

Phase change material

AR0135 Design Informatics

dr.ir. Wim van der Spoel



Lecture overview

- Phase change materials
 - Types, properties and behaviour
 - Applications
- Design considerations

Phase change materials

Phase Change solid- liquid

Ice 0°C -> Water 0°C

Energy = 333 KJ/kg

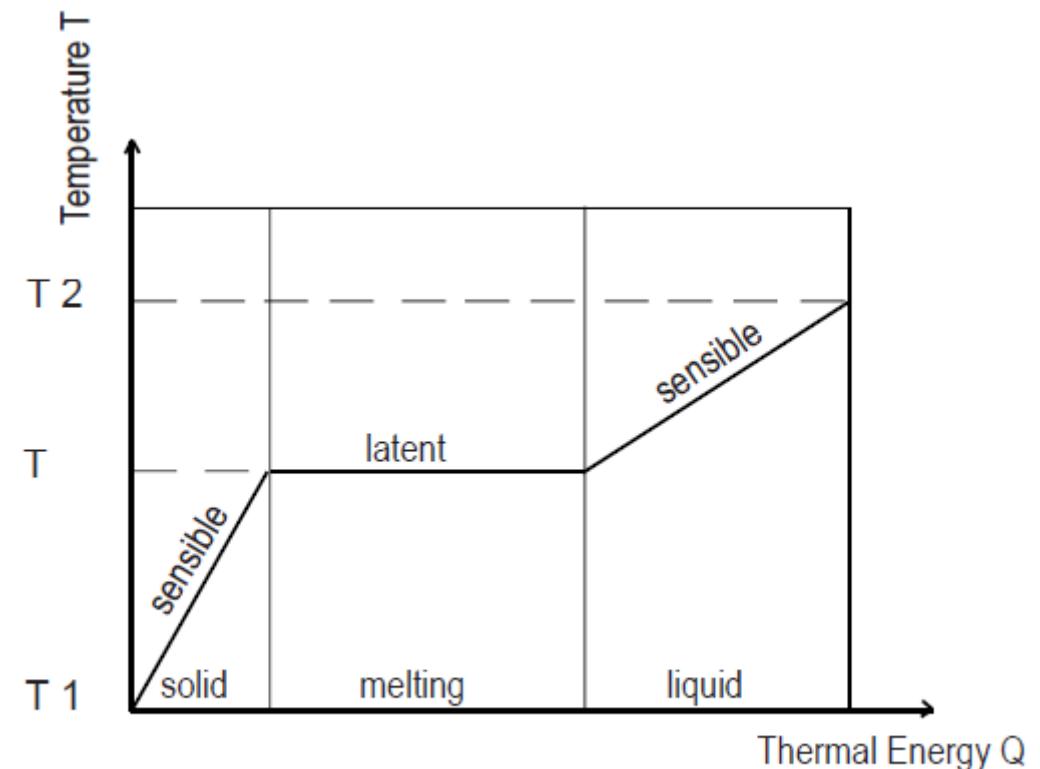
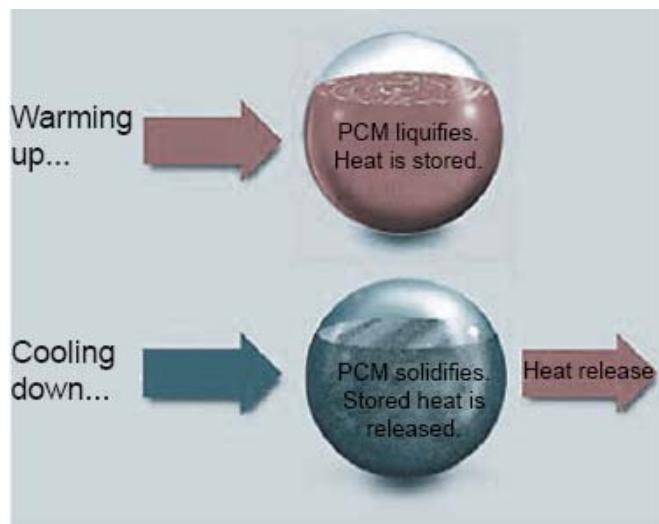


