Plus-ICE ™

PHASE CHANGE MATERIALS (PCM)

THERMAL ENERGY STORAGE (TES)

DESIGN GUIDE

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1.0- INTRODUCTION

1.1. THERMAL ENERGY STORAGE:

Typical cooling load profile in Figure: 1.1.1 can be considered as the universal load pattern for any given cooling application. This pattern depends on the location/position, occupational pattern and specific internal gains but in principle Thermal Energy Storage (TES) System looks into total cooling load area i.e. kWh (Ton-hr) demand over a certain time span rather than peak load which is the main criteria for conventional design load.

Thermal Energy Storage (TES) is the temporary storage of high or low temperature energy for later use. It bridges the time gap between energy requirement and energy use. Most TES applications involve a 24 hour storage cycle and a typical TES load shifting strategy can be seen in Figure: 1.1.2. While the output of the TES is always thermal energy, the input energy may be thermal or electrical.

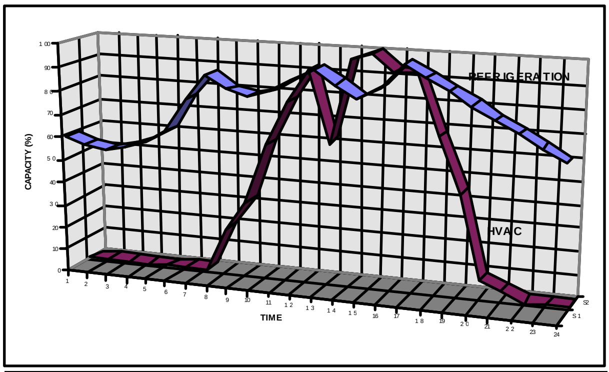


Figure 1.1.1.: Typical Building Load Profile

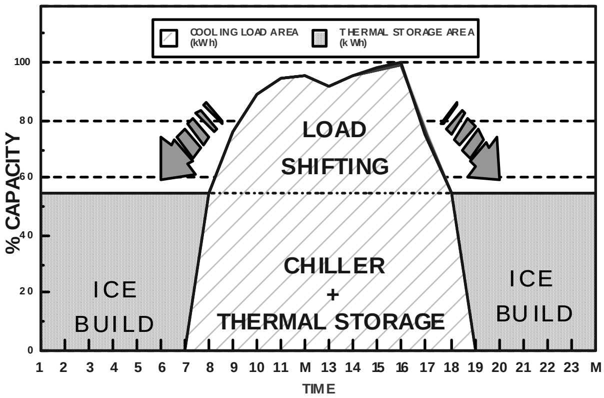


Figure 1.1.2: TES Load Shifting Strategy

1.2 - ELECTRICITY SUPPLY / COOLING LOAD RELATIONSHIP;

Primary energy source such as Hydro, Gas, Coal and Nuclear fuels can be transformed directly into Electricity as a power source for industrial and household appliances. In principle, electricity generation has to be balanced with the exact time of the consumption to satisfy the fluctuating demand at the lowest possible cost.

However, this phenomena its own creates problems, on one hand, constantly fluctuating seasonal and specific time demands which are outside their control and on the other hand, the essential specific running time requirement of electricity generation plants which do not necessarily match the demand.
Utility companies aim to generate electricity using different types of primary energy sources to offset peak demands and a typical UK electricity generation pattern can be seen in Figure :1.1.1.

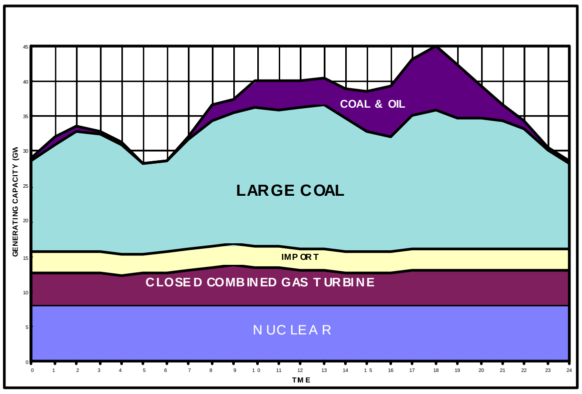


Figure 1.2.1: Typical UK Daily Electricity Generation Profile

The Cooling Load in Figure :1.1.1 and the Electricity Generation in Figure: 1.2.1 generally falls into the mid-day or early evening periods. Almost every modern society has a mid-day or late evening peak electricity demand.

This essential demand force utility companies to build new additional peak demand power stations which require considerable investment and they are in operation only during peak demand periods and shut down the rest of the time. They use expensive primary energy sources and are subject to the standard cost of maintenance, consequently production cost per kWh is 3-4 times higher than the standard base load electricity production cost. The average level of the UK electricity cost details can be seen in Figure: 1.2 and this additional cost is reflected directly to the end user by means of "Demand Charges".

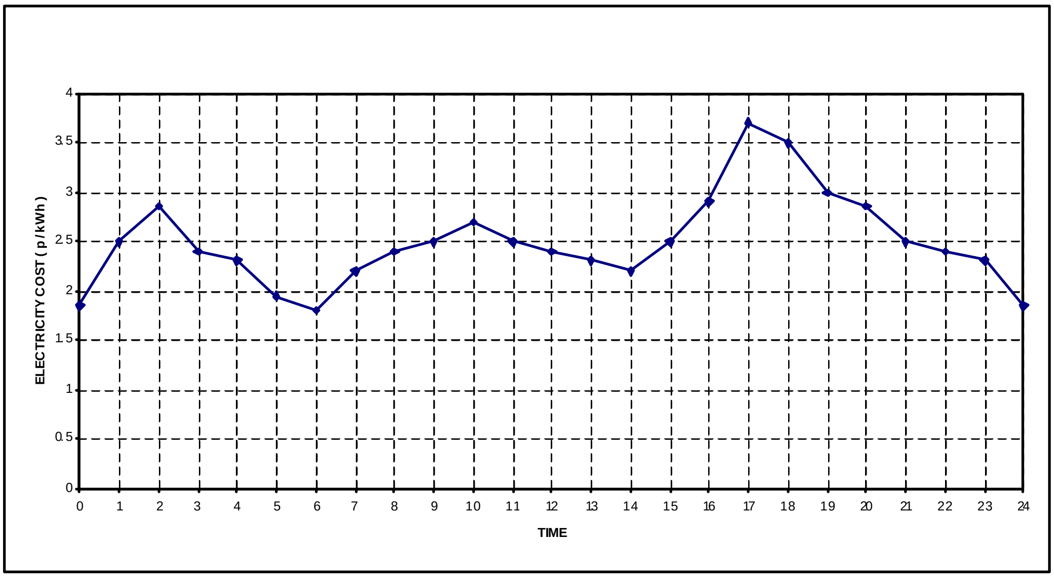


Figure 1.2.2 - A typical UK Daily Electricity Pool Prices

Considering the significant load on modern office building air conditioning and industrial / processes refrigeration impact on their overall electricity supply network, the utility companies diverted their attention towards reducing this short peak demand in addition to their costly exercise of building new power stations.

Utility companies in the majority of the developed world have already reached their peak and shifting the short time peak electricity demand became an essential part of their distribution strategies. Consequently, utility companies developed various incentive schemes to support any energy saving and load shifting applications by means of subsidising the initial investment cost and offering off peak rates.

1.3 - TES ADVANTAGES:

1.3.1- Cheap Electricity Rates:

In principle, TES utilises excess electricity energy from the national grid during off-peak periods to shave the demand during the peak period. Consequently, utility companies normally offer incentives by means of reducing off-peak time electricity cost for such schemes. However, the rate structure and peak demand periods widely depend on the country and even different regions within the country.

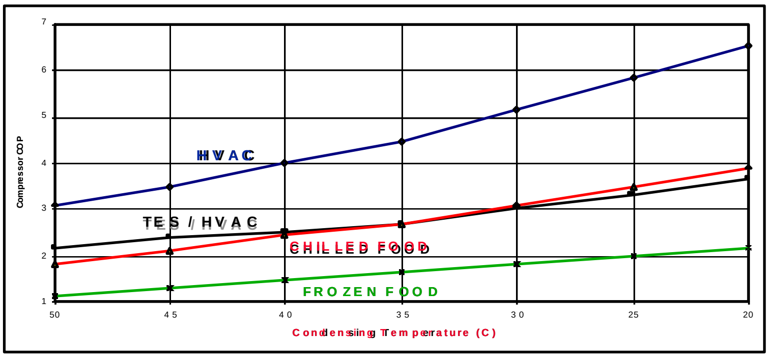
In England, the off-peak period is between 12.00 PM and 7.00 AM at an average rate of average 2.68 p/kWh against the standard charge of 7.35 p/kWh. In the USA, due to the large air conditioning load this structure has been generally divided into Winter and Summer charges but still offers similar incentives for lower demand charges 2.75 cent/kWh for winter, 3.40 cent/kWh for Summer against 5.45 cent/kWh for winter and 6.75 cent/kWh for summer standard charges respectively.

It can be clearly seen that **o**ff-**p**eak cooling running costs are almost half of those of a conventional system without taking into account the additional demand charges which tips the balance further towards the TES systems.

1.3.2 - Lower Ambient Operation:

In many countries the variations between day and night time ambient temperatures reaches up to 10-15 Deg C and consequently any type of heat rejection equipment operates more efficiently.

The head pressure (Condensing Pressure) changes proportionally with the ambient temperature and the lower the ambient temperature, the lower the condensing pressure which can be achieved in any type of mechanical refrigeration.



Notes; 1) HVAC Chiller Evaporation at 3 °C, R134a Refrigerant
2) TES/HVAC Chiller Evaporation at -13 °C, R134a Refrigerant
3) Chilled Food Evaporation at -13 °C, R404a Refrigerant
4) Frozen Food Evaporation at -35 °C, R404a Refrigerant

Figure 1.3.2.1 Ambient Effect on Supermarket Refrigeration Machinery Efficiency

A typical example of a cooling system operating data Vs condensing temperature can be seen in Figure : 1.3.2.1. In a climate where the night ambient temperature drops below the thermal storage temperature, the storage system can be charged by means of **FREE COOLING** from existing heat rejection equipment such as Condensers and Cooling Towers.

