SUREFIT

SUstainable solutions for affordable REtroFIT of domestic buildings

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WP4 - Deliverable D 4.3

PCM Panel

Dissemination Level

PU	**Public**	**x**
CO	Confidential, only for members of the consortium (including the Commission Services)	
CI	Classified, as referred to in Commission Decision 2001/844/EC	

Document History

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1	30/11/2021	Z.Ure, H.Beasley (EPS)	Creation of the document
2	20/12/2021	Z.Ure, H.Beasley (EPS)	First draft for partners
3	1/4/2022	Zafer Ure, Monika Zdrojkowska	Second draft for partners

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Abbreviations

PCM	Phase Change Material
TES	Thermal Energy Storage
UNOTT	University of Nottingham
MPCM	Microencapsulated PCM

Publishable summary

The SUREFIT project aims to demonstrate fast-track renovation of existing domestic buildings by integrating innovative, cost-effective, and environmentally conscious prefabricated technologies. This will be achieved through a systematic approach involving key stakeholders (building owners/users, manufacturers, product/services developers) in space heating, cooling, domestic hot water, lighting and power generation.

This deliverable presents the optimisation, design and manufacture of a Thermal Storage medium for integration into buildings and heat pumps for the period from M7 to M15 in the scope of Work Package 4 – Fabrication and lab testing of technologies.

The report has been complied by Phase Change Material Products Ltd with the contribution of UNOTT, as the partners responsible for the work package under which project work was carried out during this period.

Introduction

Leading Beneficiary: UNOTT

Participants: PCM

Task description:

Work package 4 involves fabricating and testing the key components and assembling the components into complete prototypes of technologies. These technologies will be tested in the lab to assess their performance under the nominal set conditions. The testing results will be used to modify and improve the design of the final prototypes, if necessary, which will be used in WP6 (field tests). The availability of this prototype system for field trials will be Milestone 3.

The components and innovative technologies will be produced after determining their sizes for renovation of different types of building in WP 2. The production of these technologies will be undertaken by different participants of the project Consortium; each participant is assigned to produce one package of technologies according to its expertise in collaboration with other participants.

PCM and CJR will produce PCM technology as PCM panel and thermal storage medium for integration into building and heat pumps. Use will be made of fire retardant to avoid fire/flammability of PCM wax based materials. Different types of PCM made from natural non-flammable materials will be investigated with desired temperature ranges for applications.

This deliverable report concentres on the selection, design and manufacture of a Thermal Storage medium as stated above.

1 Thermal Energy Storage

Thermal Energy Storage (TES) is the temporary storage of high or low temperature energy for later use. It bridges the gap between energy requirement and energy use. A thermal storage application may involve a 24 hour or alternatively a weekly or seasonal storage cycle depending on the system design requirements. Whilst the output is always thermal, the input energy may be either thermal or electrical.

Reduced running cost - load shifting provides reliable operation and lower annual electricity/energy running costs.

Reduced Machinery - Shifting some of the peak load may enable designers to reduce the main machine size.

Increased Capacity -As a retrofit application, the additional TES load may increase the system output without any additional machinery.

Green Solution -Reduced machine size means reduced energy consumption, giving lower direct and indirect CO2 emissions.

Flexible System -The overall machinery capacity and TES capacity can be exactly matched to system loads.

Stand-By Capacity -In case the main machinery fails, the stored energy can be utilised to handle the system loads, thereby providing a degree of back-up facility

In full storage systems, the entire daily design loads are generated off peak and stored for use during the following peak periods. In partial storage systems, only a portion of the daily load is generated during off peak and used during peak periods to top up the system.

During the peak period, the load is satisfied by a simultaneous balancing operation of the installed machinery and stored energy in order to satisfy the overall daily design duty.

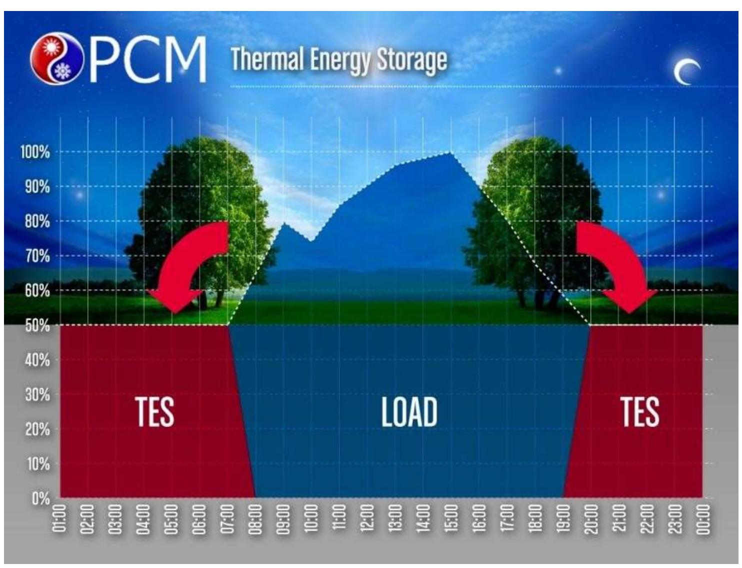


Figure 1 - Load shifting

Phase Change Materials (PCM) are capable of freezing and melting at temperatures above or below 0°C (32°F), hence offering new opportunities for environmentally friendly and economical systems for both new and retrofit process as cooling or heating load shifting applications.

PCMs are ideal products for thermal management solutions as they store and release thermal energy during the process of melting & freezing (changing from one phase to another).

When such a material freezes, it releases large amounts of energy in the form of latent heat of fusion, or energy of crystallization. Conversely, when the material is melted, an equal amount of energy is absorbed from the immediate environment as it changes from solid to liquid.

For daily TES, the PCM selection is implemented according to the specific building elements, to maximize performance, minimize costs and avoid user impacts (installation, maintenance, decommissioning). Especially, methods and technologies are studied for refurbishing cases, since that represents the main application. To this end, different building stocks and climate zones are taken into account to classify different technologies.

1.1 PCM Classification

Depending on the phase transformation, PCMs are available as solid-solid, solid-liquid, solid-gas and liquid-gas PCMs.

Solid-liquid PCMs can be categorised as organic compounds, inorganic compounds and eutectic mixtures according to chemical composition

- Eutectics tend to be solutions of salts dissolved in water that have a phase change temperature below 0°C (32°F).
- Salt hydrates are specific salts that are able to incorporate water of crystallization during their freezing process and tend to change phase above 0°C (32°F).
- Organic materials used as PCMs tend to be polymers with long chain molecules composed primarily of carbon and hydrogen. They tend to exhibit high orders of crystallinity when freezing and mostly change phase above or below 0°C (32°F). Examples of materials used as positive temperature organic PCMs include alcohols, waxes, oils, fatty acids and polyglycols.
- Solid-Solid PCMs that undergo a solid/solid phase transition with the associated absorption and release of large amounts of heat. These materials change their crystalline structure from one lattice configuration to another at a fixed and well-defined temperature, and the transformation can involve latent heats comparable to the most effective solid/liquid PCMs.

- Molten Salts are naturally solid salt materials which turn liquid when they are heated above their transition temperatures and act as a PCM energy storage material.

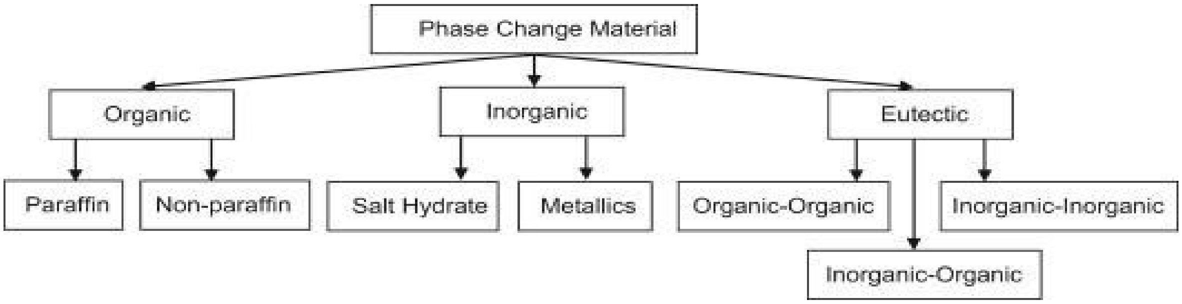


Figure 2 - PCM Classicisation

	Eutectic material	Organic material	Inorganic material
Examples	• Inorganic-organic • Inorganic-inorganic • Organic-organic	• Paraffin • Fatty acids • Alcohol • Ester • Polyethylene glycol	• Salt hydrate • Metallic
Advantage	• Wide range of phase change temperature • Good chemical and thermal stability • High heat capacity • No or little supercooling	• Non-corrosive • Good chemical and thermal stability • No supercooling • High heat of fusion • Low vapor pressure • Nontoxic	• Nonflammable • Inexpensive • High heat of fusion • Good thermal conductivity
Disadvantage	• Leakage during the phase transition • Low thermal conductivity	• Low thermal conductivity • Low phase change enthalpy • High changes in volumes during the phase transition	• Corrosion • Phase decomposition • High supercooling effect • Loss of hydrate throughout the process • Insufficient thermal stability • Weight problem

Table 1-Comparison of organic, inorganic and eutectic PCMs [1]

Organic PCMs are classified as paraffin and non-paraffin. They usually do not display corrosive characteristics and have congruent melting. The range of a paraffin PCM's melting point is typically from -12°C to 71°C, storing latent heat of 120-198 kJ/kg. Comparatively, the paraffin is safe, reliable and cheap with high latent heat, while non-paraffin is more expensive and corrosive.

