Circular Phase Change Material
for social architecture in Rotterdam

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P2 Report

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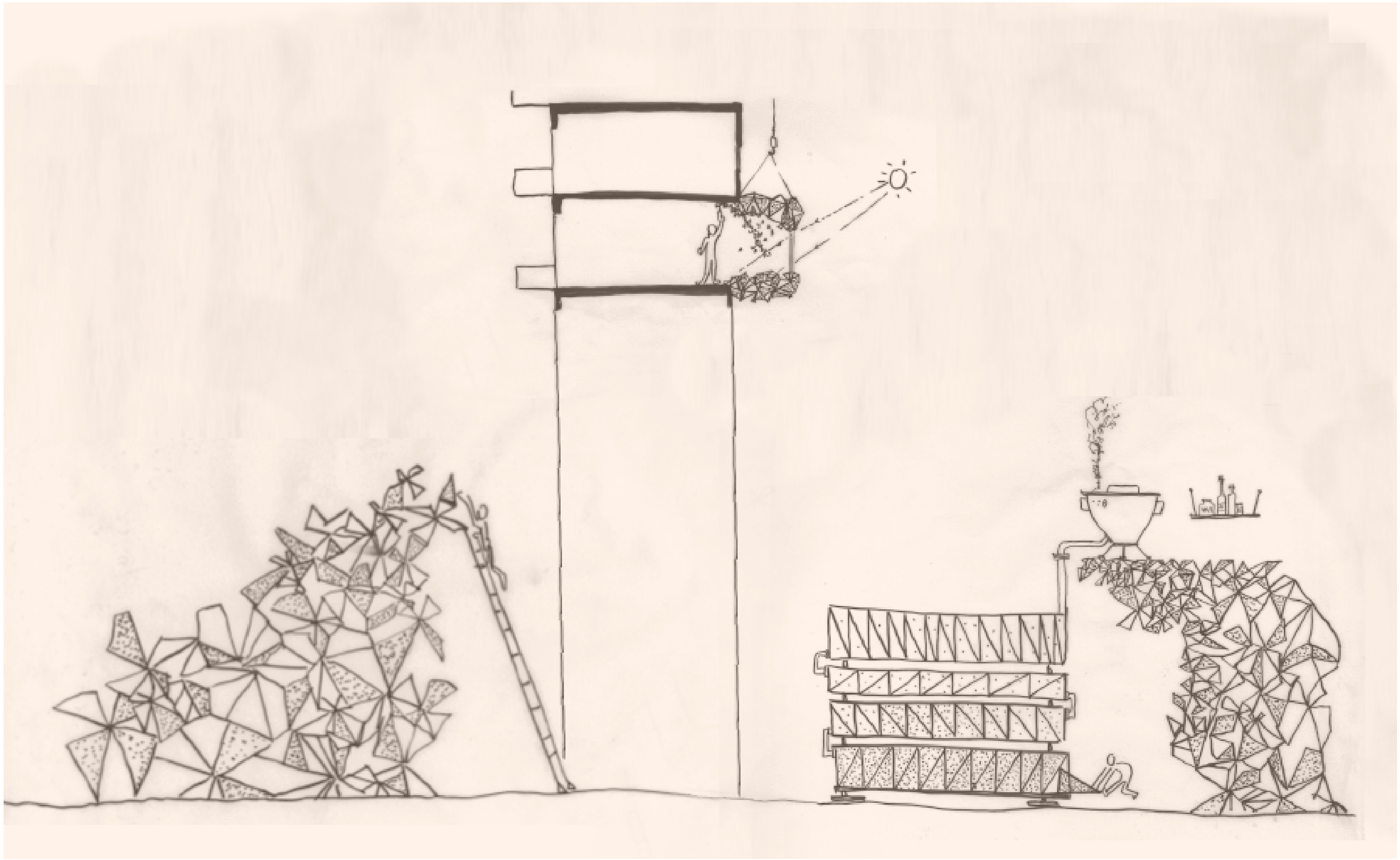

First imagination of PCM manufacturing method

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1 Introduction

1.1 Problem Statement

Global: Sand
According to the development of worldwide expansion towards 10 billion inhabitants of planet earth in 2050, 66% of the population worldwide will live in urban areas. And for constructing these areas, resources are needed. The resources used in the built environment, of which the sectors for building and infrastructure specifically, are becoming scarce. Relatively unexpected, 79% of these resources contain sand. Sand is used in many products ranging from concrete to glass. Where sand seems an innocent ingredient, it has become the world's third most used resource besides air and water. Qualitative sand has a cubic shape and is mostly found in rivers or quarries, which makes it a perfect aggregate. The sand that makes us assume we have enough of, is actually spherically shaped sand; formed by the wind. This type is mostly found in deserts and remote areas but not useful for the building sector. Illegal excavation of sand from beaches, quarries, forests or islands shows that it sand has turned from a local resource to a valuable trade product instead. Illegal and violent actions to nature, ecosystems, people and societies are the unfortunate result.In conclusion, the sand industry is developing into a complicated industry that leads to socio-political, economic and environmental problems.

Local: Socio-demographic problems in Rotterdam
In Rotterdam, Bospolder - Tussendijken (BoTu) is one of the poorest neighbourhoods of the city, however, announced to become an energy neighbourhood within 10 years time. The Merwe-Vierhavens district (M4H) is transformed and developed to become a Makers District. Both neighbourhoods used to have a strong relationship in the past; the M4H provided employment for the inhabitants of BoTu and other adjacent neighbourhoods. Nowadays, they only share the same threat: urban development driven and decided by the free market and thus monetary means, whereby its identity and qualities are at stake. I see the architects role as one to question this development and to aim for (urban) development that balances social and sustainable profit with monetary profit.

1.2 Fascination for Phase Change Materials (PCM)

The answer to the scarcity of sand is Phase Change Materials, in this project. Depending on the applicability and production process it could replace concrete both in climatological and in load bearing function. The climatological aspect directly relates to the energy transition ambitions of Rotterdam. This means that PCM is used as a medium to bridge to worldwide issue of sand scarcity to the local problem of achieving energy ambitions in one of the poorest neighbourhoods of Rotterdam, where solving socio-demographic problems actually have the main priority. The result is thus to combine these factors and to use the PCM application and production process to react on the posed energy transition ambitions and at the same time to deal with the actual socio-demographic issues. This can be done taking into account the history and environment of the neighbourhood, in which the adjacent neighbourhood plays an important role.

The absolute (conceptual) summum of climate regulation by PCM in my perspective, is the following: imagine a PCM built home that regulates the indoor temperature constantly by its visual phase change; it creates a house that lives as an living organism. It does not need any artificial input to stay alive and ensures a comfortable living environment for the people it hosts. By its presence the temperature in a room is consistent through all seasons.

This project consists of a technical element and a social component. The place where the two meet could be considered as my final graduation product; tangible and intangible. In this graduation project the technical element is the Phase Change Material containing device / module. As a reaction on the current resource developments of sand worldwide, the PCM application offers a sustainable and durable alternative for the built environment. Especially in terms of circularity, (embodied) energy, destructive extraction and exhaustion.

Within the built environment PCM has not yet gained too much attention and its current application methods are probably not widely known among the majority of actors in the industry. However, with its great potential for future use the approach to create a simple but essential variant of this product contributes to the recognition of the 'state of the art' image that it currently has. Researching the realistic and accessible application of it is not only beneficial for the reputation of PCM, but also for the social impact of such a process. Instead of seeking to find an innovation that needs specific expertise and complex manufacturing processes with a perfect final product, the aim here is to create an accessibly manufacturable product or an affordable price so that the implementation of it takes into account the realistic current situation. The final product from this research objective leads to a relatively conceptual but realistic product. It might as wel have great potential for further research.

1.3 Objectives

1. An alternative building material to sand

Qualitative (potential) replacement of concrete in the built environment emphasises on the two main qualities of the material. The design application of PCM has more potential than its current use, especially regarding future prospects about the warming of our environment. An integral design combines the loadbearing structure and heat storage capacity of the PCM wehereby it could develop towards a building material that combines structural and climatic abilities.

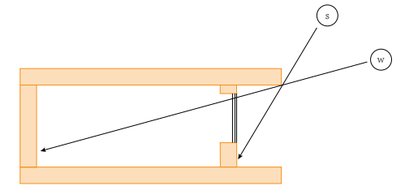
2. Energy reduction + re-use by thermal energy storage

The potential of PCM enables a reduction of energy usage for cooling and heating. Ideally, the application ensures a consistent indoor temperature so that no further (artificial) heating is needed. This would reduce the average energy consuption by 50%. Storing heat that is already present by various sources potentially enables re-use of available (thermal) energy, so that less energy is necessary by additional (natural) sources.

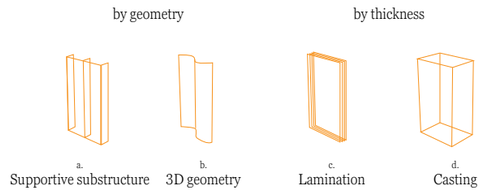
3. Mutualism between M4H and BoTu

The reconnection of both neighbourhoods. BoTu delivers employees that identify themselves with this location. In return , they receive skills, education, salary and a product directly applicable to upgrade their homes. BoTu inhabitants hereby contribute to their own district and municipal ambitions of becoming an energy neighbourhood, positively. Besides that, they will better their circumstances directly. The social way to emancipate BoTu effectively.

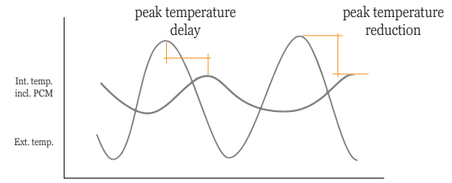
1. Thermal mass as a design principle



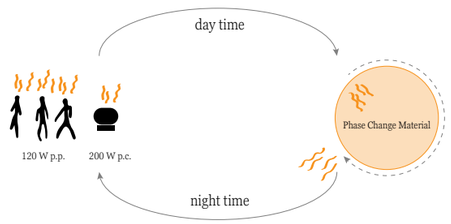
2. Loadbearing structure of a homogenous material



1. Consistent indoor climate by use of PCM

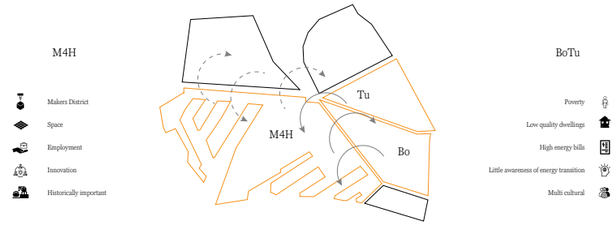


2. Re-use of present energy



1. Fulfilling next economy industry in M4H
Location

2. Emancipating BoTu
Relation



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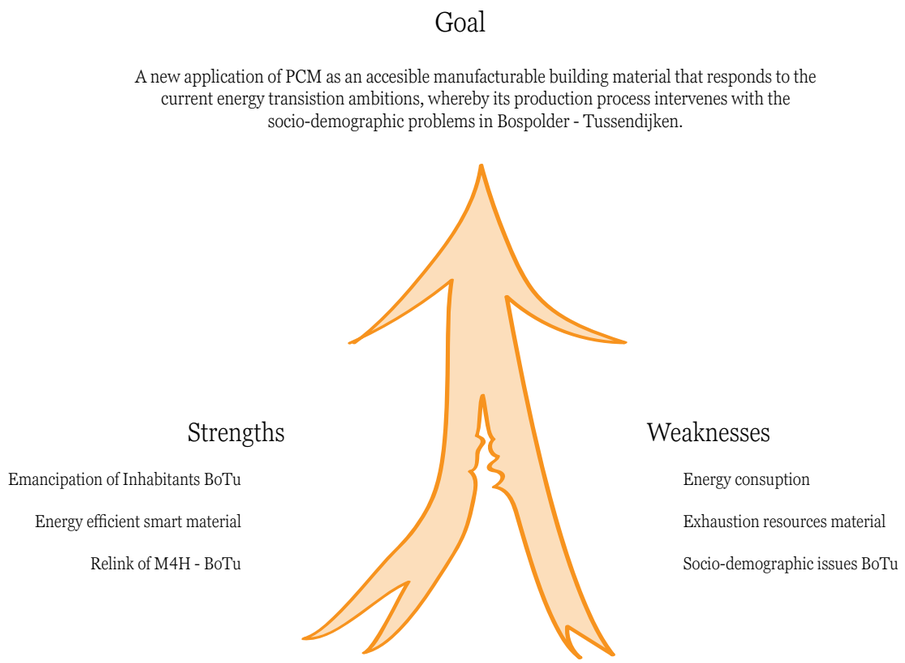
1.4 Research question

Main research question

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?

Sub-questions

- How could PCM be used to respond to the energy transition assignment?
- How could PCM be accessibly produced?
- How could PCM be produced to diminish the socio-demographic issues in Bospolder- Tussendijken?
- Which PCM is suitable regarding the previously mentioned questions?
- How could the historic relation between Bospolder - Tussendijken and the Merwe-Vierhavens district be restored so that both districts benefit from it?
- How could an urban development in Merwe-Vierhavens district be realised whereby social and sustainable profit balance monetary profit?
- What are the socio-demographic problems of Bospolder-Tussendijken?
- What architectural intervention could fulfil the answers to these questions?



1.5 Research methodology

The problem statement: SAND
This textual and graphical work contains a wide introduction of sand and the posed problem related to it. Because of the shocking impact of the truth about sand scarcity, I choose to make an individual booklet about this resource. It can be seen as an atlas for sand. The division within de booklet:

Introduction
Ecology of sand
Economy of sand
The future of sand

The RESEARCH
Introduction and Methodology
Although presented after the material research, the order of presentation does not represent the chronological act of research. Inevitably there has been switched back and forward to take into account social and material properties. This process is shown in the introduction and methodology of the research book.

Material research
I THEORY
This chapter contains the material research about PCM. It starts with a broad introduction, followed by current applications studied in case studies. Furthermore it narrows down to the orientation of different material types and their properties, taking into account the social function of the material production process a specific matrix is presented, in order to give overview. Literature research is conducted to gain the requested knowledge.
II PRACTICE
This theoretical approach of finding the right material is then opposed by the reality of available materials which could function as a PCM. This part of the research contributes to the ambition to find an accessible and accessibly manufacturable PCM. The outcomes directly relate to the production process which define the primary demands for the design brief.

Social Resilience Research
I BoTu
The BoTu research contains qualitative and quantitative research about the socio-demographic situation of Bospolder - Tussendijken. Together with the analysis of the municipality policy for this neighbourhood, a social resilience concept is formulated. This influences and elaborates inevitably on the production process of the PCM modules but also on the factory itself.
II M4H
The research of M4H relates the BoTu situation to the historic relation it had with this adjacent neighbourhood and puts it into perspective regarding the foreseen future relation. Besides this historic meaning, also the municipal ambitions of M4H are researched which result in a location and relation of the supposed architectural representation of the research.

Material Research

Phase Change Materials **Climatological + load bearing capacity**

Theory

Matrix

Available materials **Low tech modification**

Practical

Accessible manufacturable PCM + collection method

+

Specific PCM choice with accessible production process

Social Resilience Research

Social Resilience Research **Municipal policy**

Qualitative + Quantitative

BoTu

Concept strategy for social resilience

Historic meaning **Municipal ambitions**

M4H

Location and connection

+

Social intervention embedded by the relinking of the two neighbourhoods

Technical
Phase Change Material

Social
BoTu + M4H

Phase Change Materials

Material Research

Parameters for PCM research

In order to achieve this, several desirable objectives of the PCM application combined form an integrated product that will enlarge the chance of succesful outcome. They function as the guidelines through this specific material research.

A Climate regulation
First of all, the properly functioning of the material for climate regulation is the most important objective. By the properties of the material, this functioning is defined. It is the essence of the material and therefor directly resulting in effectivity. It would be great to come to a new way of climatising our environment; not by machines or (active) installations but by passive ones. A material that could do the same as an electric device purely by its physical composition, is absolutely fascinating. It indicates that our desire for invention and development results in neglected outcomes which influences the climate we live in while actual durable solutions are closer to the natural rhythm and more obvious than we actually think.

The terminology used to explain this behaviour is *thermal mass*. Just as water and concrete do for example, thermal energy can be stored in mass. The mass warms up by its direct contact with the surrounding. In a later stage of the day, this thermal energy is then released which warms up the space. This working principle is independent of any machinery or artificial energy consuming support (e.g. gas or electricity). Therefor it is a passive method that could contribute to temperature regulation in architecture. Interesting enough is that conventional materials rely on a high material density, but PCM does not in particular. The working principle comes form the phase transitions triggered by the stimulus of temperature. Conclusively, the use of PCM is much more light weight than convential (concrete) materials.

Storing energy and releasing it on a later moment contributes to a sustainable living situation due to the fact that less energy is consumed so that less energy has to be produced. Besides that, this concept also re-uses present thermal energy by storing it in the phase transition.

B Structural use
Structural use of the PCM would enlarge the possibilities of application and could even result in a fully integrated building concept, where one element has the structural and climatological functioning combined. This formulated objective is rather ambitious but worth researching. Mostly used PCM's in architecture have phase transitions from solid state to liquid state and vice versa. It seems very contradictory with the proposed ambition of structural use of PCM, but structural use can also imply any structure and not merely the loadbearing structure of a building. This research zooms in on different scales of structuring and building with PCM.

C The accessible manufacturing process
Due to the socio-demographic issues found in BoTu, the choice for an accessible manufaturing process over a specialised process intervenes with the problematic situation. The idea that the manufacturers earn a salary and produce the module for sustaining their home themselves is fantastic. This way the now 'state-of-the-art' PCM becomes a common material or product. This enlarges plausibility for wide acceptance for a new material under the future users. Also, it takes away the unemployment that is currently present. Manufacturing the product requires skills so potential educational value is also embedded. The effect of this ambitious goal for the material research is that most probably the ideal material found is not merely defined by its climatic use potential.

D Biobased
The origin of materials is rather important. Concluding from the Sand Atlas an I am eager to find an ecofriendly alternative to sand. Although to some extend all materials and choices we make do have an impact on nature, the objective here is formulated as bio-based. Having the possibility to regrow or naturally dispose the material after use would enhance the idea of an ecologically fair product and emphasises on the recycling of materials. So also within the circulair economy this could have a meaning.

E Inexpensive
This research approach relies on a realistic situation, with the potential of actual future creation which means that also the costs have to be analysed. Regarding the ambition of accessible manufacturability, expensive resources would disable reaching the foreseen social and climatiolocial impact.

	Desires	**Necessary research**	**Specific research information**
A	*Climatic regulation (fully)*	*Material research (matrix)*	*Thermal conductivity* *Latent heat of fusion* *Melting temperature*
B	*Structural application*	*Encapsulation techniques*	*Micro* *Macro*
C	*Accessible manufacturing process*	*Production process*	*Not state of the art* *No specialist equipment* *No specialist education needed*
D	*Biobased*	*Formation of material*	*Origin of material* *Recyclable ?* *Abundant feedstock supplies*
E	*Inexpensive*	*Production process and material*	*Derives from B+C+D*

Introduction to PCM

Strictly by definition, all materials are to be considered Phase Change Materials (PCM's); every material has its own specific melting temperature. When a material changes from one phase to another it embodies energy or excretes energy, depending on its characteristic spherical pressure (related to temperature). Transformations for example, go from solid to liquid, from liquid to gas or vice versa. These endothermic and exothermic enthalpies are reliable chemical reactions that make use of thermal energy. By using the principle of the phase changes thermal energy can be temporarily stored or released from the material.

In fact, it functions as a thermal battery, over bridging the time between the available energy and the moment of usage of that thermal energy (Harland, Mackay, Vale, 2010) PCMs therefore can be applied in a heating concept and cooling concept, however, these materials are favoured to cooling than to heating (DuPont, 2017).

Latent versus Sensible

PCM´s are considered smart materials due to their latent heat storage capacity properties which is activated by the specific melting temperature of the substance. More conventional energy storage materials as rock, water or concrete are sensible heat storgae materials. This means that the accumulation of thermal energy in the material is sensible at the surface of the material; the substance itself warms up as well. For latent heat capacity materials this is not the case; the material doen not warm up and remains consistent in temperature while it absorbs the thermal energy as seen in figure X. Comparing the two types of heat storage materials, PCM's store 5-14 times more heat per unit volume than sensible heat storage materials (Demirbas, 2006). This implicates the light weight character of the material. Using this advantage, smaller heat storage units can be used to achieve similar effect, depending on the material choice. This results in heat flux control when applied in the right way.

PCMs have obtained much interest for their various applications in the building industry; building energy efficiency, solar heating systems and air-conditioning systems. For example, it can have similar function in architecture as (thermal) mass. However, the advantage of using the innovative product lies in its specific weight, heat storage capacity, and minimal volume change during phase change. In lightweight structures the introduction of PCM is convenient. Where heavy weight materials cannot be used the PCM is a valuable substitute. For example as passive heat storage in lightweight buildings. (Harland, Mackay, Vale, 2010) However, the application in the building envelope seems to be a relevant option as well. This smart material has another smart character; its luminous appearance of opaqueness and transparency triggered by the same temperature, for example used in tensile fabric structures (Lorens, 2015).

The material origin varies in three categories; organics, inorganics and eutectics. Eutectics are considered a combination of the first two categories resulting in a specific third material type.

Concluded from the matrix on the previous page, the suitable types of PCM seem:

- *SSPCM*
- *Hydrated salts*
- *Organic eutectic mixtures*
- *Organics in pure form*

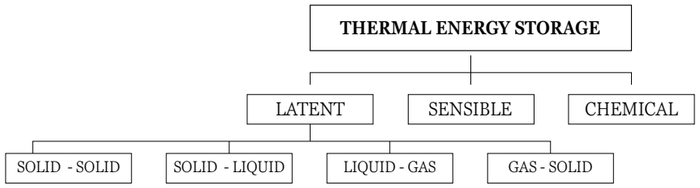


Figure 1: 3 Types of thermal heat storage (Zalba et al., 2003)

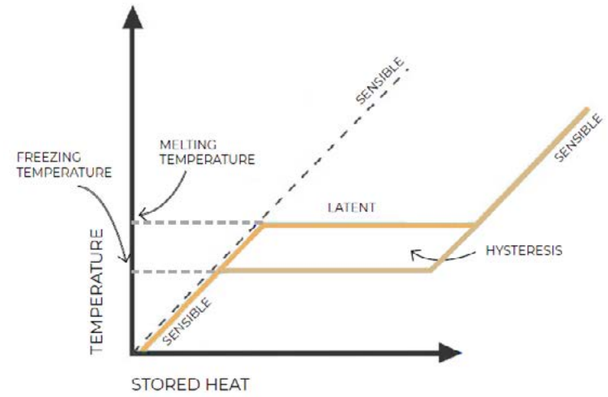


Figure 2: Latent heat storage and sensible heat storage (Ferugia, X)

In theory

Material property research
Overview of Solid - Liquid PCM's

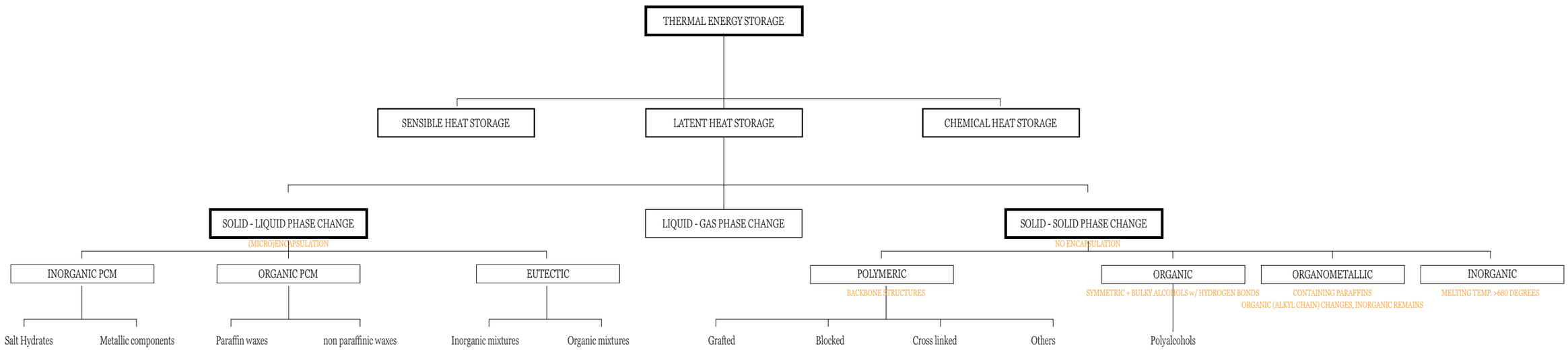
In order to find the right PCM for the within the desired research objectives, the analysis of most important PCM's is an important notice. Constructing a reference frame, giving an overview of these types and their properties, facilitates deliberate material choice. This is the matrix which follows after a brief description of the types of PCM's in this research.

Inorganics: hydrated salts
Most commonly know is Glauber's salt (Na2SO4·H2O). As this molecular structure indicates, hydrated salts are composed of water and a mineral substance. They are the cheapest commercial PCM's available (Auerbach, 2018). They are a rather attractive type due to their hight TES capacity of around 240 kJ/kg (Baetens et al., 2010). In addition, they have a high thermal conductivity of about 0.5W/(mK). In contrary to theses beneficial properies, there are several down sides of this material. Supercooling and phase segregation are risks when using this material. Phase segregation implies that the composition of the material degradates into multiple elements after certain amount of cycles. Water is seperated from the salt in liquid phase and during this procedure congruently the formation of lowe salts occurs. This irreversible process is a restriction to the functioning lifetime because of it is losing TES capacity. Another remark to be mentioned is the critical thickness used for a container: the thickness is limited because otherwise the segregation of both components is permanent.

Organics: paraffin waxes
Within the category of organic PCM's a binary division can be made, based upon the origin of the material. Paraffin waxes come from petrochemical processes, while natural organic PCM's have a ecofriendly origin. Paraffins have a non-sustainable origin by their petrochemical production method. Paraffins that are commercially available are relatively low cost materials. Also they do not overcome supercooling. Their thermal storage density ranges from around 120 kJ/kg to 210 kJ/kg. Also the great variety of melting temperature from 20 to 70 ºC is an advantage (Baetens, Petter Jelle, Gustavsen, 2010). Even so is their modest volume increase when changing from solid to liquid.

Organics: non-paraffinic waxes
Besides the waxes based on a petrochemical origin, fatty acids are the natural equivalent. Fatty acids have many superior properties. They contain the following characteristics: proper melting temperature range, high heat capacity, congruent melting, little or no supercooling during phase transition, lower vapor pressure, non-toxic, non-corrosive to metal containers, good chemical and thermal stability, low cost, non-flammability and small volume change (Yuan et al, 2014). Pure fatty acids have a low thermal conductivity property (Yuan et al., 2014). The storage and heat release during the solidification and melting process is therefore relatively slow. In order to efficiently store thermal energy, this is a unpleasant characteristic for a PCM. Properties of (saturated) acids with a carbon number from 10 to 18. Generally known, the latent heat and phase change temperature increase for an acid containing a higher carbon number (thus longer carbon chain length). However, this means that also the melting temperature of the material rises.

Fatty acid esters retrieved by the esterification with alcohol contain proper phase change temperature, higher latent heat, lower degree of supercooling, higher thermal reliability. Therefore fatty acid esters are obtained by usage of alcohol are more suitable to be applied to low temperature phase change energy storage than fatty acids.



Eutectics: organic mixtures

The combination of pure fatty acids to a mixture allows for lowering the melting temperature of the eutectic. This way the PCM could be modified to meet new standards (Yuan et al, 2014). The latent heat capacity hereby is also modified to the combination of both values from the pure fatty acids. The melting procedure is relatively easy. Both substances are brought in liquid state by (slow) heating. Mixing the substances together and gradually cooling down the mixture will result in an eutectic mixture, that is able to withstand seperation depending on future use. Some of these eutectics are La-Ca and Ma-La combined in a specific weight ratio. Most common oils and fats are composed of diverse combinations of fatty acids, they can be considered organic eutectis. On the right there is portrayed an inventarisation of fatty acids within commonly used oils.

Eutectics: inorganic mixtures

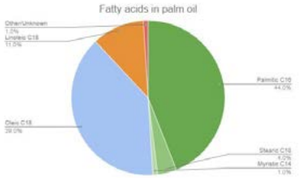
Inorganic eutectics are different hydrated salts combined, in order to reach a different substance with different properties. On average, the melting points of these inorganic mixtures are somewhat higher than that of its natural equivalent.

Other compositions

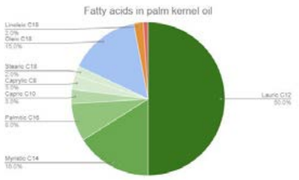
Combining PCM's with other materials, makes a composite. Examples of additional used materials to be combined with the fatty acid are; carbon nanotubes, (CNTs), carbon fibre, expanded graphite (EG), activated carbon, silica fume (SF).

Form stable PCM´s are also a type of composites, one could state. The host material takes up the liquid PCM by its capillary system. This prevents the PCM from leakage and no further encapsulation is required. It is cost effective and the shape will remain stable. Besides this, it comes in flexible dimensions (Yuan et al., 2014). The conductibility is the other advantage of form stable PCMs.

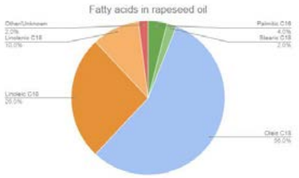
Fatty acid in palm oil	%	type
Palmitic C16	44	
Stearic C18	4	
Myristic C14	1	
Oleic C18	39	
Linoleic C18	11	
Other/Unknown	1	



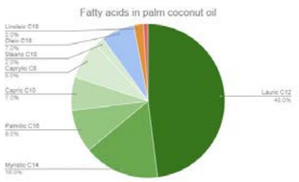
Fatty acid in palm kernel oil	%	type
Lauric C12	50	
Myristic C14	16	
Palmitic C16	8	
Capric C10	3	
Caprylic C8	3	
Stearic C18	2	
Oleic C18	15	
Linoleic C18	2	
Other/Unknown	1	



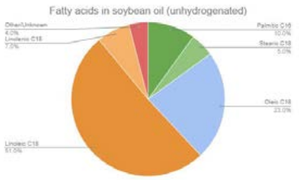
Fatty acid in rapeseed oil	%	type
Palmitic C16	4	
Stearic C18	2	
Oleic C18	56	
Linoleic C18	26	
Linolenic C18	10	
Other/Unknown	2	



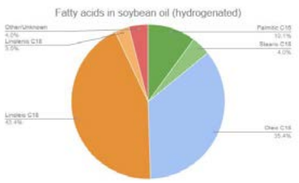
Fatty acid in coconut oil	%	type
Lauric C12	48	
Myristic C14	16	
Palmitic C16	9	
Capric C10	7	
Caprylic C8	8	
Stearic C18	2	
Oleic C18	7	
Linoleic C18	2	
Other/Unknown	1	



Fatty acid in soybean oil (unhydrogenated)	%	type
Palmitic C16	10	
Stearic C18	5	
Oleic C18	23	
Linoleic C18	51	
Linolenic C18	7	
Other/Unknown	4	



Fatty acid in soybean oil (hydrogenated)	%	type
Palmitic C16	10	
Stearic C18	4	
Oleic C18	35	
Linoleic C18	43	
Linolenic C18	3	
Other/Unknown	4	



Overview of Solid - Liquid PCM's

Solid - Solid PCM's

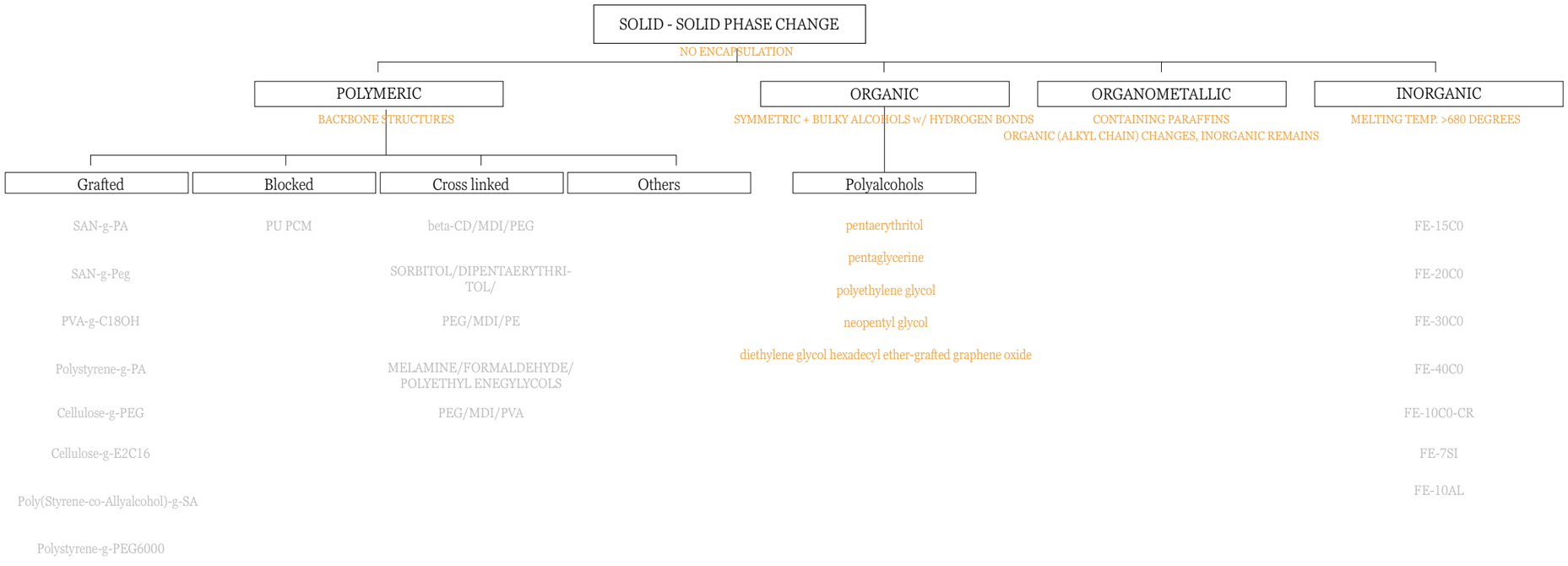
Overview of notable SS PCM's

Solid-solid PCM's are different than form stable PCM's and composited. Ideally, SS PCM's do not need any other material or additive in order to maintain their solid character. The molecular structure is hereby defining the state. Just as with Liquid Crystal Displays (LCD) of our telivision, one could say the same principle counts for these type of PCM's. Phase change is not that binary, that a substance is either solid or liquid. There consist stages in between, which are defined by the molecular structure. The material acts as if it has mobtained the latent heat capacity of a liquid state material, but remains (partially) in solid state whereby its stability is guaranteed to a certain extend. In theory this sounds perfect; one could produce a material block that contains load bearing properties and climatic properties. However, this type of PCM is not yet developed and researched enough that any appplication or use would be inexpensive or proven to be durable over longer time.

On molecular level, the stabilty of the substance can be guaranteed by a polymeric backbone, that contains soft segments. The soft segments change from semi-crystalline to amporphous, whereby its latent heat capacity is enabled (Fallahi et al., 2017). The backbone remainds intact so that the substance remains in its phase state.

The melting temperatures and enthalphies are highly various and depend on the type of SS PCM. The polymeric types range from 10 to 65 degrees celscius, where the inorganics melt uptil about 1000 degrees Celsius.

Utilising this specific PCM type in the project in order to gain an accessible manufacturable building materials is higly implausible due to the expected costs, highly skilled personel that is required and the limited tests that the scientific researched report about with stable outcomes. This type is, unfortunately, still too state-of-the-art to integrate in the project it seems. It requires a specialist production. In conclusion, this also has effect on the objective to find a loadbearing functioning PCM. The objective shalle herebey be transformed so that the encapsulation techniques of PCM will now take the load bearing ability instead of the material itself.