This technique is particularly suitable for sensible chilled water and PCMs (Eutectic) thermal storage systems. Typical annual weather data and daily ambient profile for London, England can be seen in Figure :1.3.2.2 and Figure 1.3.2.3 respectively.

Free Cooling schemes become extremely beneficial for many buildings that have winter day cooling loads such as large computerised offices, banks, dealer rooms, sport halls, hospitals, theatres etc., food processing such as dairy, brewery and industrial process applications,

A Free Cooling strategy provides cooling with little or no chiller operation and as a result gives significant energy savings. Free Cooling can be applied to both the chilled water and heat rejection side of the system and offers unmatched overall system performance.

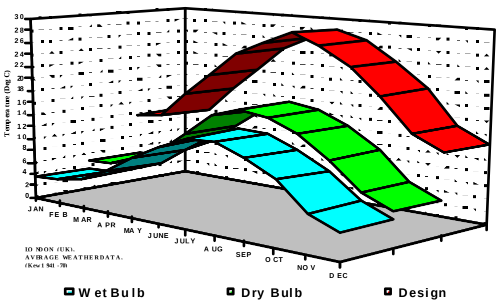


Figure 1.3.2.2 Annual Mean Temperature

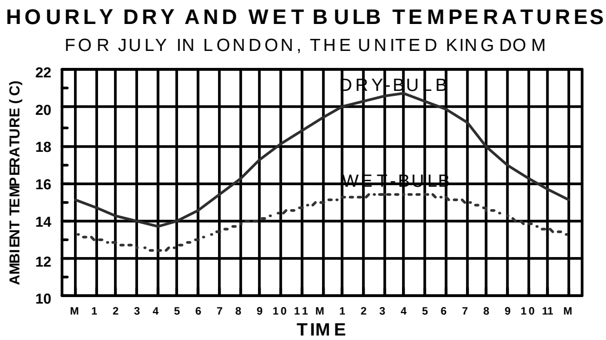


Figure 1.3.2.3 - A typical UK Daily Summer Ambient Profile

1.3.3 - Smaller Chiller / Running at full load:

Chillers for thermal storage applications are generally in the region of 30-60% smaller than the conventional system chillers due to the longer running periods and large latent heat storage capacity to satisfy the maximum demand. Consequently, chiller(s) run most of their expected life span running at full load during the charging mode and if it is required to supplement the operation for partial storage strategy.

1.3.4 - Future / Expansion additional capacity:

Any future or additional cooling/heating demand can be easily satisfied by means of changing the thermal storage strategy for the system. In principle, the additional capacity can be provided by shifting from a full storage to a partial storage or even weekly storage system depending on the required additional capacity over the existing capacity limits.

1.3.5 - Large Short Term Load:

TES becomes essential for short period large energy requirements. Prime examples are churches, sport halls, theatres etc. for space conditioning and food processing, dairy, brewery, processing and gas turbine air inlet gas cooling for industrial applications.
The time span for the duration of peak demand is usually in the region of a couple of hours a day. Nevertheless, the conventional system has to be designed to satisfy the maximum demand which is not required most of the time. If the cooling load can be spread by means of TES, the cooling apparatus can be reduced dramatically.

1.3.6- Full Stand-by Capacity:

The stored thermal energy can easily provide reasonable safety periods for any regular and/or emergency repair works to be carried out without disturbing the system. Full Stand-by capacity becomes quite essential for industrial and continuous space conditioning applications.

1.3.7 - Environmentally Friendly Option:

Surprisingly, an integrated TES design approach does not only provide an economical initial installation but also offers considerable environmental benefits by means of reducing both the direct global warming impact via reduction in refrigeration machinery hence reduced refrigerant charge and the reduction in the indirect global warming impact attributed to the CO_2 emission related to electricity generation.

If one can shift the peak refrigeration demand by means of Thermal Energy Storage to off-peak periods, the system will not only be running more economically by means of lower energy costs and reduction in maximum demand charges but also the refrigeration systems will be relying on less CO_2 emission based power generation plants and effectively less overall CO_2 emission for the system as a whole, Figure 1.3.7.1.

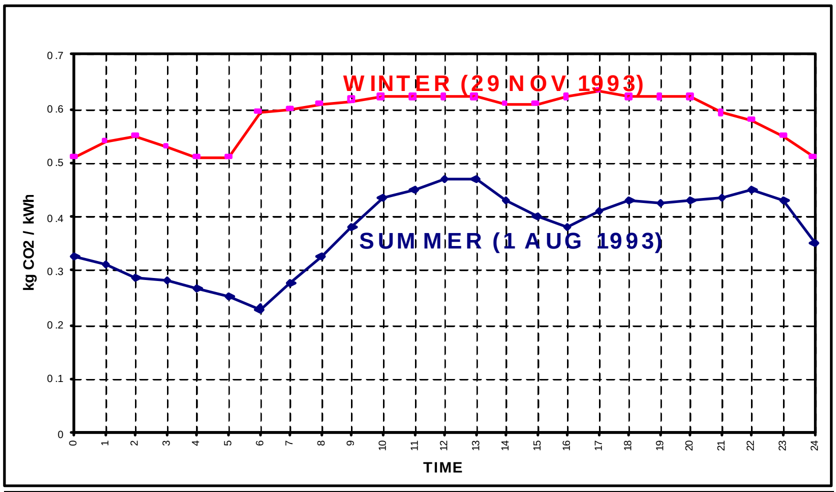


Figure 1.3.7.1 : England & Wales Electricity Generation Daily CO_2 Emission Profile

Furthermore, the lower ambient temperatures as illustrated in Figure 1.3.2.2 and 1.3.2.3 result in lower energy consumption due to a lower condensing temperature operation as well as the possibility of utilising smaller refrigeration machinery. Consequently, the systems direct and indirect global warming impact as part of the **TEWI** calculation can be reduced for any given system with additional financial benefits.

1.4 - DESIGN CRITERIA:

In principle, all TES systems have the same fundamental concepts, and consist of the following similar fundamental equipment.

1) The cooling machine provides cooling or alternatively heating source capacities which may directly match the load or to be added to storage.
2) A storage system which may either accept excess cooling/heating capacity from the cooling/heating source or supply to a required type of load.
3) A load which can accept cooling/heating from either cooling/heating equipment or storage system separately or combined operation.

UNITS:

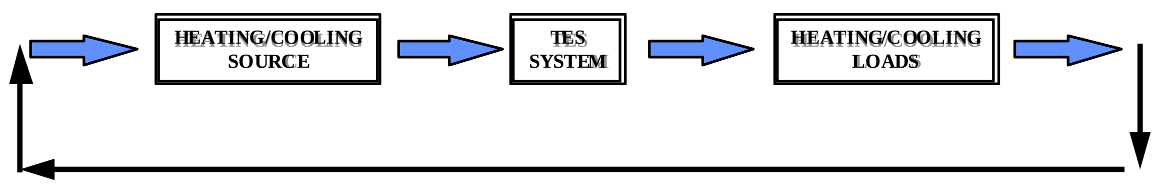
	SI	IP	Imperial
POWER	kW	Btu/hr	Ton
ENERGY	kWh	Btu	Ton-Hour
ENERGY DENSITY	kWh/m	Btu/ft	Ton-hr/ft
VOLUME/ENERGY	m^3/kWh	ft3/Btu	ft^3/Ton-hr

CONVERSION;

	kWh	Btu/hr	Ton-hr
kWh	1	3.409	0.284
Btu/hr	0.293	1	8.3×10^{-5}
Ton-hr	3.52	12,000	1

The following Cardinal rule applies whatever the type of system or components used to achieved to satisfy the demand.

"THE CAPACITY OF THE COOLING/HEATING SOURCE OVER THE DESIGN TIME MUST BE EQUAL TO THE SYSTEM LOADS PLUS SYSTEM LOSSES OVER FULL DESIGN PERIOD"



For a daily cycle the 24 hours capacity of the cooling/heating source must be equal to the system load plus losses over a 24 hour period and the same fundamental concept can be applied for weekly or seasonal storage systems.

In principle, **" THE PERFORMANCE OF ANY TYPE OF TES SYSTEM WILL BE A FUNCTION OF LOAD, WATER FLOW RATES, WATER CIRCULATION TEMPERATURES AND AMBIENT TEMPERATURES".**

1.4.1 - Storage Techniques:

Designers all over the world have developed over the years different techniques and many unique applications but the main design criteria remains the same as "FULL" or "PARTIAL STORAGE".

FULL STORAGE systems shift the total cooling/heating load to the off-peak period and the cooling/heating source is never used during the peak period in order to achieve the maximum economy, this type of system results in a smaller cooling/heating source but a larger storage volume.

PARTIAL STORAGE system utilises the cooling/heating source during the peak periods in order to reduce the initial storage capacity. This type of system is widely used to limit the demand during the peak period and this technique is called

DEMAND LIMITING which is a type of Partial Storage system whereby the excess capacity is supplemented by a TES source in order to stay below the maximum electrical demand limit. Any of the above techniques can be used either over a daily cycle (DAILY PARTIAL / FULL STORAGE) or longer period of weekly or seasonal (WEEKLY PARTIAL / FULL STORAGE).

In principle, FULL STORAGE provides the most economical running cost with a penalty of larger initial investment cost and volume (space) requirement and PARTIAL STORAGE cost is relatively cheaper in comparison with full storage but the running cost may be higher.
Both of the above techniques can be applied for either an existing system or new installation. The practical applications show that if a TES system is applied carefully in full consultation with the utility companies, the existing system modification cost can be recovered in a very short depending on the application and a new installation can be provided within the same budget limits as conventional systems.

2.0 - CURRENT THERMAL ENERGY STORAGE TECHNOLOGIES;

Thermal Energy Storage (TES) in simple terms can be explained as **" Storing High or Low Temperature energy for later use in order to bridge the time gap between energy availability and energy use "**.

