheer curtain
Light filtering
Polyester textile



Design: overview

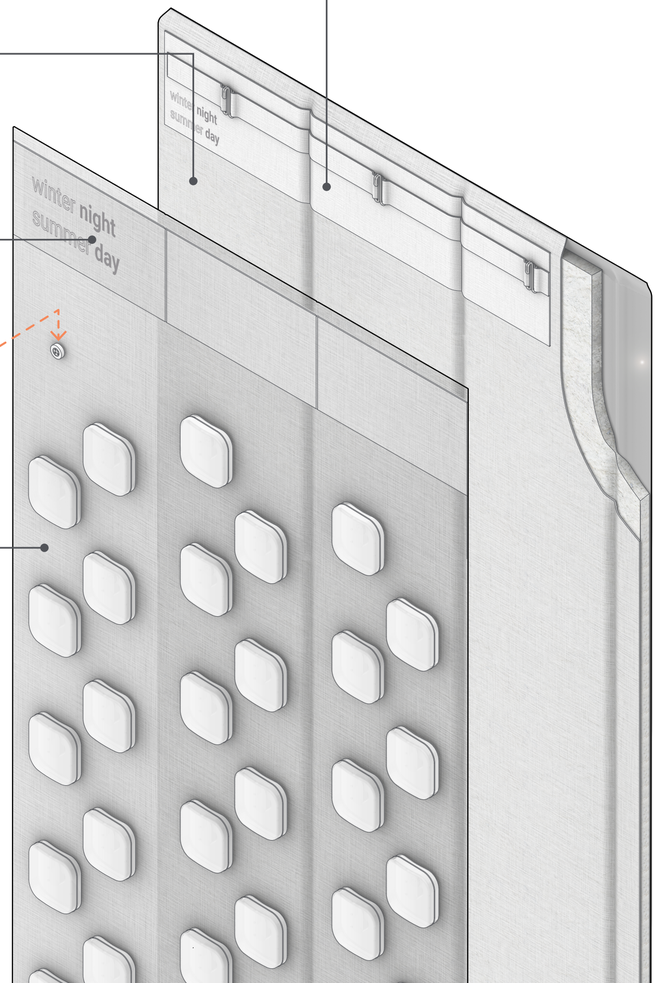
Pleating cord

Insulation curtain
Polyester textile
10 mm polyester wadding
Aluminum lining
U-value: 5 W/m2 K

Hard PET plates
Structural support
Even folding
145 mm wide
Embroidered description

Encapsulation

Sheer curtain
Light filtering
Polyester textile



Design: overview

Suspension system

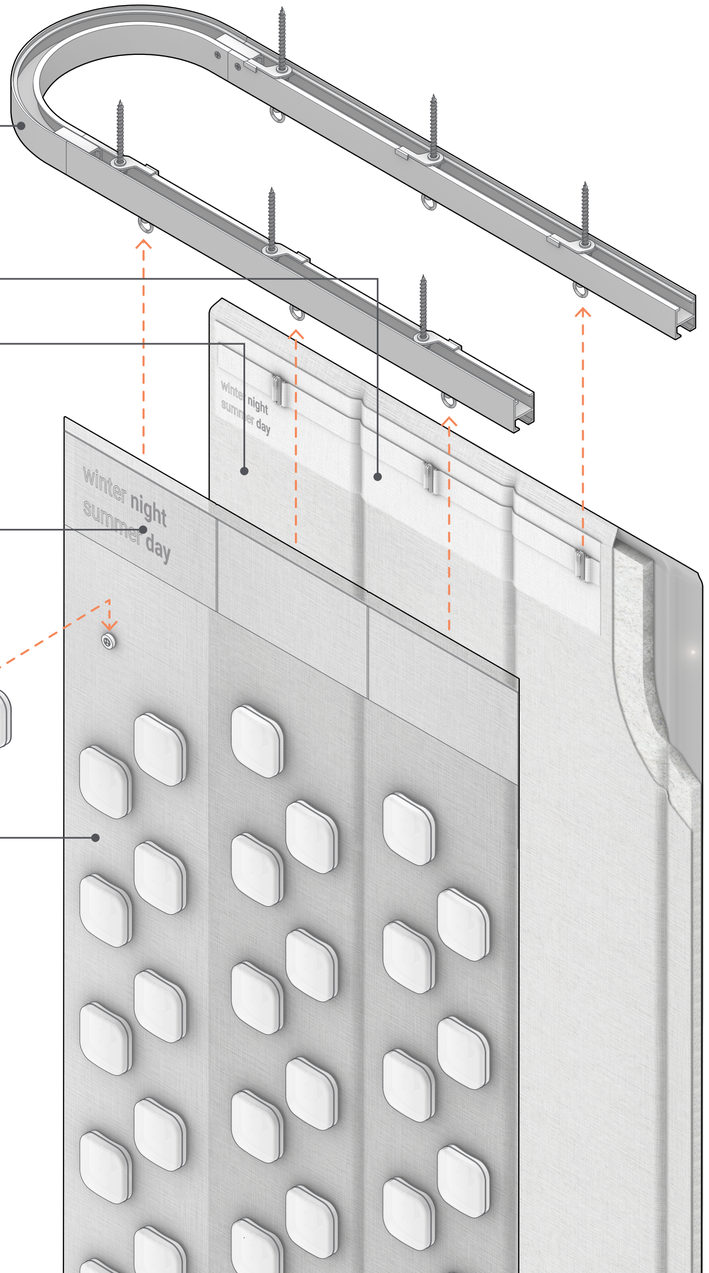
Pleating cord

Insulation curtain
Polyester textile
10 mm polyester wadding
Aluminum lining
U-value: 5 W/m2 K

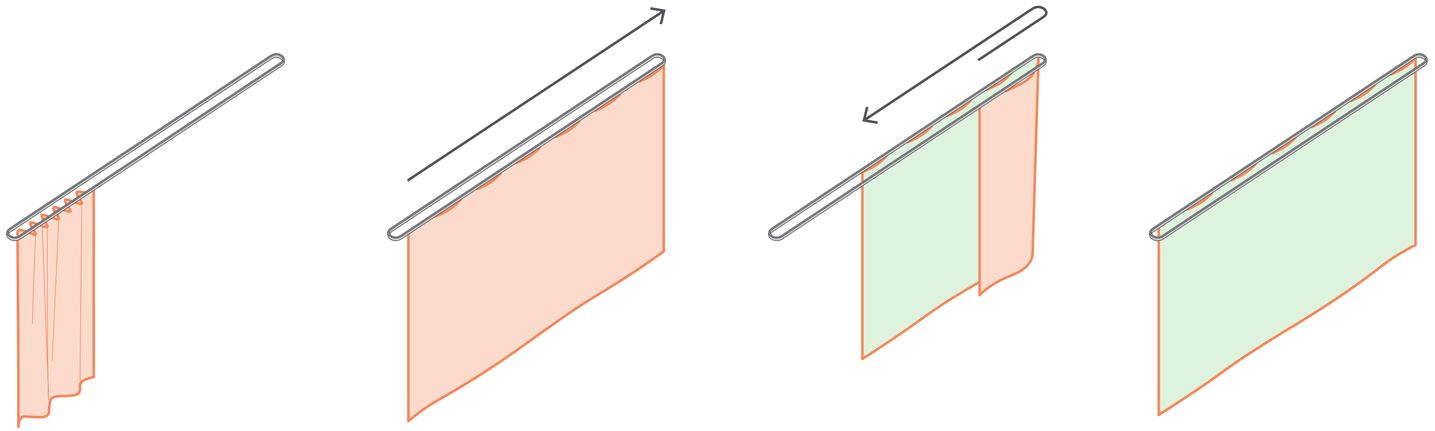
Hard PET plates
Structural support
Even folding
145 mm wide
Embroidered description