Matrix

Properties			INFO	Kinetic	Thermal			Physical				Chemical			Sustainable			Economical
				Supercooling	Latent heat fusion	Condutivity	Melting point ◦C	Segregation/decomposition	Density kg/m³	Volume change	Toxic	Flammable	Corrosive	Biobased	Biodegradable	Behaviour	Costs
Organic	Fatty acids: CH3(CH2)nCOOH,	**Caprylic acid**		No[2]	148.5 kJ/kg [4]	Low: 0.149 W/(mK) [4]	16 ◦C [4]	No	901 (L) - 981(S) [4]	Small[2]	Nontoxic[2]	Flammable [10]	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	?
	between 155 and 180 kJ/kg.	**Capric acids (CA)**		No[2]	152.7 kJ/kg [4]	Low: 0.153 W/(mK) [4]	32 ◦C [4]	No	878 (L) - 1004(S) [4]	Small[2]	Nontoxic[2]	Flammable [10]	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	?
	melting temp: 17 - 64 (no 21)	**Lauric Acids (LA)**		No[2]	183 kJ/kg [9]	Low	44 ◦C [9]	No	870 [11]	Small[2]	Nontoxic[2]	Flammable [10]	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	?
	High LHF [2]	**Stearic Acid (SA)**		No[2]	222 kJ/kg [9]	Low	69 ◦C [9]	No	940 [11]	Small[2]	Nontoxic[2]	Flammable [10]	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	$1.43–$1.56/kg [3]
		Palmitic Acid (PA)		No[2]	185.4 kJ/kg [4]	Low: 0.162 W/(mK) [4]	64 ◦C [4]	No	850(L) - 989(S) [4]	Small[2]	Nontoxic[2]	Flammable [10]	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	$1.61–$1.72/kg [3]
		Oleic Acid (OA)		No[2]	High[2]	Low	-	No	-	Small[2]	Nontoxic[2]	Flammable [10]	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	$1.67–$1.76/kg [3]
	biodiesel	**Crude Glycerine**		No[2]	High[2]	Low	-	No	-	Small[2]	Nontoxic[2]	Flammable [10]	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	$0.22–$0.29/kg [3]
		Undecylenic acid		No[2]	141 kJ/kg [11]	Low	24.6 ◦C [11]	No	-	Small[2]	Nontoxic[2]	Flammable [10]	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	?
		Myristic acid (MA)		No[2]	190–204.5 kJ/kg [11]	Low	51.5–53.6 ◦C [11]	No	860 [11]	Small[2]	Nontoxic[2]	Flammable [10]	Noncorrosive[2]	No	Depends	Reacts w/ environment (acidic) [3]	?
	Paraffin waxes	**Paraffin C14**		No[2]	165 kJ/kg [1]	Low: 0.2W/(mK) [2]	4.55 ◦C [1]	No[2]	-	Large[2]	Nontoxic[3]	Flammable [10]	Noncorrosive[2]	No	Depends	Biocompatible [3]	Inexpensive[2]
	CH3(CH2)nCH3	**Paraffin C15–C16**		No[2]	153 kJ/kg [1]	Low: 0.2W/(mK) [2]	8 ◦C [1]	No[2]	773 [11]	Large[2]	Nontoxic[3]	Flammable [10]	Noncorrosive[2]	No	Depends	Biocompatible [3]	Inexpensive[2]
	120 kJ/kg to 210 kJ/kg	**Paraffin C16–C18**	*fatty acids through hydrodeoxyge*	No[2]	152 kJ/kg [1]	Low: 0.2W/(mK) [2]	21 ◦C [1]	No[2]	776 [11]	Large[2]	Nontoxic[3]	Flammable [10]	Noncorrosive[2]	Possible [8]	Depends	Biocompatible [3]	Inexpensive[2]
	melting temp 20 - 70	**Paraffin C13–C24**		No[2]	189 kJ/kg [10]	Low: 0.21 W/(mK) [10]	23 ◦C [1]	No[2]	773 - 796 [11]	Large[2]	Nontoxic[3]	Flammable [10]	Noncorrosive[2]	No	Depends	Biocompatible [3]	Inexpensive[2]
		Paraffin C16–C28		No[2]	189 kJ/kg [11]	Low: 0.2W/(mK) [2]	43 ◦C [1]	No[2]	773 - 806 [11]	Large[2]	Nontoxic[3]	Flammable [10]	Noncorrosive[2]	No	Depends	Biocompatible [3]	Inexpensive[2]
		Paraffin C18		No[2]	244 kJ/kg [10]	Low: 0.15 W/(mK) [10]	28 ◦C [1] [10]	No[2]	776 [11]	Large[2]	Nontoxic[3]	Flammable [10]	Noncorrosive[2]	No	Depends	Biocompatible [3]	Inexpensive[2]
		Paraffin C20–C33		No[2]	189 kJ/kg [11]	Low: 0.2W/(mK) [2]	49 ◦C [1]	No[2]	788+ [11]	Large[2]	Nontoxic[3]	Flammable [10]	Noncorrosive[2]	No	Depends	Biocompatible [3]	Inexpensive[2]
		Paraffin C22–C45		No[2]	23.2 kJ/kg [11]	Low: 0.2W/(mK) [2]	27.5 ◦C [1]	No[2]	794+ [11]	Large[2]	Nontoxic[3]	Flammable [10]	Noncorrosive[2]	No	Depends	Biocompatible [3]	Inexpensive[2]
		Paraffin C23–C50		No[2]	189 kJ/kg [11]	Low: 0.2W/(mK) [2]	67 ◦C [1]	No[2]	779 [11]	Large[2]	Nontoxic[3]	Flammable [10]	Noncorrosive[2]	No	Depends	Biocompatible [3]	Inexpensive[2]
		Paraffin wax		No[2]	173.6 kJ/kg [4]	Low: 0.167 (L) - 0.346 (S) W/(mK) [4]	64 ◦C [4]	No[2]	790 (L) - 916 (S) [4]	Large[2]	Nontoxic[3]	Flammable [10]	Noncorrosive[2]	No	Depends	Biocompatible [3]	Inexpensive[2]
		Octadecane		No[2]	200 kJ/kg [10]	Low: 0.2W/(mK) [2]	28 ◦C [10]	No[2]	-	Large[2]	Nontoxic[3]	Flammable [10]	Noncorrosive[2]	No	Depends	Biocompatible [3]	Inexpensive[2]
		Polyglycol E 400		No[2]	99.6 kJ/kg [1]	Low	8 ◦C [1]	No	-	Small [11]	Nontoxic	Flammable [10]	Noncorrosive[2]	Yes	Yes	Biocompatible	-
		Polyglycol E 600		No[2]	127.2 kJ/kg [4]	Low: 0.189 (L) W/(mK) [4]	22 ◦C [4]	No	1126 (L) - 1232 (S) [4]	Small [11]	Nontoxic	Flammable [10]	Noncorrosive[2]	Yes	Yes	Biocompatible	-
		Polyglycol E 6000		No[2]	190 kJ/kg [1]	Low	66 ◦C [1]	No	-	Small [11]	Nontoxic	Flammable [10]	Noncorrosive[2]	Yes	Yes	Biocompatible	-
		Dodecanol		No[2]	200 kJ/kg [10]	Low	17.5–23.3 [11] or 26 ◦C [10]	No	-	Small [11]	Nontoxic	Flammable [10]	Noncorrosive[2]	Yes	Yes	Not biocompatible	-
		Tetradodocanol		No[2]	205 kJ/kg [1]	Low	38 ◦C [1]	No	-	Small [11]	Nontoxic	Flammable [10]	Noncorrosive[2]	Yes	Yes	Not biocompatible	-
		Biphenyl		No[2]	190 kJ/kg [1]	Low	71 ◦C [1]	No	-	Small [11]	Nontoxic	Flammable [10]	Noncorrosive[2]	Yes	Yes	Not biocompatible	-
	polyethylene crosslinked	**HDPE**		No[2]	200 kJ/kg [1]	Low	100 ◦C [1]	No	-	Small [11]	Nontoxic	Flammable [10]	Noncorrosive[2]	Yes	Yes	Not biocompatible	-
		Trans-1,4-polybutadiene		No[2]	144 kJ/kg [1]	Low	145 ◦C [1]	No	-	Small [11]	Nontoxic	Flammable [10]	Noncorrosive[2]	Yes	Yes	Not biocompatible	-
		Propianide		No[2]	168 kJ/kg [1]	Low	79 ◦C [1]	No	-	Small [11]	Nontoxic	Flammable [10]	Noncorrosive[2]	Yes	Yes	Not biocompatible	-
	Aromatic [4]	**Naphtalene**		No[2]	147.7 kJ/kg [4]	Low: 0.132 (L) - 0.341 (S) W/(mK) [4]	80 ◦C [4]	No	976 (L) - 1145 (S) kg/m³ [4]	Small [11]	Nontoxic	Flammable [10]	Noncorrosive[2]	Yes	Yes	Not biocompatible	-
		Erythitol		No[2]	90 kJ/kg [1]	Low	118 ◦C [1]	No	-	Small [11]	Nontoxic	Flammable [10]	Noncorrosive[2]	Yes	Yes	Not biocompatible	-
		Acetamide		No[2]	241 kJ/kg [11]	Low	82 ◦C [11]	No	-	Small [11]	Nontoxic	Flammable [10]	Noncorrosive[2]	Yes	Yes	Not biocompatible	-
		Propionamid		No[2]	-	Low	-	No	-	Small [11]	Nontoxic	Flammable [10]	Noncorrosive[2]	Yes	Yes	Not biocompatible	-
		H2O		Yes	333 kJ/kg [1]	0.59 W/(mK)	0 ◦C [1]	No	1000 [16]	Small [11]	Nontoxic	Nonflammable	Corrosive	Yes	Yes	Biocompatible	Cheap
Inorganic	*Hydrated salts*	**LiClO3-3H2O**		Yes [2]	253 kJ/kg [1]	High: 0.5W/(mK) [2]	8 ◦C [1]	Phase decompositioning [2]	-	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	Cheap [2]
	AB.nH2O [3]	**Mn(NO3)2-6H2O**		Yes [2]	125.9 kJ/kg [2] [10]	High: 0.5W/(mK) [2]	25.8 ◦C [10]	Phase decompositioning [2]	-	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	Cheap [2]
		LiNO3-3H2O		Yes [2]	296 kJ/kg [1]	High: 0.5W/(mK) [2]	30 ◦C [1]	Phase decompositioning [2]	-	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	Cheap [2]
		Zn(NO3)2-6H2O		Yes [2]	246.5 kJ/kg [1]	High: 0.5W/(mK) [2]	36 ◦C [1]	Phase decompositioning [2]	-	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	Cheap [2]
		Na2CO3-10H2O		Yes [2]	146.9 kJ/kg [1]	High: 0.5W/(mK) [2]	34 ◦C [1]	Phase decompositioning [2]	-	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	Cheap [2]
		CaBr2-6H2O		Yes [2]	155.5 kJ/kg [1]	High: 0.5W/(mK) [2]	30 ◦C [1]	Phase decompositioning [2]	-	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	Cheap [2]
		Na2HPO4-12H2O		Yes [2]	265 kJ/kg [1]	High: 0.5W/(mK) [2]	35 ◦C [1]	Phase decompositioning [2]	2190 [11]	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	Cheap [2]
		Na2S2O3-5H2O		Yes [2]	201 kJ/kg [1]	High: 0.5W/(mK) [2]	47.5 ◦C [1]	Phase decompositioning [2]	1750 [11]	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	Cheap [2]
		Na(CH3COO)·3H2O		Yes [2]	264 kJ/kg [1]	High: 0.5W/(mK) [2]	57.5 ◦C [1]	Phase decompositioning [2]	1450 [11]	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	Cheap [2]
		Na2P2O7-10H2O		Yes [2]	184 kJ/kg [1]	High: 0.5W/(mK) [2]	70 ◦C [1]	Phase decompositioning [2]	-	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	Cheap [2]
		Ba(OH)2-8H2O		Yes [2]	265.7 kJ/kg [4]	High: 0.65 (L) - 1.23 (S) W/(mK) [4]	48 ◦C [4]	Phase decompositioning [2]	1937 (L) - 2070 (S) [4]	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	Cheap [2]
		Mg(NO3)2-6H2O		Yes [2]	162.8 kJ/kg [4]	High: 0.49 (L) - 0.61(S) W/(mK) [4]	89 ◦C [4]	Phase decompositioning [2]	1550 (L) - 1636 (S) [4]	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	Cheap [2]
	Glauber's salt	**Na2SO4-H2O**		Yes [2]	254 kJ/kg [2] (377 MJ/m3 [3])	High: 0.5W/(mK) [2]	32.4 ◦C [4]	Phase decompositioning [2]	-	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	Cheap [2]
		CaCl2 6H2O [4]		Yes [2]	190.8 kJ/kg [4]	High: 0.54 (L) - 1.088 (S) W/(mK) [4]	29 ◦C [4]	Phase decompositioning [2]	1562 (L) - 1802 (S) [4]	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	Cheap [2]
		(NH4)Al(SO4)-6H2O		Yes [2]	High: 240 kJ/kg [2]	High: 0.5W/(mK) [2]	32-35 ◦C	Phase decompositioning [2]	-	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	One of the cheapest[2]
		MgCl2·6H2O		Yes [2]	168.6 kJ/kg [4]	High: 0.57 (L) - 0.69 (S) W/(mK) [4]	117 ◦C [4]	Phase decompositioning [2]	1450 (L) - 1569 (S) [4]	Large	Nontoxic[3]	Nonflammable[2 3]	Corrosive [2]	Yes	Yes	Reacts with skin and metals	Cheap [2]
		NaNO3		Yes [2]	172 kJ/kg [1]	Good [2]	307 ◦C [1]	Phase decompositioning [2]	-	-	Nontoxic	Nonflammable[2]	Corrosive [2]	Yes	Yes	Biocompatible	Cheap [2]
		KNO3		Yes [2]	266 kJ/kg [1]	Good [2]	333 ◦C [1]	Phase decompositioning [2]	-	-	Nontoxic	Nonflammable[2]	Corrosive [2]	Yes	Yes	Biocompatible	Cheap [2]
		MgCl2		Yes [2]	542 kJ/kg [1]	Good [2]	714 ◦C [1]	Phase decompositioning [2]	-	-	Nontoxic	Nonflammable[2]	Corrosive [2]	Yes	Yes	Biocompatible	Cheap [2]
		NaCl		Yes [2]	492 kJ/kg [1]	Good [2]	800 ◦C [1]	Phase decompositioning [2]	-	-	Nontoxic	Nonflammable[2]	Corrosive [2]	Yes	Yes	Biocompatible	Cheap [2]
		Na2CO3		Yes [2]	275 kJ/kg [1]	Good [2]	854 ◦C [1]	Phase decompositioning [2]	-	-	Nontoxic	Nonflammable[2]	Corrosive [2]	Yes	Yes	Biocompatible	Cheap [2]
		KF·4H2O		Yes [2]	231 kJ/kg [10]	Good [2]	18.5 ◦C [10]	Phase decompositioning [2]	1450 [11]	-	Nontoxic	Nonflammable[2]	Corrosive [2]	Yes	Yes	Biocompatible	Cheap [2]
		K2CO3		Yes [2]	235.8 kJ/kg [1]	Good [2]	897 ◦C [1]	Phase decompositioning [2]		-	Nontoxic	Nonflammable[2]	Corrosive [2]	Yes	Yes	Biocompatible	Cheap [2]
Eutectic	*Inorganic eutectics*	**58.7% Mg(NO)3-6H2O+ 41.3% MgCl2-6H2O**		Yes	132 kJ/kg [1]	Good	59 ◦C [1]	Phase decompositioning	-	Large	Nontoxic	Nonflammable	Corrosive	Yes	Yes	Reacts with skin and metals	Cheap
		66.6% CaCl2-6H2O+ 33.3% MgCl2-6H2O		Yes	127 kJ/kg [10]	Good	25 ◦C [10]	Phase decompositioning	-	Large	Nontoxic	Nonflammable	Corrosive	Yes	Yes	Reacts with skin and metals	Cheap
		48% CaCl2 + 4.3% NaCl + 0.4% KCl + 47.3 H2O		Yes	188 kJ/kg [10]	Good	26.8 ◦C [10]	Phase decompositioning	-	Large	Nontoxic	Nonflammable	Corrosive	Yes	Yes	Reacts with skin and metals	Cheap
		47% Ca(NO3)2·4H2O+ 53% Mg(NO3)2·6H2O		Yes	190.8 kJ/kg [1]	Good	29 ◦C [1]	Phase decompositioning	-	Large	Nontoxic	Nonflammable	Corrosive	Yes	Yes	Reacts with skin and metals	Cheap
		60% Na(CH2COO) ·3H2O+ 40% CO(NH2)2		Yes	136 kJ/kg [1]	Good	30 ◦C [1]	Phase decompositioning	-	Large	Nontoxic	Nonflammable	Corrosive	Yes	Yes	Reacts with skin and metals	Cheap
		66.6% Urea + 33.4% NH4Br		Yes	161 kJ/kg [1]	Good	76 ◦C [1]	Phase decompositioning	-	Large	Nontoxic	Nonflammable	Corrosive	Yes	Yes	Reacts with skin and metals	Cheap
	Fatty acid eutectic	**Palm Kernel Oil [5]**		No[2]	74.35 (L) - 75.24 (S) kJ/kg [5]	Low: 0.2 W/(mK) [5]	26.53 (L) - 23.30 (S) ◦C [5]	No		Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Biocompatible	´abundant feedstock st
		Sunflower oil		No[2]	2115 kJ/kg K [21]	Low: 0.16 [20]	- 17 ◦C [21]	No	930 [20]	Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Biocompatible	´abundant feedstock st
		Coconut Fat [6]		No[2]	106.17 (L) - 107.34 (S) kJ/kg [6]	Low: 0.18 W/(mK) [6]	22.63 (L) - 17.44 (S) ◦C [6]	No	924 [19]	Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Biocompatible	´abundant feedstock st
	80% butterfat, 16% moisture and 2%	**Butter**	*wide melting range*	No	1465 (-40◦C) - 2300 (40◦C) kJ/kg K [13]	0.163 (S) - 0.329 (L) W/(m.K)	10 (L) - 40 (S) ◦C [13]	No	-	Small	Nontoxic	Flammable	Noncorrosive	Yes	Yes	Biocompatible	Cheap
		Beef tallow		No	-	0.2217 W/(m.K) [15]	40-50 ◦C [12]	No	1053 [16]	Small	Nontoxic	Flammable	Noncorrosive	Yes	Yes	Biocompatible	Cheap
		Pork Lard		No	-	0.1590 W/(m.K) [15]	34-44 ◦C [12]	No	-	Small	Nontoxic	Flammable	Noncorrosive	Yes	Yes	Biocompatible	Cheap
		Poultry fat		No	-	-	23-40 ◦C [12]	No	-	Small	Nontoxic	Flammable	Noncorrosive	Yes	Yes	Biocompatible	Cheap
		Human fat		-	-	0.2008 W/(m.K) [15]	0 (S) - 36.6 (L) ◦C [17]	No	-	Small	Nontoxic	Flammable	Noncorrosive	Yes	Yes	Biocompatible	?
	(wt.%)	**Lauric - Capric (27 - 73)**		No[2]	120 (L) - 113 (S) kJ/kg [9]	Low	18 - 20 (L) - 16 (S) ◦C [9]	No	-	Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	-
	(wt.%)	**Lauric - Palmitic (80 - 20)**		No[2]	147 (L) - 149 (S) kJ/kg [9]	Low	32.7 - 35.6 (L) - 29-20 (S) ◦C [9]	No	-	Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	-
	(wt.%)	**Lauric - Stearic (85 - 15)**		No[2]	152 (L) - 155 (S) kJ/kg [9]	Low	34 - 36.7 (L) - 31 (S) ◦C [9]	No	-	Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	-
	(wt.%)	**Palmitic - Stearic (72.5 - 27.5)**		No[2]	159 (L) - 161 (S) kJ/kg [9]	Low	51.1 - 53.8 (L) - 50 (S) ◦C [9]	No	-	Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	-
	(wt.%)	**Lauric - Capric (55 - 45)**		No[2]	143 kJ/kg [11]	Low	17-21 ◦C [11]	No	-	Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	-
	(wt.%)	**Palmitic - Capric (23.5 - 76.5)**		No[2]	171.2 kJ/kg [11]	Low	21.8 ◦C [11]	No	-	Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	-
	(wt.%)	**Lauric - Myristic (66 - 34)**		No[2]	166.8 kJ/kg [11]	Low	34 ◦C [11]	No	-	Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	-
	(wt.%)	**Lauric - Palmitic (69 - 31)**		No[2]	166.3 kJ/kg [11]	Low	35 ◦C [11]	No	-	Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	-
	(wt.%)	**Lauric - Stearic (75.5 - 24.5)**		No[2]	182.7 kJ/kg [11]	Low	37 ◦C [11]	No	-	Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	-
	(wt.%)	**Myristic - Palmitic (58 - 42)**		No[2]	169.7 kJ/kg [11]	Low	42.6 ◦C [11]	No	-	Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	-
	(wt.%)	**Myristic - Stearic (64 - 36)**		No[2]	182.4 kJ/kg [11]	Low	44.1 ◦C [11]	No	-	Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	-
	(wt.%)	**Myristic - Stearic (65.7 - 34.3)**		No[2]	162 kJ/kg [11]	Low	50-52 ◦C [11]	No	-	Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	-
	(wt.%)	**Palmitic - Stearic (64.2 - 35.8)**		No[2]	181.7 kJ/kg [11]	Low	52 ◦C [11]	No	-	Small[2]	Nontoxic[2]	Flammable	Noncorrosive[2]	Yes	Yes	Reacts w/ environment (acidic) [3]	-
Solid - solid	*Polyalcohol as SS-PCM*	**pentaerythritol [2]**	*C(CH2OH)4*	-	289.0–339.5 kJ/kg [11]	-	185–187 ◦C [11]	No	-	None	Nontoxic	-	Noncorrosive	Yes	Depends	Solid	Expensive
melting temp30 - 600 de	*Polyalcohol as SS-PCM*	**pentaglycerine**	*CH3C(CH2OH)3)2*	-	172 kJ/kg [11]	-	82 ◦C [11]	No	-	None	Nontoxic	-	Noncorrosive	Yes	Depends	Solid	Expensive
	Polyalcohol as SS-PCM	**polyethylene glycol**		-	70 kJ/kg [18]	-	25-60 C [18]	No	-	None	Nontoxic	-	Noncorrosive	Yes	Depends	Solid	Expensive
	Polyalcohol as SS-PCM	**neopentyl glycol**	*(CH3)2C(CH2OH)2*	-	110–119 kJ/kg [11]	-	42-44 ◦C [11]	No	-	None	Nontoxic	-	Noncorrosive	Yes	Depends	Solid	Expensive
		diethylene glycol hexadecyl ether-grafted g	*esterification reaction*	-	70 (L) - 72 (S) kJ/kg [7]	Low: 0.2346 W/mK [7]	43.3 (L) - 29.4 (S) ◦C [7]	No	-	None	Nontoxic	-	Noncorrosive	Yes	Depends	Solid	Expensive

Conclusions from Matrix

Conclusions reflecting on formulated desires

Paraffin does not meet the criteria because its petrochemical nature, unless formed by natural fatty acids as counts for Paraffin C18 - C18.

Only the combination of pure fatty acids (hereby it becomes an organic eutectic mixure) enables a suitable melting temperature around for a habitable room (21-23 winter, or 23 - 25 summer). CA, LA and UA have potential in pure form application depending on the use of the designed system.

Polyglycol E600 seems to have perfect characteristics for direct application.

The same counts for Dodecanol; depending on the source information.

Hydrated salts have suitable properties but: phase decompositioning occurs has to be minimalized when applied and slight adjustments have to be made to the reach desired melting temperatures.

Palm Kernel Oil and Coconut fat have ideal properties regarding melting temperature, bio-based origin and thereby the possibility of recycling.

Butter has a wide range for the melting temperature (30 degrees difference). However, adjusting this - perhaps by mixing with NaCl - would be valuable for further research.

Ideally, all organic PCM's shall be gained from abundent feedstock supplies.

Organic eutectics as LA - CA (55/45) and PA - CA (23.5/ 76.5) have ideal melting points.

Coconut fat, Palm Kernel Oil do not need modification and proceedings to reach the desired melting point around room temperature than other organic eutectics.

SSPCM's have unsuitabe melting temperatures and need specialised (scientific) procedures to be manufactured.

Latent heat fusion properties are not leading values in choice for PCM type since they are relative to the amount that is applied. Within the concept there is room for unlimited amount of PCM.

The thermal conductivity properties are lower for organics than for non-organics. What follows is that organics have a somewhat better insulational property but do need smaller scale encapsulation in order to be in contact with more medium. Inorganic compounds have higher thermal conductivity and would by definition be more suitable for larger scale encapsulation.

Questions for further research

What encapsulation size fits which thermal conductivity?

What is the latent heat capacity of common oils, as sunflower oil?

How could the melting point of an organic material be adjusted?
- melting of 2 components, of which one with lower melting temperature, for several hours above the temperature of the material with highest melting point

Does this way of mixing withstand decompositioning?

Fatty acids do not but inorganic salts do have decompositioning behaviour after many cycles, how is this risk taken away in existing applications of the material?

How is flame redarding adjustment done for organic PCM's.

What are the encapsulation materials and techniques?

How can a fatty acid be obtained in commercial economy or circular economy manners?

How can polyglycol E600 be obtained inexpensively and without too many proceedings?

How are hydrated salts made?

	Frying oil		LHC 169 J/g
1/3	Rapeseed Oil	%	LHC [J/g]
	Palmitic acid	4	185,4
	Stearic acid	2	222
	Oleic acid*	56	172
	Linoleic acid*	26	164
	Linolenic acid	10	164
	Other	2	Other
	Average		**170 J/g**
2/3	Sunflower Oil	%	LHC [J/g]
	Palmitic acid	6	185,4
	Stearic acid	4	222
	Oleic acid*	16	172
	Linoleic acid*	73	164
	Other	1	Other
	Average		**169 J/g**

Oleic acid*
$\Delta_{fus} H^o$ = 45.62 kJ/mol
mass = 282 g/mol
LHC = 172 J/g

Linoleic acid*
$\Delta_{fus} H^o$ = 45.88 kJ/mol
mass = 280.45 g/mol
LHC = 164 J/g

Encapsulation techniques

PCM´s have the tendency to melt when properly used. Direct application of this material is not wishful. It melts and might smell, thus very inconvenient. In order to prevent this from happening, encapsulation techniques have been developed on various scales: micro scale and macro scale. In brief, classified as nanoencapsulation counts uptil 1 µm size, microencapsulation focusses on 1 µm to 1 mm size, whereas the macroencapsulation is supposed to function as a container for the substance larger than 1 mm (Pendyala, 2012). It is important to notice that although encapsulation enables comfortable application for the user, it does form a thermal barrier between the PCM and the environment, even so it is cost increasing to use encapsulation (Jamekhorshid et al., 2014).

Microencapsulation

There are several techniques in chemistry which ensure microencapsulation for PCM molecules. This technique is the best option in terms of increasing the heat transfer rate, preventing leakage and volume change and reducing the reactivity with the outside environment (Jamekhorshid et al., 2014). The microencapsulation is essentially the covering of a PCM molecule with a microscopic coating. This coating can be a polymer or an inorganic shell.

For physical methods, the microcapsule wall is applied in a mechanical way, around the core of the capsule. During pan coating substance containing a solid is heated up, so that the solid melts around the liquid particles, widely used in pharmaceutical industry. Air-suspension coating suspends the substance upwards by air stream, during this process the substance is dried and coated. Centrifugal extrusion brings solid and liquid particles together after moving them around spirally, ending up in a chemical bath they are coated. Vibration nozzle is based on lamination of particles, however, mostly used in form-stable PCM fabrication. Spray drying on the other hand is a process where core and shell (intimite amounts) are sprayed in a hot chamber, whereby evaporation ensures encapsulation (Jamekhorshid et al., 2014).
Physic-chemical methods result in solid and stable particles. Ion gelation is used in pharmaceutical industry most often, and not for PCM's (yet). Coacervation is simply described, the dissoving polymer that encapsulates a low molecular substance. Sol-gel is a relatively new technique for microencapsulation (Jamekhorshid et al., 2014).

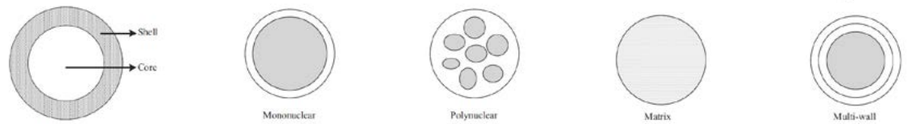
Overall, microencapsulation techniques often require expensive and specialised equipment or highly skilled executors.

Macroencapsulation

For a more accessible production process of PCM macroencapsulation offers four possibilities according to (Pendyala, 2012):

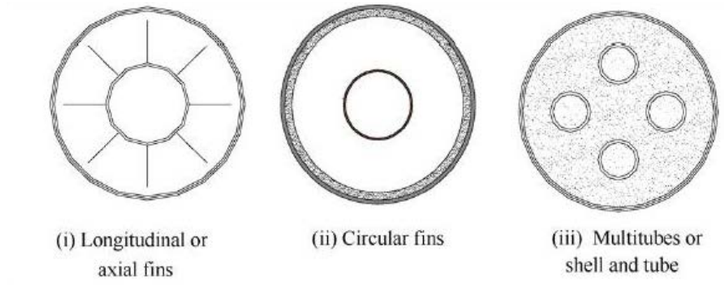
1. Impregnation of high conductivity porous material with the PCM
2. Dispersion of high conductivity particles in the PCM
3. Placing of metal structures in the PCM
4. Use of high conductivity, low density materials

Morphology of Microcapsule
Jamekhorshid et al., 2014



	Microencapsulation technique	Advantages	Disadvantages
Physical methods	Pan coating	Low-costequipment	High skill level required Difficult to control
	Air-suspension coating	Low cost Higher productionvolume	High skill level required Agglomeration of particles
	Centrifugal extrusion	Suitable forbioencapsulation	High temperature
	Vibrational nozzle	High yields of production Easy toscale-up	High temperature
	Spray drying	Equipment and know-how widely available Versatile Easy toscale-up	High temperature Agglomeration of particles Remaining uncoated particles
	Solvent evaporation	Low cost	Lab scale production
Physic - chemical methods	Ionic gelation	Low cost Low temperature	High wall permeability
	Coacervation	Versatile Efficient control of the particle size	Aldehyde as hardener Difficult to scale-up Agglomeration
	Sol-gel	Inorganic shell with high thermal conductivity	Still under research

Overview of microencapsulation techniques (rewritten from Jamekhorshid et al., 2014)



Conductivity optimisations for macroencapsulation containers (Pendyla, 2012)

Quick sampling

Impregnation of high conductivity porous material with the PCM is based in the idea that a PCM could have a porous host material so that it is fully integrated combination. Often those materials are high cunductivity materials as graphite, aluminum or copper. Dispersion of high conductivity particles in the PCM is based on the same principle but without one major disadvantage; too small pores prevent the mixture from conducting properly. The placing of metal structures in PCM is another macroencapsulation technique. Steel or stainless steel shaped containers as spheres or cilinders belong to this category. The conductivity depends on the diameter of such shaped container but could be increseased by the use of fins on the interior side. Finally, the use of high conductivity, low density materials is an alternative for the use of steel, which is relatively expensive. Plastics or carbon is mostly used for this last encapsulation technique (Pendyala, 2012); it is light weight, inexpensive and can be transparant. The use of a transparant container emphasises on the phase change occurance in visual sense, which is a huge architectural quality.

In conclusion, plastic macroencapsulation will be a cheap, architectural (and visual), light weight solution for encapsulation vegetable based PCM's for the module.

Stackable plastic containers (pcmenergy.com)

Ceramic seald capsule (Wickramaratne et al., 2018)

Rubitherm aluminum panel (Rubitherm)

In order to find the balance between practice and theroy I tried to sample two types of PCM. Coconut fat and hydrated salts from Rubitherm show their behaviour in two different states; semi-solid and liquid. Conclusively, the hydrated salts and coconut fat melt around the same temperature of 20 - 23 degrees and with the same speed. The apperance of hydrated salts seems more translucent in liquid state than coconut fat in the sense that it seems colourless. However, little residue seems to appear in the hydrated salt composition, whereas coconut oil is homogenous.

Hydrated Salt
Semi/solid state

Coconut fat
Semi/solid state

Hydrated Salt
liquid state

coconut oil
liquid state

Interviews

Croda
Interview

In my curiosity I contacted Croda; a company that manufactures bio-based PCM located in a former candle factory in Gouda. It cannot get more Dutch! Marco Auerbach, Technology Development Manager of Croda, was hospitable to receive me as a visitor and shared with me his enthousiasm about the material.

Material choice
For choosing the right PCM, specific properties attached to the materials, are very important. We name it a PCM when it has a Latent Heat Capacity (LHC) of 150 - 165 J/g. Also thermal conductivity of the material is something to take into account. This conductivity is specific for the type of material and is lower for bio-based PCM's than for paraffins for example. Actually this properties counts more for sensible heat properties / materials. Impurities of the material (or mixture) have effect on those material properties. They change the LHC and the melting temperature range of the PCM. Factors on molecular scale that influence this are branching, double bonds, and unsaturated structures. They decrease the melting temperature but also the LHC. Frying oil gained from waste material is polluted and very impure. It would need many purification processes, which increase the costs of the final material as a PCM. My estimation is that frying oil will have a LHC of around 20 J/g in impure state. This value competes with sensible heat storage materials and thus would be not very useful. For example, if we look at the gaining of paraffin from petroleum, many purification processes on various scales are used to finally end with a pure material. Firstly large scale separation is used and furthermore chemistrical segregation processes occur.

Coconut fat is already much more pure, it might be an option. However, if we look at the composition of it we see it is composed of several fatty acids. Perhaps combining the preferred fatty acids leads to a more specific material with desirable properties. It seems plausible that ending with a LHC of around 60 - 80 J/g is the final performance. This means that at least two to three times more of the material has to be applied for the same climatic performance. Perhaps Palm Kernel oil would be an even better choice.

Natural oils are flammable and the materials that we produce here have a flammability much better than paraffin. The flaming point of a material is the temperature by which it shows a first flame but when it does not burn yet. The burning point is the temperature where it burns and is flammable, on average this is around 20 degrees higher than the flame point. The bio-based PCM's we make here burn at around 160 degrees. A paraffin wax does at, let's say, 50 degrees lower. The containers used are not specifically for flame retardant purpose.

Material
The biobased product that we make in this factory is a chemical reaction of specific substances, which optimises the properties for the PCM material, to be used as such. The process is very scientific and costly, it demands a specialist manufacturing process. The PCM's produced have a wide range of melting temperature. This comes to being by combining different substances which means that they are not all based on the same components mixed in a different way. The idea of these bio-based PCM's is that they are very accessible in their application, regarding their specific melting range of e.g. 1-2 degrees, and that they do not interfere negatively with surrounding materials. They are not corrosive, so they are biocompatible; getting in touch with them physically does not result in wounds or irritation. Although we don't tell our clients this, it should be the origin of the material composition.

Hydrated salts are very corrosive. For metallic materials and for the human skin, so it is a dangerous application. In this case the encapsulation choice is mostly plastic, which is also the only protection between the PCM and the surrounding. Autarkis has optimised the shape op the plastic container, in such a way that two orientations are suitable only for its durable usage: horizontally and vertically (only 1 orientation). If used in a different way, the risk of segregation comes to existence. THe PCM container is about two centimeters thick: if used wrongly the salt segregates from the water, whereby its latent heat capacity is disabled. At that moment, the mixture becomes a sensible heat storage component, something not desirable. For salt hydrates therefor the container dimensions are very important.

Encapsulation
For encapsulation techniques the first reason is to prevent leakage. With macroencapsulation the risk of leakage is larger than with microencapsulation. If you drill a hole in the wall where there is a PCM hidden behind the gypsum, leakage is inevitable. It makes a mess and it the working principle of the PCM application is lost. Macro encapsulations can be RVS or HDPE or PE, however, PE might even be risky for example when using hydrated salts. There are various shapes available: modular stackable components, flat containers or spheric ball shapes of various sizes. A ball shape is actually very inefficient in combination with PCM. That spheric shape has

geometrically seen the smallest ratio of surface / volume. However, when PCM is applied, optimal surface contact with air (or other medium) is preferred. The example of the Global- e-systems project using PE balls of 10 cm diameter and a hydrated salt as PCM has been disappointing. With such size of ball shaped containers only the outside 1 centimeter of the PCM crystallizes which indicates not all PCM is efficiently in use. Also with a diameter of 10 centimeters the segregation takes place, as I mentioned before.

For microencapsulation, the shape is not specifically designed but more defined by the molecular structure and encapsulation technique. Here it actually is a ball shaped encapsulation as well, but very small. Only 5 micrometers is the actual size of the element; smaller than a hair. There is a wide range of possibilities for applying this type of PCM. For example, in gypsum wallboard! And no leakage will occur when you drill a hole in the wall due to the microscopic size of these PCM elements. Not specifically interesting for your desired application of PCM. Microencapsulation is expensive and a specialized process.

We have several non Solid - Liquid PCM's as well. They are composites. The gelly one contains a PCM and a polymer, the dark one is a composite of three materials and contains graphite as third additive. Graphene has a better performance, but is significantly more expensive (200-300 euros a kilogram). By combining the PCM with additives, obviously you lose the LHC of the new composition. For the composite with three materials, this is around 75 - 80 % of the PCM in pure state.

These three samples are :

1) gelly two component mixture
2) semi-solid three component mixture (with graphite)
3) sandwich panel of aluminum foil containing the 2)

PCM Technology

Interview

In my curiosity I also contacted PCM Technology; a company that manufactures ydrated salts as PCM, located in a modest factory in Ootmarsum. Gerard Oortman, Director of PCM Technology, shared with me his enthousiasm for salt hydrates and showed me around in the factory.

