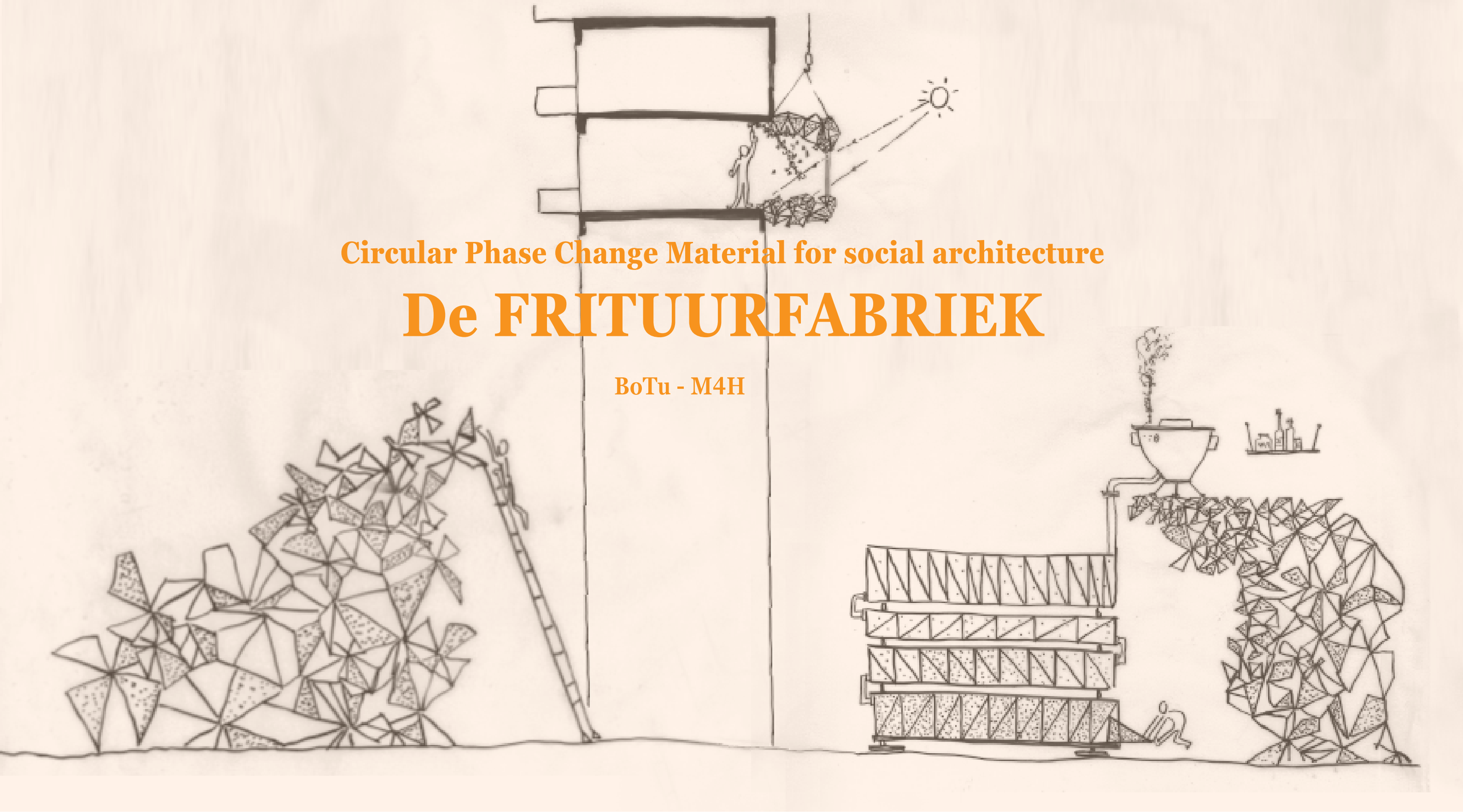


Circular Phase Change Material for social architecture

De FRITUURFABRIEK

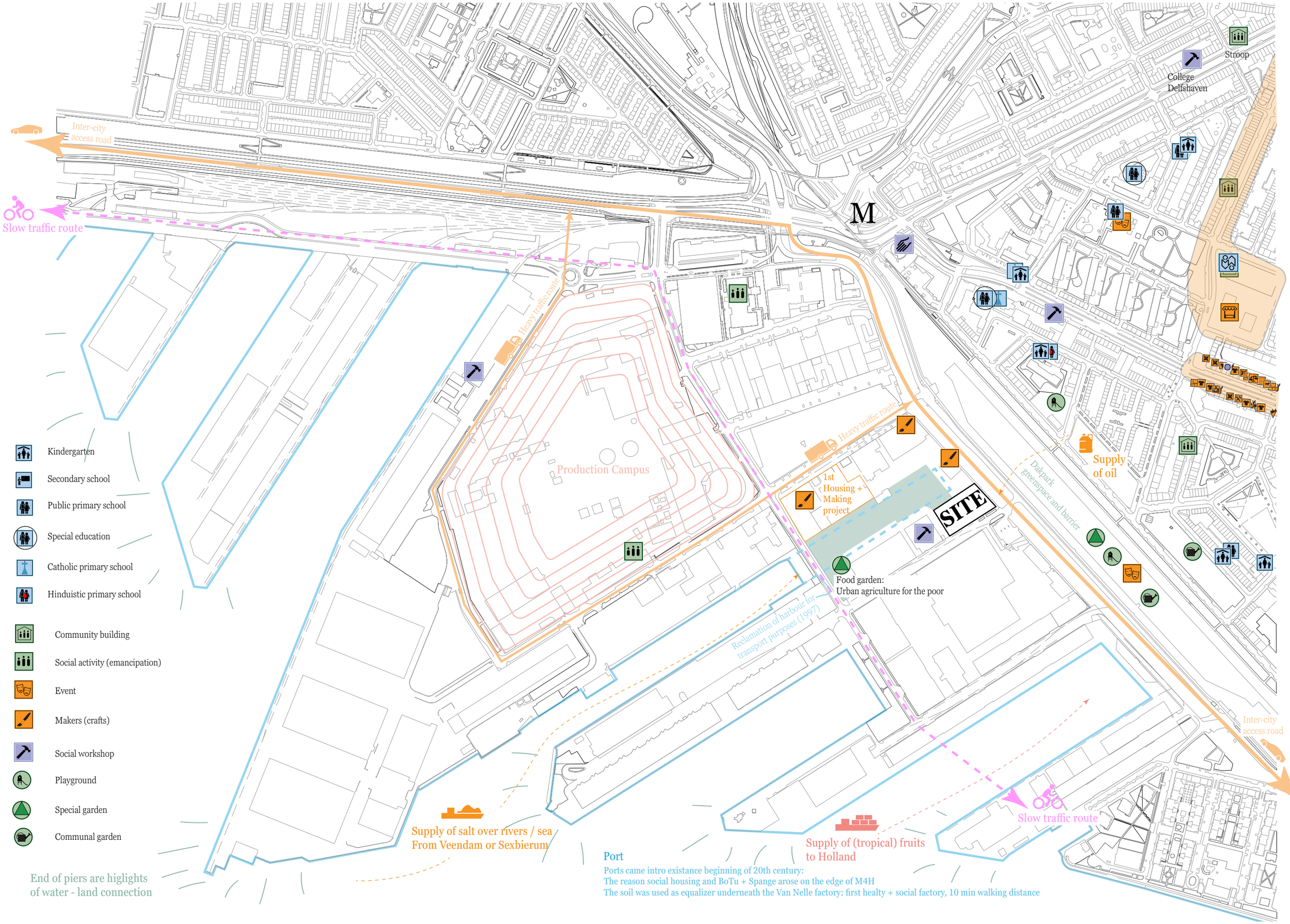
BoTu - M4H

Matthijs van Mulligen
GRADUATION TU Delft

5th of July, 2019

Site analysis

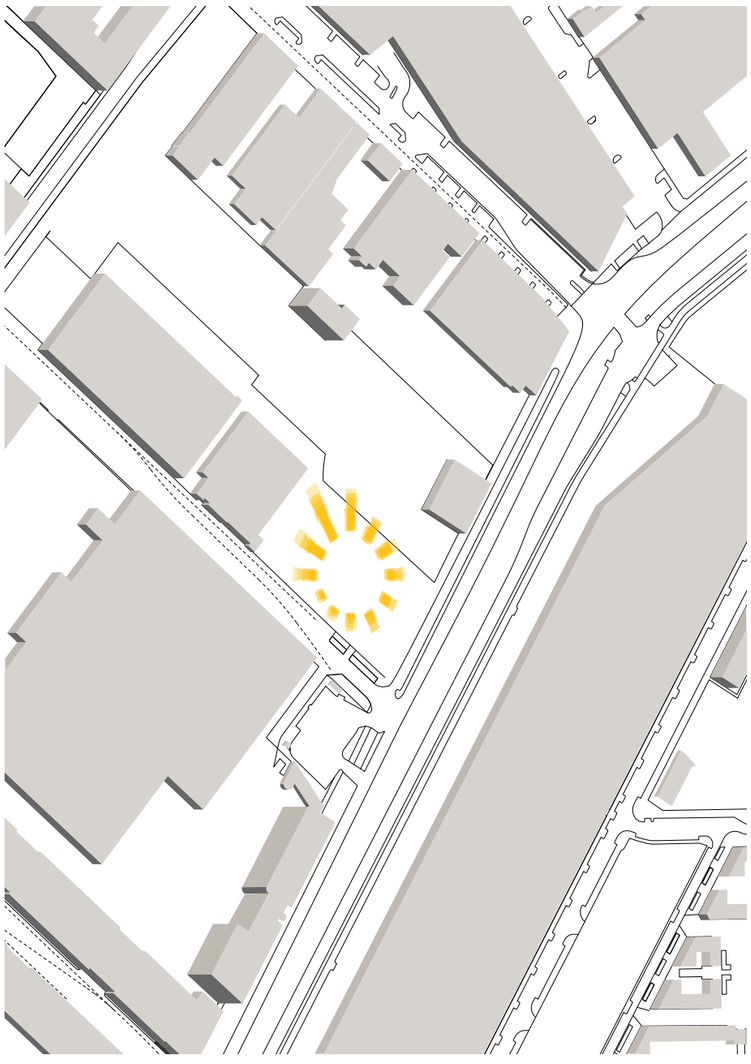
Area analysis



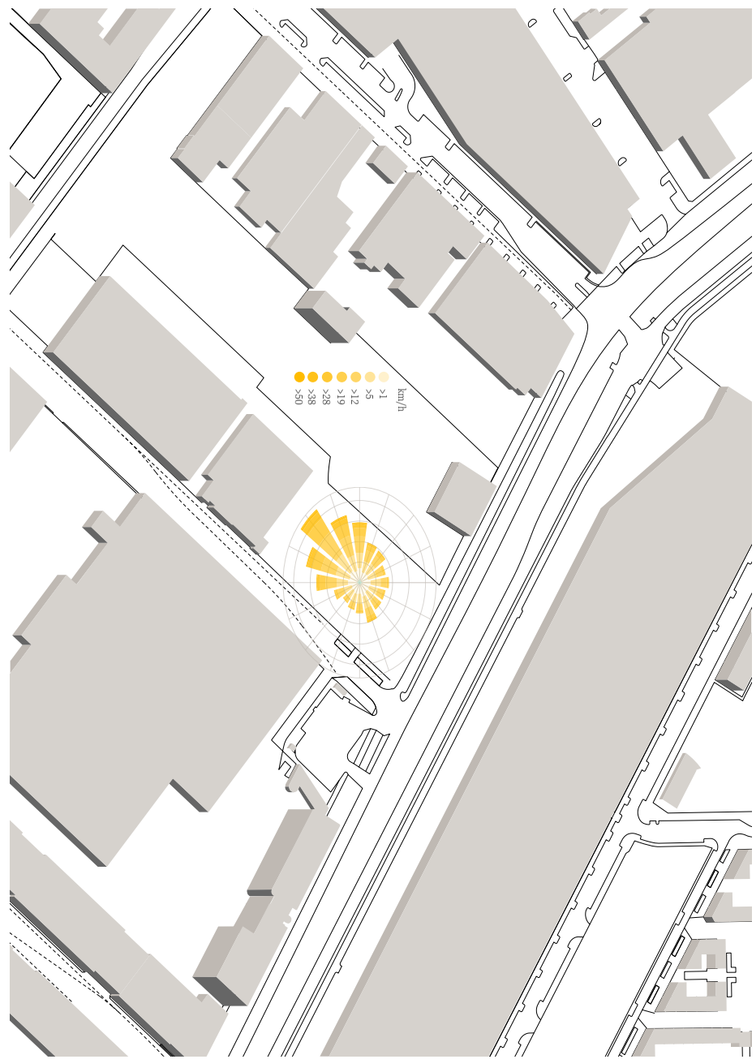
Site analysis

wind direction in winter and autumn

site

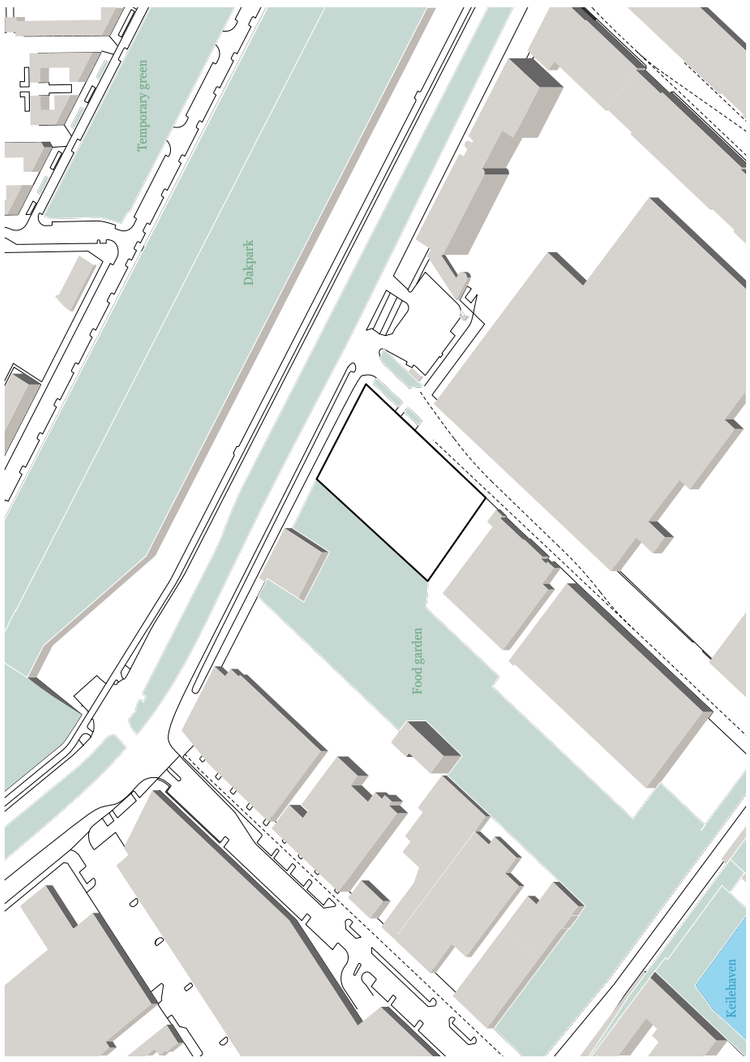


wind direction in summer and spring

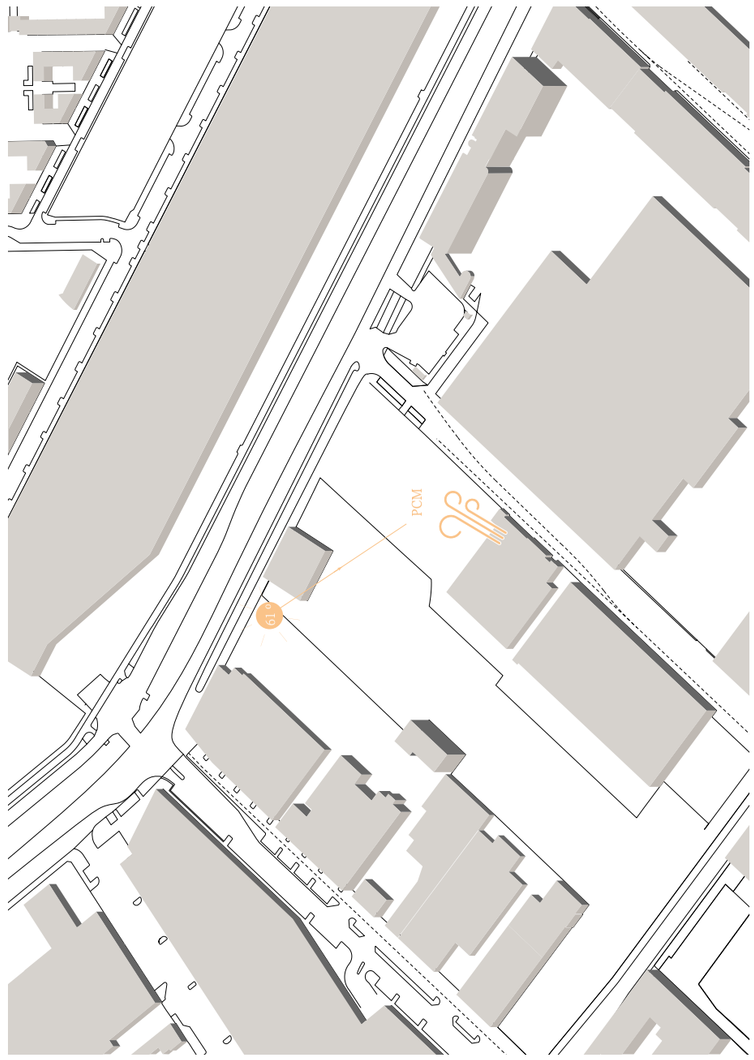


prevailing wind speed

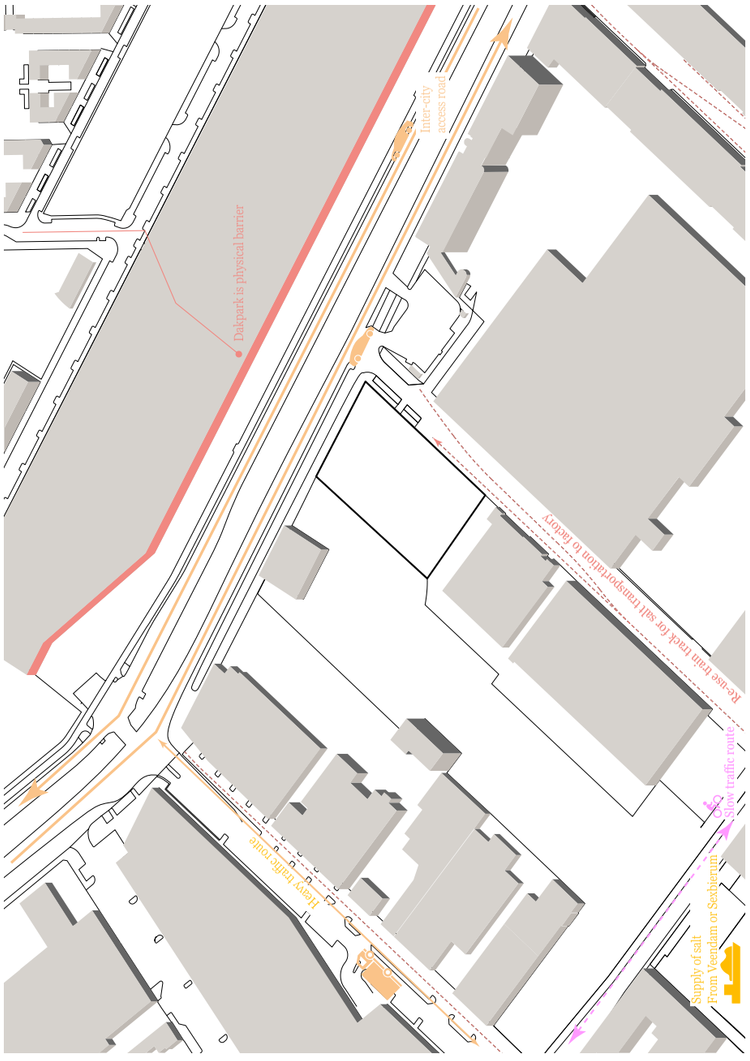
Site analysis



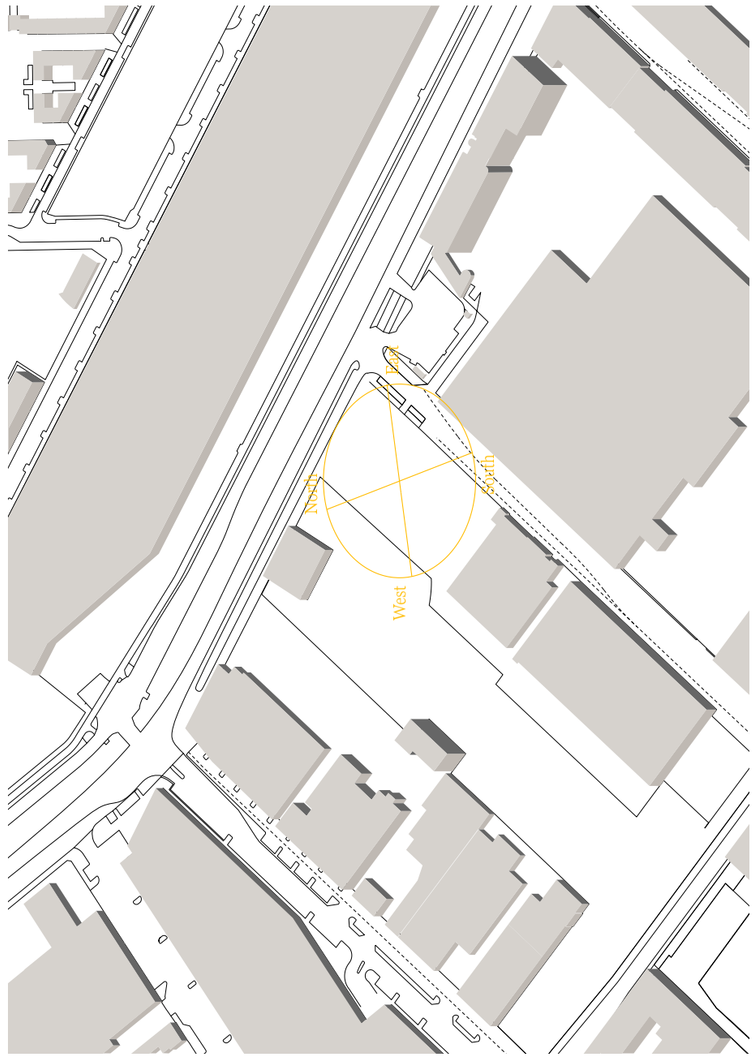
green & blue



important influences on PCM



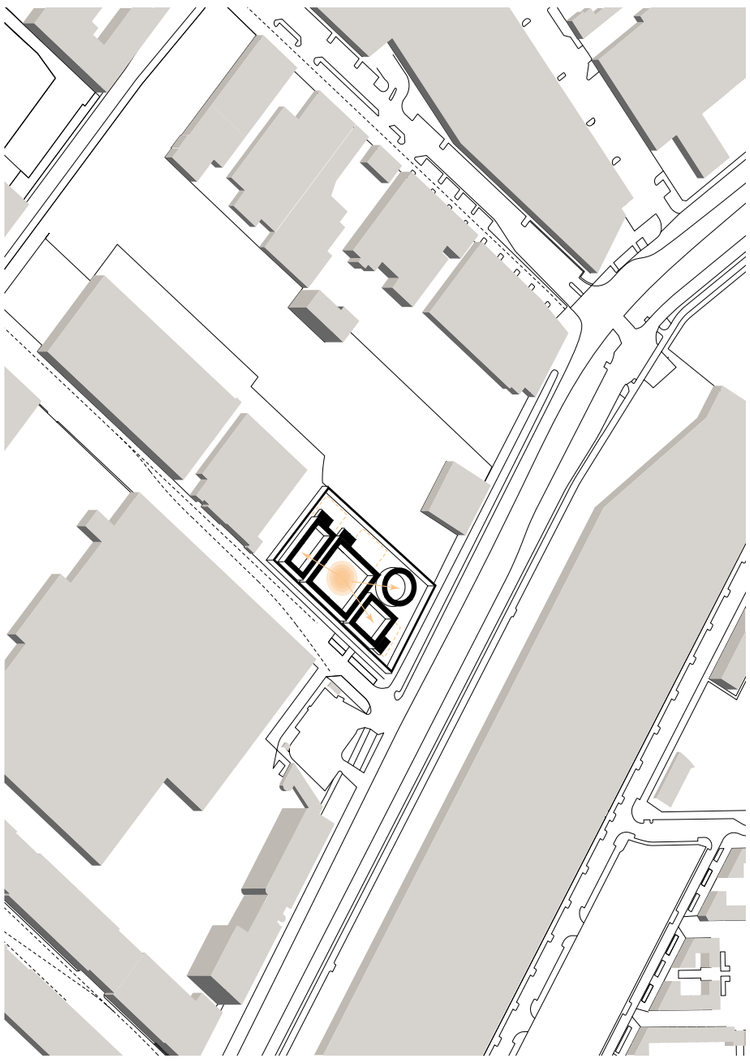
mobility & infrastructure



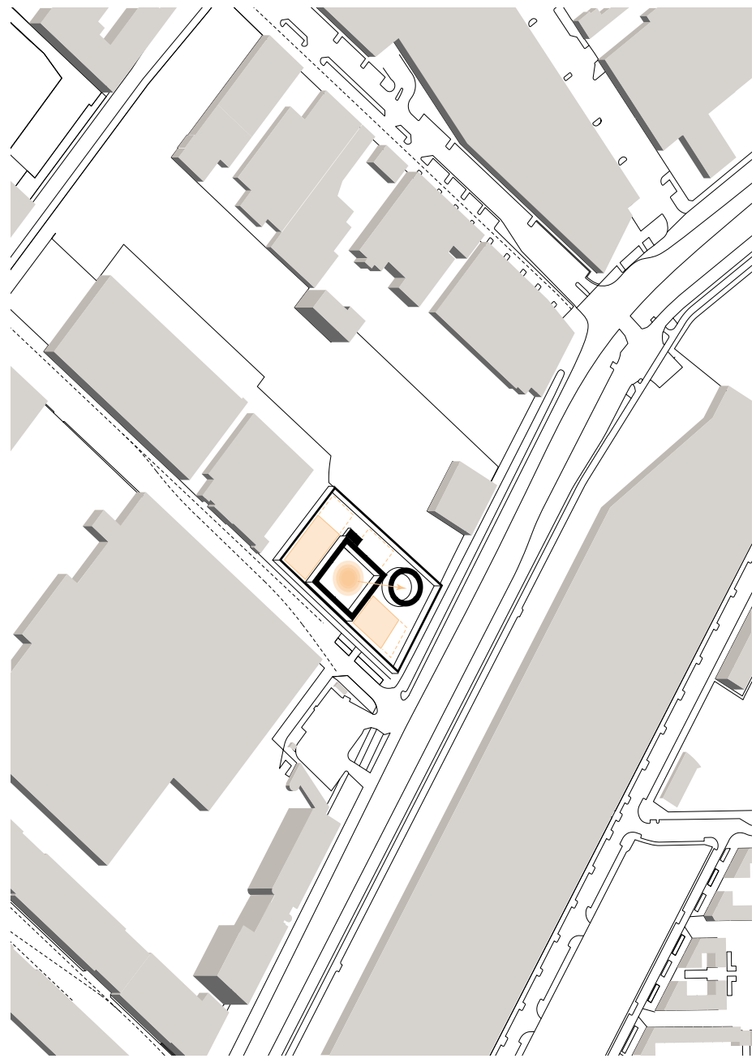
sun

Spatial concept