Encapsulation

Sheer curtain
Light filtering
Polyester textile



Design: looping track



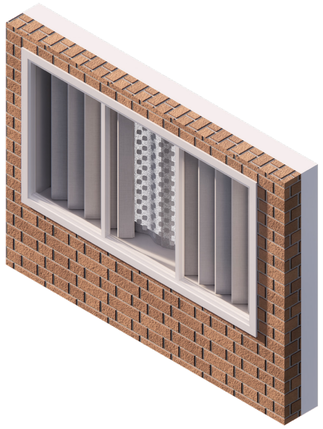
Design: operational concept

Three product variants

- Basic
- Standard
- Premium

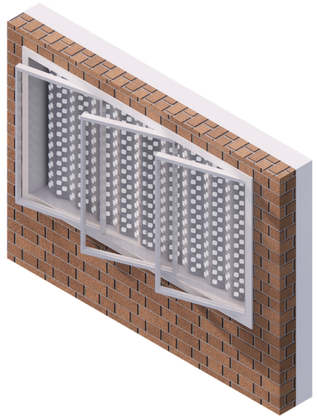
Daytime summer

- PCM faces the room
  Absorb internal heat
- Insulation curtain is partially closed
  Reflect solar radiation



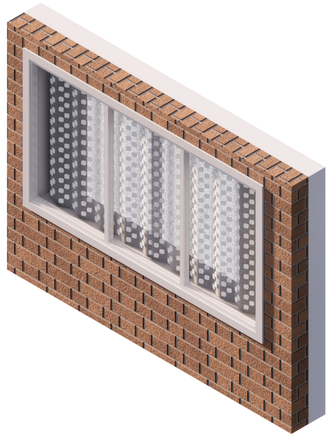
Nighttime summer

- PCM faces the window (open)
  Discharge heat toward the outdoors
- Insulation curtain is closed
  Darken the room



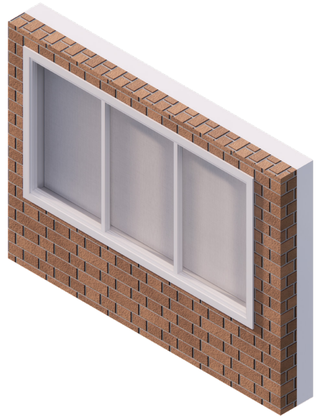
Daytime winter

- PCM faces the window
  Absorb solar radiation
  Simultaneously transmit daylight
- Insulation curtain is open
  Let daylight in



Nighttime winter

- PCM faces the room
  Discharge heat indoor
- Insulation curtain is closed
  Reduce heat loss



Design: operational concept

	Sheer (PCM) curtain:	Insulation curtain:
Facing room:	winter **night** summer **day**	**optional**
Facing window:	winter **day** summer **night**	winter **night** summer **day**

Design: track components

Track connector
Aluminum 6463, T4

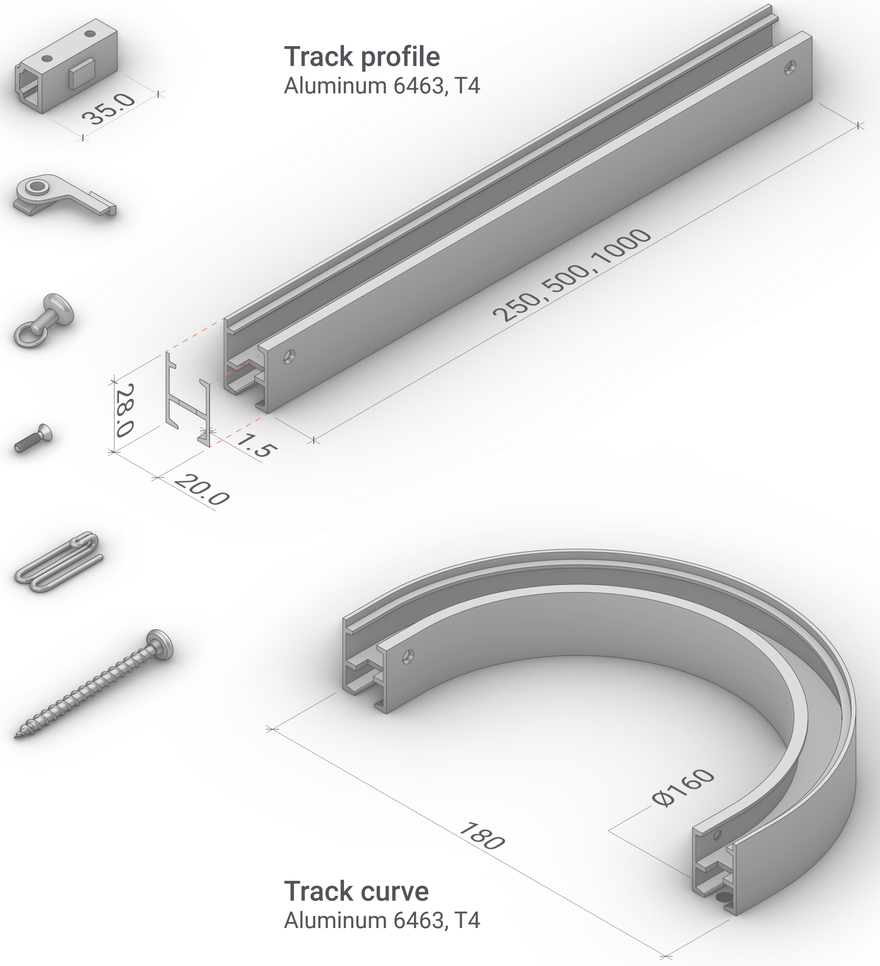
Mounting bracket
Aluminum 413.0

Glider
Aluminum 413.0

Track screw
M3 x 10 mm
Stainless steel

Hanger
Aluminum 6463, T4

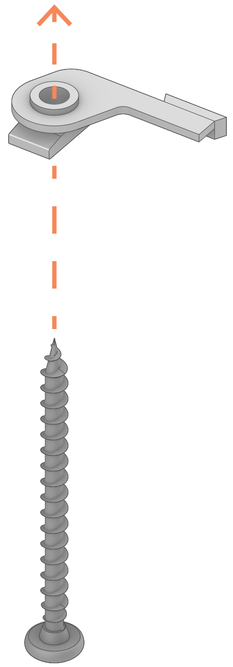
Bracket screw
60 x 5 mm universal
Stainless steel