Water and Phase Change Materials (PCM's) constitute the principle storage media for HVAC and Refrigeration purposes but Coil, Rock and Solid Materials are also used as storage media.

2.1 WATER STORAGE:

Water has the advantages of universal availability, low cost and transport ability over other systems and in principle the simplest thermal energy storage is a water tank which can store hot or cold water during the off-peak periods and be withdrawn during the peak periods.

There are many application techniques of water storage but the main criteria can be described as **" mixing the return water with the stored volume in such a way to provide uniform supply temperature to the system".** The following techniques have been successfully applied commercially throughout the world.

- Labyrinth Method:
This system was developed by Japanese Engineers and has been successfully applied in commercial buildings since 1950. Water flows back and forth through high and low apertures in adjacent cubicles in order to minimise the temperature swing for the supply water.

- Temperature Stratification:
The return water from the system can float normally above the stored chilled water and the same principle is applicable for a +45 ºC (+113 ºF) water supply which can successfully float above +39 ºC (+102 ºF) return water, since the density difference is much larger.

- Flexible Diaphragms:
The natural temperature stratification can be replaced by a sheet of coated fabric diaphragm which is anchored securely at the mid point of the tank, this floats up and down depending on the water supply and return volumes and as a result the diaphragm dramatically improves storage and constant supply temperature accuracy.

- Empty Tank Concept:
The Empty Tank concept can be described as the installation of as many tank sections which can be used to pump chilled water back and forth between the numbers of compartments. This technique provides an excellent separation of temperature for HVAC applications.

2.2 - ICE STORAGE SYSTEMS;

Ice production techniques can be divided into two main groups namely ***"Dynamic"*** and "***Static"*** systems. and the produced ice can be used either ***directly*** or indirectly to chill the product or system.
The direct usage generally remains within the food sector to chill products such as fish, vegetables, meat, poultry etc. and indirect usage generally utilised for the latent heat cooling effect for process cooling such as ice storage, TES systems for air conditioning and process cooling as secondary cooling medium.

2.2.1 - Static Ice Production Systems

This technique is probably the oldest in use. In principle, the ice formation and melting takes place without any physical removal of the ice . The most common used techniques are as follows:

-Ice on Coil

Refrigerant or Glycol water solution at a temperature of between -4°C and -10°C is circulated within a serpentine coil, which is submerged in an insulated tank of water in order to form ice on it. The ice builder tank consist of a low pressure air pump or paddle blade to agitate the system in order to achieve even distribution of ice melting and formation. The thickness of ice is measured by a sensor to control the operation and the relevant details can be seen in Figure : 2.2.2.

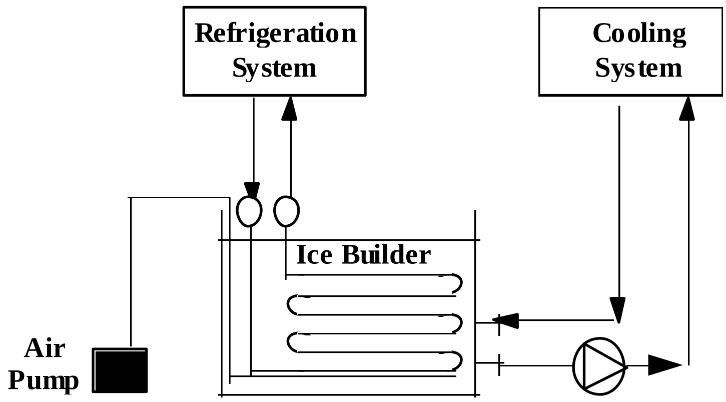


Figure 2.2.1 : Ice Builder Concept

Ice Banks:

The ice bank consists of a pressurised, closely packed polyethylene tube heat exchanger. Low temperature glycol solution is circulated through the tubes, which freezes the water around them. The water in the insulated tank is almost frozen solid at the end of the charging cycle. The control of the system can be provided by the ice level sensor in the tank. The system water is circulated through the tank for both techniques, to satisfy the cooling demand Figure : 2.2.2.

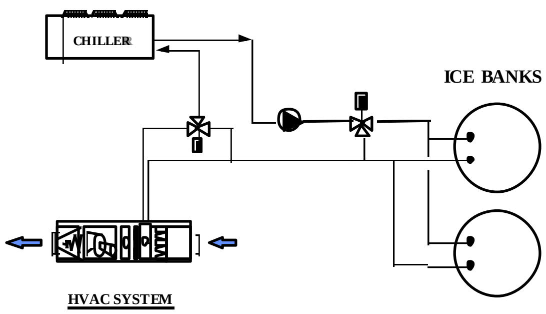


Figure 2.2.2 : Ice Bank Systems Encapsulated Ice Storage

The charging and discharging cycle can be controlled by water levels in an inventory tank which is subject to level change due to ice expansion and contraction during the freezing and melting process respectively or by process fluid temperatures.

2.2.2 - Dynamic Ice Production Systems

Ice is periodically harvested from the freezing apparatus to a storage bin and the stored energy is recovered by circulation of water through ice in the bin to supply the chilled water system during normal operation. There are many commercially available systems in the market and the most common used systems are as follows:

Ice Harvester:

Ice is built on a vertical surface which is the evaporator section of the refrigeration system. Water is circulated from the storage tank, over the plates until a certain thickness, normally in the region of 8-10 mm ice is formed. This freezing process takes approximately 20 minutes .The ice is harvested by means of hot-gas by-pass from the delivery port to the evaporator plates to warm the surface to about +5 ºC, resulting in the ice in contact with the plates melting and falling into a sump or ice tank, to which chilled water from the system is circulated.

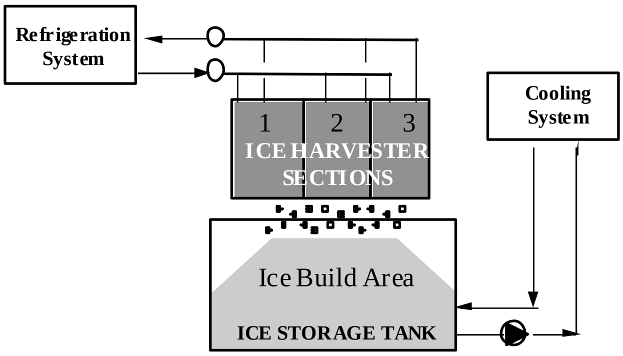


Figure 2.2.4 : Ice Harvester

Tubular Ice:

In principle this technique is identical to the Ice Harvester system, the only difference being that the ice is produced within a tube rather than on the surface of plates. The storage and system applications are identical to the ice harvester techniques.

Ice Flakes:

A revolving freezing apparatus produces ice flakes continuously and the flake ice is collected at the bottom drum of the machine for later use by means of circulating chilled water through the ice tank to satisfy the cooling demand.

Slurry Ice:

In this system a binary solution is cooled below its freezing temperature within a Falling Film, scraper, vacuum or supercooling heat exchangers as illustrated in Figure 2.2.5. The refrigerant which is circulated outside the tube supercools the binary solution into millions of fine crystals which are then pumped into a storage tank for later use, or directly to satisfy the process load. During the cooling mode, warm solution is circulated through the storage tank where it is cooled by the crystallised solution and then pumped directly to satisfy the air conditioning chilled water circuit.

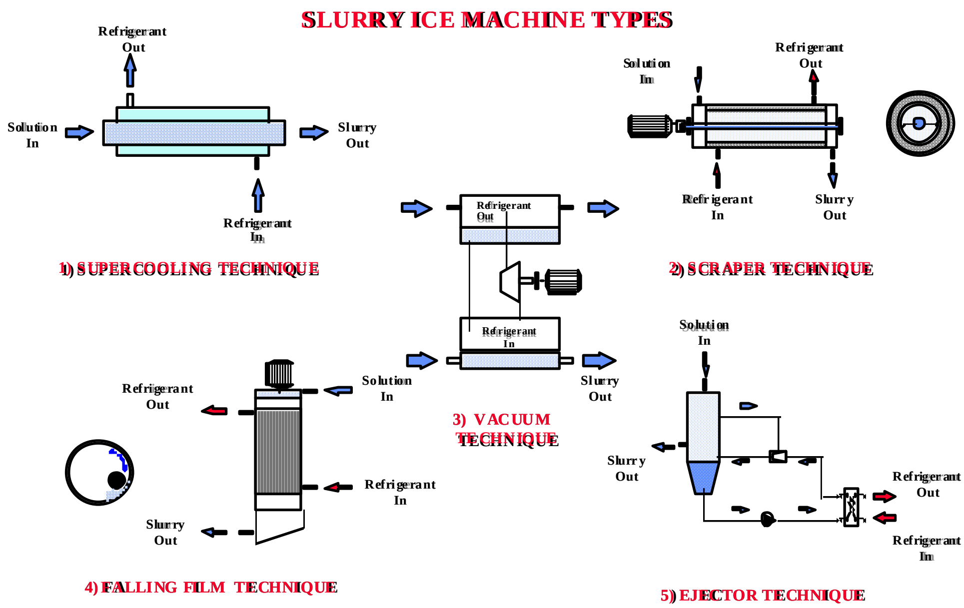


Figure 2.2.5. Slurry Ice Generator Types

2.3. - SPECIAL APPLICATIONS:

-Seasonal Storage:

This type of system aims to utilise seasonal temperature variations over prolonged periods for later use. Most research has been linked to storing heat from a Solar Source for heating and Ice/Snow storage for air conditioning purposes but waste incineration, nuclear cooling water, industrial reject heat have been also used for seasonal thermal storage.

An excavated pit system in Illinois State University and a container ice system in Kansas State University have been successfully applied for cool storage. Seasonal energy can be also stored in the form of sensible heat storage and the most common applications are the lake storage, tanks, excavated pits for either cooling or heating purposes.

Canada and Sweden are the leading countries for such systems. Solar ponds are widely used in Israel, Switzerland and England for hot water storage and some applications utilise an artificial lake which is constructed in front of the building specifically for TES for chilled water system of the air conditioning.