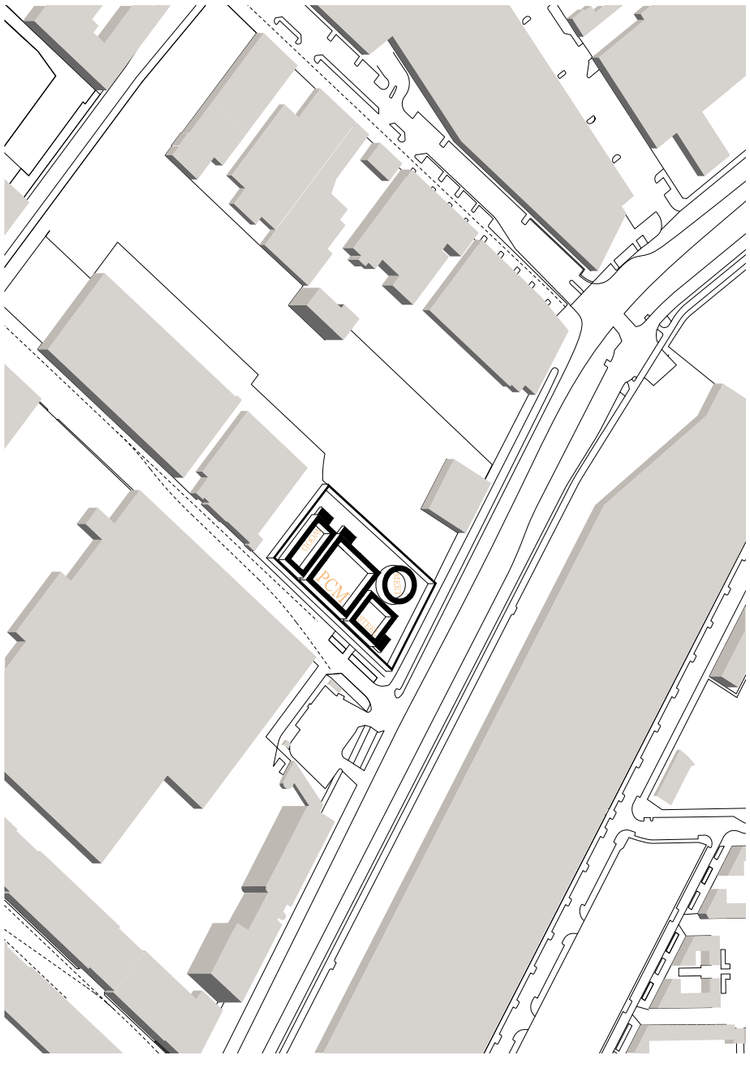
The Factory



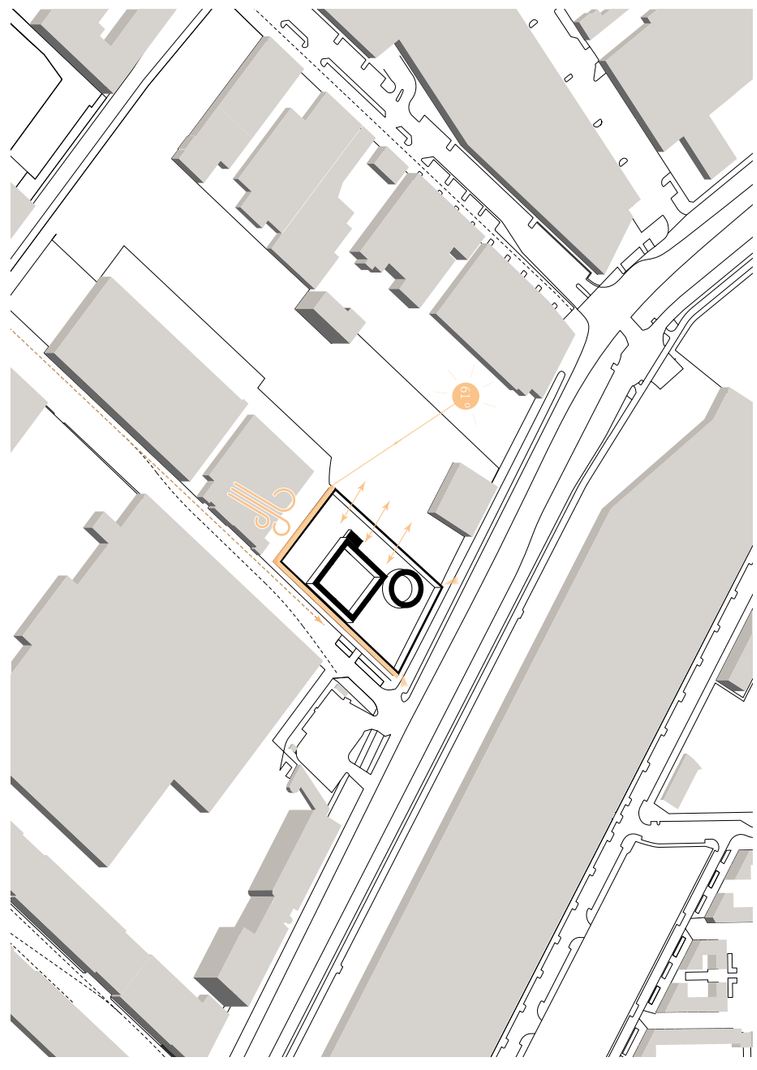
interior relation on base of thermal energy



PCM workshop + meeting room: space for expansion

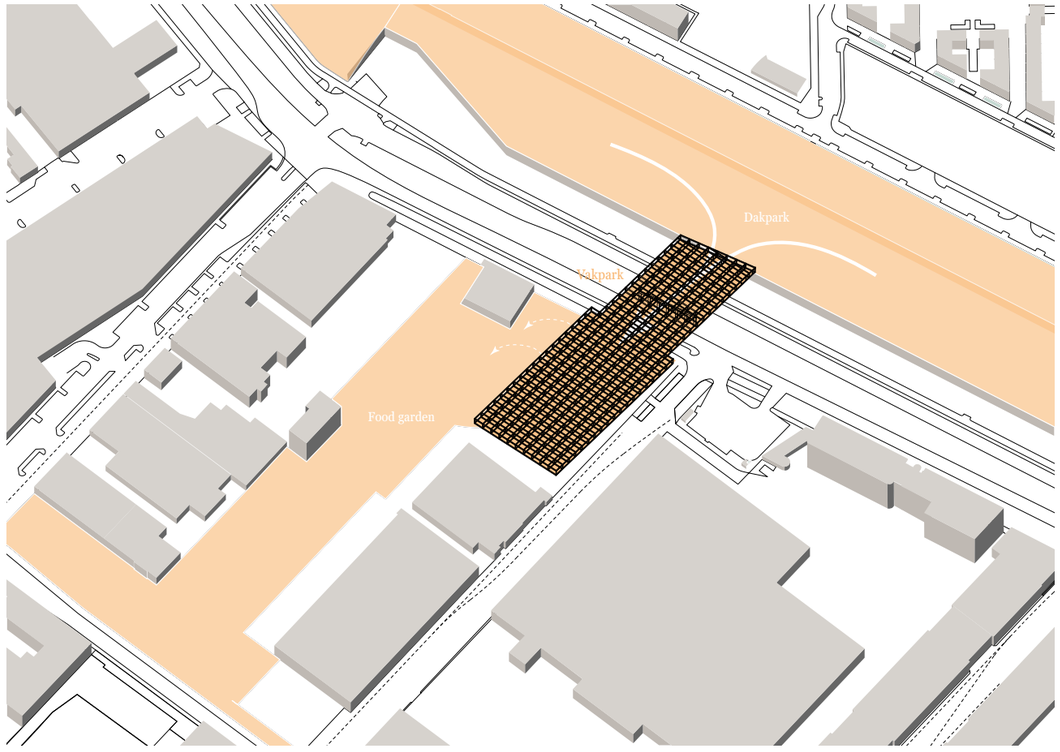


functions factory

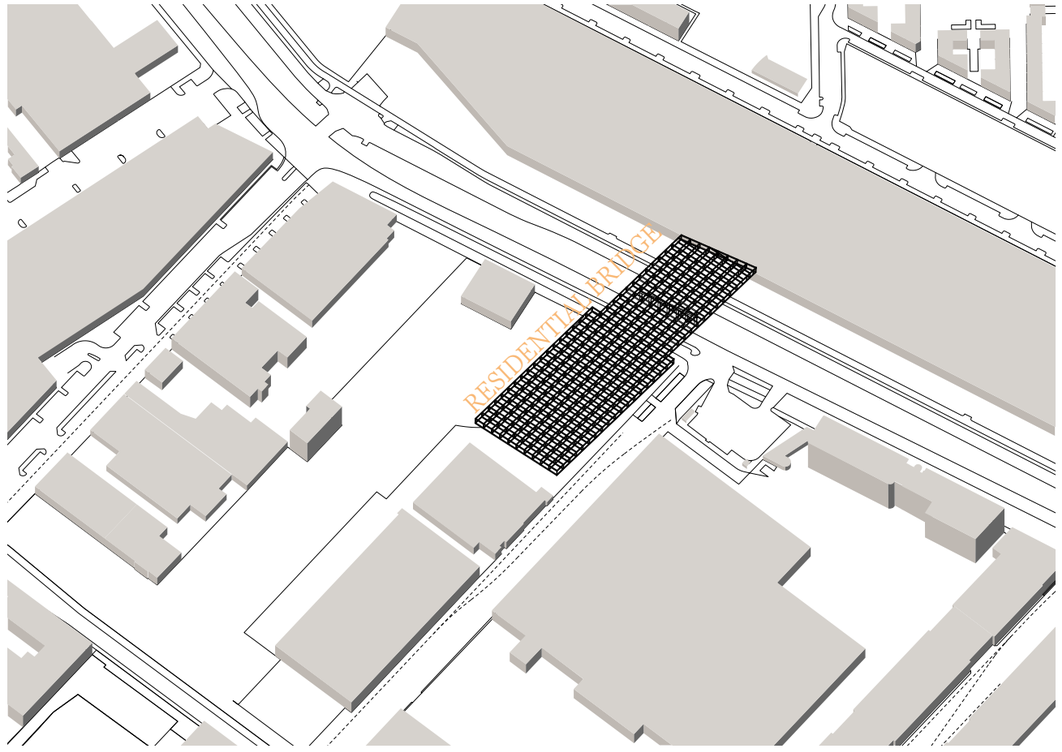


connection to surrounding

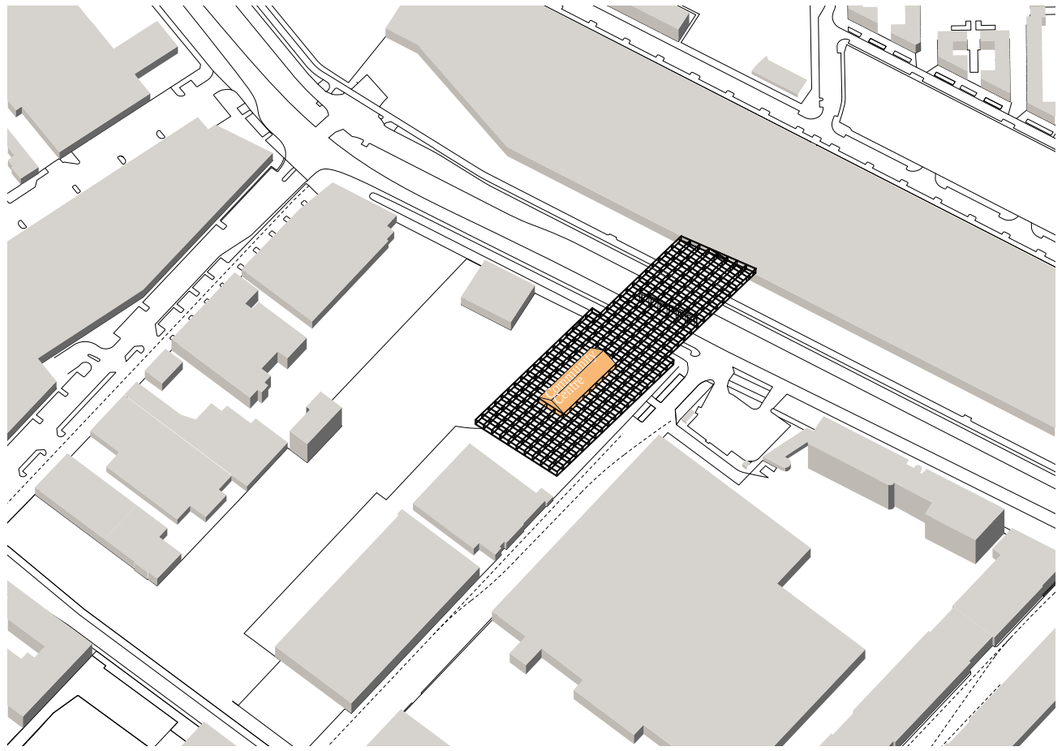
Site analysis



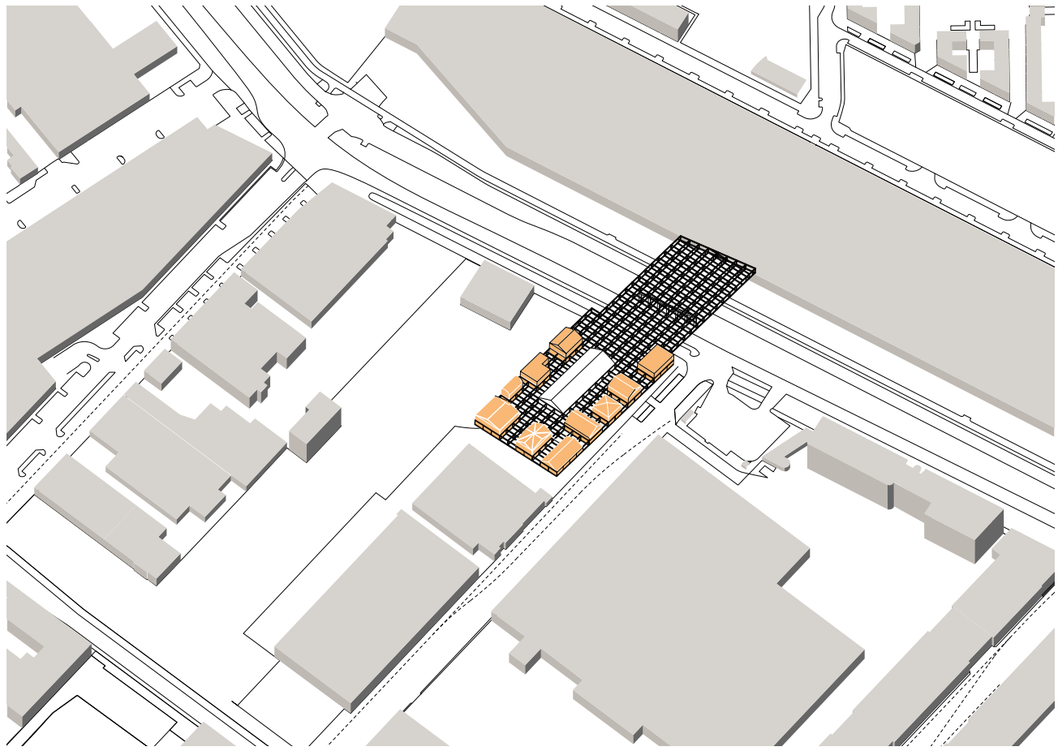
Vakpark as connection between Dakpark and Voedseltuin



public function of bridge



public function

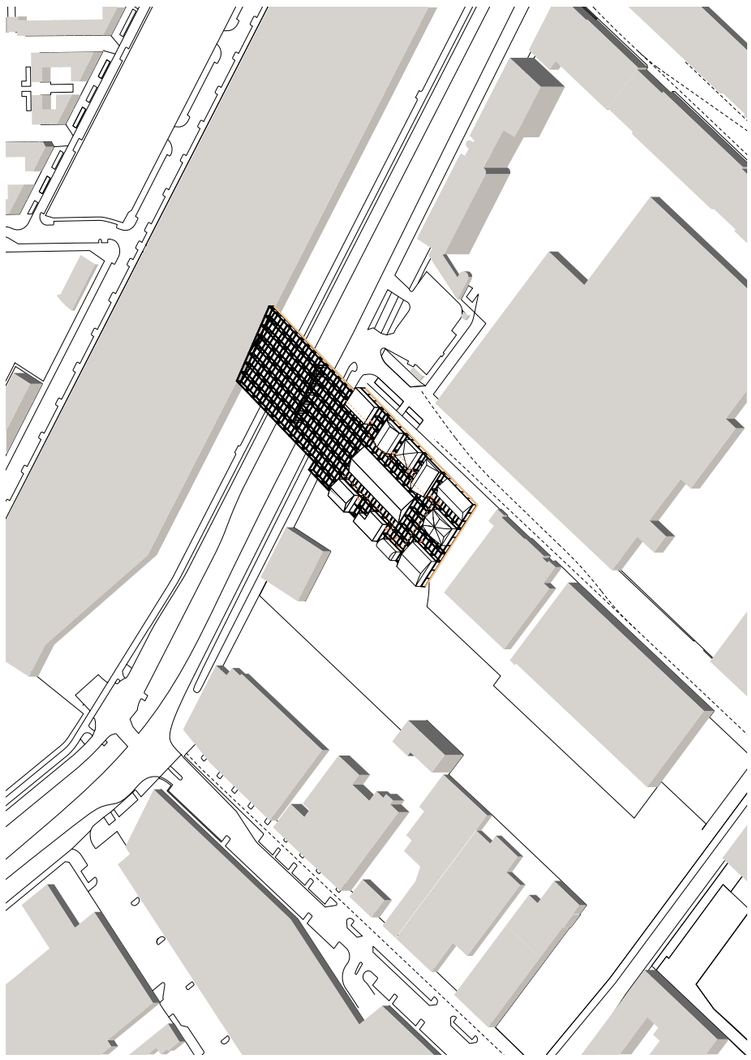


BoTu neighbourhood extension

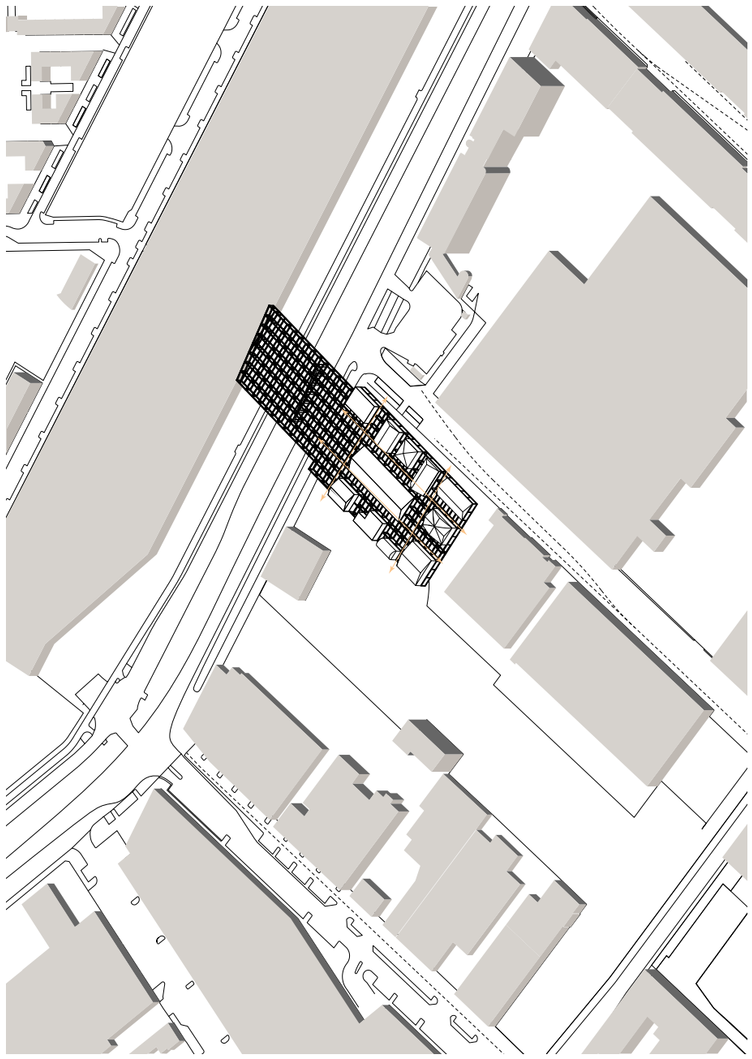
Vakpark

Site analysis

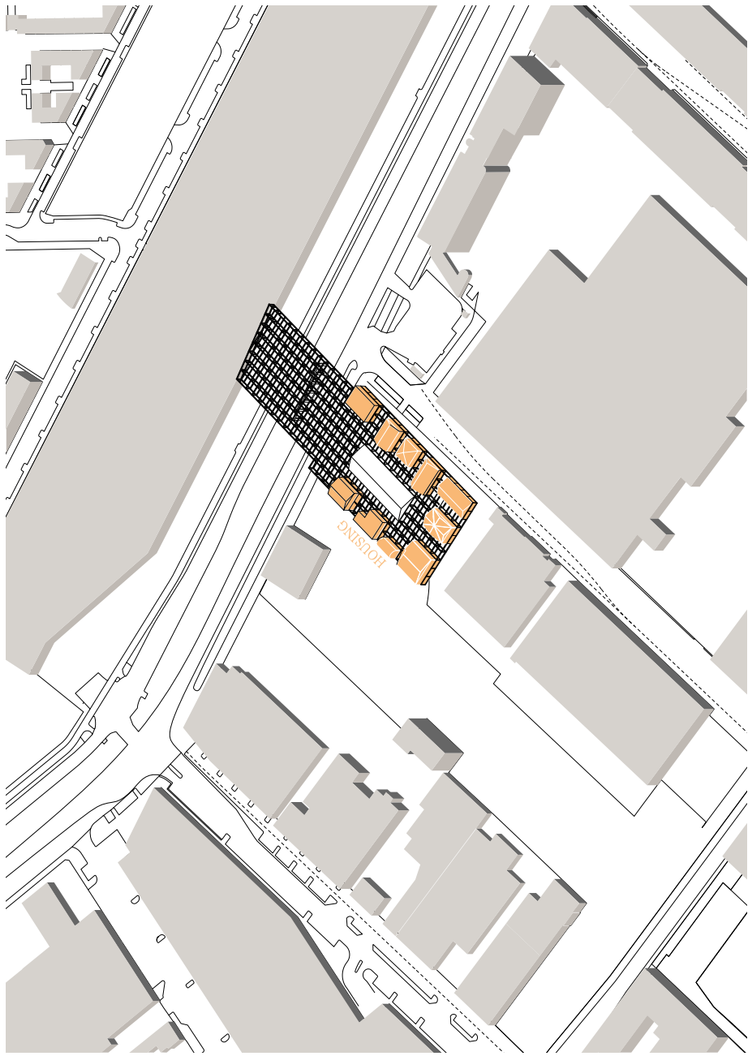
BoTu2.0: extension



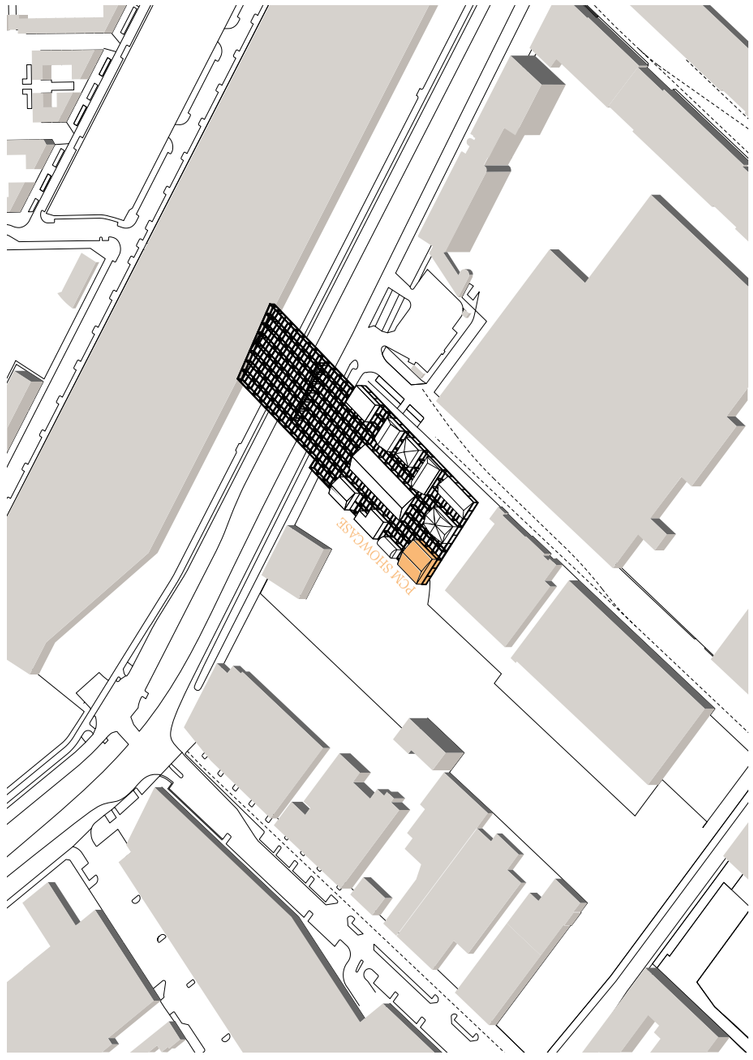
public ground and collective 'street in the sky'