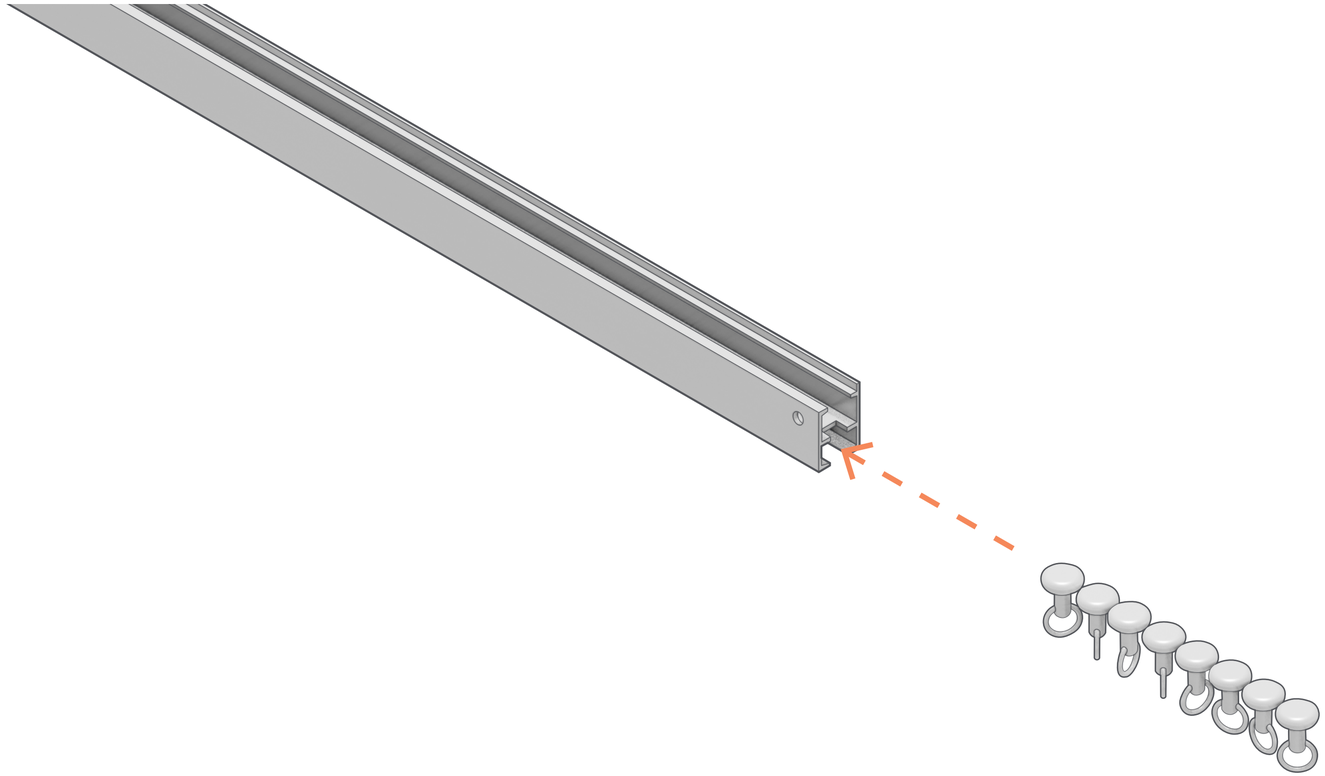
Track profile
Aluminum 6463, T4

Track curve
Aluminum 6463, T4

Design: assembly



Design: assembly



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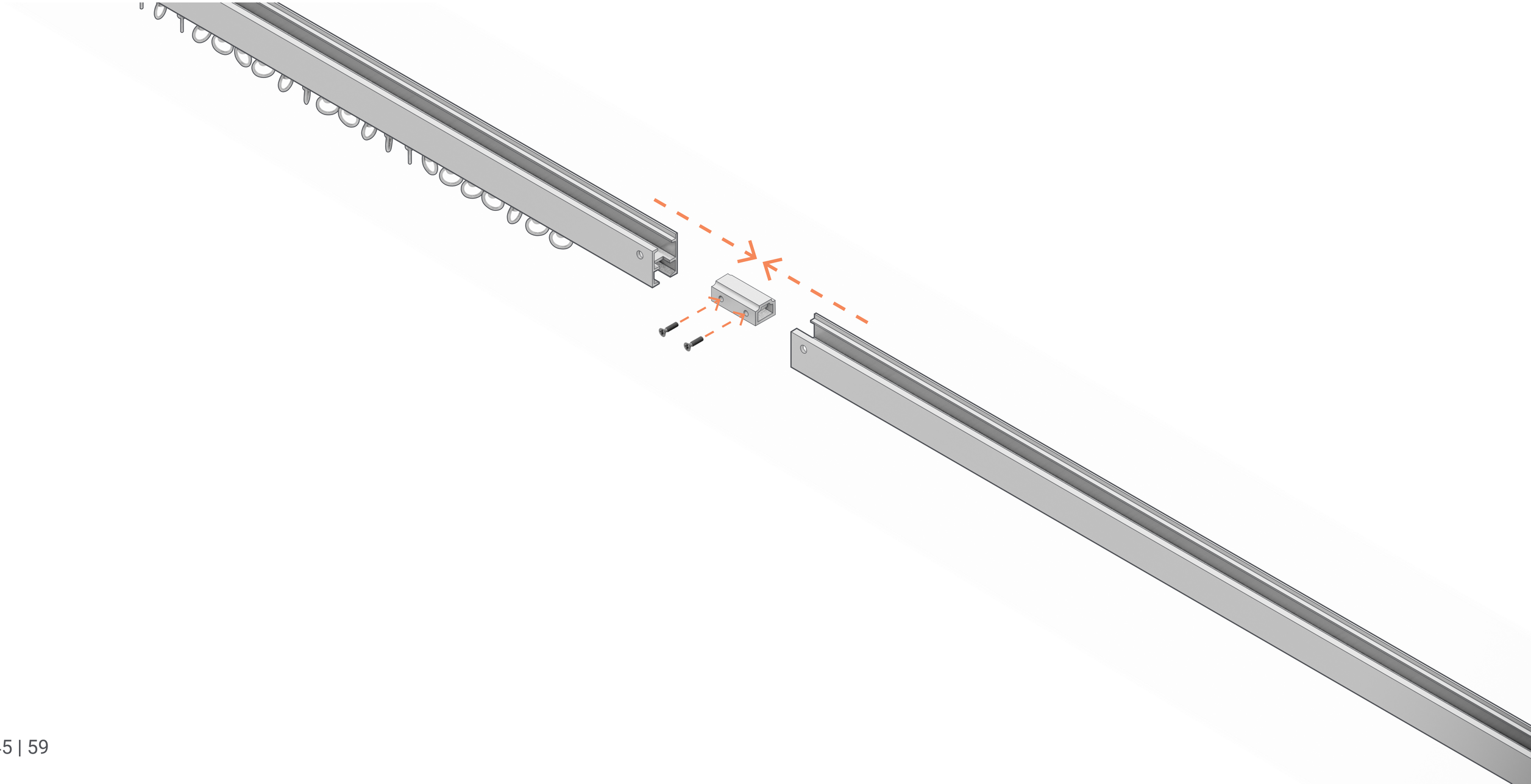
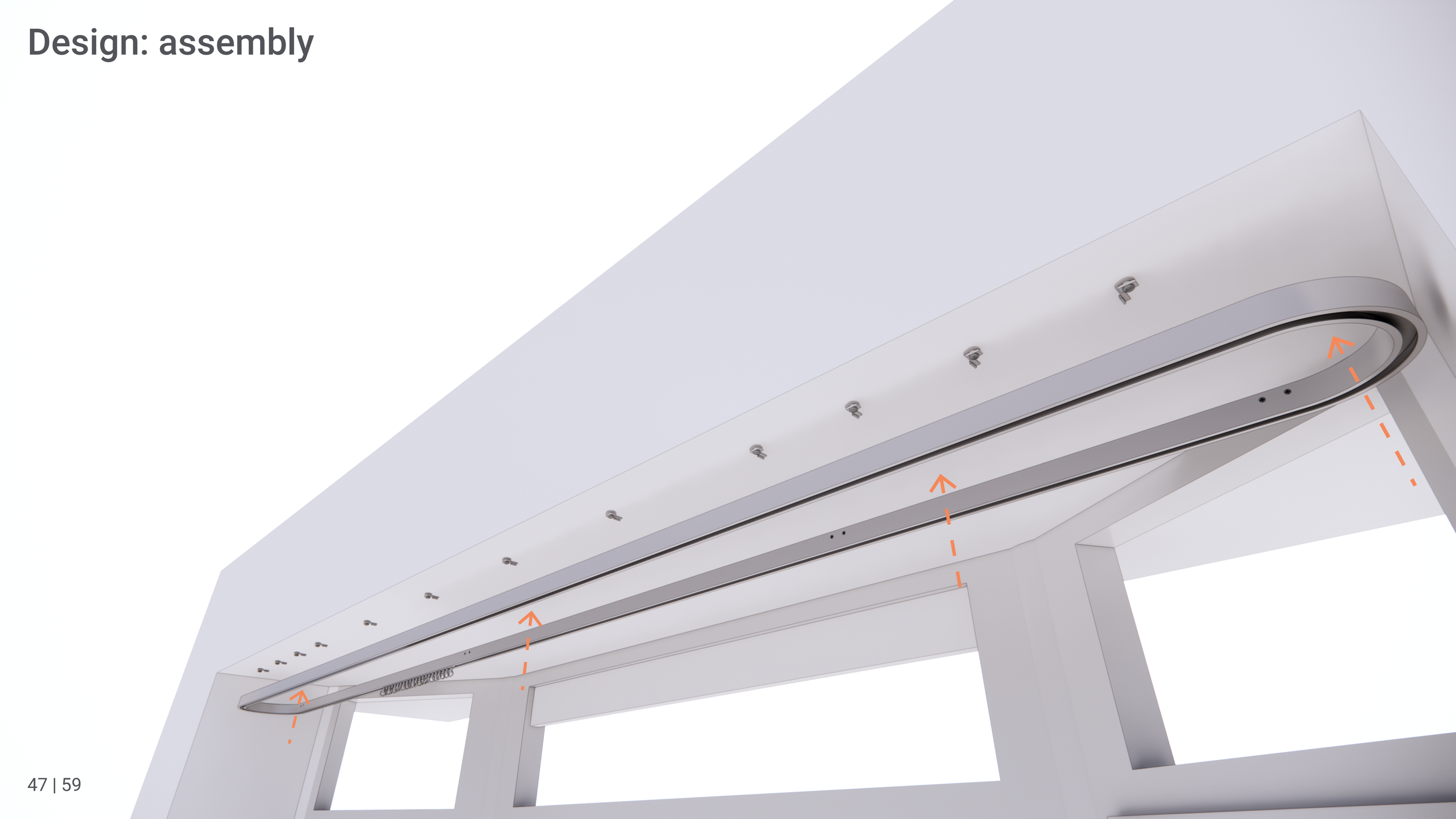