Energy

333 KJ/kg = 1 °C -> 80 °C

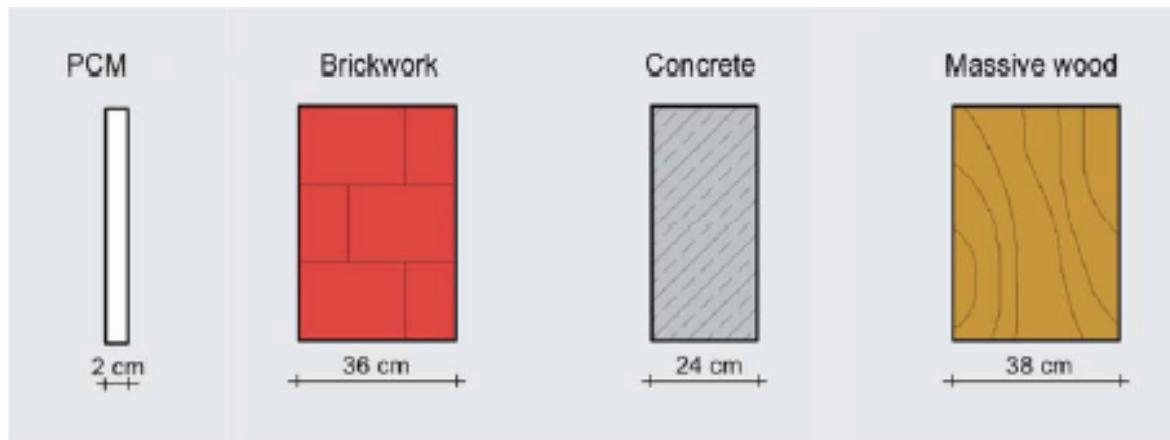


Phase change materials



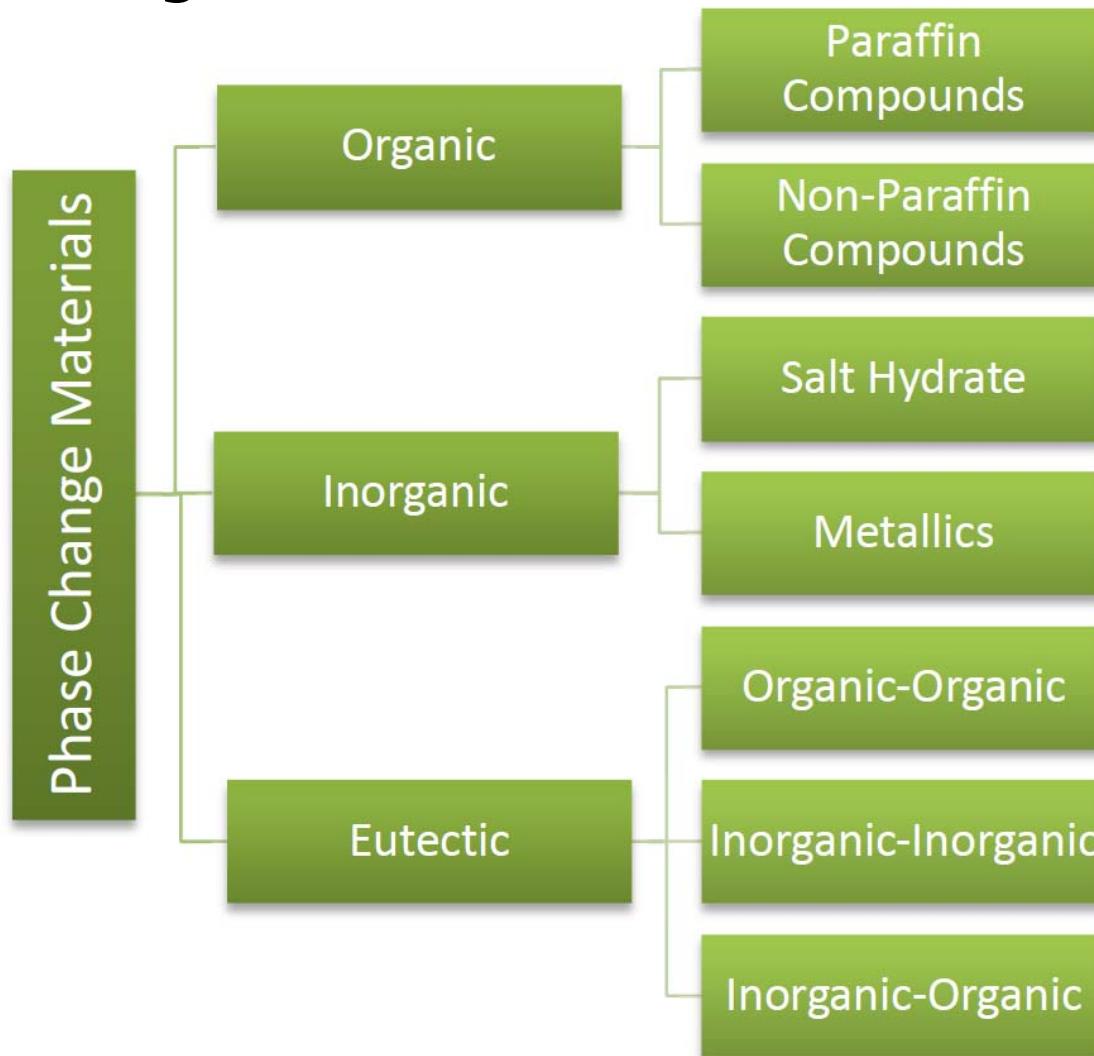
Phase change materials

Comparison of thermal mass :