spatial concept between dwellings



functions on second level

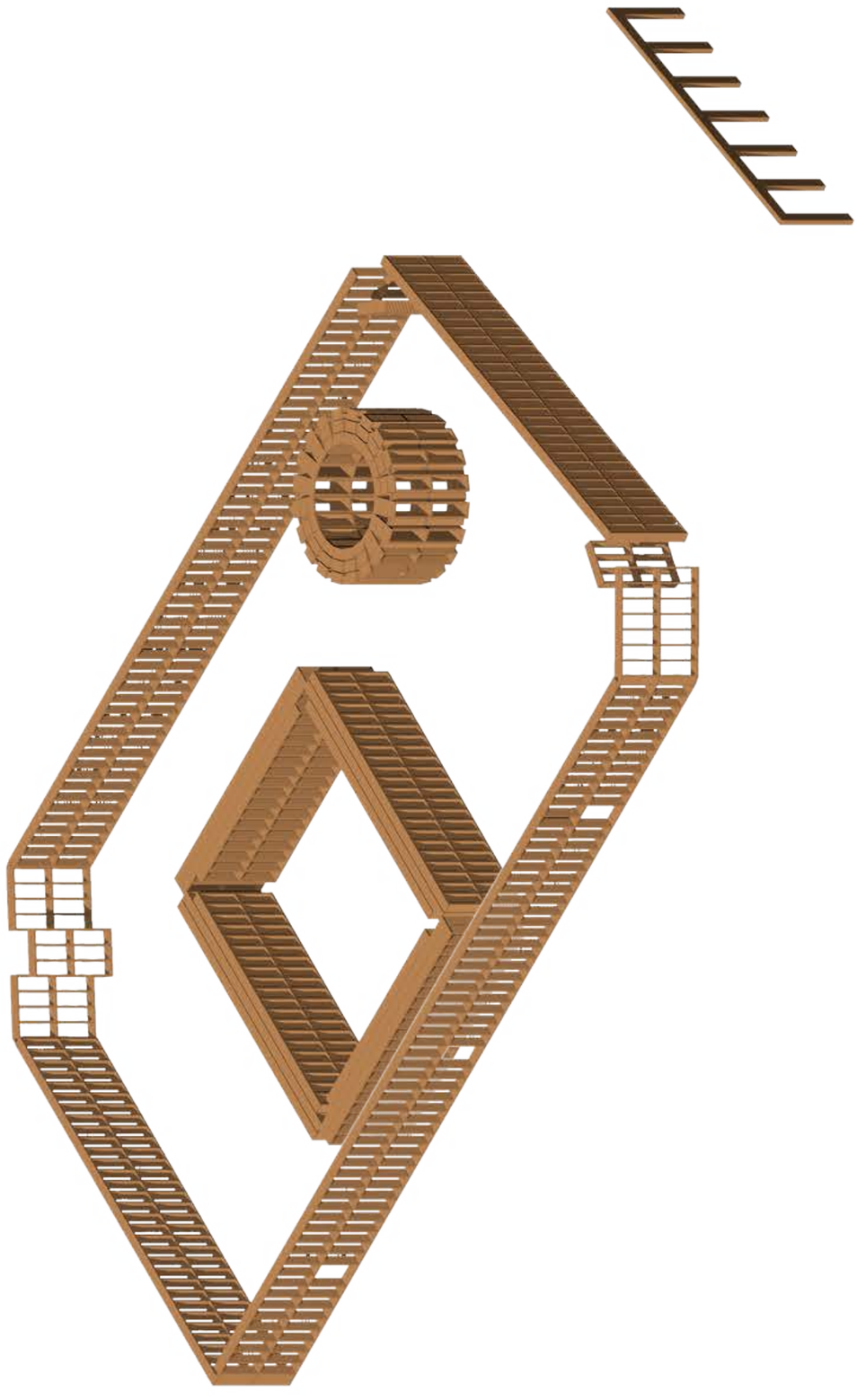


PCM showcase: museum and representative of social sustainable movement

Structure

Structural isometric view

The Factory

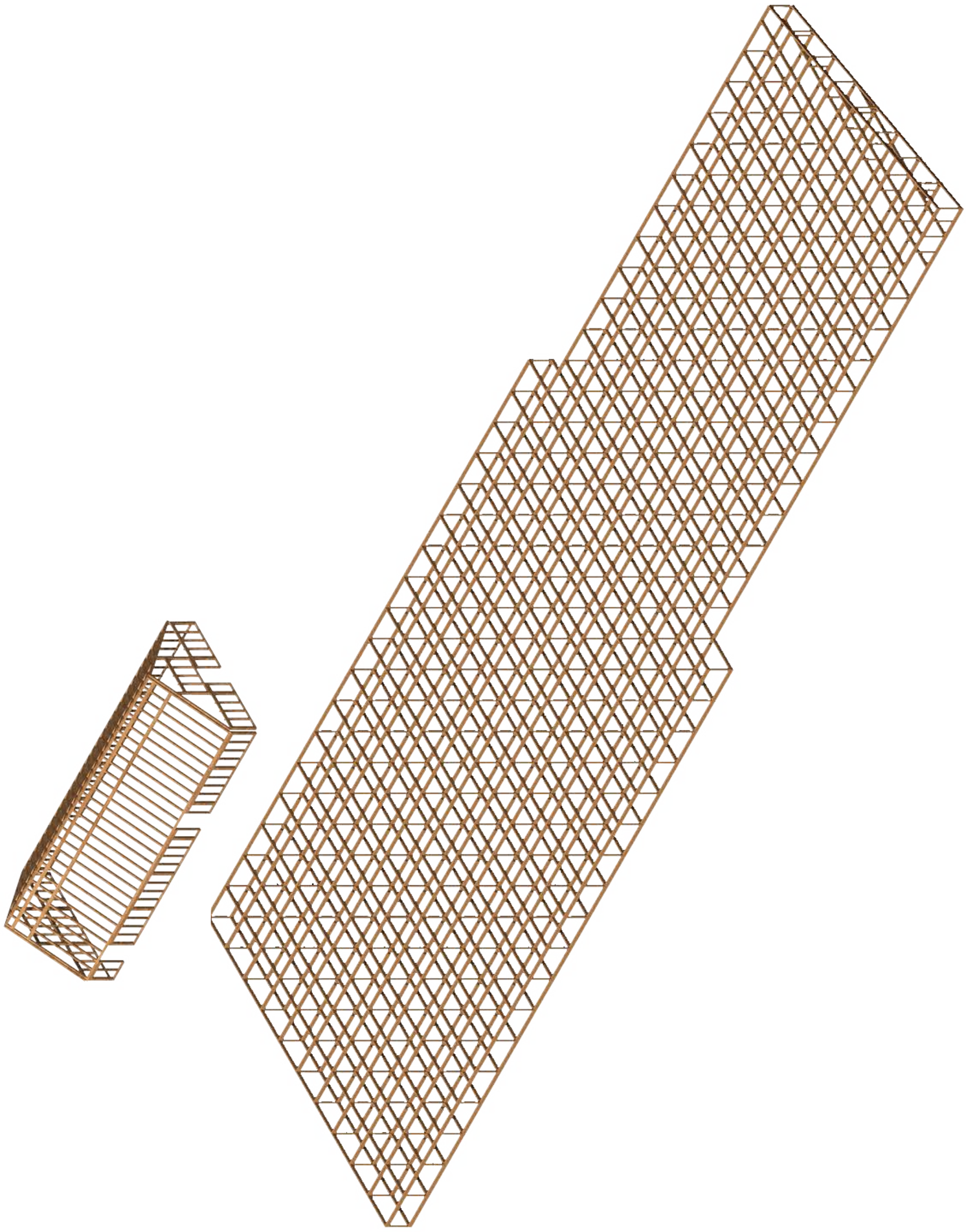


Vierendeel spaceframe of laminated accoya timber

Public extension ground level BoTu: residential park

Structural isometric view

Vakpark + community centre

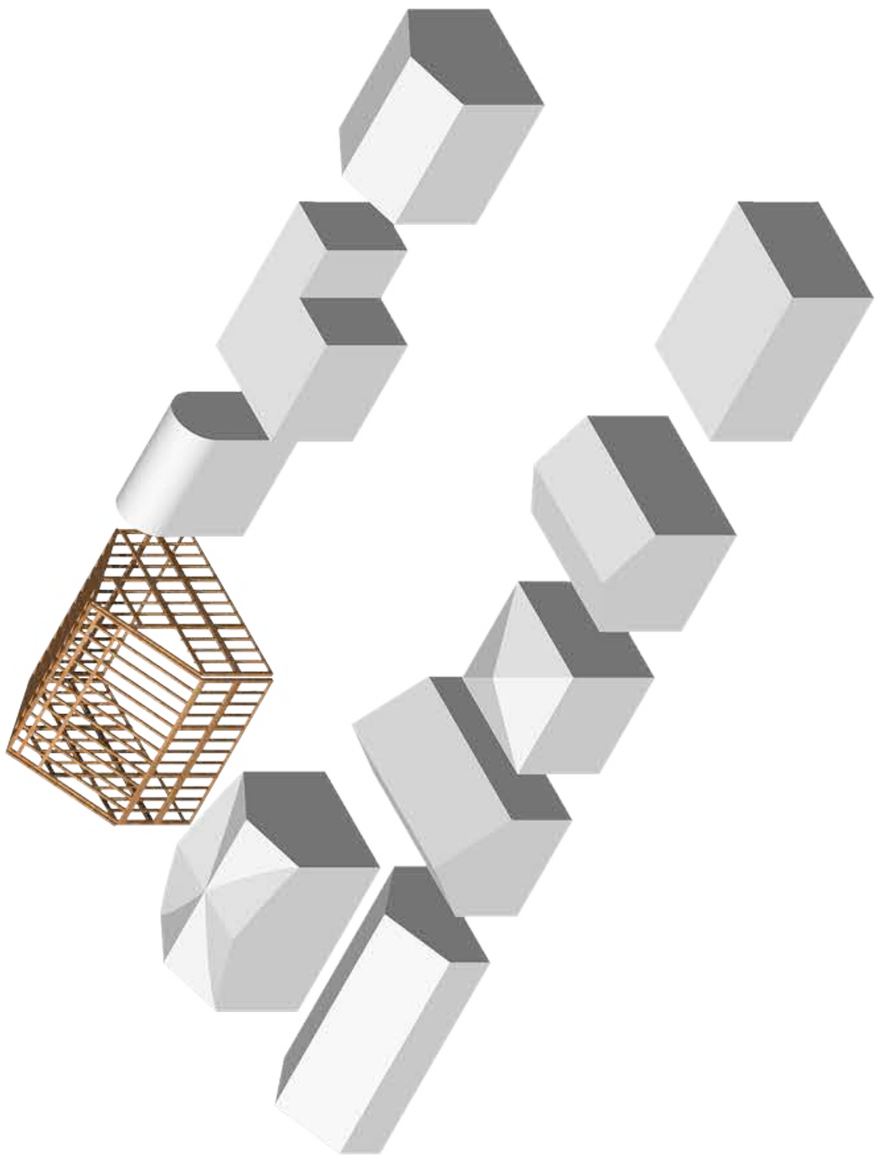


Vierendeel spaceframe of laminated accoya timber

Public extension ground level BoTu: residential park

Structural isometric view

BoTu2.0: extension



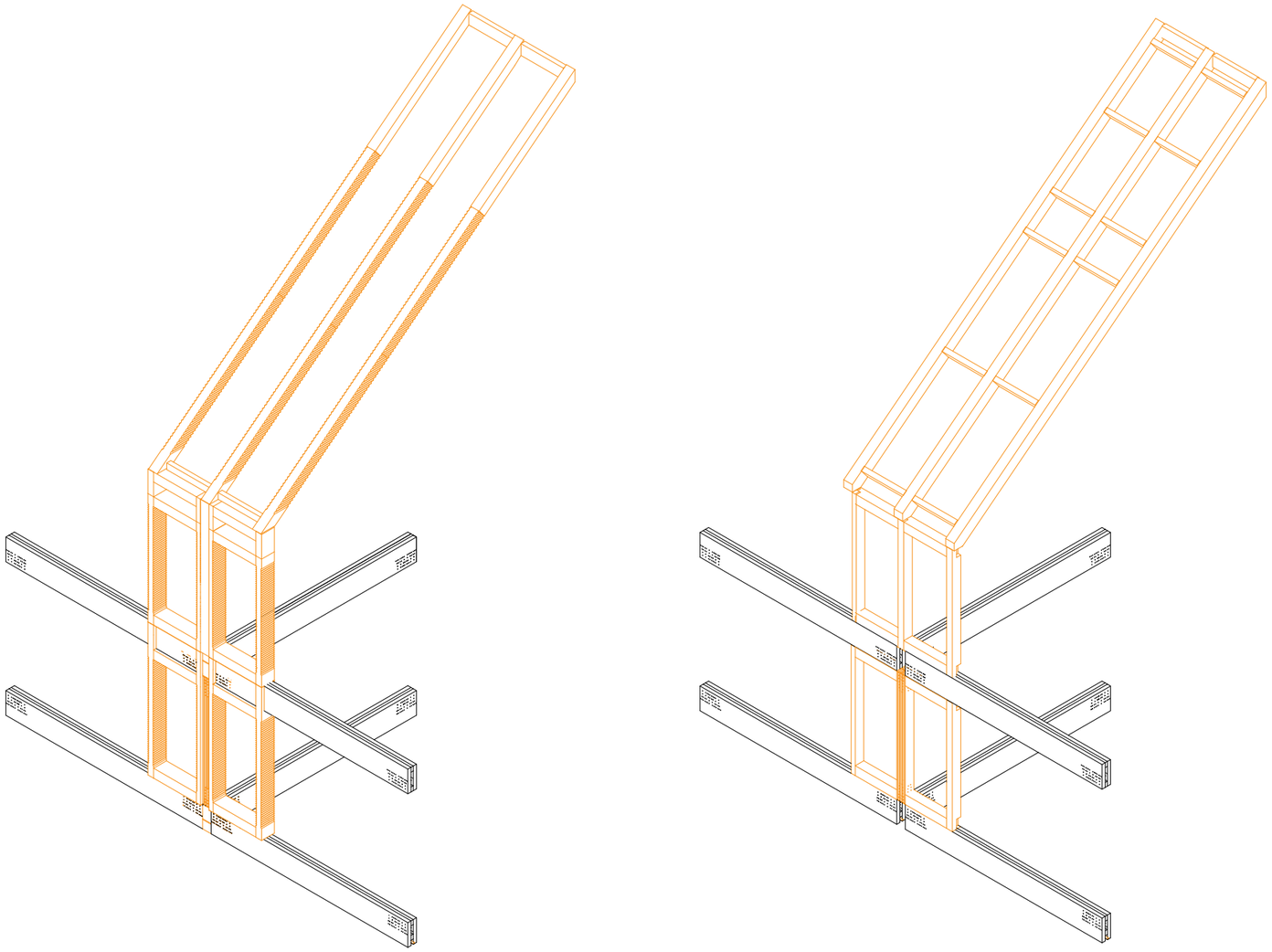
BoTu extension: one PCM dwelling

Unrestricted affordable urban expansion for inclusivity

The building system

Generic building system

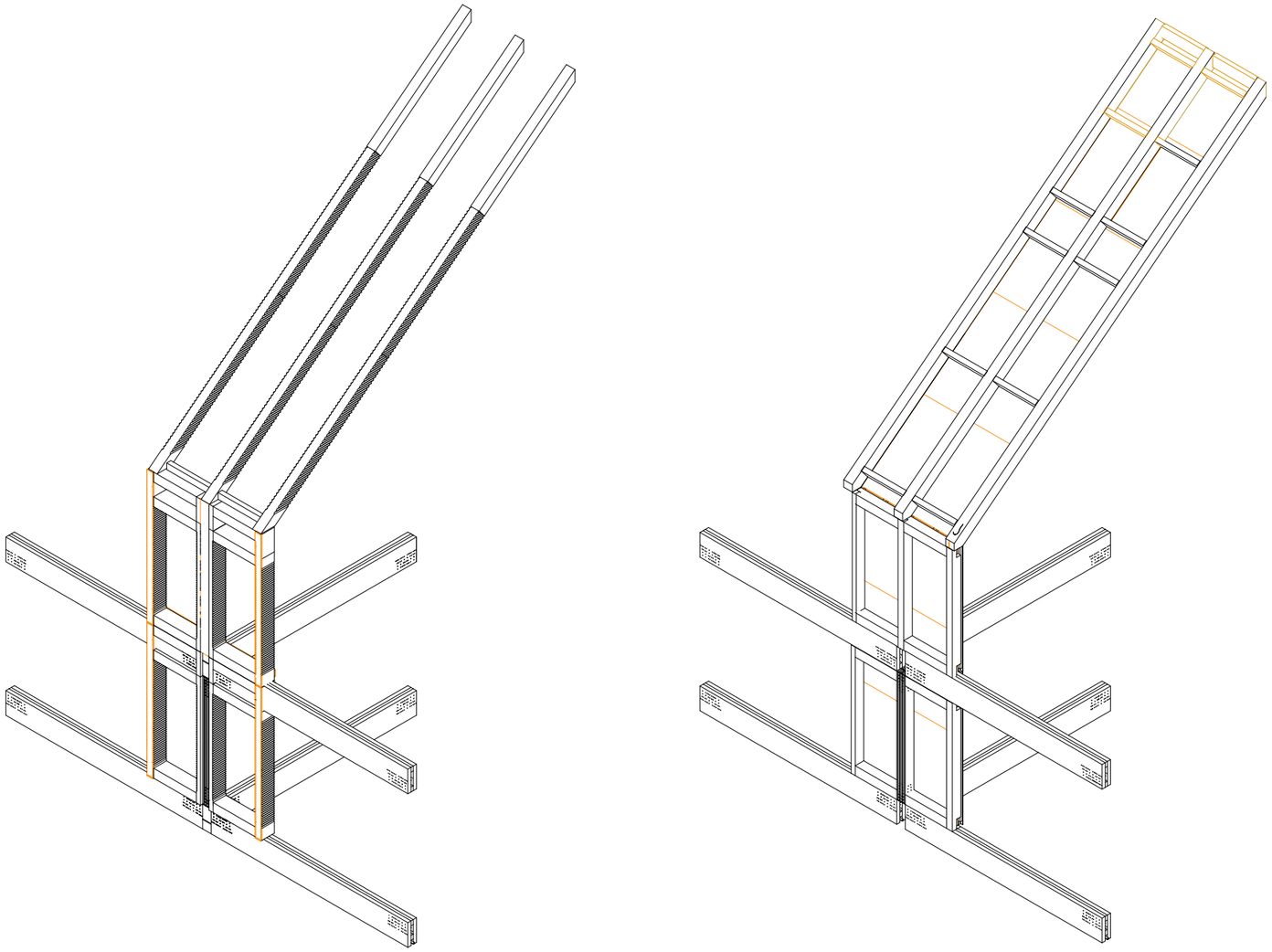
PCM vs. Timber frame



Primary structure

Generic building system

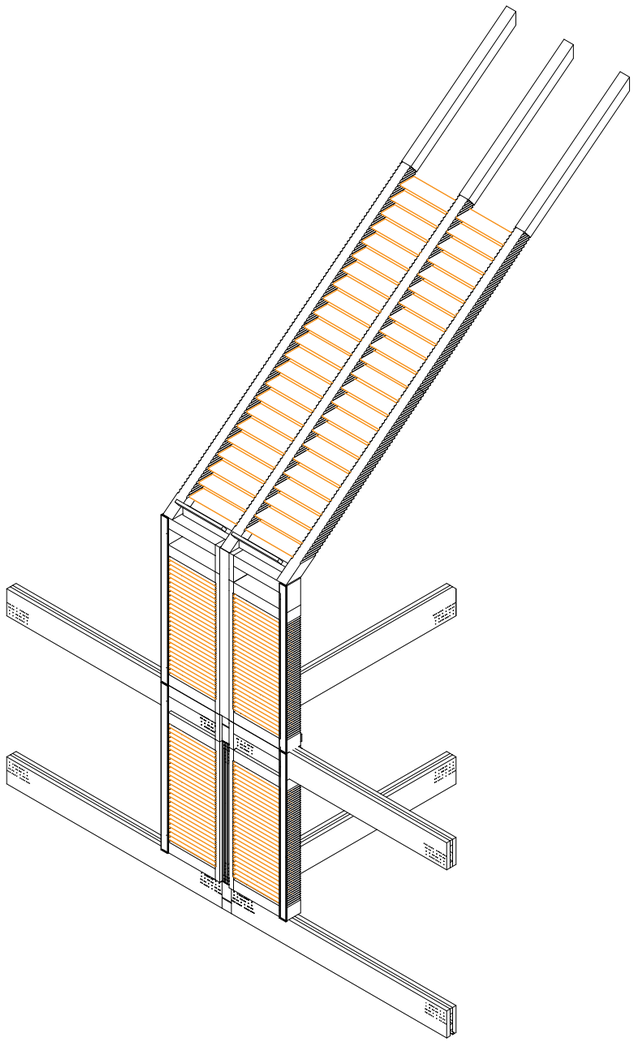
PCM vs. Timber frame

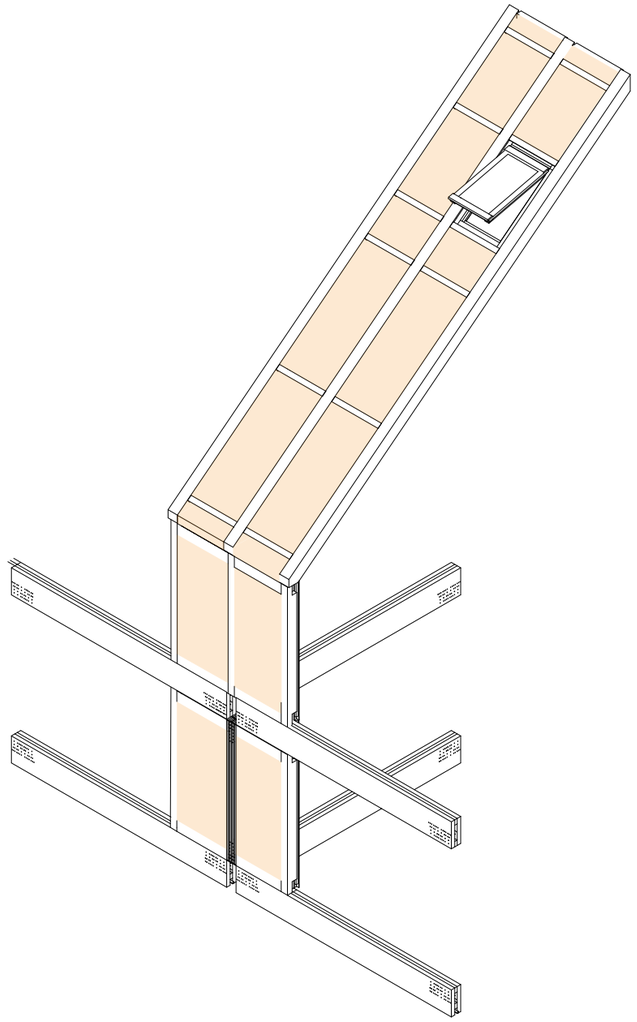


Secondary structure

Generic building system

PCM vs. Timber frame

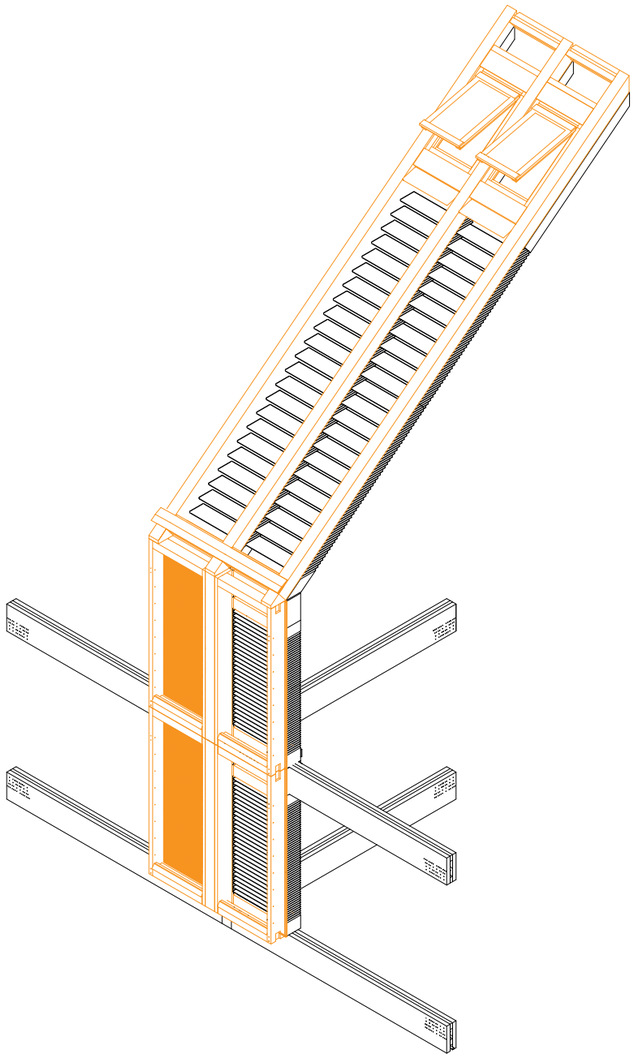


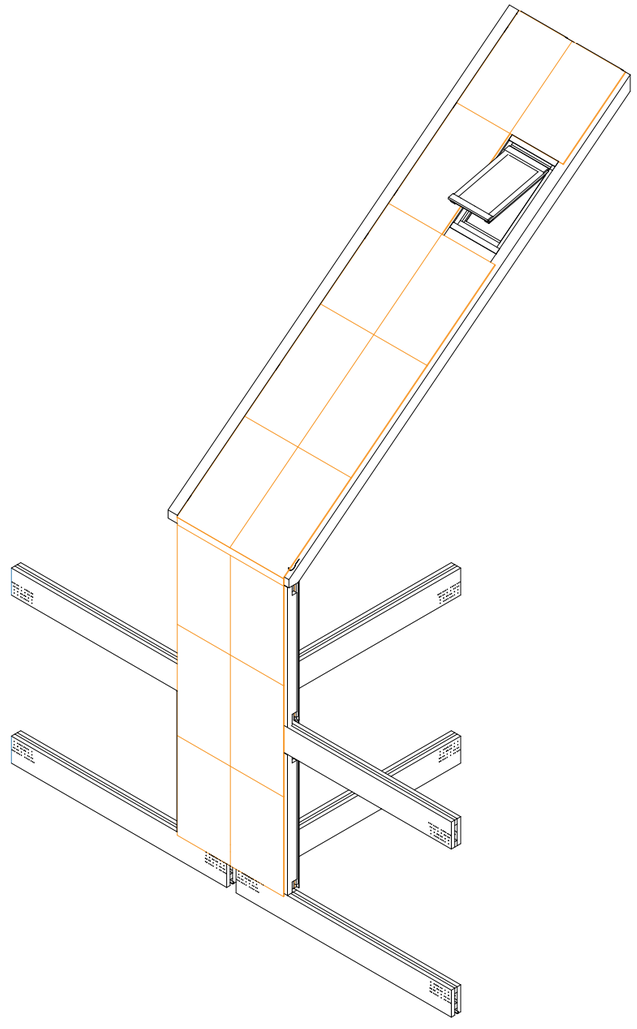


Thermal layer

Generic building system

PCM vs. Timber frame

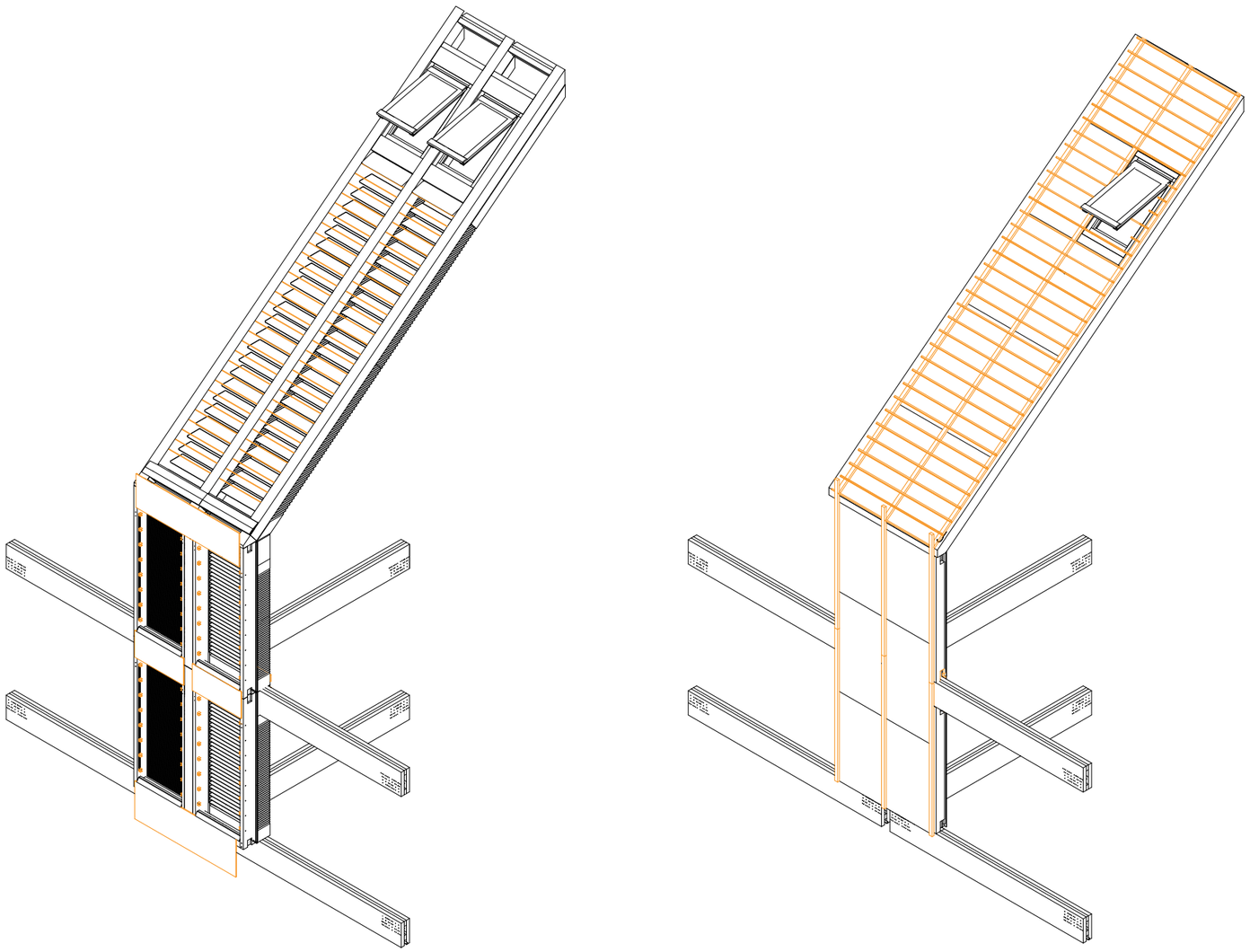




Additional climatic layer

Generic building system

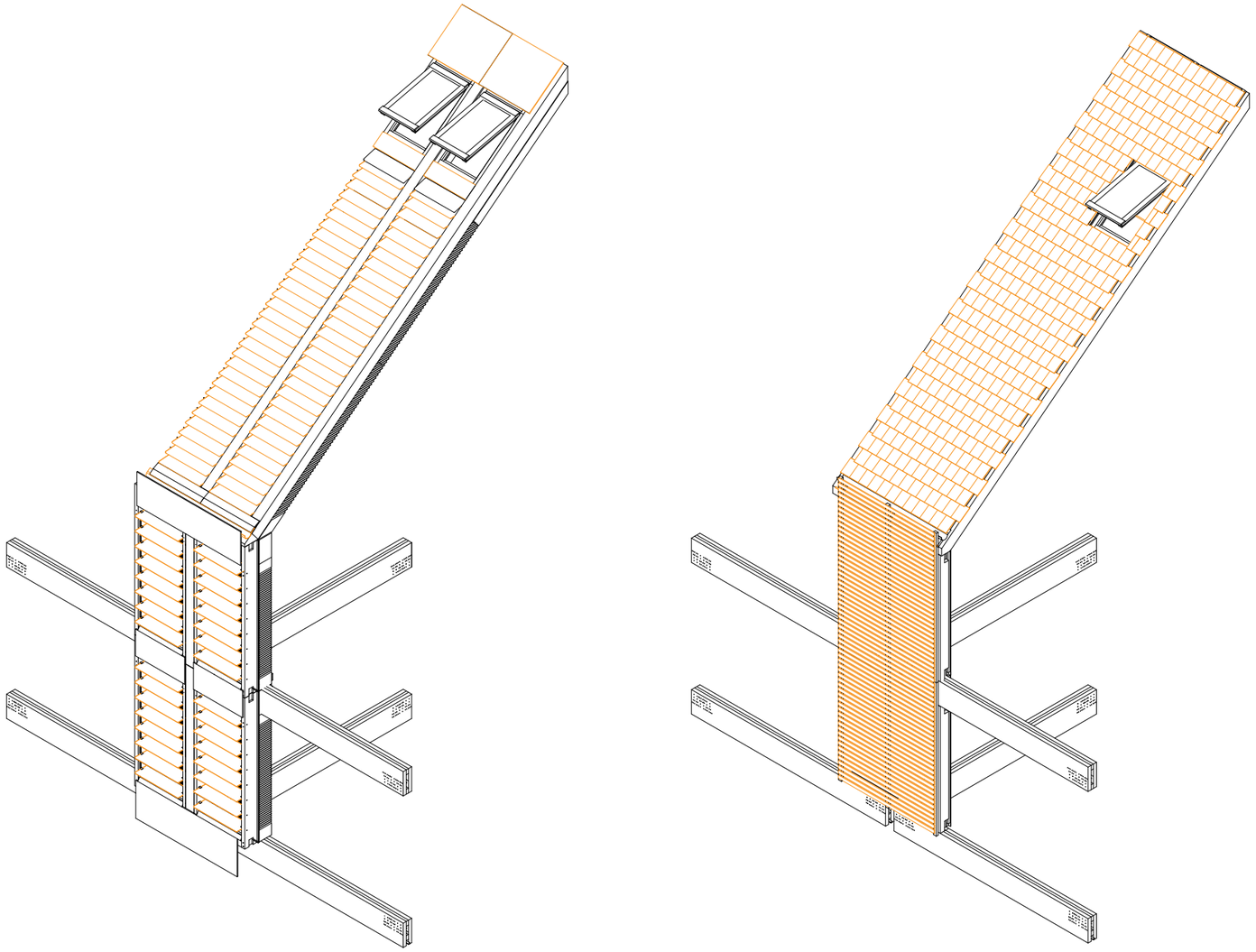
PCM vs. Timber frame



Facade structure

Generic building system

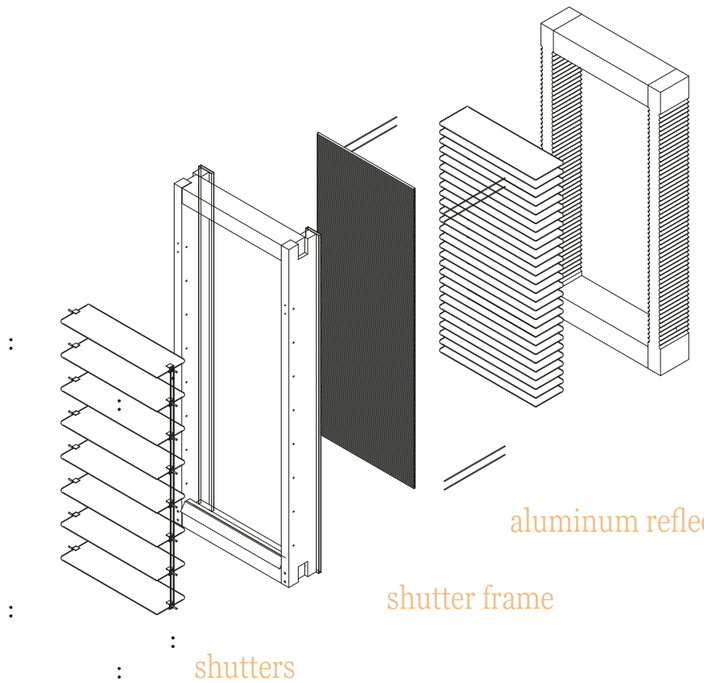
PCM vs. Timber frame



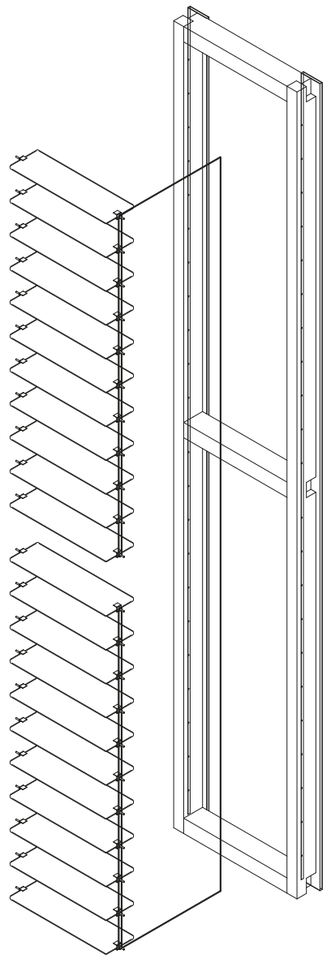
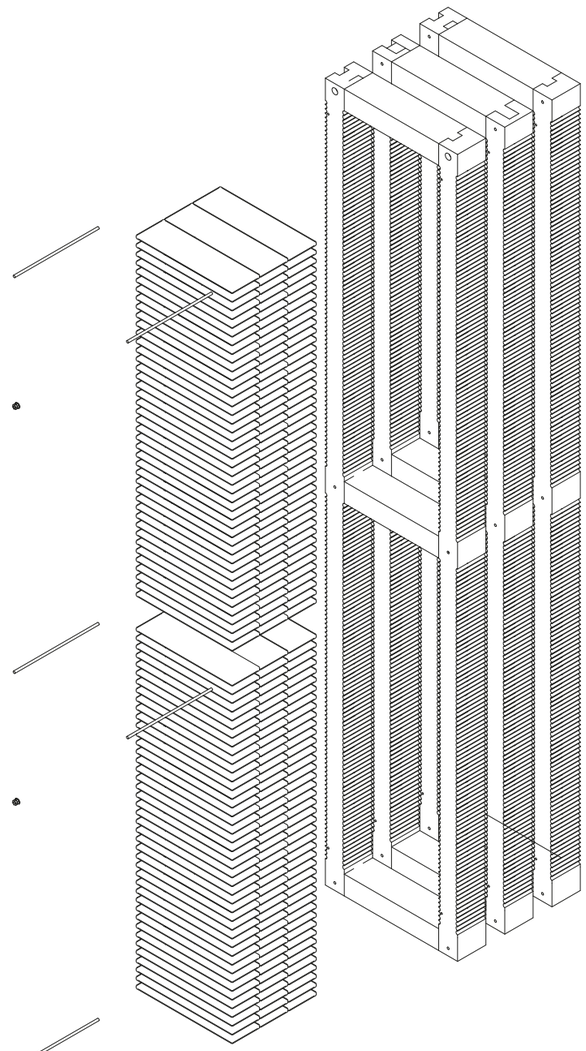
Facade cladding

PCM building system

Assembly of facade stacks



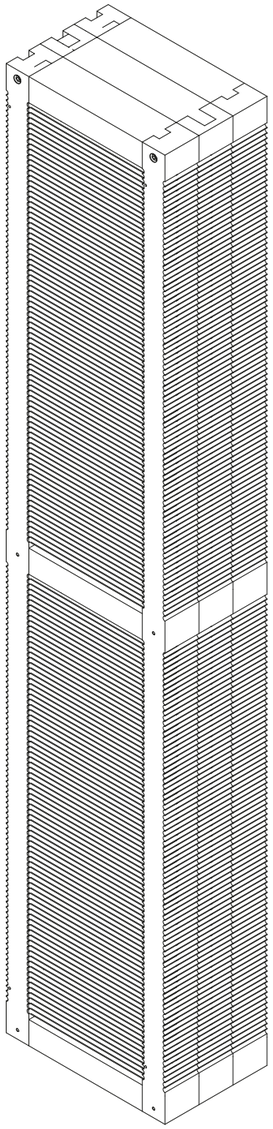
Dwelling

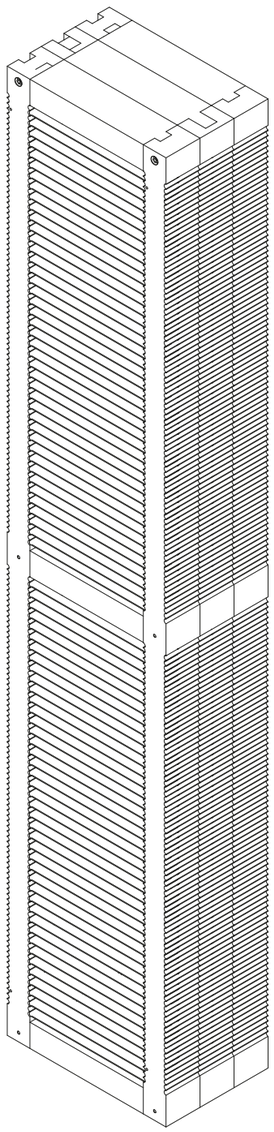
Factory

PCM building system

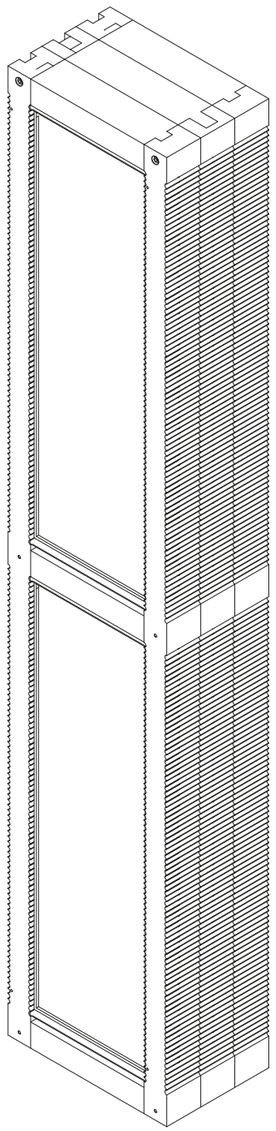
Flexible use of facade stacks



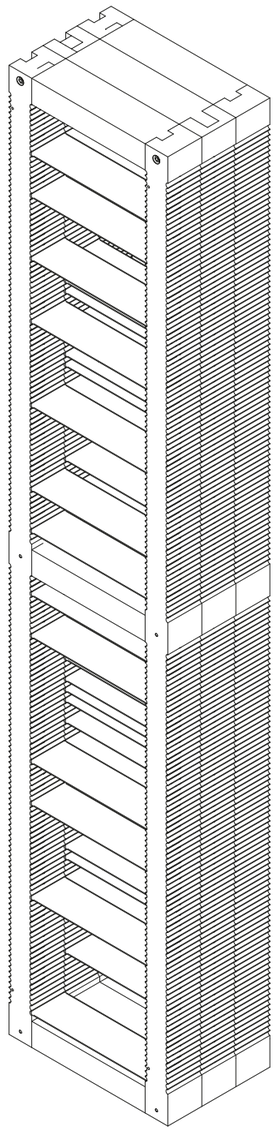
impermeable



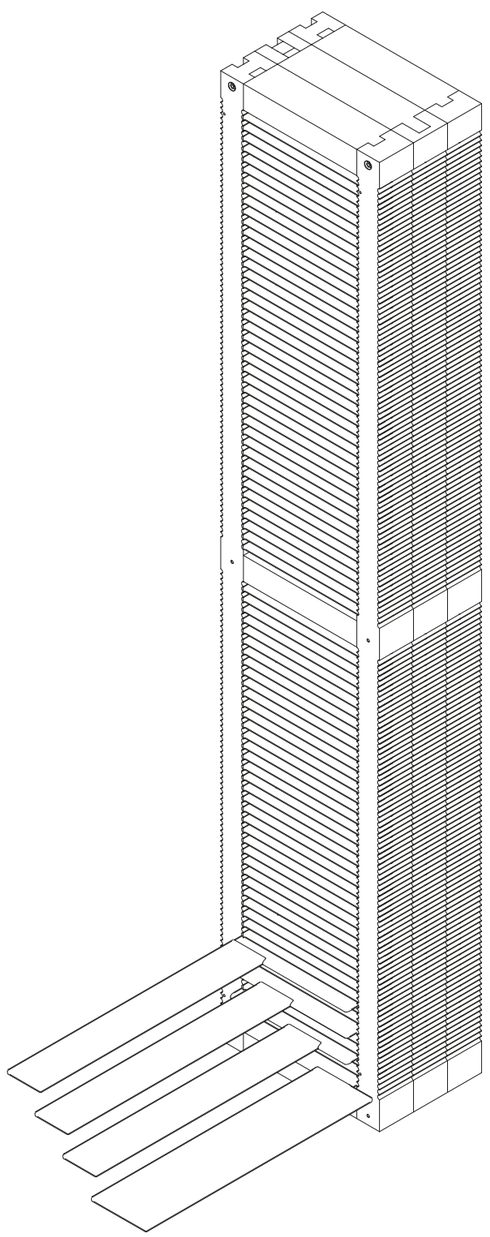
permeable



window frame