Design: assembly

Design: assembly



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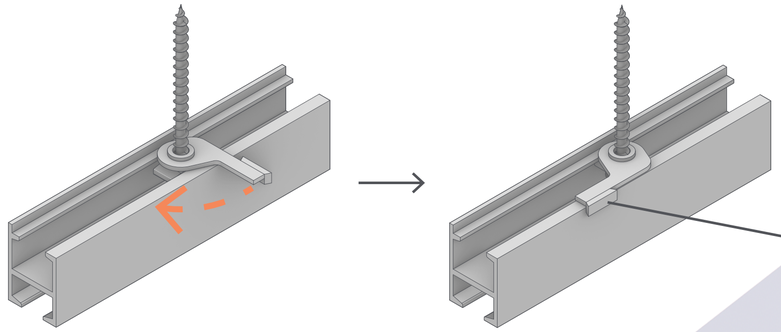

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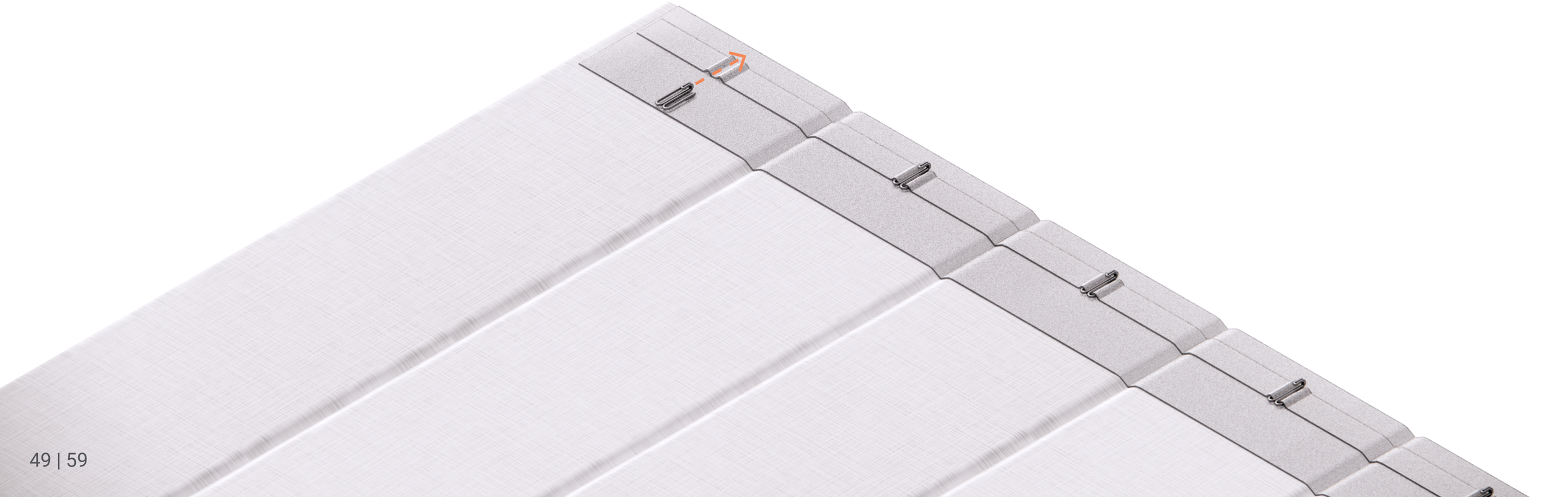