On the other hand, inorganic PCMs have higher heat of fusion per unit mass with lower cost and flammability. Figure 3 shows available PCMs with a melting point (-100°C-200°C) against relative melting enthalpies. It is clear that PCMs with the highest enthalpies are the salt hydrates.

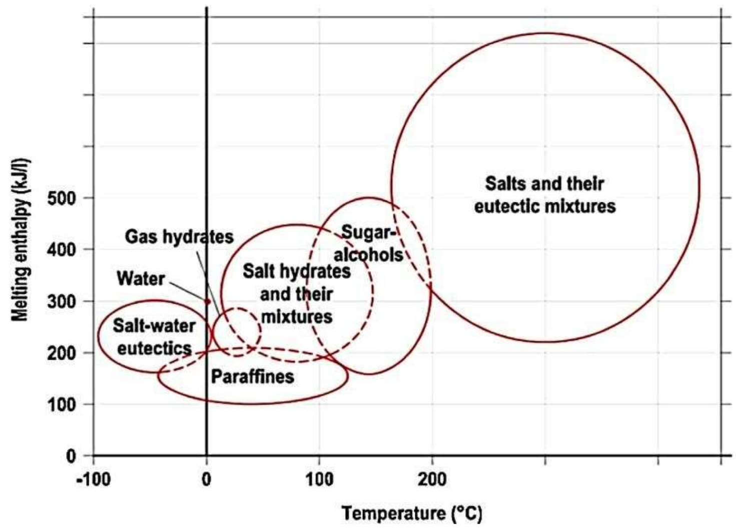


Figure 3 - Melting enthalpy and temperature for a range of PCM [2]

With regard to selection of PCMs, Figure 4 presents a summary of selection criteria for PCMs in terms of thermodynamic, kinetic, chemical and economic perspectives. More precisely, it has been highlighted in the literature that the three key properties for any potential PCM are "suitable melting temperature, desirable heat of fusion and thermal conductivity as specified by the practical application" [3].

The key property governing initial selection of PCM for a given application is the melting point, where the latent heat of fusion is released. Additionally, PCM is favourable with large latent heat of fusion per unit mass, offering great heat storage capability, in other words, with lower volume; the PCM can absorb/release higher amounts of energy. Furthermore, high thermal conductivity is desirable to enable swift charging and discharging of heat using minimal temperature difference.

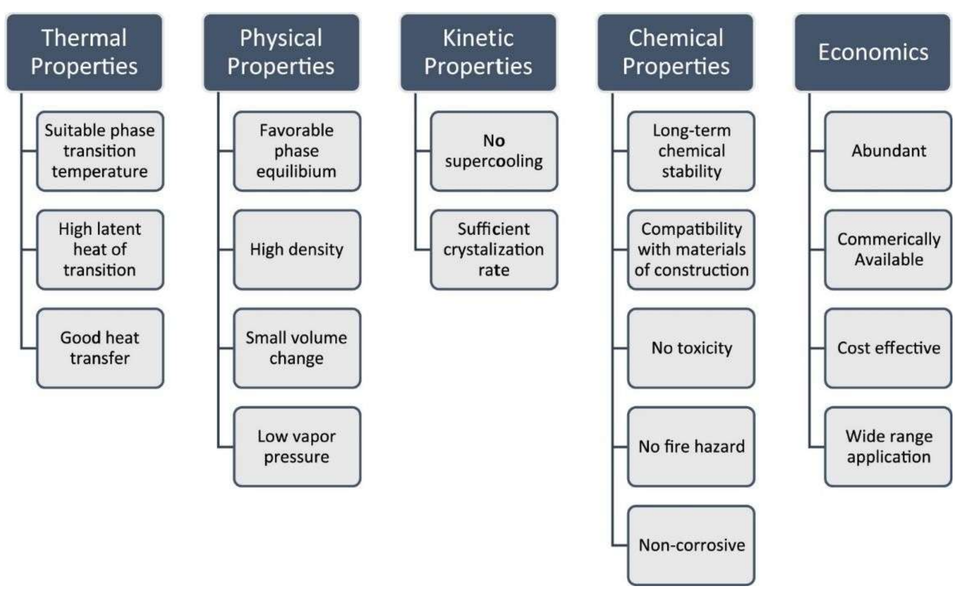


Figure 4 -Selection criteria for PCMs [3]

PCMs are required to undergo phase change in the desired operating temperature range for providing thermal comfort. In terms of the indoor thermal comfort, the suggested indoor room temperature is in the range of 23.5℃ to 25.5℃ in summer and 21℃-23℃ in winter [3]. As stated in the literature [4], the preferable PCM melting point should be 1℃ to 3℃ higher than the average room temperature, in order to maximize the benefits of a diurnal PCM cycle. Therefore, PCMs with melting temperature in the range of 18℃-29℃ are considered for adoption in the built environment. Based on the review of the literature, Figure 5 presents the available PCMs with the melting temperature range of 0℃ to 35℃. The paraffin-based organics offer the highest fusion enthalpies within the desired comfort zone.

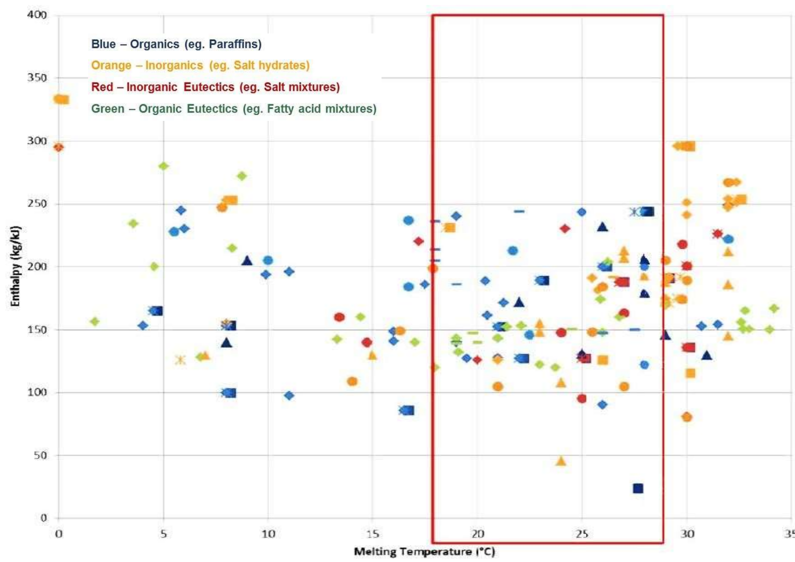


Figure 5 - PCMs in the melting temperature range of 0℃ to 35℃

There are many products available from a range of suppliers. Table 2 lists the commercially available PCMs by a number of manufacturers. The majority have latent heat capacities between 100-200kJ/kg; the paraffinic PCMs have the highest (above 200kJ/kg) but with low thermal conductivity (0.2 W/mK), whereas the salt hydrates have higher thermal conductivities and are less expensive.