-Ground Couple Storage:

The earth is used as a storage medium which provides the heat source for use usually for space conditioning. In practice, two types of ground couple storage, namely direct heating/cooling and heat pump systems have been applied.

The direct system stores available heat and/or coolness in a buried media i.e. vessel or localised volume of ground and the stored energy can be recovered when required satisfying the demand. On the other hand, the heat pump system removes heat from or rejects heat to the ground storage media for space conditioning.

- Packed Rock Beds:

A variety of solids namely rocks can be used to store thermal energy for later use. A packed rock bed which may also be called a pebble bed or rock pile storage utilises the available thermal energy by means of circulating through a packed rock bed to add heat to or remove heat from the system for charging and discharging respectively. The energy can be transferred from a fluid but the most common systems utilise air due to the high heat transfer coefficient between air and rock.

- Low Temperature CO_2 Storage System:

Carbon Dioxide offers the most compact latent heat storage system due to the commercially obtainable triple point which allows the utilisation of a single substance as static latent heat of fusion storage and in the mean time the liquid overfeed continues the discharging operation and vapour compression technology to charge the system.

Carbon Dioxide can be stored at it's triple point of -57 ºC (-70 ºF) and 518 kPa with solid fraction of 70-80 % by mass and the system can provide 140 kJ/Kg thermal storage capacity within the required volume of 166.6 MJ/m^3.

- Cogeneration:

Cogeneration offers the facility to utilise the waste heat from the engine which is the driving force for the generators or alternatively to enable to use those system over a 24 hour period which increases their economic viability. In practice, there are two types of cogenaration systems which have been successfully applied in industry.

The first type of system utilises the waste heat from the engine to drive an absorption chiller for cooling or direct heat storage facility.

The second type of system utilises the excess electric energy to drive an electrically driven chiller and/or heat pump to charge any type of thermal storage or direct cooling/heating requirement.A successful district heating with cogenaration system has been applied in Des Moines, Iowa, USA where many large buildings utilise their stand-by generators as cogeneration plants to drive either an Absorption chiller/s or electrically driven chiller/s along side their standard air conditioning chillers during the peak demand period.

In other words, they produce their own electricity during the peak demand period or even in some cases, sell the excess power back to the utility grid. If it is carefully designed, the cogeneration system offers the most economical return for the investment.

-Thermochemical Energy Storage:

Recent research shows that various alcohols and ketones are potential thermochemical storage media but due to the relative cost and complexity, no commercially viable systems have yet emerged.

Typical examples are the mixture of Sulphuric Acid and water, and alternatively Sodium Hydroxide and water, Systems in which the water is separated by the heat input to the mixture and as soon as the two substances are mixed, the chemical reaction of the substances liberates heat.

2.4 - EUTECTIC (PHASE CHANGE MATERIAL) ENERGY STORAGE:

A substance can exist in the solid, liquid or gaseous states depending on the temperature and pressure of the storage conditions. The three phases may exist together in equilibrium but two phase states are commonly used in practice. The latent change of certain substances can be used to store heating or cooling for later use.

The substances used for latent heat storage are called " Phase Change Materials (PCMs)" which provide the advantages of smaller size, constant temperature during phase change, lower stand-by losses over sensible energy storage materials.

The most commonly used form of Phase Change is the heat of fusion between solid and liquid phases, although solid/solid and liquid/gas phase changes can also be used.

- Phase Change Materials (PCMs) & Eutectics:

The basic and most commonly used form of PCMs is the water/ice phase change at 0°C (+32 ºF) Salt Hydrates, Organics and Clathrates are also widely used in industry.

Salt Hydrates are compounds of salt and water and have the advantage of high latent heat of fusion due to their high water content but the salts also create major disadvantages of life cycle in the form of phase segregation during the charging and discharging mode which results in heavier salt settling at the bottom of the solution and consequently, the TES capacity of the solution changes. The process is progressive and irreversible.

Eutectics on the other hand are mixtures of two or more substances mixed in such a way as to provide the desired melting/freezing point. The mixture melts completely at the design temperature and has the overall composition in both liquid and solid phases which has the main criteria of a PCM.

Organics have low density and poor thermal conductivity. They are relatively expensive and combustible. The prime example is paraffin wax.

Clathrates (Gas Hydrates) are a mixture of chemical substances in which one chemical substance is bound inside another in a cage-like fashion. In practice, water forms the bonding structure for the clathrates for thermal energy storage applications. The most commonly used clathrates are R-11, R-12 and R-22 refrigerants.

Solid-Solid PCMs that undergo a solid/solid phase transition with the associated absorption and release of large amounts of heat are the latest addition to PCM range. 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.

Such materials are useful because, unlike solid/liquid PCMs, they do not require nucleation to prevent supercooling. Additionally, because it is a solid/solid phase change, there is no visible change in the appearance of the PCM (other than a slight expansion/contraction), and there are no problems associated with handling liquids, i.e. containment, potential leakage, etc. Currently, this range remains between 25 °C (77°F) upto +180 °C (356 °F).

3.0- PlusICE THERMAL ENERGY STORAGE TECHNOLOGY

3.1- General

PlusICE (Positive Temperature PCM) system utilises Mixtures of non-toxic Eutectic (Phase Change
Material) solutions which have freezing and melting points higher than those of water. This Thermal Energy Storage media is encapsulated in a unique cylindrical beam design which can be used for any large commercial, industrial or institutional applications that uses chilled water, hot water and refrigerant in their HVAC, refrigeration or process applications.

PlusICE like any other TES technologies stores cooling / heating excess capacity generally during the night-time taking advantage of lower ambient and in addition to off-peak electricity rates. If the ambient temperatures are sufficiently low enough, it offers the possibility of free TES charging without running the chillers.

Furthermore, the disadvantages of a conventional HVAC chiller and ice (water ice) storage system can be overcome by utilising the latent heat capacity of various “Eutectic” mixtures without the need for minus circulation temperatures.

Finally, the positive (Plus) temperatures ranges offered by the PlusICE solutions opens a new and challenging horizons for the heat rejection and heat recovery TES applications.

3.2. Eutectic (Phase Change Materials) Background;

Although the term “Eutectic” is widely used to describe the materials we are interested in, a better description would be “Phase Change Materials” (“PCMs”). A true eutectic is a mixture of two or more chemicals which, when mixed in a particular ratio, have a freezing/melting point which is lower than the corresponding freezing points of the component chemicals. During the freezing/melting process (phase change) the composition of the solid and liquid phases are identical.

Unfortunately, very few of the documented PCMs (a number of which are listed in Table 3.2.1) are true Eutectics and so many have to be modified to obtain a material suitable for long term use.

Material	Melting Point (ºC)	Heat of Fusion (kJ/kg)	Latent Heat (MJ/m^3)
$MgCl_2.6H_2O$	117	169	242
$Mg(NO_3)_2.6H_2O$	89	163	252
$CH_3COONa.3H_2O$	58	226	287
$MgCl_2.6H_2O$/ $Mg(NO_3)_2.6H_2O$	58	132	201
$Na_2HPO_4.12H_2O$	34	265	379
$Na_2SO_4.10H_2O$	32	251	335
$Na_2CO_3.10H_2O$	32	233	340
Waxes	28 to 4	220 to 245	170 to 195
Polyethylene glycols	28 to -15	146 to 155	165 to 175
$CaCl_2.6H_2O$	27	191	298
Glauber's salt + additives	24 to 4	wide range	wide range
$CaCl_2.6H_2O$/ $CaBr_2.6H_2O$	15	140	249
Water	0	335	335
Range of water/salt Eutectics	0 to -64	wide range	wide range

Table 3.2.1 - Range of commonly used PCMs

PCMs can be broadly grouped into two categories; ***"Organic Compounds"*** (such as polyethylene glycol) and ***"Salt-based Products"*** (such as Glauber's salt). Each group of PCMs comes with advantages and disadvantages some of which are listed in Table 3.2.2.

	Advantages	Disadvantages
ORGANIC	Simple to use Non-corrosive No supercooling No nucleating agent	Generally more expensive Lower latent heat/density Often give quite broad melting range Can be combustible
SALT-BASED	Generally cheap Good latent heat/density Well defined phase change temperature Non-flammable	Need careful preparation Need additives to stabilise for long term use Prone to supercooling Can be corrosive to some metals

Table 3.2.2 - Characteristics of PCMs

Much work has been done over the years on one particular PCM, namely Glauber's salt or sodium sulphate decahydrate. This salt is readily available, cheap, non-corrosive, and non-toxic (although historically it has been used as a laxative!). It normally freezes at +32.5 ºC (+90.5 ºF), which has made it ideal for use in solar heating and heat rejection applications. It is possible to depress the phase transition temperature to conventional HVAC chilled water ranges of +5 (+41 ºF) ~ +13 ºC (+55 ºF) by the addition of other salts.

However, Glauber's salt melts incongruously ,in other words, upon melting, the salt tends to separate into a saturated solution with insoluble anhydrous sodium sulphate crystals. These crystals are heavier than the saturated solution hence they settle out of solution due to gravity. When the PCM is next frozen these crystals are unable to recombine with the saturated solution, resulting in a loss in TES capacity. This occurs during each freeze/melt cycle, and results in continual loss of performance.

Many attempts have been made to eliminate this segregation with varying degrees of success. The fundamental behind this work has been to thicken the mixture to such an extent that crystals that form during melting are held suspended in the solution. If this can be achieved, the crystals will then be recombined into the main body of the PCM during the next freezing cycle, so no loss of performance will occur.

A wide variety of thickening agents have been tried in the past, but historically the most widely used material was a clay-like substance which behaved in a manner similar to quicksand. When added to an aqueous solution, such as the PCM mixture, and stirred vigorously, the mixture is thin and pourable, but if it is left to stand, the clay absorbs the solution in spaces between its particles and traps it in a fairly rigid structure thus preventing any anhydrous crystals from settling out. If this mixture is then agitated, it reverts to being a thin liquid again. This clay-like thickening agent has been used extensively in early PCM development work, but later field applications show that separation remains a problem.

More recent work has concentrated on using other thickening agents, in particular synthetic polymer gels. A number of suitable polymers have been identified which can function effectively in the harsh environments of the PCM mixture.

