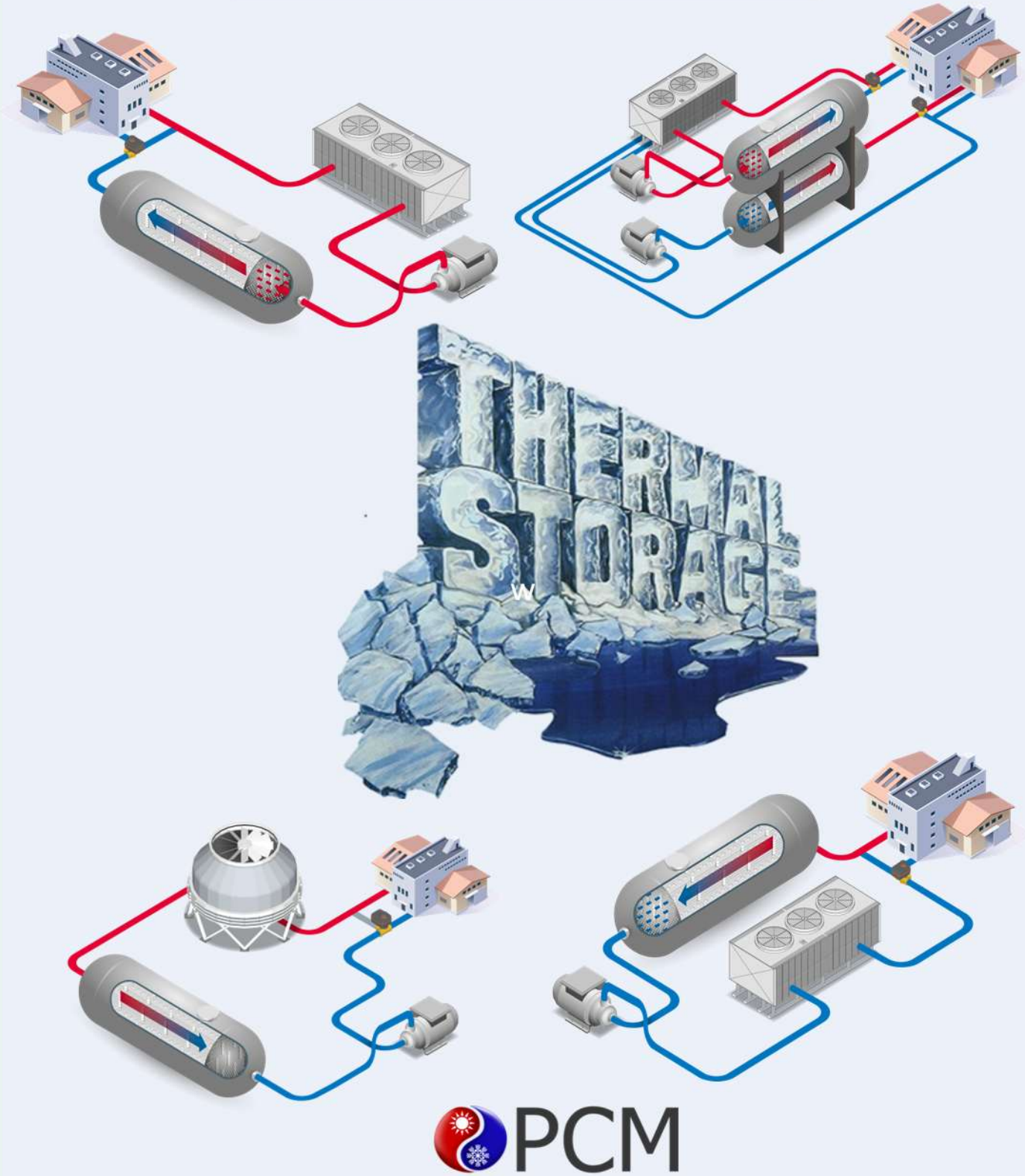
APPLIED SYSTEMS

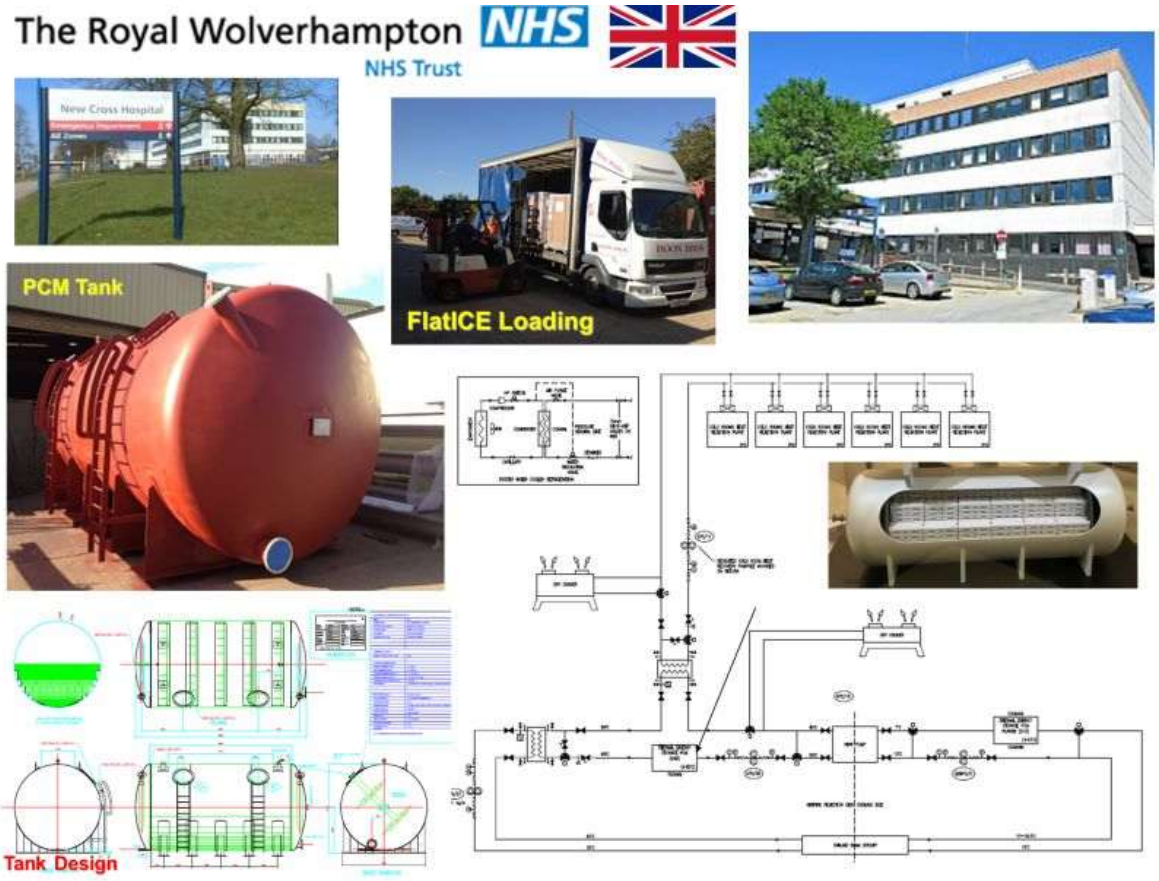


PCM

www.pcmproducts.net

The Royal Wolverhampton Hospital PCM-TES application, UK

By simply operating the installed cooling infrastructure over-night design is based on adding a 30 m3 (7,925 USG) TES tank filled with 6,000 self-stacking HDPE rectangular containers filled with +10C (50F) PCM solution providing 1,500 kWh (426 RT-h) load shifting TES capability.



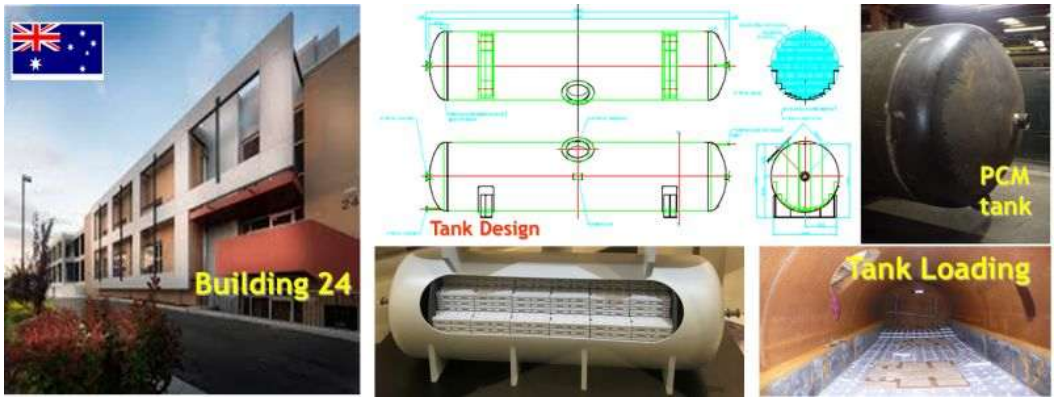
Western Sydney University, PCM-TES Application. AUSTRALIA

In Australia the difference between the day and night ambient conditions could be as much as 15~20C (30~40F) which offers a significant efficiency increase if one can run the chillers over-night. And therefore, save significant power consumption for a given daily load.

Furthermore, this coupled with reasonable incentives for the electricity rates can significantly lower the annual running cost by load shifting capability of the air conditioning office installation.

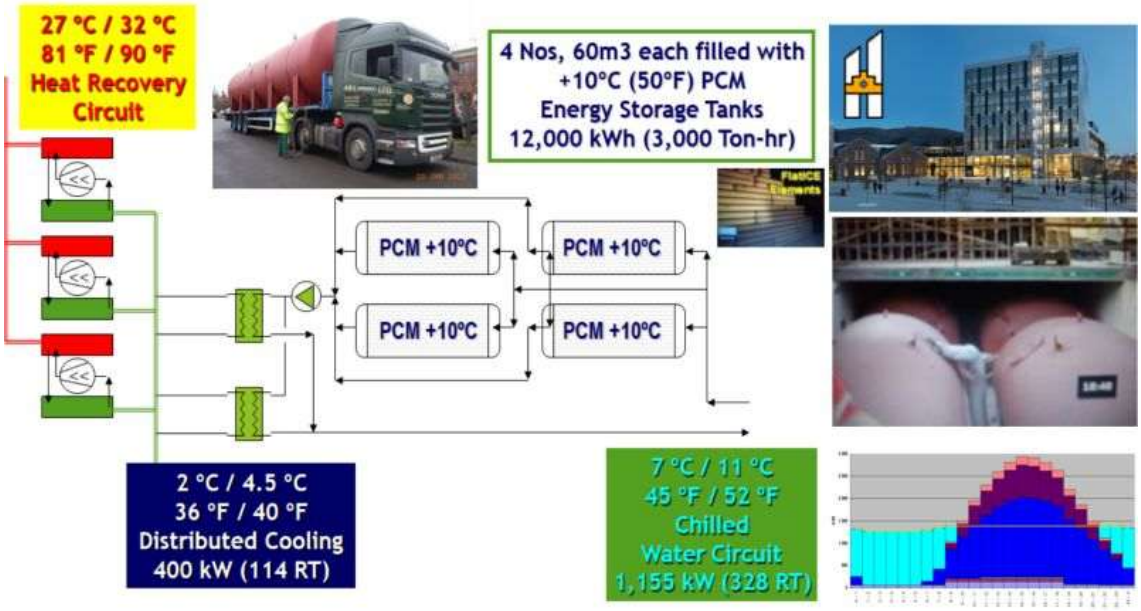
As the actual electricity consumption is reduced due to higher efficiency night operation and also the number of chillers are reduced by the TES this installed system offers significant environmental benefits too.

By simply operating the installed cooling infrastructure over-night design is based on adding a 13 m3 (3,434 USG) TES tank filled with 2,600 self-stacking HDPE rectangular containers filled with +10C (50F) PCM solution providing 550 kWh (156 RT-h) load shifting TES capability.



University of Bergen, Høgskolen i Bergen Energy Centre, NORWAY

The renovation of the campus of the Bergen University College was completed in 2014. This project covers 50.983m2 occupied areas to supply 2.600 MWh heating and 1.060 MWh cooling on a yearly basis. The peak load of the system is 2.830kW for heating load. 3.000kW for cooling load is provided with the combined HP/chiller system complete with a phase change material (PCM) in order to handle the peak cold.
PCM cold storage is based on 47.000 encapsulated salt-hydrate PCM elements filled with 10C (50F) PCM solution. The FlatICE self-stacking elements (500 x 250 x 32 mm) are stacked within cylindrical tanks. The stack FlatICE containers forms a shape similar to plate heat exchanger whereby the water is ideally flowing through the tanks and is passing in between the PCM elements providing extensive heat transfer surface area. There are four tanks providing a total volume of 240 m3 (63,401 USG) .
All four tanks yield a storage capacity of 12 MWH (3,000 RT-h) and this stored energy in return provides 1.600 kW cooling for 7 hours. The design is based on PCM storage covers the peak cooling load on daily basis. Over-night while the heat pumps providing heating for the student accommodation the waste cooling energy is stored within the PCM storage and they are charged using this waste energy. During the day PCM-TES is integrated within the chilled-water distribution loop, the designed installed chiller cooling capacity was reduced with 53%.



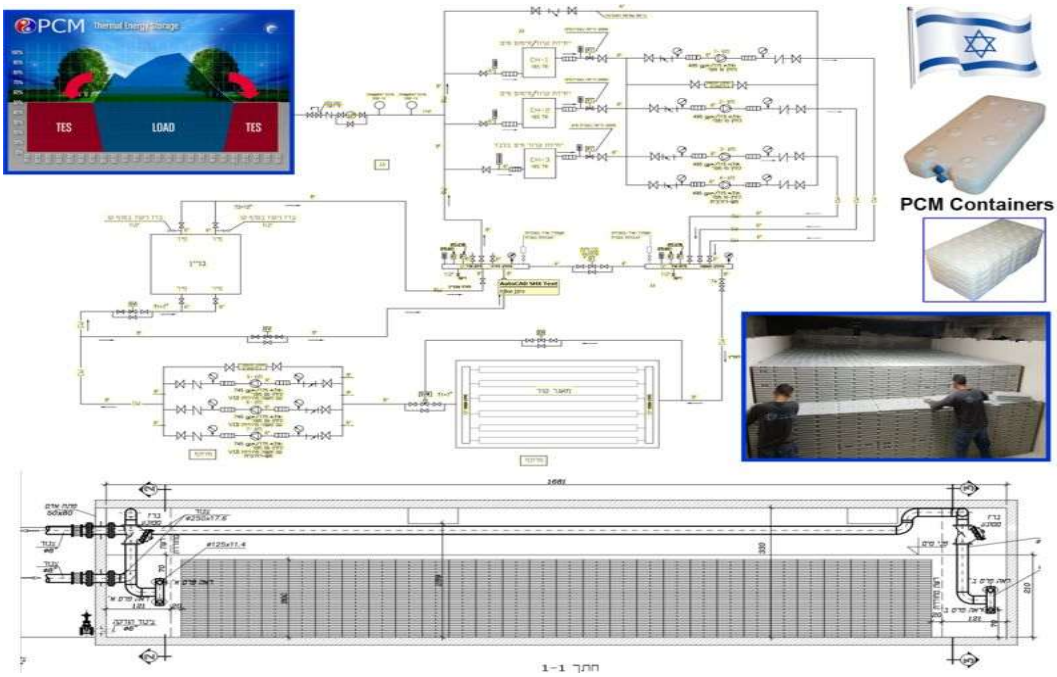
Techtronic Industries Company Limited 創科實業有限公司-CHINA

Existing chilled water-based A/C system provides cooling for the clean rooms and production areas which is essential to keep the production going 24/7. By simply running the existing chillers over-night utilising spare capacity to build 4.25 MWh (1,200 ton-h) +8C (47F) PCM thermal energy storage day-time one can shut down the chillers for a few hours in order to avoid these punitive electricity rates.