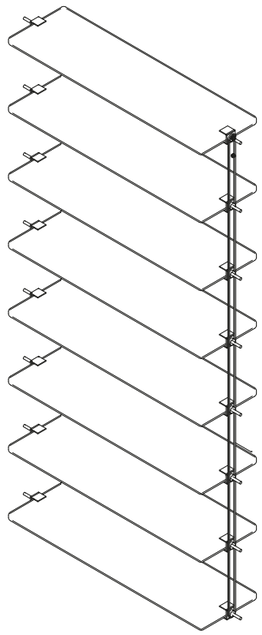
storage



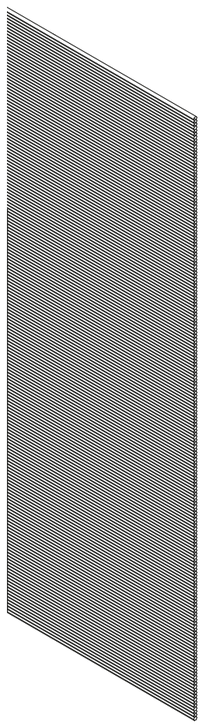
stairs

PCM building system

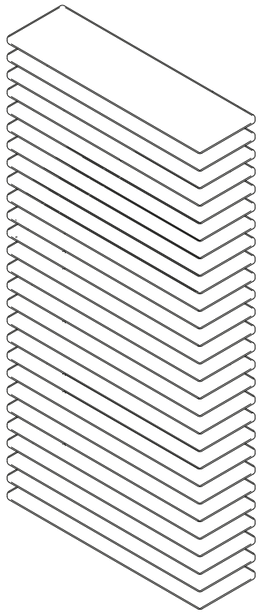
Climate regulation instruments



Shutters for shading + ventilation



Aluminium plissé curtain



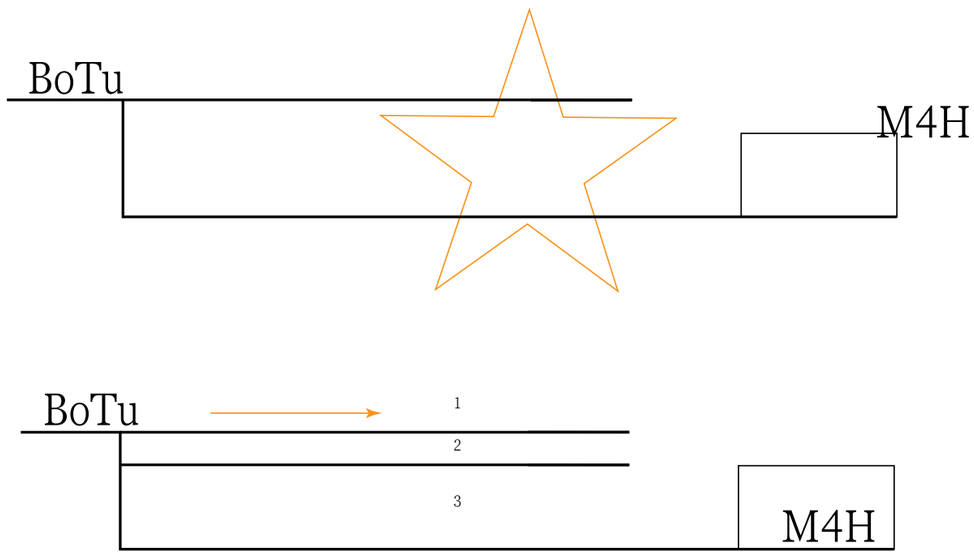
PCM T21-T28

Concept

of connecting BoTu - M4H

Frituurfabriek:
Change Mater
archit

Spatial concept of connection



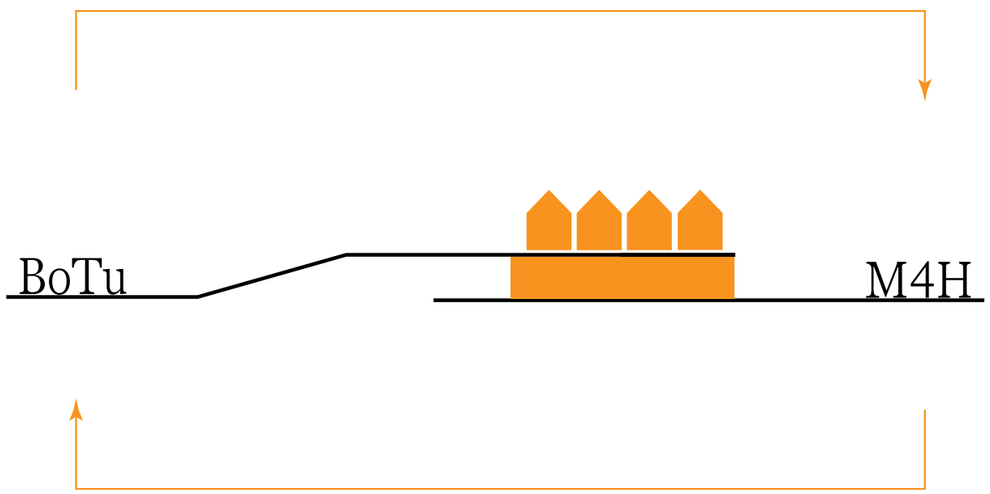
BoTu - M4H Mutualism

Craftsmanship: practically educated people

Innovation: passive cooling system by upcycled waste oil

Resources: used frying oil

Responsibility: cooperative ownership of factory



€ Salary

PCM Sustainability: cooling element for energy transition ambitions

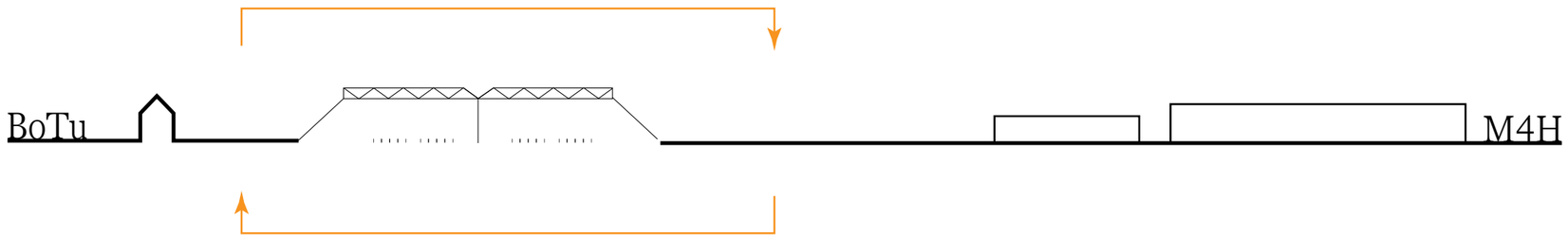
Education + Skills: language, teamwork and new skills

Self-worth: self-esteem/responsibility feeling from professional to private environment

Historic relation

BoTu - M4H

1916



Relation of existance

Economical

Physical

1980

Only visual connection

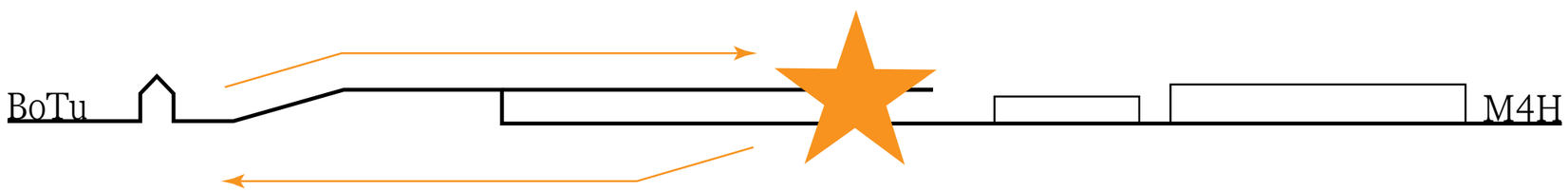
Unemployment by invention of container

2014

No relation

Dyke ensures alienation

2020



Reconnection

Economical

Physical

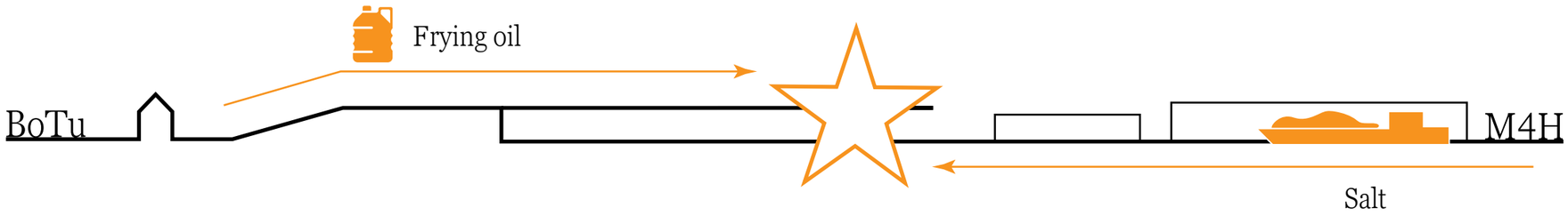
Sustainable

Educational

Responsible

Elaboration on mutualism of BoTu - M4H

Resources



BoTu extension
for emancipation

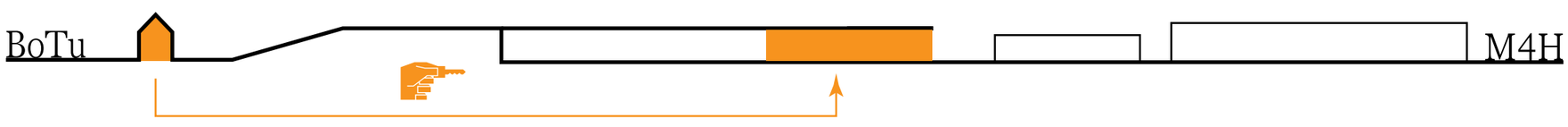
M4H
Makersdistrict for innovation

Sustainable relation: PCM

Economical relation: €

Educational relation:
Skills + knowledge

Responsible relation:
Cooperative ownership



Emancipation

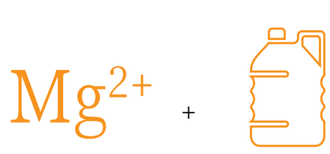
Social impact by design

The productive city

How could PCM, as an alternative to sand, be produced as an accessible manufacturable building material that responds to the current energy transition ambitions, whereby its production process intervenes with the socio-demographic challenges in Bospolder - Tussendijken?