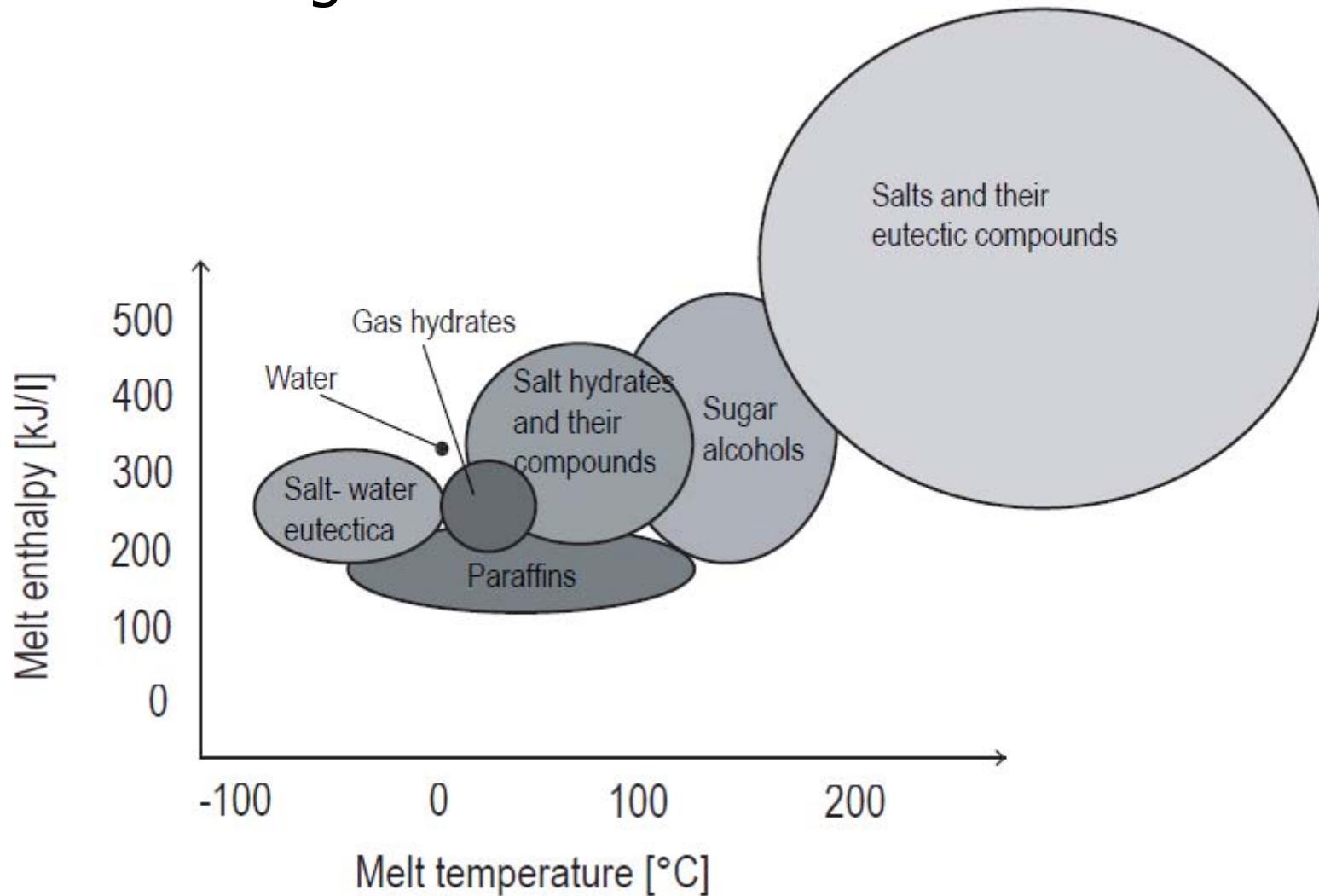


ΔT approximately 15 °C:

Phase change materials



Phase change materials



Phase change materials

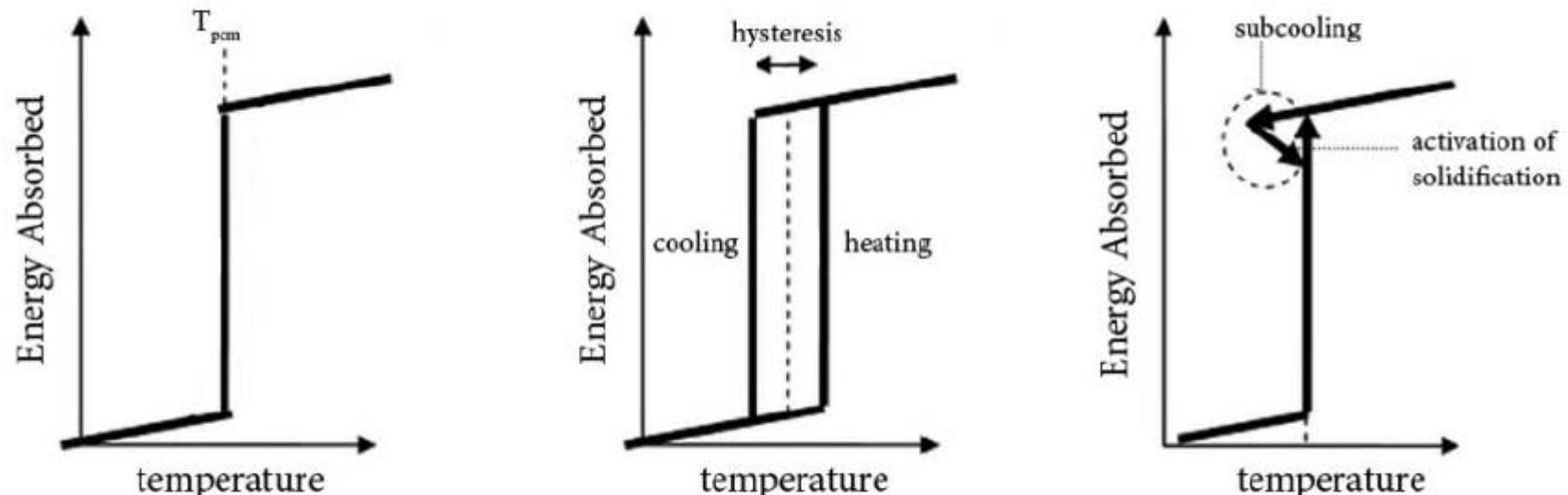
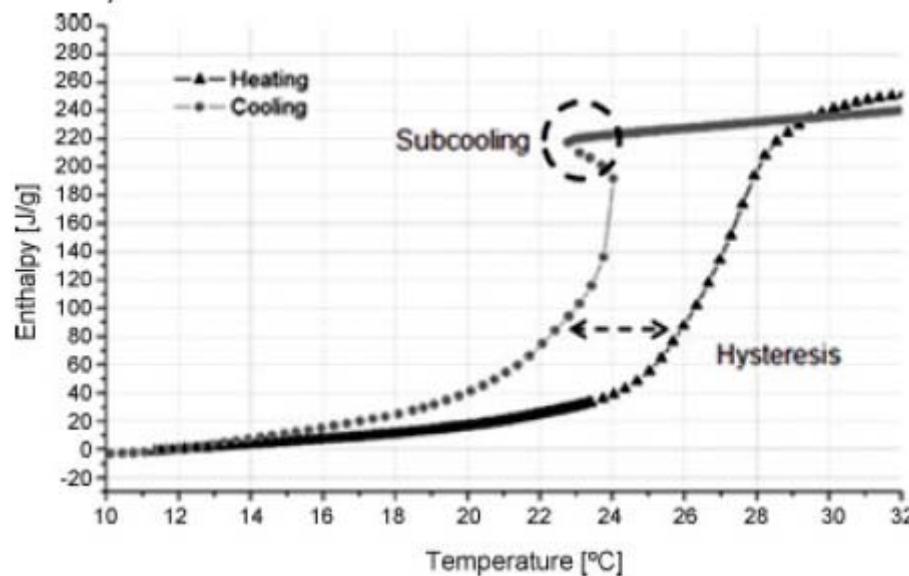