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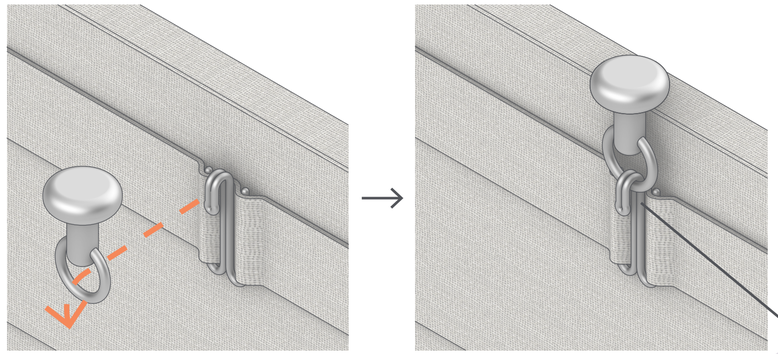
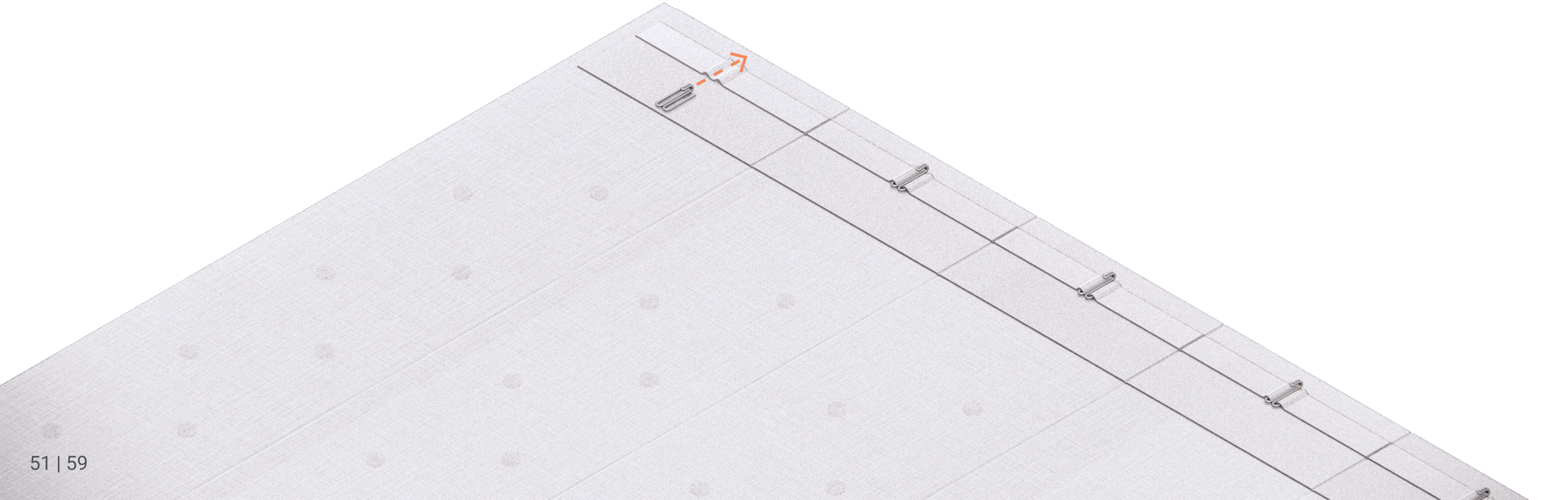


Design: assembly



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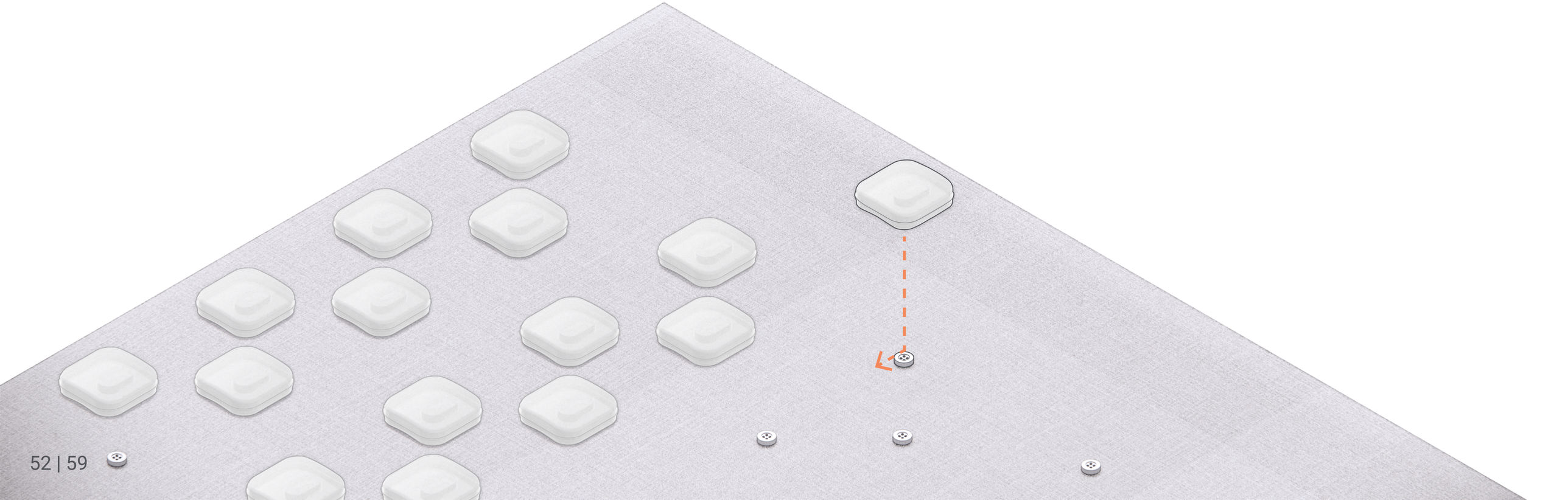

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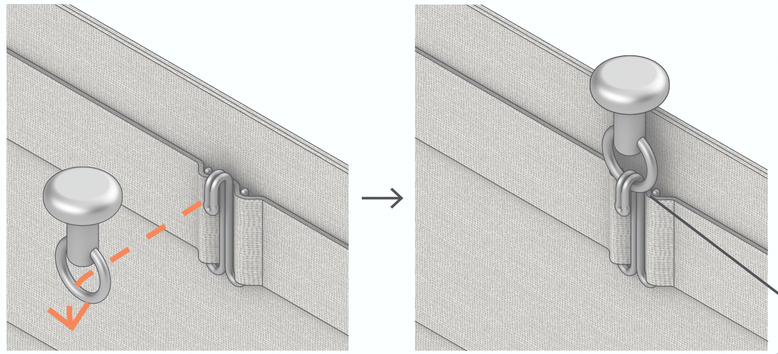
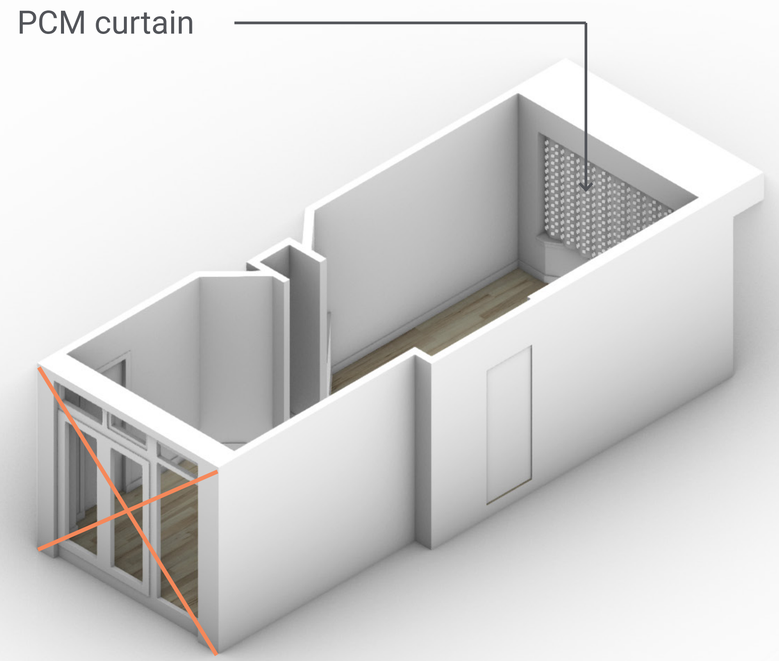