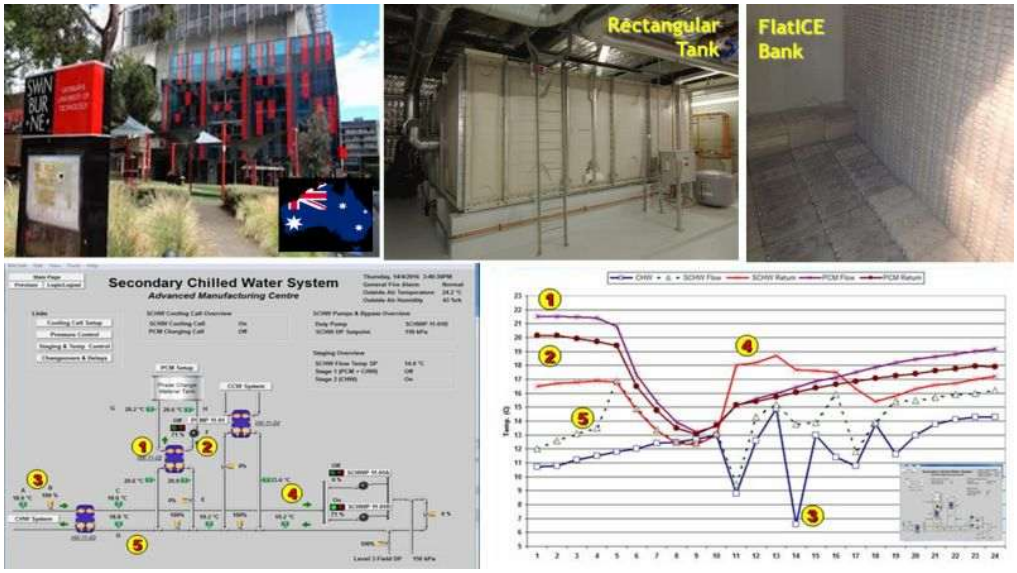
TITANIUM COMMERCIAL BUILDING A/C APPLICATION, ISREAL

Like any commercial building whereby a large cooling demand required during day time but very little or no cooling demand over-night, Installed PCM Thermal Energy Storage (TES) offered a great opportunity to utilise the cooling machinery over-night using lower electricity rates as well as higher efficiencies due to lower night time ambient in Israel and effectively enabling to shift the peak loads.
100 m3 (26,417 USG) TES tank loaded with 20,000 FlatICE filed with +9C (49F) PCM solution providing 4.5 MWh (1,278 RT-h) TES capacity



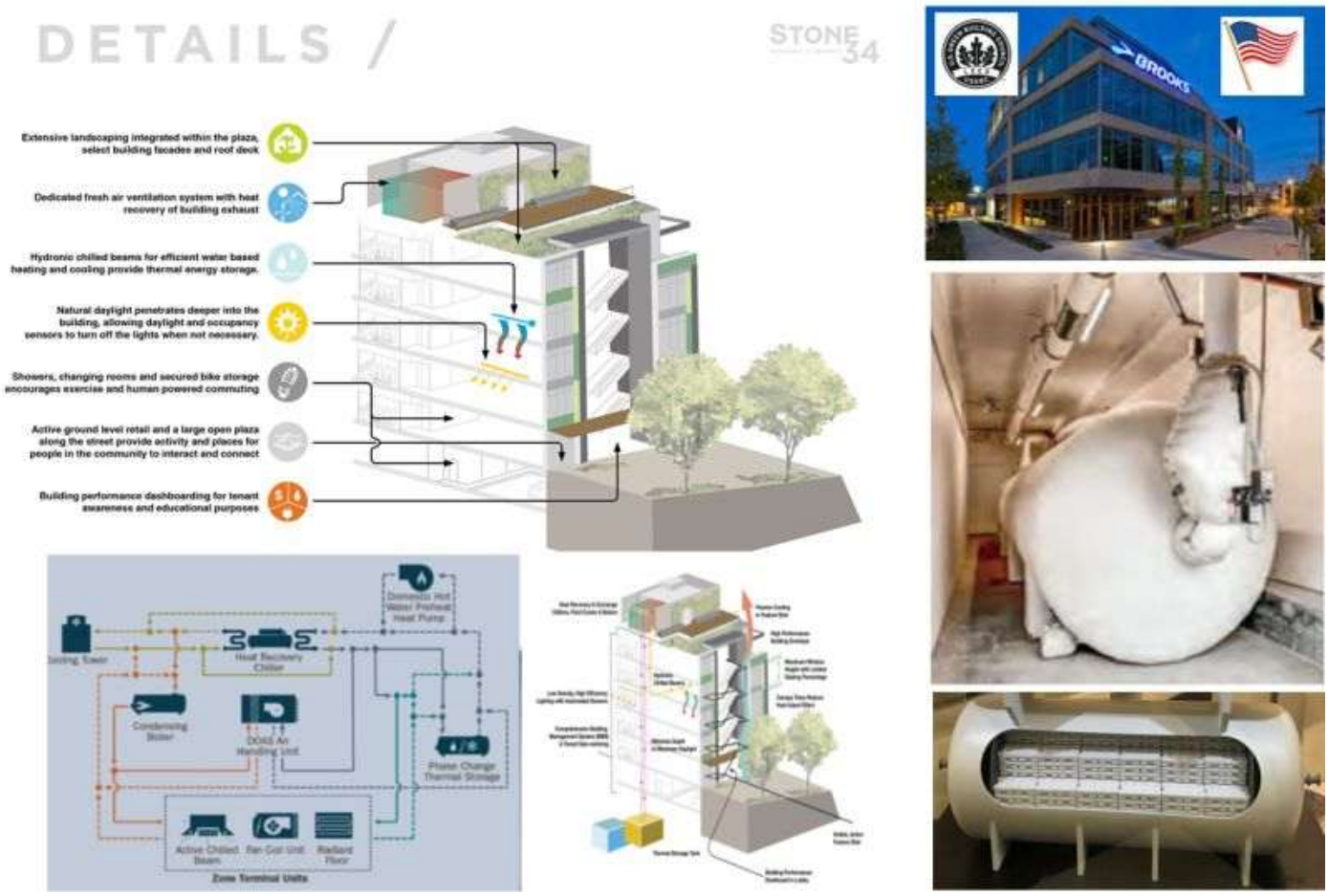
Swinburne University, AMDC Building, Hawthorn Campus, AUSTRALIA

In Australia the difference between the day and night ambient conditions could be as much as 15~20C (30~40F) which offers a significant efficiency increase if one can run the chillers over-night. And therefore, save significant power consumption for a given daily load.
As the actual electricity consumption is reduced due to higher efficiency night operation and also the number of chillers is reduced by the TES this installed system offers significant environmental benefits too.
By simply operating the installed cooling infrastructure over-night design is based on adding a 29 m3 (7,660 USG) TES tank filled with 5,770 self-stacking HDPE rectangular containers filled with +15C (59F) PCM solution providing 1,3 MWh (370 Ton-h) load shifting TES capability.



Stone 34, Office Building, Seattle, USA

Stone 34, a 5-story, 127,000-gsf office building designed by LMN Architects and developed by Skanska Development. It is a LEED Platinum BD+C and O+M certified building located in Seattle and completed in 2014.
Stone34 earned early accolades as one of the most efficient commercial office buildings in the USA as it is designed to reduce water and energy by more than 75% of other comparable buildings.
Additionally, Stone34 provides an advanced “thermal envelope” to allow holding in heat in winter and cool air in summer, as well as technical elements like hydronic heating and chilled beams to keep the interior comfortable for tenants and visitors.
TES system is based on placing 5,000 self-stacking HDPE containers filled with +10C (50F) PCM solutions in 25 m3 (6,604 USG) pressurized tank providing 1,250 MWh (355 RT-h) as opposed to any water ice TES is considered to be an essential part of achieving the lower energy consumption towards obtaining LEED platinum certificate



Statoil Building, 5020, Bergen, NORWAY

By simply operating the installed cooling infrastructure over-night, one can build as much as 1,300 kWh (370 RT-h) based on installing 30 m3 (7,925 USG) tank filled with 5,800 rectangular self-stacking HDPE containers filled with +10C (50F) PCM solution.



Somacis Graphics – PCM-TES Retrofit – Dongguan-China

Rapid growth of industry and domestic power demand somehow well passed the power generating capability of the grid and therefore for a few hours of the day local electricity rates are punitively expensive in order to discourage power consumption so the grid can be stabilised. operational costs.

Hence, any type of TES is beneficial to shift the loads and avoid this excessive power charges as well night cooler ambient higher efficiencies.

Existing chilled water based A/C system provides cooling for production areas which is essential to keep the production going 24/7.

By simply running the existing chillers over-night utilising spare capacity to build 4.25 MWh (1,200 ton-h) +8C (47F) PCM thermal energy storage day-time one can shut down the chillers for a few hours in order to avoid these punitive electricity rates. TES tank is a site built concrete tank next to the existing plantroom.

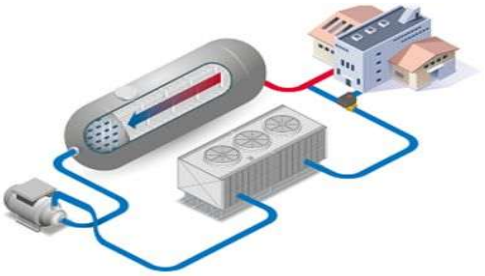
By simply shifting the day peak loads to off-peak night period it is estimated not only a reduction of approximately 15~20% actual power consumption but most importantly avoiding day time punitive electricity rates overall annual running cost could be reduced dramatically. These savings are so impressive as it is estimated a payback less than 2 years for the overall retrofit PCM-TES installation in their factory in China. Installation is carried by an investment company who has already installed a few similar PCM-TES system as an Energy Management Contract.



Royal College of Physicians Headquarters PCM-TES Retrofit, London, UK

The difference between the day and night ambient conditions in the UK could be as much as 10~15C (20~30F) coupled with big incentives for the electricity rates which is almost 1/3 of day peaks this load shifting capability offers a way to save considerable annual running cost for any air conditioning office installation.
As the building operates during standard office hours and therefore air conditioning loads are significantly lower during out of office hours and weekends. This spare capacity is utilised to charge 40 m3 (10,566 USG) PCM Tank filled with rectangular self-stacking containers filled with +10C (50F) PCM solution providing 2,000 kWh (568 RT-h) load shifting TES capability.









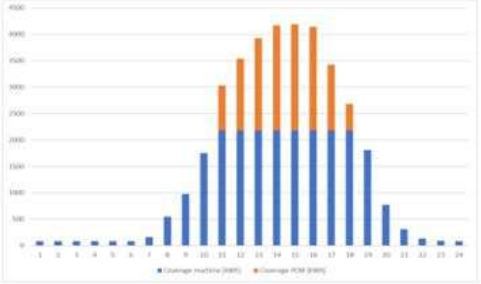
Økern Portal, OSLO, NORWAY

Økern Portal regeneration is designed to be a regional hub of high-end transport links and modern housing development in the centre of Oslo. It aims to emerge as re-definition of public spaces and based on demolishing two adjacent buildings and adding a 50,000 square meter extension along the site's perimeter. Økern Portal aims to achieve a BREEAM-excellent rating. To this end M&E design utilise as much as off-peak energy as possible by dry coolers and PCM based TES combination of adding 4 Nos PCM tanks filled with stackable rectangular HDPE containers filled with +13C (55F) PCM solution providing 12,000 kWh (3,410 Rt-h) TES capability so majority of the year.









Netherlands Cancer Institute, PCM-TES, Amsterdam, NETHERLANDS

The difference between the day and night ambient conditions in the Netherlands could be as much as 10~15C (20~30F) coupled with big incentives for the lower night-time electricity rates in comparison with day peaks PCM-TES load shifting capability offers a way to save considerable annual running cost for any air conditioning office installation. As the building operates during standard office hours and therefore air conditioning loads are significantly lower during out of office hours and weekends.

By simply operating the installed cooling machines over-night, one can build as much as 2,000 kWh (568 RT-h) based on adding a 45m3 / (11,359 USG) Filled with rectangular self-stacking HDPE containers filled with +8C / (47F) PCM solution. The overall annual running cost are significantly reduced due to electricity rate incentives. As this load shifting also reduced the number of chillers required for the peak loads it also provided a cost natural installation in comparison with conventional systems.





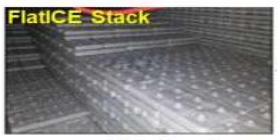




Hitachi Chemical Electronic Materials (Guangzhou) Ltd. 日立化成电子材料（广州）有限公司 - PCM based Chilled Water TES Application, Guangzhou, CHINA

By simply utilising the excess capacity over-night from the installed chillers existing system charges the PCM tanks using conventional +5ºC (45ºF) water and later this stored energy utilised during day time to reduce the peak power demand. Existing chilled water system extended using 2 no's 72 m3 (19,020 USG) TES tanks filled with 14,400 FlatICE containers in each tank. Electricity supply rates differ significantly during the day and any load shifting helps to reduce the overall operational costs. Existing chilled water-based A/C system peak loads are shifted by simply adding 6.4 MWh (1,900 ton-h) +8ºC (47ºF) PCM thermal energy storage (TES) tanks with minimal modifications for the chilled water circuit.





PCM材料摆放



扰流板







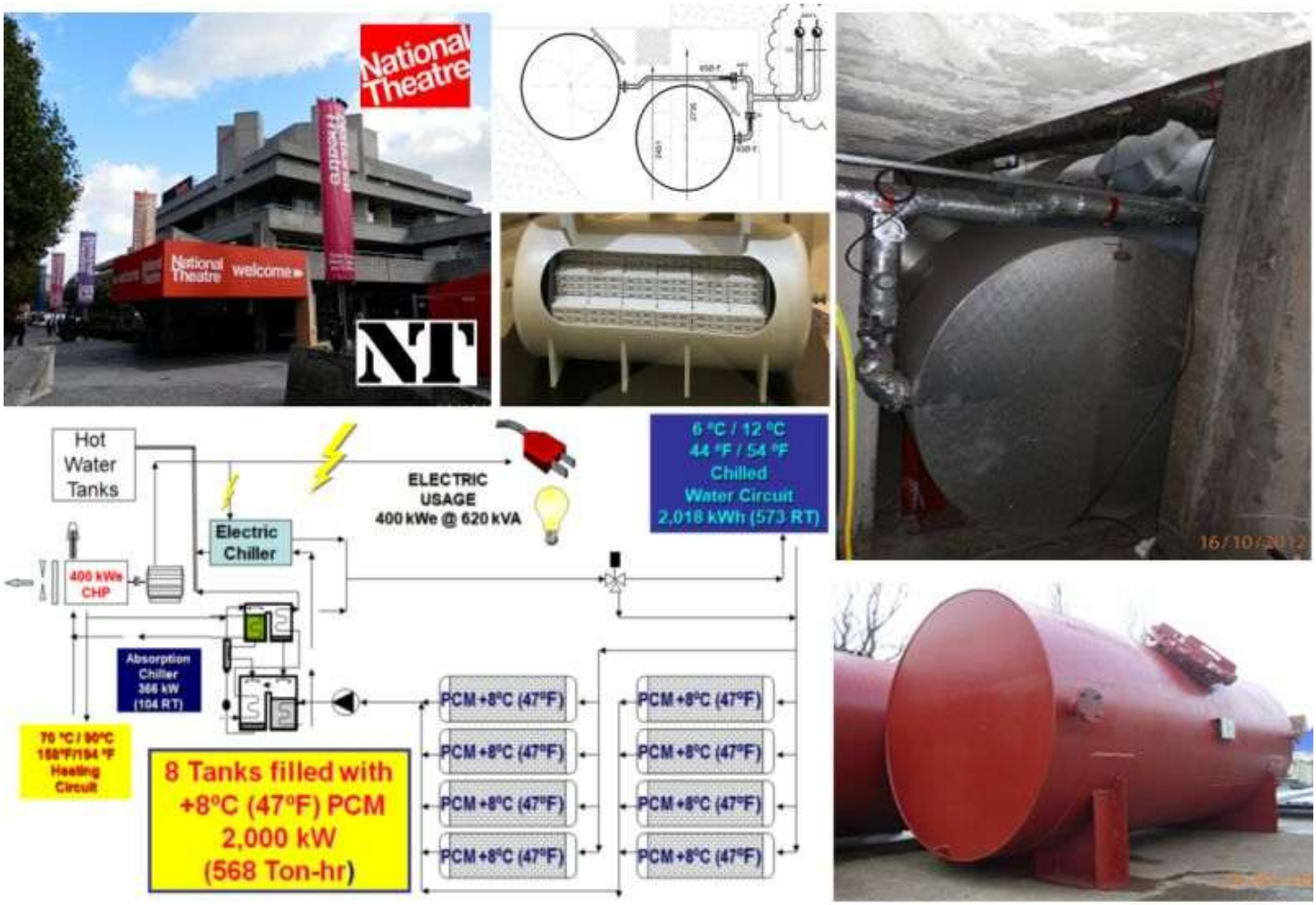
NATIONAL THEATRE, SOUTHBANK, CHP system PCM-TES, LONDON, UK

The renovation of the National Theatre in London aimed for a significant reduction in CO2 emission and to that end it is decided to have a Combine Heat & Power (CHP) system.
Although this building house the main shows but also fair bit office element is part of the building which requires office hours building services such as water, electricity, cooling and heating all year round. On the other hand, shows take place out of office hours generally in the evening period.

Electricity requirement is the main driving factor for the sizing and therefore 400 kWhe CHP plant is installed. During office hours CHP may be fully utilized for the office electric requirement and the waste heat from the CHP engine not only provides the hot water requirement but also surplus waste heat from the CHP plant drives the absorption chillers to charge +8C(47F) PCM tanks. Nearly 2 MWH (568 RT-h) waste energy is stored free of charge and later this cooling is used as a cooling source by the theatre cooling system for the 2~3 show periods.