Accessible production process

PCM of frying oil and Mg^{2+}



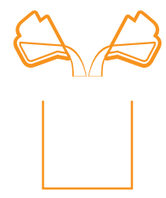
Waste: $^{2+}$ ion

Biobased PCM

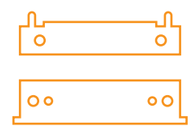
Frying oil

Horeca + Domestic waste collection

Filtering fat



Mixing



Molding container (HDPE)

PCM modules for passive cooling

Pre-factory stage

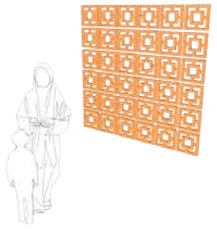
Pre-factory

Can cooler

Laptop cooler

Heating buffer

Table top

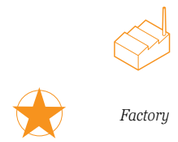


Family picture frame

Shutters

PCM modules for passive cooling

Factory stage



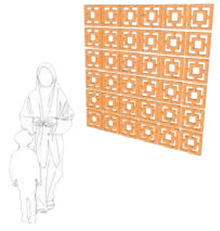
Factory

Can cooler

Laptop cooler

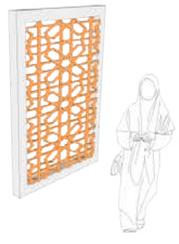
Heating buffer

Table top



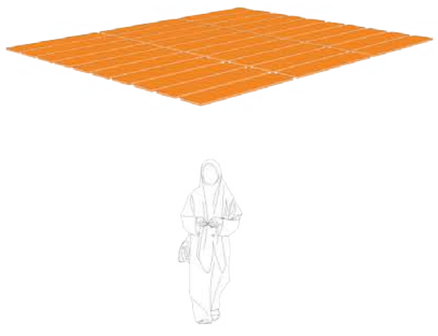
Family picture frame

Shutters

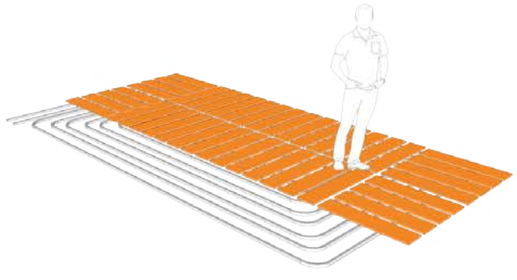


Mashrabyia

Passive airco



Ceiling

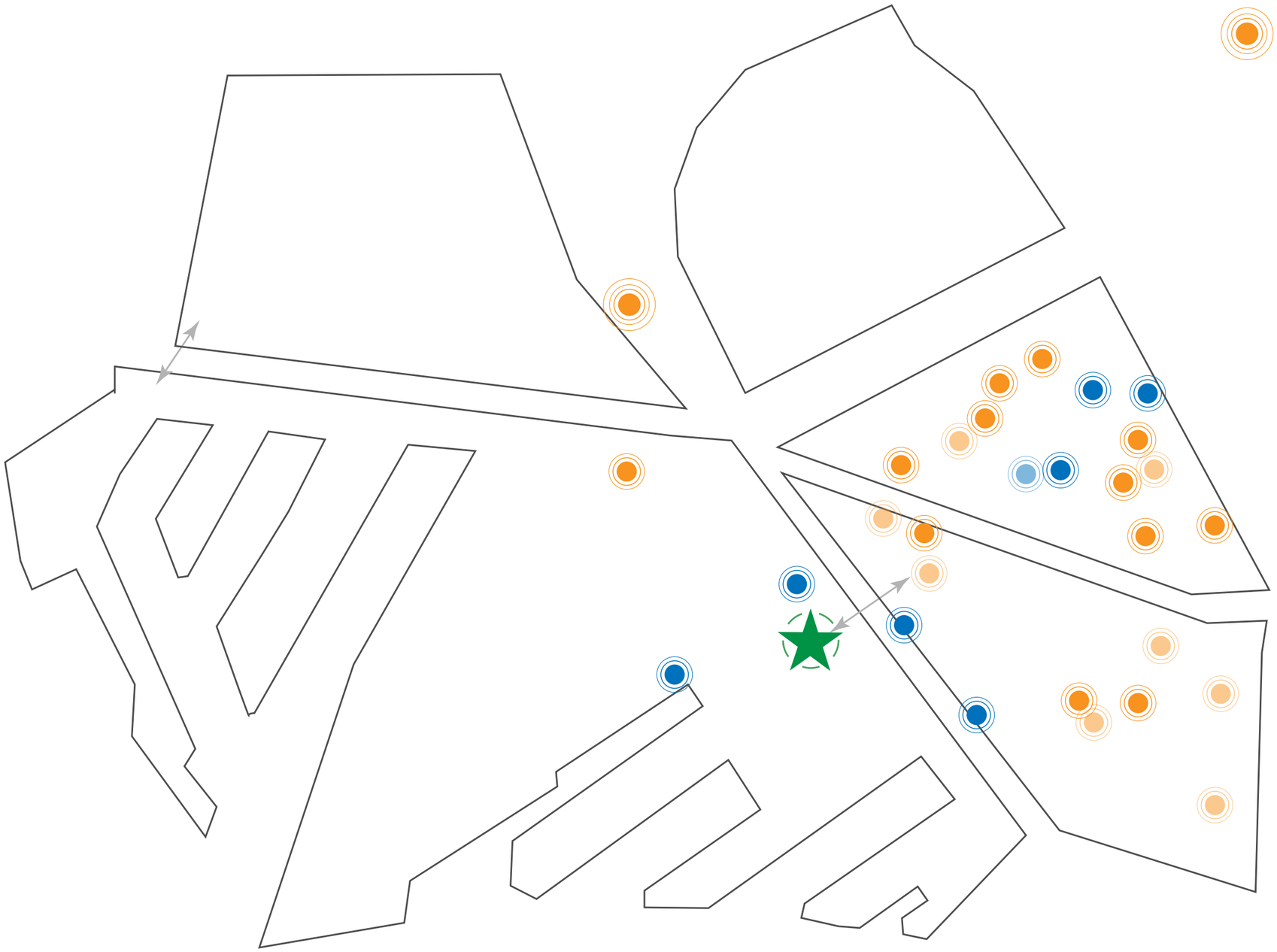


PCM Floor heating

** most relevant i.c.w. housing renovations*

Phased implementation of production + awareness by education

Places of productions of any scale



Pre-factory stage

1 Educational

Squares

Schools

Children farm + public garden

2 Workshop

Market stand

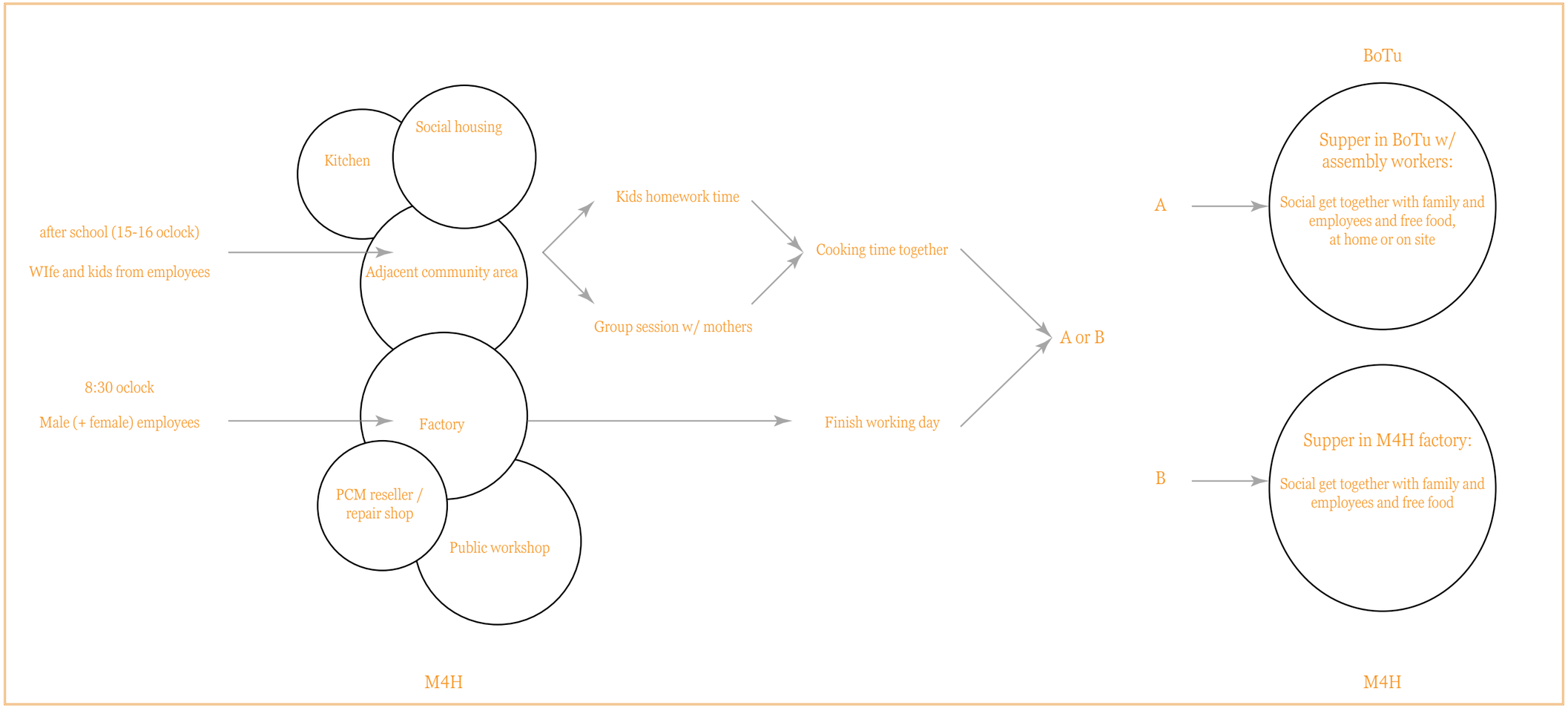
Various (participation) projects

Factory stage

Factory

More than a factory

Additional program



3 Stages of emancipation

Variation of skills, people and locations

Pre-factory

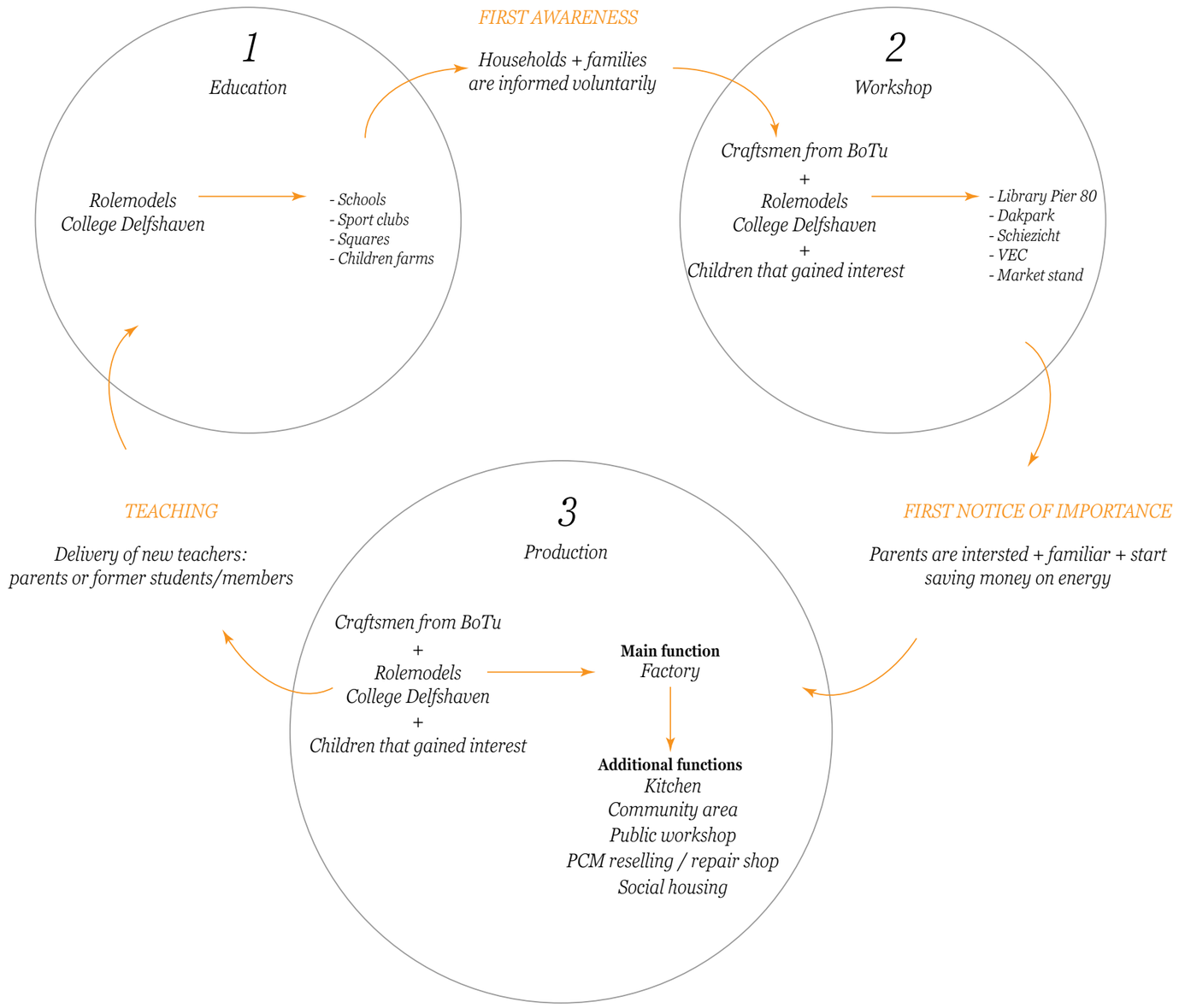
Factory

Post-factory

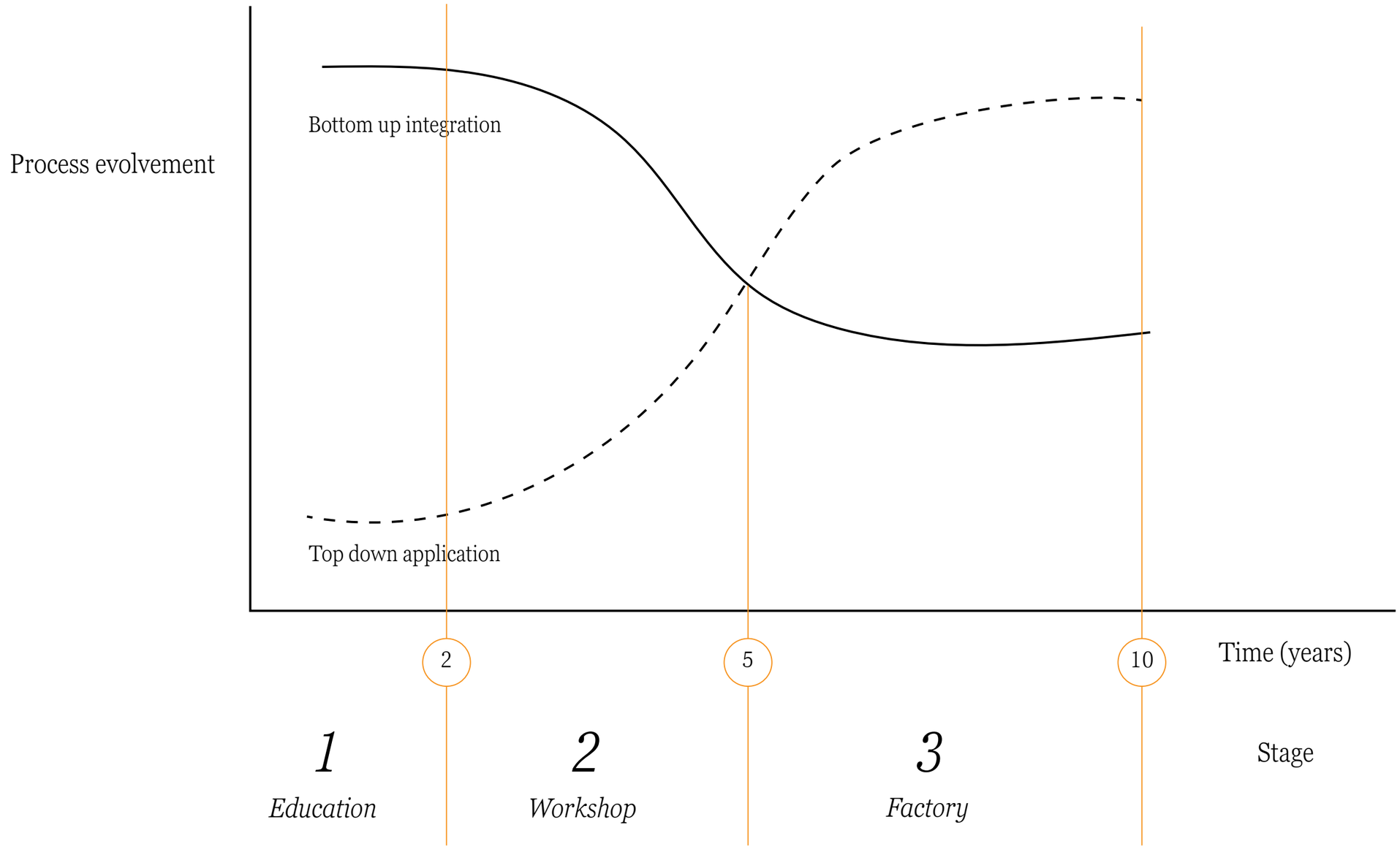
	Social durability	*Phase*	*Functions*	*Reward / attractivity*
A	*New generation*	**Pre-factory**	*Education (on site)* *Workshops (on site)*	*New skills* *Take-home PCM gadgets*
B	*All people*	**Factory phase**	*Kitchen* *Community area* *Public workshop* *PCM reselling / repair shop*	*Free food* *Free guidance / assistance / counselling* *Cheap workshop* *Cheap re-use or upgrading of existing module*
C	*Diversity of jobs*	**Factory + post factory phase**	*PCM factory:* *PCM filtering + mixing* *Plastic capsule production* *Carpentry* *Social housing*	*Salary* *Career potentials* *Free nights for X amount of S/M scale PCM modules* *Cheap new house for leading employees*

Phase description

Variation of skills, people and locations



Timeline


Process evolvement
Bottom up integration
Top down application
2
5
10
Time (years)
1
Education
2
Workshop
3
Factory
Stage

PCM renovation application

Calculation amount of PCM for complete cooling load
Gijsingflat renovations in BoTu

1 or 2 kg / m³ GFA

1 kg = energy level A / B
2 kg = energy level < C

Study of dwelling in Gijsingflats:

Surface *= 63 m² GFA*
Ceiling height (est.) *= 2.7 m*
Volume total *= 170.1 m³*

Ambitions of renovating uptill label A
Thus 1 kg PCM per m³
170,1 kg PCM needs to be integrated.

Rule of thumb for surface application:

Apply 10 kg/m2 because
60% of ceiling is available (office)
70 - 90 % ceiling available for dwellings
Desired actual amount is 7 kg/m² for whole surface

Hydrated salts
LHC *= 190 - 200 J/g*
Density *= 1500 kg/m3*

Frying oil
LHC *= 170 J/g*
Density *= 1000 kg/m3*

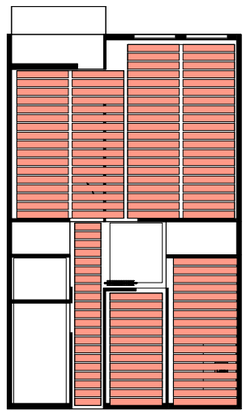
multiply for same efficiency
LHC *= 1.17*
Density *= 1.5*

170,1 kg PCM needs to be integrated
170*1.5*1.17 = 300 kg PCM
7 kg / m2 for 300 kg PCM

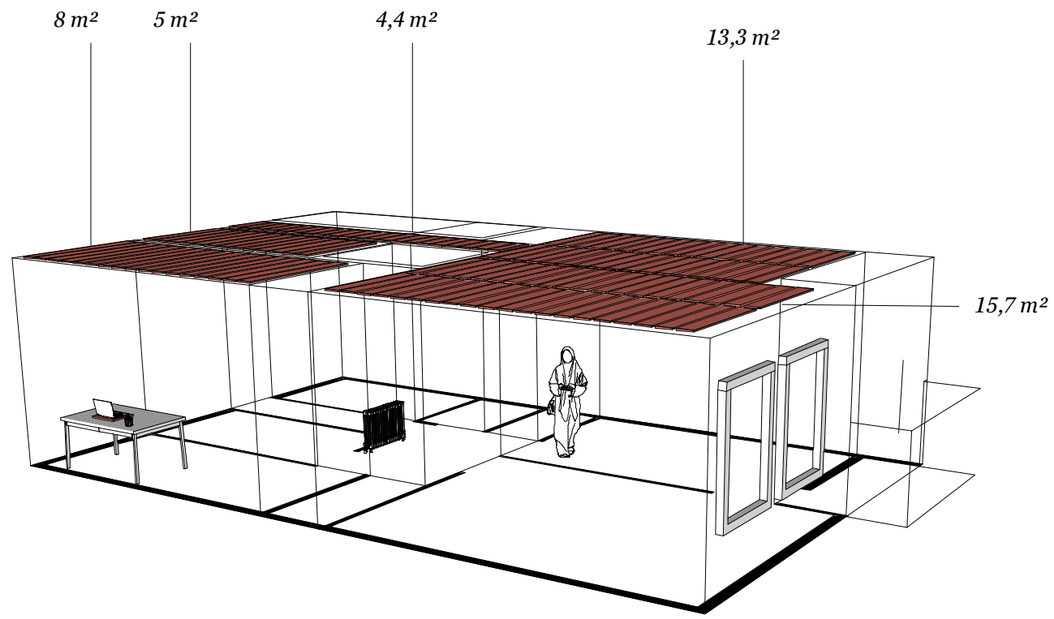
44 m² PCM (10 kg/m²)