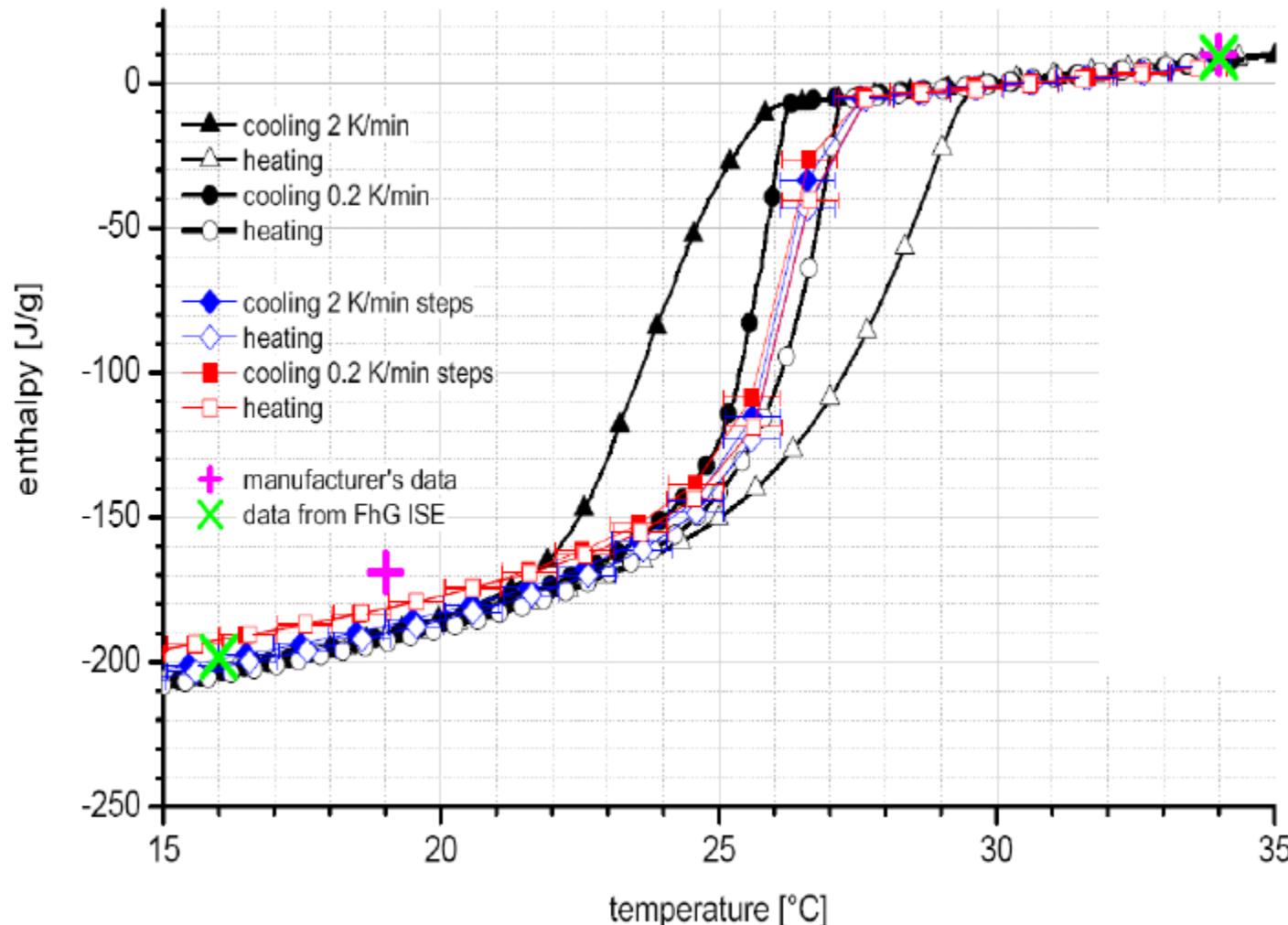
Chart 2: Ideal melting (left), Hysteresis (center) and Subcooling (right) in PCMS. (source: Mehling and Cabeza (2008))

Phase change materials



Phase change materials

Paraffin RT27



Phase change materials

	Advantages	Disadvantages
Hydrated Salts	<ul style="list-style-type: none">- Higher I_{pc} than Paraffin- Generally cheaper than Paraffin- Non flammable	<ul style="list-style-type: none">- Corrosive to most materials- Phase separation- Subcooling- Leakage
Paraffin	<ul style="list-style-type: none">- Inert to most materials- Chemically and thermally stable- Low or no Subcooling	<ul style="list-style-type: none">- Lower I_{pc} than Hydrated Salts- More expensive than Hydrated Salts- Flammable- Leakage
Polymer encapsulated Paraffin (PEP)	<ul style="list-style-type: none">- Inert to most materials- Chemically and thermally stable- Low or no Subcooling- Low flammable- No leakage	<ul style="list-style-type: none">- Lower I_{pc} than Paraffin and Hydrated Salts- Less conductive- More expensive than Paraffin and Hydrated Salts

Phase change materials

Product	Type	Melting point (°C)	Heat of fusion (kJ/kg)	Thermal conductivity	Manufacturer
	Water	0	334	0,60	
RT 20	Paraffin	22	172	0,88	Rubitherm GmbH
Climsel C 23	Salt hydrate	23	148		Climator
E23	Salt hydrate	23	155	0,43	EPS Ltd.
Climsel C 24	Salt hydrate	24	108	1,48	Climator
TH 24	Salt hydrate	24	45	0,80	TEAP
RT 26	Paraffin	25	131	0,88	Rubitherm GmbH
RT 25	Paraffin	26	232		Rubitherm GmbH
STL 27	Salt hydrate	27	213	1,09	Mitsubishi Chemical
S 27	Salt hydrate	27	207		Cristopia
AC 27	Salt hydrate	27	207	1,47	Cristopia
RT 27	Paraffin	28	179	0,87	Rubitherm GmbH
RT 30	Paraffin	28	206		Rubitherm GmbH
E28	Salt hydrate	28	193	0,21	EPS Ltd.