The modules from PCM Technology are contain about 1,4 kg of PCM in 1 liter. This is a relatively high density and thus rather efficient. For paraffin waxes or other PCM´s this is ratio is about 1-1 or even less. Autarkis mentions that 10 kg per m2 should be applied in order to reach an effective amount of PCM for room temperature control. In practice, it is 6 kg - m2 average that is applied in ceilings. Due to the fact that not all false ceiling panels can be covered with PCM containers (because of specific use of these panels by ventilation or fire systems). In other words, 60% of the ceiling is covered with 10 kg/m2. Often, we even advice to take 5% extra amount, so that we can guaranty it works according to the desired needs.The hydrated salt combination used for our PCM's is composed of 95% CaCl and 5% of different salts, that eventually define the melting trajoct of the requested PCM module. CaCl comes from the production of MgCl, and is actually a waste product in this process located in Veendam. It might be seen as a salt hydrate and not as an eutectic mixture because an eutectic is about 50% of each substance. This hydrated salt is primarily CaCl. Within the 5% of additional different salts, some salts are used that do not melt during the functioning of the PCM so that cristallisation takes place of the other amount of present salts. Salts need a crystallisation-guide, that ensures equal crystallisation within the substance and prevents from subcooling. In liquid state, these particles are visible and seem a residue. It is tested on 10,000 cycli and loses in this time less than 10% capacity. If we calculate the amount of years that it can be used properly, according to the tests, it is for about 27 years. Payback time is 7 years for the cooling expenses and 1,5 years for a datacentre's cooling load.

When I proposed my new compostion of frying oil and coconut oil, it did not seem plausible enough to Gerard. He suspects difficulties of segregation. "I did some tests with 2 PEG (Poly Ethylene Glycol) types with different melting points. I thought it would be easy but I ended up with a composition the still contained two different melting temperatures." If the same occurs with the fatty acids is not quite sure, assuming the information gained from Marco Auerbach, it might even be possible.

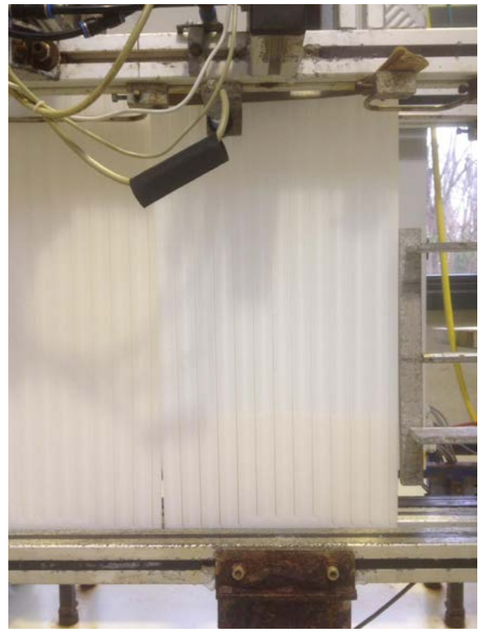
Encapsulation
The encapsultion for these hydrated salts are HDPE containers with a patented design. The tickness is maximum of 15 mm due to the segregation of hydrated salts in larger volumes. The white containers are tested on leakage before and after they are filled with the PCM solution. After filling the container the air pressure test in a isolated chambers measures 4 millibar in order to find possible leakage. The thickness of the container is 0,6 mm which has a thermal resistancy of 1/2 or 1 K.

An alternative encapsulation is produced by PCM Technology as well. Instead of the large containers used for floor heating systems, small capsule mats are tested at the moment. One that allows for connection of the piping system directy into the PCM panel. PCM used for this one is a dry pellet capsule.

Subsidy
It is possible to get subsidies for the production of PCM in the Netherlands. The RVO uses a minimum efficiency of 110 J-g latent heat capacity. However, the hydrated salts prodroduced by PCM Technology reach the efficincy of about 190 - 200 J /g. For the subsidy this has no effect, for the application a double efficiency decreases the necessary amount of volume by half.

Application
PCM applications in the floor are only usefull if the module is not placed low in the floor. Therefor placing them underneath the piping is relatively useless, it will expose the thermal energy not directly to the top floor or room, but more to the construction underneath. With the panels composed of fermacel, a light weight alternative for concrete, is applied to host the pcm module and the piping system of the floor heating. Thickness of this floor is limited. This application is usefull for wet or dry construction of floors. Wet floors are anhydryte floors for example, but also dry types as a wooden top floor does allow for this PCM application. Wet floors are not wishful for specific building renovations, as the dutch canal houses.

Encapsulation space: 40 PCM is pumped around an machinally fills the HDPE containers, then it falls in the 'crib' before it is tested on leakage (not in photograph)



HDPE containers is being filled

Case studies

The case studies give new insights in the use of PCM. These cases show the seemingly unlimited options of the material. Where the state-of-the-art image momentarily limits the enthousiasm for its wide implementation in the built environment, this brief analysis gives shows the other side.

In this case study analysis 16 projects are analysed. All are compared according to similar properties regarding climatic performance, material property and type, location of implementation, the system to which it contributes, additional indormation, working principle in different stages of the day and year. Also for some principle details are shown. Some information was hard to find, thus not all of the study cases are ‘complete’ according to the template. For the study cases different measurements have been found for the same comparing values, for example this counts for the contibution to energy performance.

The results of this overview of current applications of PCM in the built environment are presented in a matrix. From the comparison of those 16 projects some rules of thumb are extracted. The different applications also function as an inspiration for the PCM modules to be designed, produced and installed accessibly.

Legend

Water flow on desired room temperature

Warm water flow

Chilled water flow

Warm air exhaust

Controlled air supply

Thermal energy produced by sun, people and devices

Natural airflow (warm)

Natural air flow / ventilation (cold)

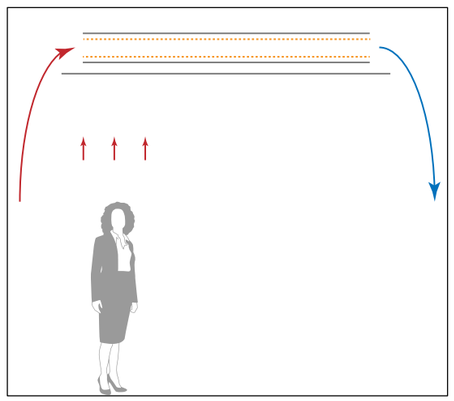
01 DRIJVEND PAVILJOEN

In the auditorium, PCM is applied on top of the false ceiling. The heat demand is rapidly changing due to its functional use. The temperature fluctuations are decreased by the PCM. For cooling during the day, the recirculation of air alongside the PCM and by the indirect adiabatic coling in combination with sorption and solar collectors.
In the evening the HVAC / natural ventilation ensure ‘rechargement’ of the PCM: cold air solidifies the material.

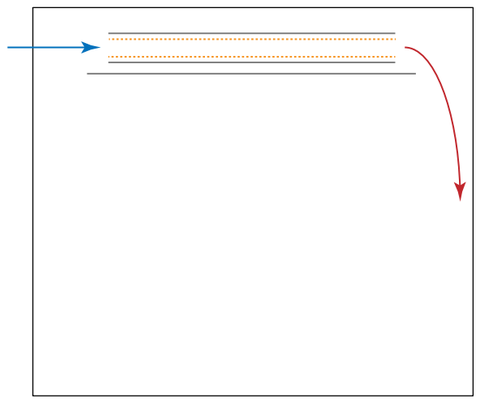
Specific information

Located in:	Ventilation shaft
type:	?
amount:	2000 kg total
capacity:	W/m²
melting temperature:	? °C
medium:	Air
efficiency increase:	? %
combined with:	Night ventilation
main use:	**Cooling** / heating
system:	**Active** / passive
function building:	Auditorium
project type:	**New** / renovation
additional:	-

Rotterdam, The Netherlands
Temperate climate



Occupied space



Empty space

02 WILO

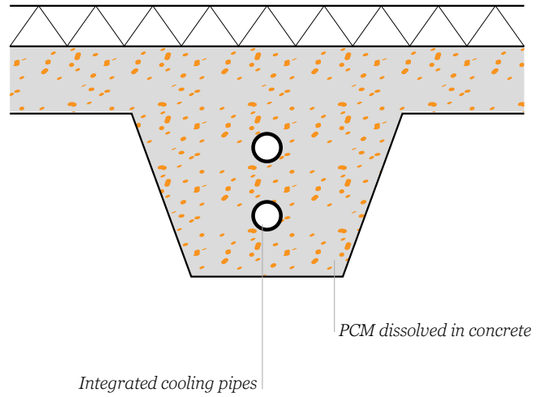
The office building contains a multifunctional roof. By perforated steel plate the functions for acoustic needs and climatological needs are optimised. The concrete poured (in-situ) contains a mixture of Micronal PCM whereby its thermal storage function increased by more than 50%. The weight of the micronal PCM is only 4% of the total roof weight.

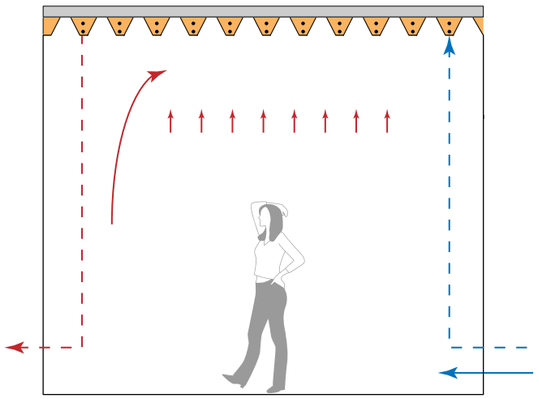
The combination of a tube system carrying water ensures an equal division of the PCM cooling function over the whole space. This prevents local heat sources from activating the PCM locally in the roof structure.

Specific information

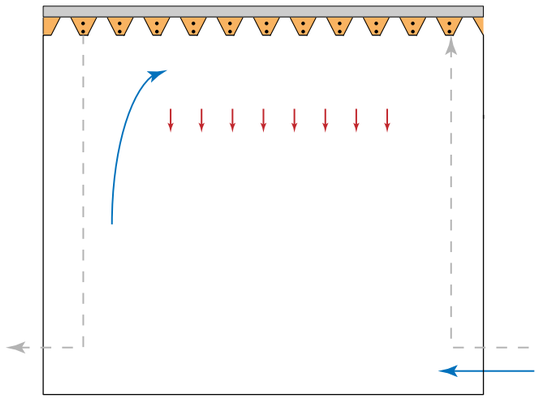
Located in:	Concrete roof
type:	Micronal 5030 X
amount:	4 % of weight roof structure
capacity:	? W/m²
melting temperature:	21 °C
medium:	Air + water
efficiency increase:	40 - 50 % or cooling
combined with:	- Piping system w/ water - Natural ventilation
main use:	**Cooling** / heating
system:	Active / **passive**
function building:	Office
project type:	**New** / renovation
additional:	PCM was soluted in water. This PCM solution was then added to the water that the concrete needs to solidify: integral mixture.

Westzaan, The Netherlands
Temperate climate

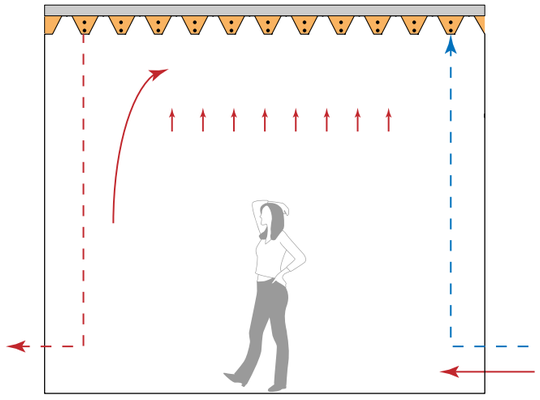




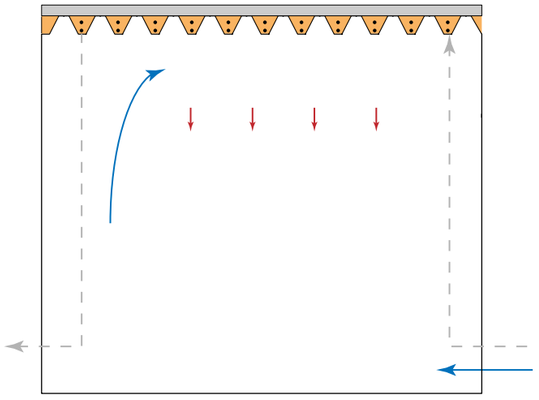
Summer / Day



Summer / Night

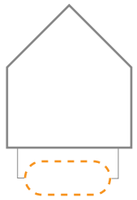


Winter / Day



Winter / Night

03 COUNCIL HOUSE 2

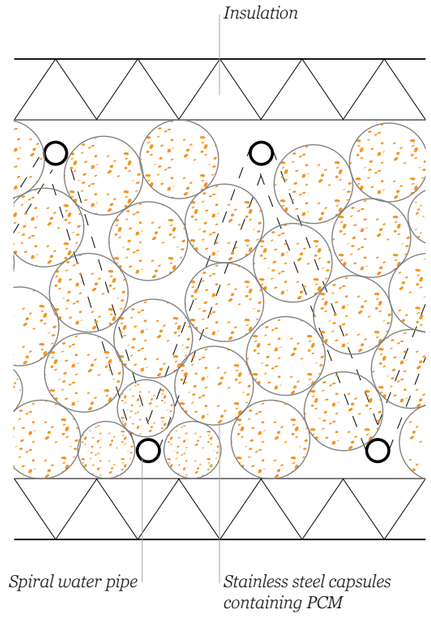


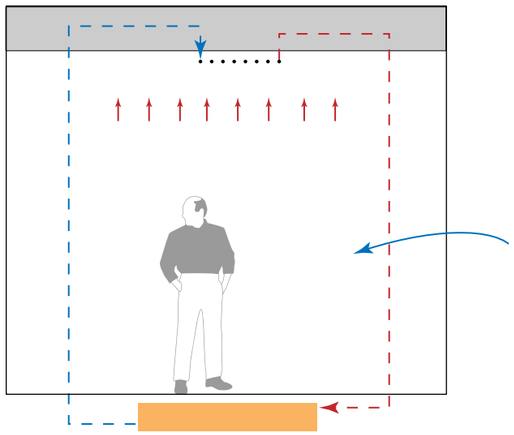
For the chilled ceilings, water is pre-cooled by three large tanks containing a total of 10,000 steel balls with a salt solution. The freezing point of the PCM is 16 degrees. From the chilled ceiling the water returns 2-3 degrees warmer so that heat exchange takes place in the PCM tanks.
To recharge the battery in summer, cool night air is used to cool the water in the closed system. The water is put through a cooling tower on the roof, where evaporative cooling takes place.
In winter time, the night air cooling the floors has sufficient capacity to cool the water of the chilled ceilings. Then the water flows through the battery to recharge the PCM tanks.

Specific information

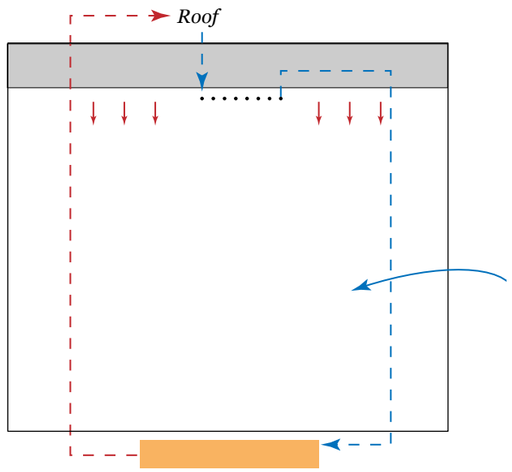
Located in:	Tank in the basement
type:	Salt hydrates
amount:	10,000 steel balls
capacity:	? W/m²
melting temperature:	16 °C
medium:	Water
efficiency increase:	100 % for cooling
combined with:	- Chilled ceiling panels - Piping w/ water - Natural ventilation - Evaporative cooling
main use:	**Cooling** / heating
system:	**Active** / passive
function building:	Office
project type:	**New** / renovation
additional:	Functions as a thermal battery in the basement of the building.

Melbourne, Australia
Temperate oceanic climate

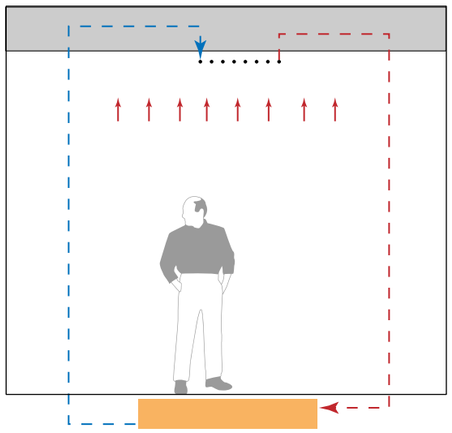




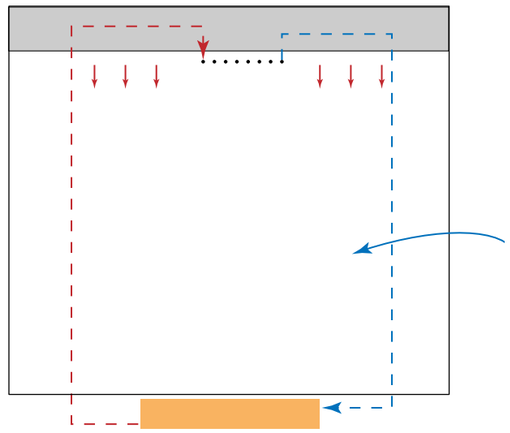
Summer / Day



Summer / Night

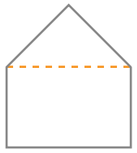


Winter / Day

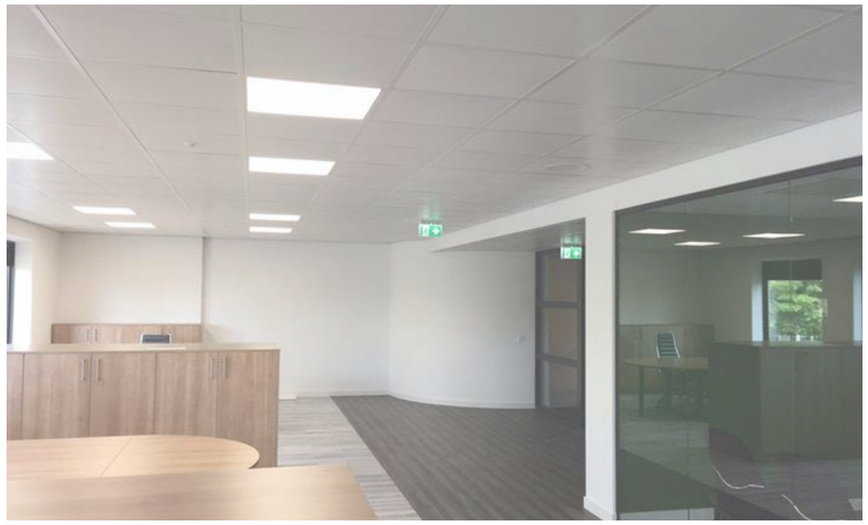


Winter / Night

04 HOGESCHOOL ROTTERDAM



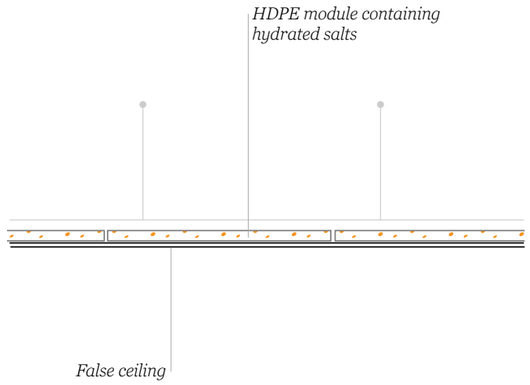
The ´climate ceilings´ do not contain water for cooling the room. The medium used is a Salt hydrate that is encapsulated in large plastic packages. The heat produced by machines and humans during the day is captured by the phase transition of the material.
In the night time (artificial) ventilation allows the PCM to expose the energy in the form of heat, to its surrounding. Hereby the phase transition from liquid to solid occurs. The climate ceiling is brought back in its original state, just below the desired room temperature.

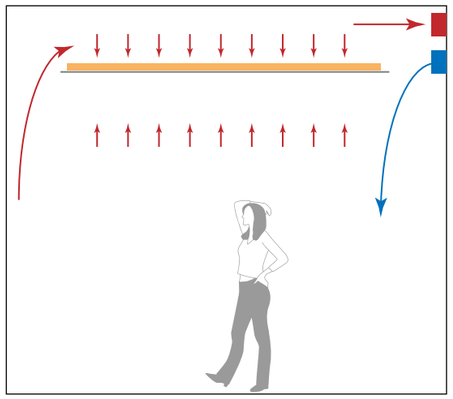


Specific information

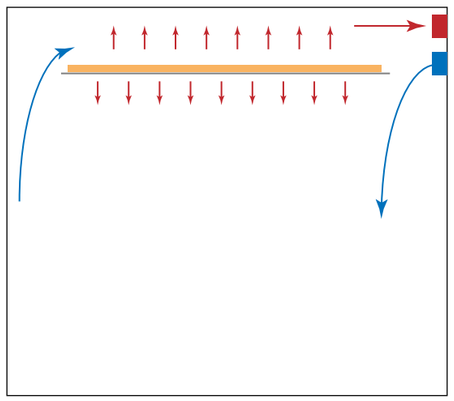
Located in:	Ceiling
type:	Salt hydrates (calcium hexahydrate)
amount:	10 kg /m²
capacity:	20 W/m²
melting temperature:	21 - 23 °C
medium:	Air
efficiency increase:	30 %
combined with:	Night ventilation
main use:	**Cooling** / heating
system:	Active / **passive**
function building:	Office
project type:	New / **renovation**
additional:	-

Rotterdam, The Netherlands
Temperate climate

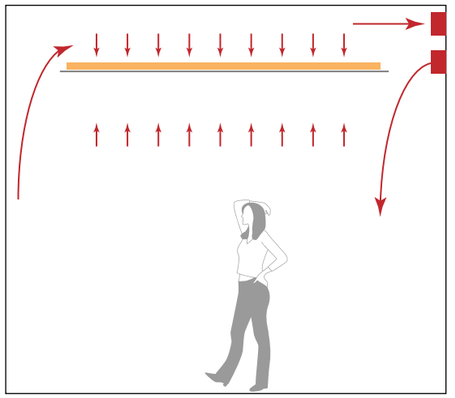




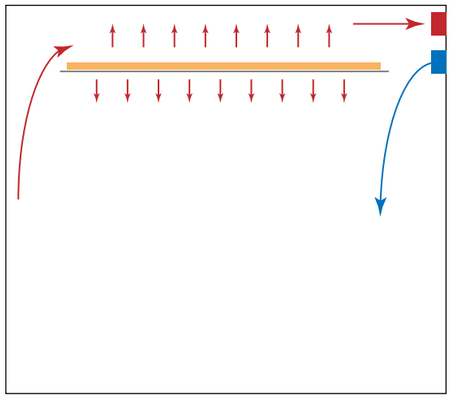
Summer / Day



Summer / Night



Winter / Day



Winter / Night

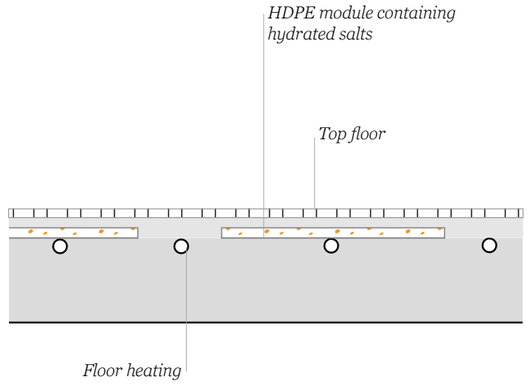
05 ECOFACTORIJ

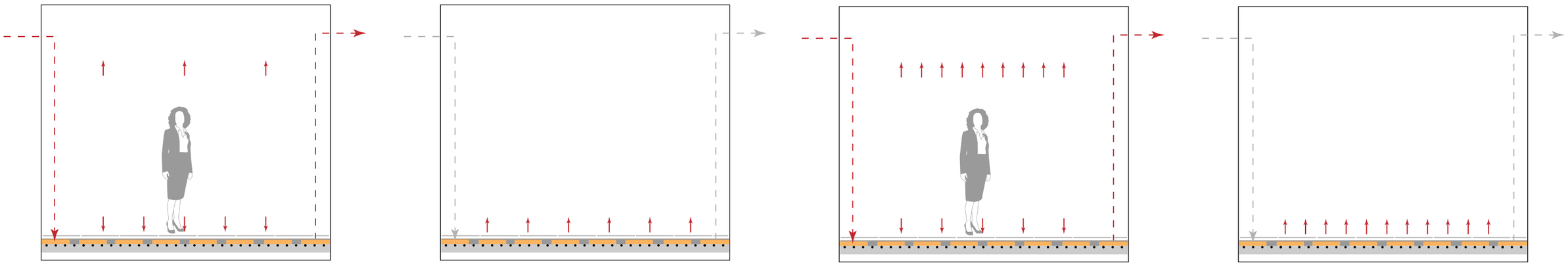
Even in the floor systems PCM (salt hydrates) is applied in the synthetical shutters. The PCM filled elements are placed on top of the water carrying pipes of the floor heating. To increase maximum energy transmission, extra surface id added between the PCM elements and the piping, by aluminum conductors. This way the floor is equally heated.
For sustainable dwellings and offices, this particular application ensures heat storage during the day. And over night this thermal energy is exposed to the room, reducing the heating demand. This seems a fruitful combination with using a heat pump or solar collectors, financially and in terms of energy efficiency

Specific information

Located in:	Floor
type:	Salt hydrates (incl. paraffin, glycol, alcohol)
amount:	6 kg/m²
capacity:	35 W/m²
melting temperature:	25 °C
medium:	Water
efficiency increase:	30-40 % (80 % i.c.w. PCM wall)
combined with:	- Floor heating system - Additional winter heating
main use:	Cooling / **heating**
system:	Active / **passive**
function building:	Dwelling (or offices)
project type:	**New** + renovation
additional:	1) Limited thickness makes it suitable for renovation projects. 2) High melting temperature for heating function.

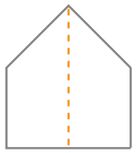
Apeldoorn, The Netherlands
Temperate climate





Summer / Day | Summer / Night | Winter / Day | Winter / Night

06 ECOFACTORIJ



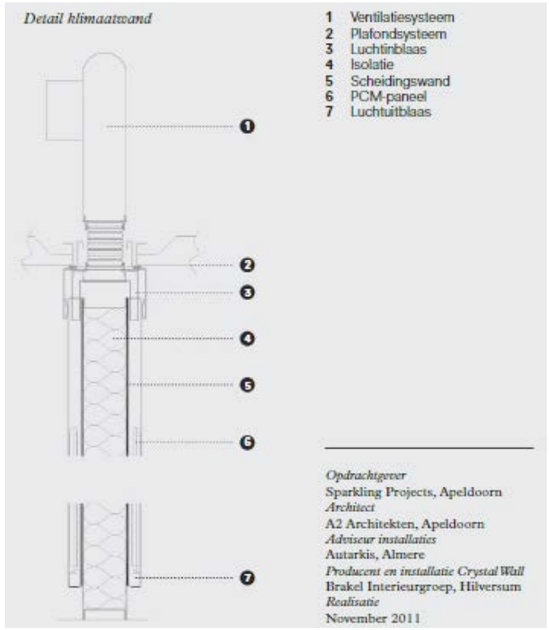
Crystal walls are a completely new application of PCM in architecture. The wall consists of insulation, and PCM surface on both sides of the insulation. From above, a single ventilation shaft is split and blows air on equal sides of the panel. The PCM surface is thus used to absorb the heat in the room, with which the incoming air is pre-heated.
At night the system works vice versa: the PCM releases the heat into the room so less energy is used for (pre-)heating the space the next day.

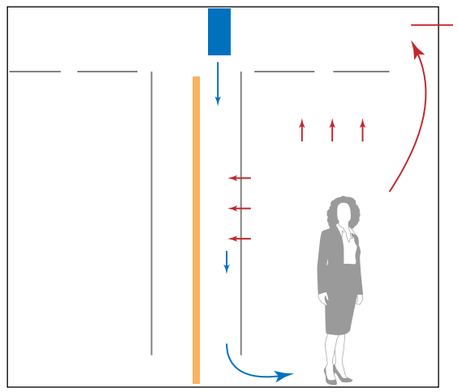
The wall panels have a aluminum finish which enables not just convective heat exposure but also radiative heat exposure to the air.

Specific information

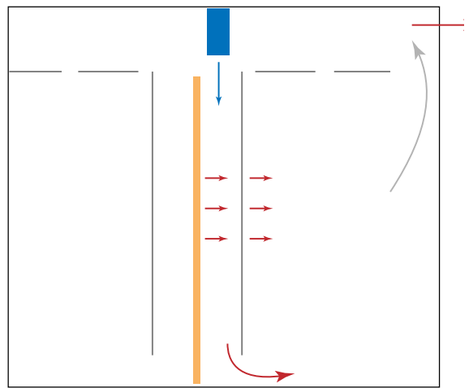
Located in:	Wall panel
type:	Salt Hydrate (incl. paraffin, glycol, alcohol)
amount:	10 kg/m2
capacity:	50 W/m²
melting temperature:	20 °C
medium:	Air
efficiency increase:	40 - 50 %
combined with:	- Cavity for ventilation - Radiatve metal panel
main use:	**Cooling** / heating
system:	**Active** / passive
function building:	Office
project type:	**New** / renovation
additional:	-

Apeldoorn, The Netherlands
Temperate climate

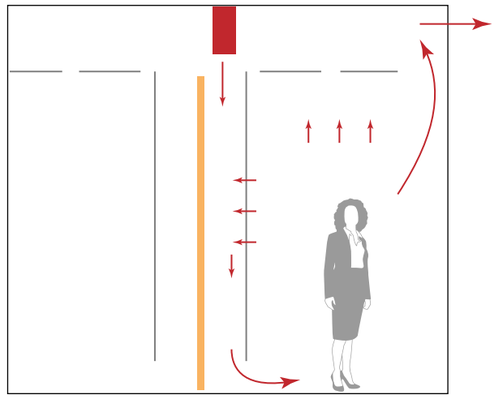




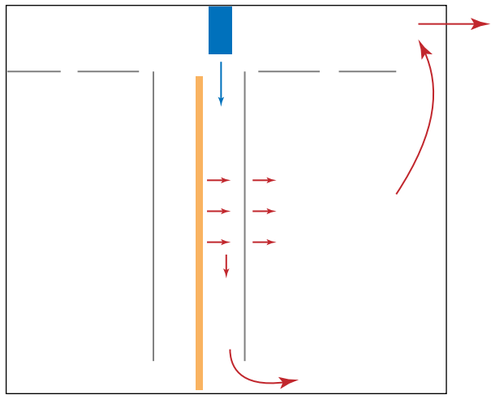
Summer / Day



Summer / Night



Winter / Day



Winter / Night

07 PUIGVERD DE LLEIDA

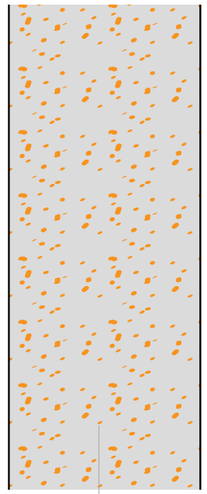
The PCM used in this set up was the commercially available Micronal PCM from BASF with melting point of 26 degrees. The integration in concrete has been done by applying the microencapsulated PCM as an extra aggregate. The amount was 5% of the total weight of the structure. It shows significant temperature changes of 2 degrees at night (heating) and 3 degrees during the day (cooling).

The overall strength of the concrete is still high enough for conventional usage of this PCM-concrete. The risk with this application is leakage, which would result in oxidation and a fundamentally insecure structure.

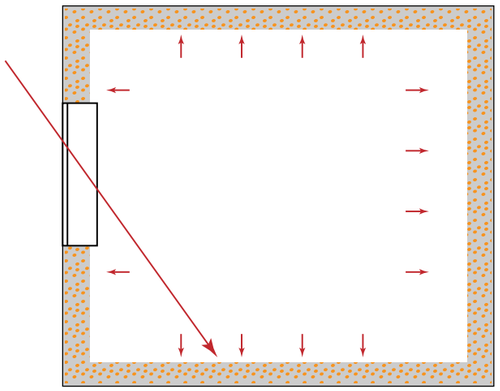
Specific information

Located in:	Concrete wall
type:	Micronal (BASF)
amount:	5 % of total weight
capacity:	? W/m²
melting temperature:	26 °C
medium:	Air
efficiency increase:	2 - 3 °C, % unknown
combined with:	Conrete as host material
main use:	**Cooling** / heating
system:	Active / **passive**
function building:	Test set-up
project type:	**New** / renovation
additional:	1) Microencapsulated PCM as additional aggregate in concrete mixture. 2) Strength of concrete is sufficient for (potential) commercial use.

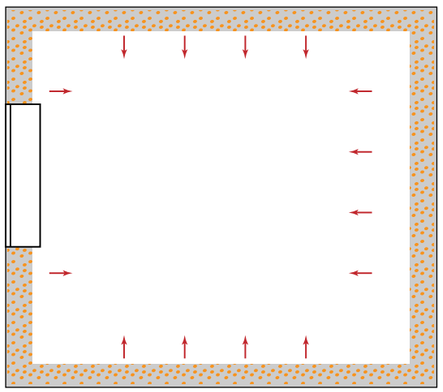
Puigverd de Lleída, Spain
Continental climate



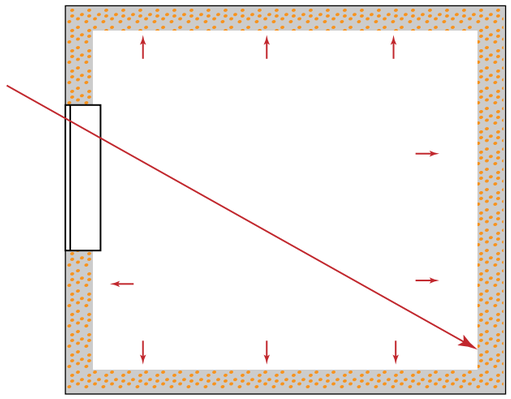
120 mm concrete including microencapsulated PCM



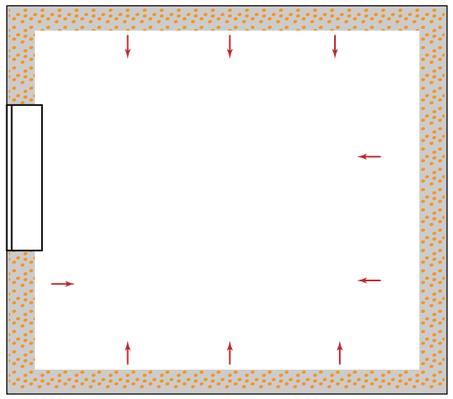
Summer / Day



Summer / Night

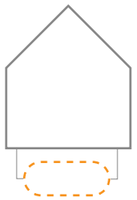


Winter / Day



Winter / Night

08 WATERWEG WONEN

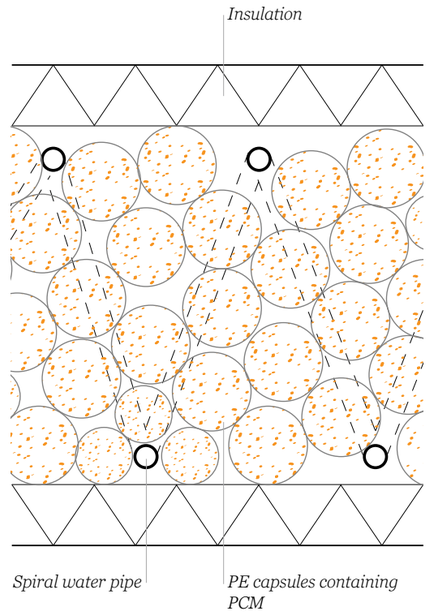


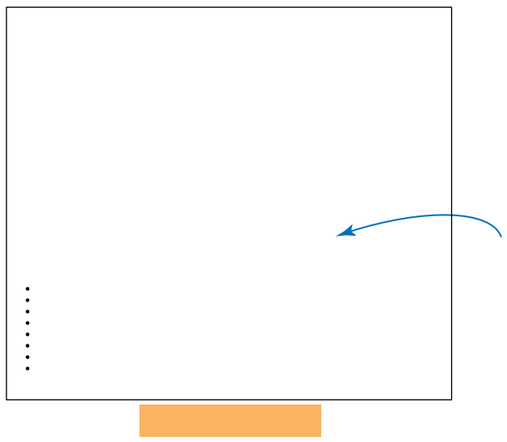
The PCM storage tank has been designed to support two biomass energy generators for two apartment blocks. The biomass is produces from non-recyclable wood. In combination with the PCM storage tank, the system allows for delayed use of the already produced thermal energy. This combination is the first of its kind in The Netherlands.