Sources: *http://phasechange.com.au/product* + *PCMTechnology (Gerard Oortman)*

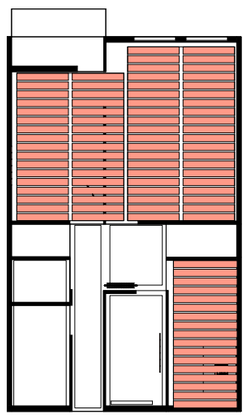
A



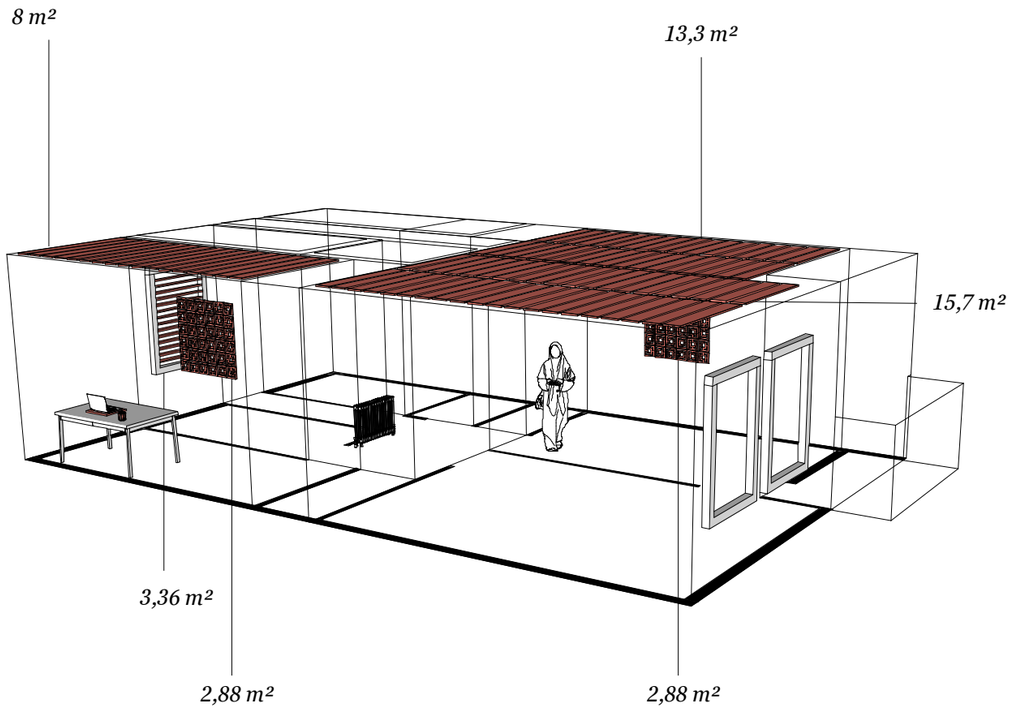
Total of 46 m²

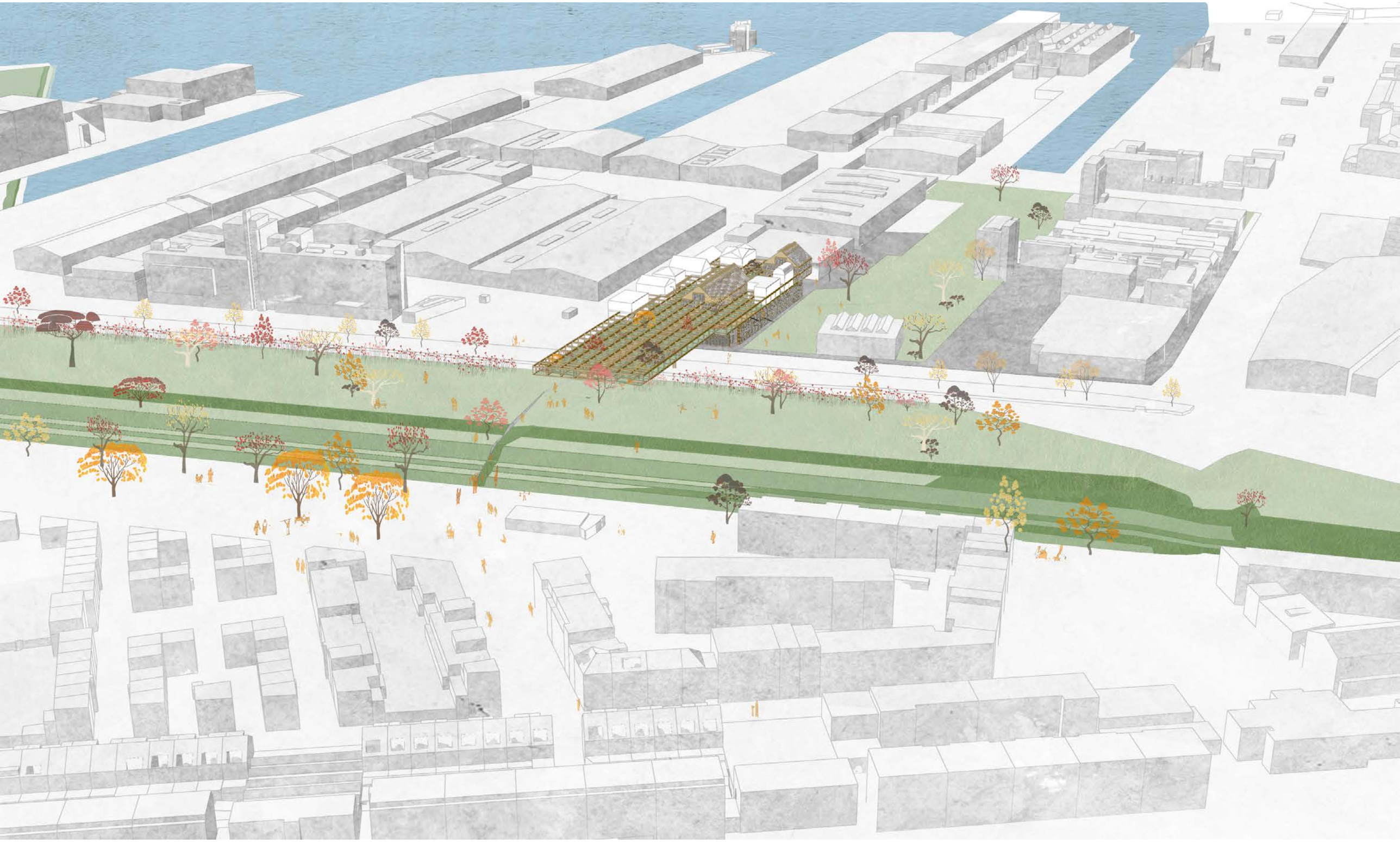


B



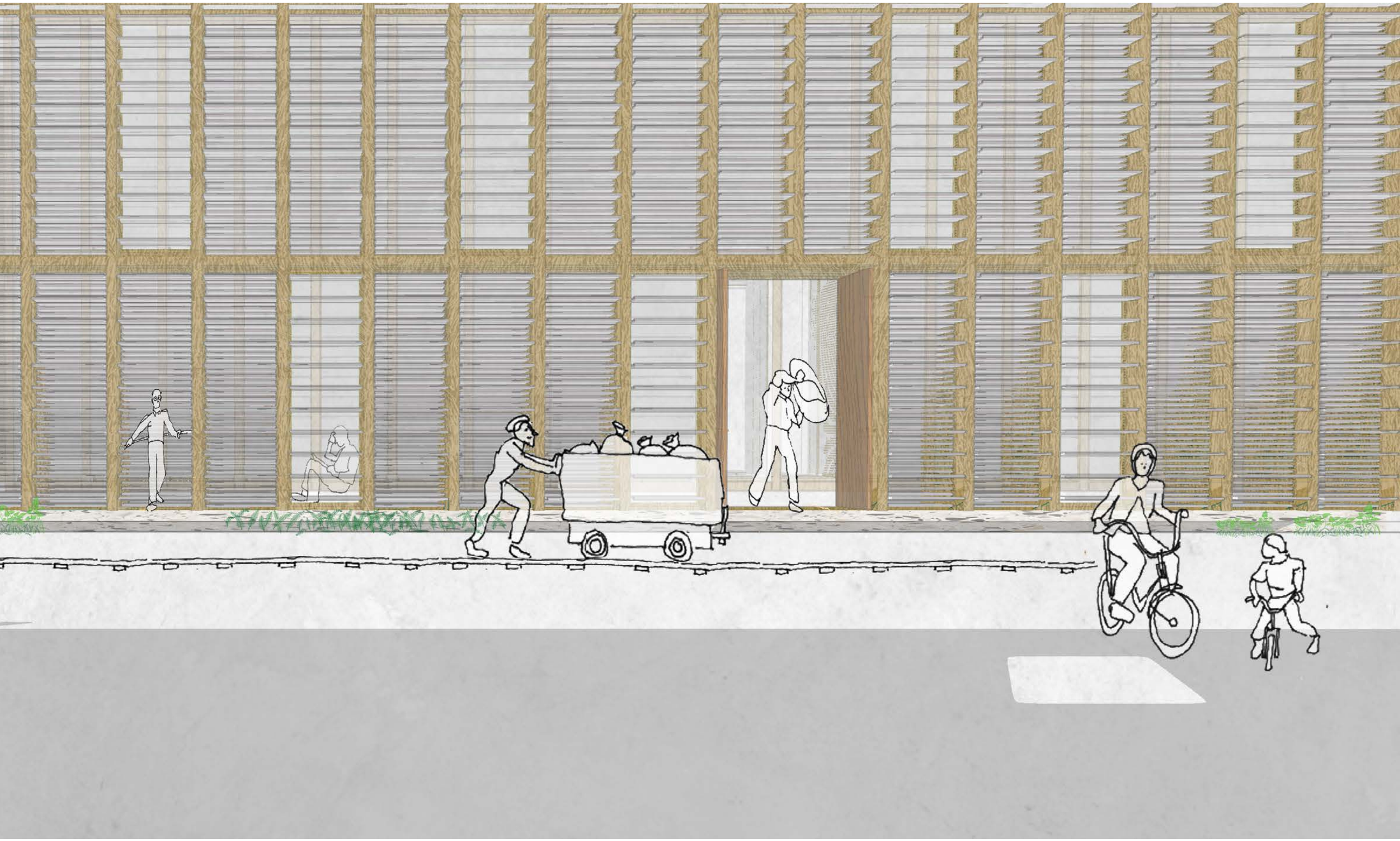
Total of 45,72 m²



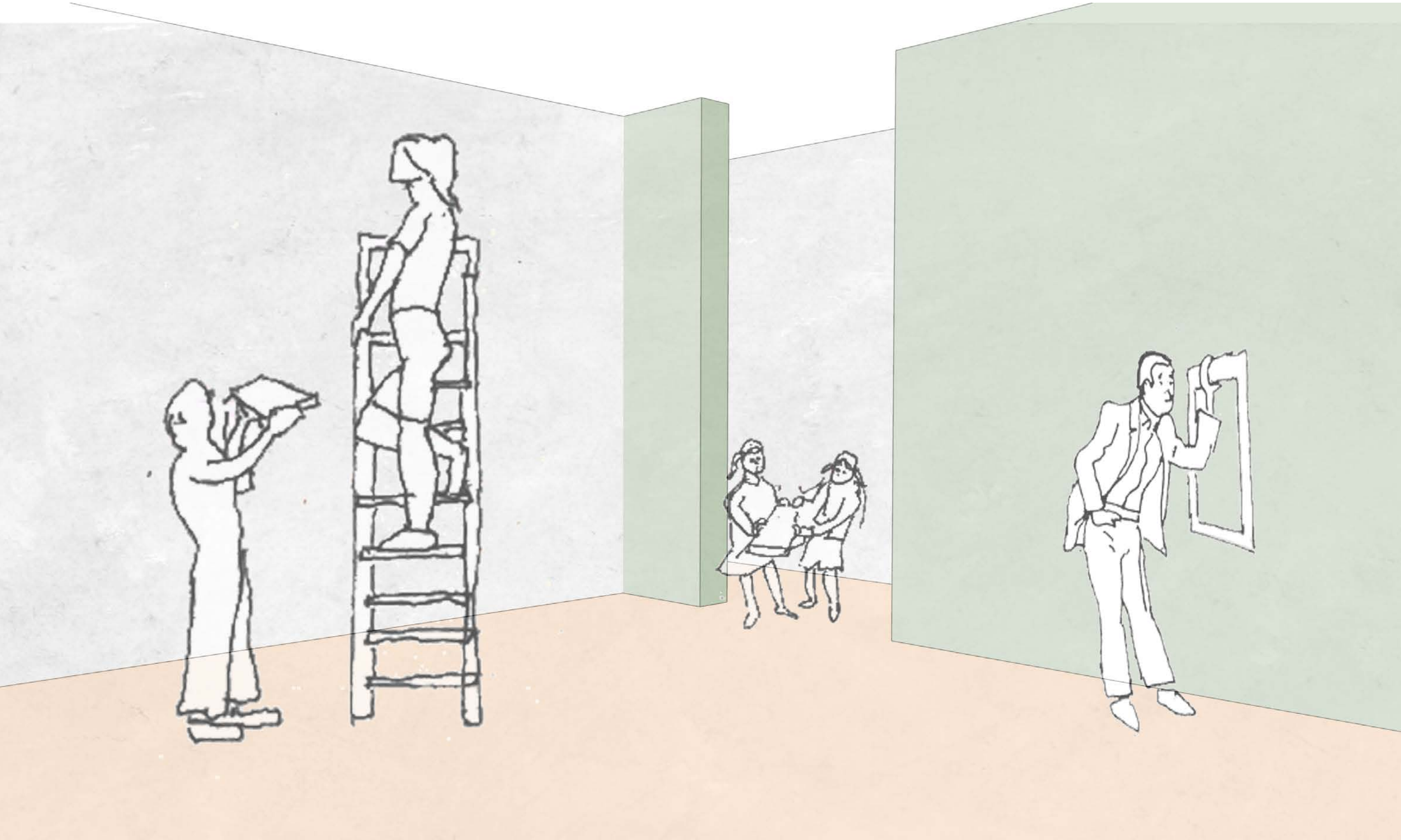


Birdview from BoTu

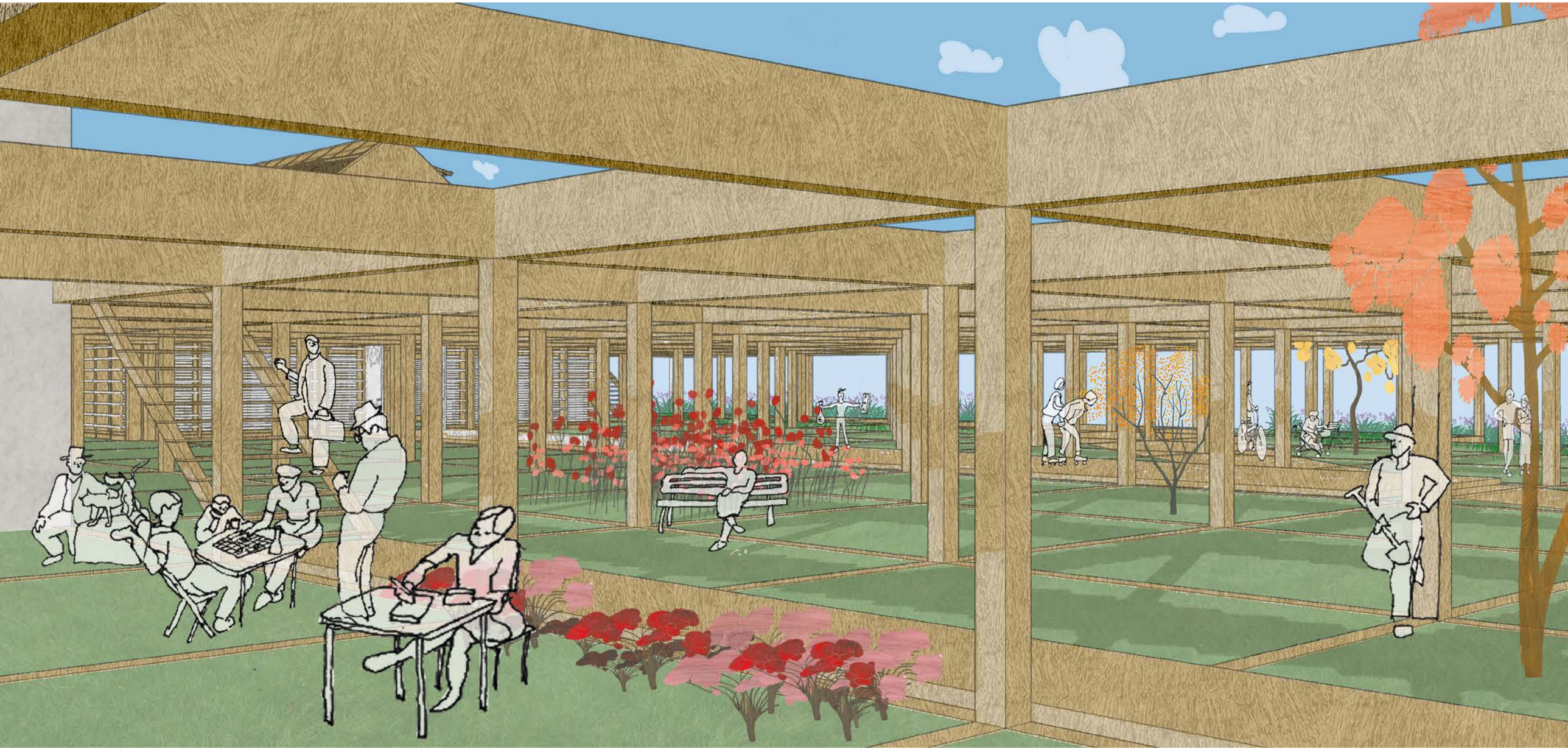
Factory



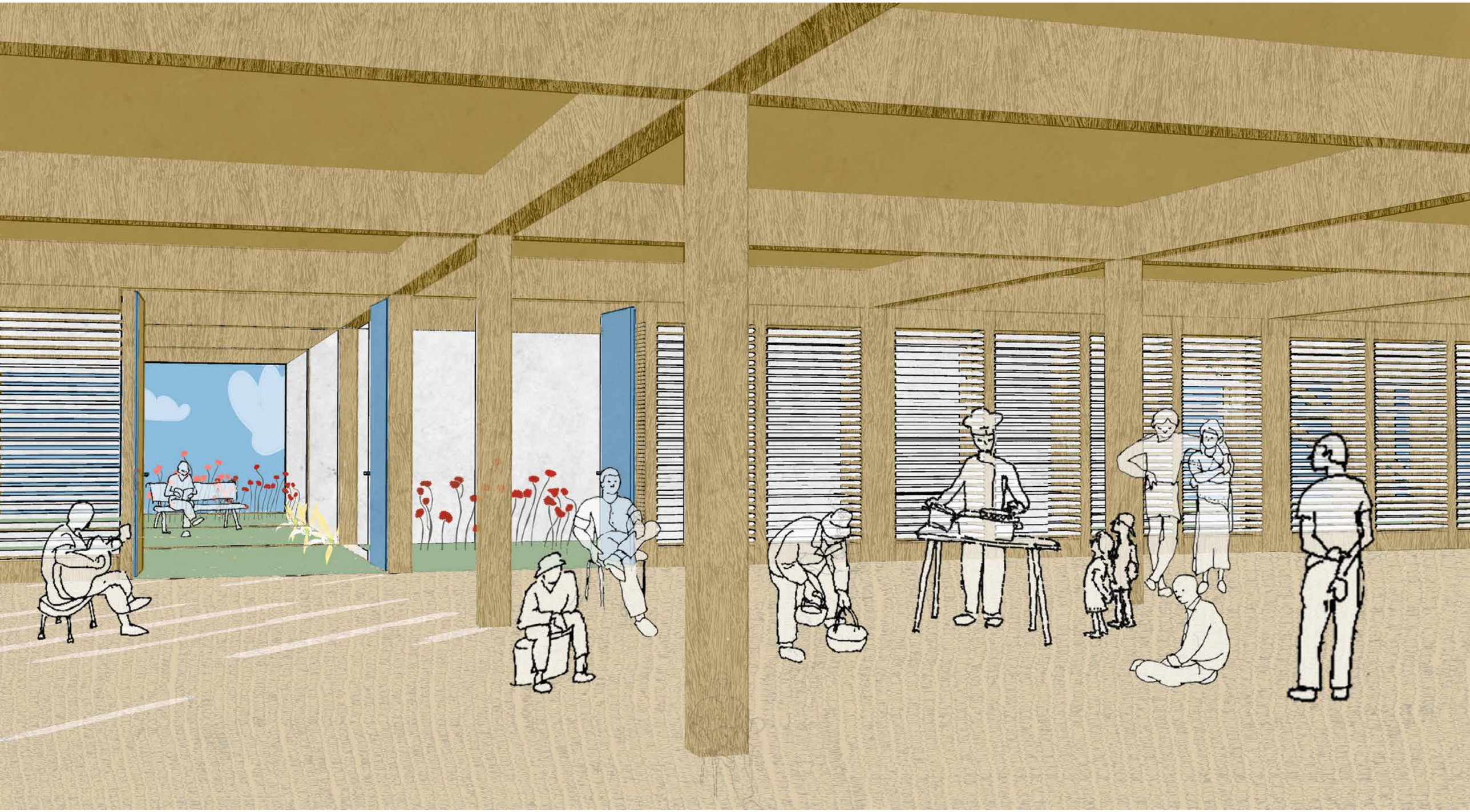
Mg2+ and frying oil supply by boat and train track



Renovation at the neighbours



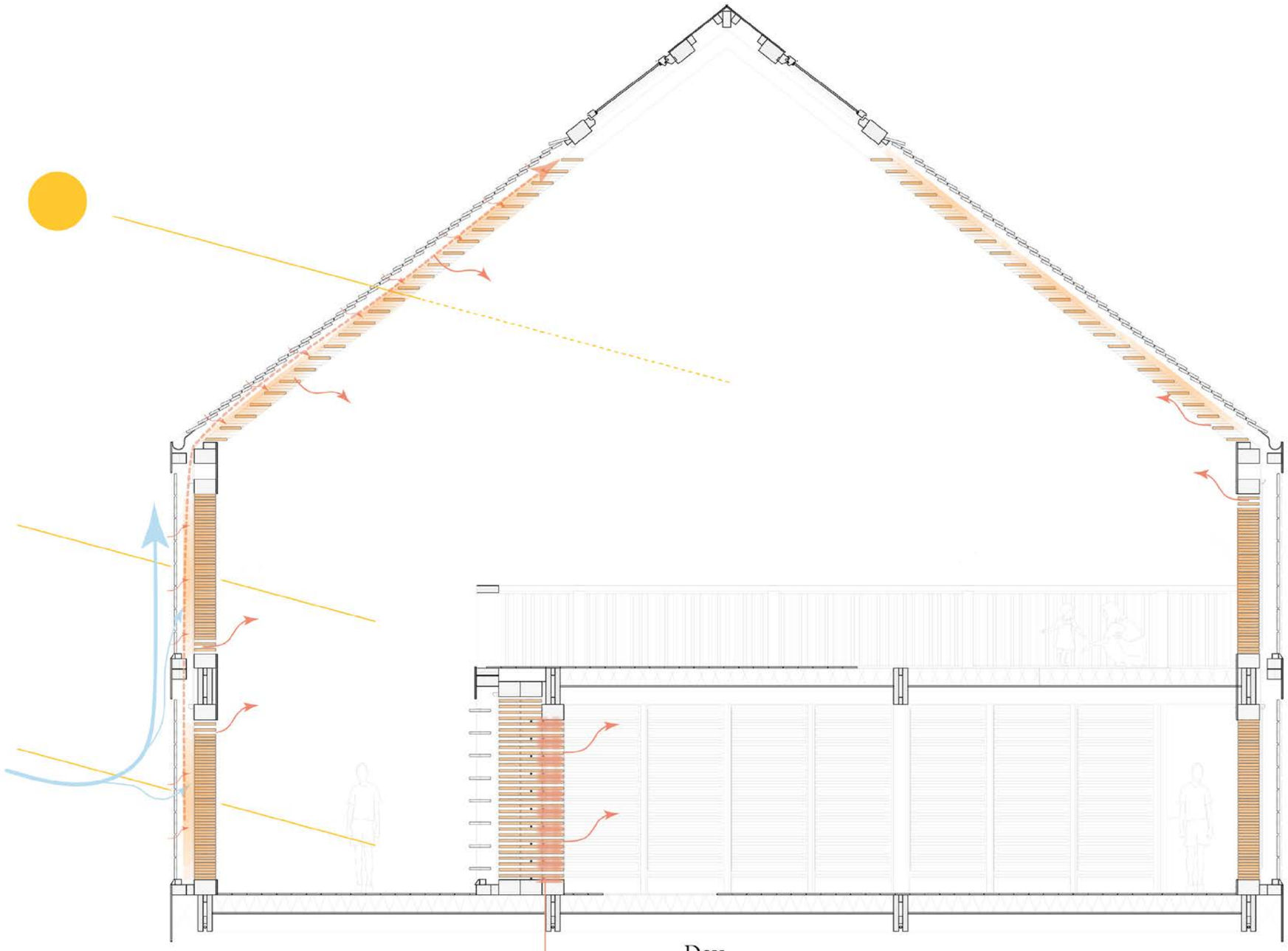
Vakpark



Workshop PCM making in the community centre

Climate

WINTER DAY

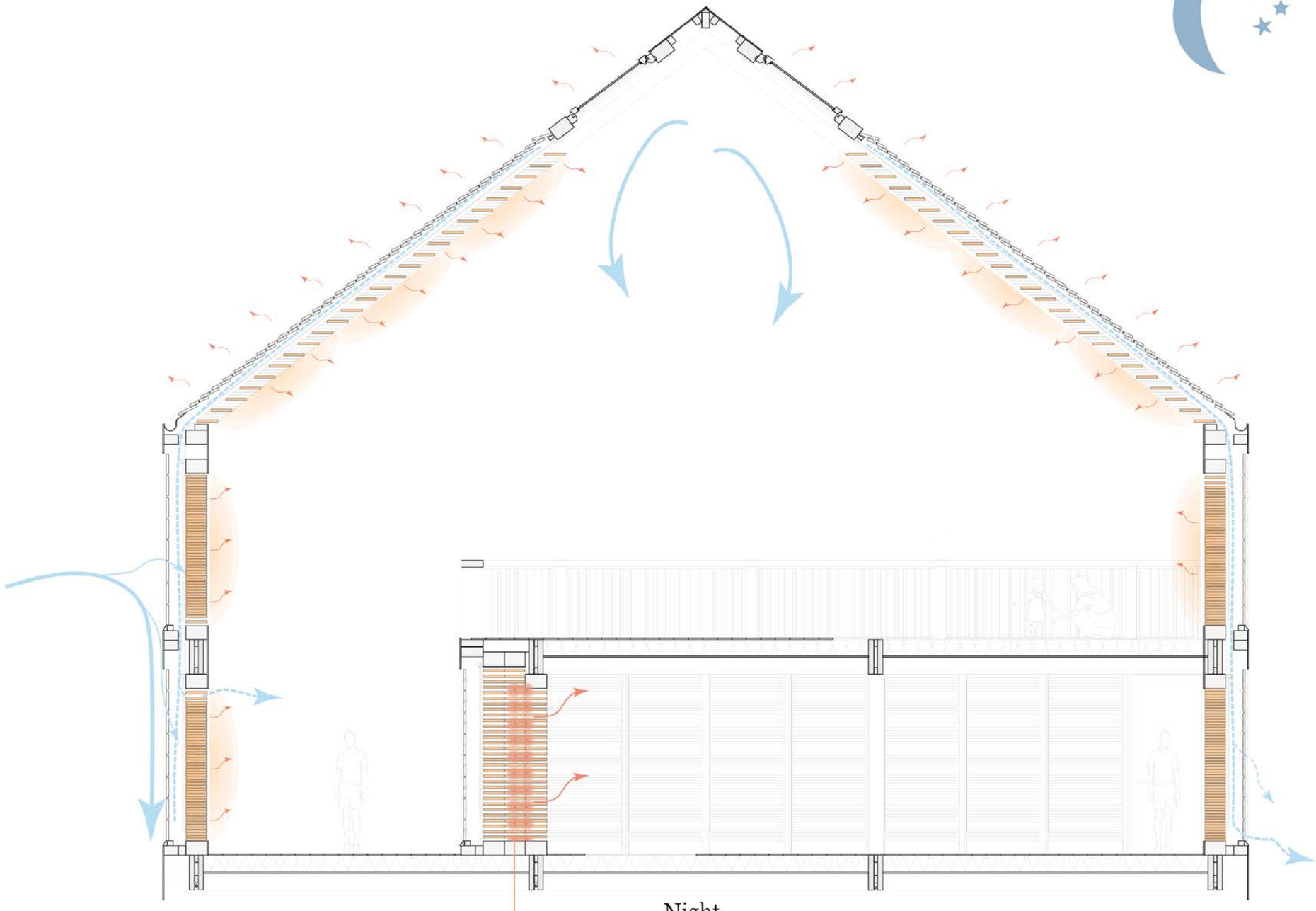


Day

T_outside	*0 °C*
T_cavity	*0 - 8 °C*
T_inside, summer zone	*8 - 15 °C*
T_inside, winter core	*18 - 21 °C*
Sun hours	*1.8*
Sun angle	*14° min.*
Solar irradiance	*527 W/m²*

PCM function	*Heat storage by sun and cavity heating*
T_PCM wall	*T15 - T17*
T_PCM roof	*T15 - T17*
T_PCM winter core	*T21 - T23*
Curtain_wall, summer membrane	*Open: allowing PCM to store solar irradiance*
Curtain_wall, winter membrane	*Closed: avoiding losses by reflecting interior heat*
Curtain_roof	*Open: allowing PCM to store solar irradiance*
Factory heating supply	*Active*

WINTER NIGHT

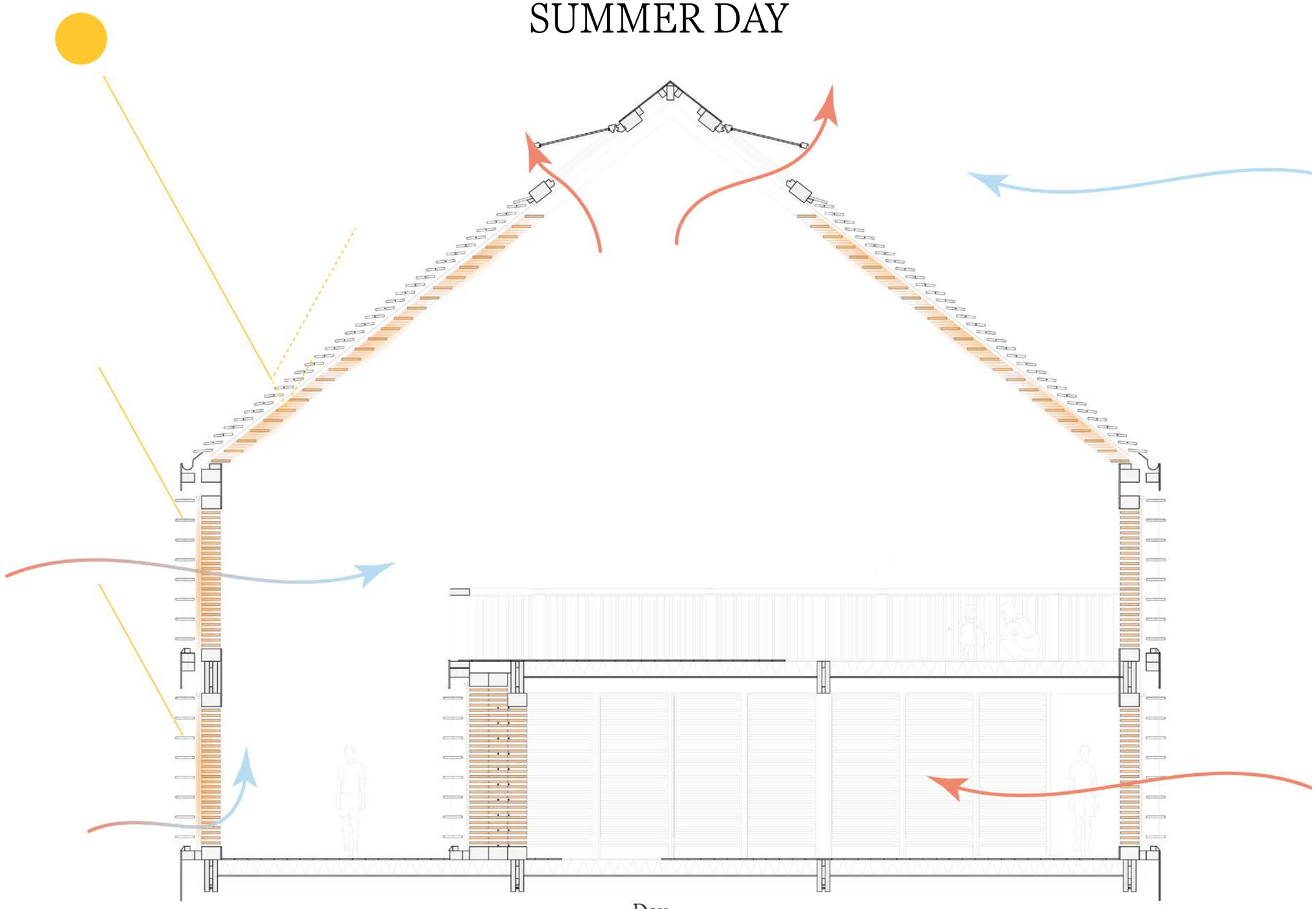


Night

T_outside	*-10 °C*
T_cavity	*-10 °C*
T_inside, summer zone	*0 - 8 °C*
T_inside, winter core	*18 - 21 °C*
Sun hours	*0*
Sun angle	-
Solar irradiance	-

PCM function	*Charging for daytime: exposing thermal energy by night ventilation*
T_PCM wall	*T15 - T17*
T_PCM roof	*T15 - T17*
T_PCM winter core	*T21 - T23*
Curtain_wall, summer membrane	*Closed: avoiding losses by reflecting interior heat*
Curtain_wall, winter membrane	*Closed: avoiding losses by reflecting interior heat*
Curtain_roof	*Closed: avoiding losses by reflecting interior heat*
Factory heating supply	*Active*