Design: performance evaluation

Living room of old Dutch intermetiate terraced home

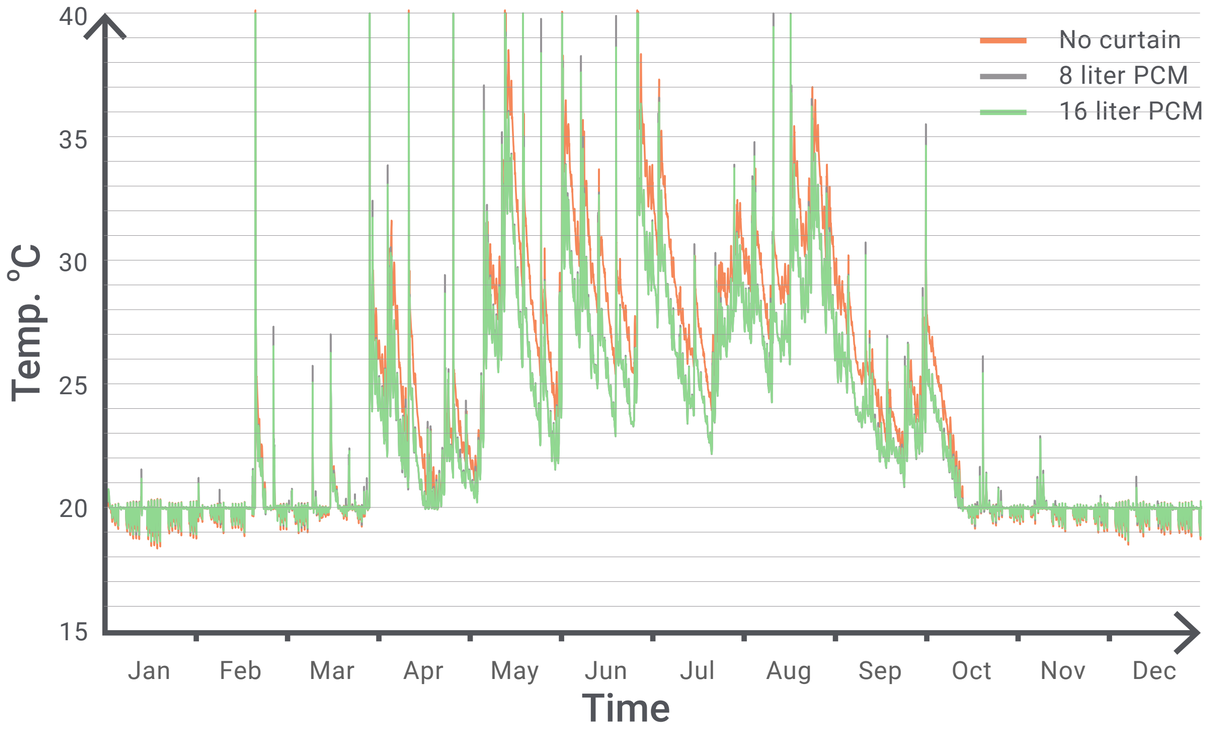
Floor area:	28.8	m²
Window area:	4.48	m²
Room height:	2.70	m
Construction:	0.58	W / m² K
Window:	2.90	W / m² K

Without curtain
With curtain but no PCM
With curtain and 8 or 16 liters of PCM



Design: performance evaluation

South facing window



	Heat load			Energy bill	
Without curtain:	1971		kWh	270,8	EUR
Curtain without PCM:	1820	(-151)	kWh	250,1	EUR
Curtain with 8 liter PCM:	1818	(-153)	kWh	249,9	EUR
Curtain with 16 liter PCM:	1813	(-158)	kWh	249,2	EUR

Conclusion & reflection

Does it work?

Is it cost-effective?

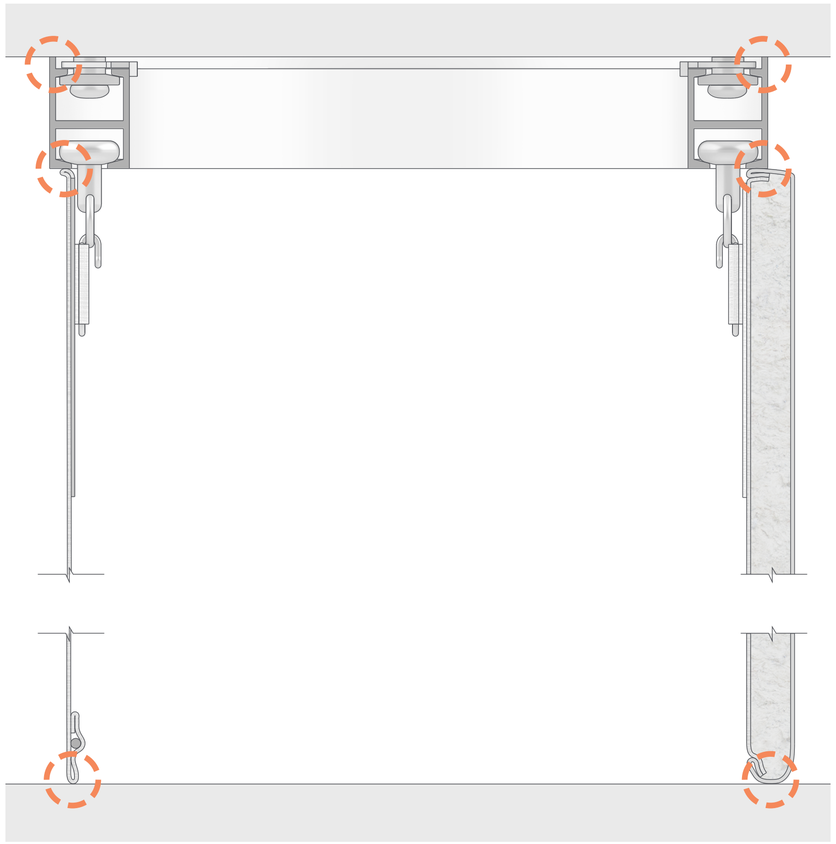
Would I buy this product?