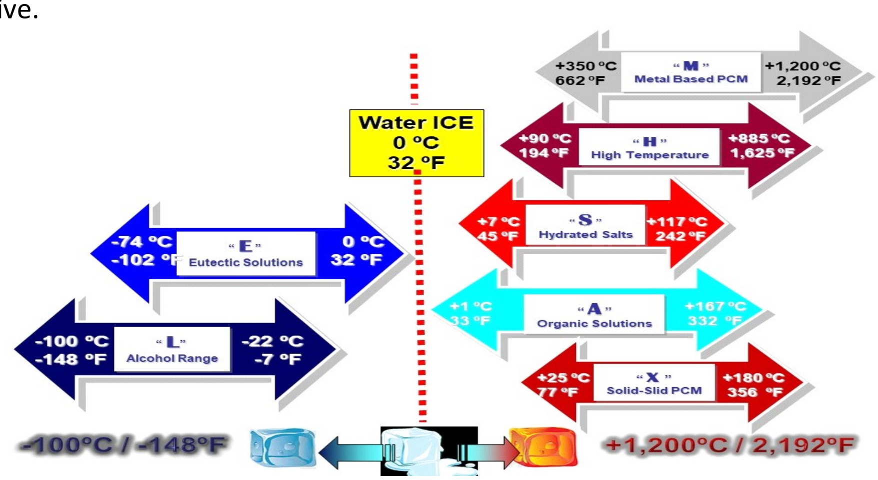


Table 2- Commercially available PCM options

Product	Type	Melting Point (℃)	Latent Heat Capacity (kJ/kg)	Thermal Conductivity (W/mK)	Manufacturer
RT18HC	Paraffin	18	260	0.2	Rubitherm GmbH
S19	Salt hydrate	19	160	0.43	PCM Products
RT21	Paraffin	21	155	0.2	Rubitherm GmbH
RT21	Paraffin	21	190	0.2	Rubitherm GmbH
CT21	Bio-based	21	176	0.18	Croda
Climsel C21	Salt hydrate	21	134	0.93	Climator
S21	Salt hydrate	22	170	0.54	PCM Products
A22	Paraffin	22	145	0.18	PCM Products
A22H	Paraffin	22	216	0.18	PCM Products
RT22HC	Paraffin	22	190	0.2	Rubitherm GmbH
S23	Salt hydrate	23	175	0.54	PCM Products
A23	Paraffin	23	145	0.18	PCM Products
E23	Salt hydrate	23	155	0.43	EPS Ltd.
Climsel C24	Salt hydrate	24	140	0.74	Climator
TH24	Salt hydrate	24	45.5	0.8	TEAP
A24	Paraffin	24	145	0.18	PCM Products
RT24	Paraffin	24	160	0.2	Rubitherm GmbH
CT25	Bio-based	25	186	0.21	Croda
S25	Salt hydrate	25	180	0.54	PCM Products
A25	Paraffin	25	150	0.18	PCM Products
A25H	Paraffin	25	226	0.18	PCM Products
RT25	Paraffin	25	170	0.2	Rubitherm GmbH
RT25HC	Paraffin	26	230	0.2	Rubitherm GmbH
A26	Paraffin	26	150	0.21	PCM Products
RT26	Paraffin	26	180	0.2	Rubitherm GmbH
STL27	Salt hydrate	27	213	1.09	MitsubishiChemical
S27	Salt hydrate	27	183	0.54	PCM Products
S27	Salt hydrate	27	207	-	Cristopia
AC27	Salt hydrate	27	207	1.47	Cristopia
Climsel C28	Salt hydrate	27	170	0.98	Climator
RT27	Paraffin	28	179	0.87	Rubitherm GmbH
A28	Paraffin	28	155	0.21	PCM Products
RT28HC	Paraffin	28	250	0.2	Rubitherm GmbH
A29	Paraffin	29	226	0.18	PCM Products

Table 3 - Commercially available PCMs in melting temperature range of 18-29℃

To address the issues of low thermal conductivities of PCMs, heat transfer enhancement techniques are essential. Figure 6 illustrates common heat transfer enhancement techniques adopted for PCMs. In general, improvements are focused on heat transfer and thermal conductivity.

Regarding heat transfer enhancement, geometric aspects are considered, for example with fins and multiple PCMs to increase the area of heat transfer and consequently improve the thermal performance. On the other hand, improving the thermal conductivity of PCMs is another important option, by impregnation of porous materials of high thermal conductivity, dispersion of high thermal conductivity materials/nanoparticles and/or dispersion of low-density materials into the base PCM [5]. Furthermore, the combined technique concerning increasing the heat transfer area and enhancing the thermal conductivity of PCM simultaneously is also promising for adoption.

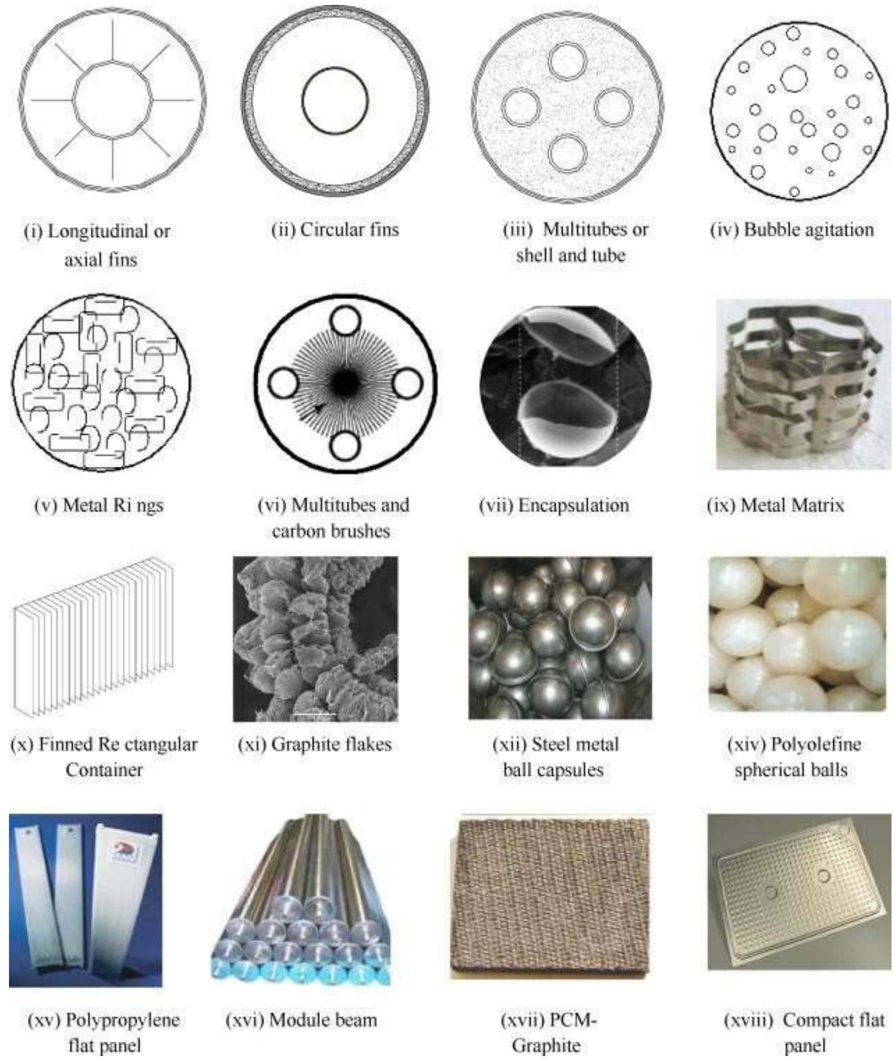


Figure 6 - Heat transfer enhancement techniques for PCMs

In terms of PCM integration, encapsulation is the most common method, encasing the PCM to avoid leakage and subsequent performance losses. Generally, encapsulation of PCMs can be implemented through a variety of approaches, for example direct incorporation and immersion, bulk storage, macro-encapsulation (above 1mm), microencapsulation (0-1000μm), Nano-encapsulation (0-1000nm), shape-stabilised and slurry.

1.2 PCM Technologies

According to scientific bibliography and to what is already sold in the market, the main existing technologies used for building installations are depicted in the following table, together with a preliminary description of advantages and disadvantages.

Technologies here exposed and considered are products of PCM Products Ltd (SUREFIT partner), Rubitherm GmbH, PCM Energy, BioPCM, Croda, Climator, Du Pont Inc., InsolCorp Inc and other companies offering similar solutions around the world.

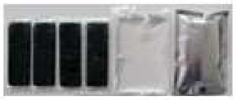
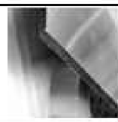
	Name	*Advantages*	*Disasdvantages*
	Pouche	Low cost, high PCM density	Envelope weakness
	Metal container	High mechanical and chemical strength, high PCM density	Weight, high cost
	Plastic container	high PCM density, good mechanical and chemical strength	
	Soaked panel or sponge	Direct installation	Leakages, healthiness, low PCM density, PCMs constrains
	Panels	Direct installation	Low PCM density, PCMs constrains
	Granule mixing	Direct miscibility	Cost
	Macro-encapsulated	Direct installation, good mechanical and chemical strength	
	Micro-encapsulated	Direct miscibility, good PCM density and chemical strength	Cost
	Direct mixing	Direct miscibility, high PCM density	PCMs constrains

Table 3. Advantages and disadvantages of PCM technologies.

1.3 Encapsulated PCM Products

Most aqueous salt based PCM solutions have a tendency to either absorb moisture from the atmosphere (hygroscopic), or lose water through evaporation, and therefore they must be encapsulated in air tight/sealed containers. Although organic solutions can be exposed to air as they are not water based, contamination and fire risk due to low flash point make it necessary for them to be encapsulated in air tight containers.

Salt based PCM solutions are corrosive and the most practical and economical method is to use plastic containers. However, plastic becomes soft temperatures above 50C which restricts the application range to below +80~+90ºC (176°F ~ 194°F) levels.