As most of the evenings throughout the year there is a show this stored PCM-TES energy is utilised on a daily basis and once depleted they are ready to be charged next day.

If the heat is not available to drive the absorption machine an electric chiller can be utilised to charge the PCM-TES tanks using the surplus power generated by the CHP plant to improve the seasonal efficiencies.



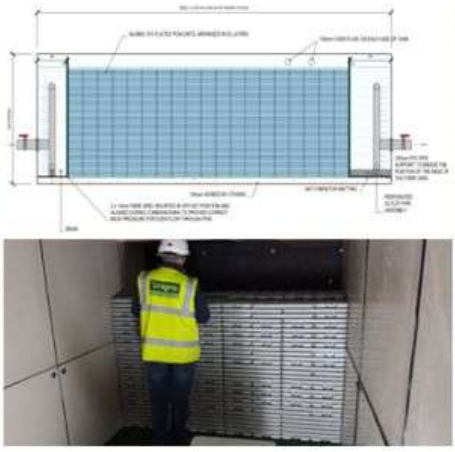
FARMILOE BUILDING, PCM-TES Retrofit, LONDON

The Farmiloe Building dates back to Victorian periods with typical architectural characteristic completed by Browne & Robinson in 1868. The Farmiloe Building became a Grade II listed building on 1991 and used by George Farmiloe & Sons as its base until 1999. In 2014, plans were announced to transform the building to a state of then art offices as a development programme. Being right in the center of London and Grade II status did not deter project team to explore environmentally friendly technologies to reduce its impact as much as they can.

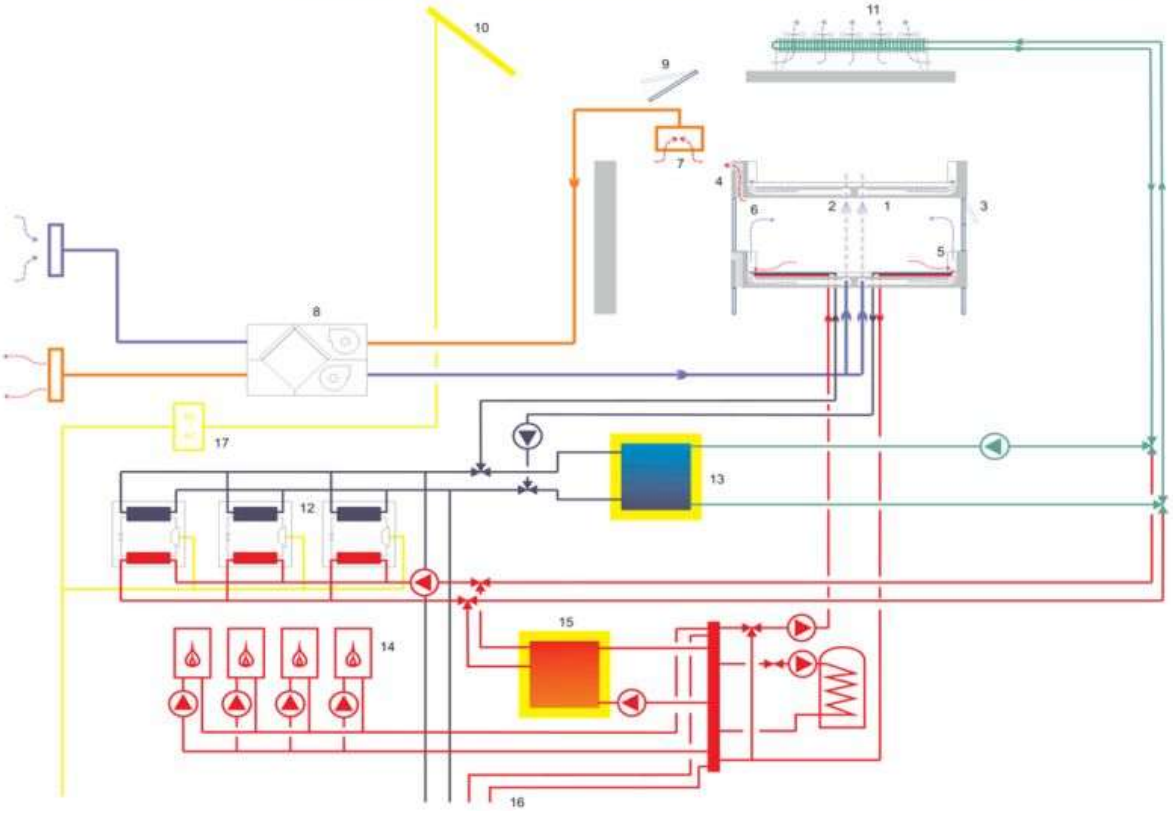
To this end, a Thermal Energy Storage (TES) is considered to be useful tool to shift the peak load and effectively reduce the machinery size and handle daily load variations. The following energy strategy is applied to achieve the minimum impact of the building;

PCM tank stores the waste energy from the heat pumps while the heat pump is utilised for the heating services. Building is provided with approx. 1,500 kWh (426 ton-h) +13C (55F) PCM thermal energy store that is cooled at night using lower cost of energy or when the ambient temperature is cooler, increasing the coefficient of performance of the heat pump. The thermal store is then used during day peak periods to drive the cooling systems instead of using the heat pump for cooling or top up the cooling loads while the heat is running. This waste heat recover / free cooling concept drastically reduced the amount of energy used by the HVAC system.



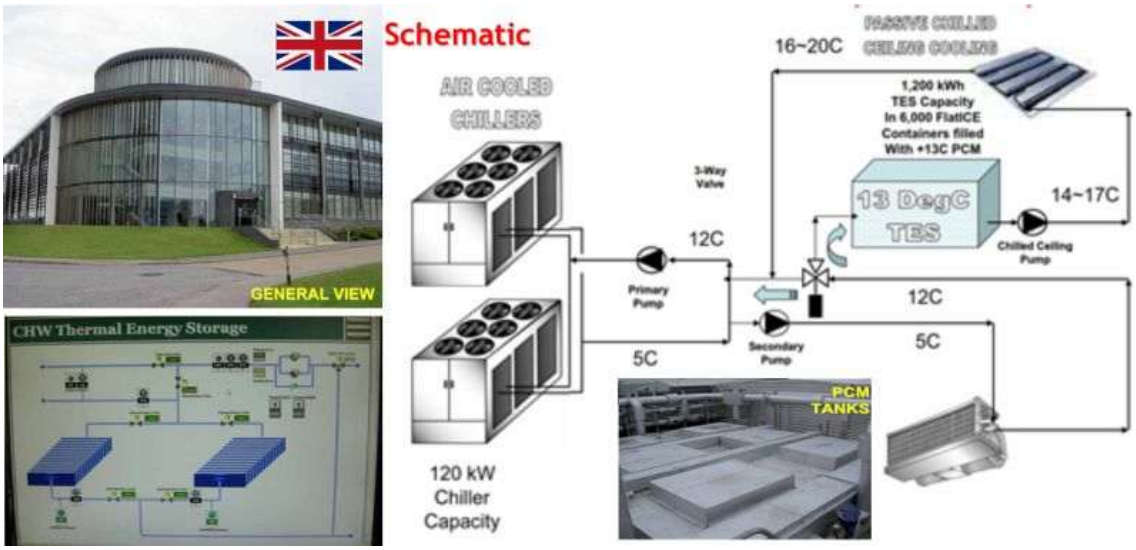






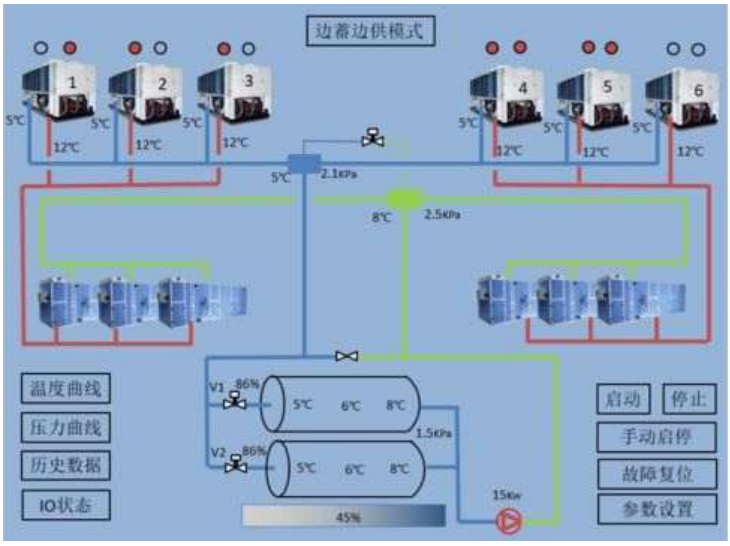
China Shipping Building, Felixstowe, UK

The difference between the day and night ambient conditions in the UK could be as much as 10~15C (20~30F) coupled with big incentives for the electricity rates which is almost 1/3 of day peaks this load shifting capability offers a way to save considerable annual running cost for any air conditioning office installation.
As the building operates during standard office hours and therefore air conditioning loads are significantly lower during out of office hours and weekends.
TES is based on placing 6,000 FlatICE containers filled with +13C (55F) PCM solution providing 1,200 kWh (341 RT-h) TES capacity.



Guangdong Singwear Garments Co., Ltd (廣東欣薇尔服裝有限公司) - PCM-TES Retrofit Application, Donguang, CHINA

By simply utilising the excess capacity over-night from the installed chillers existing system charges the PCM tanks using conventional 5C (47F) water and later this stored energy utilised during day time to reduce the peak power demand. Electricity supply rates differs significantly during the day and any load shifting helps to reduce the overall operational costs.
Existing chilled water based A/C system peak loads are shifted by simply adding 5.3 MWh (1,500 ton-h) +8C (47F) PCM thermal energy storage (TES) tanks with minimal modifications for the chilled water circuit.
Compared to the original system, incorporation of PCM System, it is recorded that
the daily electricity consumption is reduced by 882.98 kWhe (6150.2 - 5267.2) which correspondences to an energy reduction rate of approximately 14.36%.





Somacis Graphics – PCM-TES - Dongguan-China

Existing chilled water-based A/C system provides cooling for production areas which is essential to keep the production going 24/7.

By simply running the existing chillers over-night utilising spare capacity to build 4.25 MWh (1,200 ton-h) +8C (47F) PCM thermal energy storage day-time one can shut down the chillers for a few hours in order to avoid these punitive electricity rates. TES tank is a site built concrete tank next to the existing plantroom.









BANK SOUTH PASIFIC, DATA CENTRE, PCM-TES, PAPUE NEW GUINE

By simply operating the installed cooling infrastructure over-night, one can build as much as 50% daily cooling loads by spreading the cooling load over 24 hours.

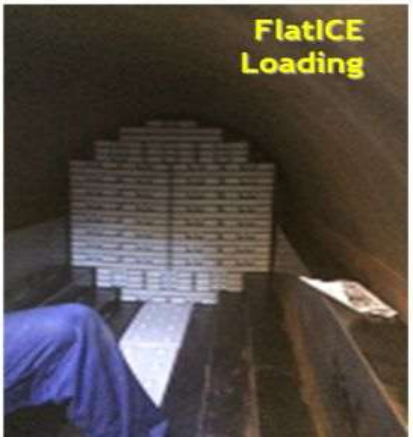
To this end for this bank cooling a new 10 m3 (2,641 USG) tank installed as part of the existing chilled water circuit and the tanks filled with +8C / (47F) rectangular HDPE PCM containers providing 420 kWh (120 RT-h) addition for the system by simply utilising the existing installed system.

As PCM-TES tank has no moving parts and it is a sealed pressurized tank it has no maintenance requirements and therefore offers a very cost effective back-up / stand-by capability for any IT applications whether as a retrofit or green field sites around the World.









AU Optronics (友達光電)- PCM based TES Taiwan

Existing chilled water-based A/C system peak loads are shifted by simply adding 7.4 MWh (2,100 ton-h) TES using +8C (47F) PCM solution in rectangular HDPE containers placed in rectangular tanks with minimal modifications for the chilled water circuit as a retrofit application.

By simply shifting the day peak loads to off-peak night period it is estimated not only a reduction of approximately 15~20% actual power consumption but most importantly avoiding day time punitive electricity rates overall annual running cost could be reduced dramatically. These savings are so impressive as it is estimated a payback less than 2 years for the overall retrofit PCM-TES installation in their factory in Taiwan. Installation is carried by an investment company who has already installed a few similar PCM-TES system as an Energy Management.





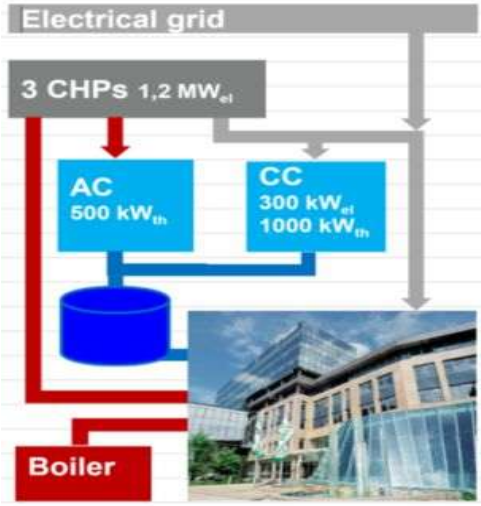




Dekra HQ, Stuttgart- PCM based TES application, GERMANY

Office building with 62,000 m2 floor area and high cooling demand TES application in Stuttgart / Germany is designed by Fraunhofer Institute for Solar Energy Systems ISE. Design is based on self-supply of electricity via combined heat and power (CHP), increase of renewables energies in the electrical grid and manage supply peaks and gaps with variation during the day by means of load peaks on the demand side.

In order to help the load shifting it is decided to have a small 10 m3 (2,641 USG) PCM-TES tank filled with +15C (59F) PCM solution providing 440 kWh (125 RT-h) TES capacity. As the cooling is provided by an absorption chiller which cannot produce water temperatures lower than 5C (41F) and therefore conventional water ICE-TES was not an option.













PREMERA Data Center– ORCAS PHASE II, PCM based TES system, Seattle, USA

As part of the data centre extension for Premera – Blue Cross healthcare facility near Seattle PCM based TES is incorporated enabling storing thermal energy from the water-cooled chillers and therefore improve the overall system efficiency.

Data centre cooling / heating & humidity control is provided via AHU's and DOAS units served from a central plant and multi-temperature pipework system as indicated in the below schematic layout.
During normal operation mode CHW circuit operates +6.6C (44F) flow and +14.4C (58F) return while the condensing circuit of water-cooled chiller operating at +18~30C (65~85F) levels. PCM based TES tank is designed to stay mid-level of the heat rejection circuit and filled with +21C(70F) PCM encapsulated in 5,535 HDPE rectangular containers.

A custom-made 30m3 (7,925USG) TES tank provides a thermal energy storage capacity of 1,400 kWh (397 RT-h) which is enough time to provide a stabilisation buffer function for the water-cooled chillers operating efficiently as well as utilising waste heat from the chiller by bridging the gap between energy availability and energy use and therefore save considerable energy for the overall operation.







Lusail Towers District Cooling PCM-TES Back up TES, Qatar

Although existing DSC provides chilled water for the full loads for all four buildings all year round but it is essential to provide a back-up system for the critical services such as IT rooms in case of any issues with the DSC system. During normal operation mode +40C (39F) cold water provided by the DSC charging total 11 no's 18m3 (4,755 USG) tanks filled with +6.5C (43.70F) PCM which encapsulated in 50mm (2") x 1m (3ft) long HDPE TubeICE containers.

Total 198m3 (52,306 USG) TES tanks provide a stand-by cooling capacity of 7,920 kWh (2,250 RT-h) which is enough time to give the back-up chillers to start and reach their full load operations without adding any pull-down loads of the main circuit so the supply temperature for the cooling system is not affected.

Under emergency it may take 15~30 minutes for the chillers to load and provide the full cooling capacity it is vital to eliminate any additional thermal inertia pull down loads from the chilled water pipework during the initial 15~30 minutes. PCM based TES by absorbing that short period cooling loads and effectively enabling the chillers to catch up and provide vital emergency loads without any impact on the chilled water supply temperatures.



FEDERAL CENTER SOUTH Office Building PCM-TES , SEATTLE, WASHINGTON, USA

Cooling load shifting is becoming vital part of any facility management and in order to achieve this Seattle building is provided with a tank filled with 4,500 Rectangular HDPE PCM containers filled with +13ºC (47ºF) PCM solution providing 1,050 kW (300 Ton-hr) PCM Energy Storage for the building.







CleanTech-2 Building PCM-TES , SINGAPORE

By simply operating the installed cooling infrastructure over-night, one can either build as much as 50% daily cooling loads or alternatively reduce the number of chillers as much as by half by spreading the cooling load over 24 hours.