3.3- PlusICE PCM SOLUTIONS ;

Following extensive research, PCM have managed to identify a number of satisfactory PCM, PCM and polymer combinations which suit the majority of air conditioning and refrigeration applications. PlusICE Eutectic PCM composition is non-toxic, non-combustible and inorganic. The majority of the salt hydrates are not subject to any volume change, i.e. expansion or contraction during the phase change process and, hence, no thermal stress for the PlusICE beam.

Eutectic salts have been used since the late 1800s as a medium for the thermal storage applications. They have been used in such diverse applications as refrigerated transportation for rail and road applications and their physical properties are, therefore, well-known.

PlusICE salt hydrates developed and placed into the PlusICE containers have been thoroughly tested in both an accelerated life cycle programme and in applications. Salt hydrates have performed reliably with no degradation in either composition or storage capacity. All the PlusICE components can be expected to meet or exceed the life of its associated chiller, and process equipment. The relevant temperature range and the technical details of the PlusICE range can be seen in Table 3.3.1.

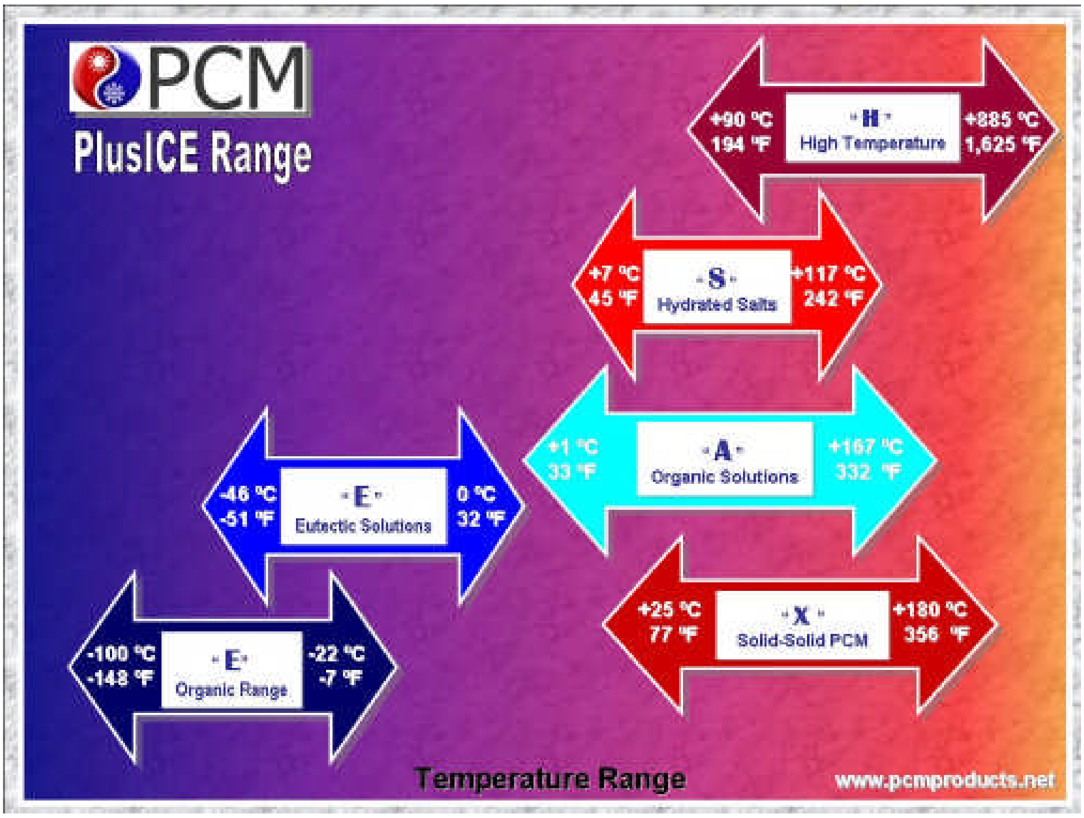


Table 3.3.1 – PlusICE Solutions

A typical PCM freezing and melting curve can be seen in Figure 3.3.2 for type A8. Other solutions also indicate a similar pattern of freezing and melting curves within their intended temperature ranges.

Extensive accelerated freeze / melt tests which simulate daily charging and discharging mode for a typical TES system have been carried in order to evaluate the expected life time performance and a typical example of a *PlusICE* beam freezing/melting cycle can be seen in Figure 3.3.2.

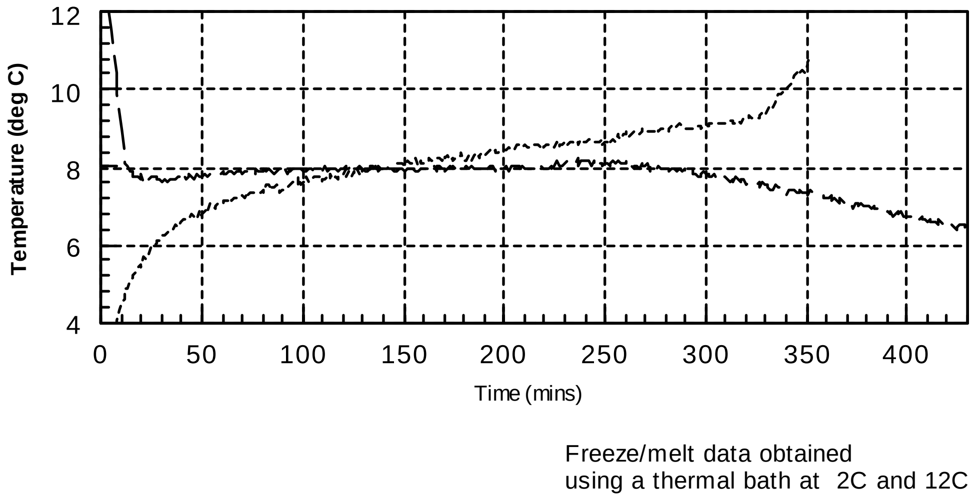


Figure 3.3.1- *PlusICE* / A8 Freezing and Melting Curve

PlusICE phase change material (PCM) are developed in a wide range of operating temperatures between +4ºC and +89ºC covering the majority of the chilled water, heat recovery and heating applications.

The wide range of PlusICE technology enables the designer to utilise as much as free cooling energy storage operations. This technique can be applied not only for the chilled water circuit but also for the heat rejection side of the system can be charged to offset the daytime peak electricity consumption.

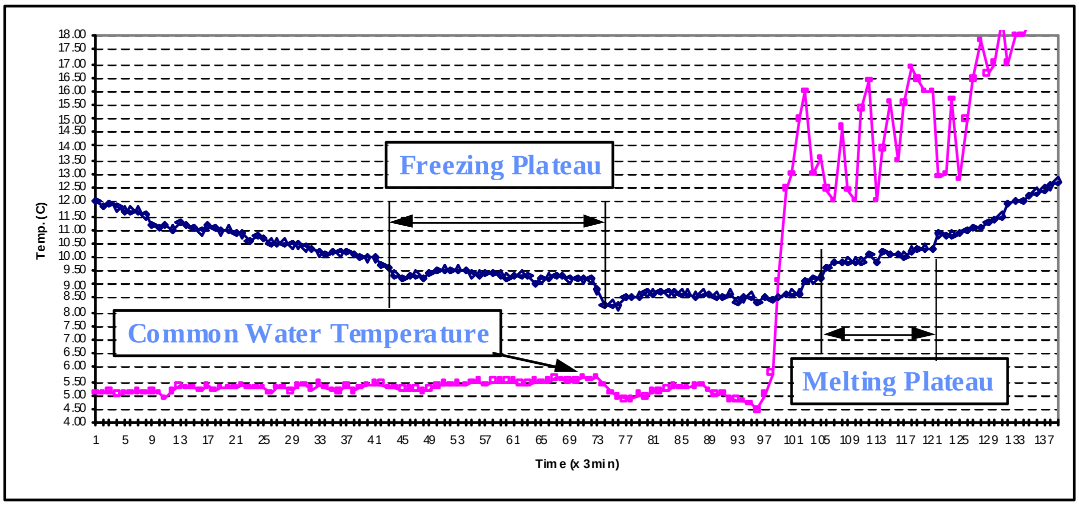


Figure 3.3.2.A Typical PlusICE (E-10) PCM Beams Freeze/Melt Cycle

The latent heat of fusion from the salt hydrates allows the PlusICE system to have a larger thermal energy storage capacity relative to its physical size and therefore storage space requirements can be as low as 1/4th of the chilled water storage system as illustrated in Figure 3.3.3. This is a similar space efficiency found in the conventional ice storage system with the additional benefit of operating in a most energy efficient and conventional temperature ranges without the need for a costly and complex glycol and/or refrigeration system.