Can it be improved?

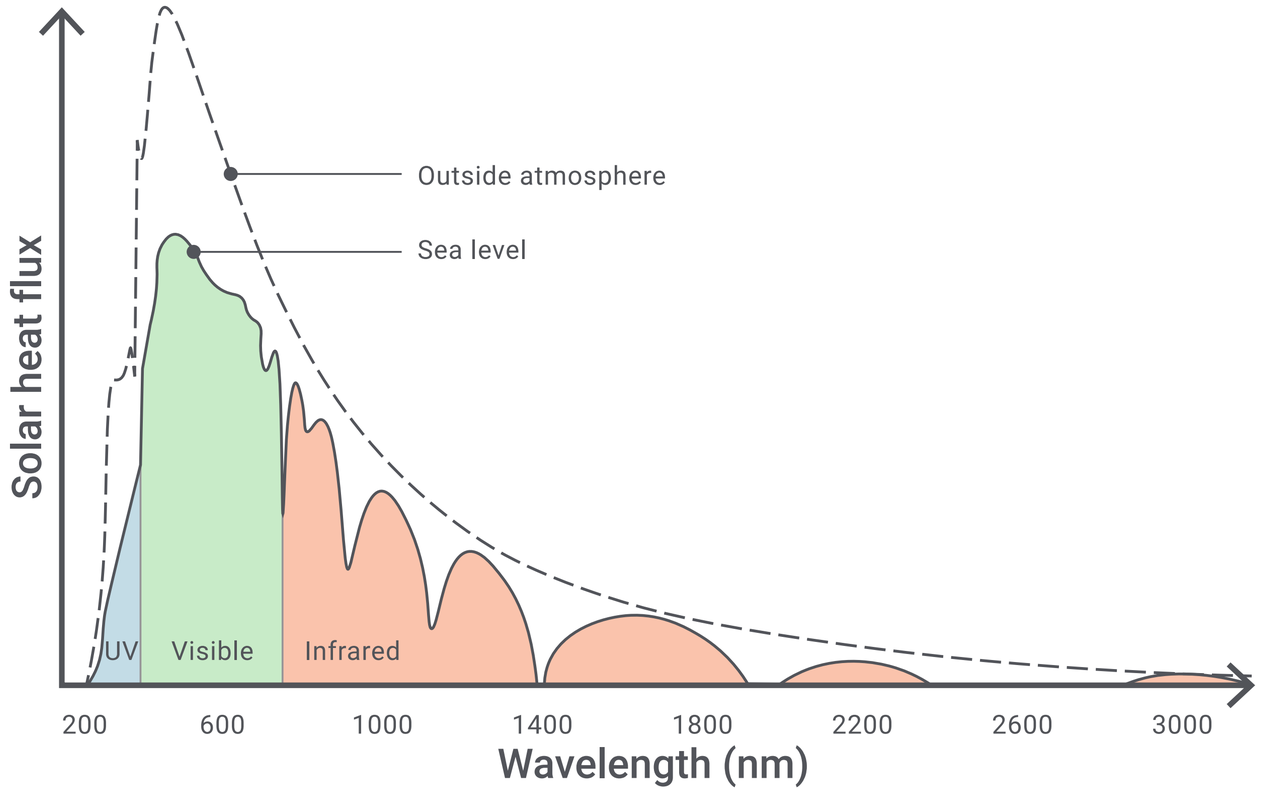
How can **phase change material** be incorporated into a **cost-effective product** to increase the thermal inertia of **lightweight dwellings** in a Cfb climate to enhance passive cooling and heating throughout the year?

Thank you!

Appendix



Appendix



PCM type			
Paraffins	**Non-paraffins**	**Salt hydrates**	**Eutectic mixtures**
Advantages	**Advantages**	**Advantages**	**Advantages**
High latent heat of fusion (120 - 210 kJ/kg)	High latent heat of fusion (155 – 180 kJ/kg)	High latent heat of fusion (180 - 240 kJ/kg)	Sharp melting points
Chemically stable	Small volume change	Thermal conductivity (Ca. 0.5 W/m K)	Properties can be designed to match specifications
No supercooling	No supercooling	Cheap & abundant	
Non-corrosive and non-toxic		Non-flammable	
Low vapour pressure		Sharp phase change	
Drawbacks	**Drawbacks**	**Drawbacks**	**Drawbacks**
Thermal conductivity (ca. 0.2 W/m K)	Thermal conductivity (ca. 0.15 - 0.17 W/m K)	Supercooling	Expensive
Large volume change during phase change	Expensive	Phase segregation	
Flammable	Flammable	Corrosive to metal	

Appendix

Hand calculations:

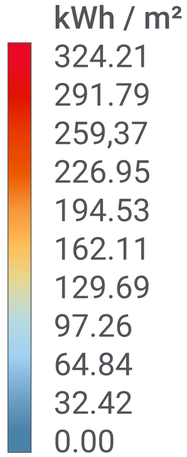
$Q = m \cdot \Delta h$

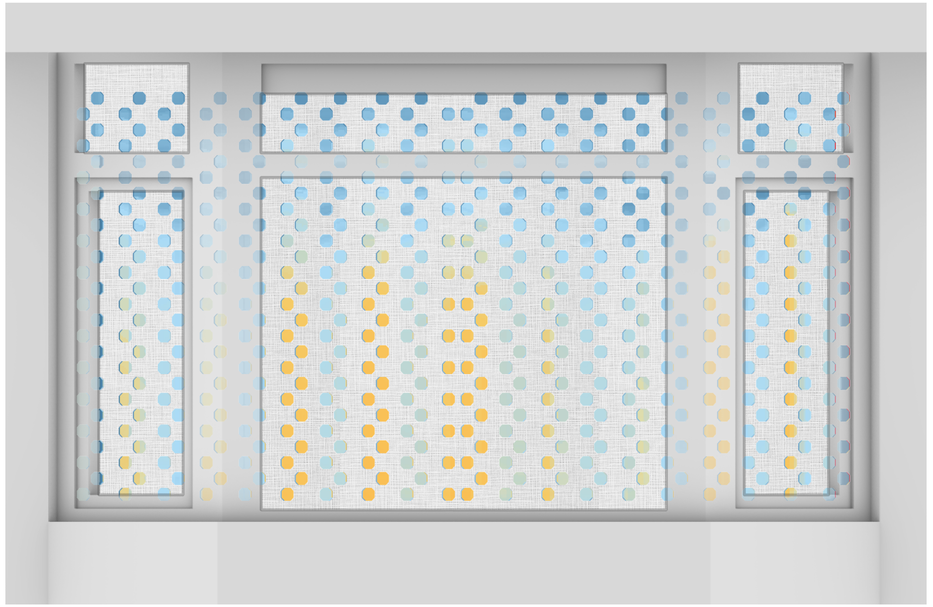
$Q = 24 \cdot 9$

$Q = 216\ kJ = 60\ Wh$

$60\ Wh \cdot 157\ heating\ days = 9.42\ kWh$

Fairly similar to MATLAB





Appendix

Encapsulation

Property	PET Polyethylene Terephthalate	PMMA Polymethyl methacrylate	PC Polycarbonate	LLDPE Linear low density polyethylene
Material family	Thermoplastic	Thermoplastic	Thermoplastic	Thermoplastic
Impact strength (kJ/m²), Notched	6.2 - 6.8	1.9 - 2.1	10.1 - 83.1	590 - 1000
Transparency	Optical quality	Optical quality	Optical quality	Transparent
Service temp. (°C)	(-58) - 65	(-75) - 56	(-47) - 116	(-79) - 97
UV resistance	Fair	Good	Fair	Poor
Water (Salt)	Excellent	Excellent	Excellent	Excellent
Flammability	Highly flammable	Highly flammable	Slow-burning	Highly flammable
Recycle (#)	Yes (1)	Yes, others (7)	Yes, others (7)	Yes (4)
Density (kg/m³)	1290 - 1390	1170 - 1200	1190 - 1210	918 - 940
Embodied energy (MJ/kg), Typical	68.7 - 76.8	107.0 - 118.0	100.0 - 111.0	69.8 - 77.2
Price (EUR/kg)	0.61 - 1.08	1.59 - 2.22	2.11 - 2.69	0.78 - 0.96

Weight suspension system

Item	Quantity	Volume m³	Aluminum Total weight (kg)	Steel Total weight (kg)
Track				
- 1000 mm	4	1.383e-4	1.493 (6463, T4)	4.259 (AISI 409)
- 500 mm	2	6.903e-5	0.372 (6463, T4)	1.063 (AISI 409)
- Curve	2	3.086e-5	0.167 (6463, T4)	0.475 (AISI 409)
			2.03	5.80
Connector	8	3.832e-6	0.083 (6463, T4)	0.236 (AISI 409)
Mounting bracket	18	8.251e-7	0.039 (413.0)	0.111 (CB-30)
Glider	40	1.085e-6	0.115 (413.0)	0.325 (CB-30)
Hanger	40	9.1e-7	0.098 (6463, T4)	0.280 (AISI 409)
Screws & bolts				
- 60x5 Sencys	18		0.136	0.136
- M3 bolts	16		0.015	0.015
			2.43 kg	6.66 kg
Embodied energy (First life)			293 MJ (21.2 kg CO_2)	195 (17.9 kg CO_2)
Recycling			-202 MJ (-14.1 kg CO_2)	-90.7 MJ (-9.85 kg CO_2)
			91 MJ (7.1 kg CO_2)	104.3 MJ (8.05 kg CO_2)

8 liter curtain set

Item	Material	Quantity	Volume (m³)	Total weight (kg)
Encapulation	PET	520	2.893e-6	2.020
PCM	SP24E	520	1.546e-5	12.000
Insulation	PET (polyester)	4.9 m²	0.100 kg/m²	0.490
Textile	PET (polyester)	9.8 m²	0.118 kg/m²	1.160
Button	PET	520	1.633e-7	0.114
Reflective lining	0.01% aluminum 99.9% PET	4.9 m²	0.099 kg/m²	0.484
				16.37 kg
Embodied energy (First life)				408 MJ (19.7 Kg CO_2)
Recycling				-214 MJ (-9.31 kg CO_2) (excl. PCM)
				194 MJ (10.39 kg CO_2)
Suspension system				+2.43 kg +91 MJ +(7.1 kg CO_2)
				18.80 kg 285 MJ (17.49 kg CO_2)

Appendix

8 liter set cost estimation

Item	Quantity	Material (EUR / kg)	Manufacturing (EUR / unit)	Total Cost (EUR)
Track	5 m	1.71 - 1.97	0.9570	1.64 - 1.89
Connector	8	1.71 - 1.97	0.0670	0.92 - 1.06
Mounting bracket	18	1.73 - 2.04	0.2206	6.87 - 8.10
Glider	40	1.73 - 2.04	0.2396	16.58 - 19.56
Hanger	40	1.71 - 1.97	0.0014	0.10 - 0.11
Screws & bolts				*3
Encapsulation	520	0.614 - 1.08	0.1150	36.72 - 64.58
PCM	12 kg	3.31		39.72
Textile	1.160 kg	*1.12 - 1.46		1.30 - 1.69
Insulation	0.49 kg	**3.00		1.47
Button	520	0.614 - 1.08	0.0507	16.19 - 28.47
Reflective lining	0.484 kg	*1.12 - 1.46		0.54 - 0.71
				125.05 - 170.36
Assembly + Additional expenses (25%)				31.26 - 42.59
				156.31 - 212.95

*Material and manufacturing cost per kg
**Rough estimation based on market analysis

Simulation: Heating load

Configuration	North (kWh)	East (kWh)	South (kWh)	West (kWh)
Without curtain:	2583	2030	1971	1978
Curtain without PCM:	2355 (-228)	1868 (-162)	1820 (-151)	1843 (-135)
Curtain with 8 liter PCM:	2352 (-231)	1866 (-164)	1818 (-153)	1843 (-135)

Data Sheet

RUBITHERM Phase Change Material

SP24E

The creation of the latent heat material RUBITHERM® SP has led to a new and innovative class of low flammability PCM. RUBITHERM® SP consists of a unique composition of inorganic components.
RUBITHERM® SP is used as macroencapsulated material. Densities of 1,0 kg/l and more can be achieved. This and all properties mentioned below make RUBITHERM® SP to the preferred PCM used in the construction industry. Both passive and active cooling can easily be realized e.g. air conditioners.
We look forward to discussing your particular questions, needs and interests with you.

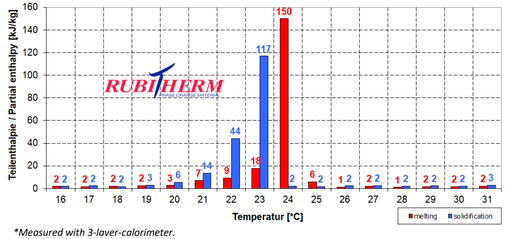
Properties:
- **stable performance throughout the phase change cycles**
- **high thermal storage capacity per volume**
- **limited supercooling (2-3K depenndig on volume and cooling rate),**
- **low flammability, non toxic**
- **different melting temperatures between -50°C und 70°C are available**
- **encapsulation necessary, minimum volume: 50ml**

The most important data:

	Typical Values	
Melting area	**24-25** main peak: 24	[°C]
Congealing area	**23-21** main peak: 22	[°C]
Heat storage capacity ± 7,5% Combination of sensible and latent heat in a temperatur range of 15 °C to 30°C.	**180**	[kJ/kg]
	50	[Wh/kg]*
Specific heat capacity	**2**	[kJ/kg·K]*
Density solid at 15°C	**1,6**	[kg/l]
Density liquid at 35°C	**1,5**	[kg/l]
Volume expansion	**~6**	[%]
Heat conductivity	**~0,5**	[W/(m·K)]
Max. operation temperature	**45**	[°C]
Corrosion	corrosive effect on metals	

The product must be initialized (melt, homogenize and cool to 0 ° C) once before use to achieve the specified properties.
SP-products may absorb release water if stored improperly. This can result in a change of the physical properties given. Storing in closed containers mandatory.

Beispiel / example: SP24E Teilenthalpie / Partial enthalpy distribution*



*Measured with 3-laver-calorimeter.

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