SUMMER DAY

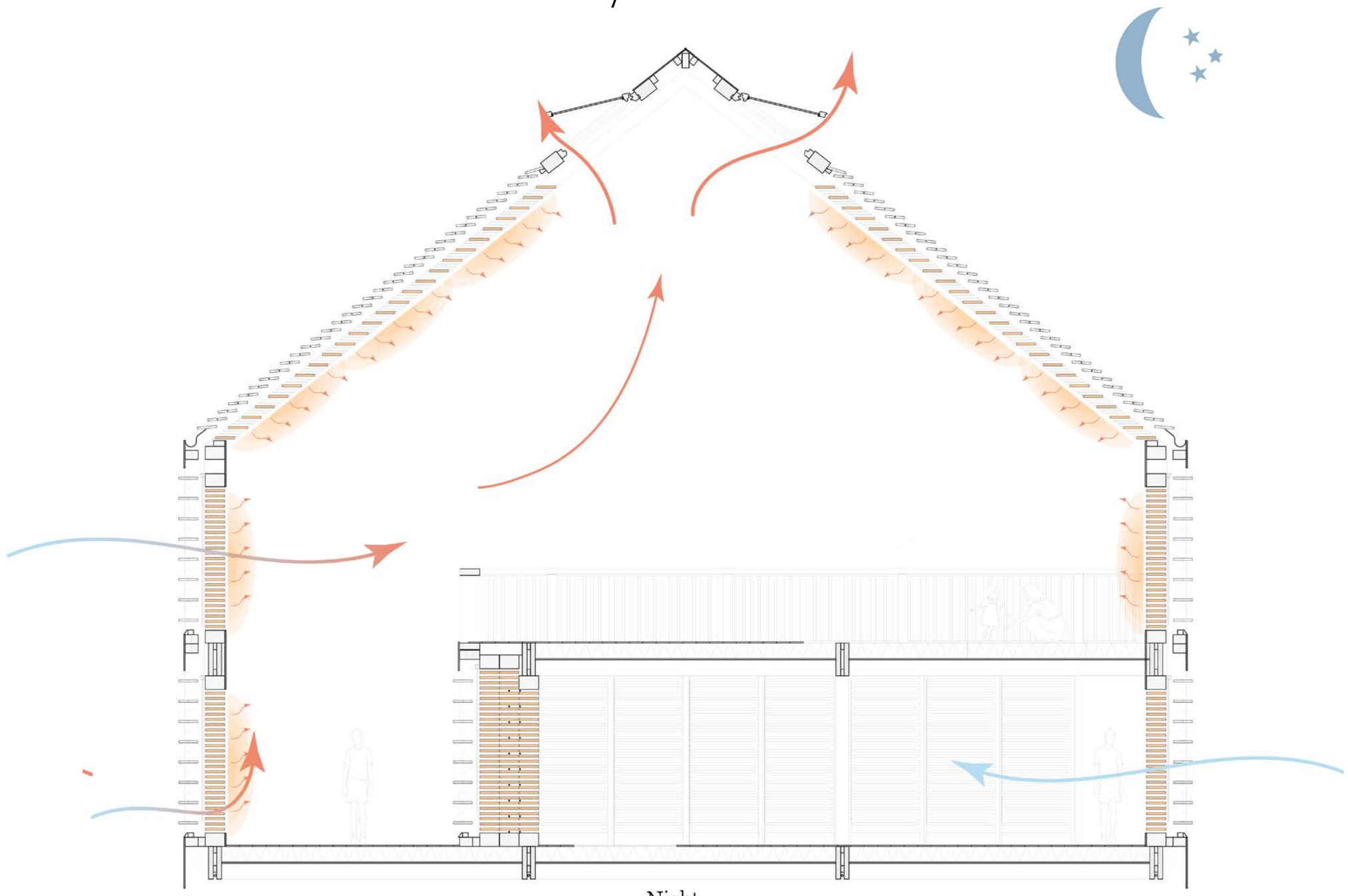


Day

T_outside	*30 °C*
T_cavity	*30 °C*
T_inside, summer zone	*25 - 30 °C*
T_inside, winter core	*18 - 25 °C*
Sun hours	*6.3*
Sun angle	*61° max.*
Solar irradiance	*755 W/m²*

PCM function	*Heat buffer (e.g. as 'evaporative' - now meltive or endothermic - cooling)*
T_PCM wall	*T28*
T_PCM roof	*T28*
T_PCM winter core	*T21 - T23*
Curtain_wall, summer membrane	*Open: maximum ventilation*
Curtain_wall, winter membrane	*Closed: reflecting heat but allowing ventilation*
Curtain_roof	*Closed: reflecting heat but allowing ventilation*
Factory heating supply	*Only in cold nights*

AUTUMN / SPRING NIGHT

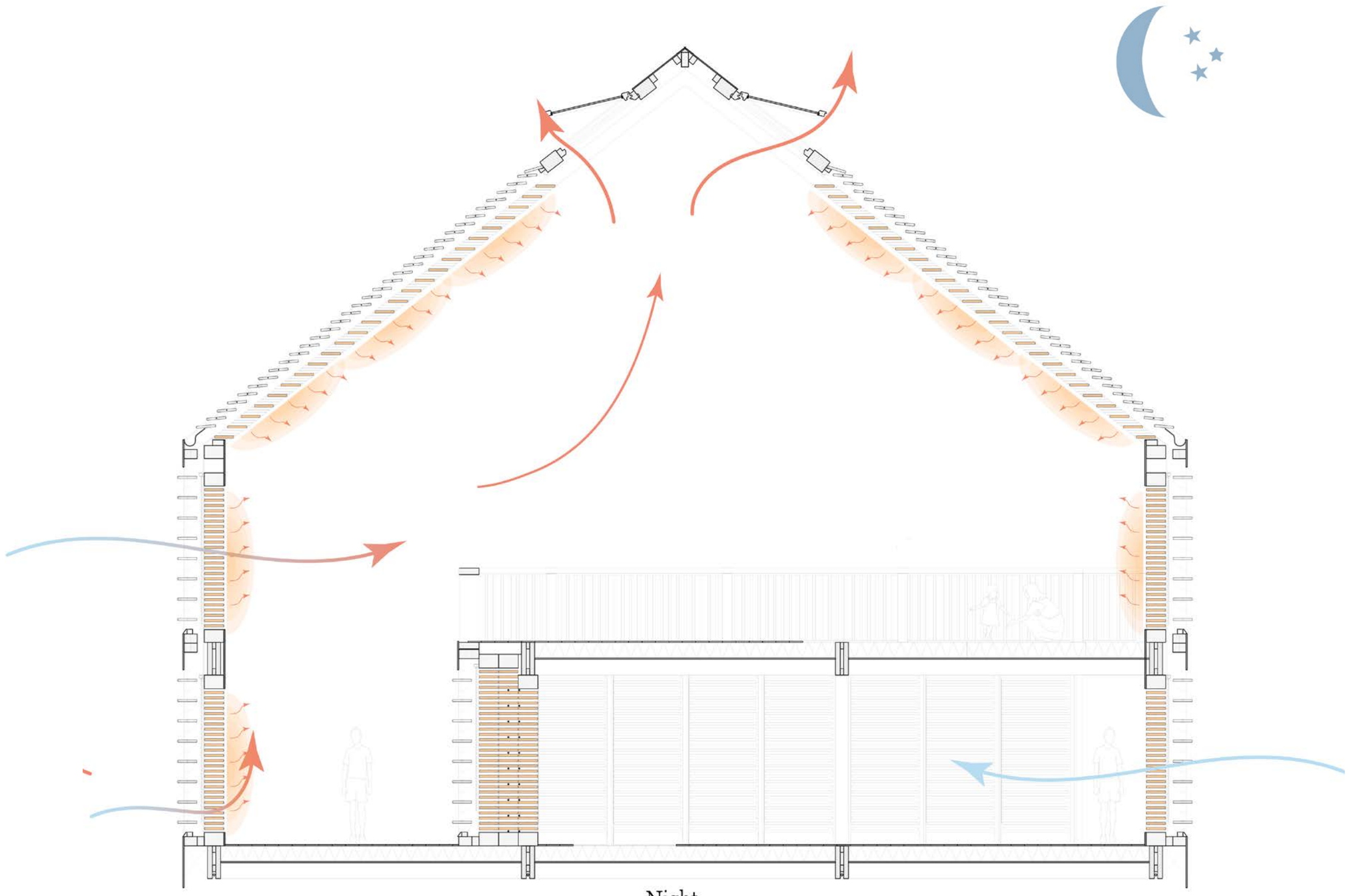


Night

T_outside	*25 °C*
T_cavity	*25 °C*
T_inside, summer zone	*30 - 25 °C*
T_inside, winter core	*18 - 25 °C*
Sun hours	*0*
Sun angle	-
Solar irradiance	-

PCM function	*Charging for daytime: exposing thermal energy by night ventilation*
T_PCM wall	*T28*
T_PCM roof	*T28*
T_PCM winter core	*T21 - T23*
Curtain_wall, summer membrane	*Open: maximum ventilation*
Curtain_wall, winter membrane	*Closed: reflecting heat but allowing ventilation*
Curtain_roof	*Open: maximum ventilation*
Factory heating supply	*Only in cold nights*

SUMMER NIGHT

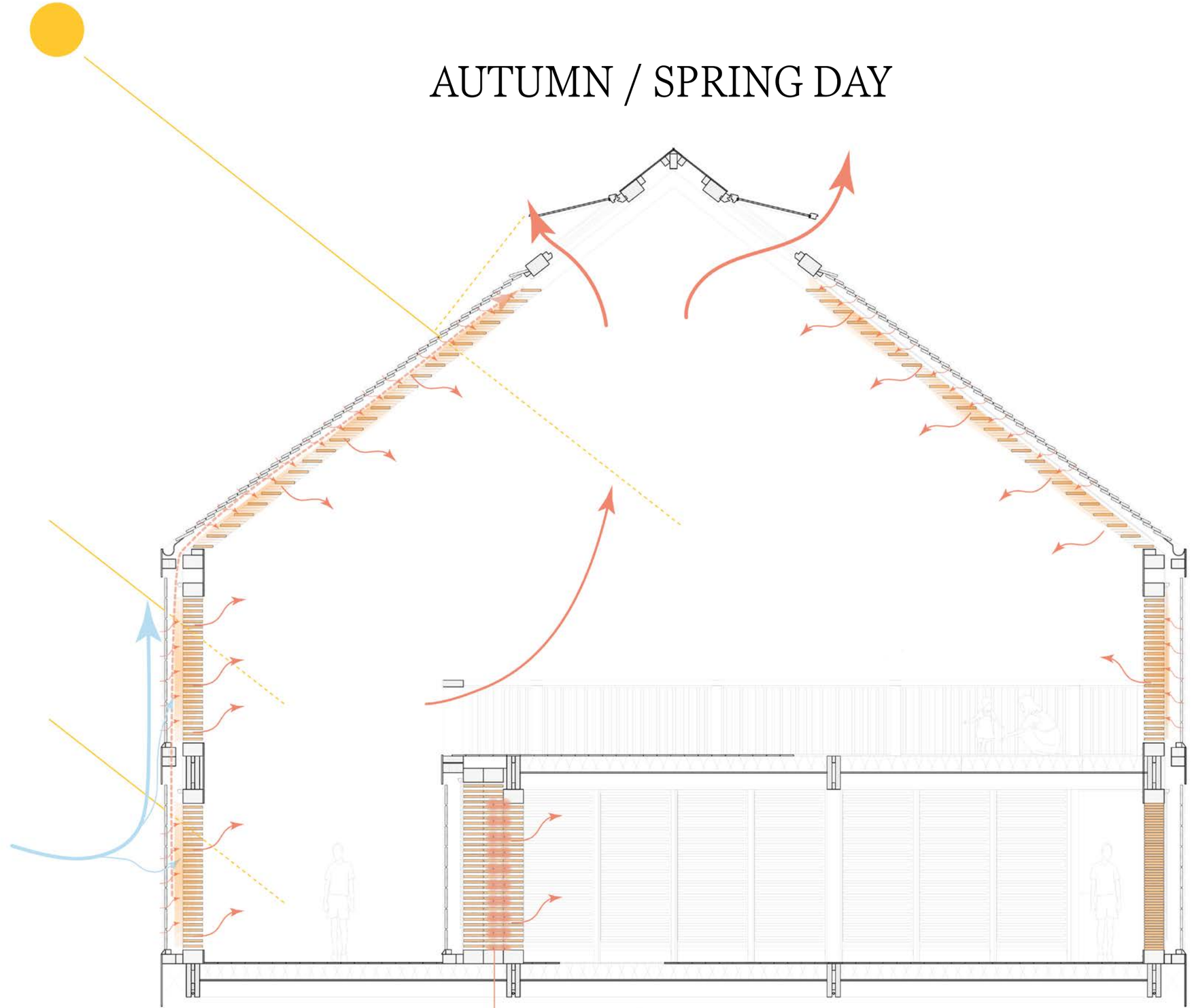


Night

T_outside	*25 °C*
T_cavity	*25 °C*
T_inside, summer zone	*30 - 25 °C*
T_inside, winter core	*18 - 25 °C*
Sun hours	*0*
Sun angle	-
Solar irradiance	-

PCM function	*Charging for daytime: exposing thermal energy by night ventilation*
T_PCM wall	*T28*
T_PCM roof	*T28*
T_PCM winter core	*T21 - T23*
Curtain_wall, summer membrane	*Open: maximum ventilation*
Curtain_wall, winter membrane	*Closed: reflecting heat but allowing ventilation*
Curtain_roof	*Open: maximum ventilation*
Factory heating supply	*Only in cold nights*

AUTUMN / SPRING DAY



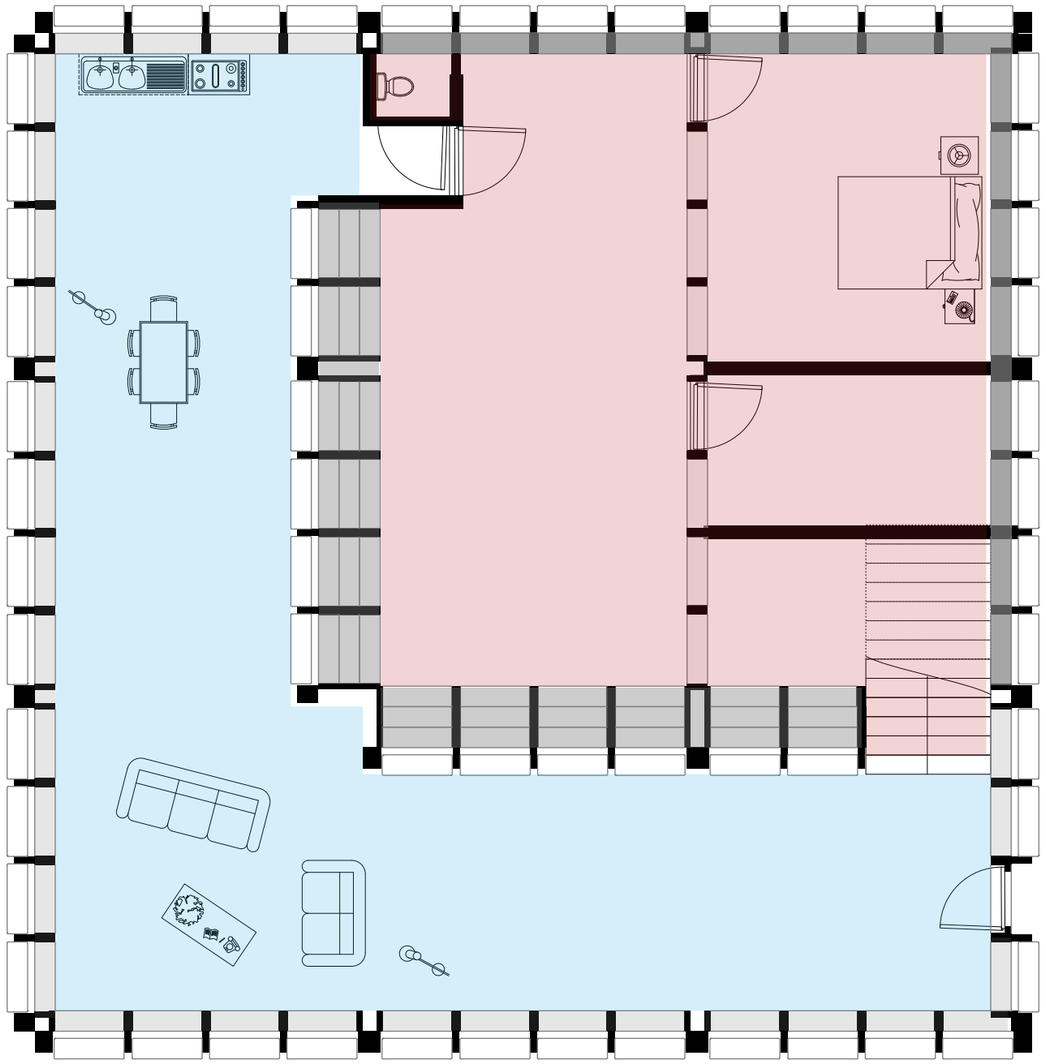
Day

T_outside	*13 °C*
T_cavity	*15 - 20 °C*
T_inside, summer zone	*15 - 23 °C*
T_inside, winter core	*18 - 25 °C*
Sun hours	*4.2*
Sun angle	*38 ° max.*
Solar irradiance	*638 W/m²*

PCM function	*Heat storage by sun and cavity heating*
T_PCM wall	*T23*
T_PCM roof	*T28*
T_PCM winter core	*T21 - T23*
Curtain_wall, summer membrane	*Open: allowing PCM to store solar irradiance*
Curtain_wall, winter membrane	*Closed: ensuring maximum room separation*
Curtain_roof	*Open: allowing PCM to store solar irradiance*
Factory heating supply	*Only for day time occupation*