Solid plastic encapsulated PCMs tend to be the most commonly used method of encapsulation. Blow moulded HDPE containers that most people are familiar as plastic containers commonly used as ice packs aren't susceptible to leakage, are relatively robust and are capable of operation within the temperature range of -100°c and 89°c.

As well as rigid plastic containers, a wide range of flexible pouches filled with various PCM solutions are produced enabling a wide range of low-cost applications. Pouches are made using thin film and they offer good heat transfer efficiency however, because they are prone to physical damage and puncture some of the organic solutions are offered in powder, granule or even solid sheet forms which offer flexibility and safety.

Although plastic, and to a certain extent pouches, are economical, their heat transfer rate and/or limited temperature range restricts their wide scale use. In order to extend the temperature range or improve the heat transfer rate, metal containers have been extensively used for special applications. Metal encapsulation is also effective at improving the heat transfer of PCMs but at a cost. Generally metal encapsulated PCMs are utilised in higher temperature applications and situations where PCMs are required outside the standard operation temperatures of solid plastic containers. However, utilising metal containers is generally more expensive and they can be prone to corrosion especially in instances where salt hydrate PCMs are used.

Organic solutions are water free and can be modified in the form of dust, granules or even solid rubber forms and they can be mixed with other products such as concrete, mortar, bricks, etc. They can be also thermoformed by simply mixing with plastic materials as part of the injection moulding process.

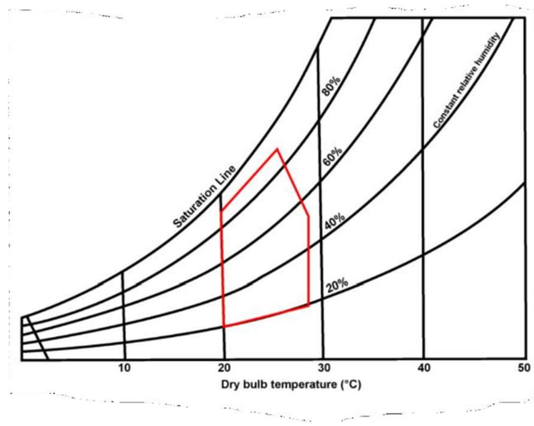
Figure 7 - PCM Encapsulation examples

2 Building Envelope TES

By introducing PCM into the building envelope it is possible to vastly increase the thermal mass of a building, helping ensure that rooms are maintained within the thermal comfort zone.

By installing PCM modules inside the building fabric itself, the end-users gain the thermal and performance benefits of PCMs without even being aware that they are in place. As the PCM module is a static system with no moving parts the passive cooling concept is considered to be a maintenance and energy free option for improving the internal conditions of any built environment applications such as:

- Air Conditioning
- Free Cooling
- Passive Cooling
- Fabric TES
- Solar Systems
- Tri-generation
- Electronic / Shelter Cooling



The application of PCMs in building can have two different goals. first, using natural heat, that is solar energy, for heating or night cold for cooling; second, using artificial heat or cold sources. In any case, storage of heat or cold is necessary to match availability and demand with respect to time and also with respect power [6]

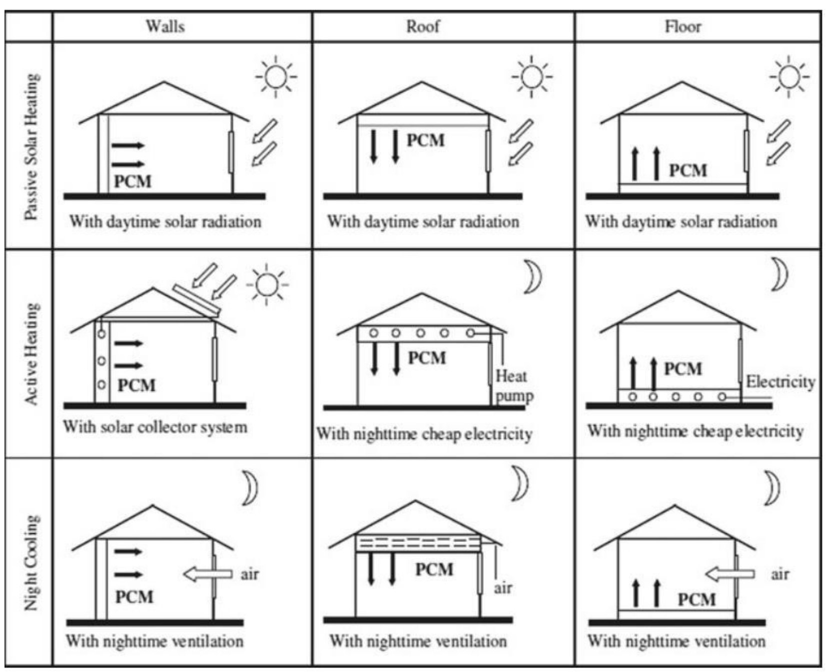


Figure 8 – Forms and effects of PCM Building envelope [6]

2.1 Passive Cooling

Passive cooling takes advantage of the naturally occurring temperature swing caused by day & night. The excess coolth available in the night can be stored in the PCM, which is then released during the day, absorbing internal and solar heat gains.

Figure 9 - Charge (Night) and Discharge (Daylight) Period

ThinICE modules can be installed at high levels so that heat goes up but doesn't come back down. This cooling effect can provide relief to building inhabitants or for electronic equipment.

If the site is located in a region where there are large day-night temperature swings, then it is possible to provide free cooling by ventilating the room at night to freeze the PCM modules by the morning. The size of the cooling machinery could then be greatly reduced leading to lower emissions, reduced maintenance costs and reduced operational costs.

For example, the cool energy available over-night is naturally stored without using any mechanical cooling in +27ºC PCM containers within the building and later the stored energy is utilised to absorb the internal and solar heat gains during day-time for an energy free passive cooling system.

The addition of as little as 25% PCM into the building fabric can increase the building thermal performance by up to 14 times in comparison to conventional building materials. Many modern building materials offer excellent insulation properties, but very poor thermal mass. PCM can help overcome these issues and help the building retain heat for much longer, increasing comfort and decreasing energy bills. PCM has 50 times higher thermal capacity in comparison with building materials as part of the building fabric, the thermal mass of the building can be increased 10~20 fold without the need for large and heavy building construction.

Figure 10 – Fabric energy storage using PCM volume

Example: For a standard 595x595mm ceiling tile, two ThinICE modules can be installed offering up to 0.96 kWh/m2 of energy storage (Using recommended S27 PCM)

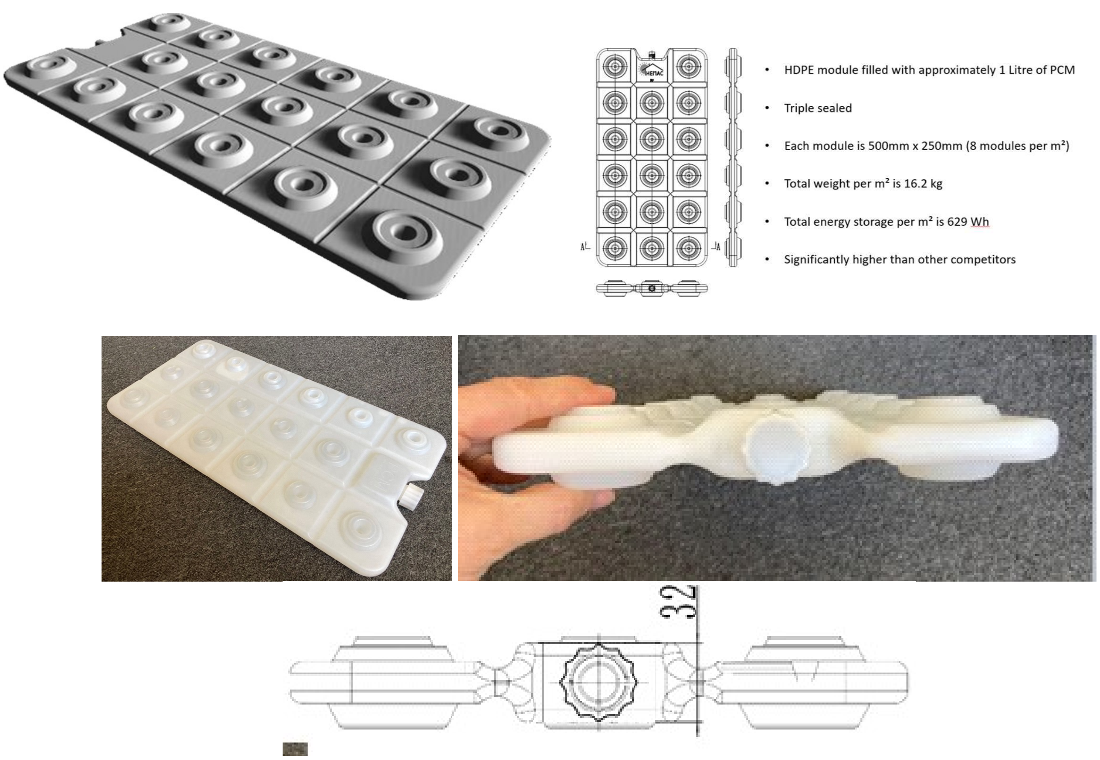


Figure 11 - ThinIce Panel Design

It is easy to upgrade these passive cooling systems into an active chilled ceiling. This greatly improves the flexibility of a conventional HVAC system. Should for any reason the HVAC machinery fails the frozen PCM modules offer an uninterruptable energy relief cooling system giving the maintenance team an opportunity to react.