Phase change materials

Compound	Melting temp. (°C)	Heat of fusion (kJ/kg)	Thermal conductivity (W/m K)	Density (kg/m ³)
<i>Inorganics</i>				
MgCl ₂ · 6H ₂ O	117	168.6	0.570 (liquid, 120 °C) 0.694 (solid, 90 °C)	1450 (liquid, 120 °C) 1569 (solid, 20 °C)
Mg(NO ₃) ₂ · 6H ₂ O	89	162.8	0.490 (liquid, 95 °C) 0.611 (solid, 37 °C)	1550 (liquid, 94 °C) 1636 (solid, 25 °C)
Ba(OH) ₂ · 8H ₂ O	48	265.7	0.653 (liquid, 85.7 °C) 1.225 (solid, 23 °C)	1937 (liquid, 84 °C) 2070 (solid, 24 °C)
CaCl ₂ · 6H ₂ O	29	190.8	0.540 (liquid, 38.7 °C) 0.1.088 (solid, 23 °C)	1562 (liquid, 32 °C) 1802(solid, 24 °C)
<i>Organics</i>				
Paraffin wax	64	173.6	0.167 (liquid, 63.5 °C) 0.346 (solid, 33.6 °C)	790 (liquid, 65 °C) 916 (solid, 24 °C)
Polyglycol E600	22	127.2	0.189 (liquid, 38.6 °C) –	1126 (liquid, 25 °C) 1232 (solid, 4 °C)
<i>Fatty acids</i>				
Palmitic acid	64	185.4	0.162 (liquid, 68.4 °C) –	850 (liquid, 65 °C) 989 (solid, 24 °C)
Capric acid	32	152.7	0.153 (liquid, 38.5 °C) –	878 (liquid, 45 °C) 1004 (solid, 24 °C)
Caprylic acid	16	148.5	0.149 (liquid, 38.6 °C) –	901 (liquid, 30 °C) 981(solid, 13 °C)
<i>Aromatics</i>				
Naphthalene	80	147.7	0.132 (liquid, 83.8 °C) 0.341 (solid, 49.9°C)	976 (liquid, 84 °C) 1145 (solid, 20 °C)

Phase change materials

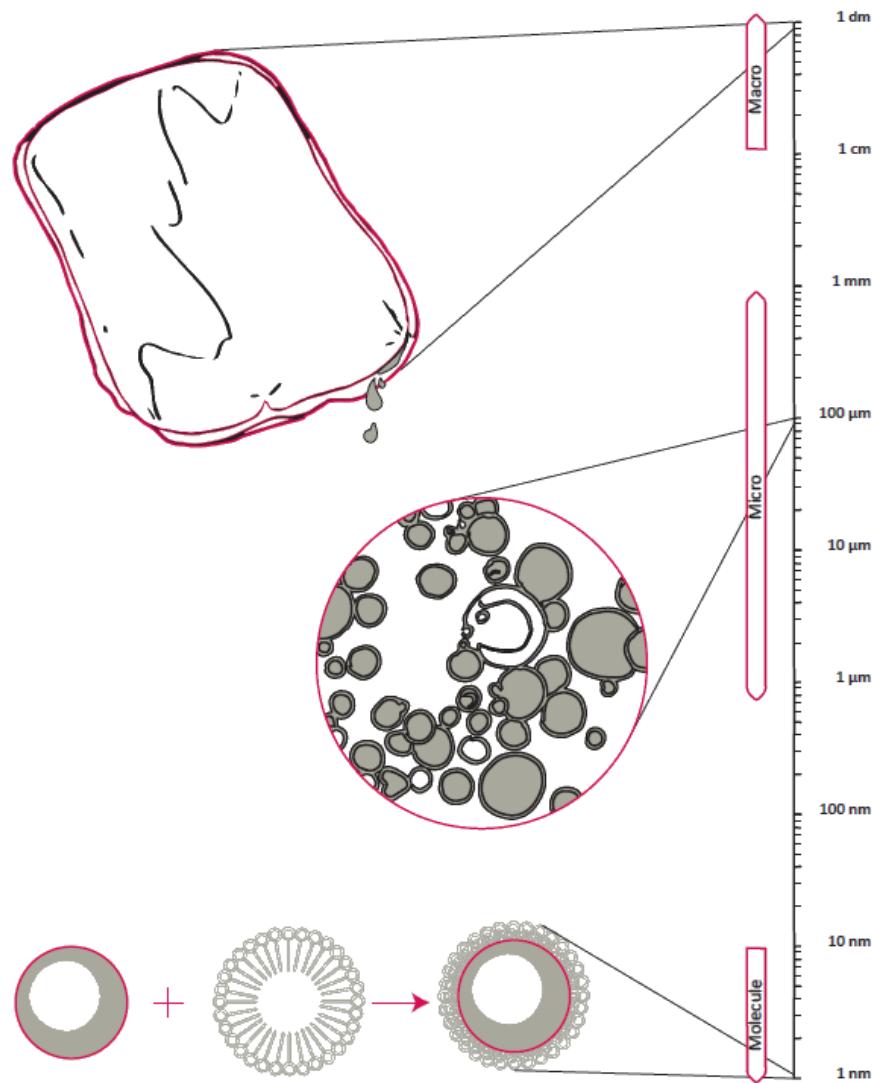
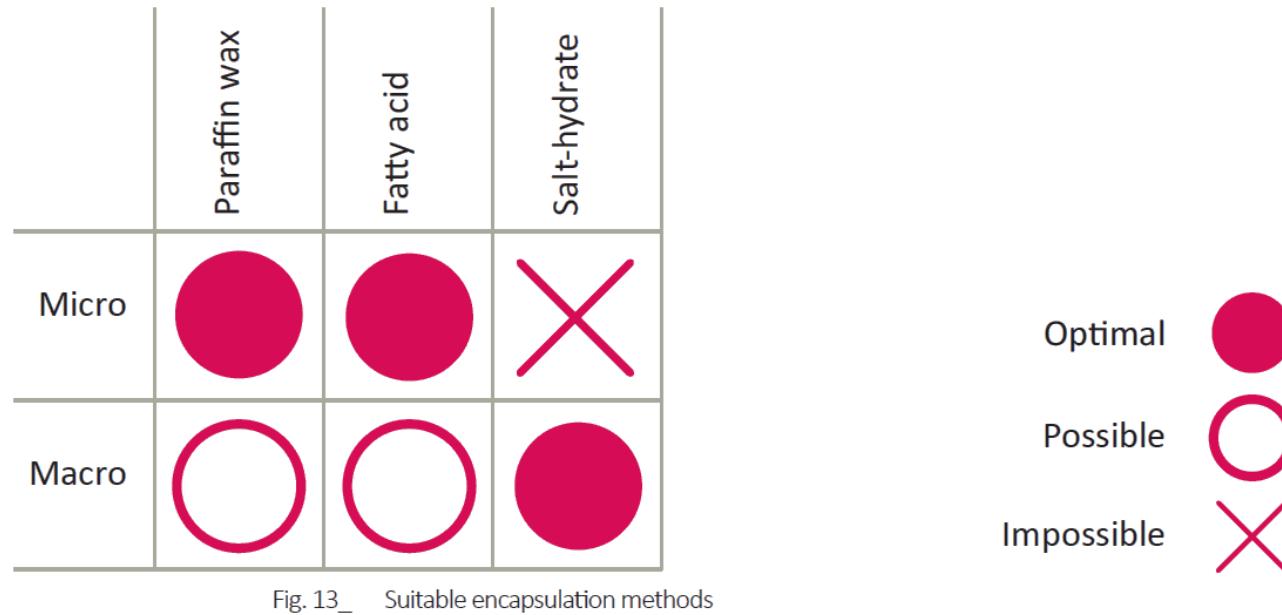