Specific information

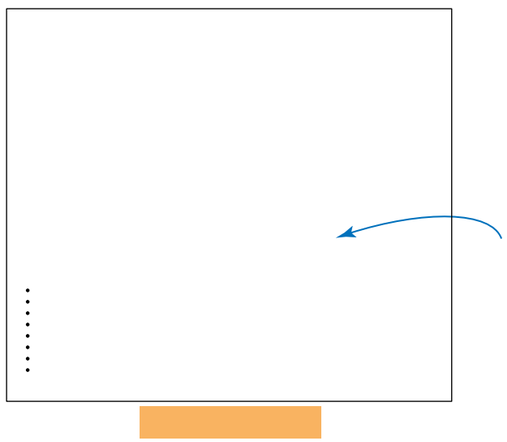
Located in:	Storage tank in basement
type:	Salt hydrate or eutectic mixture water/glycol
amount:	50,000 balls or 20,000 L
capacity:	55 kJ / 15,4 Wh per ball 28,5 kWh per m³
melting temperature:	70 °C
medium:	Water
efficiency increase:	300 - 400 % in volume
combined with:	- Heat pump - Biomass energy generator - Solar energy storage
main use:	Cooling / **heating**
system:	Active or **passive**
function building:	Office / dwelling complex
project type:	New / **renovation**
additional:	1) The balls have a diameter Ø of 50, 80 of 100 mm. 2) HDPE of PP or RVS macroencapsulation (balls)

Vlaardingen, The Netherlands
Temperate climate

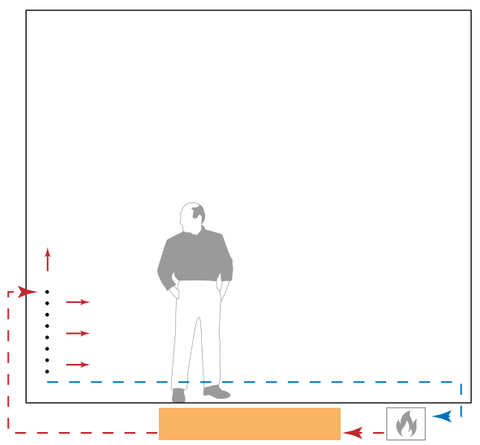




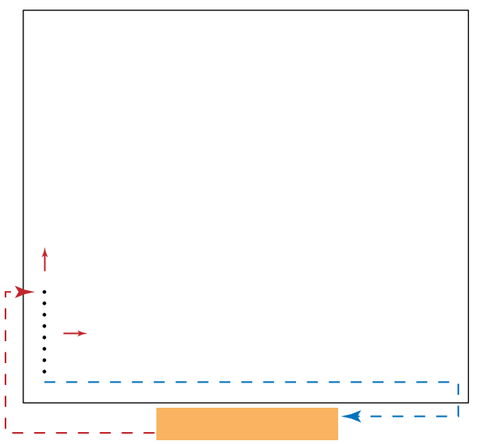
Summer / Day



Summer / Night

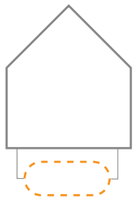


Winter / Day



Winter / Night

09 GEMEENTEHUIS WESTLAND

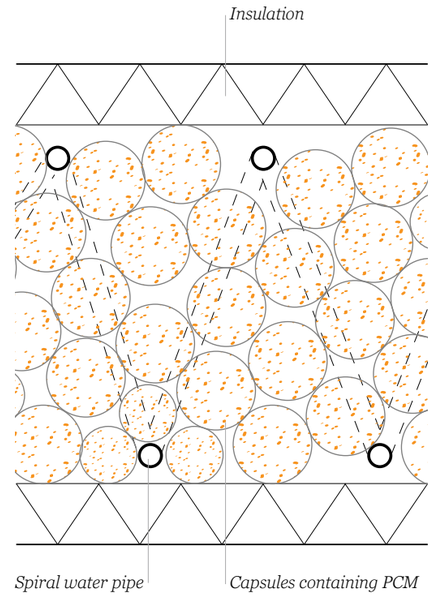


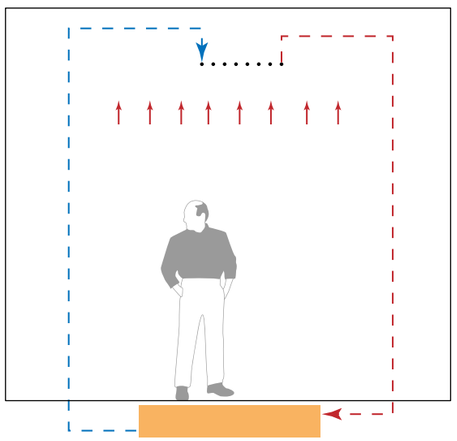
Due to the many greenhouses in the Westland area that are already using Heat storage (WKO) on large scale, the zero energy concept for this municipal building had to be independent and smaller. WKO can ruin the ecosystem if it is not in balance; it creates temperatures differences to the soil. The alternative was a PCM storage tank of 21 cubic meters, functioning as a thermal energy buffer.
The heat stored in the building mostly comes from the ICT rooms and heat produced by occupants. This is stored in the PCM buffer tank, so that at night (?) this energy warms the spaces.

Specific information

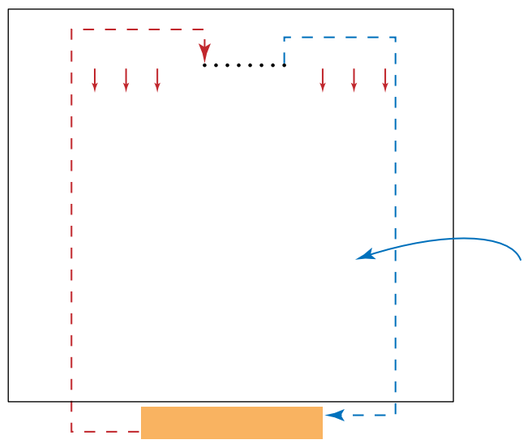
Located in:	Storage tank underground
type:	type:
amount:	21 m³
capacity:	? W/m²
melting temperature:	? °C
medium:	Water
efficiency increase:	25 %
combined with:	- Solar panels - Climate ceilings
main use:	Cooling + heating
system:	**Active** / passive
function building:	**Office** Dwelling
project type:	**New** / renovation
additional:	Ecological alternative for thermal energy storage facility (TES) by heat pumps

Westland, The Netherlands
Temperate climate





Day

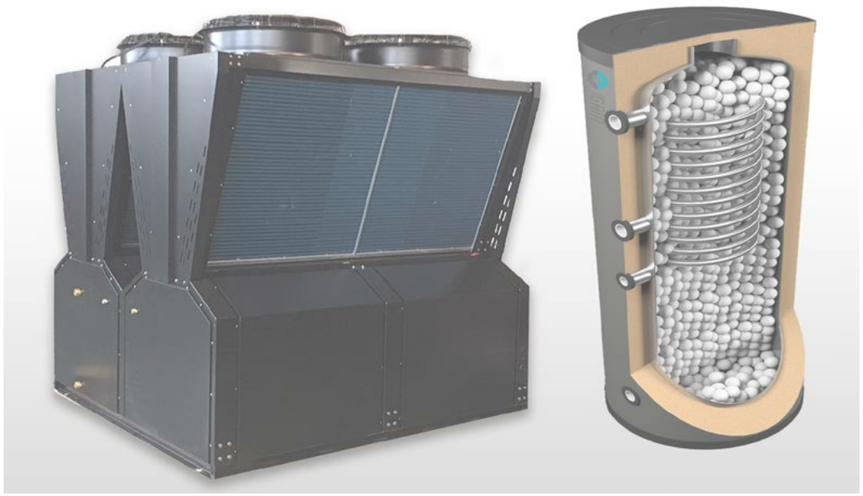


Night

10 CALDAMEG

Caldameg™ is a smart ‘heat pump and buffer system’. It could replace the conventional CV (‘central heating’) and with the addition of solar panels it is a zero energy system.
The heating system (ased on air/water) enerates 4.5 kW in combination with a PCM storage tank of 264 liter (equalivent of 1000 L water storage). The CO2 pump uses high pressure and delivers 80°C temperature. The storage tank is heated by the same system, however when the peak demand of thermal energy occurs the reserved amount of stored heat is used.

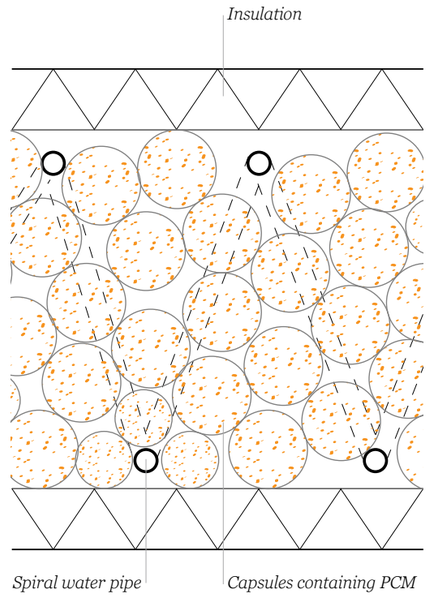
This system has various sizes and possibilities, expanding in size and capacity is done by connecting multiple storage tanks together.

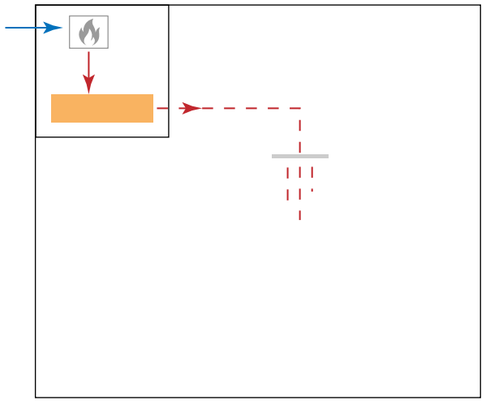


Specific information

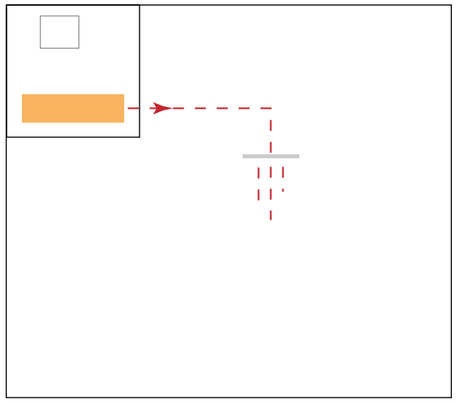
Located in:	Storage tank
type:	Salt hydrates or Polyols
amount:	264 - 2000 L
capacity:	4,5 kW - 140 kW
melting temperature:	80 °C
medium:	Water
efficiency increase:	? %
combined with:	- Solar panels - CO_2 Heat pump
main use:	Cooling / **heating**
system:	Active / **passive**
function building:	Dwelling
project type:	New / renovation
additional:	Diameter Ø 80

Any location
Temperate climate





Day



Night

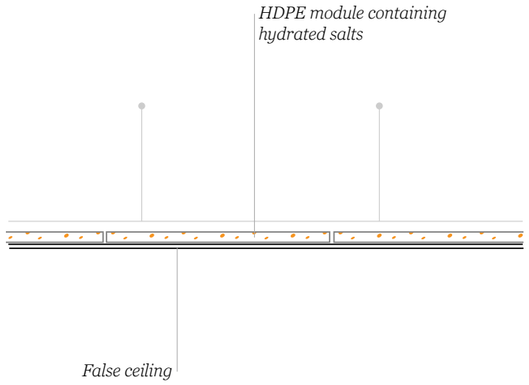
11 RIJSWIJKS LYCEUM

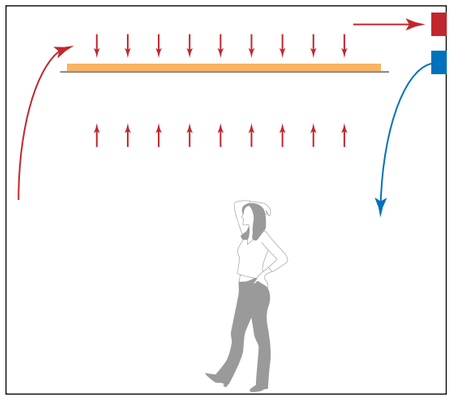
The climate ceilings applied in the ´mediatheek´ have been the last intervention to transform the school to the new energy performance regulations. There are a total of 40 computer positioned in the room. Permentently exposing thermal energy to the air in the space. The PCM ceilings have ensured a closed energy cycle. Even in winter time the PCM is capable of storing enough energy, that no additional heating is necessary during the next day.

Specific information

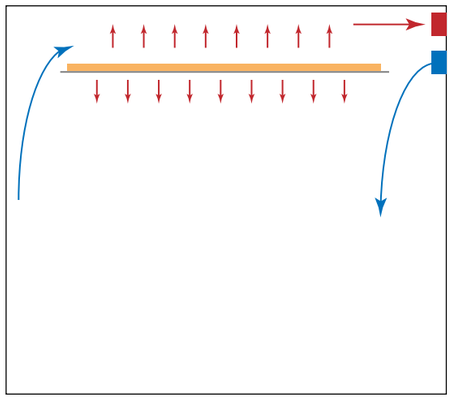
Located in:	Ceiling
type:	Salt hydrate: Calcium-Chloride (CaCl2+6H2O)
amount:	~9 kg/m²
capacity:	?
melting temperature:	18 °C
medium:	Air
efficiency increase:	25 - 50 %
combined with:	Aluminum ceiling panel
main use:	**Cooling** / heating
system:	Active / **passive**
function building:	Office
project type:	New / **renovation**
additional:	-

Rijswijk, The Netherlands
Temperate climate

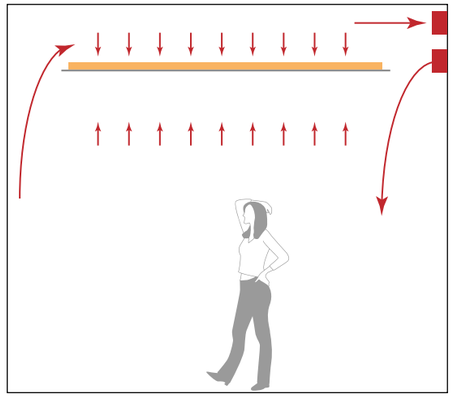




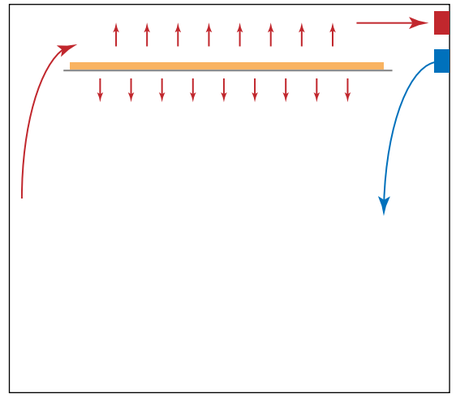
Summer / Day



Summer / Night



Winter / Day



Winter / Night

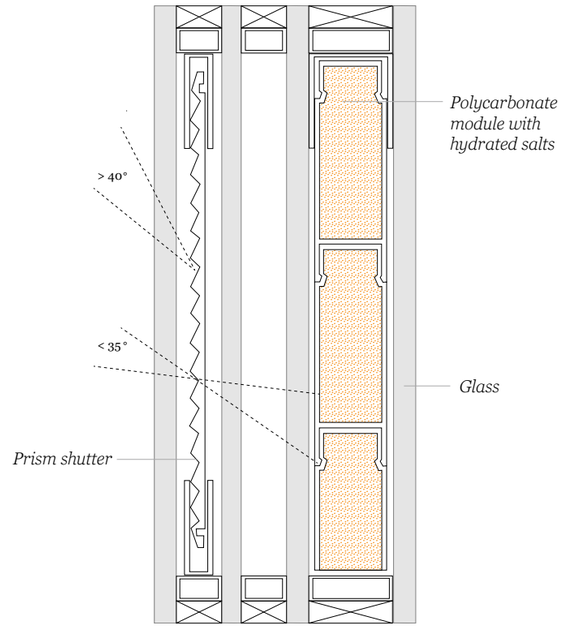
12 MINERGIE-P “IM BÄCHLI”

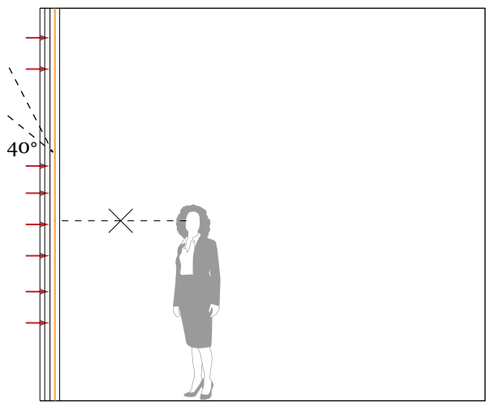
The GlassX PCM application within a window frame is one of the few uilding envelope applications existing so far. It requires multiple cavities between the quadriple safety glazing. The salt hydrate is captured in a transparant polycarbonate capsule of 15 - 20 mm thick. The GlassX Crystal product goes out from different sun heat access in the room, without compromising on daylight. Hereby, a prism is installed only allowing winter sun (from 35 degrees and lower) to enter the room. Sun light is kept out, and does not reach the PCM unit either. However, the heat exposure on the window ensures transparancy because of the PCM melting temperature (26 - 28 °C). Winter sun reaches the PCM directy and thus melting is as well. At night, in both situations the PCM exposes the extracted thermal energy to the room.

Specific information

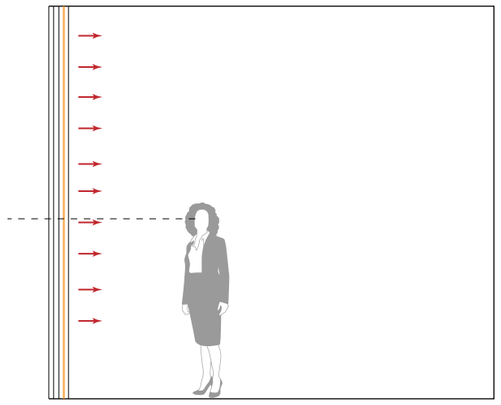
Located in:	Window
type:	Salt hydrate (CaCl2 6H2O)
amount:	?
capacity:	150 - 200 kWh/m² a year
melting temperature:	26 - 28 °C
medium:	Air / sun
efficiency increase:	30 - 50 %
combined with:	- Quadriple glazing - Prism shutter
main use:	Cooling / **heating**
system:	Active / **passive**
function building:	Dwelling
project type:	**New** / renovation
additional:	PCM in polycarbonate unit U-value: 0.48 W/m²K

Teufen, Switzerland
Temperate climate

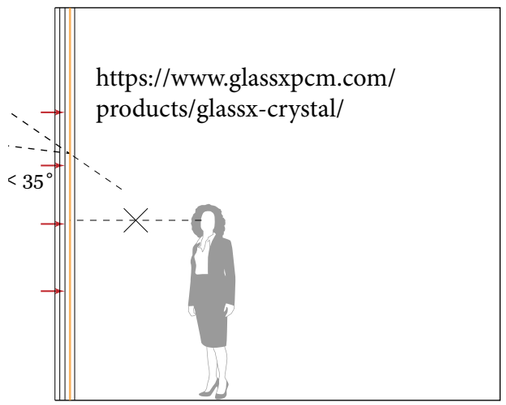




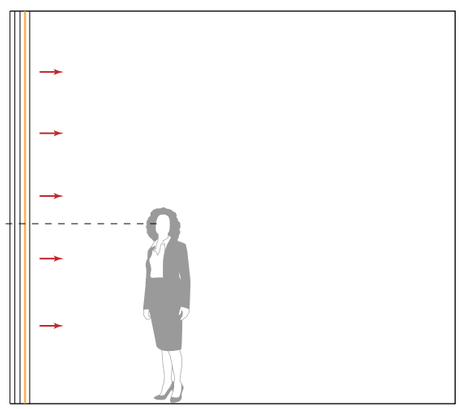
Summer / Day



Summer / Night



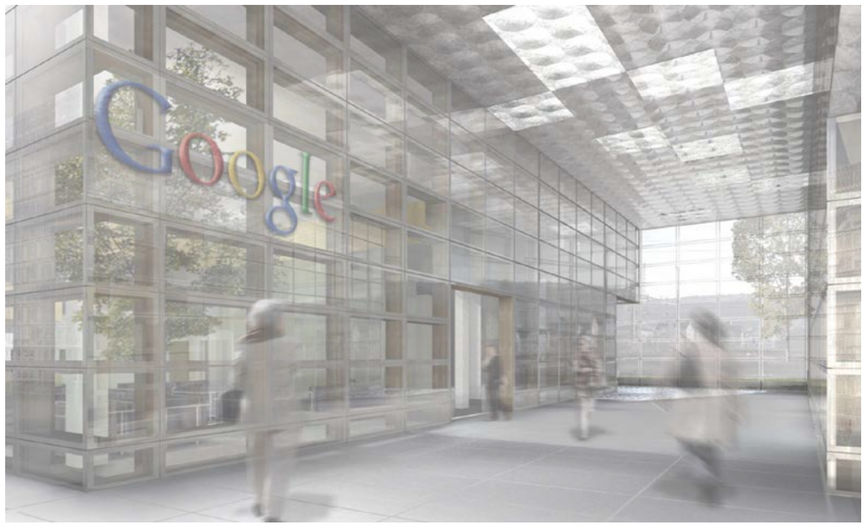
Winter / Day



Winter / Night

13 FÄRBI AREAL

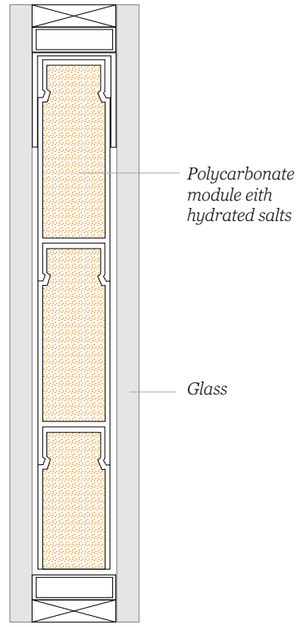
The GlassX Store product enables thermal mass properties into a transparant building envelope. The double glazing window unit contains PCM (salt hydrates) in polycarbonate packaging. The total thickness is limited to around 53 mm only. The passive system provides the benefits of a winter garden, for the climatic properties. The application of this product comes in two possible forms. The first option is a static element, unchangable and unadaptable. The PCM units are captured within two glass elements. The second option uses manouvrable PCM shutters. The changing position of the elements enables active change of climatic properties.

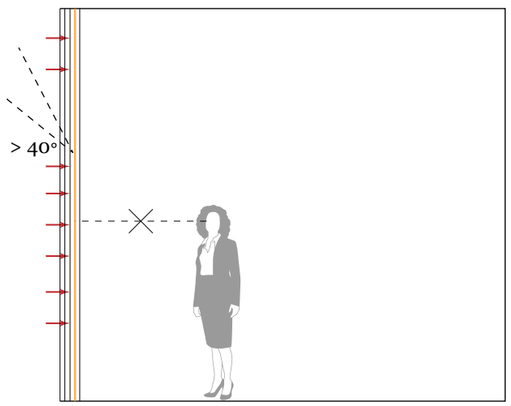


Specific information

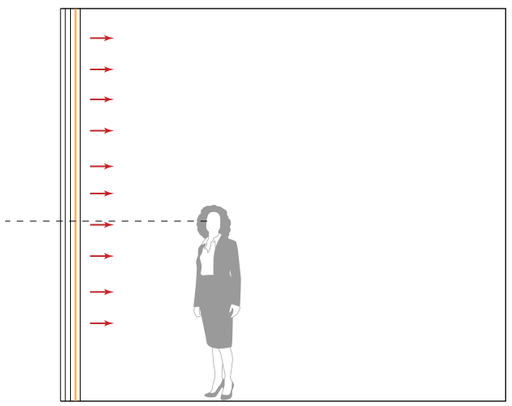
Located in:	Window
type:	Salt Hydrate
amount:	
capacity:	1185 Wh/m²
	150 - 200 kWh/m² a year
melting temperature:	26 - 30 °C
medium:	Air / sun
efficiency increase:	30 - 50 %
combined with:	Double glazing window
main use:	Cooling / **heating**
system:	Active / **passive**
function building:	Dwelling
project type:	**New** / renovation
additional:	PCM in polycarbonate unit
	U-value: 1.2 W/m²K

Zürich, Switzerland
Temperate climate

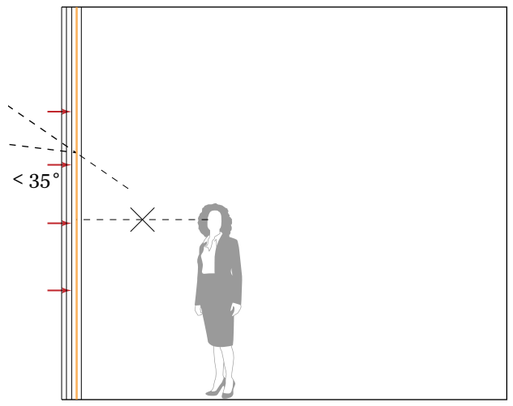




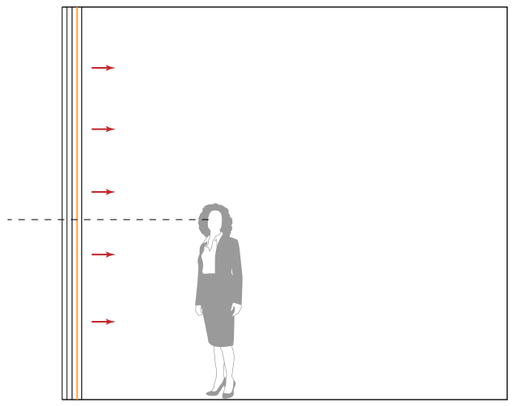
Summer / Day



Summer / Night



Winter / Day



Winter / Night

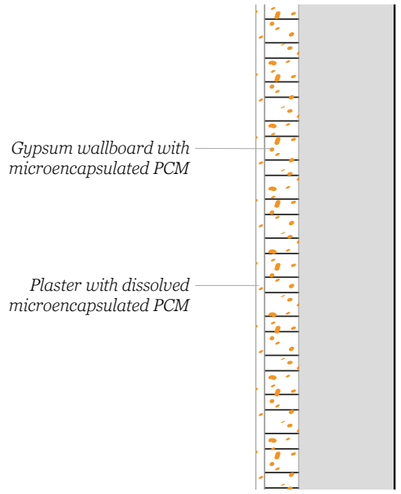
14 3-LITER-HAUS

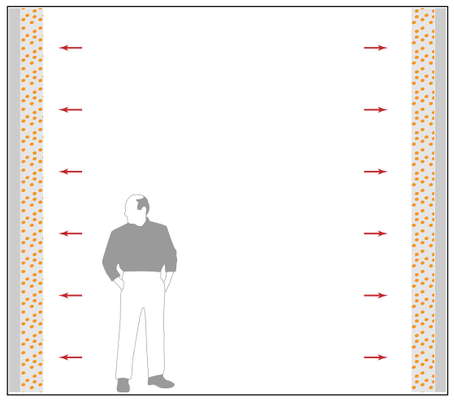
To increase the thermal heat storage capactity for the renovation of the ‘51 mdoernist building the gypsum, plaster and filler is modified to contain Micronal BASF PCM, contained in pellets. The size of the elements is microscorpic and the PCM is wax based. One third of the plaster consisting of the PCM generates the same heat accumulation capacity of 20 cm brick. The melting temperature for the indoor application is 23 degrees. It keepes the room cooler during the day, and warmer during the night. The latent heat absorbing molecules have a diameter of 2 to 20 micrometer.

Specific information

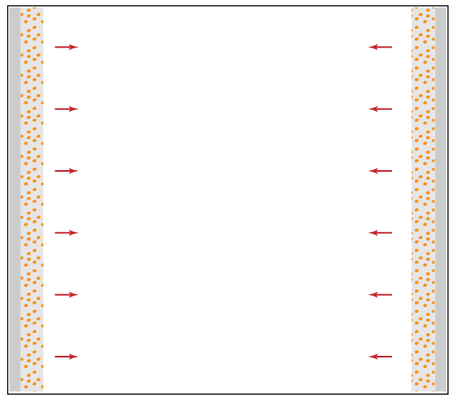
Located in:	Gypsum wall
type:	Micronal BASF, wax based
amount:	30 % of weight
capacity:	? W/m²
melting temperature:	23 °C
medium:	Air
efficiency increase:	80 % on heat demand for total concept
combined with:	-
main use:	Cooling / **heating**
system:	Active / **passive**
function building:	Dwelling
project type:	New / **renovation**
additional:	-

Ludwigshafen, Germany
Temperate climate



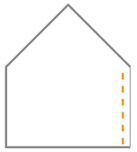


Day



Night

15 DOUBLE FACE 2.0

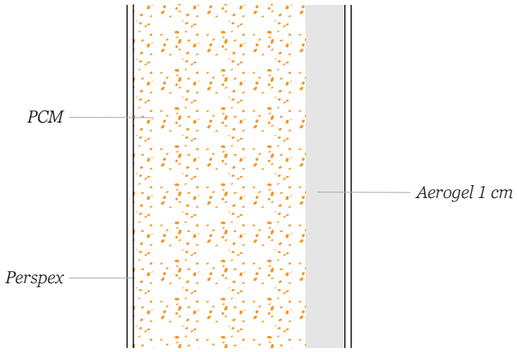


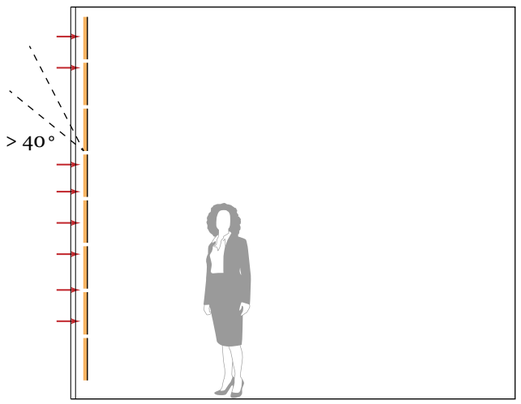
In winter time, the solar heat liquefies the PCM in the Trombe wall, which gains the thermal energy and stores it. At night, the panel is rotated 180 degrees: the ‘charged’ PCM is facing the interior and able to heat it at night. In summer time, this proces works vice versa. The panel that has taken up the heat from the interior during daytime, exposes it at night. This allows for cooling in warm periods of the year.

Specific information

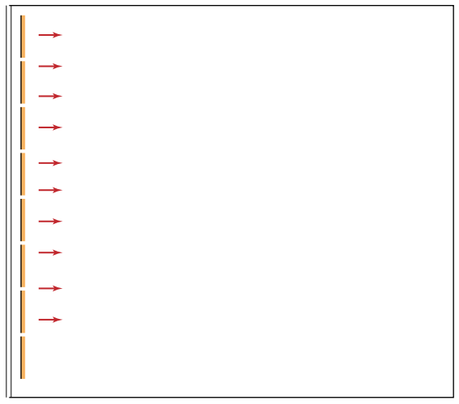
Located in:	Trombe wall
type:	Salt hydrates
amount:	?
capacity:	1.6 GJ = 75,9W=9,7W/m2 (in 5 months; winter)
melting temperature:	23 °C
medium:	**Air** / water
efficiency increase:	33 %
combined with:	- 1 cm Aerogel - Plexiglass capsule
main use:	Cooling / **heating**
system:	Active / **passive**
function building:	Test case
project type:	New / renovation
additional:	90% of wall surface covered, 10% open for air circulation.

Delft, The Netherlands
Temperate climate

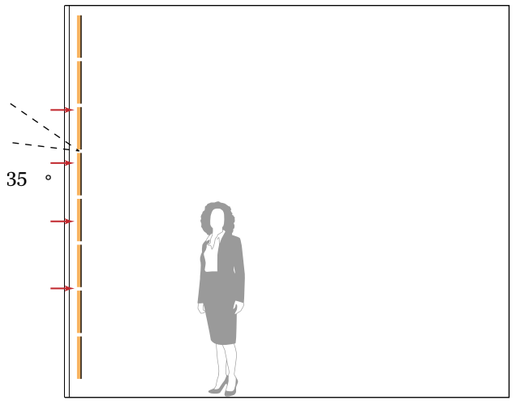




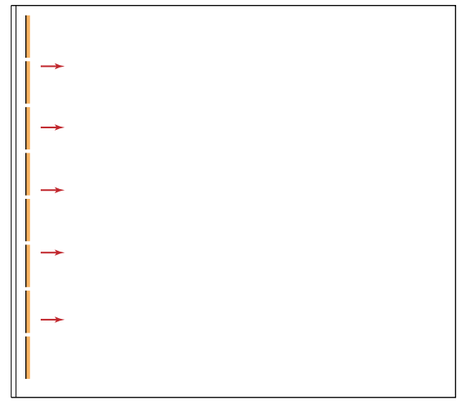
Summer / Day



Summer / Night



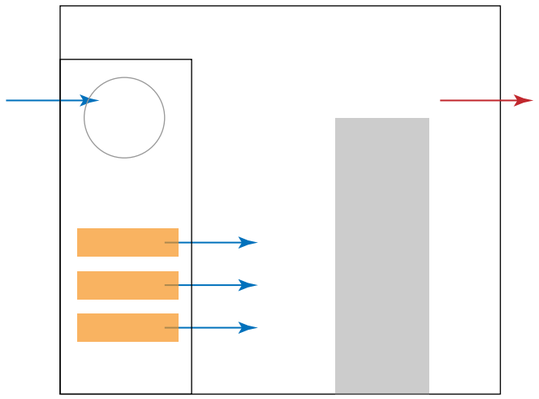
Winter / Day



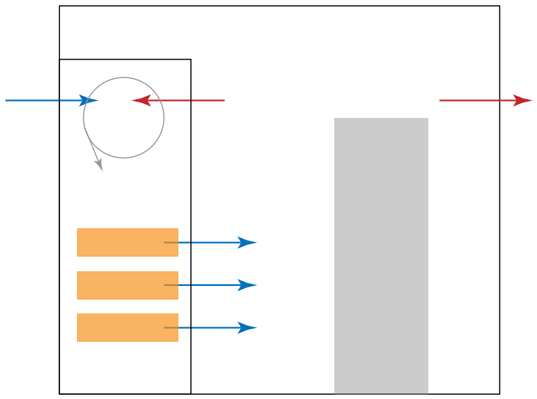
Winter / Night

16 DATACOOLING AMC

PCM cooling down data centers can result in a maximimum of 90% reduction on additional cooling demand. Small and big data centers can be cooled by PCM. Current available designs are 3, 6, 9, 12 kW PCM data coolers. All larger data centres; e.g. 25, 50, 200 kW can also be PCM cooled but require a custom design.
During the day the warm air from the server units ‘charges’ the PCM surface, embodying the thermal energy. At night the - partially - molten PCM embodies the thermal energy from the outside air. This way night ventilation is able to cool the room. When cold outside temperatures occur, the air mingles with the warm air from the server room directly.
Payback time of PCM airco for datacoolers is only 1,5 years!