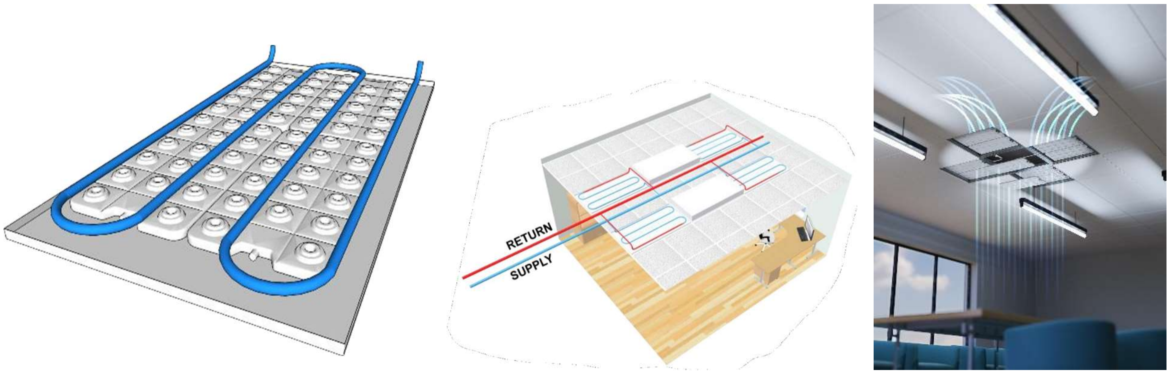


Figure 12 - Active cooling

This also offers load-shifting capabilities where a proportion of the peak cooling capacity of a system is shifted into off-peak periods. The benefit of shifting cooling into the nightly off-peak is twofold, firstly it is possible to gain access to cheaper electricity tariffs and secondly, the refrigeration equipment can be operated in lower ambient conditions leading to a higher COP.

2.2 Underfloor Heating Applications

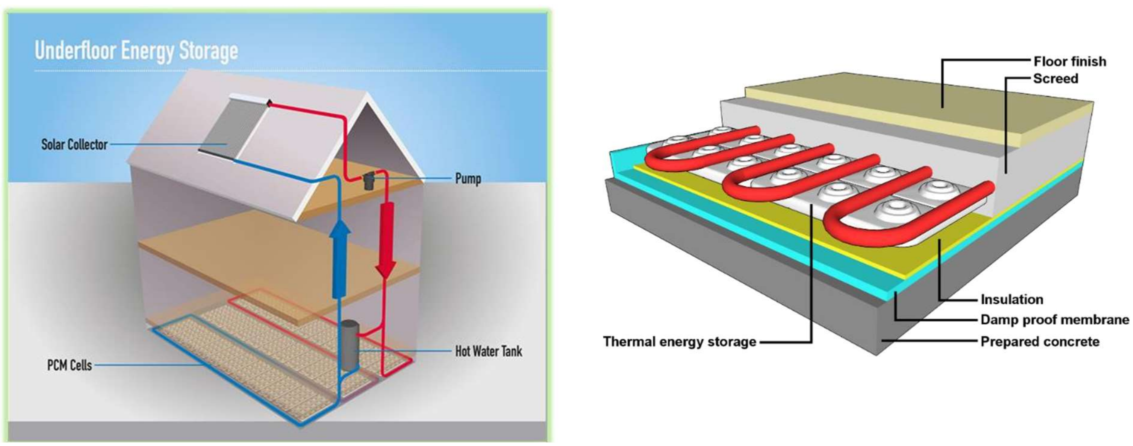


Figure 13 - Solar underfloor heating PCM energy storage application

Solar energy is only available during daylight hours and this free energy can be used either for heating or cooling but generally it is only available during a limited day period. By storing this free energy one can either produce heat or alternatively provide a cooling source.

An example of an under-floor heating using solar collectors and warm 270C (810F) PCM containers is illustrated in Figures 13 and 14.

Although conventional solar collectors may not generate enough energy to charge a water tank during winter months, they could still generate low grade heat around 30~35ºC (860F~950F) which is more than enough to charge PCM modules during day-time. Once the sun goes down the stored energy keeps the occupied space warm and the outside cold energy freezes the PCM rather than penetrating into the occupied space. This way the space conditions can be stabilized over a 24-hour day and night cycle. A typical installation is illustrated below and ThinICE is designed to house any standard underfloor heating pipes within the built-in grooves. Once the pipes are laid down over the ThinICE containers any standard floor levelling compound can be poured over the pipes to level the floor. Any screed and floor finishing materials can be applied like any standard underfloor installation. As the PCM material temperature is fixed this thermal energy storage within the floor mass will keep the floor temperatures steady irrespective of the incoming heating water supply temperatures.

Using conventional solar collectors one can store hot water in simple water tanks but once the sun goes down and water is gradually drawn and the tank cannot maintain a steady output temperature due to stratification. However, if the latent heat capacity of PCM is added to the water tank not only can the capacity of the tank be increased by as much as 3~4 times but also having fixed phase change the water, the outlet temperature can be fixed until the PCM energy is fully depleted.

Figure 14 - Underfloor PCM installation

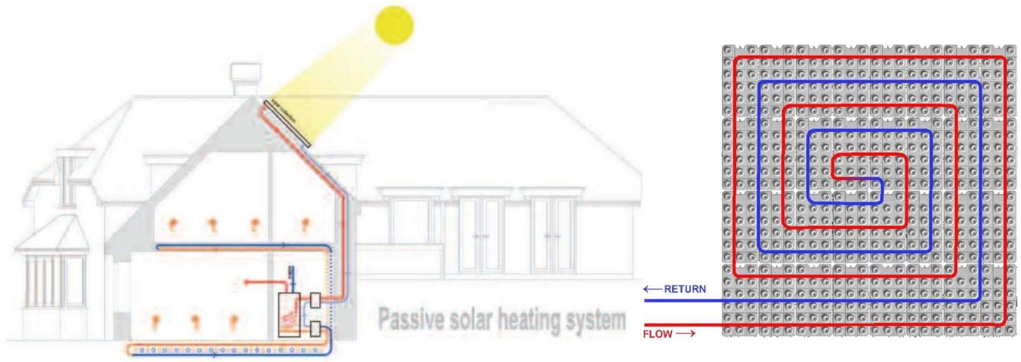


Figure 15 - Underfloor heating using PCM

2.3 Heat Pump Recovery Applications

A heat pump removes energy from one side of the refrigeration circuit either using air/water or ground sources and transfers that energy into the other side of the refrigeration cycle. Although this is a very efficient way to generate heat, if the removed energy is later required it can be considered as a waste. By simply storing this waste energy in the form of +10°C (50°F) for cold or +46°C (115°F) hot PCM energy storage, one can utilise this stored energy during peak periods and as a result the heat pump size as well as the overall system energy usage can be reduced by as much as 50% by spreading the load over a 24-hour cycle. A heat pump combined with PCM energy storage not only reduces running costs due to lower over-night electricity rates but also provides an increased combined COP (EER), which effectively reduces the overall power requirement as well. The combination of these two benefits can reduce the overall running cost of the system

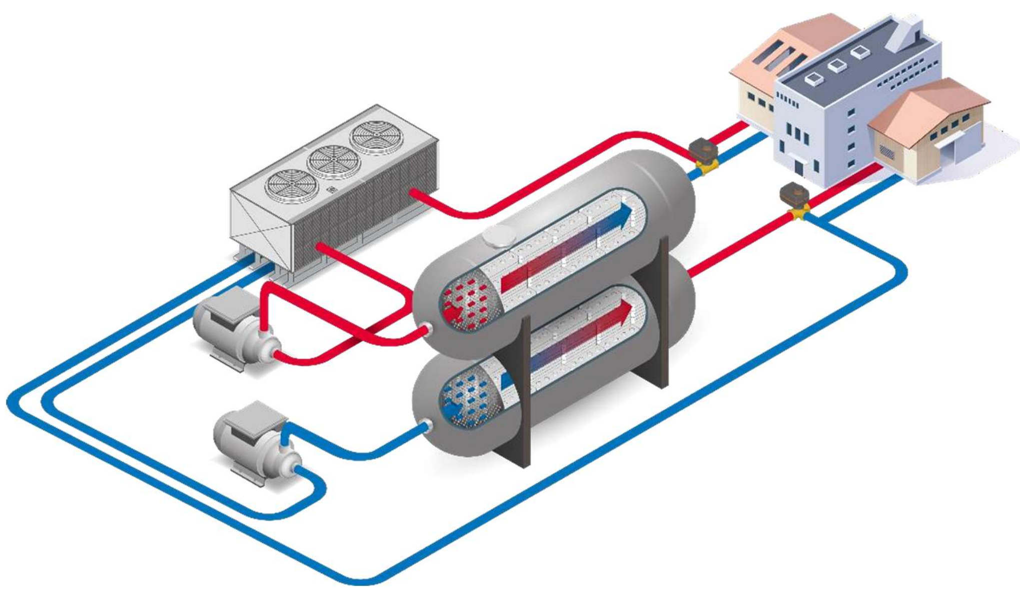


Figure 16 - Heat Pump PCM – TES

For example, using +8C and +46C PCM materials on both cold and hot side of the heat pump would spread the loads over 24 hours and reduce the machine size as much as by 50%. By also storing both hot and cold sides the overall COP nearly doubles not only reducing the running cost but also offers reliable and stand-by capacity system.