Of course considering a slightly lower night ambient conditions which offers slightly higher chiller efficiency in comparison with day. However, the overall annual running cost are significantly reduced due to electricity rate incentives. As this load shifting and reduced number of chillers also offer significant environmental benefits in comparison with conventional design. 28,800 PCM containers filled with +11.5C (52.7F) PCM solution is placed in multiple tanks providing 7,200 kWh (2,000 RT-h) TES capacity





HARAMAIN TRAIN STATIONS PCM based TES application, KSA

The Haramain High-speed Railway is network is designed to link between the cities of Makkah, Madinah, Jeddah and the developing King Abdullah Economic City (KAEC). Potentially it would be handling 60 million passengers and gradually increase to 135 million passengers by 2042.

Considering 55C (130F) peak day time ambient temperature vs. 28C (82F) night time ambient condition if one can operate the chillers during cooler night-time one could save as much as 30~40% power consumption and PCM based TES enables to store as much as ½ of the day peak loads over-night and top up cooling during day peak periods.

As the PCM-TES shift almost ½ of the peak loads from day to night condition but also by adding adiabatic cooling option which consumes 80~90% water than a comparable cooling tower for the air-cooled chiller also day 55C (130F) air on conditions dropped as low as 28C (82F) levels further 20~30% of day peak power consumption is reduced for the air condition operation.

The combination of the PCM-TES and Adiabatic Cooling system consumes almost half of the energy in comparison with a conventional and common practice applications in the Kingdom.
By simple installing various size of tanks between 73~227 m3 (19,213~60,039 USG) as part of chilled water circuit for all four main stations filled with rectangular HDPE PCM containers using +10C (50F) PCM solution providing 3.2~10 MWh (909~2,841 RT-h) TES system daily capacity load shifting throughout the high speed rail network.



Station	TES Tank Size		TES Capacity	
	m3	USG	kWh	RT-h
Makkah	227	60,039	10,000	2,841
Madhina	73	19,213	3,200	909
Jeddah	73	19,213	3,200	909
KAEC	73	19,213	3,200	909















City of Gosnells Civic Centre Cooling Expansion using PCM based TES, AUSTRALIA

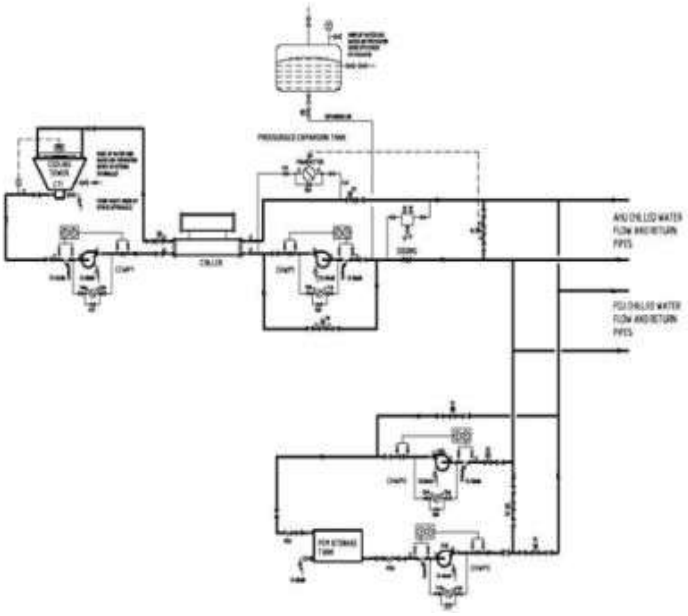
During major extension of the Gosnell's Civic Center designers instead of adding more cooling machinery they utilised the unused capacity of the existing infrastructure by simply adding a PCM-TES which is charged during out of office hours.

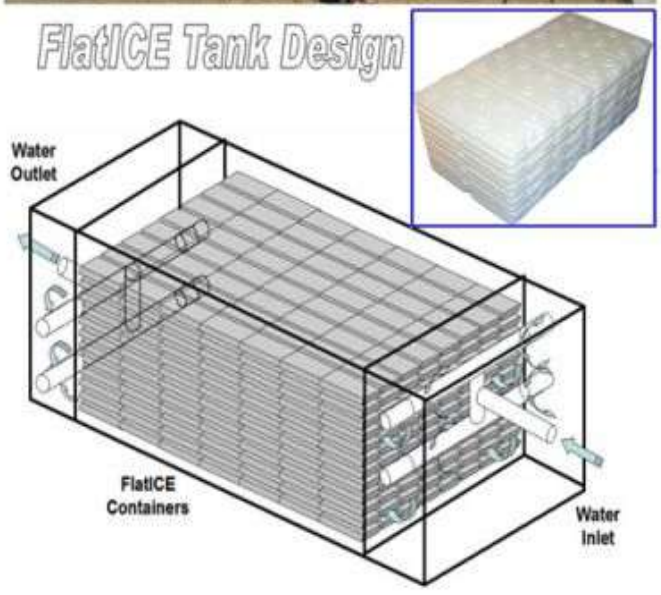
By simple installing a site built concrete 65m3 (17,171 USG) tank filled with 12,500 rectangular HDPE PCM containers filled with +10C (50F) PCM solution providing 3MWh (852 RT-h) TES system daily cooling capacity is almost doubled over-night without adding any mechanical cooling. As the building is a low profile building a simple atmospheric PCM-TES tank is constructed within the landscape area closer to the existing plantroom.

As the PCM-TES tank installation cost was far less than the whole new mechanical cooling infrastructure cost this additional cooling facility is installed without any additional cost penalties. Avoiding new mechanical cooling addition this TES concept offered an environmentally friendly solution by not having any refrigerant gases and also getting additional cooling over-night using lower ambient with higher chiller efficiency result in using less power for the same duty not to mention utilizing the lower electricity rates.









Norwegian University of Life Sciences, Campus Ås SLP, K302

Like any other educational facility bulk of the peak load occurs once the buildings are occupied but after office hours this large peak load subsides significantly. This campus PCM energy storage can be considered as a useful tool to spread the loads over 24 hours periods and thereby not only reduced the initial investment cost but also it offers reduced operational cost.
200 m3 (52,834 USG) in multiple tanks 40,000 rectangular HDPE containers filled with +10C (50F) PCM providing 9.0 MWh (2,560 RT-h) TES Capacity



GKG Precision Machine Co. Ltd., Dongguan, CHINA

Existing chilled water-based A/C system provides cooling for production areas which is essential to keep the production going 24/7.
By simply running the existing chillers over-night utilising spare capacity to build 4.25 MWh (1,200 ton-h) +8C (47F) PCM thermal energy storage day-time one can shut down the chillers for a few hours in order to avoid these punitive electricity rates. TES tank is a site built concrete tank next to the existing plantroom.



Bergen Airport PCM-TES System, T3 Energy Centre, Norway

As most of the airports around the World stop flight over-night due to noise restriction and therefore the air conditioning loads are dramatically reduced.

By simply operating the installed cooling infrastructure over-night, one can build as much as 30~40% daily cooling loads. Hence, number of chillers can be reduced as much as by half by spreading the cooling load over 24 hours.

TES is achieved by using hydrated salt based PCM in HDPE containers placed in 4x60m3 (4x16,000 USG) tanks filled with +13C / (55F) PCM containers providing 10,000 kWh / (2,840 RT-h).

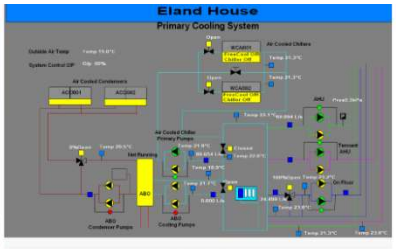


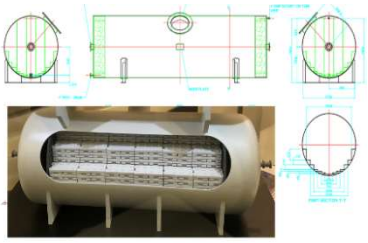
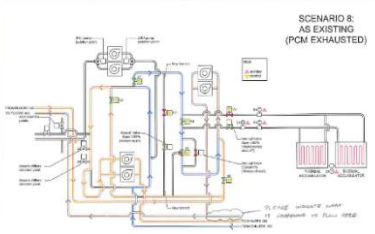


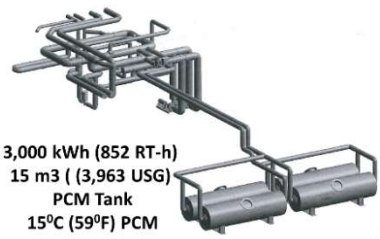



Thermal Accumulator Project Review for Eland House. London,

Thermal Accumulators as part of Energy Efficient Whitehall project funded by Technology Strategy Board. Total energy storage is calculated at approximately 3,000 kWh (852 RT-h) with storage temperature being 15^0C..



Australian Parliament Building, IT Cooling Back-up PCM_TES application, Canberra, AUSTRALIA

Although the computer / IT systems having a UPS capable of running during any power cut but lack of any back-up for the air conditioning rendered it useless unless the chamber temperatures under controlled during voting as once started cannot be stopped.

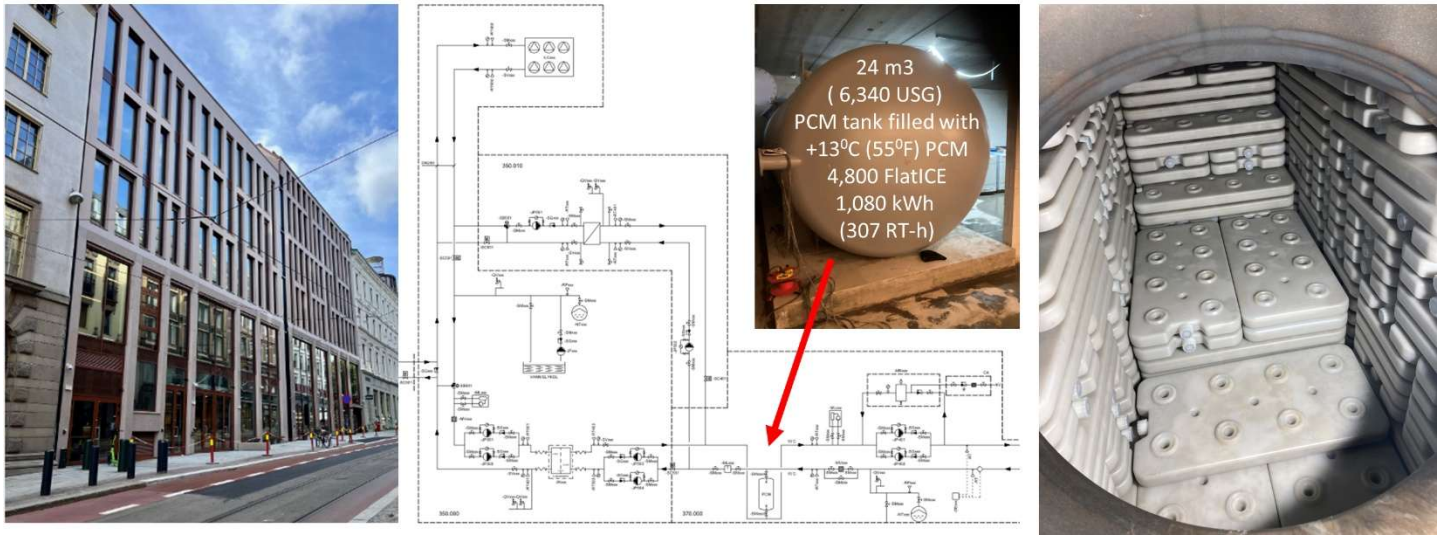
By simply placing the retrofit tanks on the supply line of the chilled water circuit using multiple 6 m3 (1,585 USG) tanks filled with HDPE rectangular self-stacking containers filled with +8C (47^0F) PCM providing 270 kWh (77 RT-h) TES capacity this retrofit TES system provides just about 2 hours cooling when there is a power failure and thereby enabling the MP's voting to be completed.

As the PCM based TES is considered maintenance free and far more reliable than generators which is far most costly and require regular and costly maintenance at least once a month to test run.



OFFICE CHILLED WATER TES, Kirkegata 23, 0153 Oslo, NORWAY,

As load shifting is a critical energy management strategy of any air conditioning application a 24 m3 (6,340 USG) TES tank complete with +13^0C(55^0F) PCM containers provided for the office building in Oslo. Installed TES tank provides 1,080 kWh (307 RT-h) chilled water-cooling loads to be shifted from peak to off-peak periods.



Prosjekt Livsvitenskap, Gaustadallen 30, Oslo, NORWAY,

Educational buildings cooling loads vary significantly and in order to avoid excessive cooling machine installation which requires upfront cost as well as on-going maintenance costs a TES is an ideal solution to spread these peak cooling loads over longer periods and shift the peak loads by means of TES facility.
To this end, new Life Science building is provided with 134m3 (35,400 USG) TES tank housing New Life Science building in University of Oslo campus enabling to shift 6,048 kWh (1,718 RT-h) cooling load and spread the overall cooling loads over longer time span. Tank is filled with 26,880 / +13^{0}C (55^{0}F) stackable HDPE containers and it is positioned on the return leg acting as a lead cooling stage and chillers provides the lag capability if and when required to top up.



Prosjekt Livsvitenskap, Gaustadallen 30, Oslo, NORWAY
26,880 FlatICE – 13^{0}C (55^{0}C)
134 m3 (35,400USG)
6,048 kWh (1,718 RT-h)



EDIOS Heat Pump heat / Cold Storage, Turin, ITALY

Thermal Energy Storage (TES) storage tanks are based on +46°C during winter and +13°C during summer TES capability, to store the energy equivalent to three days usage at average load. The main benefits of utilising the PCM thermal energy storage concept are clear and tangible. Normal working hours for the building are between 8am and 6pm and therefore the target environmental comfort conditions were aimed only at this period. During the rest of the time very little energy was needed to achieve accurate temperature control. PCM energy storage enabled the contractor to reduce by half the number of bore holes normally required by the geothermal heat pumps, in order to reject heat from the heat pumps, especially by running them during night periods.

During day-time at low/medium heating and cooling load conditions, the stored energy within these TES tanks for both heating and cooling is utilized to satisfy the building loads, lasting as much as three days without the need for the heap pumps to operate.

During high demand periods namely winter heating loads during December/January and summer cooling loads during July/August, the stored energy within the TES tanks for high temperature +46°C and low temperature +13°C storage tanks respectively are utilized to top up the peak load conditions. TES tanks level the loads by simply using the surplus capacity of the heat pump overnight and by using this stored energy to reduce the heat pump capacity requirement by simply releasing the stored energy back to system.

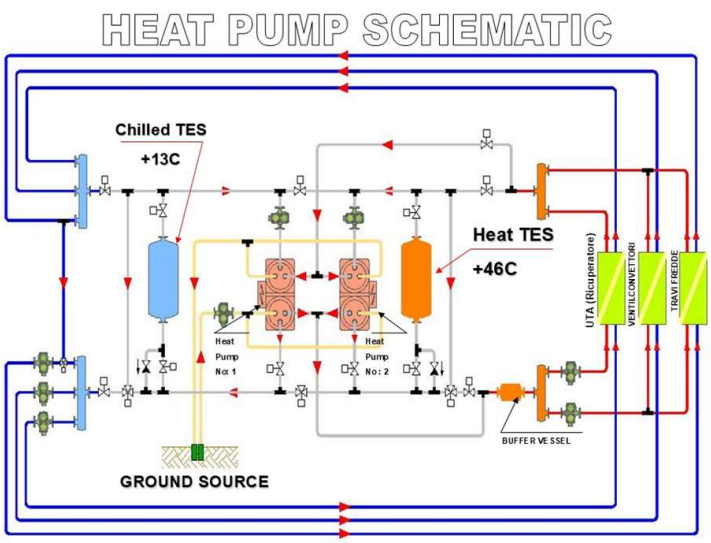
Without the use of TES storage devices, the geothermal field and heat pumps would have been doubled in size, which most of the time would only have produced unnecessary surplus energy. By halving the system size, the design managed to achieve other benefits;

- Halving the infrastructure cost
- Reduced physical sizes
- Main energy consumption is at low, night-time rates
- Electrical energy not used for heating and cooling can be used for other purposes.
-

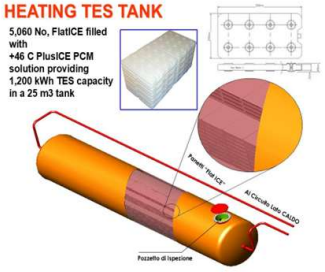


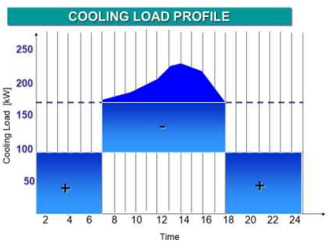


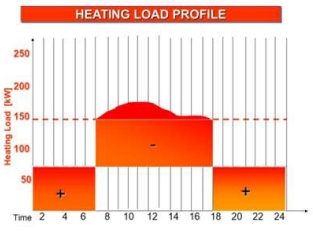












Burnley College Heat Pump application, Burnley, LANCS., UK

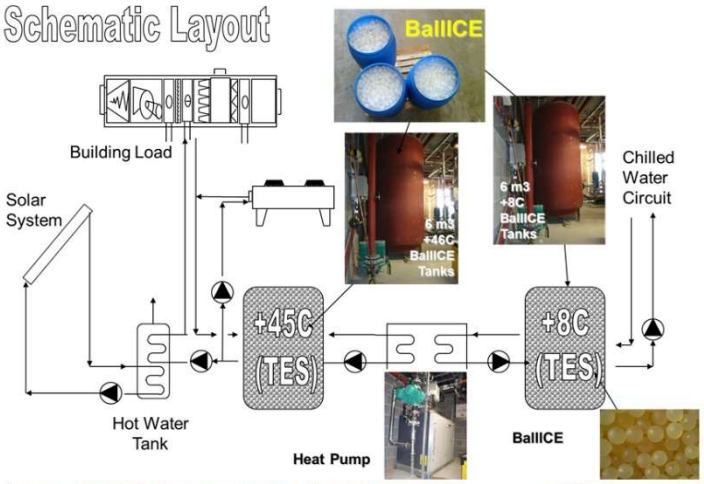
A heat pump removes energy from one side of the refrigeration circuit either using air/water or ground sources and transfers that energy into the other side of the refrigeration cycle. If the removed energy is later required it can be considered as a waste.