Summer / Day

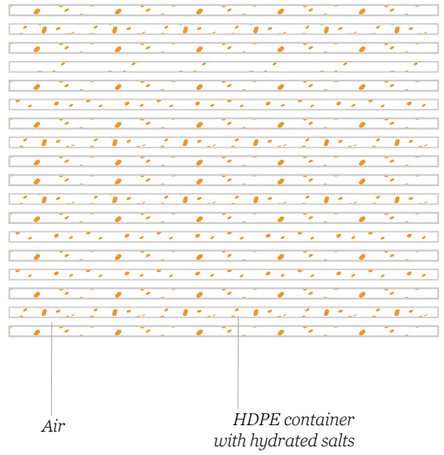


Summer / Night

Specific information

Located in:	Air shaft
type:	Salt hydrates
amount:	?
capacity:	3 - 12 kW
melting temperature:	28 °C
medium:	Air
efficiency increase:	< 90 %
combined with:	-
main use:	**Cooling** / heating
system:	**Active** / passive
function building:	Hospital
project type:	New / **renovation**
additional:	-

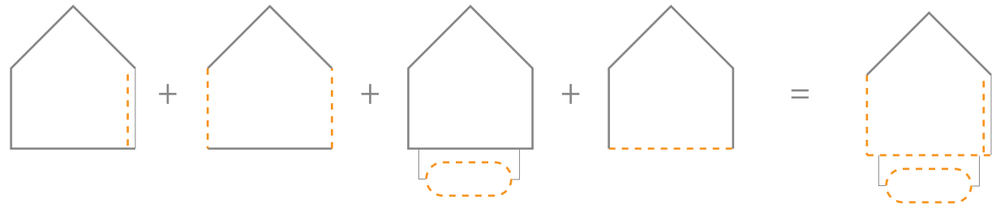
Amsterdam, The Netherlands
Temperate climate



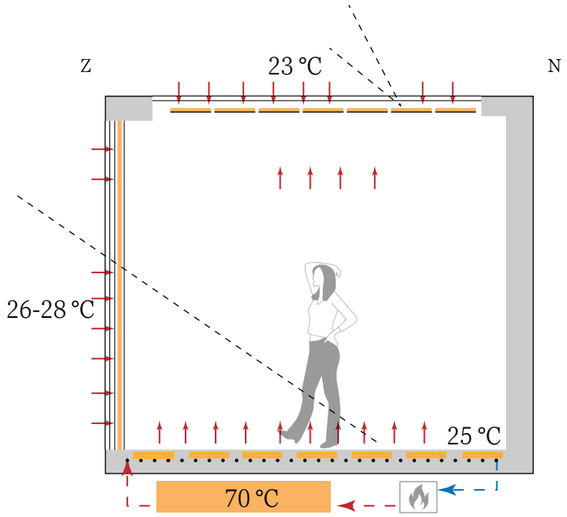
Conclusions + Combinations

Heating by PCM

Location for heating



Study case	Double face 2.0	GlassX	Waterweg Wonen & Gemeentehuis Westland	Ecofactorij
Melting temperature PCM	23 °C	26-28 °C	70 °C	25 °C
Energy performance	9,7 W/m2	1185 Wh/m²	28,5 kWh/m³	35 W/m²
Medium	air + sun	air + sun	water	water + air
PCM type	salt hydrate	salt hydrate	salt hydrate or eutectic mixture water/glycol	salt hydrate
Amount	1450 kg/m³	unknown	20,000 L	6 kg/m²
Additional information	90% of wall surface covered, 10% open for air circulation	polycarbonate capsule	PPE, HDPE or RVS capsule	good renovation application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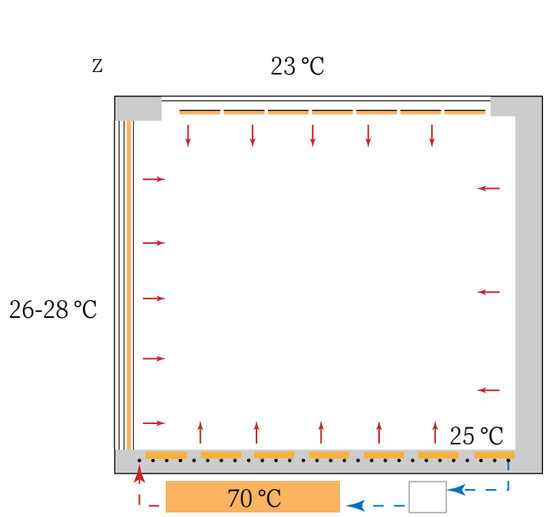
23 °C
26-28 °C
25 °C
70 °C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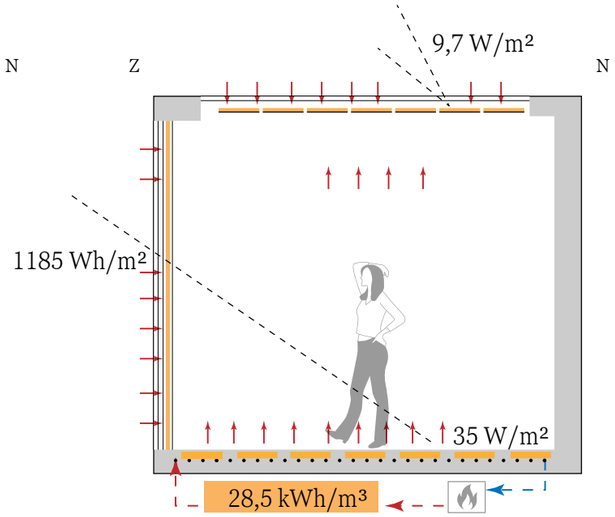
23 °C
26-28 °C
25 °C
70 °C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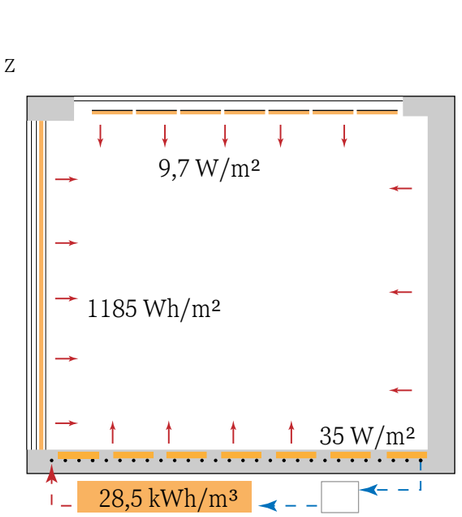
9,7 W/m²
1185 Wh/m²
35 W/m²
28,5 kWh/m³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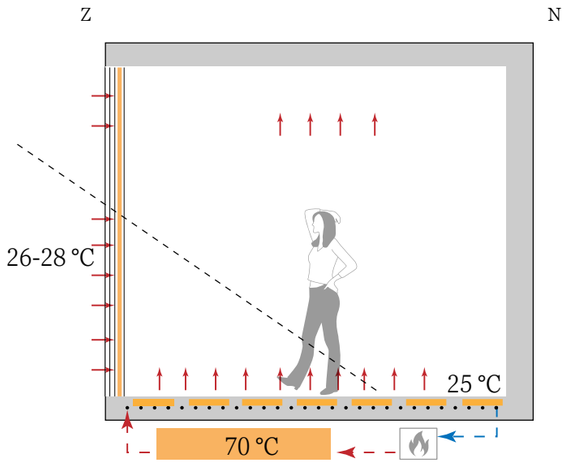
9,7 W/m²
1185 Wh/m²
35 W/m²
28,5 kWh/m³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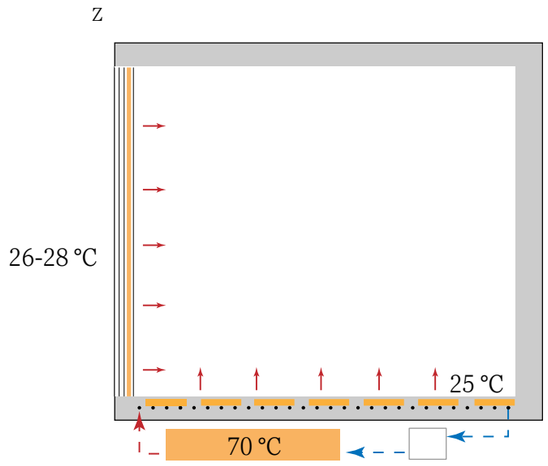
N
26-28 °C
25 °C
70 °C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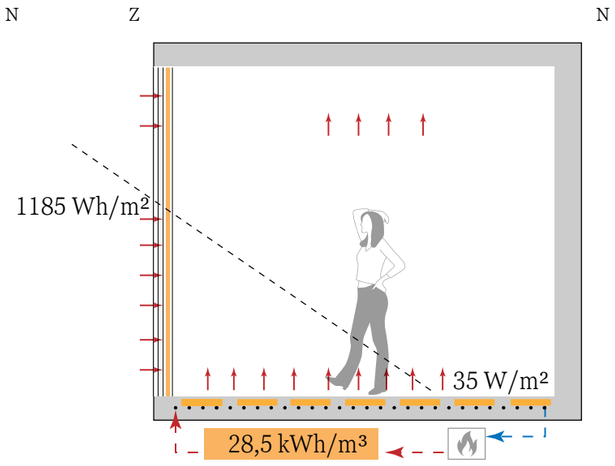
26-28 °C
25 °C
70 °C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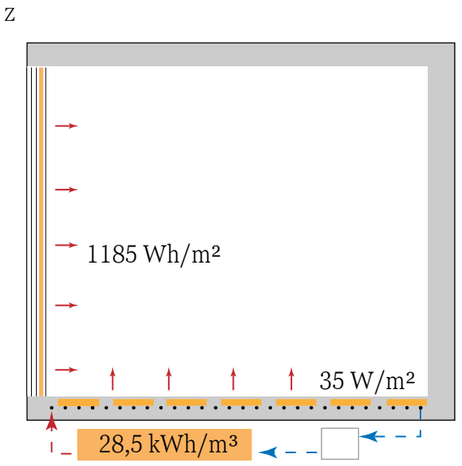
N
1185 Wh/m²
35 W/m²
28,5 kWh/m³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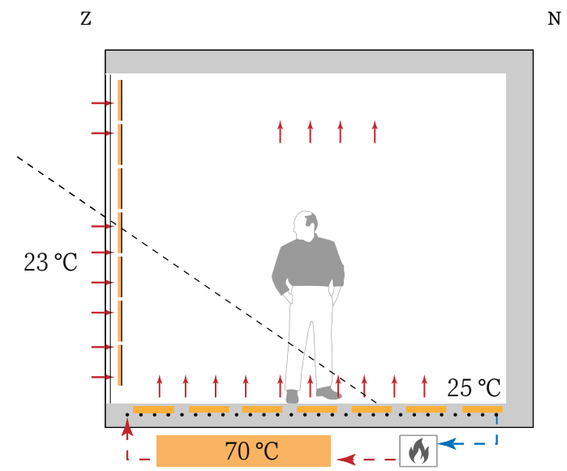
1185 Wh/m²
35 W/m²
28,5 kWh/m³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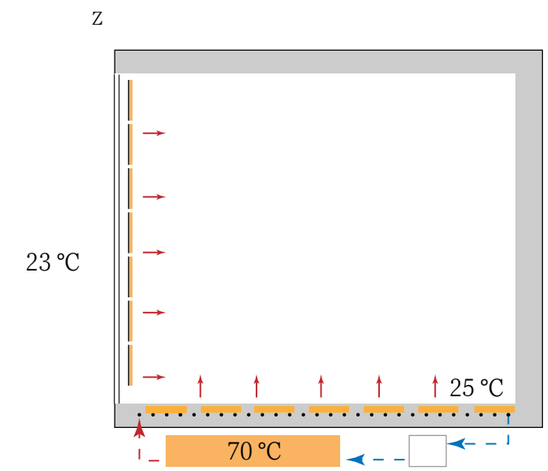
23 °C
25 °C
70 °C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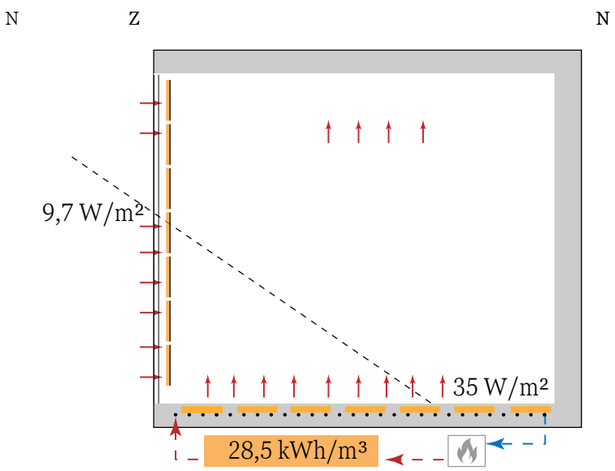
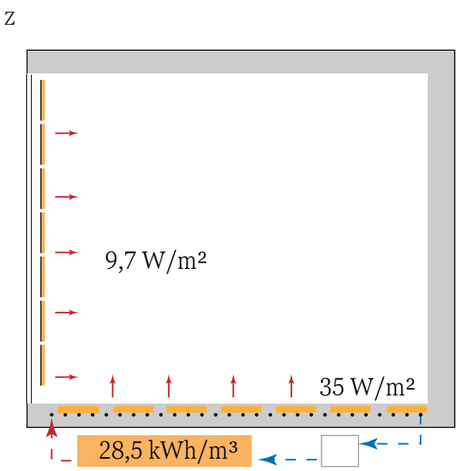
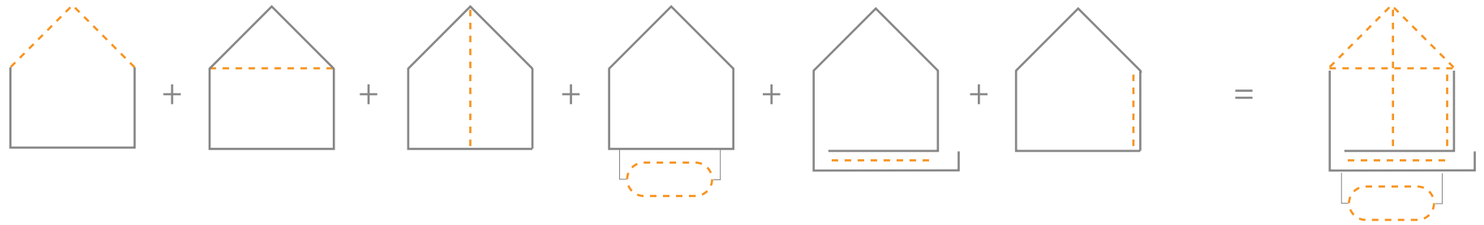
23 °C
25 °C
70 °C


Z
N
9,7 W/m²
35 W/m²
28,5 kWh/m³

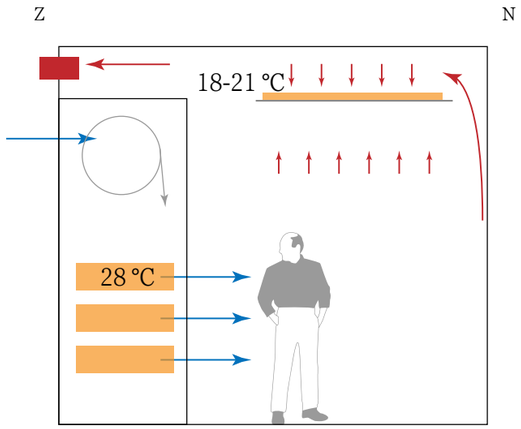

Z
N
9,7 W/m²
35 W/m²
28,5 kWh/m³

Conclusions + Combinations

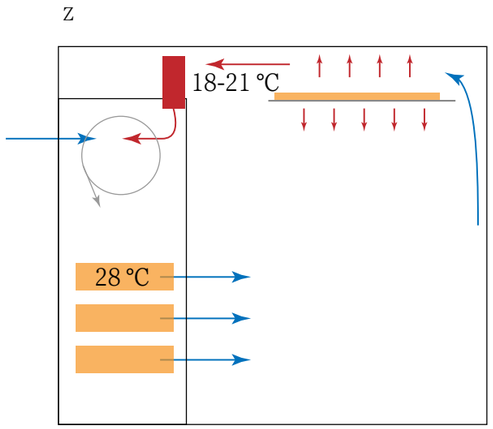
Cooling by PCM



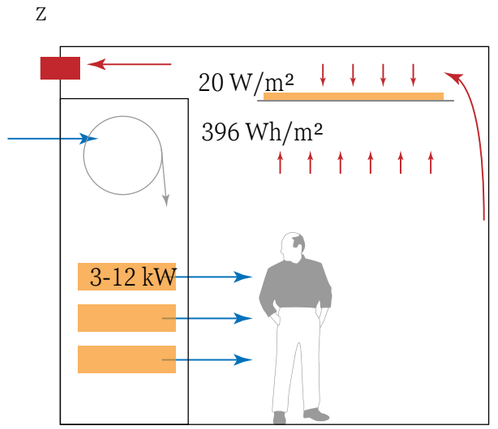
Location for heating						
Study case	WILO	Lycem Rijswijk & Hogeschool Rotterdam	Crystal wall	Council House 2	Drijvend paviljoen & AMC	3 Liter Haus
Melting temperature PCM	21 °C	18 - 21°C	20 °C	16 °C	Unknown °C	23 °C
Energy performance	?	20 W/m² 396 Wh/m²	50 W/m²	?	3-12kW 50 W/m2	?
Medium	air + water	air	air	water	air	air
PCM type	micronal 5030	salt hydrate	salt hydrate	salt hydrate or eutectic mixture water/glycol	salt hydrate	Micronal
Amount	5% of weight roof structure	10 kg/m2	10 kg/m2	estimated 4000 L	2000 kg total	30% of weight
Additional information	integrated in construction	good renovation application	aluminum panel for radiation ventilation & cooling	RVS capsules summer cooling by radiation on roof	good renovation application ventilation & cooling	good renovation application

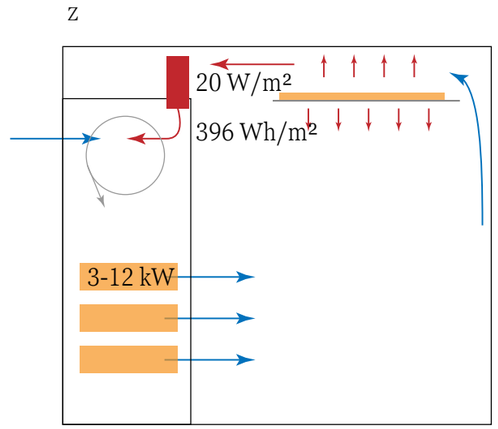


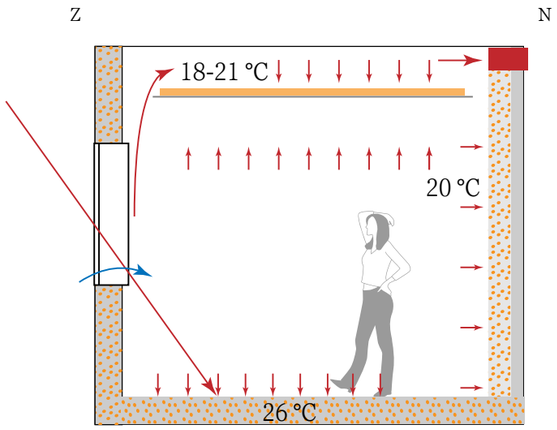
28 °C for data centres*

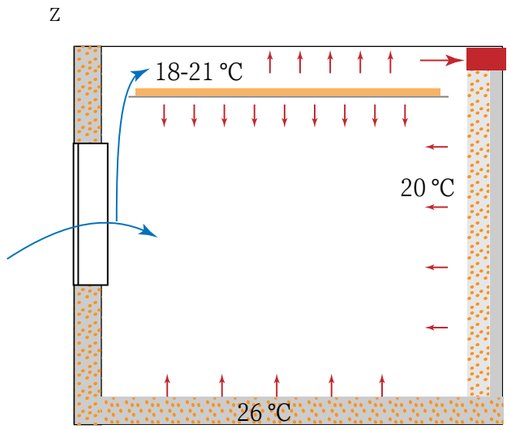


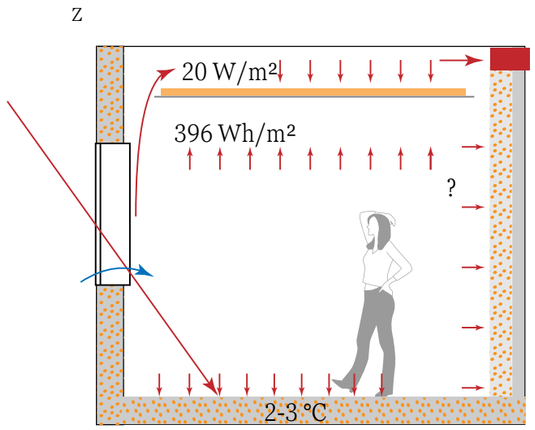
28 °C for data centres*

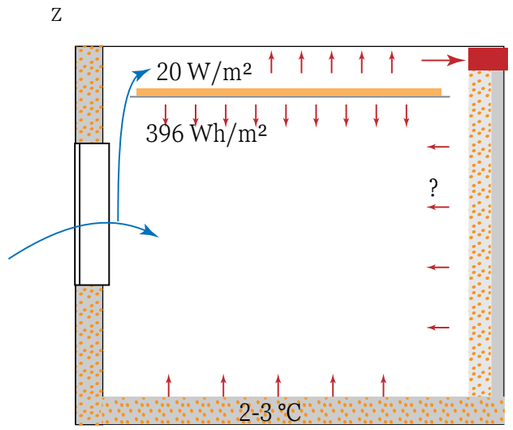


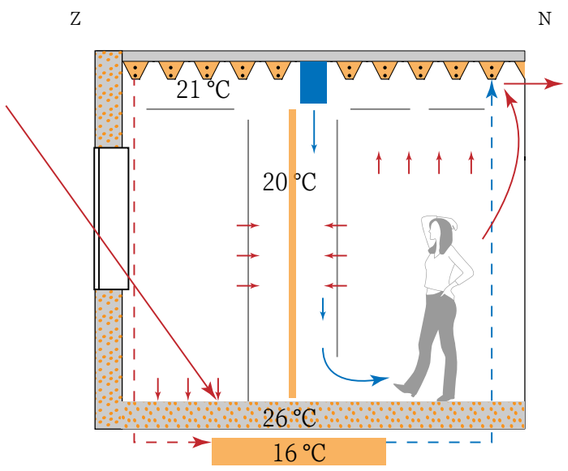


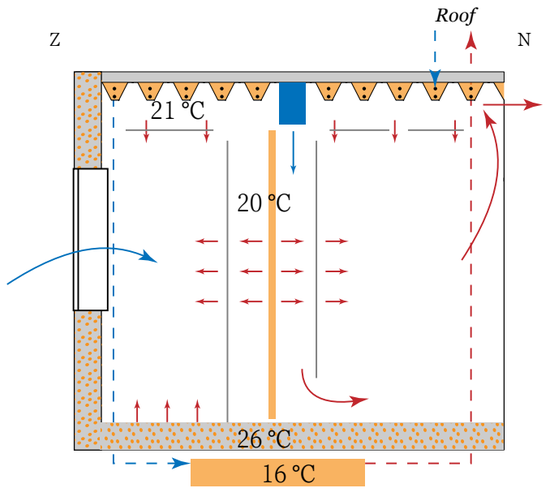


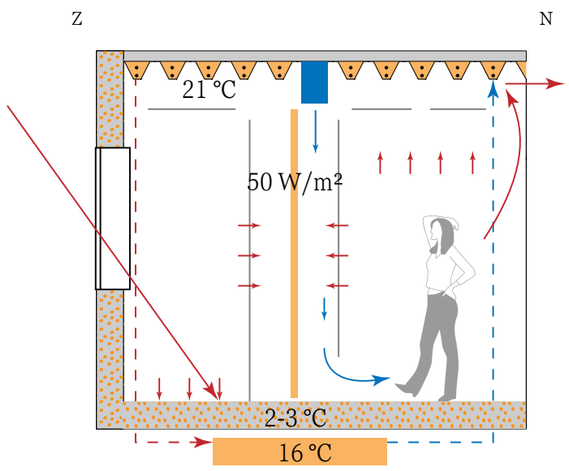


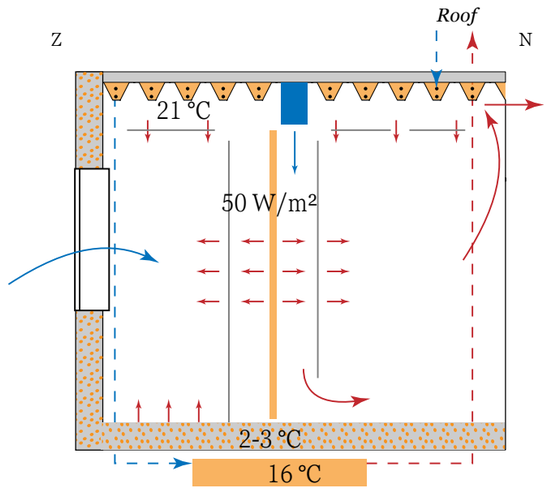












Conclusion

Comparing 16 different cases where PCM's are applied has resulted in a rather broad and informative data. Rules of thumb that can be taken from the case studies:

- For cooling a lower melting range of the material is required, mostly uptil about 21 degrees. For heating this temperature range is higher; above 23 degrees mostly, uptil 26 or 28 even.

- Another rule of thumb extracted from this comparison is that PCM for heating load is conencted to floor heating or applied at the facade of the building. For cooling it is mostly located higher level of the room; e.g. the ceiling. This is due to the buoyancy effect that explains that warm air rises.

- Using PCM applied in one service, or for one function only does not cover the complete cooling or heating load. Dwellings are to be heated, preferably, and offices to be cooled.

- Passive systems are to be used for local climatisation and not on larger scale.

- The (underground) heat buffer allows large quantities of dwellings or spaces to be climatised (heating and/or cooling), however this always happens in an active system.

- The effective amount of applied PCM per m² is 6 kg, or in average for a surface 10 kg / m². Although this depends on the latent heat capacity.

- The medium to interact with is either air or water.

- PCM should be applied on the interior side of the insulation.

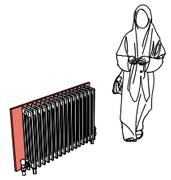
With this information the applicability for low-tech PCM modules can be made. In order to create a variety of products, that could all be combined or connected in one household the following 10 products are to be manufactored either by the people themselves or by the factory, which in essence are the same people. The scale difference implicates some level of diffculty in producing the module, related to the size, requires skills, amount of PCM and of course effectiveness.

Can cooler

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Aluminum foil*

Laptop cooler

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Glass / plastic top cover*

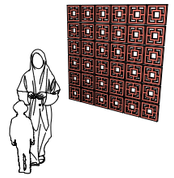


Heating buffer

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Aluminum foil*

Table top

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Glass / plastic top cover*

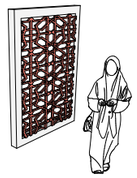


Family picture frame

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Plastic / iron connections*

Shutters

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Iron/plastic connections*
- *Rope*
- *Wooden construction*

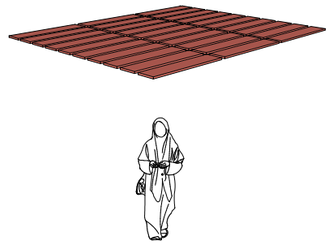


Mashrabyia

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Iron connections*
- *Wooden frame (additional)*

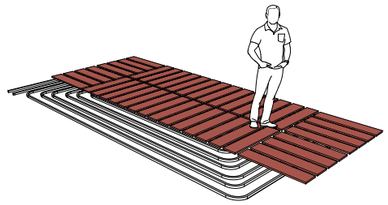
Passive airco

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Iron connections*
- *Fan (additional)*



Ceiling

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Iron connections*
- *Fan (additional)*



PCM Floor heating

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Iron/plastic connections*
- *Piping system + boiler / Electrical mat floor tiles*
- *Top floor (wood/plastic)*

In practice

Available fats

Fats in The Netherlands

The Netherlands plays an important role in tha world wide trade of vegetal resources. Oils, seeds and fats are largely imported to our country. This increases the local availabilitiy for this product, to be used as a PCM later in the process.

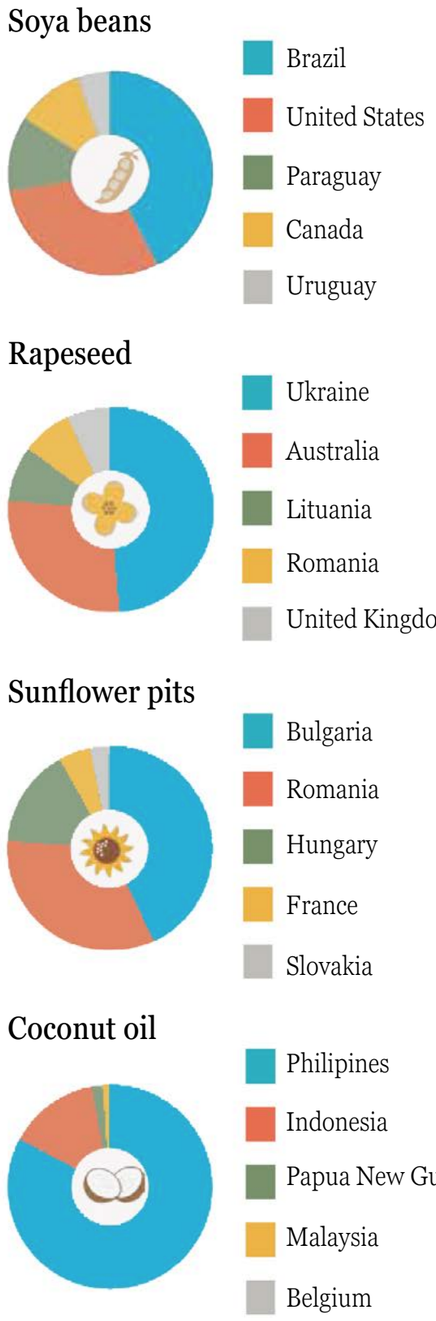
Natural fats are used mainly in four sectors, of which the major one is food. The baking and coocking requires vegetal oils, but also chocolate, soup and ice cream contain this ingredient. In total 20 - 35% of our daily diet should preferably contain calories from fats. Animal food is also an important sector that relies on the fats and oils. Besides that, also waste products from local production are used in animal food. The oleochemical industry ensures that half of our products we find in the supermarket contain aoil or fat. Products as candles, shampoo and soap contain this ingredient too. The last sector relying on the incoming fats and oils is the biofuel production. This production method is an alternative for fossil fuels.

The Netherlands has a leading position in Europe regarding the trade of thse resources. We are the leader in storing and refining the material. We occupy the third position regarding biodiesel production purposes and the fourth position for crushing and 'margarine' (vegetal butter) production.

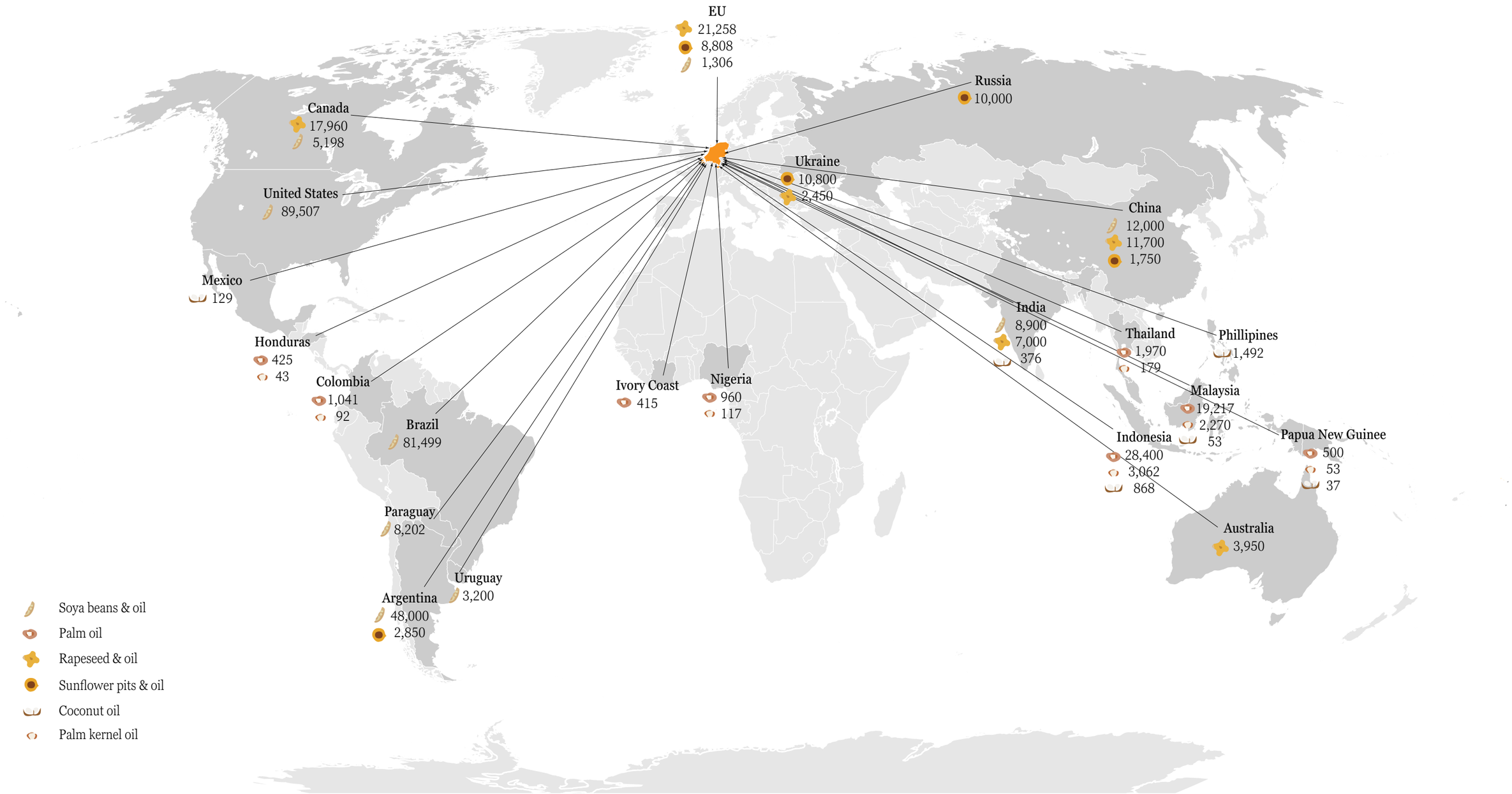
The imported resources, seeds and oils, are originally grown in tropical regions. Most of these arrive by boat. There are several companies based in the Netherlands that manufacture and process the raw material. Other than the raw material that is imported, also refined oils are imported and used for direct reselling. As we can see in the table, soya beans and palm oil are the most imported products. However, sunflower oil and coconut oil and rapeseed (oil) together are about 1/5th to 1/4th of the total imported amount. It is only since recent years unfortunately that we are resusing these large amounts of oil after their primary consumption. With these amounts there is a huge difference to be made still, especially regarding the enormous world wide growth for the demand of these resources.

From the PCM research matrix we can conclude that Coconut oil, palm kernel oil and sunflower oil containts the finest properties for low tech PCM applications. These are all present in various sectors in the Netherlands.

Import to NL	x 1,000 tons
Soya beans	3,628
Soya oil	85
Palm oil	2,834
Rapeseed	1,598
Rapeseed oil	320
Sunflower pits	632
Sunflower oil	358
Coconut oil	411
Palm kernel oil	181
Other oil seeds	296
Other vegetal oils	249
Animal fat	317
Used frying oil (UCO)	207
Fish oil	19
Other	706
Total imported volume	11,756
Internal production NL	
Oil seeds	9
Animal fat	189
Total amount of resources	11,954



World production of oil, oil seeds and fats



Redrawn from: *De Nederlandse olien- en vettenindustrie: een internationale en duurzame keten*, MVO, 2014

Re-use of fats

Upcycling vegetal fats from biodiesel to sustainable PCM module

Now that PCM's have been analysed theoretically, the most efficient PCM types are known. In practice, using these optimal materials is expensive and requires specialised manufacturing. The natural materials already consumed in our daily life offer a new approach to PCM use. As analysed before, The Netherlands has a huge amount of vegetal oils and seeds imported annually. Even so, Dutch firms manufacture and refine the resource to create useful products for several sectors. The approach used in this research relies on naturality and accessiblity and inexpensiveness of the production process of the PCM module. Herefore, the analysing the waste flows of vegetail oils for further use as a PCM is highly important and an evident element within the research.

The biobased economy is only feasable and sustainable when it does not compete with the food industry (WTC, 2013). If we use fats and oils for biomass or PCM applications than spoilage for potential eatable use is a fact. This means that waste products will gain more value over the years, in the biobased industry; the circular economy is strongly related to the biobased economy. Circular use of the vegetal oils does not put direct pressure on the production of the resource in its original tropical regions. Indirectly, it does put pressure on the waste products of this sector, which can be relatively small scale due to the fact that it could turn into domestic waste collection for example. As published in Science in 2013 *Battle for the Barrel* reflected on new maisproduction in the US causing friction since it was determined to serve only for the biofuel industry instead of the food industry.

Using the vegetal oils, organic eutectic mixtures in fact, for biodiesel is the least efficient way of reuse. However, when the vegetal oils are used for chemicals and materials, it will turn out differently. In the piramid for reusing green resources the chemical and material category finds itself as a destination one step before biofuel. Considered the most important use for green resources is health, with farma, fragrances, flavours and flowers top listed. Ideally, the waste products are then used for nutrition fabrication as fruits, fresh vegetables, food crops and fodder. After that, degraded products are preferably used for chemicals and materials, as functional molecules, fermentation products and fibres. To this category the foreseen PCM module belongs. The new use of degraded vegetal oil is used to sustain peoples homes. When the lifespan of the module is over, the same substance can be turned in to become biofuel at last. The intervention within the current waste flow thus ensures an effeciently used delay of the frying oil reaching the fat collecting companies that process it for its final destination.

In essence, the production process of PCM for the PCM module is based on the upcycling of used vegetal oils from domestic use and commercial (horeca) use.