2.1 Chilled Water Applications

Water has the advantage of universal availability, low cost and transport ability through other system components. However, water ice as latent heat energy storage can only be produced using inefficient low temperature chillers for cooling applications and if it is applied for heating using purely sensible heat storage capacity designers' have to use large storage tanks.

However, Phase Change Materials (PCM) between +4^{0}C and +13^{0}C range offer us new horizons and practical application options. One can provide a latent heat Coolth energy storage utilising conventional water chillers for new and retrofit applications without the need for any modifications as well as having the possibility of free cooling.

By storing day-time warm energy for evening periods and night-time cool energy for day-time cooling requirements, a PCM system can simply bridge the gap between energy availability and energy use and therefore has the potential to achieve considerable environmental as well as economic benefits for many heating and cooling applications.

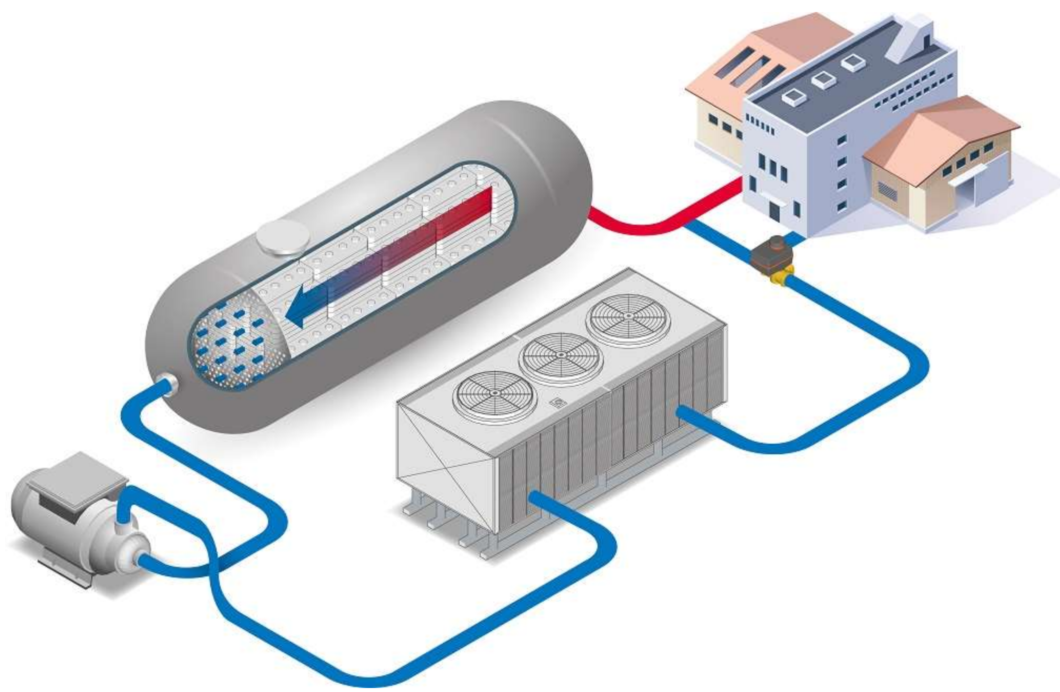


Figure 17 – Chilled Water PCM – TES

3 Design and Testing

As previously stated, PCMs with melting temperature in the range of 18℃-29℃ are considered for adoption in the built environment.

Prototype panels were developed using a selection of PCM materials with various phase change temperatures. The initial concepts were produced and tested at University of Nottingham:

Honeycomb

Figure 18 – Aluminium honeycomb panel with INERTEK 23 and Mylar Bag

Metallic Panel

Figure 19 - Aluminium Honeycomb panel S23 and Aluminium cover

Plastic Pouch Panel

Figure 20 – Plastic pouch with S27

Aluminium Pouch Panel

Figure 21 - Aluminium panel with INERTEK 23

PCM Blister panels

Figure 22 - INERTEK 23 blister panel

Figure 23 - A28 Blister panel in test box

The initial testing showed that S27 was the most efficient PCM to use in our application and therefore this was selected for testing moving forward.

PCM	Sum of Average temperature drop (°C)	Sum of Weight (kg)
A28	9.96	6.416
INERTEK 23	10.4	9.206
INERTEK 23	2.38	0.566
INERTEK 26	7.05	9.3
S23	1.22	2.1
S23	1.59	8
S27	12.881	56.35

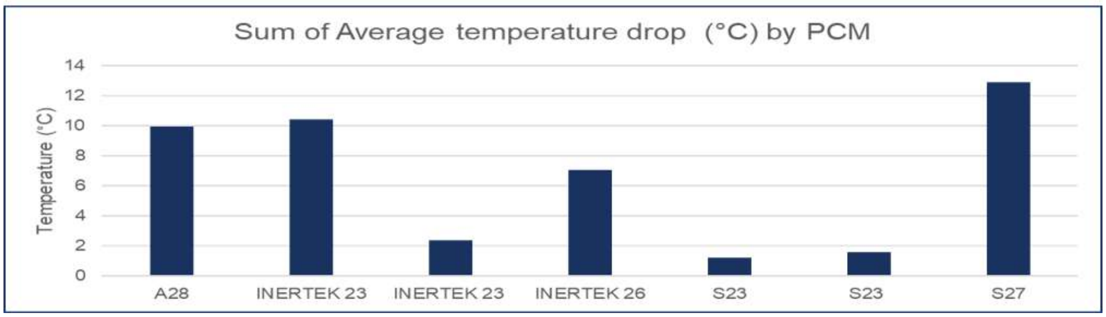


Figure 24 - Test results

Blister panels were identified as better option than pouches due to Increased heat transfer area and less prone to damage. A manufacturer was identified and instructed to produce prototypes using S27 PCM material.

Figure 25 - Blister PCM Panel prototype

The blister panel design was found problematic for filling, robustness and cost effectiveness therefore a cheaper and more robust prototype, a HDPE encapsulated panel was developed and manufactured by PCM Products.

Figure 26 - ThinIce Panel

38 Panels with S27 PCM were supplied to University of Nottingham for laboratory scale testing.

A set of 14 PCM panels were allocated in the SRB room in UoN with a total weight of 49.81kg, 3.55kg each. The testing room has a total area of 5.49 m2 and each panel measures 49 x 24 cm. The area covered by the PCM panel corresponds to 1.4 m2 representing 25% of the area. The panels were tested under different conditions to determine the impact on the room. The measurements were taken with a Data logger and 5 thermocouples.