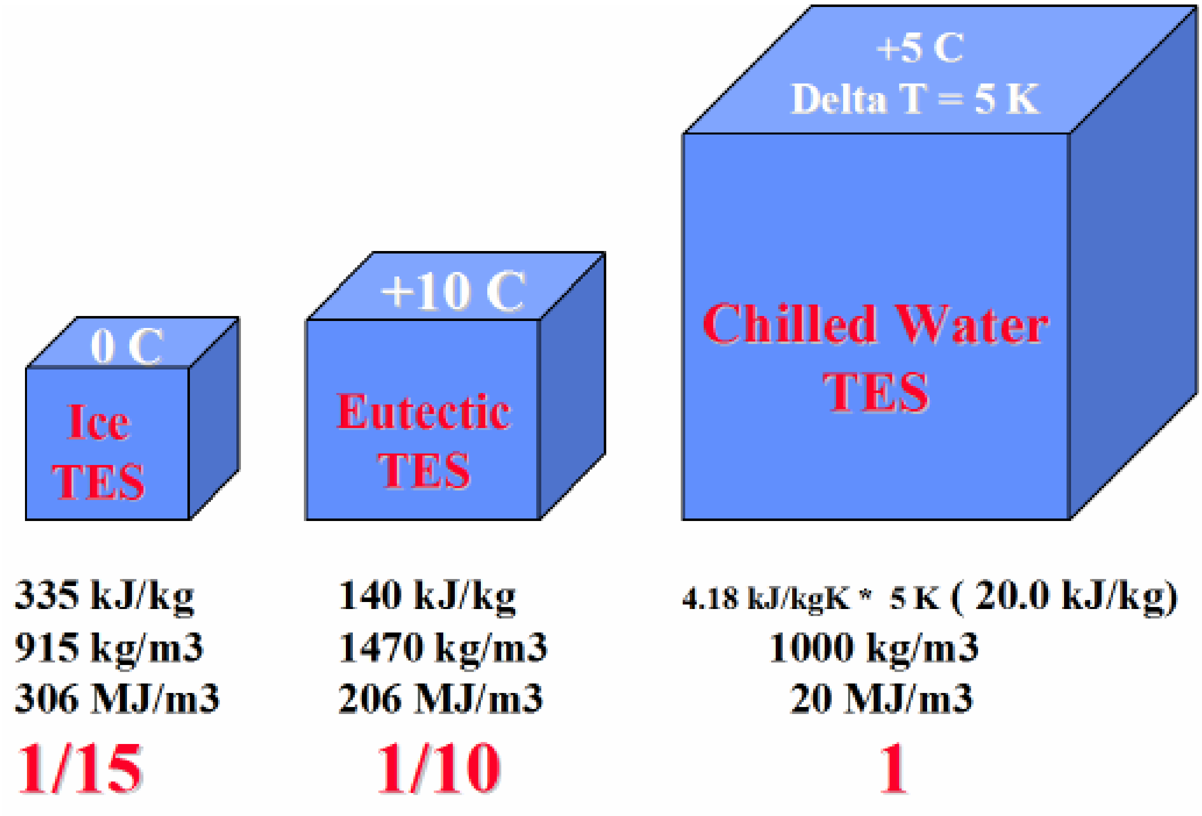


Figure 3.3.3. PCM Thermal Energy Storage Concept

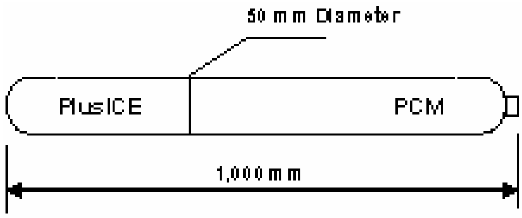
Unlike the ice storage system, however, the PlusICE system can be used with any conventional water chiller both for a new or alternatively retrofit application. The positive temperature phase change allows centrifugal and absorption chillers as well as the conventional reciprocating and screw chiller systems or even lower ambient conditions utilising a cooling tower or dry cooler for charging the TES system.

The temperature range offered by the PlusICE technology provides a new horizon for the building services and refrigeration engineers regarding medium and high temperature energy storage applications. The scope of this thermal energy application is wide ranging of solar heating, hot water, heating rejection, i.e. cooling tower and dry cooler circuitry thermal energy storage applications.

3.4 PlusICE TES Concept;

3.4.1 TubeICE Design;

TubeICE concept is based on custom-made plastic containers filled with our PlusICE Phase Change Materials (PCM) solutions which have operating temperatures between ***-50°C (-49°F)*** and ***+117 °C (+273 °F)***. They can be stacked in either cylindrical / rectangular tanks for atmospheric / pressurized systems for a variety of thermal energy storage applications.



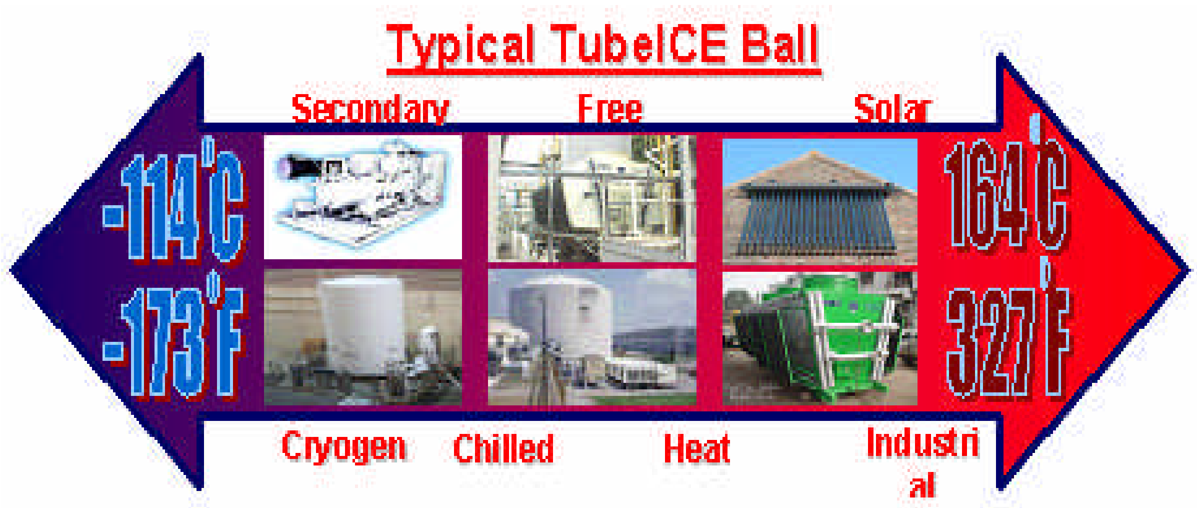
TubeICE custom-made HDPE plastic containers are filled with PlusICE PCM solutions and the filling port fully sealed after filling for safe and reliable operation.

The design of plastic container incorporates internal support columns as well as external guide circles so that the containers can be stacked on top of each other forming a self-assembling large heat exchanger within the tank. The self-stacking concept can be applied for both water and air circuits and the gap between each container provides an ideal flow passage with a large heat exchange surface.

TubeICE TES tanks can be any shape or form to suit site requirements. Tank volumes are calculated based on the required TES capacity and later designed to suit the site lay out and restrictions. Tanks can be either atmospheric or pressurised up to 10 Barg (145 Psig).

Tanks can be constructed using plastic, steel or concrete and they can be installed both under and as above ground applications. PlusICE balls are transferred into the TES tank via either tank covers or man hole from the top and the bottom. Bottom manholes are added in case the balls have to be taken out for service maintenance purposes.

Tanks can be supplied with supply and return headers providing ideal flow conditions within the tank to suit the temperature range and PCM type. This not only provides ideal heat transfer co-efficiency but also the weight and operational PCM balance can be modified to provide ideal thermal stratification conditions for the tank as a whole. PCM offers a standard range of both cylindrical and rectangular sectional tanks to match the TubeICE design to suit for any chilled water, heat recover, and heating and solar heat recovery applications.



TubeICE CAPACITY TABLE

PCM Type	Phase Change Temperature (C)	Phase Change Temperature (F)	Weight kg/TubeICE	Weight Lb/TubeICE	TubeICE (kWh/TubeICE)	TES Tank Capacity (kWh/m3)	*TubeICE (Ton-hr/TubeICE)*	*TES Tank Capacity (Ton-hr/USG)*
S89	89	*192*	2.7	*6.0*	0.124	55	*0.035*	*0.053*
S83	83	*181*	2.8	*6.2*	0.119	52	*0.034*	*0.051*
S72	72	*162*	2.9	*6.4*	0.113	50	*0.032*	*0.049*
S58	58	*136*	2.7	*5.9*	0.124	55	*0.035*	*0.053*
S50	50	*122*	2.8	*6.2*	0.081	36	*0.023*	*0.035*
S46	46	*115*	2.8	*6.2*	0.148	65	*0.042*	*0.064*
S44	44	*111*	2.8	*6.2*	0.081	36	*0.023*	*0.035*
S34	34	*93*	3.6	*7.9*	0.114	50	*0.032*	*0.049*
S32	32	*90*	2.6	*5.7*	0.135	59	*0.038*	*0.058*
S30	30	*86*	2.4	*5.2*	0.132	58	*0.038*	*0.057*
S27	27	*81*	2.7	*6.0*	0.145	64	*0.041*	*0.062*
S25	25	*77*	2.7	*6.0*	0.143	63	*0.041*	*0.062*
S23	23	*73*	2.7	*6.0*	0.143	63	*0.041*	*0.062*
S21	22	*72*	2.7	*6.0*	0.143	63	*0.041*	*0.062*
S19	19	*66*	2.7	*5.9*	0.109	48	*0.031*	*0.047*
S17	17	*63*	2.7	*6.0*	0.107	47	*0.030*	*0.046*
S15	15	*59*	2.7	*5.9*	0.106	47	*0.030*	*0.046*
S13	13	*55*	2.7	*5.9*	0.105	46	*0.030*	*0.045*
S10	10	*50*	2.6	*5.8*	0.102	45	*0.029*	*0.044*
S8	8	*46*	2.6	*5.8*	0.102	45	*0.029*	*0.044*
S7	7	*45*	3.0	*6.5*	0.099	43	*0.028*	*0.043*
E0	0	*32*	1.9	*4.2*	0.177	78	*0.050*	*0.076*
E-2	-2.0	*28*	2.0	*4.5*	0.114	67	*0.032*	*0.049*
E-3	-3.7	*25*	2.0	*4.4*	0.115	67	*0.033*	*0.049*
E-4	-3.9	*25*	2.0	*4.4*	0.104	61	*0.029*	*0.045*
E-6	-6.0	*21*	2.1	*4.6*	0.106	62	*0.030*	*0.046*
E-10	-10.0	*14*	2.1	*4.7*	0.113	66	*0.032*	*0.049*
E-11	-11.6	*11*	2.1	*4.5*	0.114	67	*0.032*	*0.049*
E-12	-12.3	*10*	2.1	*4.6*	0.096	57	*0.027*	*0.041*
E-14	-14.8	*5*	2.2	*5.0*	0.103	60	*0.029*	*0.044*
E-15	-15.0	*5*	2.0	*4.4*	0.112	65	*0.032*	*0.048*
E-19	-18.7	*-2*	2.1	*4.6*	0.110	65	*0.031*	*0.047*
E-21	-20.6	*-5*	2.3	*5.0*	0.113	66	*0.032*	*0.049*
E-22	-22.0	*-8*	2.2	*4.8*	0.096	56	*0.027*	*0.041*
E-26	-26.0	*-15*	2.3	*5.0*	0.113	66	*0.032*	*0.049*
E-29	-29.0	*-20*	2.5	*5.6*	0.109	64	*0.031*	*0.047*
E-32	-32.0	*-26*	2.4	*5.2*	0.109	64	*0.031*	*0.047*
E-34	-33.6	*-28*	2.2	*4.9*	0.100	59	*0.029*	*0.043*
E-37	-36.5	*-34*	2.7	*5.9*	0.111	65	*0.032*	*0.048*
E-46	-46.0	*-51*	2.2	*4.9*	0.100	59	*0.029*	*0.043*
E-50	-49.8	*-58*	2.4	*5.3*	0.100	59	*0.028*	*0.043*

Our standard TubeICE container design is based on 50 mm (2") diameter x 1,000 mm (39") long and once the required TES capacity is established using the above table, no of required TubeICE containers can be selected for the operating temperature range.