UK schools mainly need heating as during summer they are closed but nevertheless these schools having IT room which requires cooling even in winter periods. By simple operating ½ the size of heat pumps over 24 hours a store both hot and cold side of the heat pump enables handling day IT room cooling free via waste heat extracted from the cold TES tank. This way the combination of 4~5 heating COP plus 3~4 COP of cooling machinery provides the overall COP levels of 7~9 without any defrost as in the case of air source heat pump. In other words, putting 1 kWhe one could get combines 9 kWh thermal energy.

Sir John Thursby school had already existing both hot and cold-water tanks providing ~ 120 kWh TES capacities for both sides. A custom-made organic PCM balls (32mm / 1 ¼") manufactured so balls can be feed into the existing tanks via vent connections. New design is based utilising these existing 6m3 TES tank for both hot and cold side of the heat pumps having 45^{0}C (113^{0}F) and +8^{0}C (47^{0}F) PCM balls providing 300 kWh (43 RT-h) TES capacities respectively.

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. The combination of these two benefits can reduce the overall running cost of the system significantly.











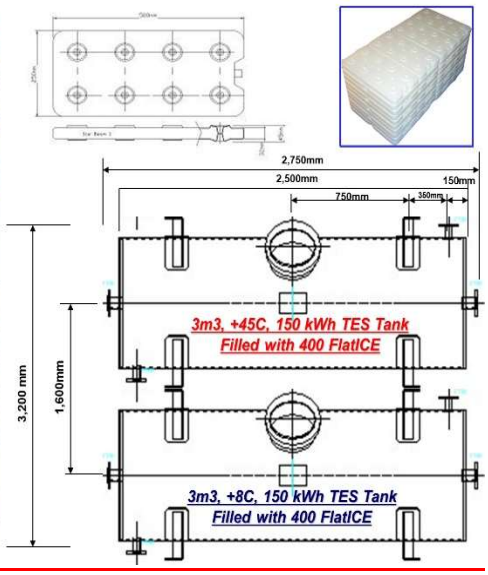




Sir John Thursby Community College Heat Pump application, LANCS., UK

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. If the removed energy is later required it can be considered as a waste.
Sir John Thursby school design is based having 3m3 TES tank for both hot and cold side of the heat pumps having 45^{0}C (113^{0}F) and +8^{0}C (47^{0}F) providing 150 kWh (43 RT-h) TES capacities respectively.

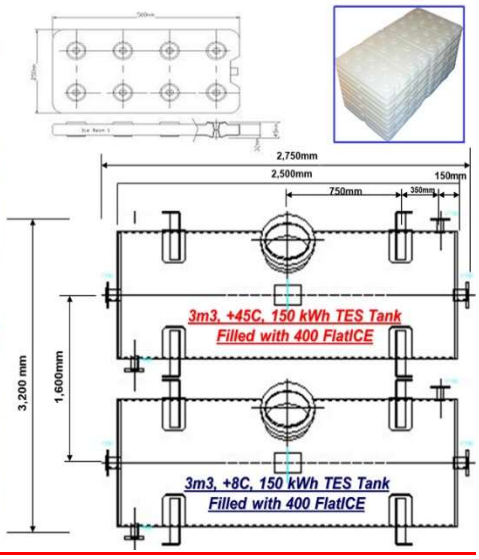


Pendle Vale College Heat Pump application, LANCS., UK

By simply storing this waste energy in the form of +10ºC (500F) for cold or +46ºC (1150F) 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%.
Pendle Vale school design is based having 3m3 TES tank for both hot and cold side of the heat pumps having 45^{0}C (113^{0}F) and +8^{0}C (47^{0}F) providing 150 kWh (43 RT-h) TES capacities respectively.

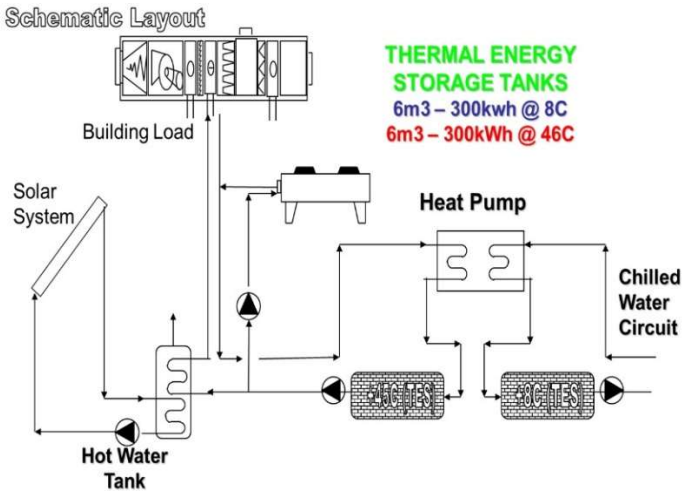


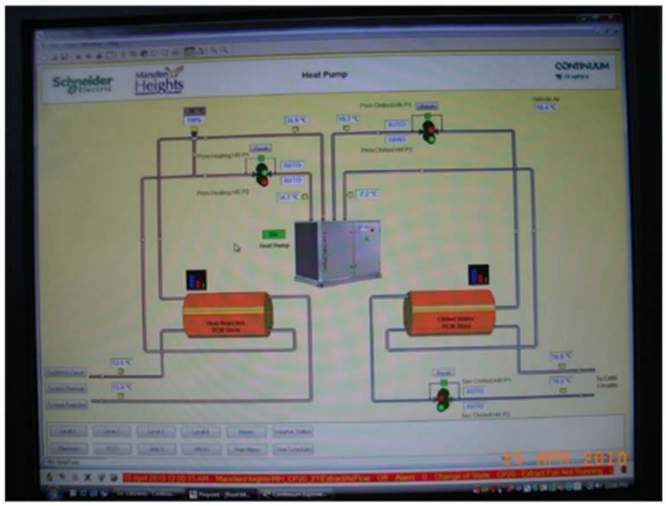



Marsden Heights Heat Pump application, LANCS., UK

By simply storing this waste energy in the form of +10ºC (500F) for cold or +46ºC (1150F) 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%.
Pendle Vale school design is based having 6m3 TES tank for both hot and cold side of the heat pumps having 300 kWh (43 RT-h) TES capacities on both side of then heat pump.









PASSIVE COOLING

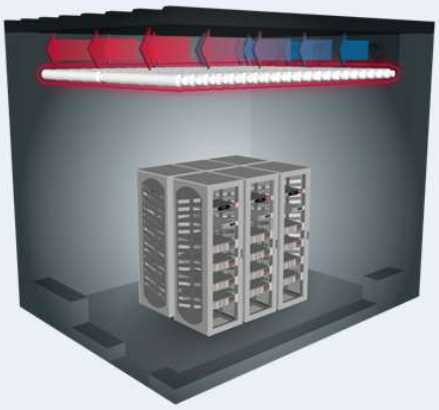


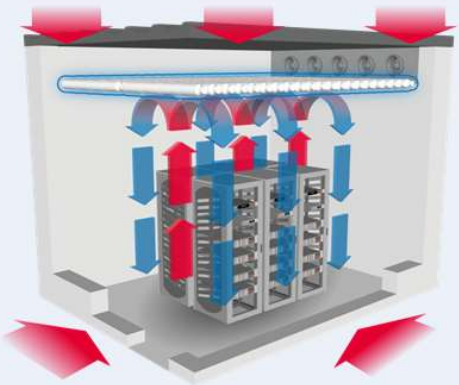












PCM

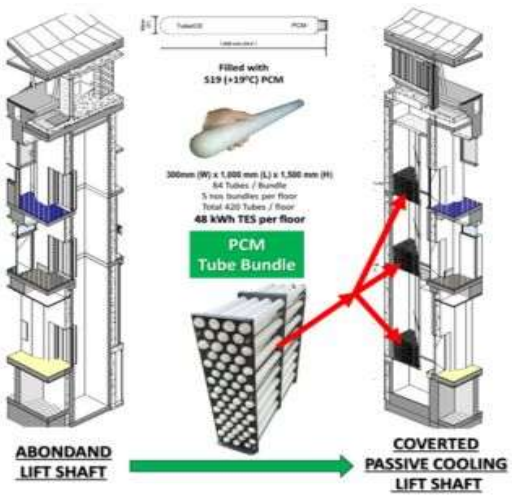
FREE COOLING APPLICATION UN AFRICA

UN ECONOMIC COMMISSION FOR AFRICA, Addis Ababa, ETHIOPIA

As part of the renovation programme an internal old lift shaft was no longer required and considering almost all year cooling demand it is decided that repurposed abundant lift shaft might be possible to convert for a free cooling using cooler air at night to freeze PCM (Phase Change Material) modules, which then provide cooling during the day to reduce the air conditioning load.

Passive cooling is provided by +19C (67F) hydrated salt based PCM material placed inside 50mm (2") x 1m (3ft) HDPE tube containers. 84 of these PCM tubes are placed within a staggered frames in order to form heat exchanger shape whereby the air can efficiently pass through the bundle.

Existing lift shaft acting like a ductwork forcing the air across these tube bundles and providing 48 kWh (14 RTh) TES capacity on each floor level. Total three floor installation providing 144 kWh(42RTh) passive cooling for the building simply storing the cooler night energy and bridge the gap between night and day time.





UNIVERSITY OF WESTMISTER, Cavendish Street Building, Passive Cooling, London, UK

As part of the drive to demonstrate passive cooling application University of Westminster in London incorporated PCM passive cooling modules within the top floor offices. Utilising the cooler night ambient by simply storing the cool energy within the PCM modules day cooling loads within the office area is absorbed by PCM modules without using any mechanical cooling machinery

During normal operation mode additional cooling as well as any latent loads i.e. humidity control loads are handled using a conventional VRV system if and when required. Same goes for the heating loads which is provided the same VRV heat pump units.

PCM based TES modules filled with +270C (800F) PCM encapsulated in 50mm (2") diameter x 1,000mm (40") HDPE TubeICE containers. Tubes are fixed at ceiling level using standard 50mm (2") pipe bracket system.



Oman Across Ages Museum Free PCM Cooling, Muscat, Oman

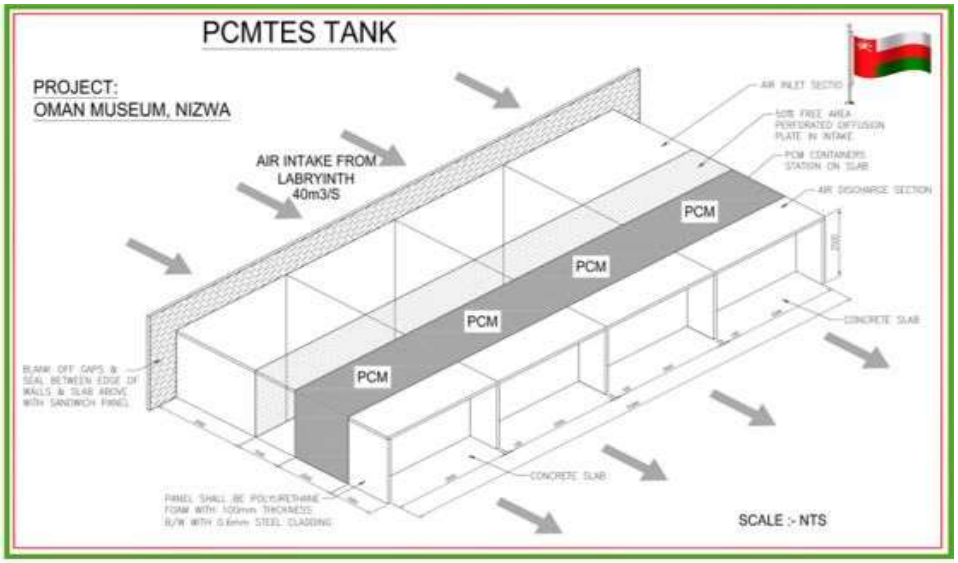
Yes even in the Middle East one can utilise free cooling by simply storing the cool night energy and utilising this FREE stored energy during day peak period in order to reduce the outside air-cooling demand during peak ambient conditions

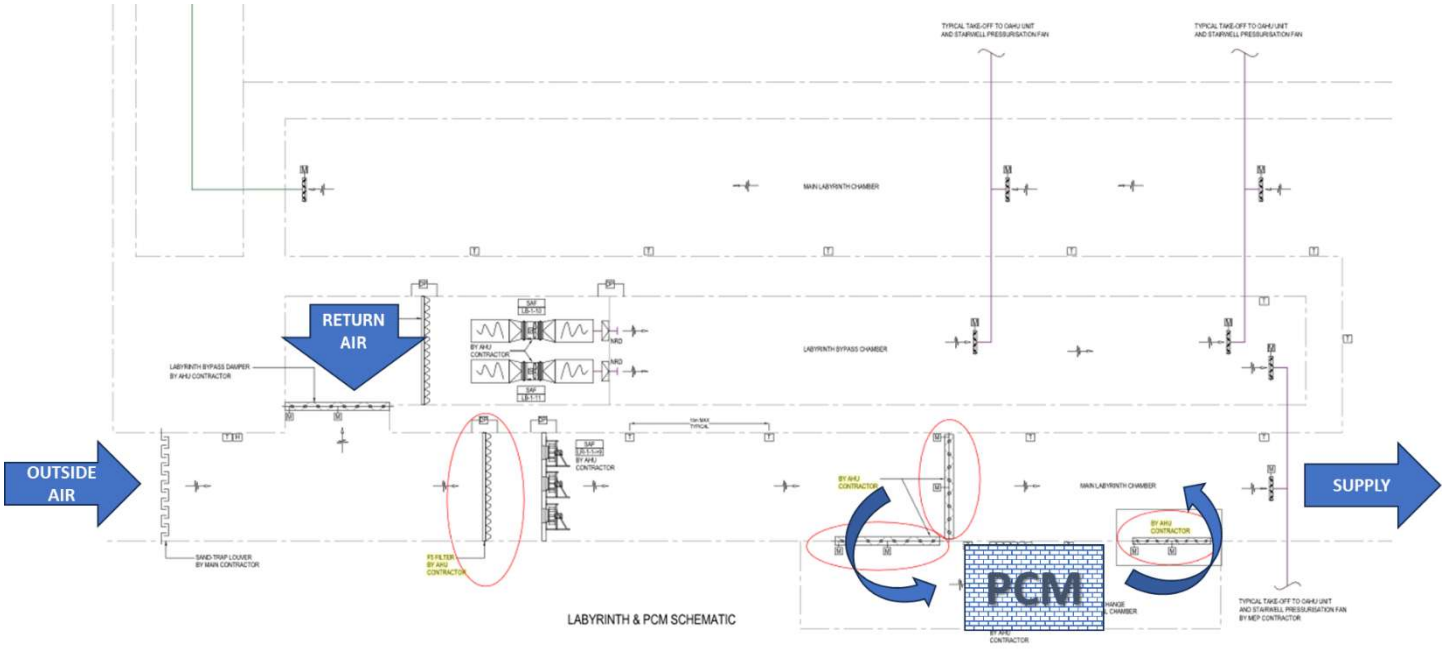
For this purpose, Oman Museum installation, a special tunnel built to accommodate the PCM containers whereby when the ambient air temperature is less than the PCM solution generally during night time, these containers freeze naturally by the surrounding cooler night ambient and later this stored energy in the form of latent heat can be released back to the air supply system during daytime to cool the incoming air for the outside air supply requirement for the museum. Almost the total daily sensible heat gains due to outside air supply can be absorbed by the passive cooling tunnel.