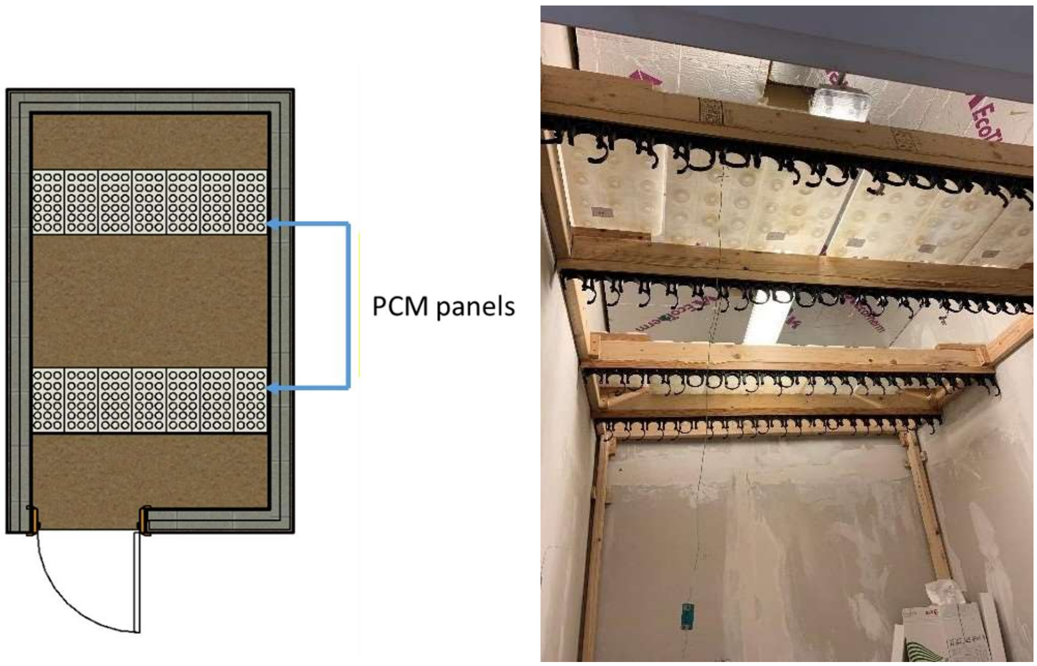


Figure 27 - Test room

The radiator was used to preheat the room for 24hrs before testing, after this period the radiator was turned off.

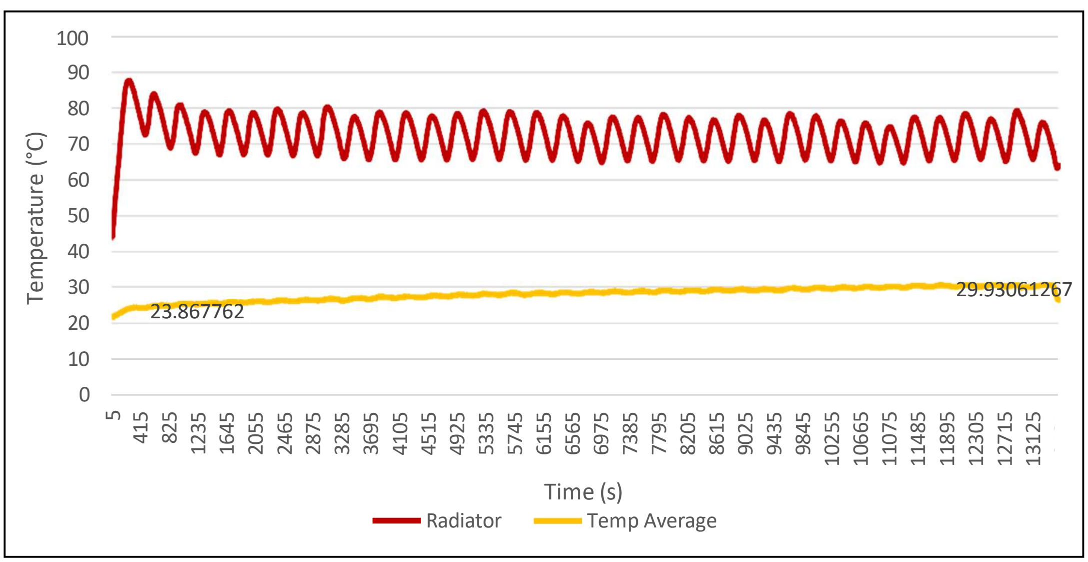


Figure 28 - Room temperature without PCM and Radiator for heating

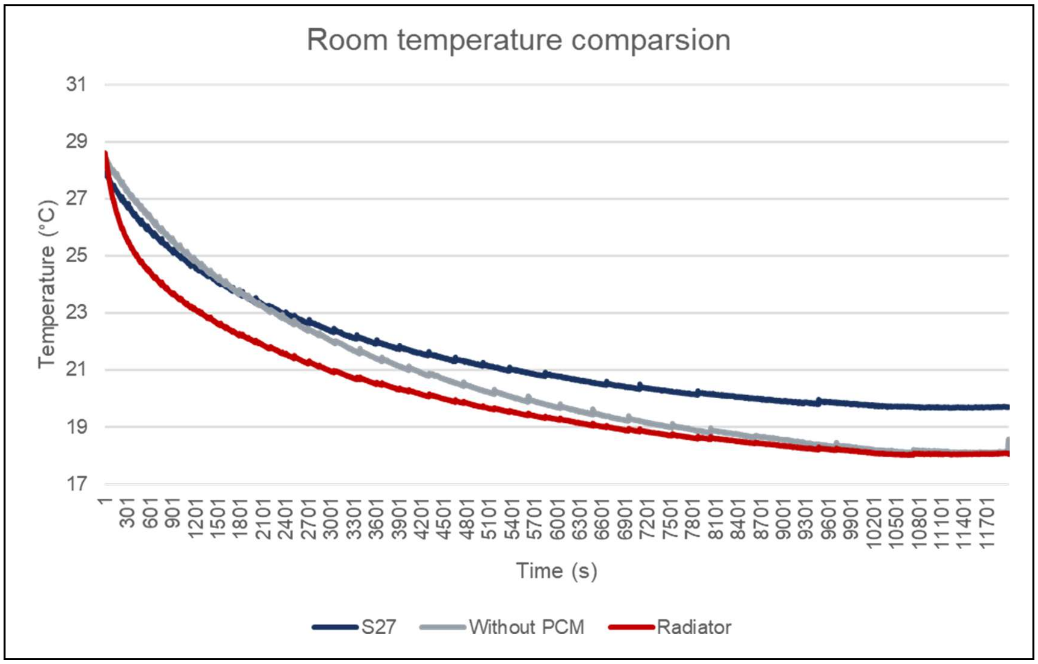


Figure 29 - Room temperature comparison

It was observed that the S27 was able to maintained higher temperatures, whereas the room without PCM presents a 1.7°C temperature decrement.

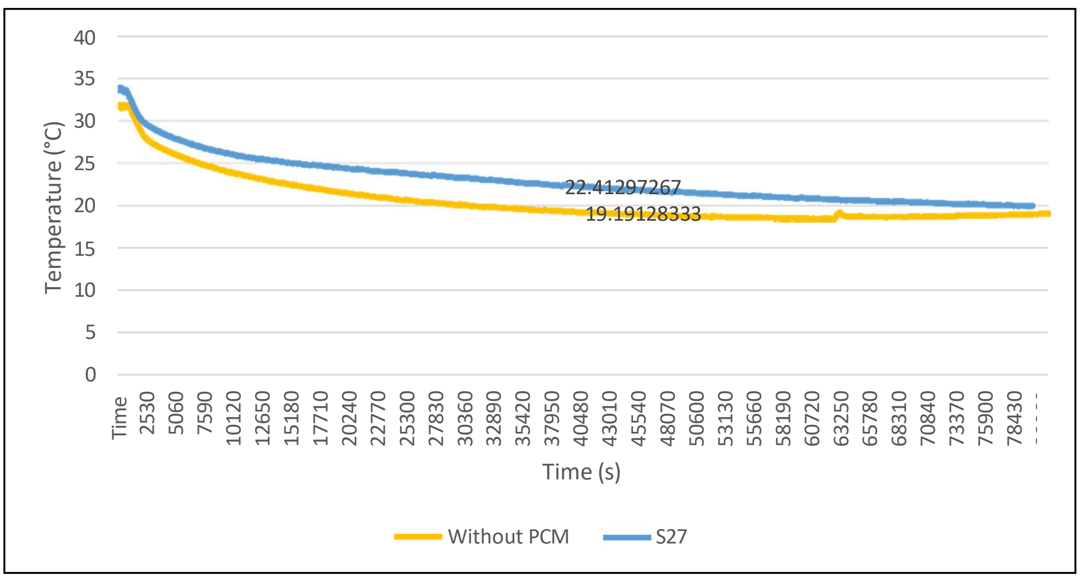


Figure 30 - Room pre heated and then heating turned off for duration of test

A second test was conducted. It is observed a maximum temperature difference of 3.3°C after 11.2 hrs.

The test was repeated with two radiators to increase the room temperature, in this case the panel temperature is 26.9°C when the room temperature is of 38.33°C.