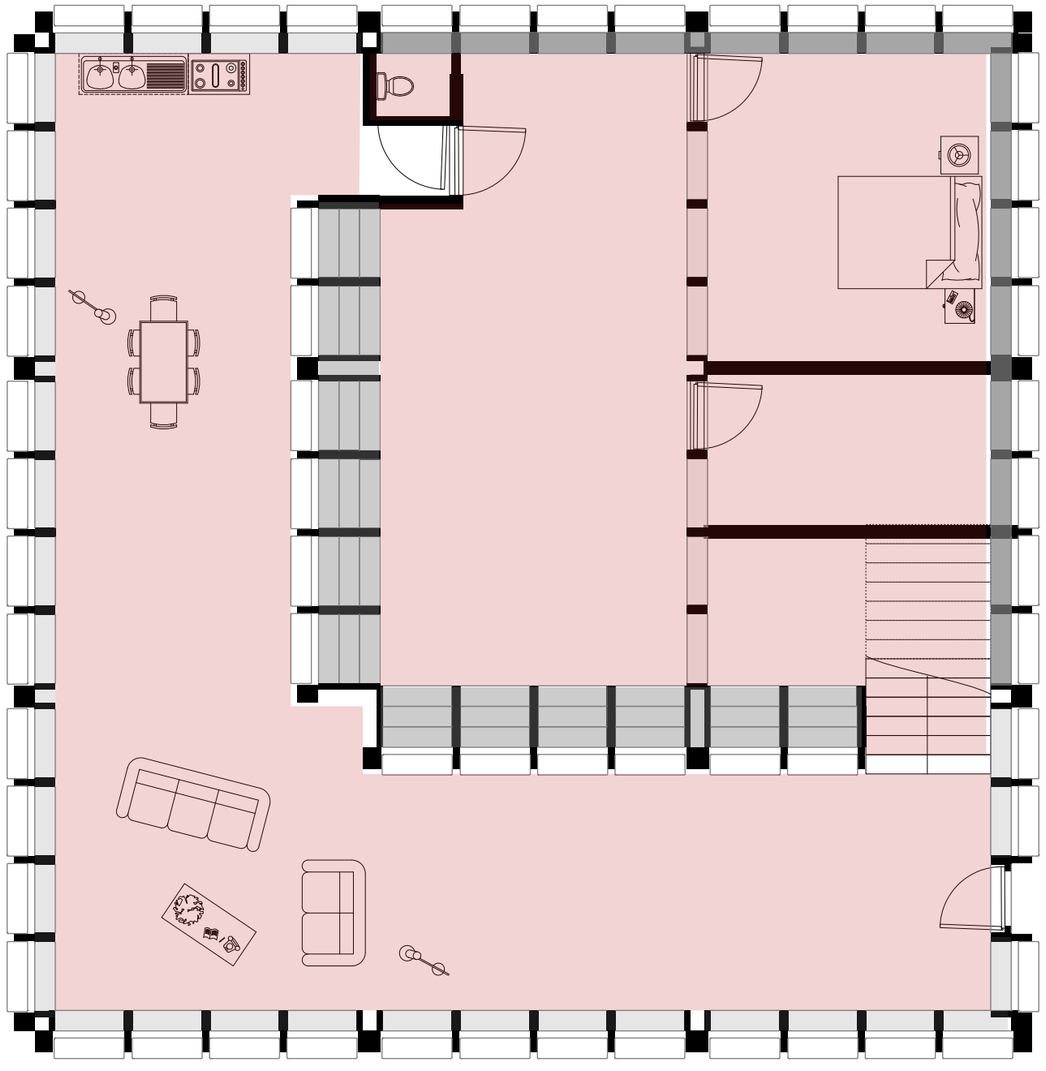
PCM DWELLING

Winter

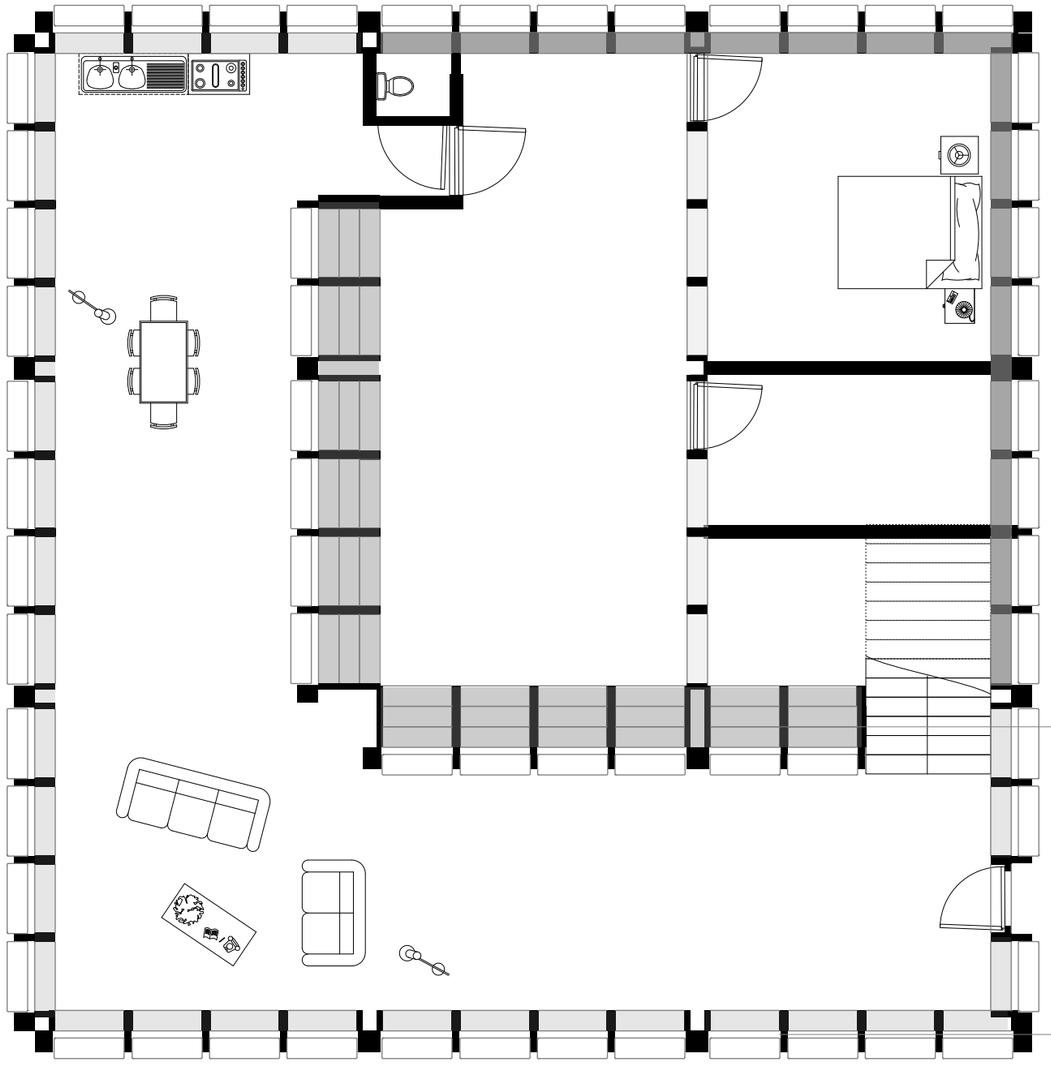


PCM DWELLING

Summer



PCM DWELLING



FACTORY

COMMUNITY CENTRE

BoTu 2.0

8 hours / day

261 days / year

Factory

Heating of the oil

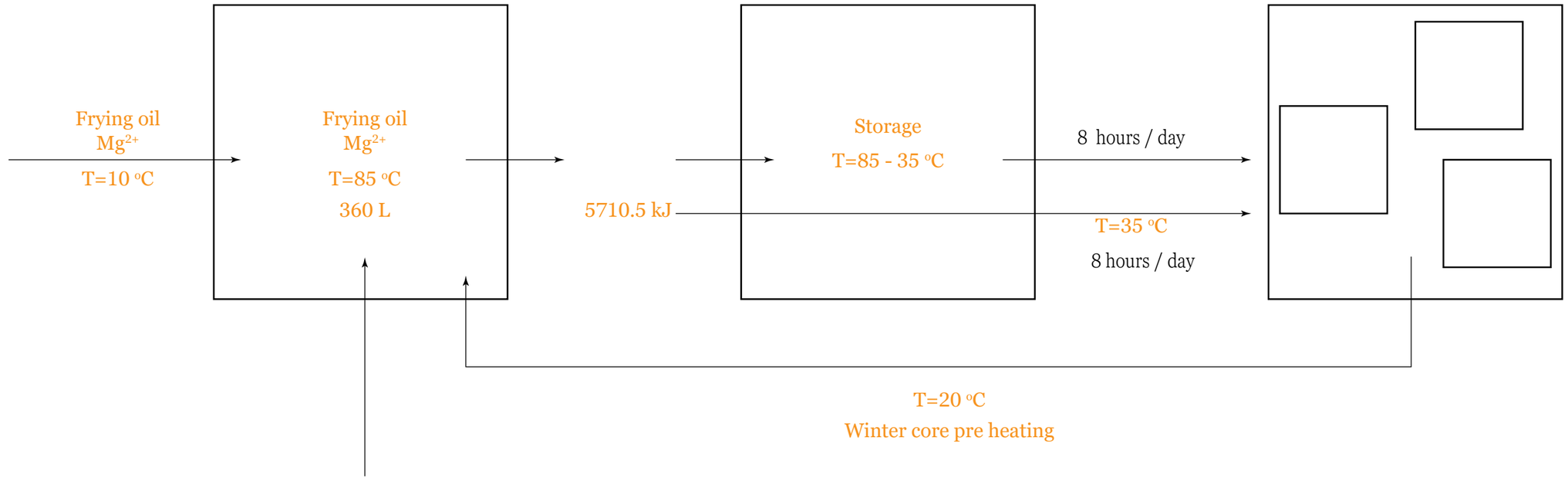
8 hours / day

Battery

16 hours / day

365 days / year

PCM Dwellings



FACTORY

PCM HEATING

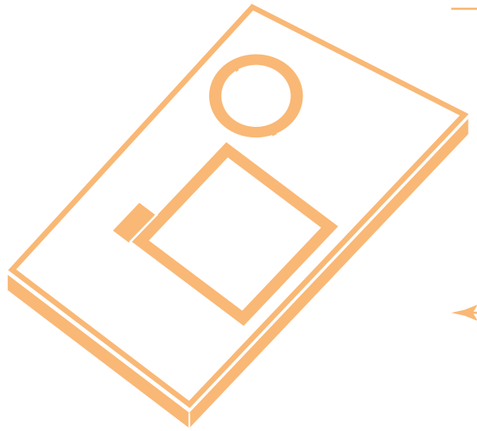
COMMUNITY CENTRE

PCM BATTERY

BoTu 2.0

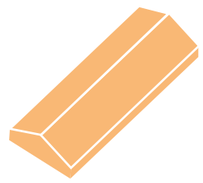
PCM CLIMATISATION

thermal energy



Resources: oil

thermal energy



Resources: oil

FACTORY

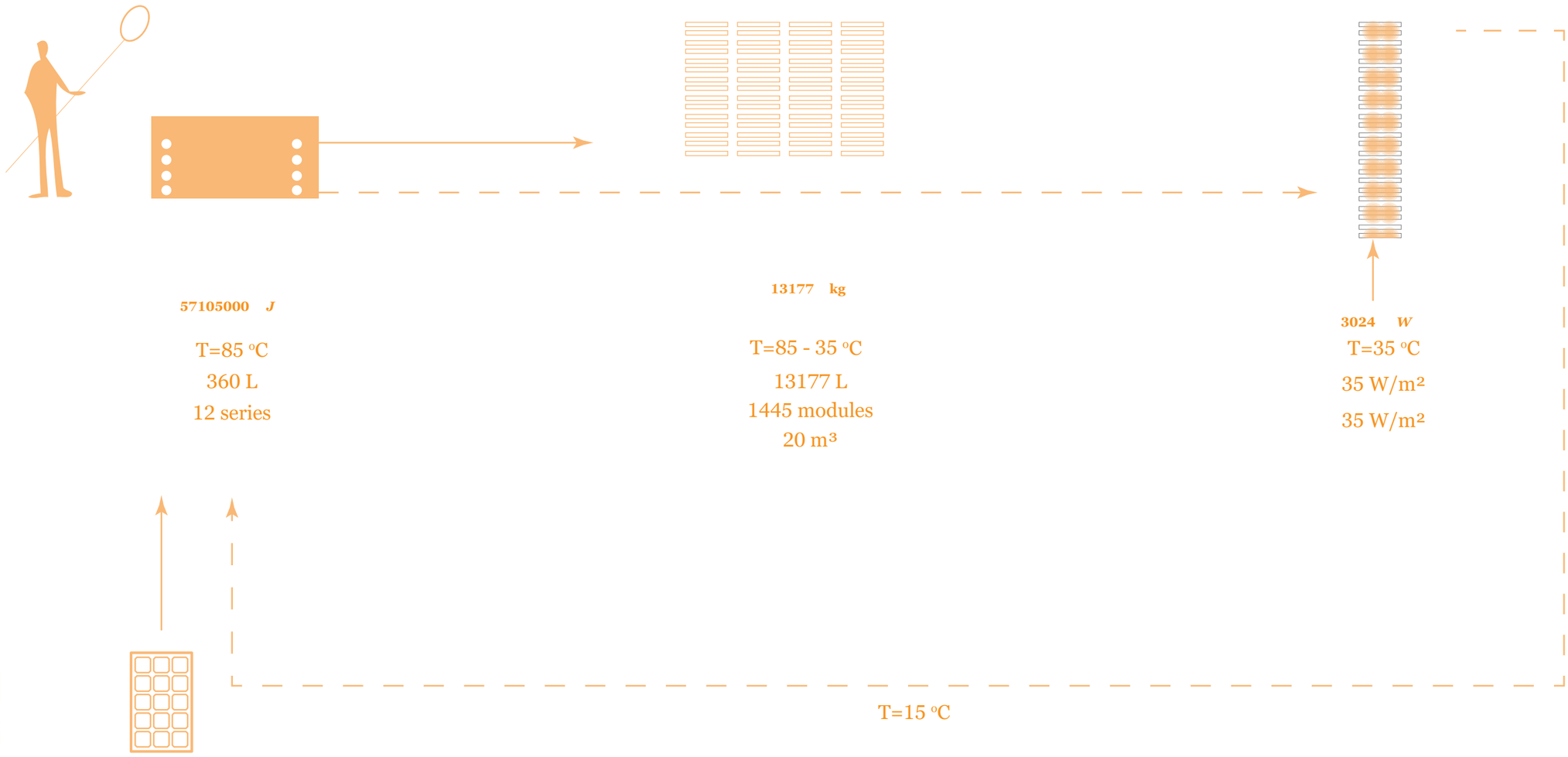
PRODUCTION

COMMUNITY CENTRE

STORAGE

BoTu 2.0

CONSUMPTION



57105000 *J*

T=85 °C

360 L

12 series

13177 *kg*

T=85 - 35 °C

13177 L

1445 modules

20 m³

3024 *W*

T=35 °C

35 W/m²

35 W/m²

T=15 °C

Frying oil

Mg^{2+}

T=10 °C

64 PV panels

130 kWh / panel / jaar

Matthijs van Mulligen

Calculation PCM distribution system:

Heat production factory, storage capacity PCM battery and thermal energy demand BoTu 2.0 PCM dwellings

PCM properties	Soortelijk gewicht frituurvet	1000	kg/m³		
	Soortelijke warmte frying oil (matrix source 21)	2115	*J/(kgK)*		
	Soortelijke warmte frying oil Standaard	1670	*J/(kgK)*		
	Vet voor benidigd renovatie 60m²	170.1	*kg*		
PCM factory process	Gewicht voor verwarming (batch)	360	*kg*		
	Volume	360	*L*		
	Temperature after heating (outpout)	85	*C*		
	Temperature before heating (input / arrival)	10	*C*		
	Delta T verwarmen	75	*K*		
	Warmteproductie per batch	**57105000**	***J***	*E = m c (delta) T*	E = 360 [kg] x 2115 [J/(kgK)] x 75 [K]
57105000 J	Inductieplaat	4000	*W*		
	Tijd verwarmen	14276.25	*s*		
	Minuten	237.9375	*min*		
	Uren	3.96	*h*		
PCM Dwelling	Heat demand standard dwelling (ref. floor heating)	35	*W/m²*		
	Size winter core	36	*m²*		
	Length of wall	6	*m*		
	Hight of wall	3.6	*m*		
	Wall surface	21.6	*m²*		m² = 6 [m] x 3.6 [m]
	Walls	4			
	Total wall surface	86.4	*m²*		
	Heat demand wall heating	**3024**	***W***		E = 35 [W/m²] x 86.4 [m²]
3024 W	Amount of dwellings BoTu 2.0	8			
	Operating time of heating	16	*h*		
	Operating time of heating	960	*min*		
	Operating time of heating	57600	*s*		
PCM BoTu 2.0	**Total heat demand BoTu 2.0**	**24192**	*W / day*		Total daily demand = 8 [dwellings] x 3024 [W]
		1393459200	*J / day*		
PCM factory process	Daily operating hours	8	*h*		
	Daily operating time	480	*min*		
	Daily operating time	28800	*s*		
	Batches per heating unit per day (series)	2			Batches / day = 3.96 [h] : 8 [h]
115200000 J	**Thermal energy production per series per day**	**115200000**	***J***		Energy production / serie = 2 [batches] x 57105000 [J]
	Required amount of batches per day	24.4	*/ dag*		Batches required for BoTu 2.0 demand = 1393459200 [J/day] : 57105000 [J]
	Required PCM heating volume	8785	*L*		Volume required for BoTu 2.0 demand = 24.4 [batches] x 360 [L]
	Equals amount of housing renovations (60m², 170,1 kg)	52	*renovations*		
	Required series (360L, 4000W)	12.1	*/ 8 hours*		Required heating series = 24.4 [batches] : 2 [batches/day]
PCM Battery	Storage capacity PCM battery	**1393459200**	*J / 8 hours*		*equal to demand BoTu2.0*
		48384	*W*		
13177 kg	**Required PCM mass**	**13177**	**kg**	*E = m c (delta) T*	E = 1393459200 [J] : (2115 [J/(kgK)] x 50 [K])
	PCM weight per panel	9.12	*kg*		
	Required PCM mdules	1445			
	Volume without contact surface for air/tubes	13.2	*m³*		
	Volume with contact surface, by factor:	19.8	*m³*		factor 1.5 -> ?
Spaceframe	Length	4.8	*m*		
	Width	4.8	*m*		
	Height	3.6	*m*		
	Volume 1 spaceframe square	82.9	*m³*		
	Battery occupance in 1 spaceframe square	**23.83**	**%**		
Electricity supply	Working days per year	261	*days*		
	Working hours per day	8	*h*		
	Induction units	12.1	*aantal*		
	Induction hours per year	2088	*h*		
	Power per induction unit	4000	*W*		
		8352000	*Wh*		
64 PV panels	**Annual required power**	**8352**	**kWh/jaar**		
	Solar panel 150 Wp/m², average production	**130**	*kWh/jaar*		
	Required amount of solar panels	64.2	*m²*		

Heat storage capacity (sun): *PCM dwelling*

SUMMER (Sun angle 61 deg.)

Month	*kWh/m² per day*	*Sun hours*	
May	4.93	6.7	
June	4.98	6.1	
July	4.87	6.3	
August	4.27	6	
average:	4.76	6.3	*755 W/m² energy delivered by the sun during 6.3 hours*

AUTUMN / SPRING (Sun angle 37 deg.)

Month	*kWh/m² per day*	*Sun hours*	
September	2.84	4.3	
October	1.68	3	
March	2.49	4.2	
April	3.71	5.2	
average:	2.68	4.2	*638 W/m² energy delivered by the sun during 4.2 hours*

WINTER (Sun angle 15 deg.)

Month	*kWh/m² per day*	*Sun hours*	
November	0.92	1.9	
December	0.61	1	
January	0.80	1.3	
February	1.46	2.8	
average:	0.95	1.8	*527 W/m² energy delivered by the sun during 1.8 hours*

1 layer of facade

1 PCM module:
11.4 L
80% of which PCM:
9.12 L (kg)

Amount PCM modules in 1 m² facade:
11.67 modules

Amount PCM in 1 m² facade:
106.4 kg

LHC frying oil:
169 kJ/kg

→ **LHC frying oil:**
17,981,000 J storage capacity

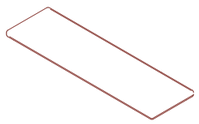
Summer: 22,680 seconds of sun
1 m² PCM: 792.8 J/s (W) storage capacity

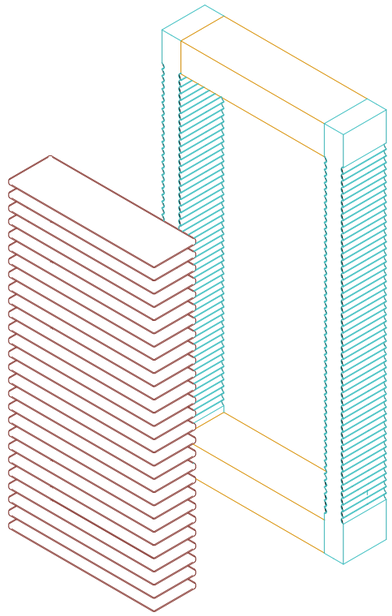
Autumn/Spring: 15,120 seconds of sun
1 m² PCM: 1189 J/s (W) storage capacity

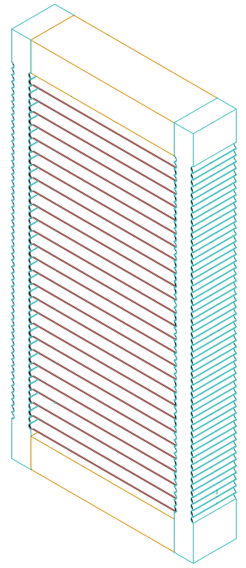
Winter: 6,480 seconds of sun
1 m² PCM: 2774.8 J/s (W) storage capacity

Conclusion:
1 wall layer is theoretically enough to absorb all solar energy of radiation per day. The storage of this energy unique and is later on the day exposed to interior of a residential space (dwelling, community centre etc.).

PCM mass in facade: *PCM dwelling*







1 PCM module:

11.4 L
80% of which PCM:
9.12 L (kg)

27 PCM modules:

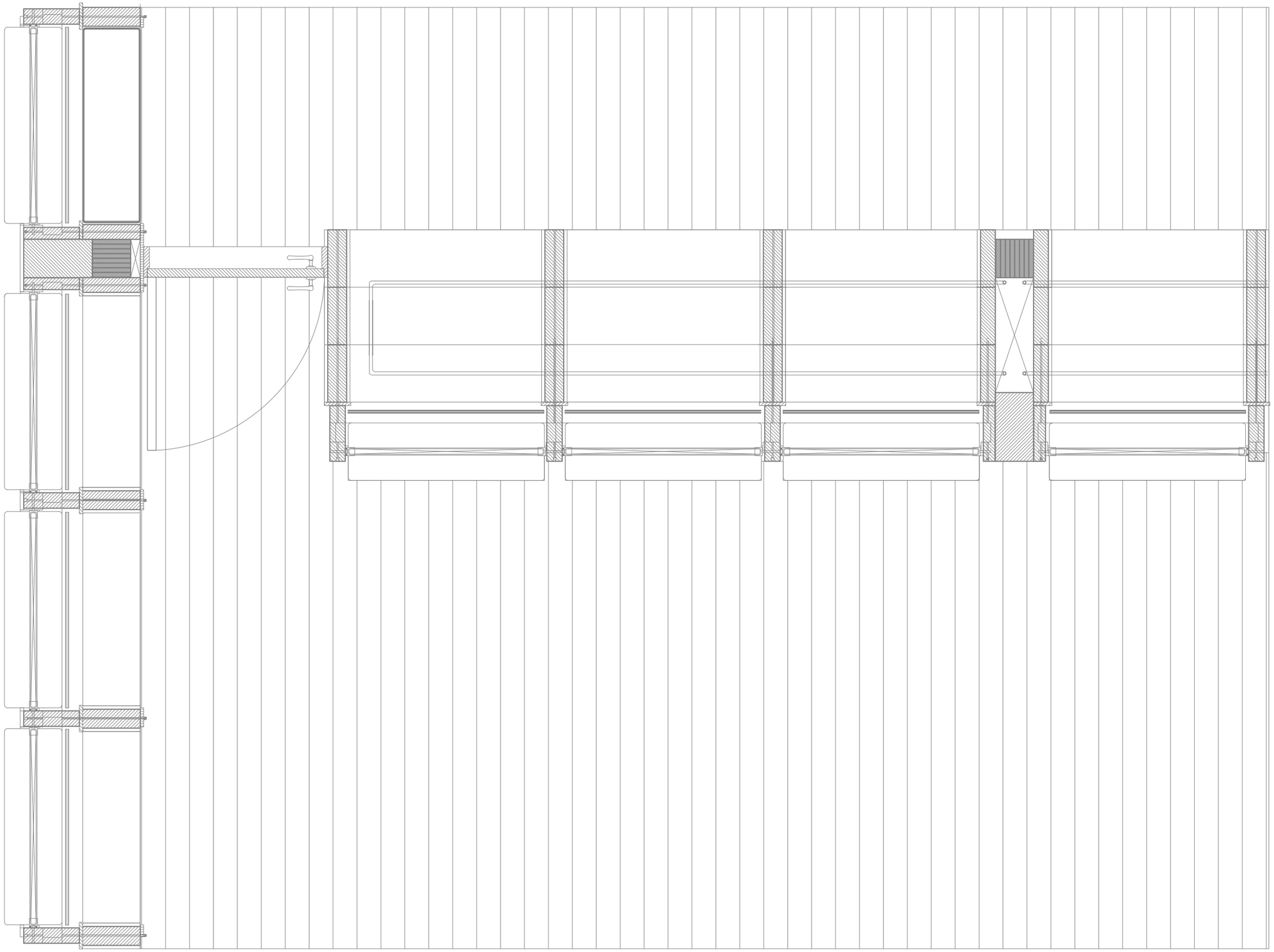
246.24 L (kg) PCM

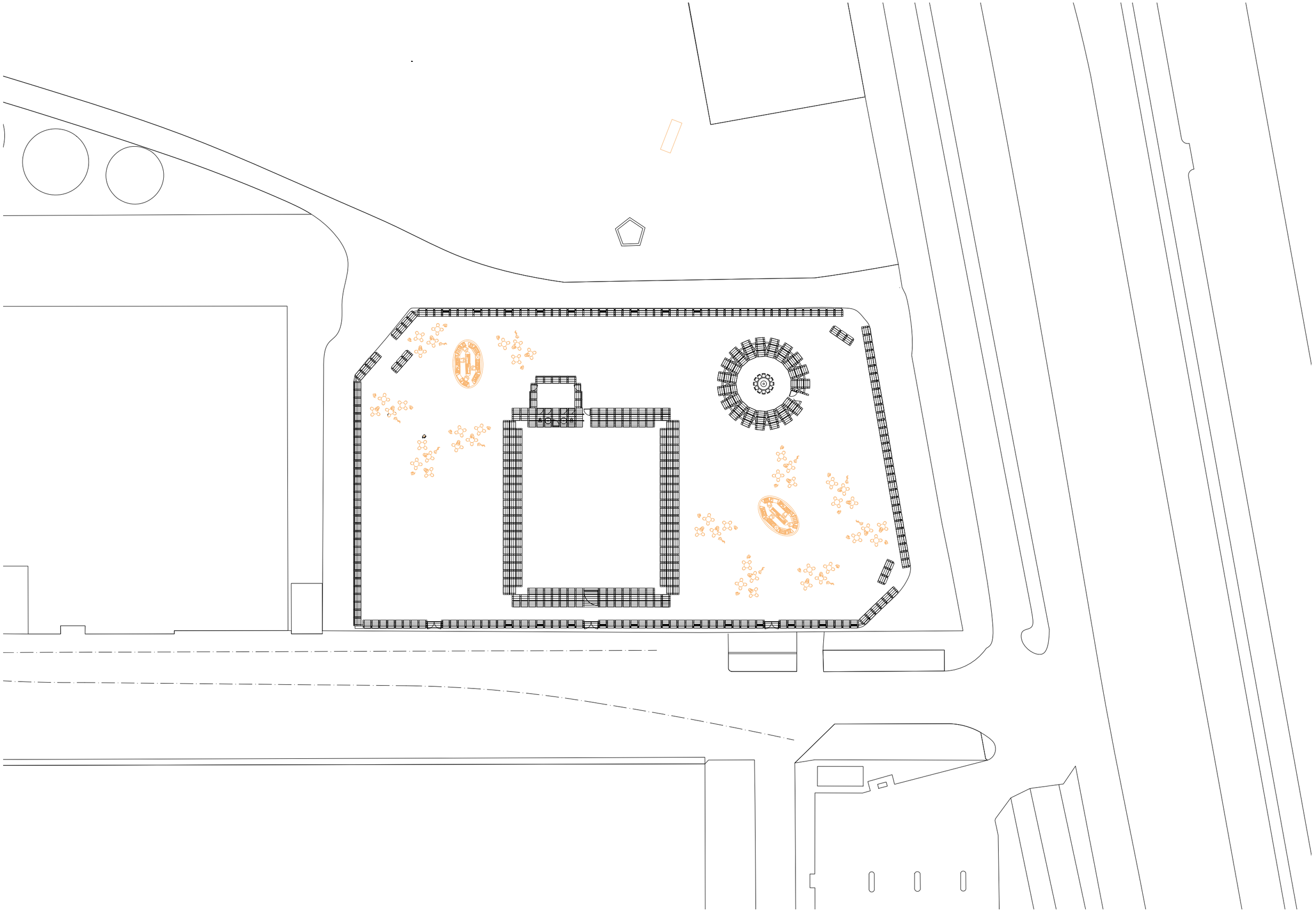
Amount PCM modules in 1 m² facade:
11.67 modules

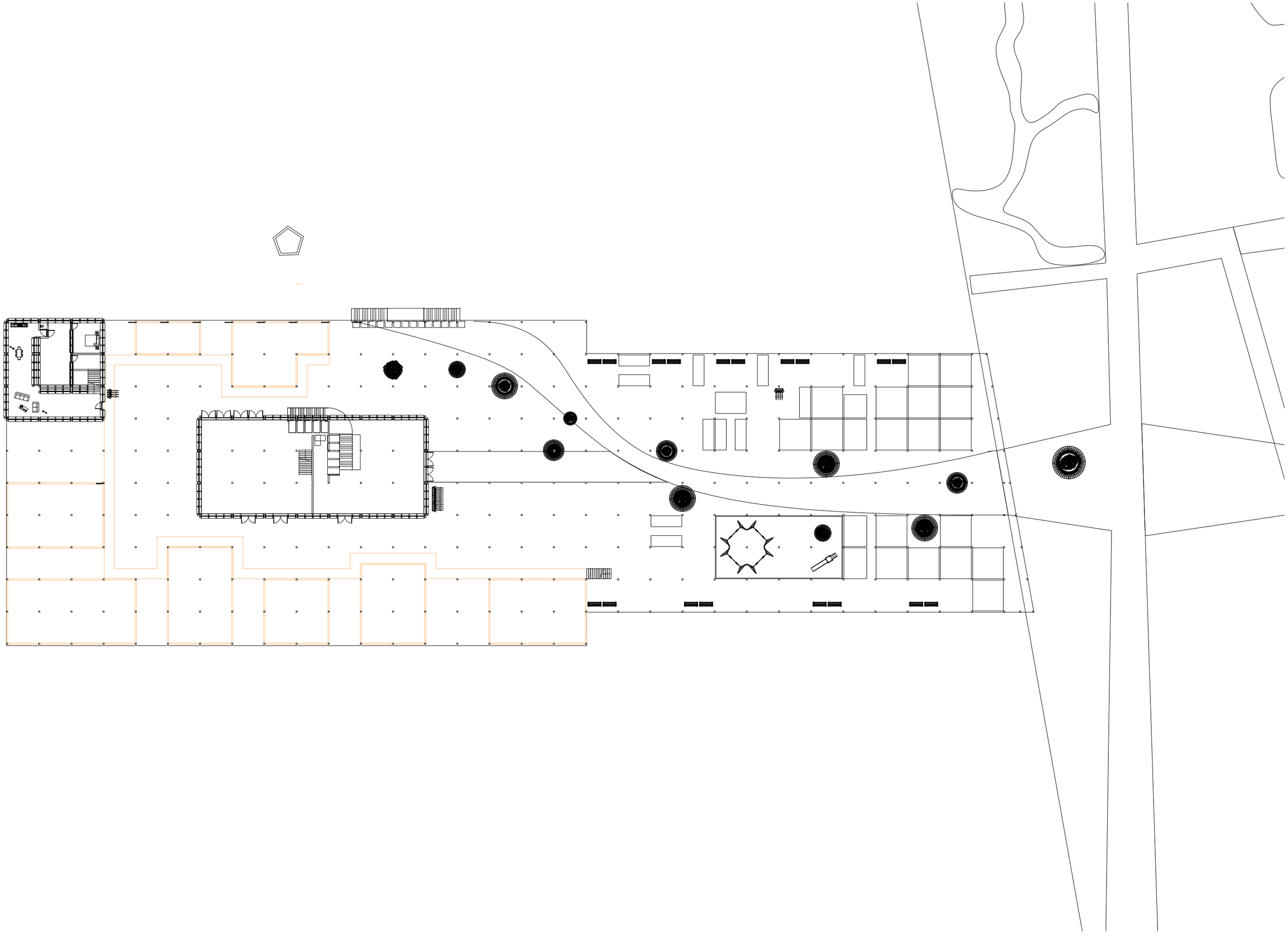
Amount PCM in 1 m² facade:
106.4 kg

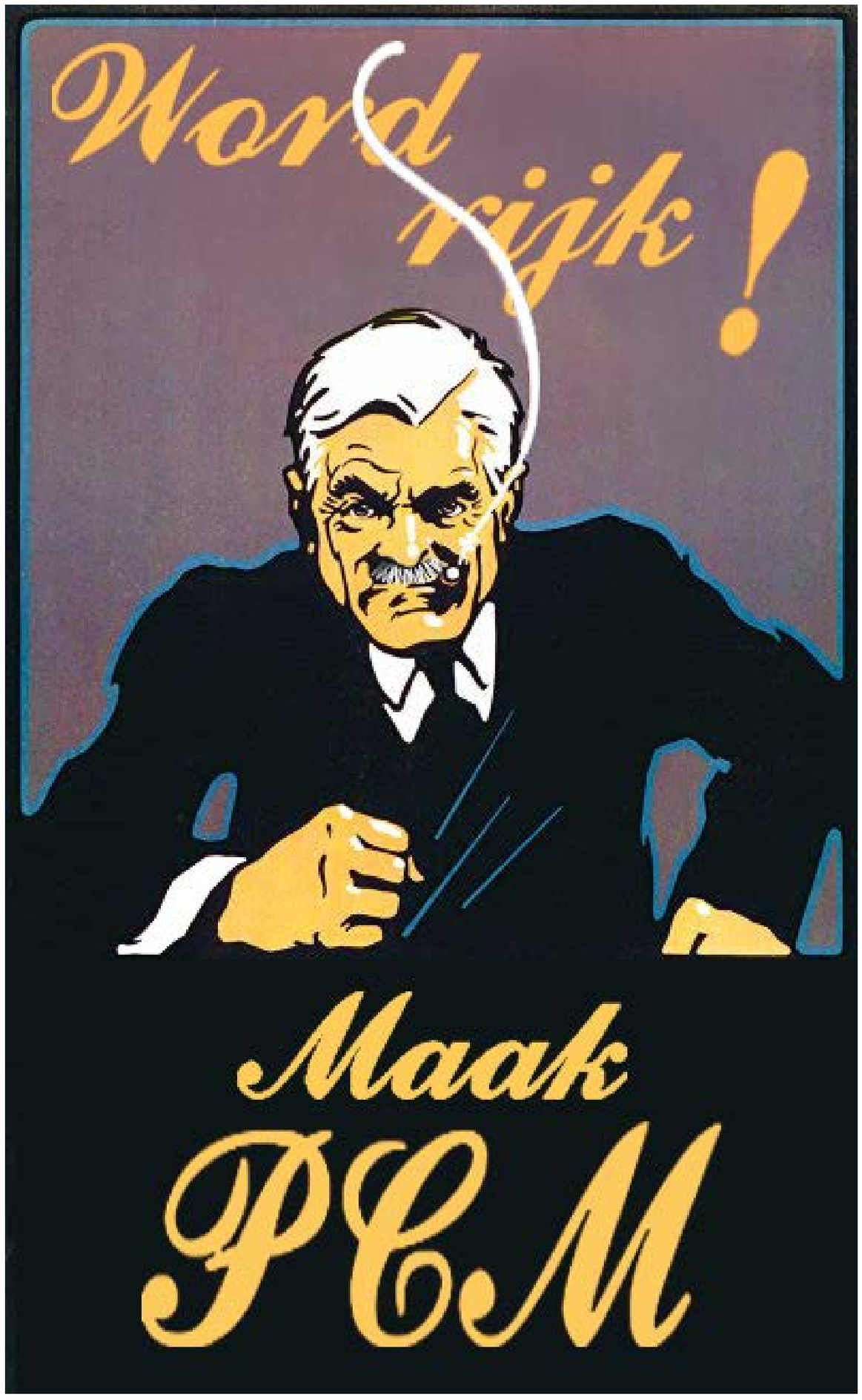
LHC frying oil:
169 kJ/kg

LHC frying oil:
17,981,000 J storage capacity





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PCM