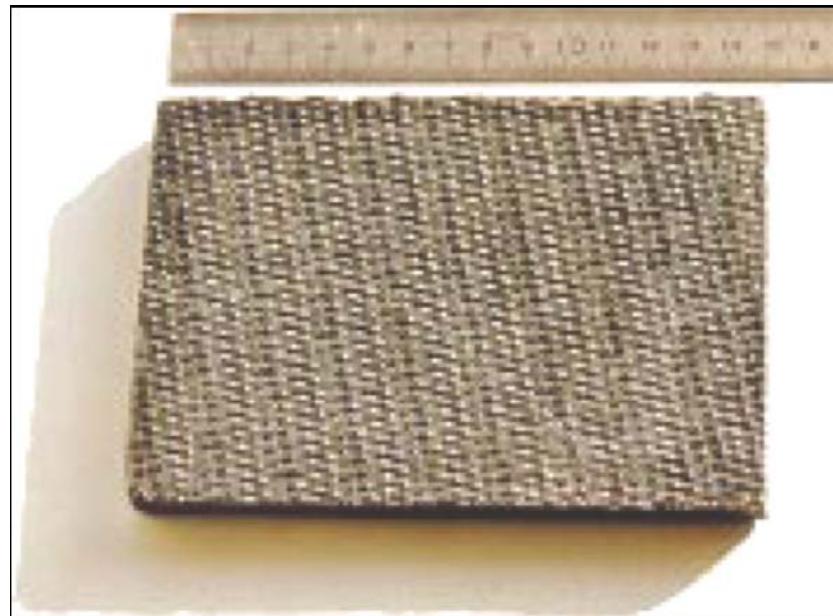
Fig. 5_Scale differences between macro-, micro- and molecule-encapsulation

Phase change materials



Phase change materials

Graphite matrix to enhance conduction



Phase change materials

PCM slurry

PureTemp Type	PT-18	PT-20	PT-23
Mass fracture PCM	0.4	0.4	0.4
Density ¹	≈933	≈933	≈933
Specific heat capacity when solid (J/(kg*K)) ²	3108	3556	3256
Specific heat capacity when liquid (J/(kg*K)) ³	3216	3676	3316
Latent heat capacity (J/kg) ⁴	75600	72000	81200
Thermal conductivity (W/m*K)	<0.6	<0.6	<0.6
Viscosity (Pa*s) ⁵	0.021	0.021	0.021
Melting point (°C)	18	20	23

Table 34. Properties of PCM slurries

Micronal® PCM – available portfolio

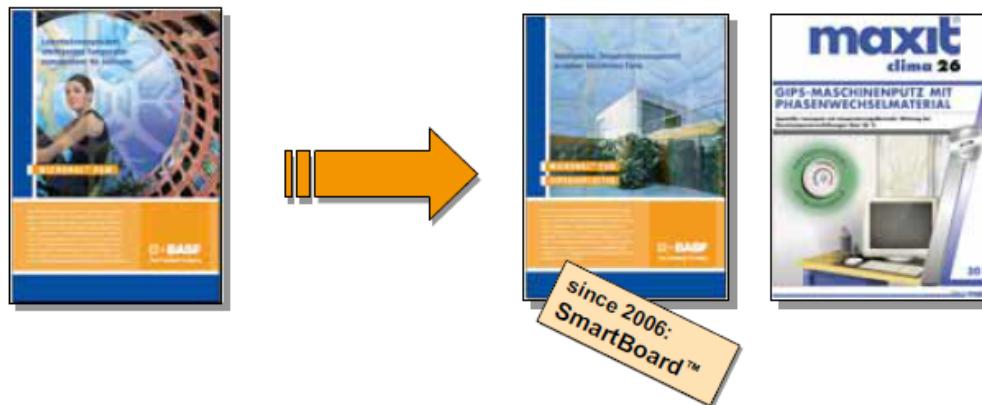


Raw Materials:

- as powder or aqueous liquid
- at 23°C / 73F or 26°C / 79F

Construction Materials:

- Micronal® PCM SmartBoard™
- Maxit Clima 26 ®



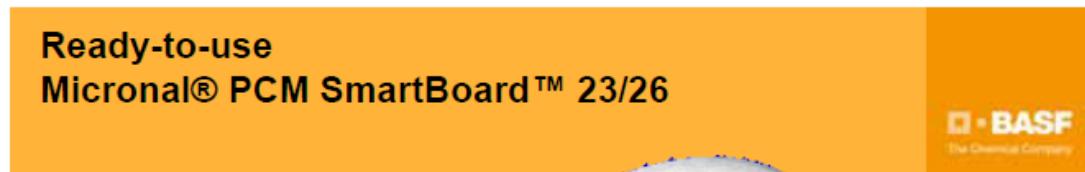
19.08.2004

Dipl. Ing. (FH) Marco Schmidt, EDK/BB-H201, BASF AG, Ludwigshafen, Germany

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As BASF is a raw material producer, it provides phase change materials as a raw material for modifying all kind of construction materials. Micronal PCM is available as aqueous emulsion with 42% solid content or as a dry powder. From this several applicable construction materials has been formulated. These are on sale in the European market for instance as gypsum plaster (maxit clima 26) or as gypsum wall board for dry wall construction (Micronal PCM SmartBoard). With this products it is an easy task for architects to choose an appropriate product to fulfill their needs for proper construction while bringing in PCM the same time.

Phase change materials



Length 2,00 m

Width 1,25 m

Thickness 15 mm

Weight 11,5 kg/m²

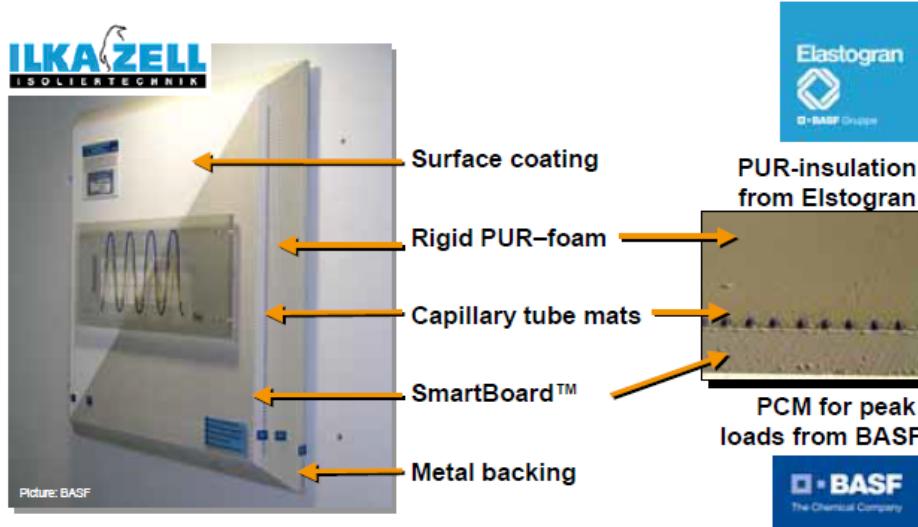
PCM content ca. 3 kg dry/m²

Heat capacity (latent) ca. 330 kJ/m²



Sandwich Element as joint development with Ilkazell Inc., Germany

BASF
The Chemical Company



19.08.2004

Dipl. Ing. (FH) Marco Schmidt, EDK/BB-H201, BASF AG, Ludwigshafen, Germany

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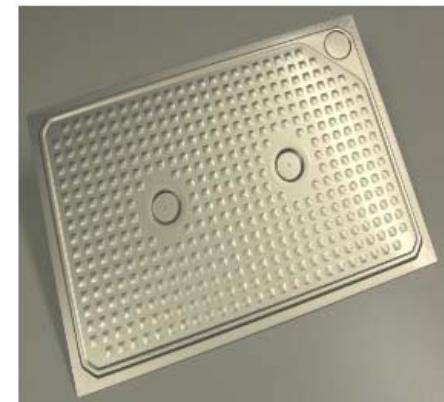
Aside of using the PCM-SmartBoard on a pure passive basis, it is also recommendable to combine the heat storage capacity in combination with cooling facilities like chillers or ground water cooling. This leads to very energy efficient and low energy consuming cooling concepts like chilled ceiling. Since such concepts work at low temperature differences between surface temperature and targeted room temperature it is possible to realize regenerative or at least smaller dimensioned room conditioning concepts.

Company Ilkazell from Zwickau, Germany, developed together with BASF (SmartBoard) and Elastogran (PUR-foam) a lightweight chilled ceiling system which offers several advantages for energy efficient office space like silent cooling, easy mounting, using of regenerative cooling sources, or very limited additional weight.

Phase change materials

RUBITHERM® CSM modules

These CSM modules are made from Aluminium with an inner and outer efficient anti-corrosion coating and can be filled with both organic based and inorganic based PCM materials, providing maximum flexibility to the user depending on intended use. This range of PCM products have outer dimension of 450 x 300 mm and covers working temperatures from -10⁰C to 86⁰C, with 4 distinct modules available off the shelf, as shown below.



CSM Panel / total thickness	Total weight with SP	Approximate stored energy SP 22	Approximate stored energy SP 29	Total weight with RT	Approximate stored energy RT	Approximate stored energy RT HC
CSM 5/5 – 10mm	1,4 kg	40 Wh	50 Wh	0,9 kg	24 Wh	35 Wh
CSM 10/0 – 10mm	1,5 kg	45 Wh	56 Wh	1,0 kg	27 Wh	39 Wh
CSM 10/5 – 15mm	2,3 kg	80 Wh	99 Wh	1,5 kg	49 Wh	70 Wh
CSM 10/10 – 20mm	3,3 kg	121 Wh	149 Wh	2,0 kg	73 Wh	105 Wh