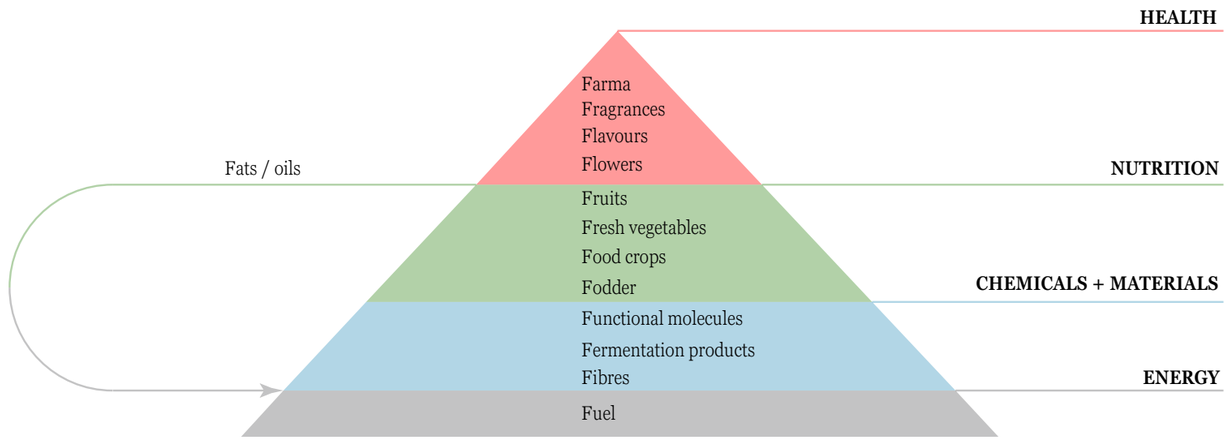


Figure X: Valuation piramid for green resources (Strategie voor een groene samenleving, 2013)

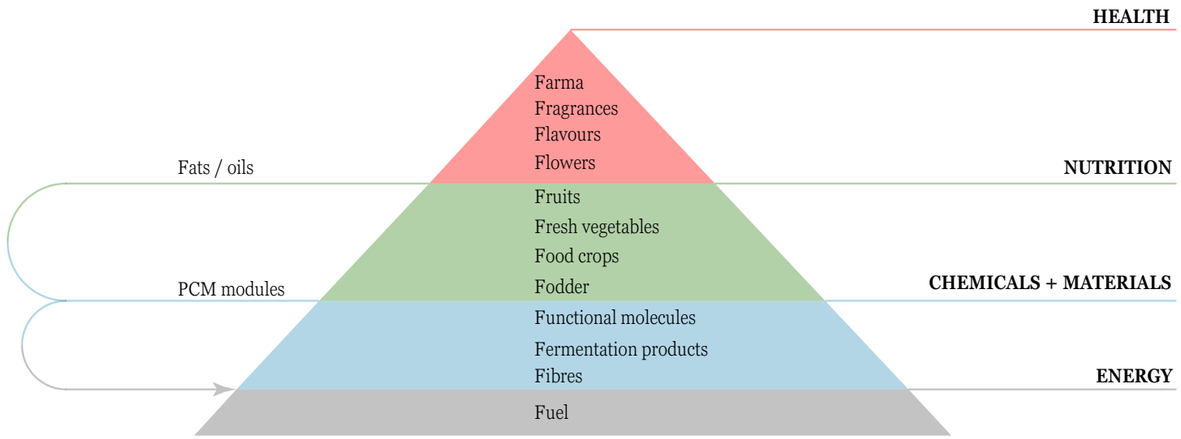


Figure X: Re-valuation of oil/fats within piramid for green resources

Collecting waste fat

Since 2015 there has been an increadible development regarding waste collection of fat in the Netherlands. On average a dutchman use 4 kg of frying oil on anuual basis. Currently 41% is already collected (MVO, 2018). However, most of this is then processed for further use as biofuel. Intercepting a part of this waste resource would enable the fabrication of PCM modules. For the current biofuel collection method of vegetal oil, there are specific yellow containers. In 2015, the campain 'Frituurvet recycle het' changed peoples perception of waste. Since then, 2530 collection points arose throughout the country.

The implementation of such domestic waste flow relies on a simple but ever so relevent element: the type of host for a container. Containers were place on multiple public places, where one would go on a daily basis. In this sence, rather social spaces in our urban environment. In the graph pictured on the right hand side the type op collection points varies from supermarkets to children farms (MVO, 2018). But also some school and sport clubs have contributed to this effort. These functions within the built environment ensure slow conciousness and awareness is created to the civilians that dispose their waste. Also a sport club or school could actively motivate their members to interact with the idea of handing in waste for re-use purposes, althoug I have very little evidence of this already happening in The Netherlands.

What material is disposed, defines its further potential use. But the reality is that none of the recycling companies exactly knows which ratio of different fats is turned in. The containers collect all types vegetal oil, from coconut fat, to palm oil, olive oil and margarine. What is required is that the oil is situated in a plastic cover, container or bottle. In the production proces of biofuel, all plastics and oils are burned, seperation of the two components does take place. Seperation of the fats does not take place.

In order to avoid this mechanism, the idea is to seperate the oils when disposed by the people. Always impurities or mistakes occur, however, this increases the pace of the production process of PCM but it is also evident for an inexpensive process. Next to the all waste oil container, there should be one for frying oil and cocnut fat seperately. To increase the awareness and success of the turned in oils, the social network of the BoTu people is targeted. Together with the integration of workshops in combination to schools, sport clubs, cooking clubs and children farms, it will have a great foundation of social implementation process.

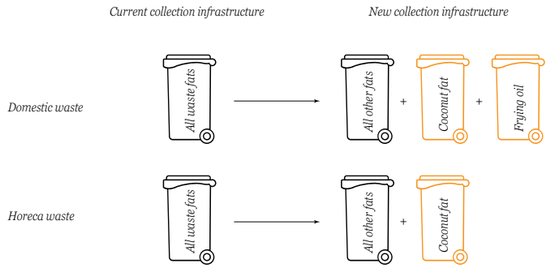
On the next page all specific yellow container frying oil collection points in Rotterdam are mapped. There seems to be none in the BoTu or M4H!

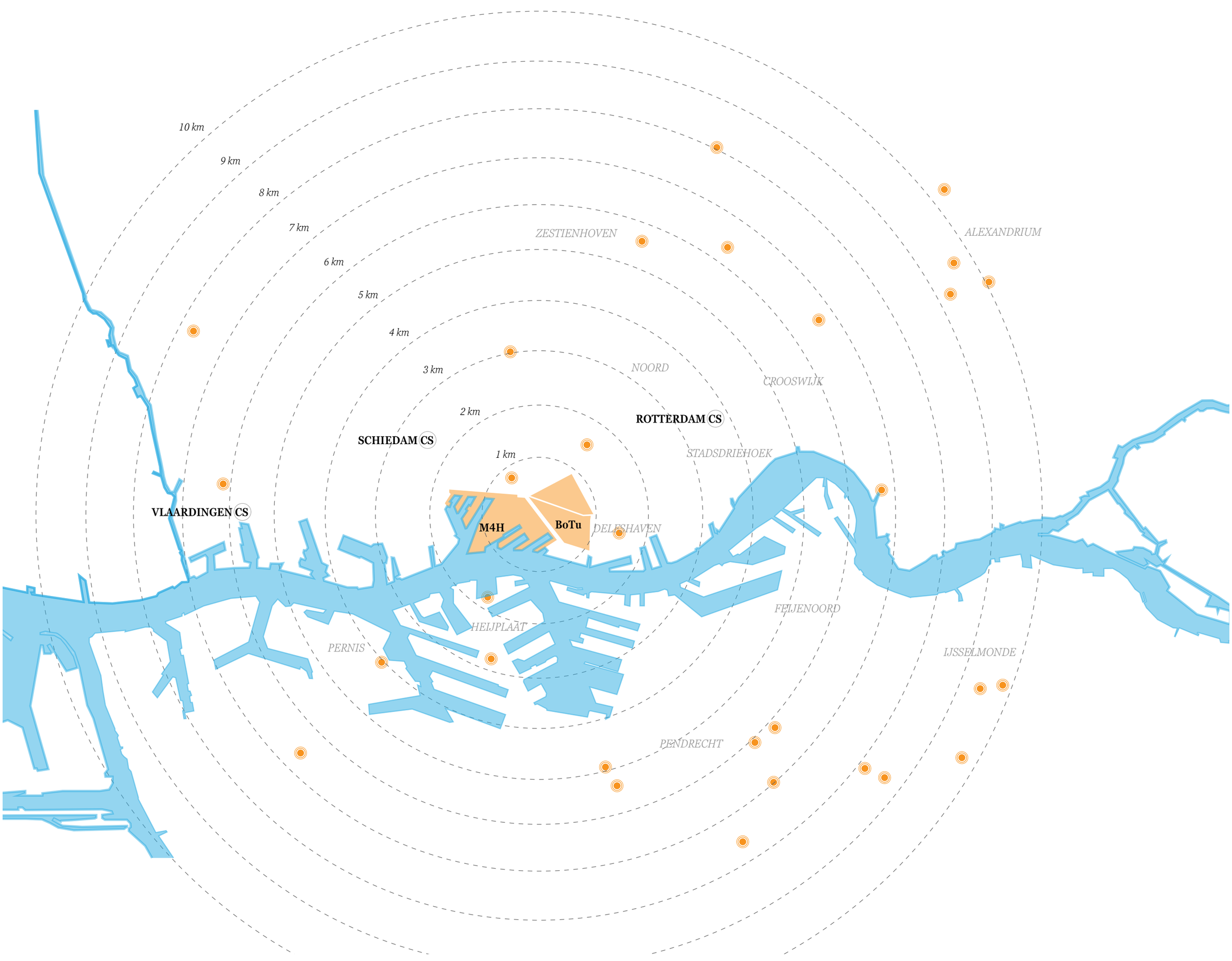
Amount of collection points through NL

Types of collection points

1. *Supermarkets 50%*
2. *Waste collection points 12%*
3. *Sport clubs 11%*
4. *Schools 2%*
5. *Childrens farm 2%*
6. *Other 23%*

Colletion strategy for specific oils




10 km
9 km
8 km
7 km
6 km
5 km
4 km
3 km
2 km
1 km
ZESTIENHOVEN
ALEXANDRIUM
NOORD
CROOSWIJK
ROTTERDAM CS
SCHIEDAM CS
STADSDRIEHOEK
VLAARDINGEN CS
M4H
BoTu
DELFSHAVEN
FEIJENOORD
HEIJPLAAT
PERNIS
IJSSELMONDE
PENDRECHT

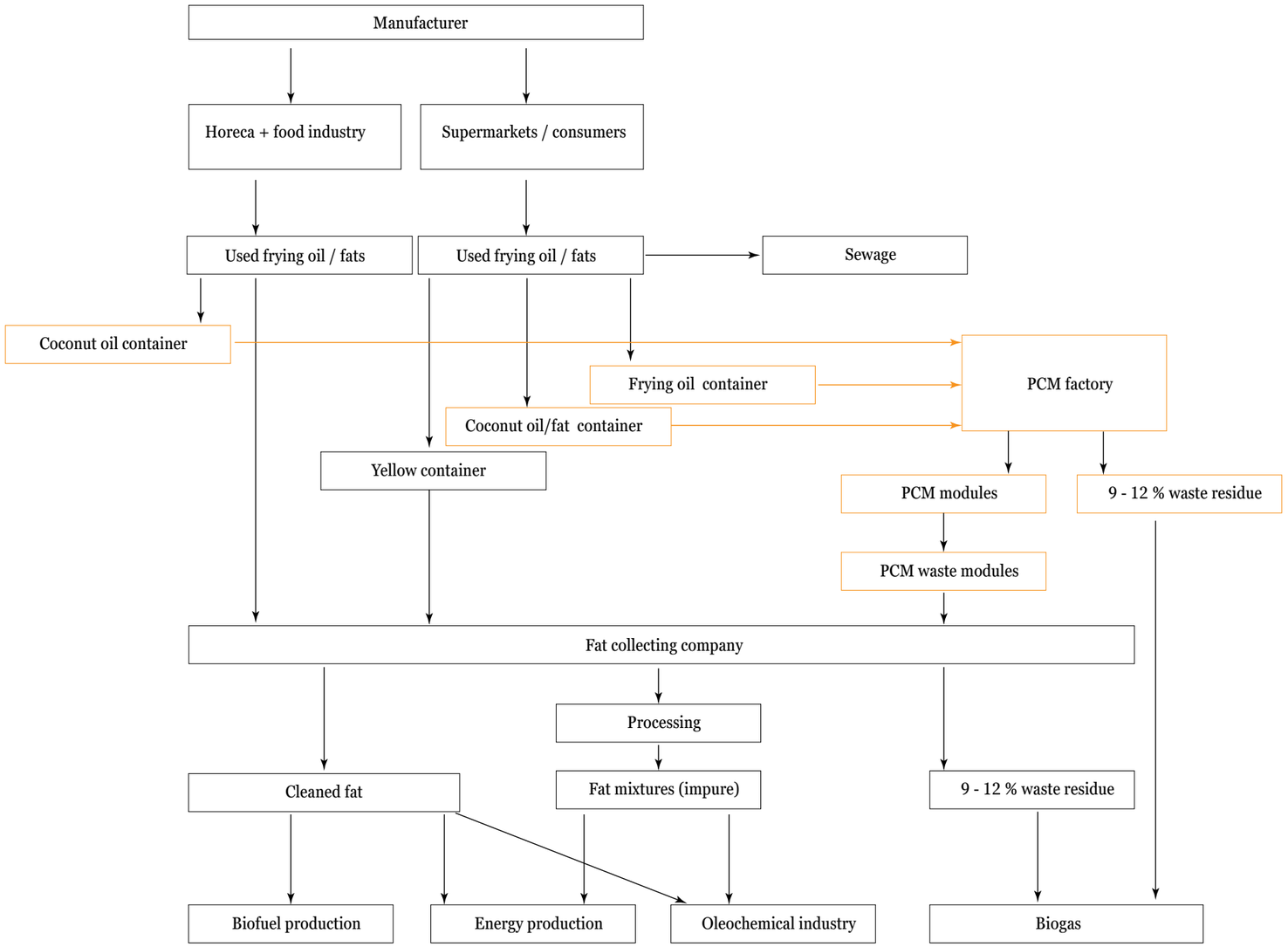
PCM in the recycling process

Now that the collection method has been determined, the collection process of waste as a resource is interrupted. The conventional method hereby changes slightly.

In the current model the production and processing of the imported resources starts with a manufacturing company, after pressing and crushing of oil seeds this company adds hexane to the raw material, in order to seperate the oil from vegetal waste. This protein rich waste material is used for animal food. The raw oil is refined and purified, which results in a transparant colour of the oil. After this hydrogenation and fractation of the refined oil enables the oil to gain specific desirable properties (e.g. melting point). This is an expensive and specialised process. The oil is now ready for the market.

Companies and consumers use the oil. It is then collected by fat recycling company. The domestic waste is (partially) collected in yellow containers. Those containers are picked up by the same recycling companies. After processing the waste oil it can be used for three different purposes, depending on qualit and composition of the substance; biofuel production, energy production and the oleochemical industry. Waste products are used for animal foor or biogas.

In the new model, seperation of the specific oils coconut oil and frying oil is done by collecting them in seperate containers. Probably, the coconut oil collection is more succesfull by letting companies hand it in due to quantity difference in use, than by domestic waste colelction. Although both take place. Collected oils are cleaned and filtered in the factory. Waste products of about 9-12% will be delivered at a waste recycling company for animal food production purposes. Production of PCM modules takes place by the use of the cleaned oils, mixed or not mixed depending on the requested melting temperature range according to heating or cooling purposes. When the lifespan of such PCM module is over, these fats are recycled for biofuel or other lower valueted processes.



Reinterpretation (in orange) of recycling process used oils source:

Adjusting frying oil to an usable PCM

The behaviour of oils determines the processes that need to be taken into account in order to reach the preferred product. The waste products that are used to create PCM modules are contaminated oils. But the oils behaviour is not oinly determined by the food rests floating in the substance; also heated oil behaves differently than unused oil from the supermarket. On molecular level a change takes place by heating. As listed on the right, the melting temperature of oils depends on four main structures. Saturation of fatty acids within a fat ensures that more energy is needed in order to break the bonds among molecules. This is even so the reason for longer fatty acids, trans configurations and double bond locations to increase the melting temperature of a substance.

Relation between molecular length and melting temperature *(Demirbas, 2006)*

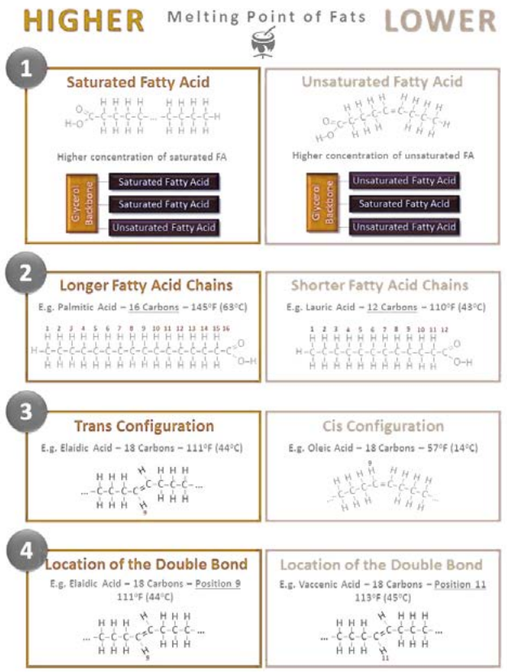
Paraffin C14	4.55	◦C
Paraffin C15–C16	8	◦C
Paraffin C16–C18	21	◦C

The degeneration process named polymerisation rises the melting temperature of a fatty acid. After heating short chained fatty acids connect among eachother and create a long chained fatty acid (Zijlstra, 2008). Therefor we assume that the used fat has a (slightly) higer melting point than unused fat as listed in the Matrix. The figure on the bottom right explains this behaviour. Besides other degeneration processes as oxidatin (resulting in bad smell), isomeration and hydrolesis this is the most relevent one to take into account.

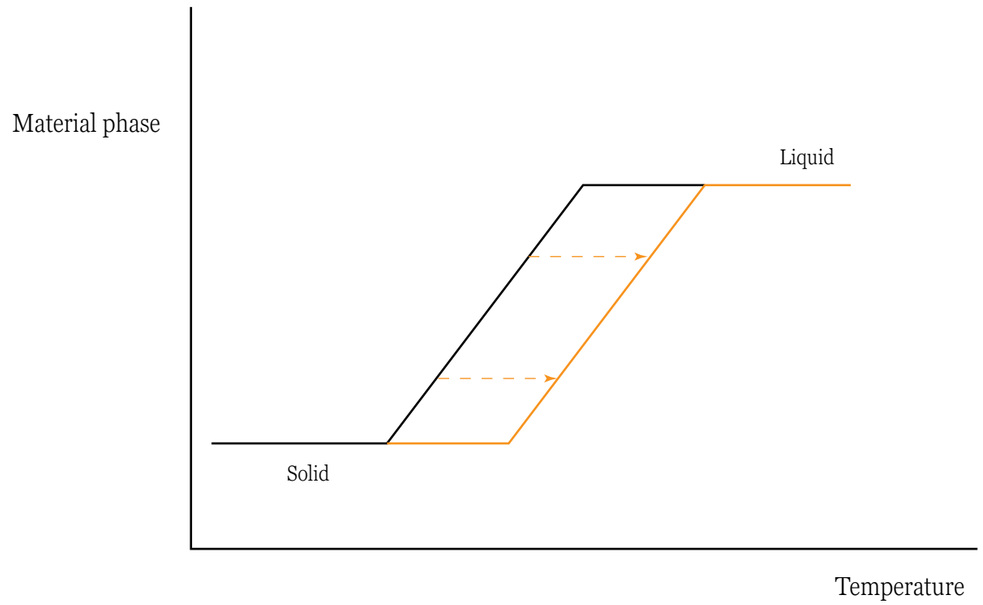
In order te reach the satisfactory melting range of the fat composition, some adjustments can be done. Hydrolesis is a widely used technique in the sector but a rather expensive and specialised one. Hydrolesis allows to modify the melting temperature by use of nickel. So in this model, hydrolesis is not realistic. In order to lower the melting temperature of pure coconut fat for cooling applications of a PCM module, the mixing of the substance with frying oil is a low tech alternative for hydrolesis. The melting temperature decreases, just as the latent heat capacity. However, the latent heat capacity for used oils is higher than for unused oils for the same reason as the melting temperature, as mentioned earliers. By mixing instead of hydrolesis, the latent heat capacities of the individual substances is not decreased, but the new composition of the mixture of both vegetable oils is relatively lower.

In conclusion, the low-tech mixing of frying oil and coconut fat in order to reach desired melting temperature ranges, theoretically enables a higher melting temperature and a higher latent heat capacity of the substance than by hydrolesis. This means that uptill the melting temperature of about 28 degrees (estimation) only two widely used vegetable oils have to be collected in order to facilitate the PCM modules of heating and cooling applications.

After all, it turned out too risky mixing coconut fat with frying oil because of the occurance of phase segregation. With the result malfunctioning of the PCM. In conversation with Dr. Duncan McMillan, Assistant Professor of Enzymology at Department of Biotechnology, TU Delft it appeared that lipids can change their behaviour through several ways; e.g. by the pH value, addition of 2+ ions and temperature. Of these influential elements, Mg2+ has the most potential influencing the melting temperature of the fat. This is a waste product from the MgCL2 productions in Veendam. And thus can also be circularly won.



Influence of heating to melting traject of fats / oil



Material meets application

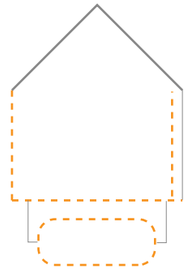
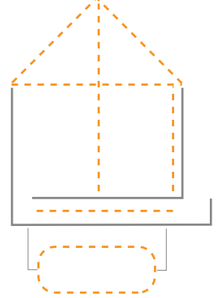
As a result of the material research, the application methods and material choice have come together, guided by several parameters. The most important influences for the choices made were:

A *Climatic regulation (fully)*
B *Structural application*
C *Accessible manufacturing process*
D *Biobased*
E *Inexpensive*

Conclusively the material choice for collected waste fat as a PCM for the purpose of sustaining peoples homes reacts on all the listed objectives, except for one: the structural application. It was too ambitious to desire a PCM that also has a load bearing function by itself. Those PCM's are still under research and therefore too expensive and specialised to be used for this project. Instead, the macroencapsulation ensures (some) structural ability. The climatic regualtive function of the PCM has been proven, and the chosen PCM modules to be manufactured have different scalen and can be combined over time within one household. In order for PCM's to work comfortably, always insulation and ventialtion is required; it is part of a larger system and thus houses fully containing PCM in order to climatise all the comfort without use of any other element, will not be likely. Coconut fat and frying oil are biobased products, and the desire to gain them inexpensively created another advantage: the upcycling and collection of waste material. This ensures very little (to zero) pressure on the production of the materials, creates a new life for the waste material wehereby its final destination of biofuel still remains and it creates awareness among the collectors and users. Using this material for PCM modules ensures no complicated processing has to be done in order to manufacture them; filtering, mixing and pouring into a container.

Hereby, all sub-questions regarding the material use have been answered. It offers great potential and proper foundation to form a social process that lets the inhabitants of BoTu interact with the production process whereby some intervention to the socio-demographic situation of that neighbourhood can be done.

PCM MATERIAL	 Frying oil 1/3 Rapeseed Oil -10 °C 2/3 Sunflower Oil -17 °C	Mg^{2+} $MgCl_2$ Salt
Pure melting temperature	-15 - -12 °C	
Waste melting temperature (assumption)	-12 - -8 °C	
Latent heat capacity	169 J/g	

PCM APPLICATION	 Heating purpose	 Cooling purpose
Melting temperature	> 23 °C	< 23 °C
Quantity for surface application	+/- 10 kg/m²	+/- 10 kg/m²
Quanitity for other application	< 10 kg/m²	< 10 kg/m²

BoTu - M4H

Bospolder - Tussendijken & Merwe-Vierhaven

Social Resilience Research

Research overview

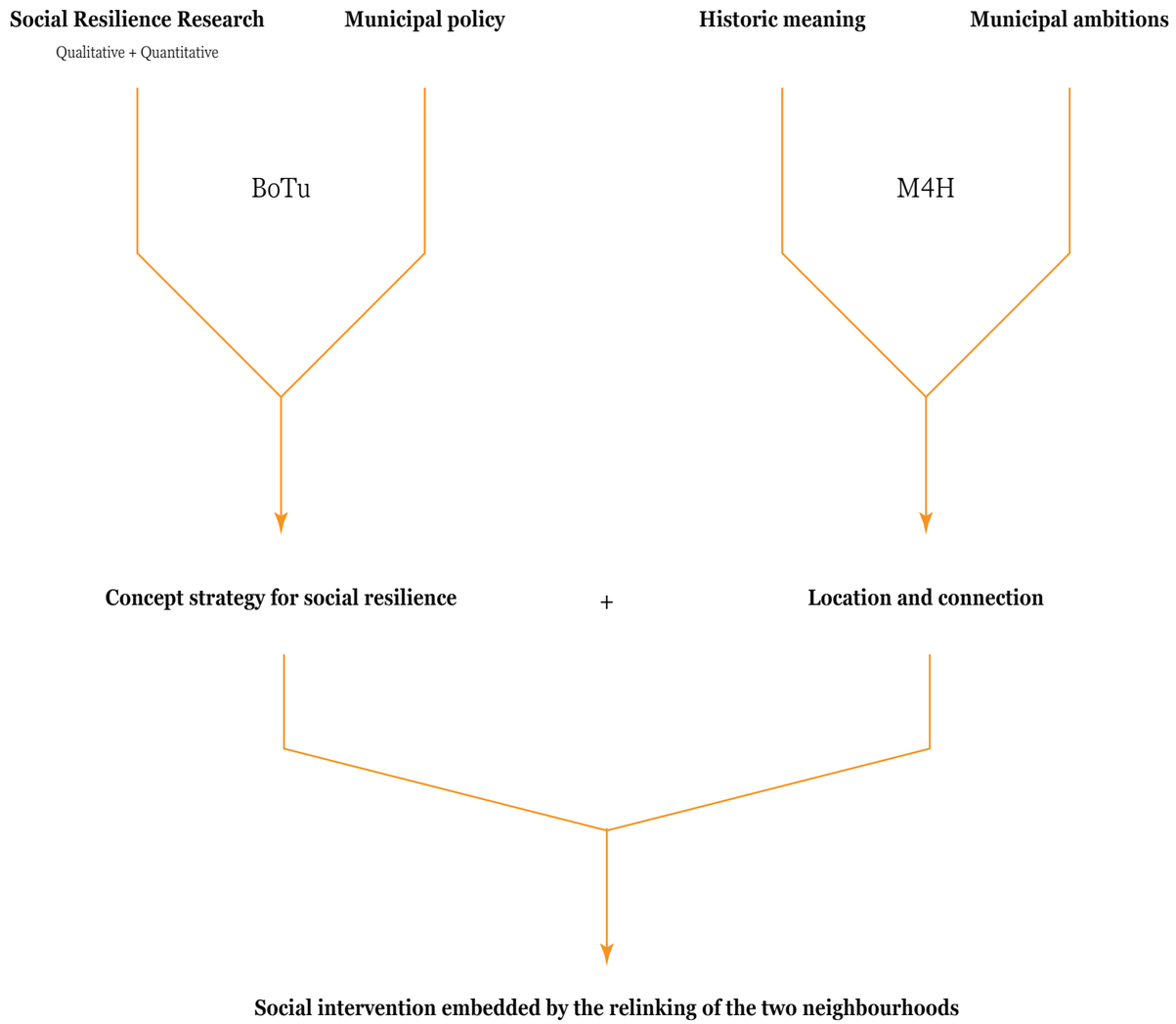
The social resilience research intents to find a link between Bospolder - Tussendijken (BoTu) and the Merwe-Vierhavens (M4H). Both neighbourhoods are absolutely special. The BoTu area is one of the poorest in the netherlands, but shall quickly become an ‘energy neighbourhood’ according to the municipality. M4H has been one of the largest fruit ports of the world but since one year has been transformed to the Rotterdam Makers District. Their historical relation ended in the 80’s. Bot neighbourhoods are afraid of parties and people that would enter the area with loads of money. The identity of BoTu will be lost and the identity of M4H will become different than the municipaly intends. In order to respect both identities, problematics and commonalities the intervention of a social factory aims to reconnect and strengthen the relationship of M4H and BoTu.

To structure my research the diagram on the right aims to give an overview in the research strategy. One that brings the seperate researches of both neighbourhoods together in order to find the cross over. The social resilience research for BoTu contains an analysis of objective and subjective sourcs in order to clearify the socio-dempgraphic problems in the area. The municipality already has an opinion about this and formulated goals. The two elements together give a strong basis for a concept strategy for social resilience. One that could ensure that people don’t have to be afraid of wealthy influences that might take over their living environment. The intention is to let the current inhabitants bring that same added value.

The M4H analysis starts with a brief review of the historic meaning of the area. Accompanied by the research of the current ambitions, this gives plausible location and connection within M4H but mainly between M4H and BoTu so that the current borders are relative. The location and connection in combination with the concept strategy for social resilience gives sight of the social intervention embedded by the relinking of the two neighbourhoods.

The material results in social benefit. The idea to have a low-tech innovation to sustain peoples homes is very interesting and relevant in this epoc. The urge of reaching the climate targets proposed for 2030 by the Paris agreement results in pressure on the renovation and innvation aspects within the built environment.

In this project I intend to create a bottum-up initiated production process whereby its success lies in
- improving the social network of an area,
- the personal development by employment and training,
- affinity and thus awareness with the built product and built environment,
- contributing to the emancipation of the local population
- sustaining the homes of BoTu inhabitants



Introduction to BoTu

Origin of Bospolder and Tussendijken
In 1886 the poldered area that was defined by the railtrack, dykes an cannals was annexated. The Mathernesserdijk, a dyke as a primary deltaic structure dating back from 1260, is the border of the area in northern direction. Nowadays it protects about three million people in the 'Zuid-Holland' province from floods. In southern direction of this dyke, Bospolder and Mathernesserpolder were created in the 14th century. Another dyke named the Groendijk split the are in half creating a polder in between dykes, named Tussendijken. This dyke no longer exists however.

Around 1910 the first urbanisation of the area took place. Inevitably this lead to the development of the water shores; the cargo ports Keilehaven, Lekhaven and IJsselhaven took place around 1912 and 1916. The majority of the people living in the adjacent neighbourhoods as Spangen, Bospolder and Tussendijken were employed in the cargo ports.

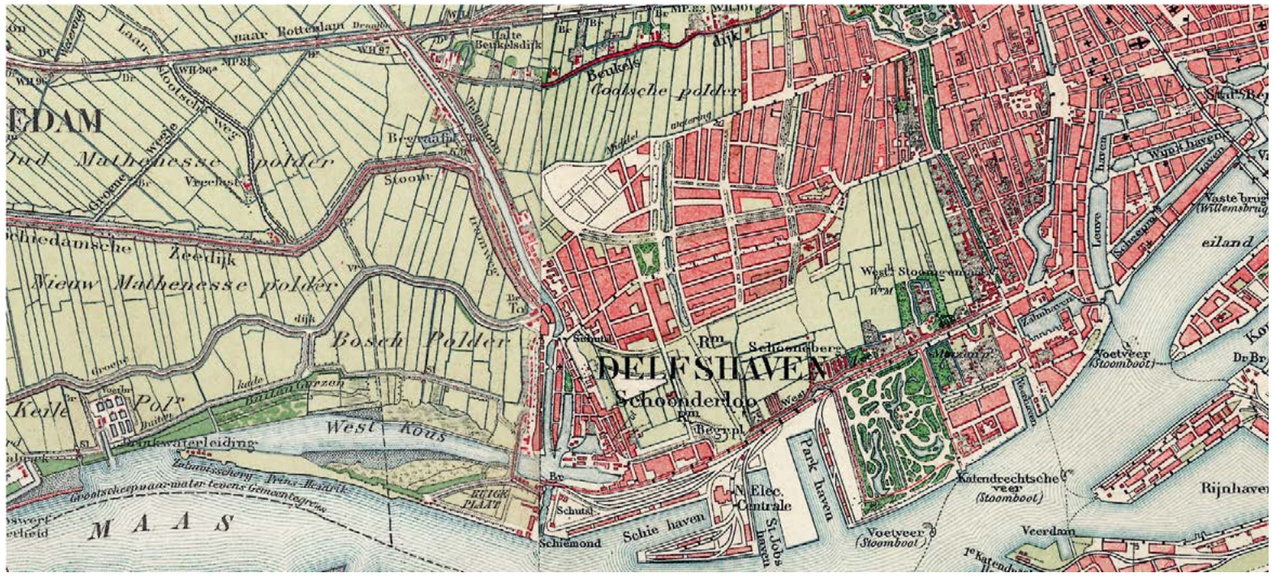
Bospolder
In 1911 the Schiedamseweg was constructed, and finally released Delfshaven from its alienated setting. The future neighbourhoods behind it, were prepared for construction and the idea was to give them the same ambiance and style as the 17th century Delfshaven. However, the municipality did not have enough money, so they set up the urban plan. Private constructors were then challanged to develop housing blocks in the area. This lead to a great variety of architectural expressions. Also the first social housing block arose in this area. In 1948 Sybold van Ravensteyn wrote that it was one of the least succesfull urban plans of Rotterdam because of a lack of space and consistancy! (Steenhuis stedenbouw/landschap en Urban Fabric, 2009).

Tussendijken
Tussendijken and Spangen were designed Spangen by P. Verhagen. It was going to be a civilised neighbourhood of higher class than Bospolder. The realised plan of 1940 had become quite different than the initial design, because of the building crisis. The streetplan was considered to be a deception, where only the schools ensures romantic places in the street view. In contrary to Bospolder and Spange, the school in Tussendijken are located at the corner of a building block, often in relation to a square. In the other neighbourhoods they were hiddin inside a building block.

The forgotten bombardment of 1943 has left its traces. Not the Kriegsmarine in the Vierhaven area was hit, but a large part of Bospolder Tussendijken. 18 hectares were destroyed. Filling up the space was done by larger and higher blocks. The street view from the Schiedamseweg was homogenous before the bombardment, but with the newly built larger volumes it became a different street which portrayes the timeline of the neighbourhood.

1970 - 2000
Around the 1980´s a new invention was introduced in the harbour: the container. To some the best invention of the last 100 years, it did change the complete organisation of the cargo ports. They became vacant which resulted in unemployment for the neighbourhoods around the M4H.

Location
The location of Bospolder - Tussendijken is actually phenomenal. It connects Schiedam to Rotterdam and has historic Delfshaven adjacent to it. On opposite side of the southern dyke there is a new innovative industrial area with a huge potential; M4H. Distance to both Rotterdam Central Station and Schiedam Central Station is 15 minutes by bike. Besides that, there is excellent infrastructure available with the metro, tram and bus connecting the area to the rest of the city. However, the schiedamseweg functions as a border between both neighbourhoods. Especially for youngsters this is a border. The neighbourhoods are specifically residential areas; so much that there is some lack of balance in functions hosted in the area. Half of the dwellings are socially affordable housing units and around 60 to 70 percent of all the dwellings belong to Havensteder housing corporation. Only a few qualitative newly built dwellings arose over the last years, such as Le Medi.



BoTu as a ‘polder’ in 1901, located outside the primary deltaic protection (dyke).

The ‘mistaken bombarding’ or now named ‘forgotten bombadment’ in the centre of BoTu (1943)
(Steenhuis stedenbouw/landschap en Urban Fabric, 2009)

Social Resilience Research

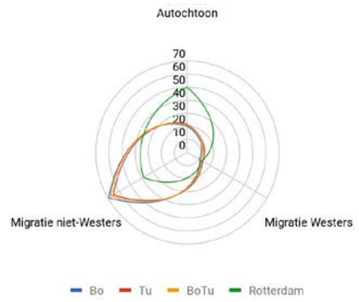
Quantitative: Demographic

Bospolder has 7,150 inhabitants and Tussendijken has 7,000 inhabitants. BoTu has an enormous amount of children; one fifth is younger than 15 years old. Additionally, it is one of the most multi-cultural areas of Rotterdam. There is a majority of 70% of people with non-western immigration background, a minority of 20 % has background of western migration and there are hardly any native Dutch without immigration background to be found: only the remaining 10% of the population. The neighbourhood BoTu contains a lot of hard (paved) surface and is relatively crowded. There are even families consisting of seven people that live in a two room apartment. For the green facilities in the area Park 1943 and the Dakpark are present, the last one is most populair.