Once the number of TubeICE containers is established the design of the holding tank can be developed to accommodate the containers with inlet and outlet diffuser headers and the following formula can be used to establish the design basic criteria.

SI Units;

$$\frac{\text{Load (kWh)}}{\text{TubeICE Capacity (kWh / m3)}} = \text{Tank Volume (m3)}$$

No of TubeICE = 440 x Tank Volume (m3)

Using the ideal aspect ratios of between 1:4~1:6, tank length can be calculated.

IP Units;

$$\frac{\text{Load (Ton-hr)}}{\text{TubeICE Capacity (Ton-hr / USG)}} = \text{Tank Volume (USG)}$$

No of TubeICE = 1.5 x Tank Volume (USG)

Using the ideal aspect ratios of between 1:4~1:6, tank length can be calculated.

TubeICE is particularly suitable for cylindrical tanks as it naturally fits within the curve of the tank and one side of the vessel is designed to have the inlet diffuser providing equal flow through the containers and the identical outlet diffuser ensures that a steady and uniform water flow across the containers at all time.

The size of the inlet / outlet pipes as well as the number of holes and sizes for the diffuser plates has to be designed to match the water circulation flow rates of the system and our design team would be more than happy to help you to develop a custom-made design to suit your operational / system requirements.

A typical TubeICE freezing and melting performance curves against various temperature difference between the surrounding water and PCM solution are illustrated in Figure 3.4.1.1 and 3.4.1.2 respectively;

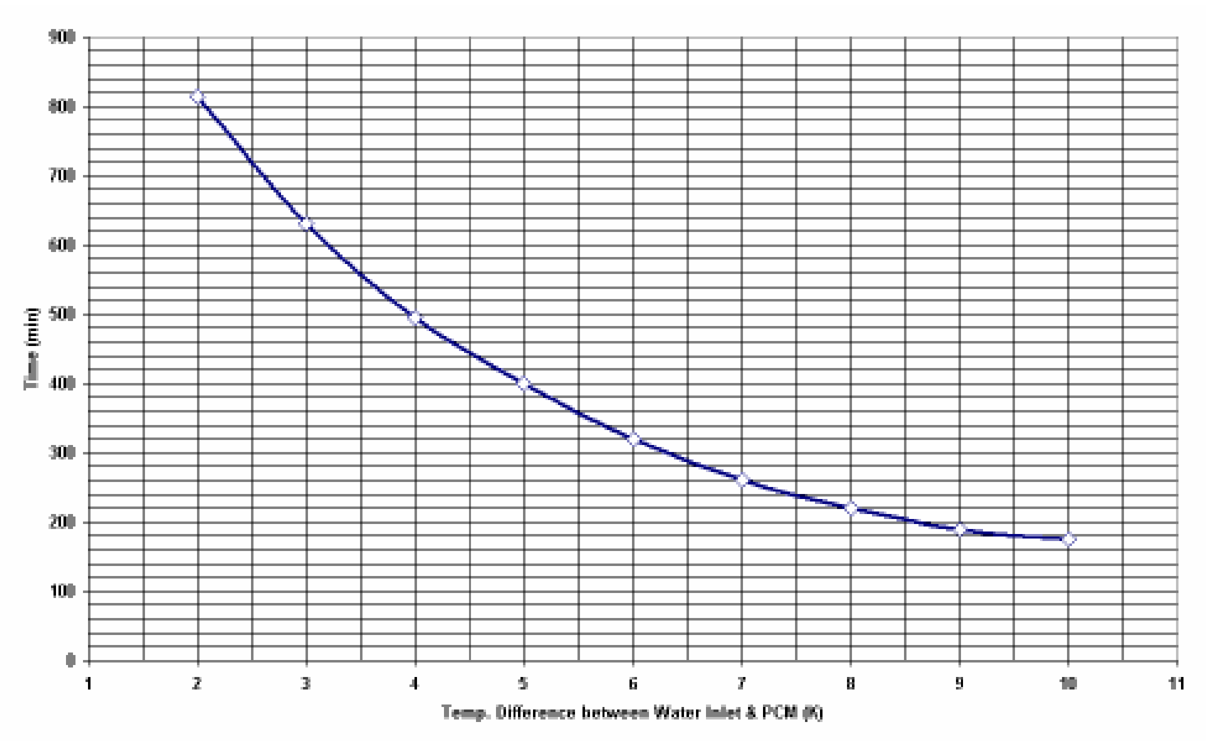


Figure 3.4.1.1- TubeICE freezing Profile

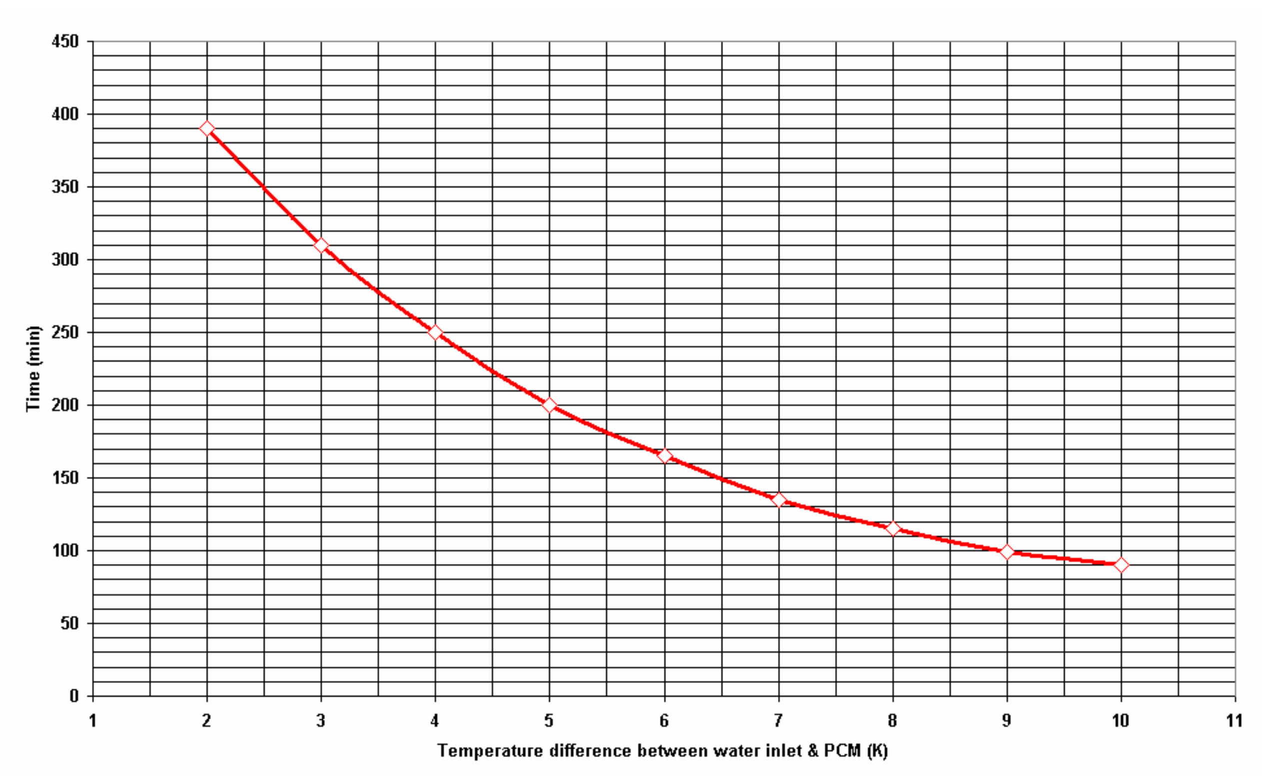
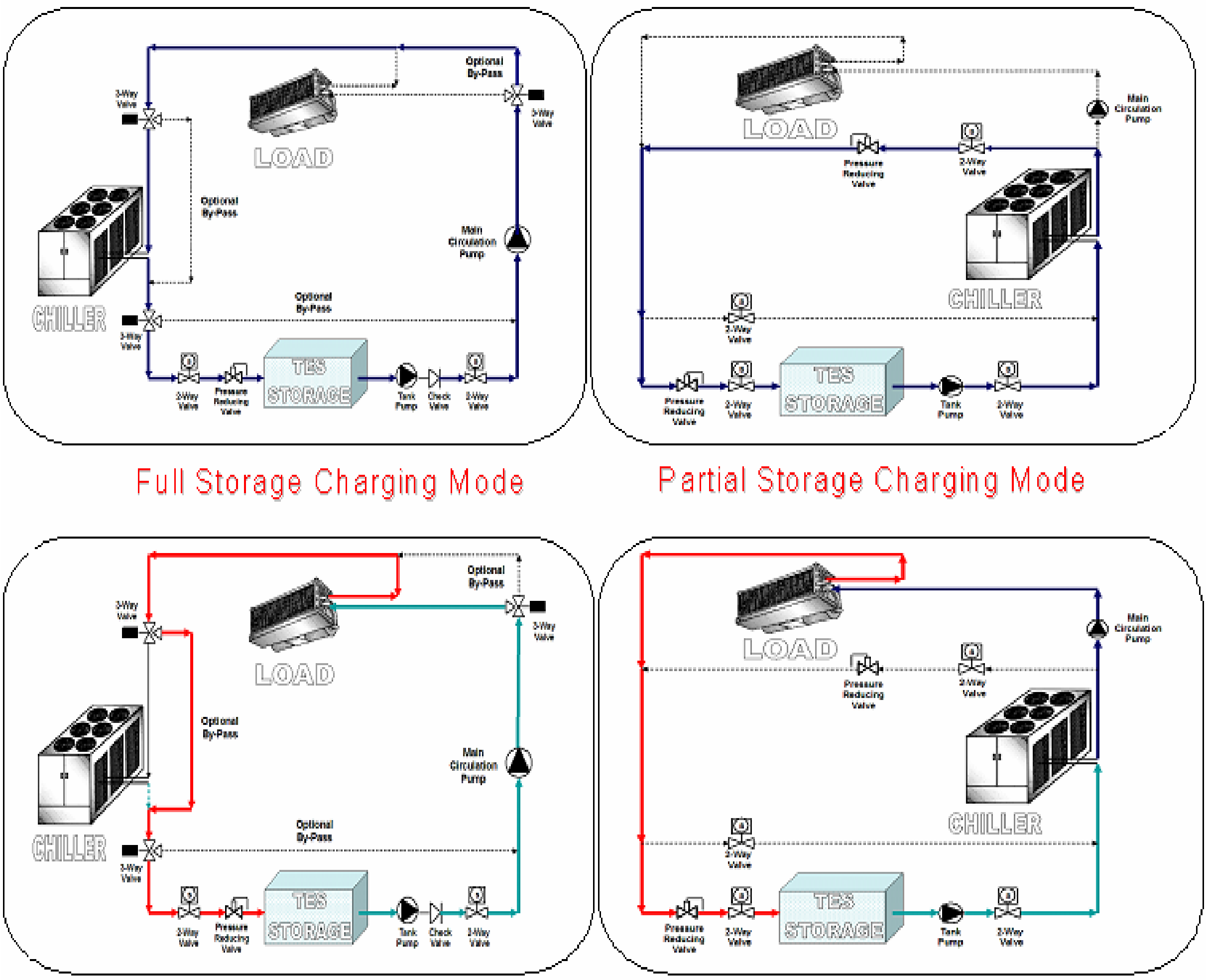