RT HC

0.9	MJ/m ²
1.0	MJ/m ²
1.9	MJ/m ²
2.8	MJ/m ²

Design considerations

Tabel 4.5 Percentielen van etmaalsommen van de globale straling (tijdvak 1965-1980) in MJ m⁻²

station en nummer	procent- punt	JAN	FEB	MRT	APR	MEI	JUN	JUL	AUG	SEP	OKT	NOV	DEC	W	L	Z	H JAAR	
DE BILT 260	1%	0,35	0,63	1,21	2,17	3,38	3,93	3,64	3,74	2,20	1,11	0,37	0,23	0,30	1,73	3,76	0,53	0,44
	2	0,42	0,79	1,61	2,66	4,28	4,91	4,44	4,43	2,72	1,24	0,45	0,25	0,36	2,15	4,56	0,71	0,58
	5	0,52	1,02	2,12	3,25	5,79	6,27	6,15	5,66	3,42	1,51	0,64	0,37	0,50	2,92	6,16	1,05	0,87
	10	0,65	1,43	2,83	4,77	7,73	8,33	7,46	7,86	4,58	2,26	0,87	0,50	0,67	3,94	7,80	1,47	1,35
	20	0,93	2,00	3,77	7,03	10,50	11,53	9,95	10,10	6,66	3,21	1,28	0,71	0,96	6,14	10,37	2,36	2,49
	50	1,82	4,14	7,60	12,72	17,30	18,17	16,26	14,91	10,38	6,02	2,44	1,47	2,22	11,67	16,40	5,43	7,76
	80	3,37	6,70	11,43	18,35	22,99	24,41	22,29	19,49	13,70	8,74	4,42	2,88	4,07	18,84	22,06	10,25	16,42
	90	4,07	7,94	13,54	20,04	24,79	26,48	24,19	21,34	15,12	9,95	5,29	3,45	5,66	21,80	24,32	12,81	20,67
	95	4,64	8,96	15,32	21,48	26,53	27,76	26,57	22,48	16,35	11,21	5,93	3,86	7,17	23,88	26,47	14,42	23,41
	98	5,46	10,28	16,10	23,12	27,42	28,71	27,61	23,60	17,61	12,17	6,66	4,21	8,81	26,35	27,81	16,01	26,19
	99	6,02	10,91	16,55	24,17	27,72	29,13	28,02	24,10	18,19	12,60	7,09	4,44	9,89	27,24	28,60	17,08	27,26

Design considerations

1 person

0.5 m² per 'seat'

Environment 15 C

Surface temp 25 C

Heat loss coefficient $h = 10 \text{ W/m}^2\text{K}$

heat loss rate 100 W/m² open space, sheltered'

heat loss rate 50 W/m² closed space

during 14400 s 4 hours

storage needed 1.4 MJ/m² open space, sheltered'

0.7 MJ/m² closed space

typically 1 MJ/m² (i.e. per 2 'user')

approximately 5 - 8 kg PCM required per m²

PCM thickness 7 - 10 mm typical, pure paraffin PCM

or 45 mm Micronal Smartboard

or 10 mm Rubithem CSM with RT HC

Design considerations

Solar supply

15 MJ/m²/d Solar (50% percentile april - september, per day on horizontal)
0.5 efficiency thermal c or rough estimate, plate covered
8 MJ/m² storage required over the day

to 'serve' one seat, about 0.15 m² horizontal solar collector (plate covered) required

If PCM at solar side

0.15 MJ/kg approximately storage in PCM

50 kg/m² PCM required

5 cm if stationary at solar side

Design considerations

by conduction loading the PCM	delta T	35	
	P	70 W	per 1m ² of seat, i.e about 0,3 m ² surface solar p
	R	0.5 K/W	maximum R of conduction between solar collector and seat
	H	2 W/K	minimum conductance / 1/R
			$H = \frac{A}{d}$
	By conduction:		$H = 380 \frac{A}{1}$ for copper
			$2 = 380 A$
			$A = 2/380 = 0,005 \text{ m}^2$ very heavy!!
			$A = 50 \text{ cm}^2$ copper bar per 'seat'
By heat pipe loading		$I_{a_eff} = 10.000 \text{ W/mK}$	
			$H = \frac{A}{d}$
			$H = 10000 \frac{A}{1}$
			$A = 2/10000 = 2 \text{ cm}^2$
			one heat pipe per seat is sufficient
Risk of heating the PCM above 25 C. How to avoid that with a passive technique?			

Design considerations

By water transport (circulation)

loading the PCM ΔT

35

P 70 W

0.0005 kg/s circulating fluid

0.5 ml/s

small!! pump energy minimal, might use PV
(with glycol little bit more)

risc of freezing; addition of glycol necessary?; risc of leakage;

expansion tank required?

dainback solar collector?

solar collector types: curved surface?

might use free convection principe for circulation if solar collector is inclined surface

Overheating the PCM can be avoided by stopping the water flow (note that the solar collector can become very hot then)

Design considerations

What about PV-cells and heating the PCM with resistance heating?

PV efficiency 15% for crystalline, about 11% for (flexible) thin film
efficiency considerably worse than thermal collector

need about 0,8 m² (crystalline) or about 1 m² of PV per 1 m² op seat area

pro: - electric control; no moving parts or liquid, overheating easily avoided

- robust, easy to incorporate in the design
- might use batteries for electrical storage if PCM is fully melted, electricity can be utilized later

Alternative is PV-cells and using a heat pump

pro: - much higher heating efficiency

con: - need heat reservoir, can be air, surface water, soil.

- quite an installation, investment, risk of failure, hard to incorporate in design

Using a Peltier element as heat pump might be a more robust alternative

COP difference with resistance heating however not so dramatic, about factor 1.5 difference

Sources

Phase Change Material; Lisa Weiblen. AR0532 Bioclimatic Design Manual, 2007

Pretty Cool Materials. Maaike de Haas, Jasper Overduin en Nick Vlaun, AR0533 Bioclimatic Design Manual, 2014

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Current research at the ZAE Bayern – Testing, data representation and modelling of PCM

http://cse.fraunhofer.org/Portals/55819//docs/buildings-xi/presentation%20mehling%20h_v7.pdf

Phase Change Materials – latent heat storage for interior climate control

<http://www.micronal.de/portal/streamer?fid=309980>

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