Considering the objective data for this neighbourhood some truely problematic values come forward. Children with an educational backdrop are highly represented in BoTu: by 69%. This is mostly a result of their shortly educated parents of which 37% of all kids have and their very shortly educated parents, 29%. This also relates to the poor reading skills of about 60%. This contributes to their low wages. On average the annual income is just 14,950 euros. The Rotterdam average is about 22,300 euro's which makes it the poorest city of The Netherlands. BoTu is one of the poorest neighbourhoods in Rotterdam. It does not perform better than some serious problematic neighbourhoods in the focus area of the city; the southern part. The municipality states: 'in fields of language, educational level, employment rate and debt problems, BoTu does as bad as some critical zones in the south' (Gebiedsvisie, 2016). According to the same municipal report, 70% of the inhabitants enjoy a 'low salary'.

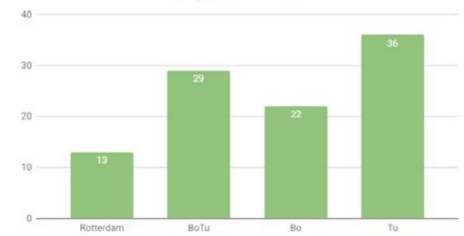
Resulting in cheap housing, 70% lives in corporation dwellings. BoTu clearly has some qualities, but there is a lot to be improved. What is clear now, is that although BoTu has been anounced as Energiewijk (energy neighbourhood) in 10 years time, the last people think about themselves is sustainability. If they even know what it means. The current situation is that mothers have to chose what to by from their last euro in order to survive and feed the family. Socio-demographic issues should be solved. In this analysis I try to get a grip on the specific problems and possible solutions.

	Bo	Tu	BoTu	Rotterdam
Native Dutch	20.3	21.5	20.9	49.9
Migration Western	10.7	13.3	12.0	12.6
Migration non-Western	69	65.3	67.2	38.2



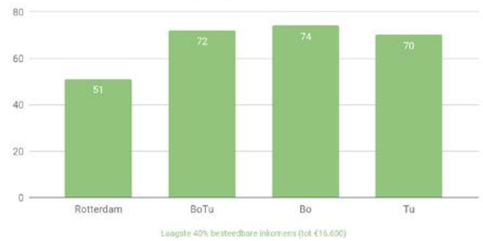
Shortly educated parents

Very shortly educated parents

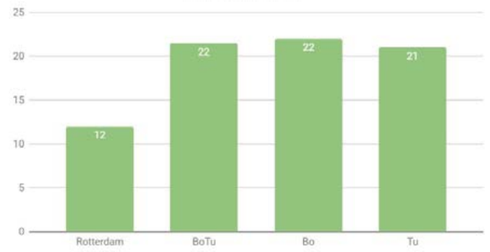


Average income household

Low income household



Social welfare benefit



Quantitative: House owners

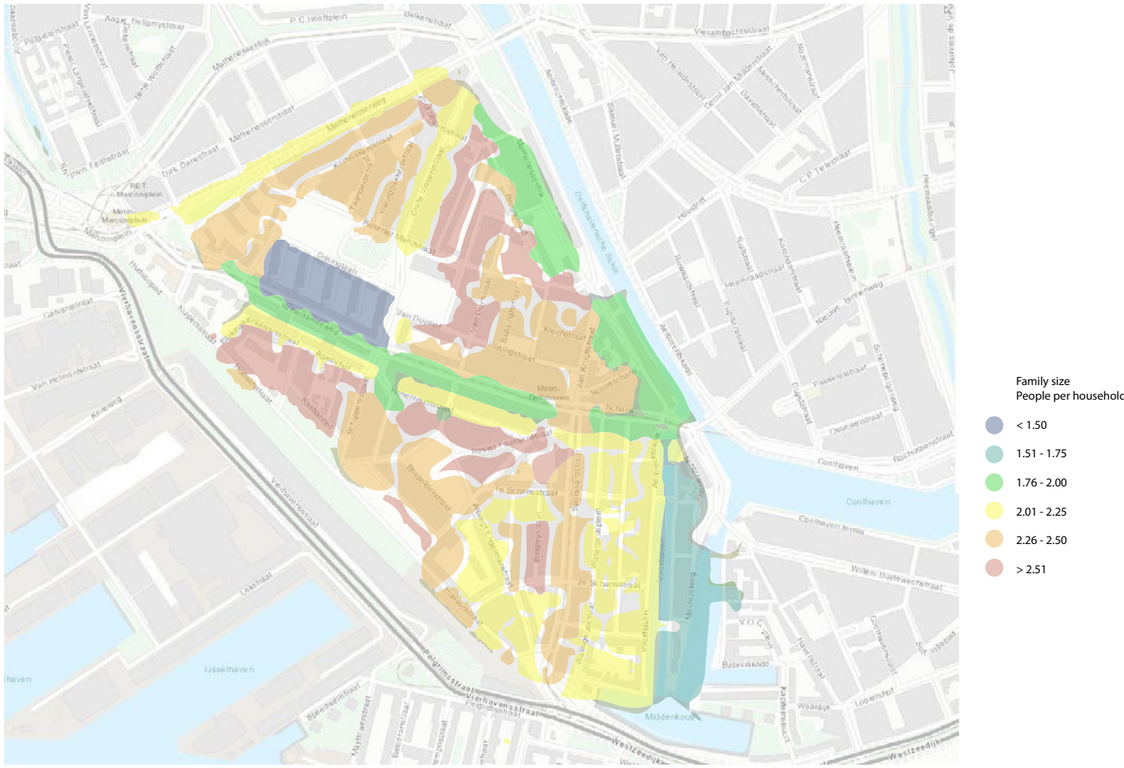
In the following maps the different groups of house owners are portrayed; the housing corporation Havensteder, private house owners that subrent it and private house owners that live there themselves. Havensteders housing blocks are situated everywhere, except for the Schiedamseweg. What is also visible is that their houses are little underrepresented at the northern and southern border of the neighbourhood. That is where some private house owners have bought their dream house, to live there with their family. New building blocks will arise on these edges and those are the first 'gentrification spots' in BoTu. Located alongside the dakpark, the value of those houses will increase. The last group is the private owners that subrent their house or shop. Mostly done in the Grote Visserijstraat and Schiedamseweg, the commercial buildings are subrented. In conclusion:

- Private houseowners rent their house alingside main shopping streets
- 70% of all houses is of corporation Havensteder, mostly located on centre
- House owners that have been capable to buy and live in the house themselves are mostly located on the edges of the neighbourhood
- Few new building sites arise alongside Dakpark

Quantitative: Family size

The family size in BoTu is relatively small according to this objectively obtained data. The smallest apartments to be found here, are the ones in the high rise (blue). There are 360 apartments of about 70 m², mostly there live single mothers or elderly. However, the most common dwellings have the size between 70 - 90 m². Large dwellings uptil 120 m² are mostly located on the edge of BoTu and represent privatelt owned family houses.

The smallest family compostion is in the apartment block high rise building. The average family in most corporation dwellings consists of around 2-3 people. The largest families consist of 3 or a little more people. This is again, situated on the edge of the neighbourhood. The numbers seem relatively low regarding the family size. The data portrays a different situation than in reality. As mentioned in the BoTu introduction, in the qualitative research we find out that there are severe situations with many people living in a small apartment.



Frying oil — LHC 169 J/g

1/3	Rapeseed Oil		%	LHC [J/g]
		Palmitic acid	4	185,4
		Stearic acid	2	222
		Oleic acid*	56	172
		Linoleic acid*	26	164
		Linolenic acid	10	164
		Other	2	Other
		Average		**170 J/g**
2/3	Sunflower Oil		%	LHC [J/g]
		Palmitic acid	6	185,4
		Stearic acid	4	222
		Oleic acid*	16	172
		Linoleic acid*	73	164
		Other	1	Other
		Average		**169 J/g**

Oleic acid*
$\Delta_{fus}H°$ = 45.62 kJ/mol
mass = 282 g/mol
LHC = 172 J/g

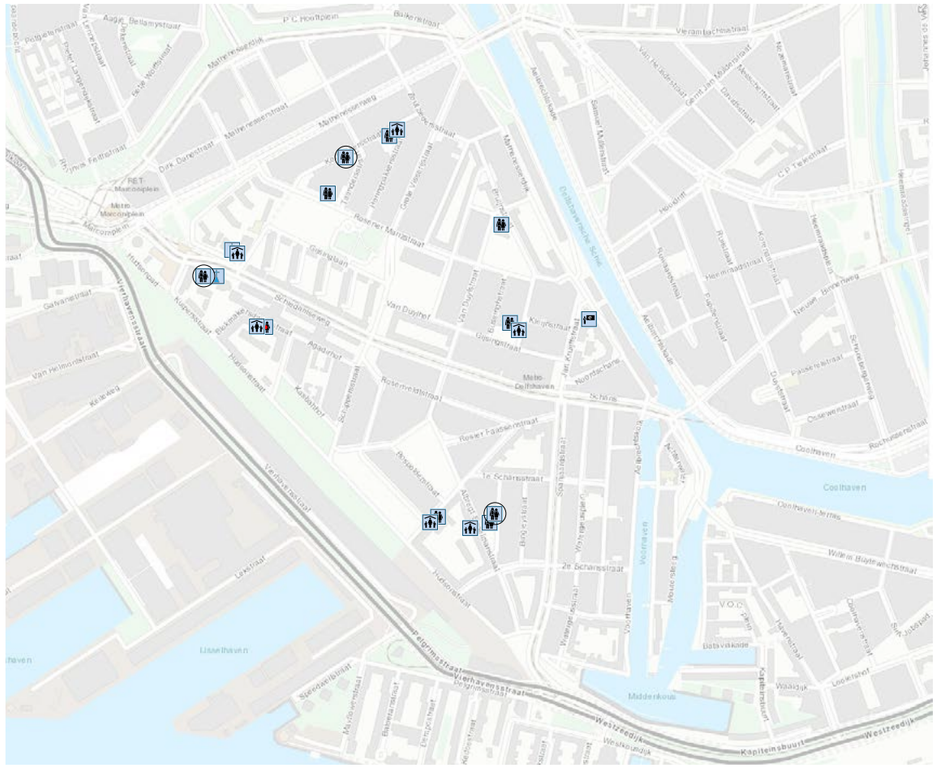
Linoleic acid*
$\Delta_{fus}H°$ = 45.88 kJ/mol
mass = 280.45 g/mol
LHC = 164 J/g

Social Resilience Research

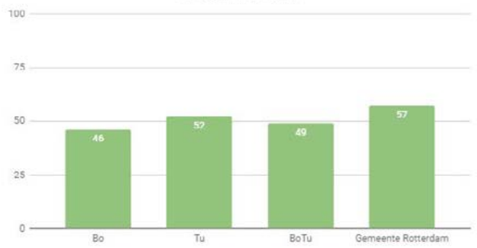
Quantitative: Education

Regarding education, there is a large influence from the family itself towards the children and their approacht to education. Girls are mostly expected to help in the household after school whereas boys may play on the streets after school. Around 69% of the children are encountering problems in school, because they start with a backdrop due to their parents origin and educational level. This is a severe number. There are many primary school in BoTu. All with their own perspective or influence: there are hindi, catholic and special schools. The secondary schools where they go to are located in the centre of Rotterdam or Schiedam. Secondary schools have a wider range than the neighbourhood level. Only a few kids do homework after school. Often it is not really supported by their parents. They lack facilities to do homework, as their own desk or a computer to work on. Few kids have their own bedroom. In total 76% of the neighbourhood has enjoyed practical education, which is an enormous quality of this particular neighbourhood. The qualification rate for labour market is on the same average as Rotterdam, strangely enough. This implies that, unrelated to the level of education, around the same percentage finishes a studies and is ready and qualified to start working. In conclusion:

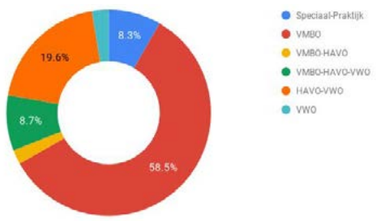
- Great variation of primary schools present
- Secondary schools are outside of BoTu (is normal)
- Only few kids do homework after school
- Many families have few to no facilities for their kids to do homework
- 76% has enjoyed practical education
- Qualification rate for labour market is around average of Rotterdam



Qualified for labour market



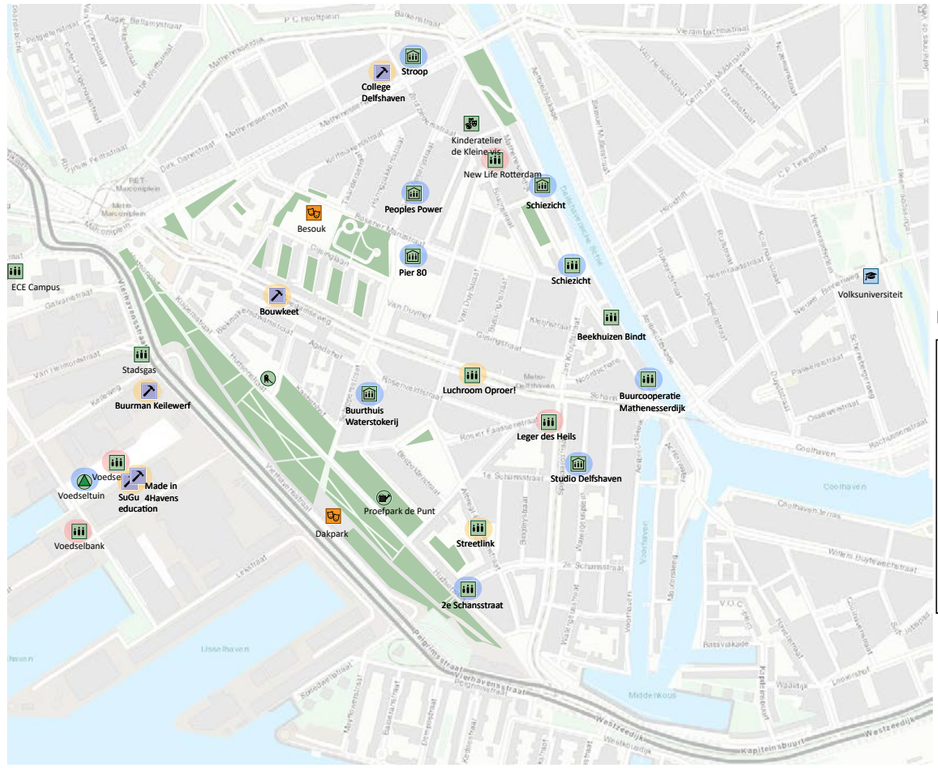
Choice for secondary school (level)



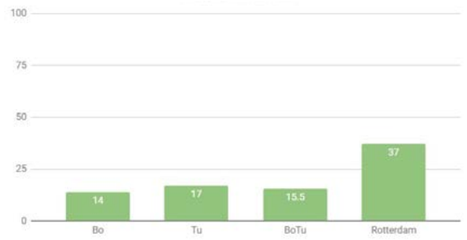
Social Resilience Research

Quantitative: Potentials

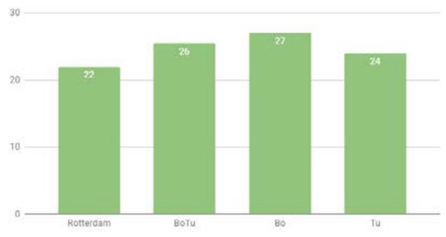
If we take a closer look at the people participating in the area, it is notable that the social involvement is large and various. The inhabitants are proud of their neighbourhood and preferably see their kids grow up in the same neighbourhoods as well. This is an indication that people are enjoying the area and that they feel comfortable. However, the unemployment rate is 17% and in total 28% is looking for a new job. Because BoTu is a residential area only 13 jobs per 100 people are present within the borders. It must be said that many initiatives react on this current development of little employment and poorly educated people. In the map on the right around 5 initiatives for poor people are shown, another seven focus on the new generation by educating them or getting them a job. Other participation initiatives are shown in blue. One specific initiative named College Delfshaven uses youngster from 15 - 23 years old for their projects. In order to contribute financially and educationally, the youngster consider it a parttime job as they get paid, in return for their rolemodel behaviour. The projects range from building, transformations and internships to educational programmes forllowed by these rolemodels. They are in essence influencers of their own age group, in a problematic neighbourhood. These are potentially perfect rolemodelsor influencers o spread the PCM-mania. It is a high amount in total and indicates the enthousiasm, problematique and perspective that BoTu has.



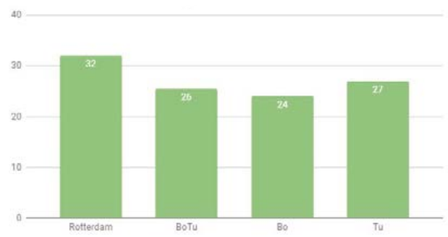
Availability of jobs within BoTu



Working <11 hrs, 15-26 yrs old



Working >12 hrs, 15-23 yrs old



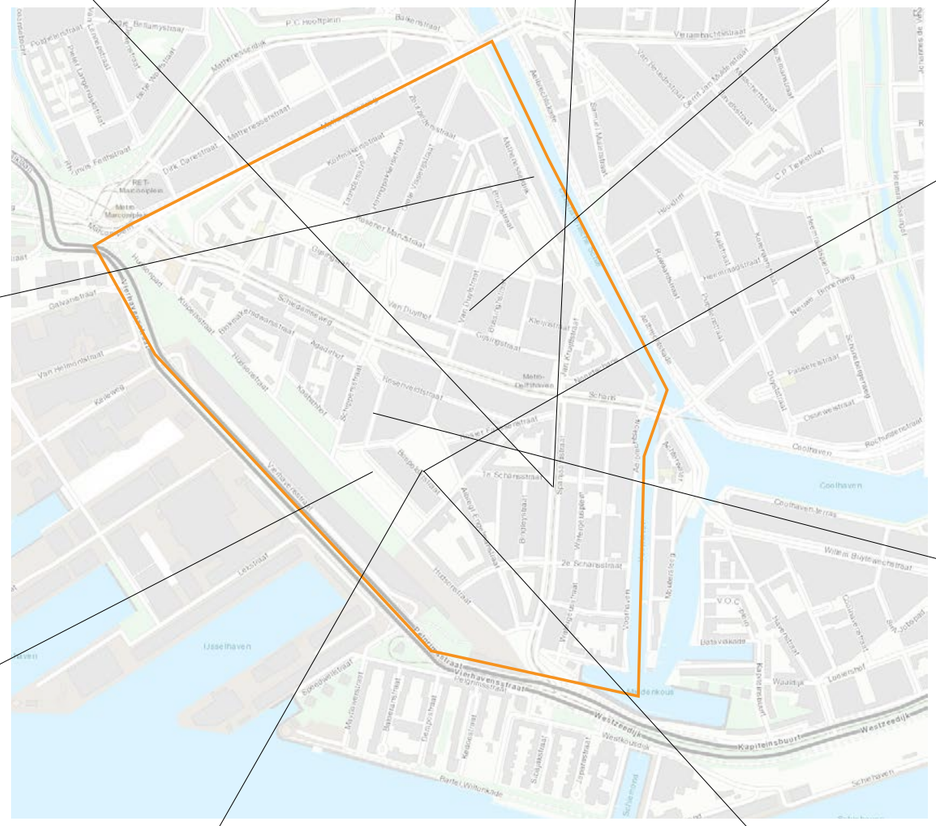
Qualitative analysis

Having a conversation

‘They have expensive clothing or a watch, but do not have their own room or a computer to do homework on. I know a family that has seven children and they live in a house with three rooms, one sleeps on the couch every night.’ - Streetlink

‘There are single mothers that have their things not sorted out properly, which they pass through to their children: resulting in financial issues because nobody has ever told them about paying their insurance bills. Or they cannot read.
‘- Streetlink

‘Ladies are expected to help in the housekeeping, homework is not to be spend time on.’



‘There was a little girl that was offered homework guidance for school in a specific course, but the father denied it, saying she was not stupid!’
- Pieter

‘There are three categories of inhabitants, the largest one is constantly trying to survive. If we have a monthly dinner, we only attract them sometimes if the price is below € 3,50 ’
- Christy de Witt

‘Educational level is determined by school and the parents. I told my son as well he ould be capable of doing VMBO or HAVO, but he is really not the right type of person for that’
- Waterstokerij

‘It is true that the kids living in this street perform better than the average of BoTu, but that is not strange if you consider the private home owners that bought their house here, opposite of the park. Many in this street are highly educated.’
- Inhabitant

“You notice it is always better if you enter the family house, if they allow you. Then you get to see the real situation and you can advice them specifically.’
- Pieter

‘In BoTu a lot of the youth lives with parents that do not raise them properly; simply because they even cannot. The boys are free to do what they want, and the ladies have to help at home. They do not stimulate the kids to study or do homework.’
- Pieter

Municipal policy

Main objectives and specific targets

The municipality has a bright vision for BoTu. Based on the problems found in the neighbourhood they correctly formulated specific objectives, in a wide range of topics. First of all the category perspective is based on the future development of social structures. Four pillars support this topic: Opportunities 'emancipator motor', pleasantly living: safety and livability, good dwelling quality; investments and lastly the identity and recognisability of the neighbourhood. Most important notice is the fact that the municipality uses the word emancipator motor. This properly indicates that the new generation is the hope for the future, but that the existing generation should adapt and be educated. It seems they are stuck in their traditions they brought from elsewhere but it misfits in the dutch society where education and (feminin) emancipation are important values. Our system is based on this and not going to school or having an educational backdrop may result in severe decrease of future potential. Besides that it costs the municipality more to take care fof the poorly educated people, because of crime and health issues that are more common amongst this group. This also indicates that poor education or narrow mindedness block ones personal development that later on even limits the individual. Therefore social activities where one helps another are important to stimulate and educate eachother.

The sustainable development formulated as the second category. The pillars supporting this objective are related to social and economical value increase of the neighbourhood. The aim is to increase the accessibility of public functions, socially and economically.

A. PERSPECTIVE

OPPORTUNITIES:
'EMANCIPATION MOTOR'

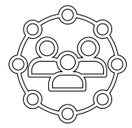
- Coherent approach for 0 - 12 yrs
- Support women + engage them with elementary school activities
- Coherent approach > 12 yrs with separation of ladies and boys
- Engaging parents with youth problems of their > 12 yrs kids
- Feminin Empowerment Movement: education, participation and language
- Activate youth development strategies
- Stimulate network among professionals with activities / meetings

PLEASANTLY LIVING:
SAFETY & LIVABILITY

- Inhabitant initiatives
- Project manager in BoTu
- Renovation old estates
- Introduction BoTu director
- Activities against criminality and youth issues

GOOD DWELLING QUALITY:
INVESTMENTS

- Selling of 680 rental houses
- Investment of 22+ mil in renovation or transformation
- Guide private house owners



'OUR' NEIGHBOURHOOD:
IDENTITY & RECOGNISABILITY

No specific approach defined

B. SUSTAINABLE DEVELOPMENT

DWELLING CAREER:
VARIATION IN HOUSING SUPPLY

No specific approach defined

SHOPPING + WORKING:
ECONOMICAL IMPULSE

- Realisation of affordable company space e.g. collective building for multiple users
- Schiedamseweg coherent approach

A PLACE FOR EVERYONE:
SOCIAL FACILITIES

- Planning societal facilities and accomodations
- Clearifying acoomodations for educational support
- Clearifying acoomodations for elderly living facilities
- Facilitating accomodation distribution

Concept strategy for social resilience

In conclusion, the objectives that I formulated through my research do not differ that much as the ones formulated by the municipality. In orange, all relevant aims are portrayed that are used in this project. First of all, inclusivity and the arrangement of large meetings among the poor BoTu people goes out from the idea to take away costs that they have currently. This can be done by free use of facilities, free food and also the opprtunity of earning money. Besides, the energy savings is the main objective architecturally seen. The educational objective reaches out to the more vulnerable people in the family; the women and children. Ideally the mothers would be taught together with the children. Seperately is also an option, since it allows for the discussion of topics about raising a child. Also, the male part of the family actually needs motivation to study. The family and their (traditional) values decide most of the habits for the children. Professionally the father figure that is already dominant could be used to function as a rolemodel within the family. The factory and production line should be well connected to other people and different cultures in order to have maximum effect.

My social resilience research + Municipality objectives

FINANCIAL

- Attractive gathering/community space taking away potential costs

- Employment by factory establishment

- (In)direct financial benefit by sustaining their homes with PCM product

EDUCATIONAL

- Educating children and parents together

- Informing mothers about raising children

- Inspiring boys to work or proceed a career

PROFESSIONAL

- (Dominant) father figure as an example

- Social activities as support for factory employees

- Increasing connection between streetculture, home situation and school

OPPORTUNITIES: 'EMANCIPATION MOTOR'

- Coherent approach for 0 - 12 yrs

- Support women + engage them with elementary school activities

- Coherent approach > 12 yrs with separation of ladies and boys

- Engaging parents with youth problems of their > 12 yrs kids

- Feminin Empowerment Movement: education, participation and language

- Activate youth development strategies

- Stimulate network among professionals with activities / meetings

PLEASANTLY LIVING: SAFETY & LIVABILITY

- Inhabitant initiatives

- Project manager in BoTu

- Renovation old estates

- Introduction BoTu director

- Activities against criminality and youth issues

GOOD DWELLING QUALITY: INVESTMENTS

- Selling of 680 rental houses

- Investment of 22+ mil in renovation or transformation

- Guide private house owners

SHOPPING + WORKING: ECONOMICAL IMPULSE

- Realisation of affordable company space e.g. collective building for multiple users

- Schiedamseweg coherent approach

Social concept

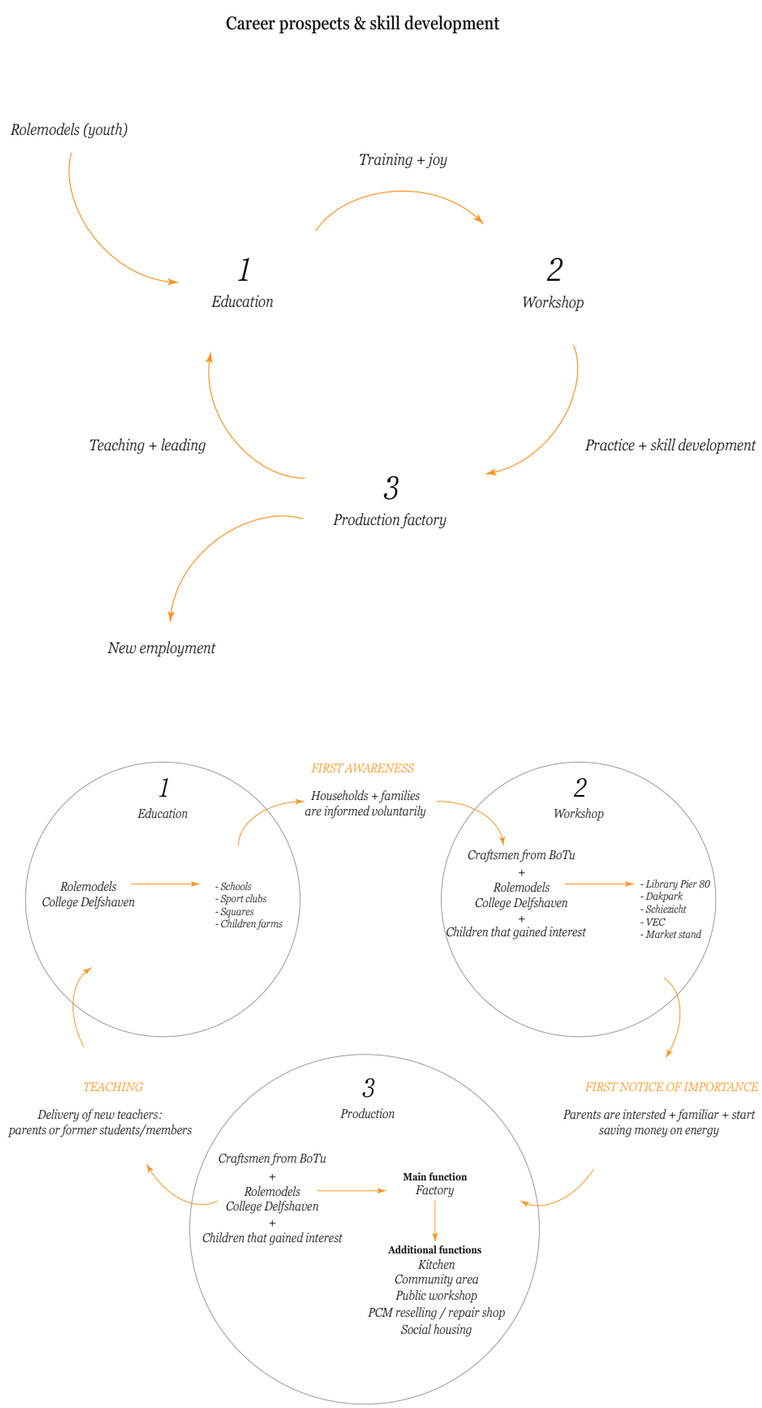
Factory and emancipation families

The concept strategy for social resilience knows three main categories: the financial, professional and educational strategy in order to cover as much as possible from the problematics in BoTu. This strategy aims to come back in the factory design. However, some qualities and aspects of these strategies are more suitable for earlier application or implementation.

To create a social support for the PCM material and for the activities around the production of it, the pre-factory stage is rather important. In short, there will be a pre-factory, factory and post-factory stage. The pre-factory stage focussed on social embodiement of the material and production, by a way of education and workshops. The factory stage contains the production of the factory with all its social functions and activities around it, and elaborates on all categories of the social resilience strategy: educational, financial and professional. The post-factory stage is about the future prospects of all involved people: the career potentials they gained after being trained, in the figure on the right this system is briefly explained.

Elaborately, the pre-factory stage of education and workshop ensures informal contact with the new material, new production and the new application. At first, children are taught by a (mandatory) educational programm to collect waste fat from home and to bring it to the activity. These activities are held at specific social cores of ones life; sport clubs, schools, children farms and squares in the neighbourhood. Trying to adress the future generation, so that even their parents get in contact with the PCM and application casually. Most probably they will, because the kids are rewarded by the fabrication of their own little PCM gadget; a can cooler or a laptop cooler. The workshop should be mobile to reach the different locations. The executors of this educational programm are the role model youngsters that are part of College Delfshaven. As portrayed in the graph on the next pages, this educational stage should take around two years.

After those two years, there is a new target group that casually knows about the activities and materials. The parents have overcome their (suspected) scepticness of PCM. In the workshops that follow, an educational programm is more specifically brought to the parents. Hosting the workshops in new locations as the library, the dakpark, schiezicht, vrouwen empowerment centrum and a stand on the market square will eventually associate the PCM module with a more definite implementation in society. The PCM modules to be produced in this workshop are one scale larger than in the previous educational programm for youngsters. During the workshop the parents learn about, money saving, the current problematic situation of BoTu regarding energy performance, re-use of waste and PCM as a means for that. The modules they produce are directly applicable in their homes. They can make a surface, for underneath the table or behind the central heating installation. They could also create an (arabic inspired) frame that hosts PCM and family pictures, as a way of chearing up the space. Last but not least, also shutter are producible. The tutors



Inclusivity

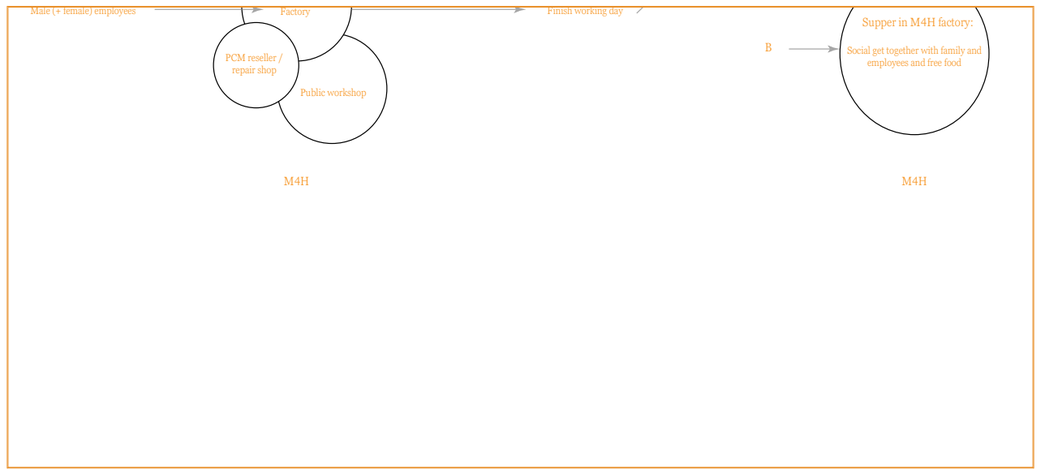
leading the workshop are the same College Delfshaven youngsters and possibly some interested children that decided to take part after their own educational experience with the material and programme. This stage takes about three years.

The realisation of the factory is a new stage. Socially seen, it is more than just a manufacturing area of PCM modules. It allows for the neighbourhood to come together, have a chat and to have dinner. This happens in the community area and can be seen as an embassy for BoTu in M4H. Adjacent to is there is a kitchen, where food is prepared by the parents and their children together (if wishfull). After a long day of working, the employees of the factory arrive in this area to dine together with their beloved ones or their fellow BoTu inhabitants. Free food is served in order to reach the very poor of BoTu. The community centre hosts language lessons, cultural activities and teaches parents about taboos or the coming of age from their children; a widely range supportive programme. Social educational centre where mother and daughter (and even sons) go after schooltime, around 15 u. Imagine:

They have a moment of private time (homework, or family time) and a moment in group setting where they talk about taboos or how to raise a child, lead by the host. Around 17:00 they will start cooking and the food is ready when the fathers finish their job. After dinner they return home together with a full belly, pocket money and an innovative (money saving) product to sustain their homes. If some employees work on site in BoTu, installing the intervention in houses, the family meets them there or at home, to eat together at the end of the day. Boys see their father working, but help their mother. Ladies the same. They still help in the housekeeping.Happy family triangle: Free food, Paid job, Kick ass innovation

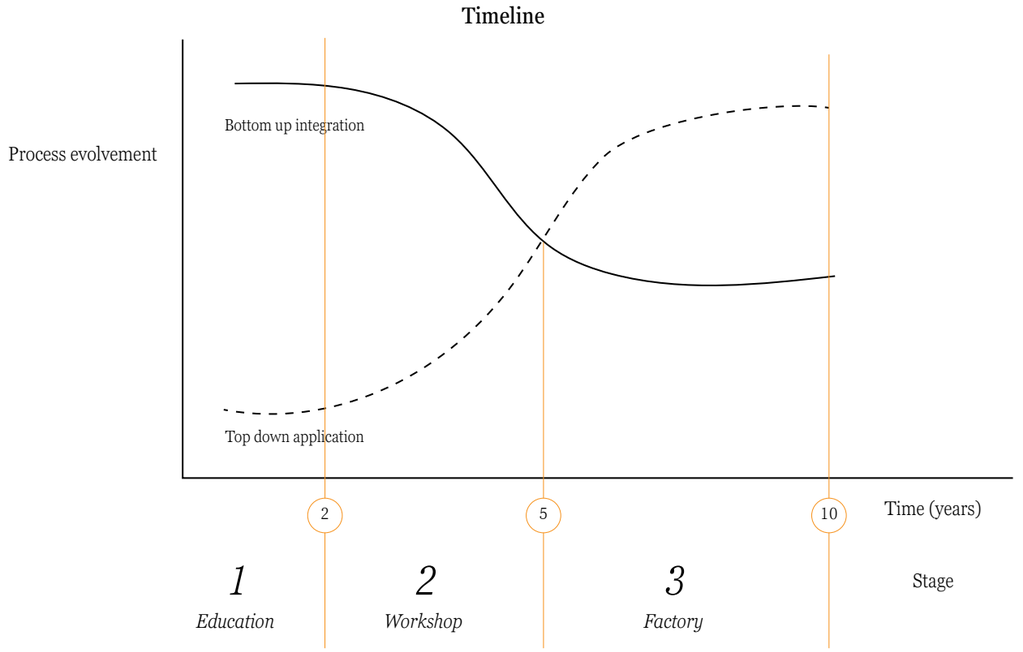
People interested in producing different things or sharing new techniques can use a public workshop that is available at low costs. It allows a broadening of the craftsmen that are already present in the factory. The people working in the factory are craftsmen from BoTu and people that have become interested during the ducational and workshop period. The idea is to build to factory together and later produce PCM in it when it is finished. This stage should take around 5 years in total.