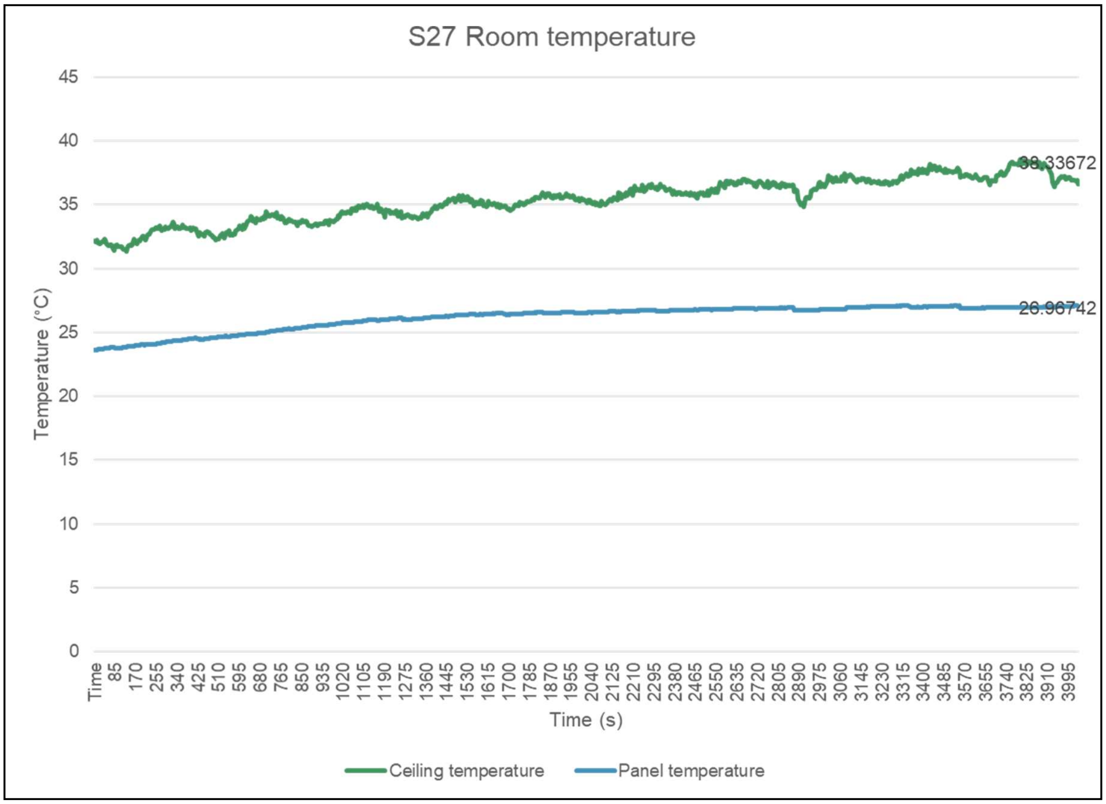


Figure 31 - Third test results

Underfloor heating was installed at PCM Products test site, this was coupled with the ThinICE PCM panels; the same panels that have been used for the passive ceiling cooling. The same principle applies to the underfloor heating system, once the UFH has charged the PCM and the room thermostat is satisfied, the UFH system will shut off and the ThinICE tiles will continue to radiate heat for an extended period of time without any heat input.

The installation process involved applying 100mm foil back insulation panels across the span of the floor, this was then protected by a dampproof membrane sheeting. Once the floor had been prepared, the ThinICE tiles were placed on the floor and the underfloor heating pipework was installed into the preformed grooves of the tiles. A layer of concrete screed was then poured onto the ThinICE and UFH pipework and allowed to dry for a week. When the screed was set, the testing for the UFH was started immediately.

Figure 32 - Underfloor heating installation coupled with PCM

Four sensors were embedded within the floor at each level, these were:

- Under insulation
- Below PCM
- Above PCM
- Floor surface

Four Sensors were also placed on the pipework to the underfloor heating set up:

- Heat Pump Flow (H/P Flow)
- Heat Pump Return (H/P Return)
- Underfloor Heating Flow (UFH Flow)
- Underfloor Heating Return (UFH Return)

The underfloor heating test was conducted for 24 hours. A solar assisted heat Pump was used to heat the PCM to 36°C in order to ensure that the 27°C PCM was charged (melted). The heat pump and underfloor heating circuit was then isolated and the PCM tiles were allowed to thaw and discharge the stored thermal energy.

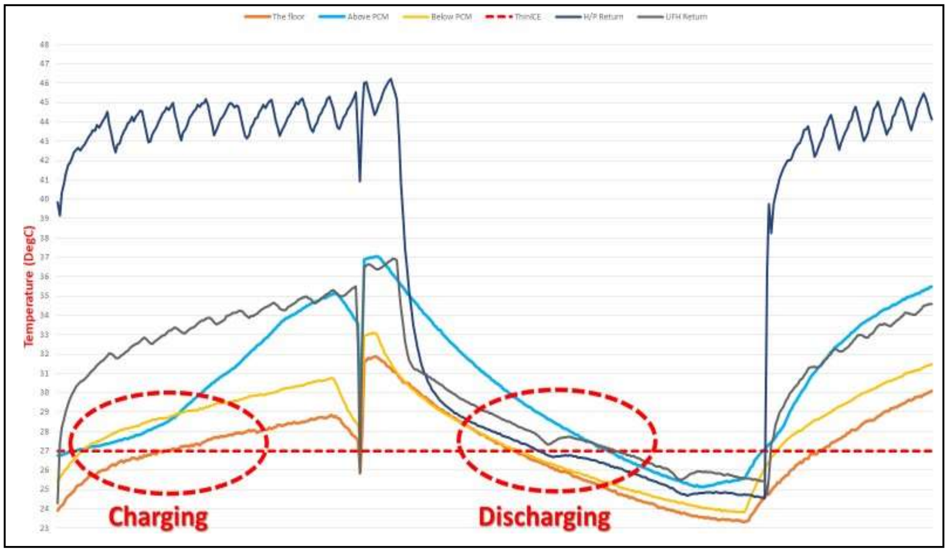


Figure 33 - Underfloor heating Daily profile

The results show that the temperature was maintained within the time period where the heat pump was switched off.

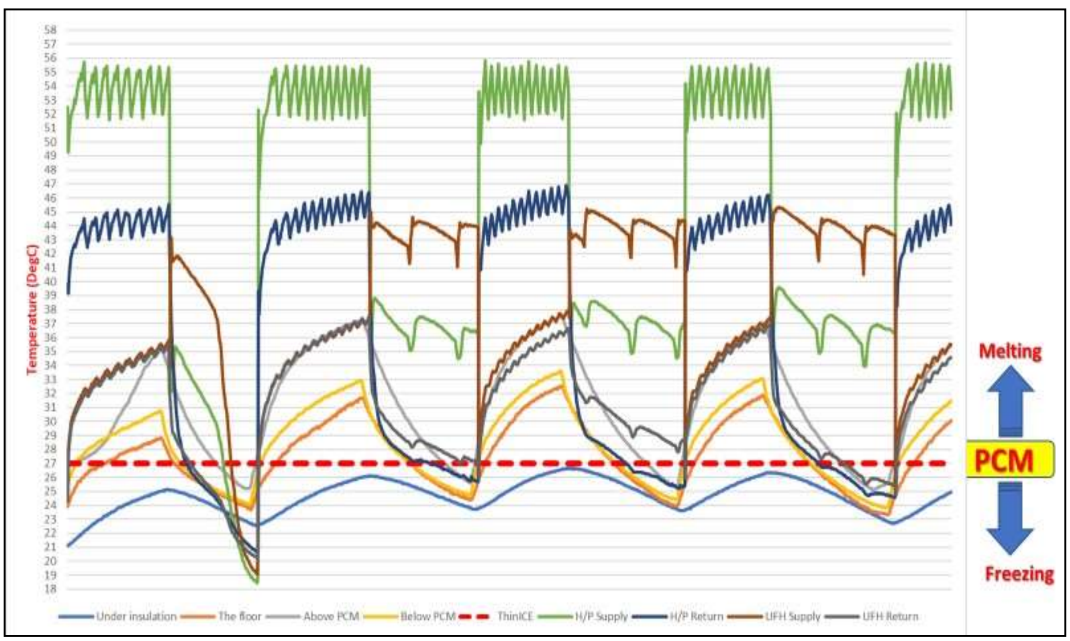


Figure 3 - Underfloor and PCM heating Weekly Profile

Figure 34 - Heat pump operation profile

Conclusions

The temperature ranges and encapsulated options offered by the proposed PCM solutions provide free ambient cooling, conventional chilled water temperature ranges for both the charging and discharging sides of the system for any HVAC applications. Hence, they can be applied to any new or retrofit application with minimal technical and economic impacts.

PCM thermal energy storage systems have no moving parts and therefore they can be considered as a maintenance free option. Furthermore, they provide a very reliable stand-by capability for many critical cooling applications such as datacentres, public transport hubs, hospitals and schools in case of any mechanical / power failures.

PCM's are stable as long as they are not contaminated and exceed their operational envelop, their life is limitless as the process is not chemical like batteries but only thermal. For example, if you ask how many times you can freeze and melt water? It is limitless unless you boil it or let it open to evaporate, you will have no water and no PCM.

All Salt based solutions use the water as the base latent heat and chemicals are dissolved in water and it is irreversible (like when you add sugar to your tea or salt into your meal) and like water you will lose the reliability if you expose them to air, over heat or over cool.

Hence, PCM solutions are stable and our in-house and field tests confirms this but the most crucial issue how they are encapsulated, applied and used.

Figure 35 - PCM Panel encapsulation examples

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