Design is based on having four identical chambers 2.5m(8') (W) x 2.0m (61/2') (L) x 2.5m (8') (H) filled with 10 wide x 58 high self-stacking HDPE PCM containers filled with 32C (90F) PCM solution.

Total 4 chambers accommodate 9,280 FlatICE filled with S32 (+32C/ F) PCM solution providing 2.0 MWh (595 RT-h) TES capacity.







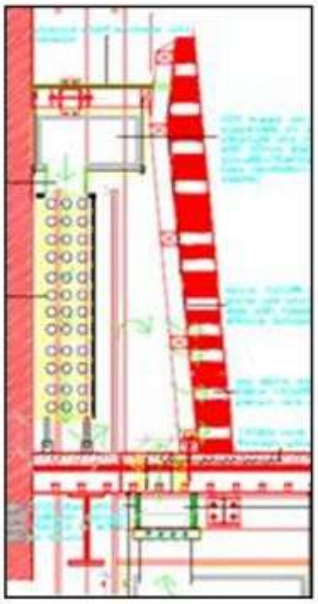
MULBERRY SHOP, BOND STREET, LONDON, UK

The building housing the Mulberry shop in central London Bond Street is a listed building with significant restrictions on any alterations and therefore it offered very little space for the external air conditioning machinery

Bulk of the cooling load is based on lights and people inside the shop and therefore 60~70% of the base load is fixed all year round irrespective of seasons.

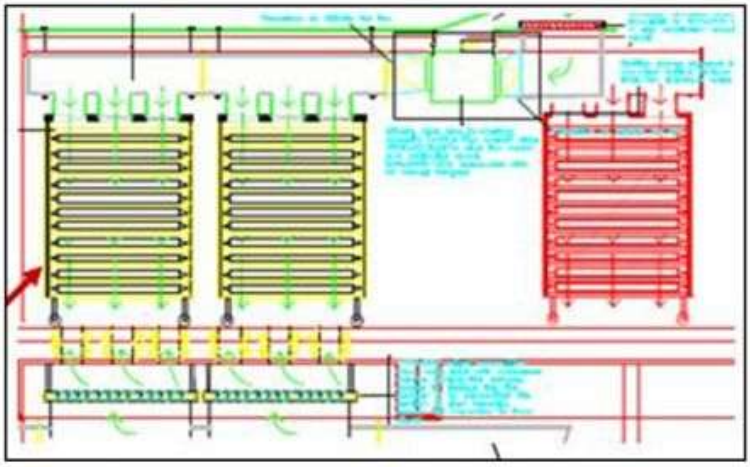
As this is a listed building with very high restriction and limited outdoor walls to install condensing units, contractors could only able to install just about 50% of the outdoor units required for the full air conditioning units. A/C system is based on split direct expansion systems and therefore only option looked like utilising the maximum amount of A/C split kits and run them runover-night or alternatively using free cooling if ambient permits (almost 6~8 months of the year) to charge the 22C (72F) PCM tube bundles and in return this stored energy can be used to top up the required missing cooling loads during day.















Linton College Passive Cooling, UK

Although schools in the UK may require cooling for only a few days of the year but the current regulations dictate to keep the upper limit below an acceptable limit. This over-heating may occur south facing classrooms.
Conventional mechanical cooling might solve this issue but cost associated with not only installation but also ongoing maintenance services cannot be accommodated with the school budgets.
The cooler night ambient is used to store cool energy within the PCM passive cooling modules placed within the false ceiling area and this stored energy enables the day cooling loads / solar gains within the classroom is absorbed by PCM modules without using any mechanical cooling machinery.
+250C (770F) PCM encapsulated in 50mm (2") diameter x 1,000mm (40") HDPE Tube containers. Tubes are fixed at ceiling level using standard 50mm (2") pipe bracket system behind the false ceiling panels. Solid ceiling panels are replaced with egg crate panels allowing air to escape to the ceiling void whereby tubes act like a heat sponge...



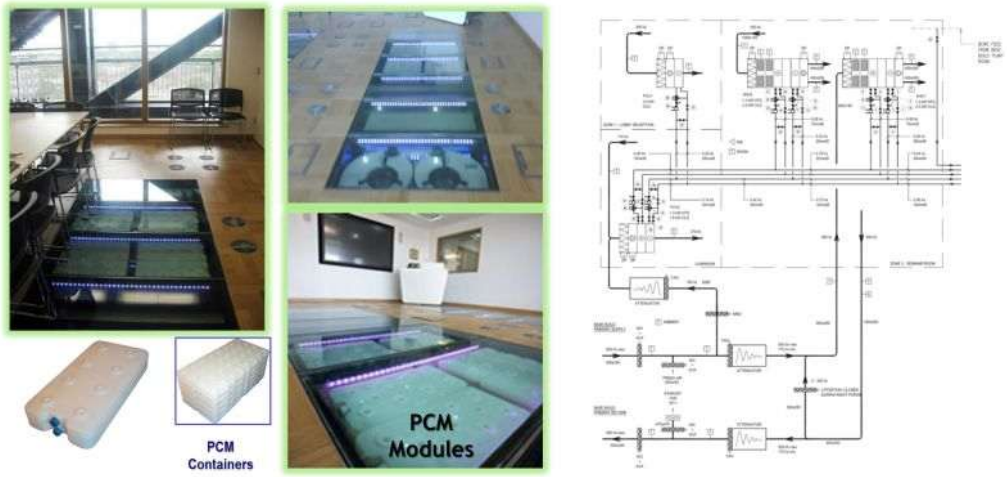
Pendle Vale College Passive Cooling, UK

Although schools in the UK may require cooling for only a few days of the year but the current regulations dictate to keep



CENTRE FOR RENEWABLE ENERGY IN BUILDINGS (CEREB) PASSIVE AHU COOLING SOUTHBANK UNIVERSITY, LONDON, UK

As part of the drive to demonstrate passive cooling application Southbank University is incorporated PCM modules within the AHU sets. By simply over-night freezing i.e. storing the cool energy in PCM modules day cooling loads within the meeting room are absorbed without using any mechanical cooling machinery. During normal operation mode additional cooling as well as any latent loads i.e. humidity control loads are handled using a conventional chilled water circuit. Same goes for the heating which is provided via AHU coils supplied from the central heating circuit.
PCM based TES modules filled with +210C (700F) PCM encapsulated in 500mm (20") x 250mm (10") x 32mm (1 ¼") rectangular HDPE FlatICE containers.



Sir John Laing Building, Free Cooling, Coventry University, UK

1,590 TubeICE filled with +27C (81F) PCM solution placed within the existing false ceiling area providing 230 kWh (65 RT-h) free cooling by simply freezing over-night and absorb the heat loads during day-time.
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. Once the TubeICE containers are filled with PCM they weigh between 2~3 kg (4.4~6.6 lbs) each depending on PCM type and by simply using standard 50mm (2") pipe brackets they can be suspended from the ceiling area to act like a heat absorbing sponge to soak up the rising heat within the enclosure.

Although it is possible to apply 12 TubeICE per m2 (~1 TubeICE / ft2) within the ceiling area but as the same area is also used for other services, the practical limit for the passive cooling modules free area could be anywhere between 40~70% of the ceiling area.
Using conventional bracket systems it is possible to hang 12 TubeICE containers per m2 ceiling area and the overall total weight could be in the region of 40kg and in return these tubes can provide anywhere between 1.7 ~2.2 kWh/m2 (0.046~0.057 TRh/ft2) energy depending on the PCM type.

Coventry University	John Laing Building, Coventry, UK		
	Pre	Post	Saving
Boilers energy (MWh)	418.8	399.3	11.35%
Total system energy (MWh)	448.8	428.9	10.58%
Total nat. gas (MWh)	418.8	399.3	11.35%
Total electricity (MWh)	30.1	30.1	0.00%
Total Carbon Emissions (Kgco2)	106,064	101,614	9.67%
Total energy (MWh)	448.8	428.9	10.58%
Total energy (MWh/m2)	0.123	0.117	10.58%
Total energy (KWh/m2)	122.6	117.2	10.58%









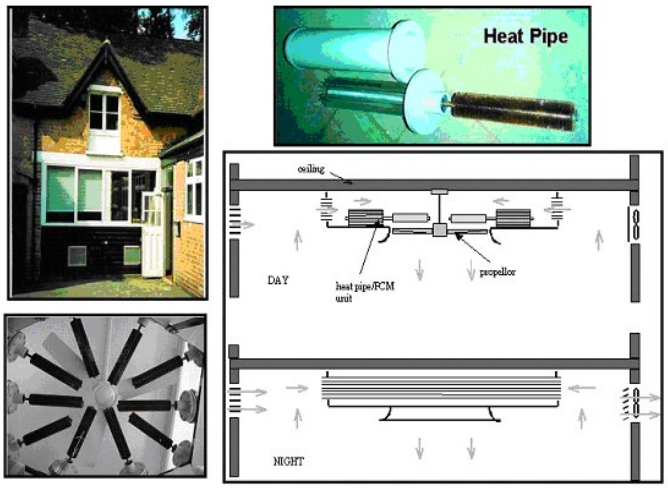


Passive Cooling Building Services Applications, Nottingham, UK

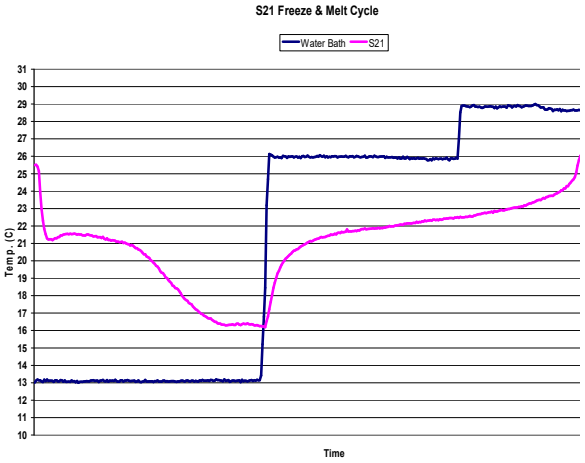
A small scale 10.8 m2 (116 ft2), 27m3 (953ft3) standard UK office complete with all the conventional internal heat gain is selected near Nottingham, UK and this office is fitted with Passive Cooling heat pipe beams as illustrated below filled with 21°C (70°F) PCM Eutectic solutions. The relevant freezing and melting curves for this specific PCM solution is also below.

This test site at Nottingham, UK operated for a whole year with full data logging and a typical peak daily operational data recorded as illustrated in Figure 4.1.3.

The recorded data proved that the system coped well with the average office internal gains throughout the year without running a single refrigeration machinery by simple utilising colder night-time air to charge these beams and release back the stored energy during peak day periods.

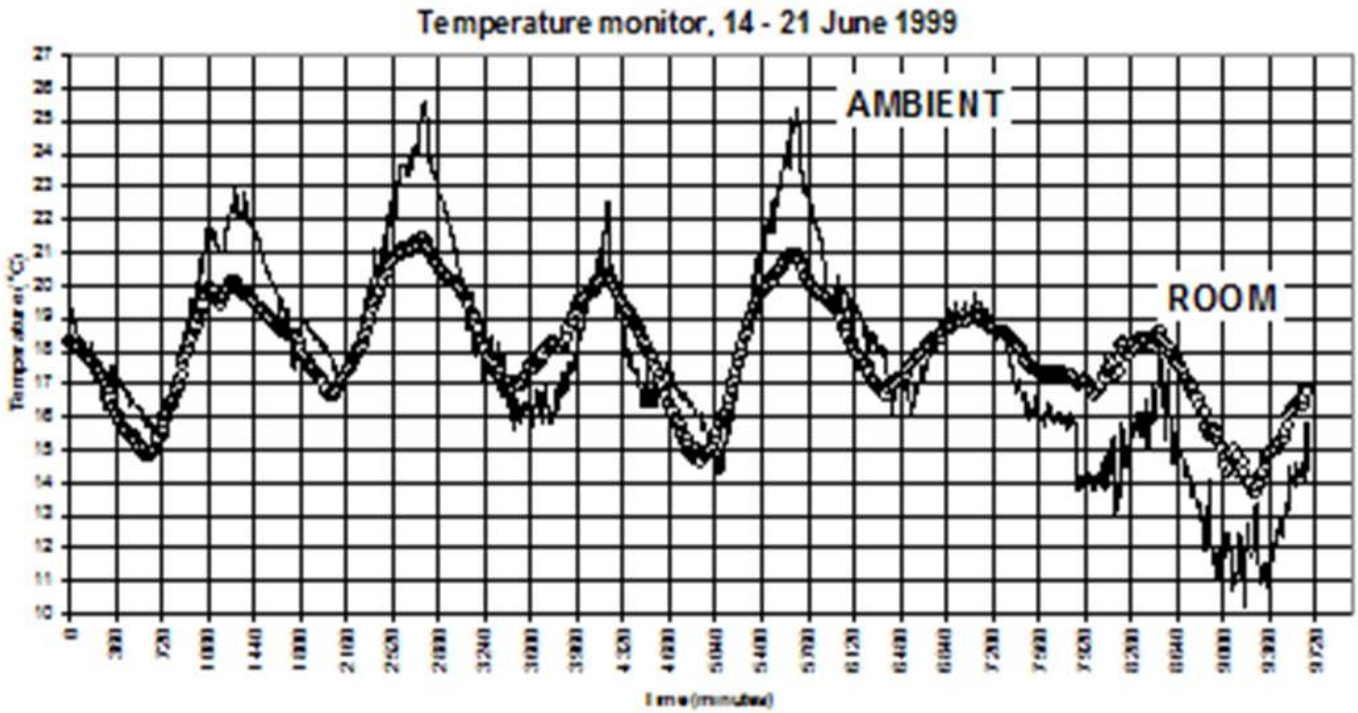


Office Passive Cooling Heat Pipe Design



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21°C (70°F) **PCM Freezing and Melting Curve**

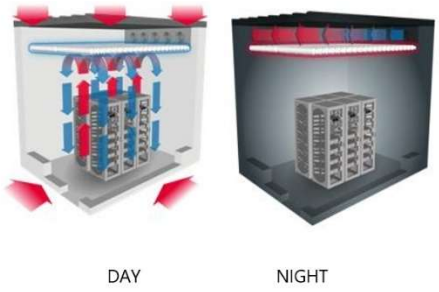


Passive Cooling Daily Operational Data

SHELTER PASSIVE COOLING APPLICATIONS;

Although, passive cooling applications are restricted in hot climate conditions for human comfort applications but PCM based passive cooling benefits can be widely applied anywhere in the World including Middle East for non-office (i.e. unoccupied) areas to cool the electronic chambers / control panels / lift shafts as they could tolerate space temperatures as high as 45 ºC (115 ºF) and as the night ambient temperatures overnight time remains less than the space temperature, it allows cool night energy to charge the PCM. This concept is widely applied for electronic chamber cooling for remote location whereby the lack of electricity eliminated the mechanical air conditioning and a typical cooling system as illustrated in Figure 4.2.1.

These systems even operate in hot countries and desert environments like the Middle East due to higher space temperature requirements in comparison with Office Cooling. A PCM solution of 32ºC (90 ºF) is sufficient to maintain the room temperature below 45ºC (115ºF) by simply using the temperature swing between day and night time as illustrated in Figure 4.2.2 for shelter passive cooling applications.



Shelter Passive Cooling Concept



Shelter passive cooling applications.



CONTROL BOX PASSIVE COOLING APPLICATIONS;

Many of the control boxes tend to have lots of electronics which generates fair bit if heat and in a sealed control, boxes this heat generated by the electronics as well as possible ambient / solar gains accumulates and the indoor temperature of these control panels may well exceed the maximum allowable temperatures of electronic components.
If one place 27~34 ^{0}C (81~93^{0}F) PCM modules inside the control boxes they would freeze over-night due to lower ambient conditions and during day-time they act like a heat sponge soaking up both internal / external heat gains and therefore keep the internal temperatures below the upper limits.
As the PCM modules require no power supply and no moving parts they are considered as a maintenance free system and in particular explosion proof locations like oil rigs / Petrochem installation PCM based passive cooling concept offers an ideal solution.
PCM passive cooling modules can be manufactured in any size / shape to fit any existing retrofit or new control panel designs.





IT ROOMS BACK-UP COOLING

As majority of the large office-based companies tend to have a central IT room and requires constant cooling even during weekends. This requirement is becoming a problematic for high rise buildings whereby any small dedicated units like mini-splits / cassette type air conditioning units are near impossible to install and therefore the owners end up running the whole air conditioning for a few tenants / owners occupying a few floors. This operating cost a significant operational cost for each client using this service over weekend.
A small PCM based TES modules like the shown below having PCM modules filled with 22~25^{0}C (70~77^{0}F) PCM solution can be charged during normal operation and the stored energy can be utilised a passive cooling for the IT rooms over the weekends 48 hours by simple operating a small fan to circulate the air over the PCM modules. Apart from weekend cooling this system can also be used an emergency cooling in case of any power failure utilising a simple DC fan with battery back.