	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*



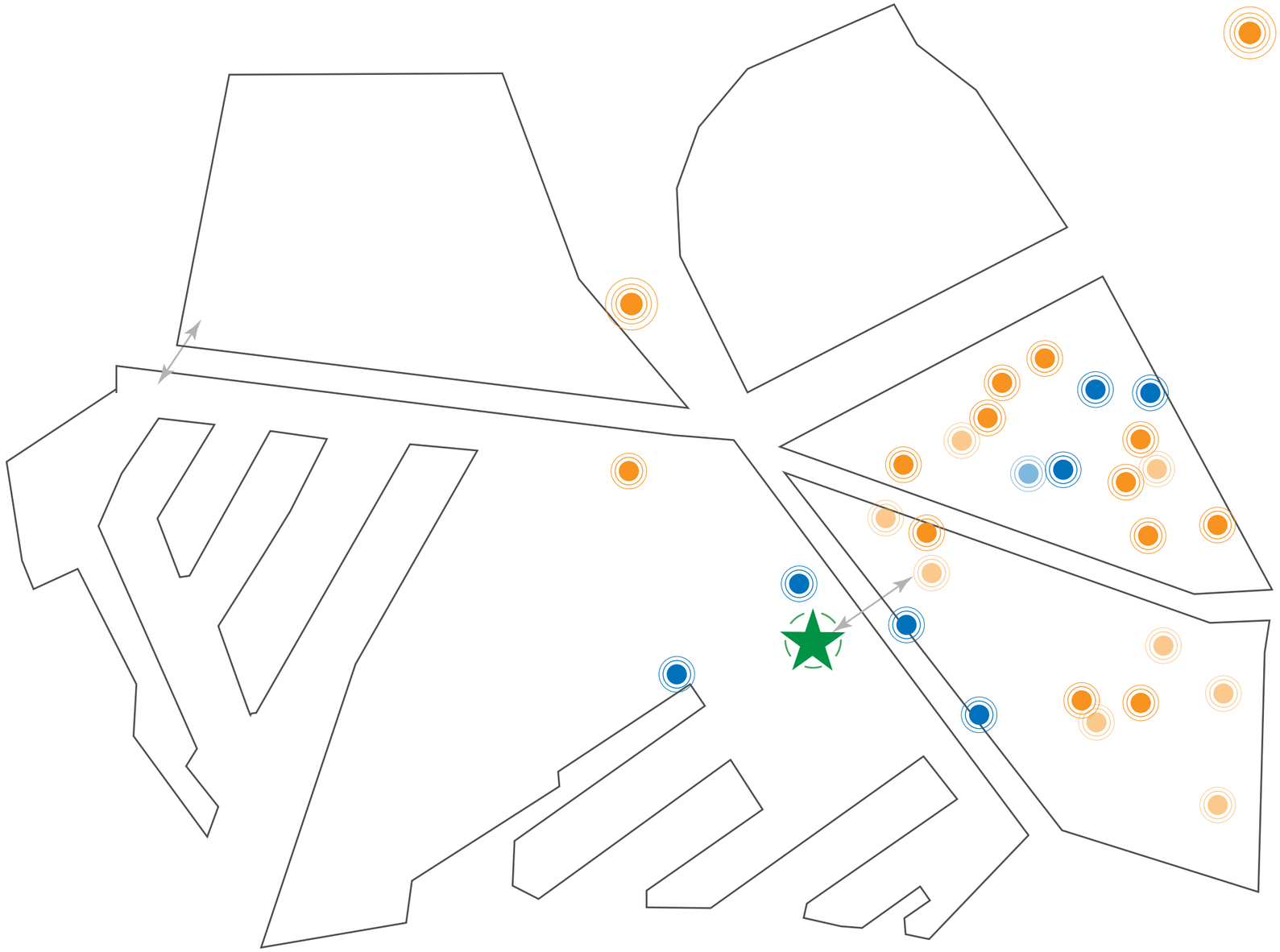
Timeline

Both of these stages, the educational and the workshop stage, take five years in total. In order to introduce the PCM to the people. This happens by rewarding educational programmes in terms of the modules they make themselves and take home. In a way this can be considered a bottom-up approach of implementation. For this social project it is very important since the people have to accept what is going on. In order to not let someone from above tell them what needs to happen, this approach lets them investigate and search for it themselves, casually. However, the factory stage is in a way the top-down approach of implementation. Only for the PCM module and not for the social activities, because they are hosted at the factory as well. The modules created in the factory are all sized modules. However, in this factory stage some larger modules are created compared to the ones in the previous stages. These modules have large impact on the energy savings for the household, but sometimes do require specific production or assembly techniques. Because the assembly of these new modules affect the households energy savings seriously, the most plausible party requesting these are the municipality or the housing corporations. Not to forget that also families that own their own house may choose for this option, though that will be a minority in BoTu. So the strategy is to start with the bottom-up introduction of the material in order to end with the top-down request and implementation of the PCM modules in the households.



Westkous 1911, boys swimming together in summer

Location of emancipation



Pre-factory stage

1 Educational

Squares

Schools

Children farm + public garden

2 Workshop

Market stand

Various (participation) projects

Factory stage

Factory

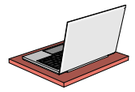
Steps	Process	Location	Learning objectives	Practical skills gained	Executors	Target group
1 *Education*	*Bottom up*	*On site* - *Schools* - *Sport clubs* - *Squares* - *Children farms*	*Educational + mandatory* - *Little creations* - *Usefull waste* - *Practial work* - *Energy transition*	*Collecting + Filtering fat* *Sewing + closing*	*Rolemodels College Delfshaven*	*Kids*
2 *Workshop*	*Bottom up*	*On site* - *Library Pier 80* - *Dakpark* - *Schiezicht* - *VEC* - *Market stand*	*Importance* - *Saving money* - *Energy transistion* - *Usefull waste* - *Social value of process*	*Collecting + Filtering fat* *Sewing + closing* *Carpentry*	*Rolemodels College Delfshaven* + *Craftsmen BoTu* + *Children that gained interest*	*Family*
3 *Production*	*Top Down*	*Factory*	*Contribution* - *Social interaction* - *Cultural differences* - *Language* - *Skills of production process* - *Waste management* - *Money saving* - *Energy transition* - *Teaching*	*Collecting + Filtering fat* *Sewing + closing* *Carpentry* *Installation / assembly*	*Educated rolemodels College Delfshaven* + *Craftsmen from BoTu* + *Children that gained interest*	*Corporations / municipality* *Families*

Module size	Development potential	PCM Product

S

Can cooler

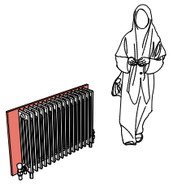
- Waste plastic container
- Vegetable PCM (reused)
- Aluminum foil



Laptop cooler

- Waste plastic container
- Vegetable PCM (reused)
- Glass / plastic top cover

Reuse old / small panel
S to M

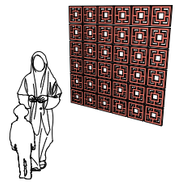


Heating buffer

- Waste plastic container
- Vegetable PCM (reused)
- Aluminum foil

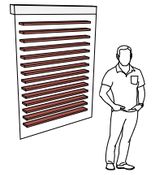
Table top

- Waste plastic container
- Vegetable PCM (reused)
- Glass / plastic top cover



Family picture frame

- Waste plastic container
- Vegetable PCM (reused)
- Plastic / iron connections

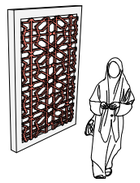


Shutters

- Waste plastic container
- Vegetable PCM (reused)
- Iron/plastic connections
- Rope
- Wooden construction

M

Reuse old / small panel
M to L

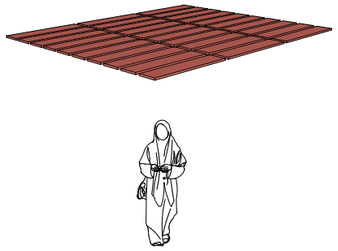


Mashrabyia

- Waste plastic container
- Vegetable PCM (reused)
- Iron connections
-Wooden frame (additional)

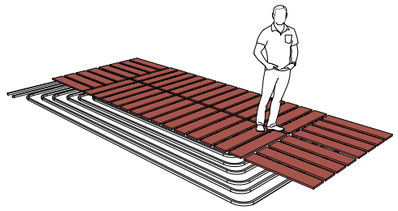
Passive airco

- Waste plastic container
- Vegetable PCM (reused)
- Iron connections
- Fan (additional)



Ceiling

- Waste plastic container
- Vegetable PCM (reused)
- Iron connections
- Fan (additional)



PCM Floor heating

- Waste plastic container
- Vegetable PCM (reused)
- Iron/plastic connections
- Piping system + boiler / Electrical mat floor tiles
- Top floor (wood/plastic)

L

PCM modules in the house

Can cooler

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Aluminum foil*

Laptop cooler

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Glass / plastic top cover*

Table top

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Glass / plastic top cover*

Ceiling

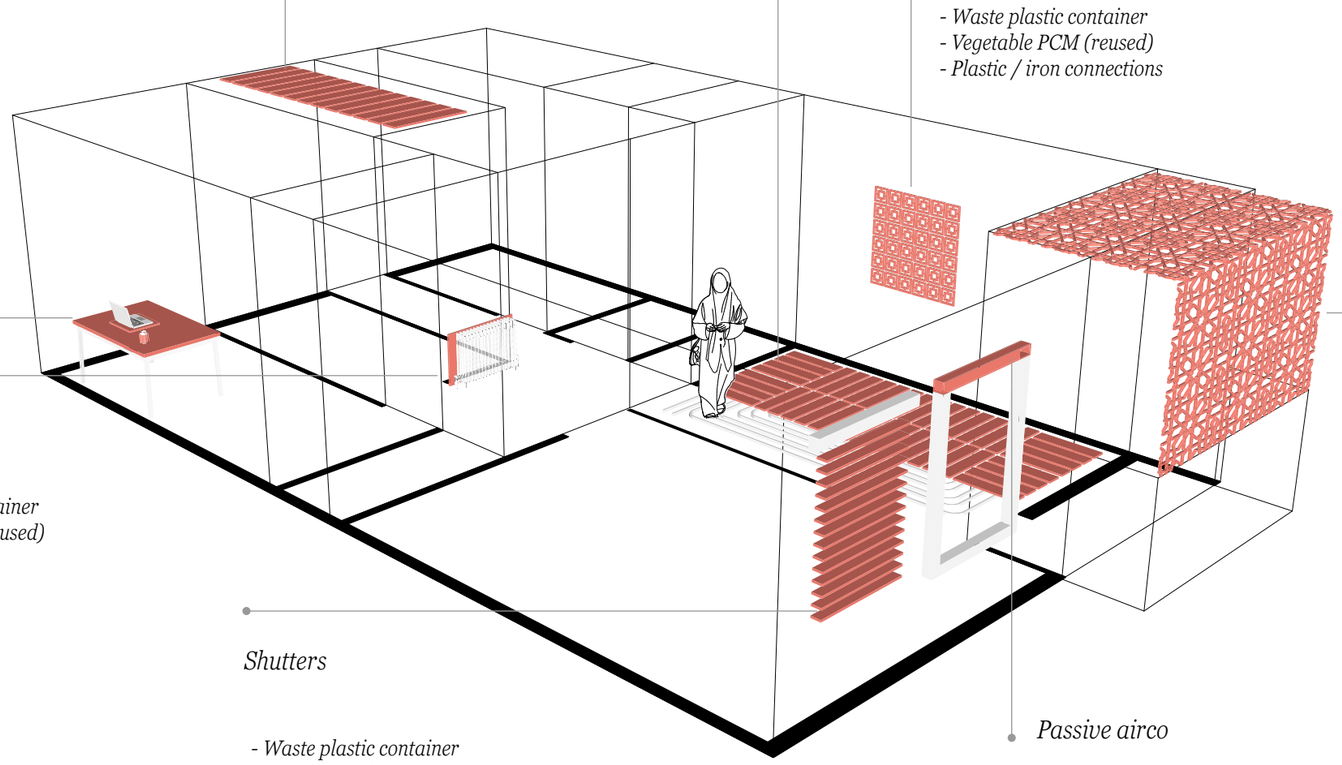
- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Iron connections*
- *Fan (additional)*

PCM Floor heating

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Iron/plastic connections*
- *Piping system + boiler / Electrical mat floor tiles*
- *Top floor (wood/plastic)*

Family picture frame

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Plastic / iron connections*



Heating btuffer

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Aluminum foil*

Mashrabyia

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Iron connections*
-*Wooden frame (additional)*

Shutters

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Iron/plastic connections*
- *Rope*
- *Wooden construction*

Passive airco

- *Waste plastic container*
- *Vegetable PCM (reused)*
- *Iron connections*
- *Fan (additional)*

Minimum effective quantity PCM

Renovation of Gijsingflat apartment

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*

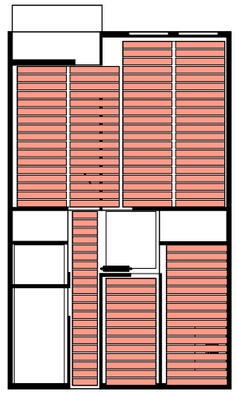
multiply for same efficiency
LHC = *1.17*
Density = *1.5*

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

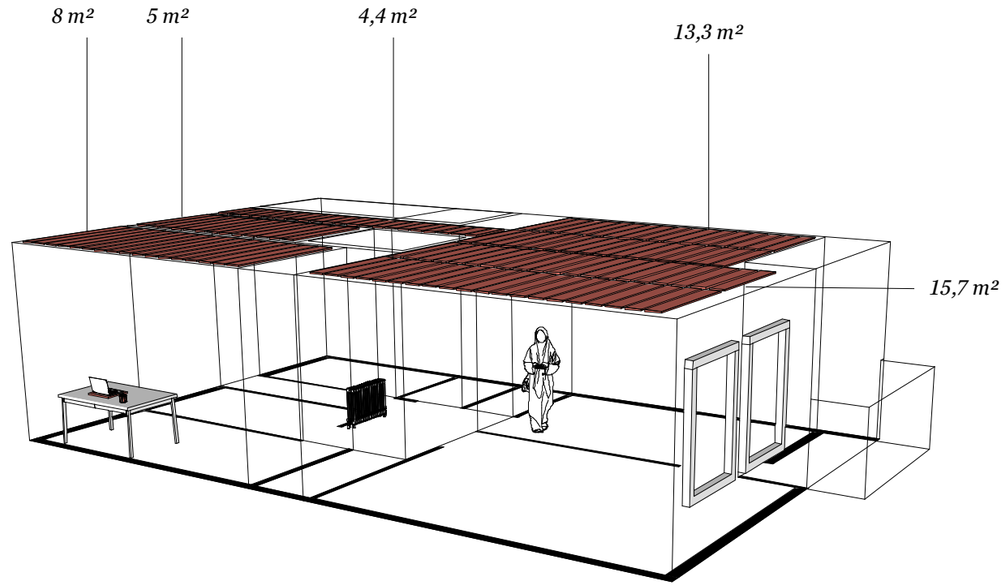
44 m² PCM (10 kg/m²)

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

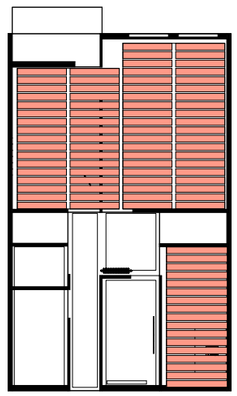
A



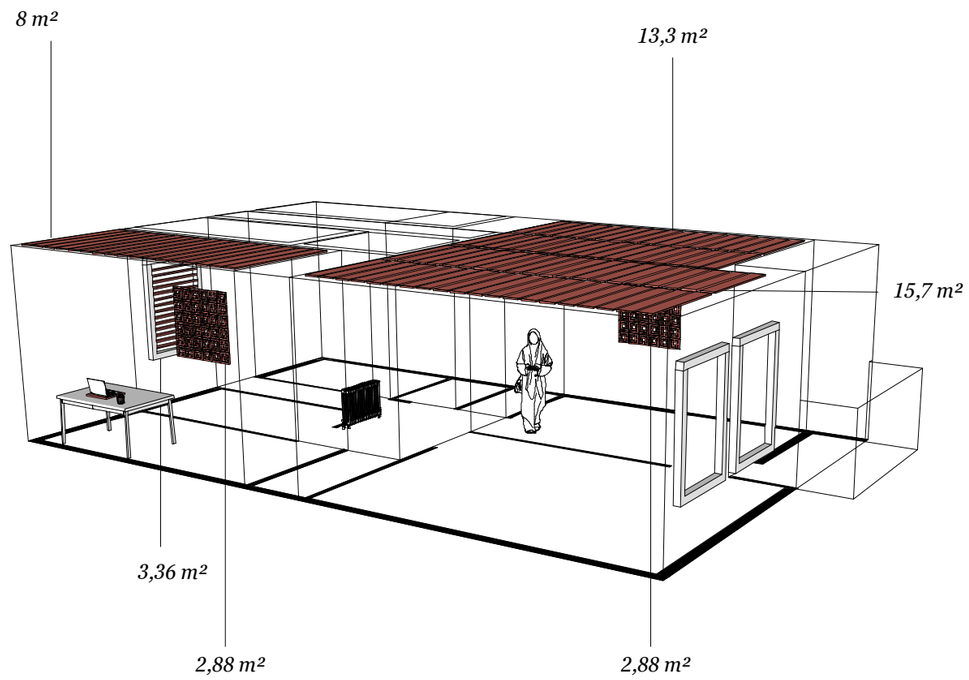
Total of 46 m²



B



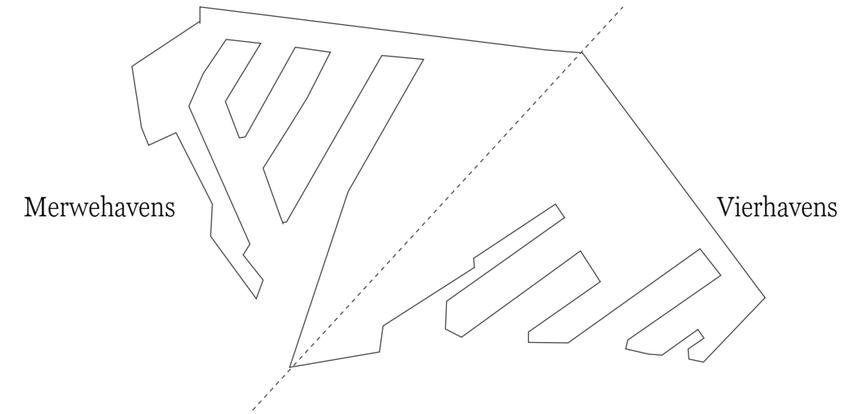
Total of 45,72 m²

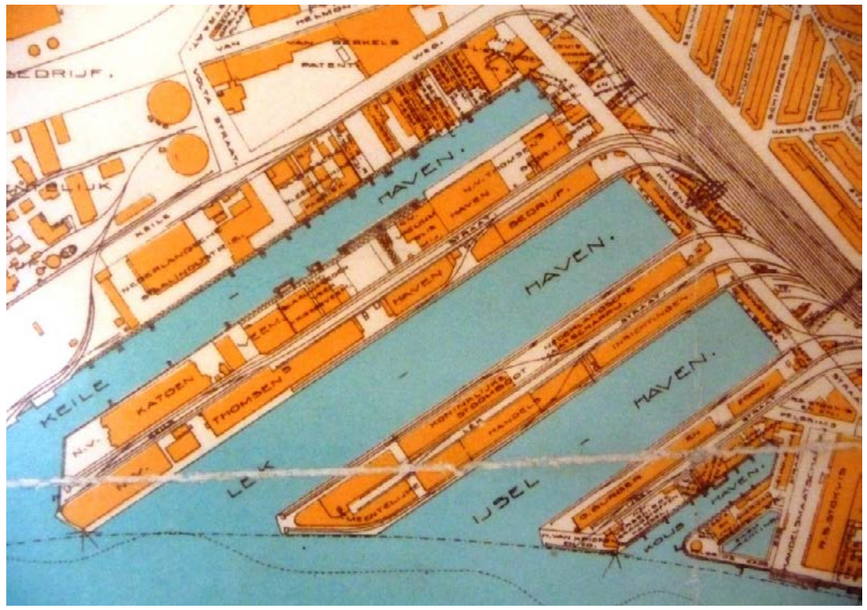


M4H

Historic meaning

The Merwe-Vierhavens came into existence as harbours for cargo and storage of fruits mostly around 1910 when the urbanisation of Bospolder and Tussendijken took place. The cargo ports Keilehaven, Lekhaven and IJsselhaven were built around 1912 and 1916. The majority of the people living in the adjacent neighbourhoods as Spangen, Bospolder and Tussendijken were employed in here. It used to be one of the biggest fruit ports of the world. It has a long history of industry of about 70 years. When the container was invented, it was used for the storage and cooling of the fruits so many people lost their jobs. Nowadays large companies as the Gas factory are still located in the area. The symbollic meaning of the water border is that it is the seperation between Dutch national territory and international territory.





Vierhaven district 1935

Gas factory Keilehaven 1924

Gas factory 1918 - 1924

Thomsens Port of Rotterdam 1924

M4H

Impression of employees before the introduction of the container (1980´s)

Keileweg: employees distribute the dried skinns over the former railway

These hangars were border security hangars; the waters behind were international territory and the street portrayed in the photograph is Dutch territory

Municipal ambition
Industry for innovation

The municipality has great ambitions for this area. Merwe Vierhavens should, together with the RDM on Heijplaat form the so called Makersdistrict since January 2018. The beautifull idea behind this is, that small scale innovative industry should get a place in this area. Now that new technologies allow for local production again, it might work opposite of what the container did to the social relationship between M4H and BoTu. The potential of this area is also defined by the rapid increase of population of Rotterdam and the fact that is actually is the only vacant area left on the northbank of the city. It is relatively big, about 100 hectares and hereby the same size as the authentic city centre named Stadsdriehoek (of which not much is left due to German bombing in 1940). The Port of Rotterdam is owner of most of the plots, but is interested in the development of it because extra attractivity of the city might increaste the port's competition position among world cities.

The Makersdistrict is initially created to let the succesfull RDM expand its capacity but also to facilitate the huge amount of start-ups, companies, institutions and initiatives in their development and it enables a decent meeting point for such different parties. There are four main goals:

1. Innovative activity (from start-up to corporate and containing a touch of 'making')
2. Employment (offered as widely ranged as possible)
3. Open innovation environment (with a diversity of companies)
4. Urban residential area (on and around the piers)
5. The showcase and try out for the circulair future of city and harbour

In other words it should become the innovative makersdistrict of the region Rotterdam where companies of different sizes and different phases of their development can be found. The central meeting space is clearly visible and there is an energetic vibe among the people with various backgrounds. There is space for experiment, on water or land, and it will be a showcase to the regional economy. The housing situated in the area is suitable and complies with the industrial character of the area. It should be a leisure area after all, containing horeca shortstay and events. Accessible collaboration among all parties present in the area. It should be the result or evidence that Rotterdam is the Make It Happen region (Visie & Strategie RMD, 2017).

In conclusion, this area seems perfect for a social factory that attracts people from the surrounding neighbourhood. It makes the M4H more diverse but also embeds the circular production technique in the right area of Rotterdam. The new technique and innovative modules that are a result of this factory fit wonderfully into the perspective that the municipality has. The new technologies allow employment to settle in M4H again, instead of what the container did in the 80; removing life and employment from the area.

M4H and RDM together as Rotterdam Makers District; a place for growth and experiment (Visie & Strategie RMD, 2017)

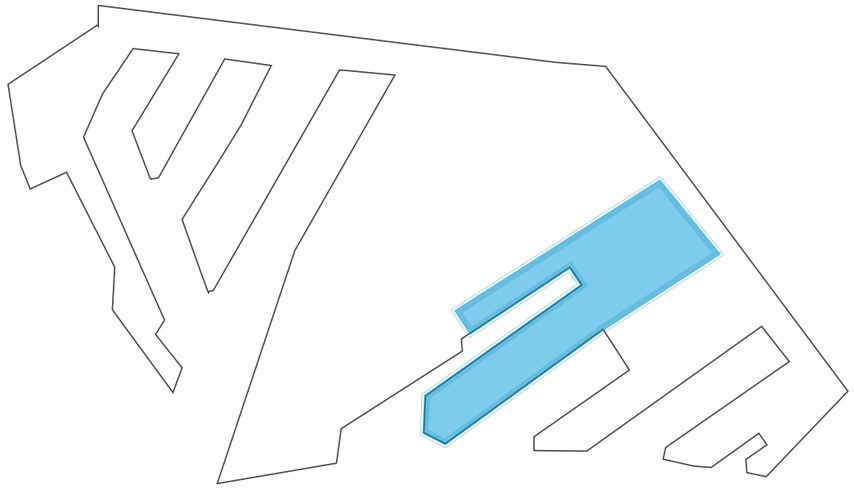
Technical entrepeneurs of the innovative makers industry in RDM (Visie & Strategie RMD, 2017)

Municipal ambition

Rotterdam Makers District sub-divisioning

The M4H is currently re-designed according to the municipalities ambitions. A broad plan is made which functions as an underlay for the upcoming developments. What is notable to mention is that it is actually is a rather complex area speaking of land ownership. The Havenbedrijf (Port of Rotterdam) possesses almost all the potential plots for development and has business concerns which leads to probability of no acceptance of residential developments. The municipality still owns a modest area within the whole district, which does allow for potential residential use. By preference of the municipality these dwellings are combined with small scale industry and innovative projects. Drawn in the map on the right.

The complete area of M4H is subdivided into three main areas; Industrial area, industrial in combination with dwellings and the area purely occupied by dwellings only. The production campus (industrial zone) is coloured dark pink. This area might have effect on the housing and additional residential areas due to its exposure of (industrial) sound and smell. The plot owned by the municipality is in the region where industry and dwellings come together; a new typology of buildings is foreseen here. The PCM factory also contains several dwellings that are used as showcases or can be won by a rewarding system of that one with many PCM modules at home might sleep several nights in the house as a prize. Also it offers to serve leading people of the company to live above their workplace.



Municpal property plots, all white are is property of Port of Rotterdam

Potential scenario 2035 (source: Delva/Gemeente Rotterdam)

Property zoning M4H

Industrial activities

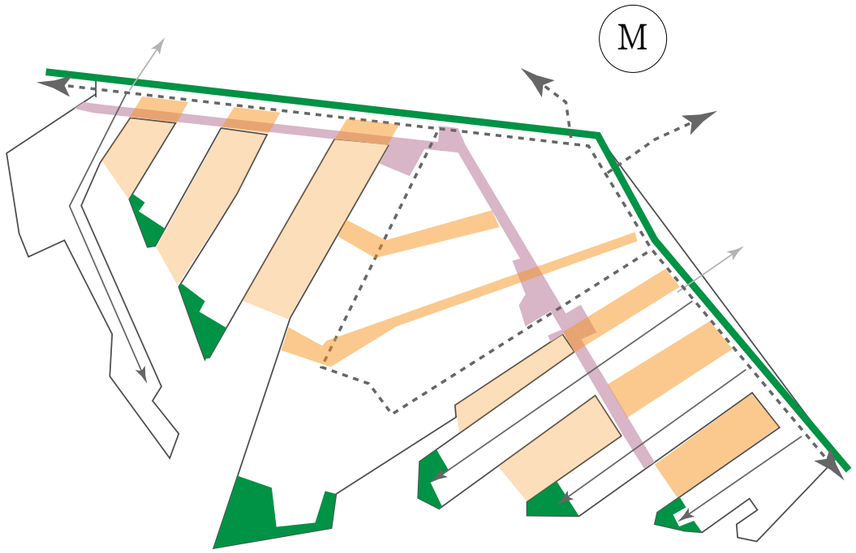
Combination of dwellings (+ high rise potential) and (smalle scale) industrial activities

Residential area

Zoning of different functions

Concept urban plan M4H

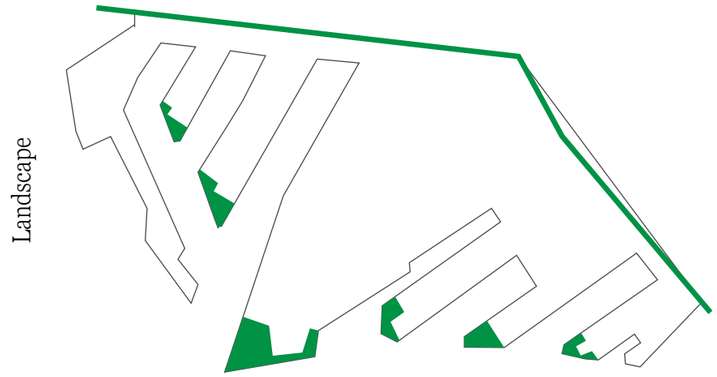
The urban plan designed for M4H has huge potential. It is strongly subdivided in four themes; landscape, backbone, fields and mobility. The landscape concept mentions that the presence of the dyke should be exaggerated. Initially this is not a very good element for reconnecting M4H to the surrounding neighbourhoods. The end of the piers however, should be reserved for leisure, they will become the green ends that provide a view over the (international) waters.
Secondly the backbone is the summary of the whole concept. All piers are connected by the backbone, but only pedestrians and cyclists may use this route. The route contains multiple spots where (commercial) and leisure activities are concentrated. It becomes the main street within the new plan.
Thirdly, the fields coloured orange may be on water or land. It is the space in between built volumes and should be reserved for open production or showcases. Visible innovation as part of the public sphere.
Lastly, the mobility concept ensure few heavy truck in the area, only on the dotted line. This system is connected to Schiedam and Rotterdam on regional roads. However, it allows for only two locations where connections to the residential neighbourhoods could be made; 1 to Witte Dorp and 1 to BoTu. This is a rather critical element of the foreseen plan.



Overall concept for urban plan

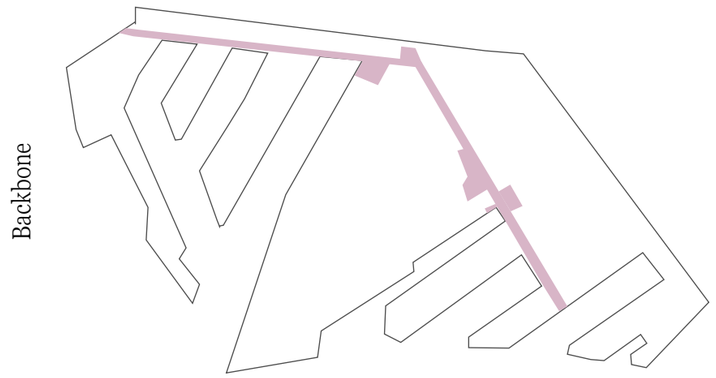
Landscape

- Exaggeration of dyke
- End of piers to spend time



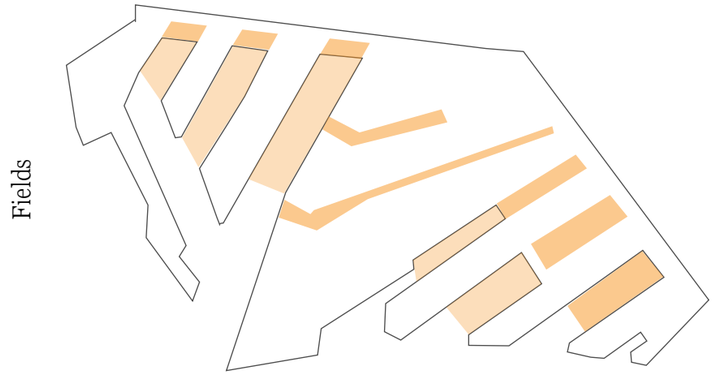
Backbone

- Public functions
- Slow traffic route
- Connecting all piers



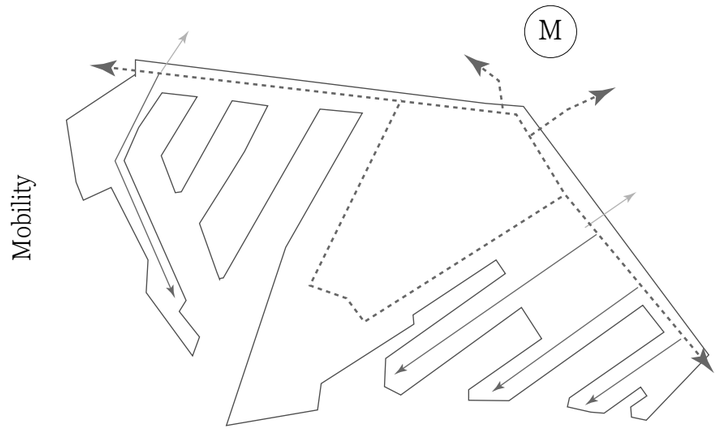
Fields

- Outside workspace
- Visible innovations
- Small factories
- Public area
- On water or land



Mobility

- Dotted line = heavy traffic
- Long visibe lines (piers)
- Traffic around industial zone
- 2 pedestrian connections to residential neighbourhoods



Conclusions

Material Research + Social Resilience Research

Material research

The social resilience research of Bospolder - Tussendijken and the spatial analysis of Merwe- Vierhaven in combination with the material research of phase change material has lead to a social and educative production process, of a climate regulative device based on waste flows and natural products, whereby renewed connection is made between the both neighbourhoods. This theoretical research hereby answeres the research question:

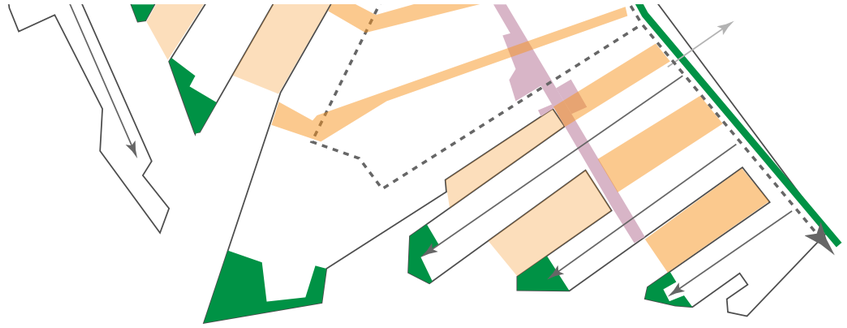
How could PCM, as an alternative to sand, be produced as an accessible manufacturable building material that responds to the current energy transition ambitions, whereby its production process intervenes with the socio-demographic challenges in Bospolder - Tussendijken?

The emancipation for the inhabitants is a durable way to educate them regarding highly relevant topics as language, culture, motherhood, finance, production skills, teamwork and leadership. This is necessary due to the socio-demographic issues in the neighbourhood. The social proces that aims to emancipate the inhabitants in a pre-factory phase and eventually in the definite factory phase. Through the timeline of the process children, parents, families and offical parties as housing corporations and the municipality are actively playing a role. The project portrays long term possibilities for both the concerned people and the technologic PCM module.

There is desperate need for low-tech and low-energy consuming interventions that an sustain peoples homes. It is a very specific goal of the municipality to transform and renovate the houses in Bospolder - Tussendijken in order to become an energy neighbourhood. The bottom-up production of these modules ensure a durable implementation of the technique, production process and sustainable function. Besides, it directly influences the financial situation of the relatively poor inhabitants. Natural products as frying oil and coconut fat provide the modules from biobased material. The use of these specific ingredients touches upon the circular economy that our society should take more into account. This is a big step towards that circularir economy in material terms but also in terms of vision. An overview is given on the last page of this chapter

All together this research s rather complete but still preliminary in the sense that it results in a design assignment of a factory, with specific demands on a chosen location. The specific goals and reasons for these desired functions have been explained in this research. In this further stage of design, this research will be tested and revised obviously. The specific design brief for the design assignment is listed on the right.

Design brief: A social factory with additional functions



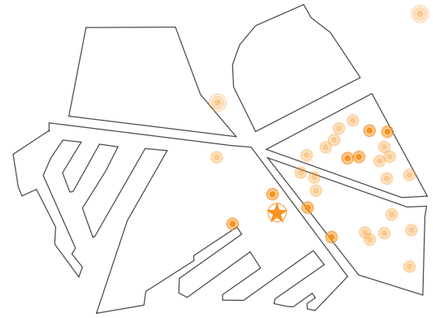
Overall concept for urban plan

Main function
Factory

Additional functions
Kitchen
Community area
Public workshop
PCM reselling / repair shop
Social housing

Overview

EMANCIPATION



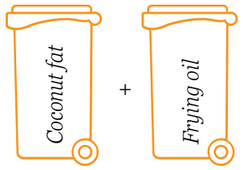
Pre-factory

Factory

PROCESS

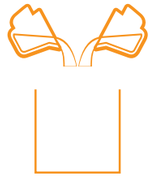
Salt Frying oil

Biobased PCM

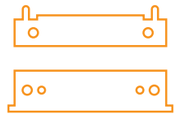


Horeca + Domestic waste collection

Filtering fat



Mixing



Molding container (HDPE)

PRODUCTS

Can cooler

Laptop cooler

Heating buffer

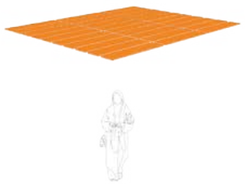
Table top

Family picture frame

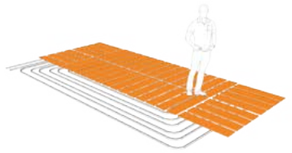
Shutters

Mashrabyia

Passive airco



Ceiling



PCM Floor heating

Material research

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