GREEN HOUSE PASSIVE COOLING APPLICATIONS;

As the name "Green House" gives a clear idea for the over-heating issues during day-time for any greenhouse installation. Solar gains gradually build up heat within the space and over-heating occurs during day-time but equally over-night cold ambient drags the space well below the lower limits of the plants.
By simply adding thermal mass in the form of PCM modules having 23~27^{0}C (F) energy absorbing capability for the day-time excess heat energy and once charged i.e. PCM melted by this heat, in return this stored energy becomes a radiant heating source for the space. Thermal mass provided by PCM modules lower the day-time temperature as well as raise the night-time temperatures and therefore keep the greenhouse well within the desirable plant conditions without the use of any external energy source.
Hence, PCM based greenhouse thermal stabilisation not only provides a very economical operation of the greenhouses but by reducing the energy consumption it makes greenhouses far more environmentally friendly option.



Positive Temperature Eutectic Solutions (PETES APPLICATIONS);

PETES applications between +4°C (39ºF) and +117°C (242ºF) can be charged using free cooling or conventional water chillers or by any free energy source and therefore offers many cost-effective energy management concepts for both New and Retrofit type process cooling / heating load shifting applications.

Passive cooling can be provided in two forms namely Passive or Active systems.

In passive system, design is based on utilising natural convection and density differences between warm and cooler air. These systems tend to be energy free design and relies on natural movements of the air circulation.

In dynamic systems air is forced over the PCM modules if and when required. Although this mechanical air movement requires power but it provides a full control of when to charge and discharge as opposed to static system only driving factor tends to be temperature different between the PCM and surrounding air.

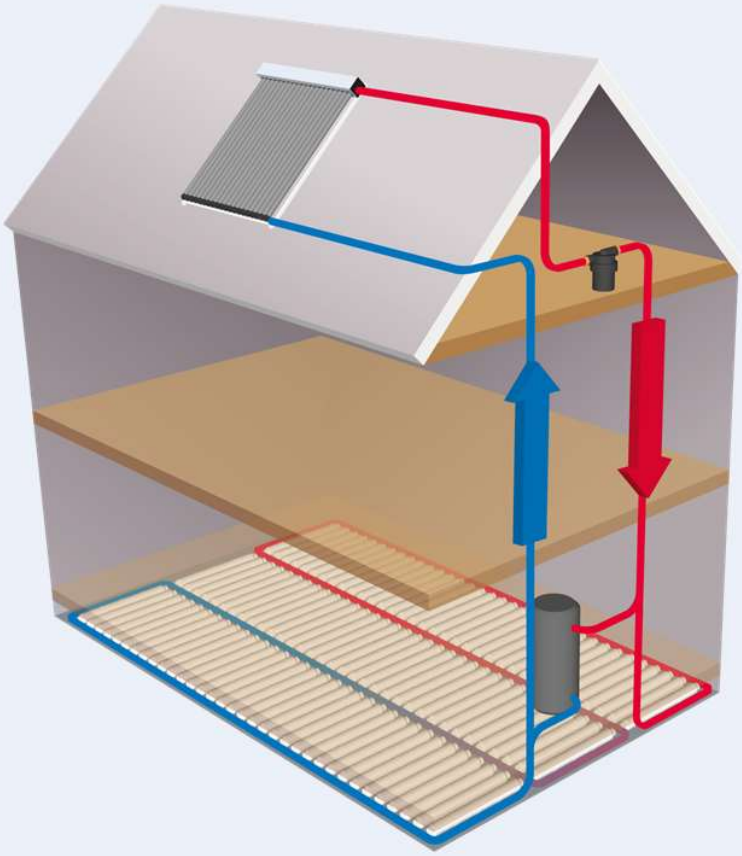
Typical application examples of both systems are highlighted in the following graph.



Passive Cooling Building Services Applications



SOLAR & HEATING APPLICATIONS



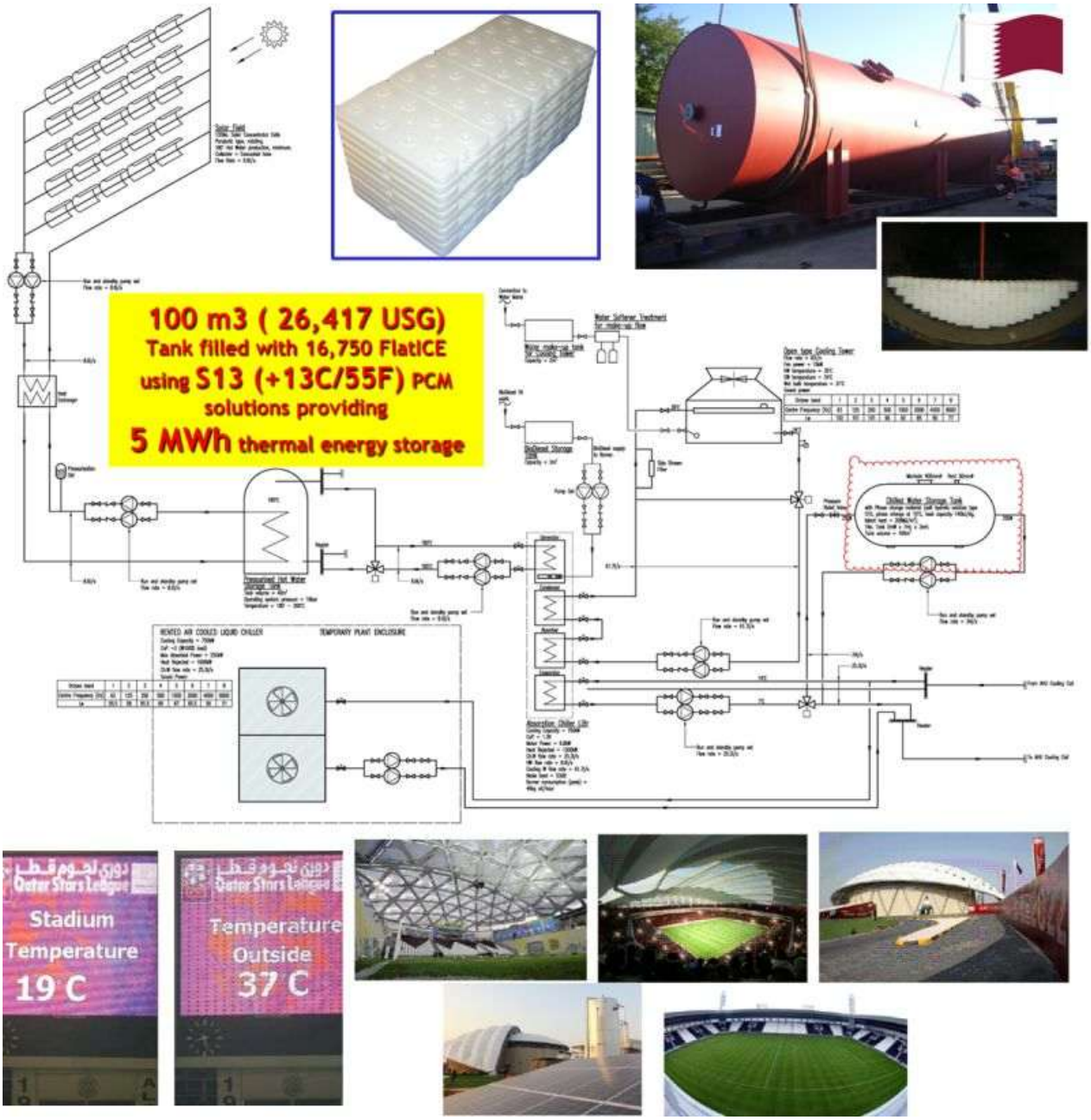
PCM

Solar Off-Grid Cooling PCM-TES application, FIFA 2022 World Cup Stadium, Doha, QATAR

As to overcome the hot weather which was the main objection for summer games for Qatar's 2022 World Cup bid, their bid committed to come up with off-grid green stadium green cooling design to cool the stadiums for both players and spectators during games. Design team came up an idea to use the solar energy to run heat driven machines all day and store the cool energy in TES tanks and later burst this stored energy into the stadium during evening games.

Solar energy generated by parabolic collectors drives the absorption chillers during day-time and the cool energy generated by the solar system placed in 100 m3 (26,417 USG) TES tank filled with 16,750 FlatICE using +13C (55F) PCM solutions providing 5 MWh thermal energy storage while the energy is available. Later when the games played during evening periods this stored energy discharged into the covered stadium and keep the spectators and players comfortable 2~3 hours.

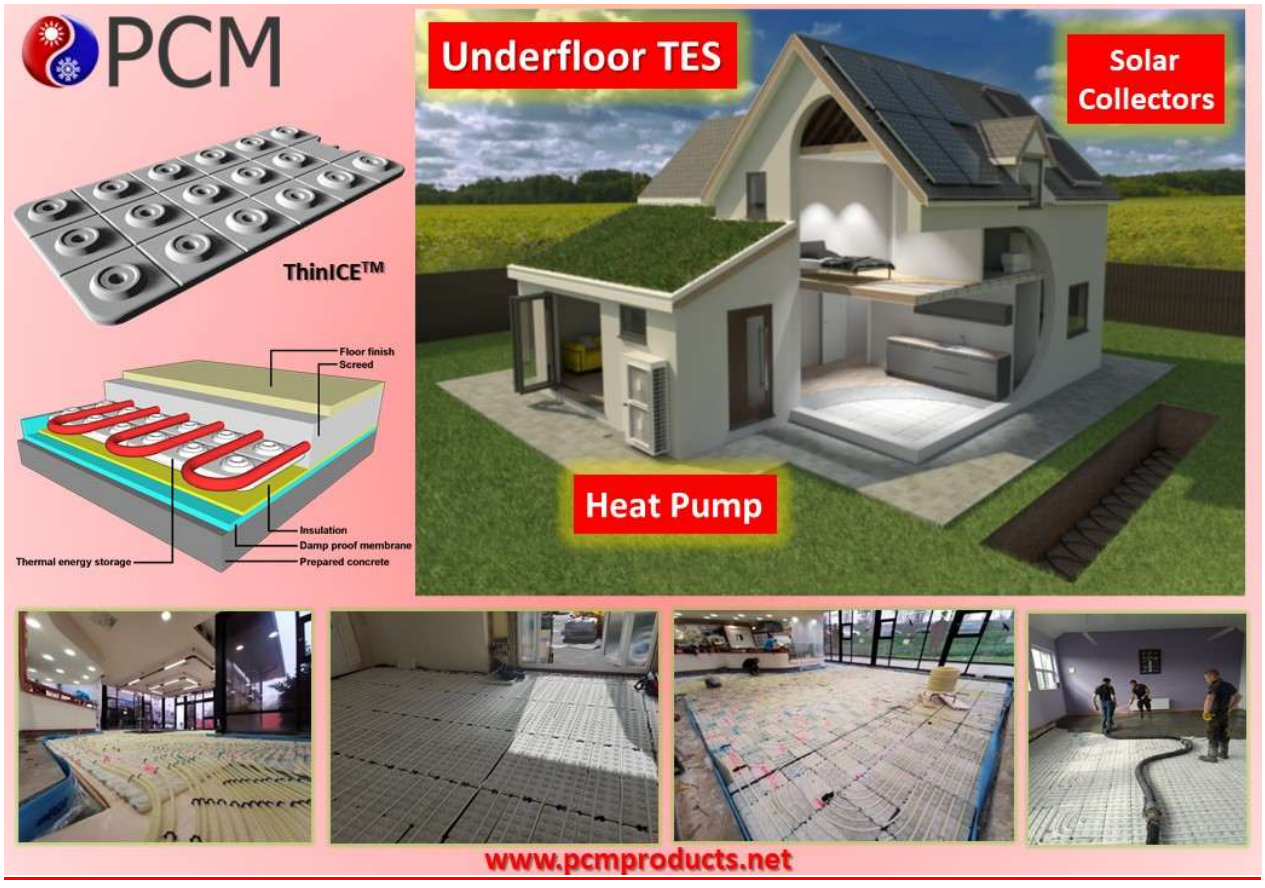
In order to demonstrate the concept A small scale stadium is built to demonstrate and prove the proposed off-grid green stadium is technically possible and during summer trial this demonstration stadium clearly proved that the proposed concept is viable and works well.



UNDER FLOOR HEATING - TES

Encapsulated PCM containers filled with 27~32C (81~90F) Phase Change Material is ideal to store any excess energy and overcome overheating.
This Thermal Energy Storage capability provides a useful tool to store any free energy such as solar as well as shifting the loads from peak to off-peak periods for any domestic or commercial under floor heating applications.





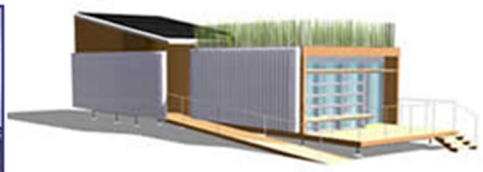
SOLAR HOUSE- USA APPLICATION

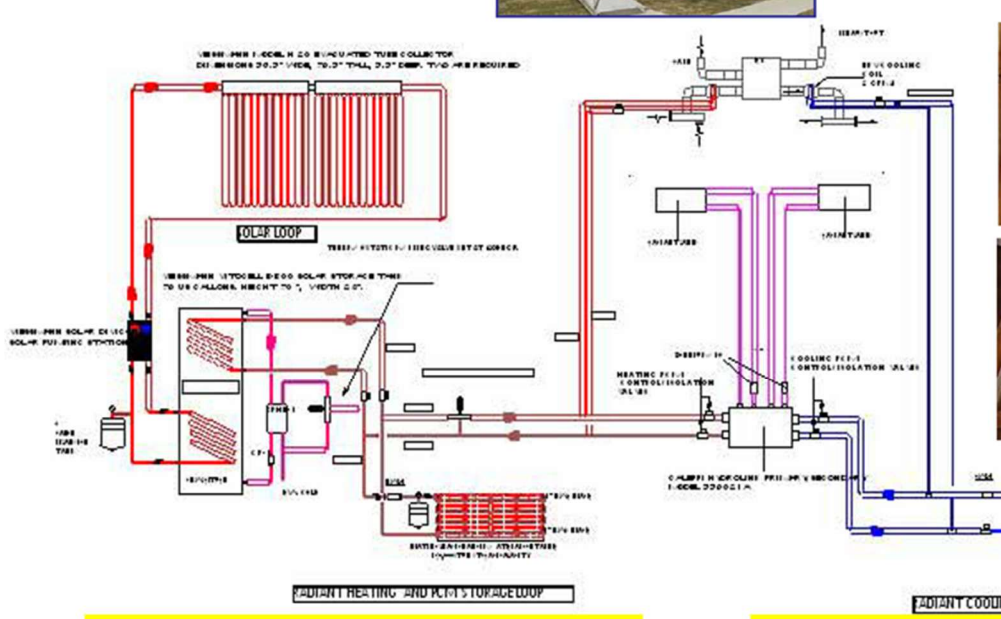
Rhode Island School of Design developed an off-grid self-sufficient house design for the 2005 Solar Decathlon Competition took place in Washington, USA.

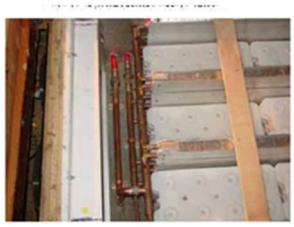
Design is based on utilising night cool energy storage in PCM based TES tanks filled with 22C (72F) for day-time cooling requirement as well as using solar collectors to produce hot water as well as store excess heat during day sun light period within the 46C (115F) warm PCM based TES tanks for night heating. Power requirements for these systems also provided via solar PV panels & battery combinations for an 80 m2 (800 ft2) typical house application.













FlatICE TES

PCM BASED HEAT STORAGE

PCM BASED HEAT STORAGE

HEAT PUMP BUFFER TANK APPLICATIONS

As the heat pumps are designed to start /stop like boilers and therefore once it starts it is vital to keep it running as long as possible and avoid the frequent start stops. This issue becomes critical for domestic heating application whereby the thermal inertia of the heating circuit is very small and therefore majority of he heat pumps require a buffer vessel to over-come this issue.

A simple water tank would be the simplest option but requires large volume & space which is not widely available in domestic environment and PCM based ball tank might reduce this volume requirement as much as 4 times plus minimise the stratification issues related to water tanks.







Enhanced borehole heat exchangers (BHEs) with integrated PCM in CYPRUS

The EU Horizon project TESSEb investigated advanced borehole heat exchangers (BHEs) with PCMs to enhance underground thermal storage and boost the efficiency of ground-coupled heat pumps (GCHPs) [63]. Traditional BHEs rely on conductive heat transfer, resulting in low thermal diffusivity and slower ground thermal response, which can lower the coefficient of performance (COP) of ground source heat pumps (GSHPs).

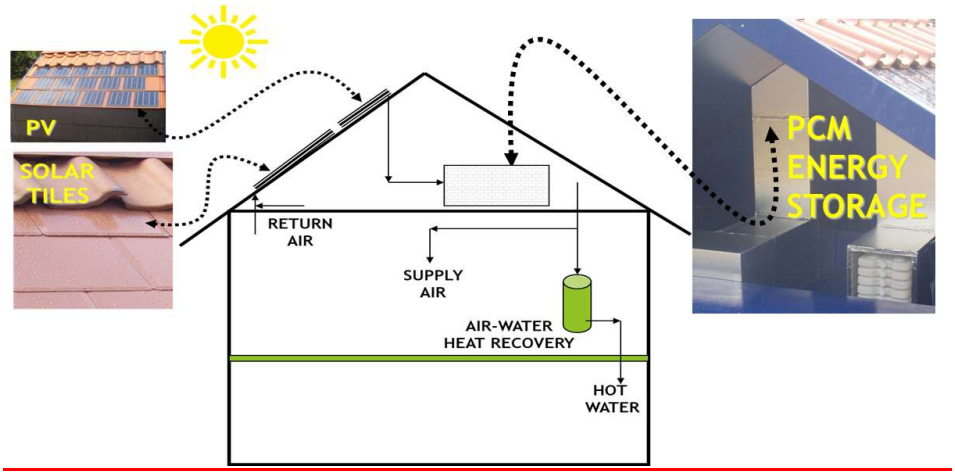
To address this, PCMs were integrated into BHEs for a GSHP system in a small building in Cyprus (Figure 23). Adding up to 35% PCM (exceeding this limit risks would compromise grout integrity) improves thermal energy storage and smooths out thermal waves through latent heat capacity during phase change.



PV HEAT RECOVERY HEATING SYSTEM

PV panels are a great option to provide free energy but by nature bulk of the solar radiation nearly 80% of it converted into heat via PV panels while only 20% power output. As there are many incentives around the World to encourage the use of PV panels in particular domestic applications but generally this free heat is not utilised.

The TRISLATE concept has been proved through technical trials in the Dublin Institute of Technology. There are two products in the range, the TRI- AIR slate which is a metal slate which collects hot air by fan during the day and cool air at night. The second product is the TRI-PV-AIR slate which collects Photovoltaic electrical energy, plus heat, plus cool energy at night. This triple function gives rise to the name TRISLATE.



GREENHOUSE THERMAL BALANCE APPLICATIONS

During day-time solar gains result in excessive indoor temperatures and this excess heat melts the PCM modules and thereby absorbs the excess heat and in return over-night indoor temperature drops and this cold energy again absorbed by the PCM modules and effectively becomes radiant heaters. This heat storage capacity provided by PCM modules stabilise and minimise the indoor temperature fluctuation.



Water Storage Tank Enhanced with PCM - ITALY

UNIFE set up a small-scale 38 m^3 building at their TekneHub Laboratory. The system's core consisted of a 5 kW multi-source (ground, sun, and air) water-to-water heat pump (HP) connected to two 100-litre tanks. Their system is comprised of two commercial PV panels (2x1.6 m^2, 300 Wp) with an integrated PCM 200-l buffer tank filled with 76 cylindrical HDPE PCM containers. PCM containers are filled with two types of PCMs namely 32 °C for summer use (S32), 10 °C for winter (S10). The tank had a total water volume of around 60 litres. An additional circulator was installed to enable the PV/T loop to operate independently and store thermal energy in the tank.

PCM	Melting temperature	Density	Latent heat	Specific heat	Thermal conductivity
	°C	kg/m³	kJ/(kg·K)	kJ/(kg·K)	W/(m·K)
S10	10	1470	170	1.9	0.43
S32	32	1460	220	1.9	0.51





Shallow PCM enhanced ground source heat rejection - ITALY

A low-cost shallow ground heat exchangers (GHEs) with integrated PCMs is installed at the TekneHub Laboratory under the CLIWAX. The system included three geothermal loops using different backfilling materials: sand (GHX1), sand mixed with paraffin-based PCM granules (GHX2), and HDPE containers (TubeICE) filled with hydrated salts (GHX3). Key properties are listed in Tables 7-9. These were paired with a 5 kW multi-source heat pump, PV/T panels, and a dry-cooler (Figure 24). PCMs, with melting points of 8 °C (heating) and 27 °C (cooling), moderated temperature extremes effectively in summer but provided limited benefits in winter, where water sufficed.

Challenges included high PCM costs, low conductivity, and compatibility issues, with paraffin offering stability at higher costs and hydrated salts showing higher storage potential but phase stability concerns. The HP achieved a winter COP above 5 by using different thermal sources. Ground regeneration via air and sun was effective, though PCM impact was modest due to the short loop's length.

Table 7 : Thermophysical properties of GHX1 backfilling material (sand).

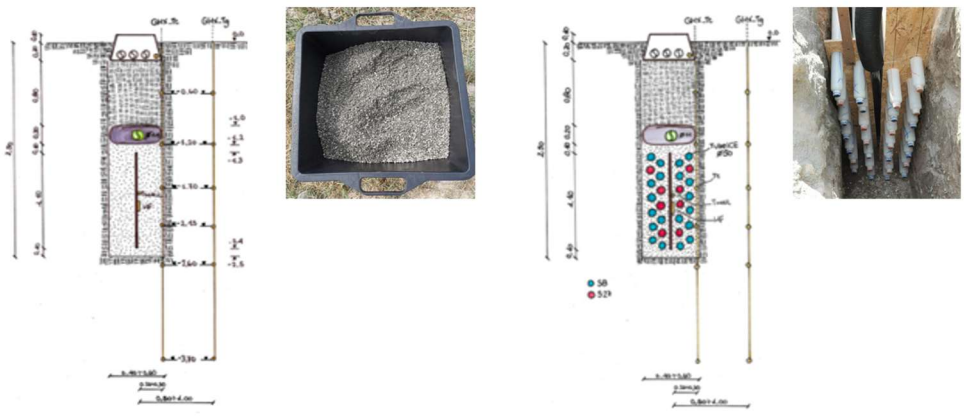
	Heating	Cooling	Unit
Dry sand	8.3	8.3	t
Water	2.5	2.5	t
Wet sand UTES (10K)	171.0	171.0	MJ

Table 8 : Thermophysical properties of GHX2 backfilling material (PCM granules).

	Heating	Cooling	Unit
Dry sand	6.1	6.1	t
Water	1.8	1.8	t
Wet sand UTES (10K)	126.5	126.5	MJ
PCM type	A8	A27	°C
Melting point	8	27	°C
Specific heat	2.16	2.22	kJ/(kg·K)
Latent heat	180	250	kJ/kg
PCM mass	174	89	kg
Product mass	348	178	kg
PCM STES	3.8	2.0	MJ
PCM LTES	31.3	22.2	MJ

Table 9 : Thermophysical properties of GHX3 backfilling material (macro-encapsulated PCM).

	Heating	Cooling	Unit
Dry sand	7.6	7.6	t
Water	2.3	2.3	t
Wet sand UTES (10K)	156.5	156.5	MJ
PCM type	S8	S27	
Melting point	8	27	°C
Specific heat	1.90	2.20	kJ/(kg·K)
Latent heat	130	185	kJ/kg
PCM mass	241	120	kg
Number of containers	112	56	–
PCM STES	4.6	2.6	MJ
PCM LTES	31.3	22.2	MJ



b c

Figure 24: Axonometric scheme of the system (a); section of GHX1 and GHX2 with detail of sand mixed with PCM granules (b), section of GHX3 with detail of PCM containers (c).

Snack-Bar of the Department of Biomedical and Specialties Surgical Sciences, University of Ferrara - ITALY

University of Ferrara installed a building demonstrator in the snack-bar of the Department of Biomedical and Specialties Surgical Sciences. The core of the system is the 25-kW multi-source water-to-water heat pump, which operates by means of two primary loops between two sensible TES tanks, one on the source-side (800 l), and one on the user-side (2x500 l).

On the source-side, the system operates between three thermal sources (ground, sun, and air) to optimise the operation, providing the snack bar with space heating/cooling. Innovative horizontal ground heat exchangers (GHXs), called Flat-Panels, were developed and installed. In July and August, the cooling activity accounted for 890 kWh_t, whilst the heating for 340 kWh_t. Consequently, the temperature just occasionally achieved values over 60 °C, even with high solar irradiance (> 800 W/m^2).

Monitoring data showed that the cooling mode allowed a net increasing of 7.6 % in peak power conversion. In terms of efficiency, the cooled panel achieved 14.3 %, whilst the not-cooled one 13.3 %. Furthermore, the cooling of PV/T panels was only functional to increase the peak power (+7.6 %) and not to increase the energy production.

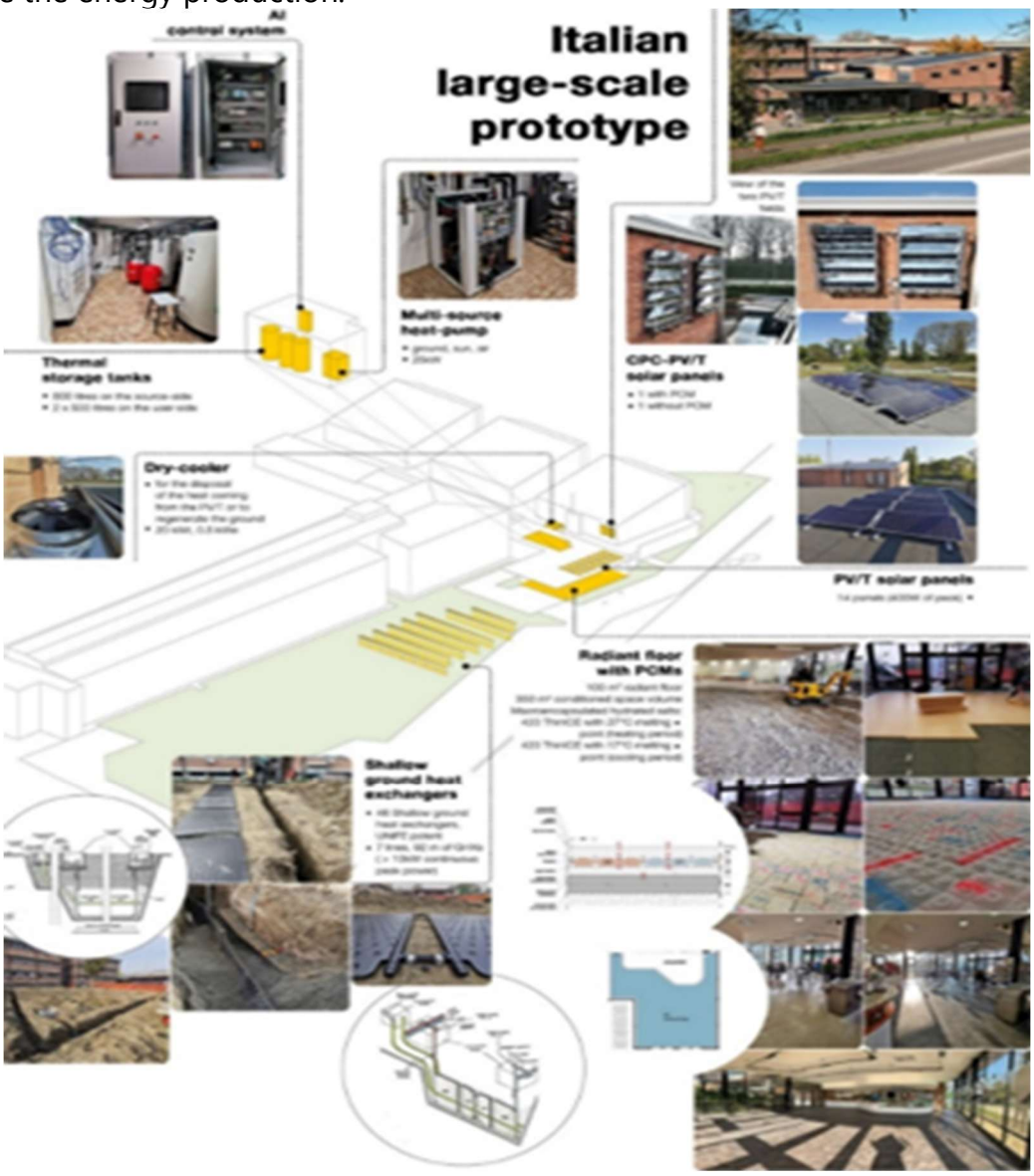


Figure 31 Axonometric scheme and description of the full-scale installation of the IDEAS system.

DESERT ROSE SOLAR DECHATLON COMPEPITION 2018, DUBAI, UAE

As part of the solar decathlon competition in UAE University of Wollongong, Australian team develop an off-grid domestic dwelling whereby the essential services like electricity, cooling and heating all provided using free energy i.e. solar & cooler night conditions.

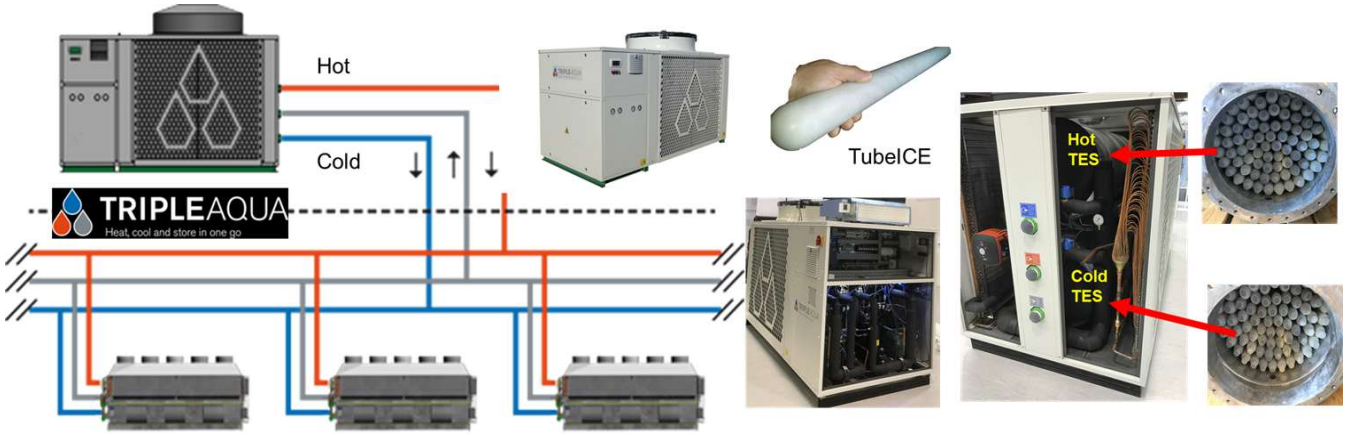
The Desert Rose HVAC system utilises an air-to-water heat pump as the primary source of cooling within the home. Unlike traditional residential HVAC systems, the Desert Rose decouples its sensible and latent cooling in the home by utilising an innovative Daikin product called Desica.

The system also employs an energy recovery ventilator which recovers waste energy and pre-cools fresh air as it enters the house. Phase Change Material (PCM) thermal storage tanks are used to cool the Desert Rose House to improve energy efficiency. PCM tanks act as a 35 kWh liquid thermal store that is cooled at night when the ambient temperature is cooler, increasing the coefficient of performance of the heat pump. The thermal store is then used during the middle of the day to drive the fan coil units instead of using the heat pump. This drastically reduces the amount of energy used by the HVAC system during peak load.



Heat pump with hot & cold PCM based buffer tanks

Triple Aqua system uses only three water pipes. A warm water pipe (28~36˚C), a cold-water pipe (12~18˚C) and one common return pipe. This system brings a warm or cold supply into each room, allowing the users or residents to remain comfortable at all times. The unique feature of this heat pump is that it has internal energy storage. Heat pump stores excess heat and cold for reuse somewhere else or at another time.



MELBOURNE / COMMONWEALTH GAMES OLYPIC VILLAGE SOLAR HOT WATER TES APPLICATION

As part of the financial planning a new housing development aimed to house athletes during games but once the games over these houses would be sold to public. However, during games the numbers of athletes occupied these building would be 4~5 higher than average family. As the organizer aimed to make this new village as environmentally friendly as possible and to this end hot water is aimed to be provided by solar.

However, as all athletes compete during day time as well as excessive hot water requirement is provided by PCM thermal energy storage tanks whereby for a give tank size PCM-TES provided 4 times higher energy density, Stainless steel balls filed with 89^0C (192^0F) hydrated salts placed inside a standard size hot water tank and this way full hot water requirement provided during games but once they are sold to public this extra energy density also utilized to cover any cloudy days for the standard family occupation.