Figure 3.4.1.2- TubeICE melting profile

TYPICAL TANK OPERATION;



Full Storage Charging Mode

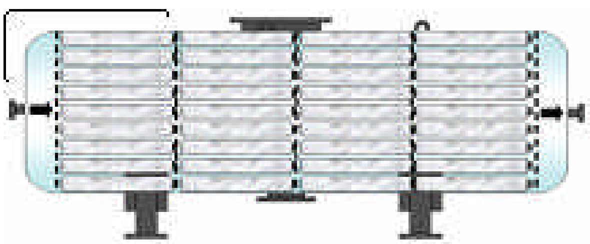
Partial Storage Charging Mode

Full Storage Discharging Mode

Partial Storage Discharging Mode

The standard cylindrical tanks can be manufactured in diameter to height aspect ratios of up to 1:5. The steel tanks are shipped plain and are generally insulated on site but plastic tanks can be supplied in 50 mm (2”) pre-insulated form as standard.

The sectional and fully internally flanged rectangular tanks are supplied in 1m x 0.5m and 1mx1m (3.28’x1.64’ and 3.28’x3.28’) complete with 50mm (2“) thick insulated sections and they are built on site to suit the site layout.



3.4.2 BallICE Design;

BallICE rubber PCM ball concept is based on custom-made moulded plastic mixtures containing our organic PlusICE Phase Change Materials (PCM) solutions. Our rubber ball PCM concept is designed for small scale mainly heat storage application such as solar and domestic heating tanks.

In principal, they can be produced in any diameter and any of our organic PCM solutions but the optimum size of 40mm in diameter using +50 ºC (+122 ºF) and +82 ºC (+180 ºF) PCM solutions are found to be most attractive options for hot water and heating storage applications respectively.

BallICE can be applied for ether cylindrical / rectangular tanks for atmospheric / pressurized systems for a variety of thermal energy storage applications.

BallICE can be applied for cylindrical & rectangular tanks for both atmospheric & pressurized systems for a variety of thermal energy storage applications.

Ball can be applied for both NEW and RETROFIT applications by simply filling the tank from any large pipe connections when they empty and as the balls are lighter than when the tank is filled with water they tend to float and fill the tank whole volume and the water flows through the balls for a fast heat exchange. TES capacities of BallICE range are as follows;

PCM Type	Phase Change Temperature (°C)	Phase Change Temperature (°F)	BallCE (kWh/Ball)	TES Tank Capacity (kWh/m3)	BallICE (Ton-hr/Ball)	TES Tank Capacity (Ton-hr/ft3)
A82	82	180	0.0200	20.09	0.0057	0.162
A70	70	158	0.0271	27.22	0.0077	0.219
A62	62	144	0.0254	25.56	0.0072	0.206
A60	60	140	0.0248	24.92	0.0070	0.200
A58	58	136	0.0264	26.57	0.0075	0.214

Using the required energy storage capacity using the following formulation the number of BallICE can be calculated.

SI Units;

Load (kWh)
-- = Tank Volume (m3)
BallICE Capacity (kWh / m3)

No of BallICE (NoT) = 16,500 x Tank Volume (m3)

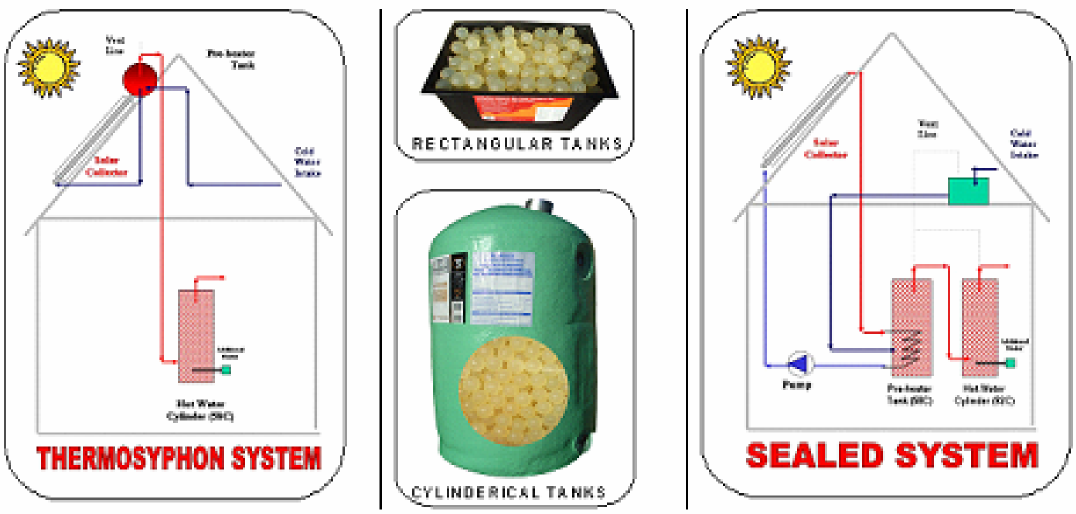
Standard size balls are in 40mm diameter and weight approx. 30 grams / ball.

IP Units;

Load (Btu)
-- = Tank Volume (USG)
BallICE Capacity (Btu / USG)

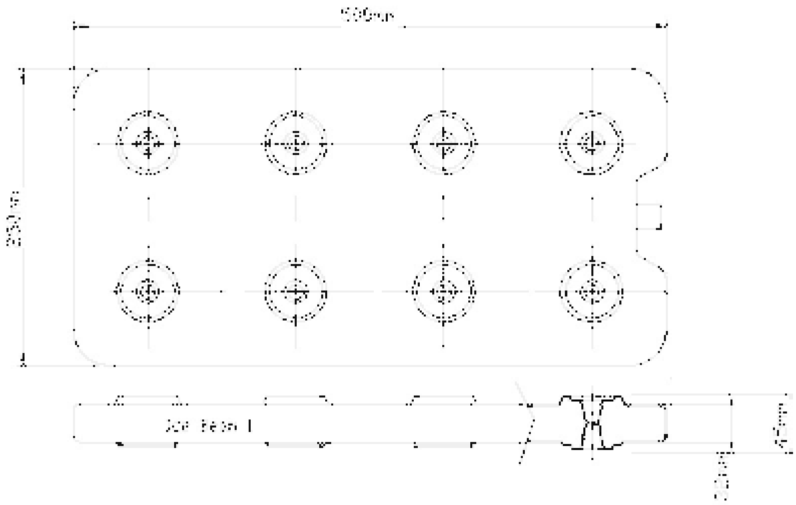
No of BallICE = 62.4 x Tank Volume (USG)

Standard size balls are in 1 ½" diameter and weight approx. 0.066 lbs / ball (1.05 Oz / ball).

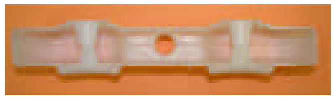


3.4.3 FlatICE Design;

Certain applications using custom-made PlusICE solutions it is possible to achieve an economical TES solution by using plastic flat containers (FlatICE) as illustrated in Figure 3.4.3.1.



FlatICE



FlatICE Cross

FlatICE Self-Stacking

Figure 3.4.3.1 - *Plus*ICE PCM filled FlatICE Container Construction

The heat transfer between the surrounding fluid water / refrigerant or alternatively air which flows outside the containers and the sealed PCM solutions takes place from both the outer surface of the plastic containers.

As FlatICE primarily design for heavier PCM solutions and therefore the relevant average freezing and melting times for a container filled with PCM incorporated in Figure 3.4.3.2 and 3.4.3.3 respectively against various temperature difference between the surrounding water and PCM.

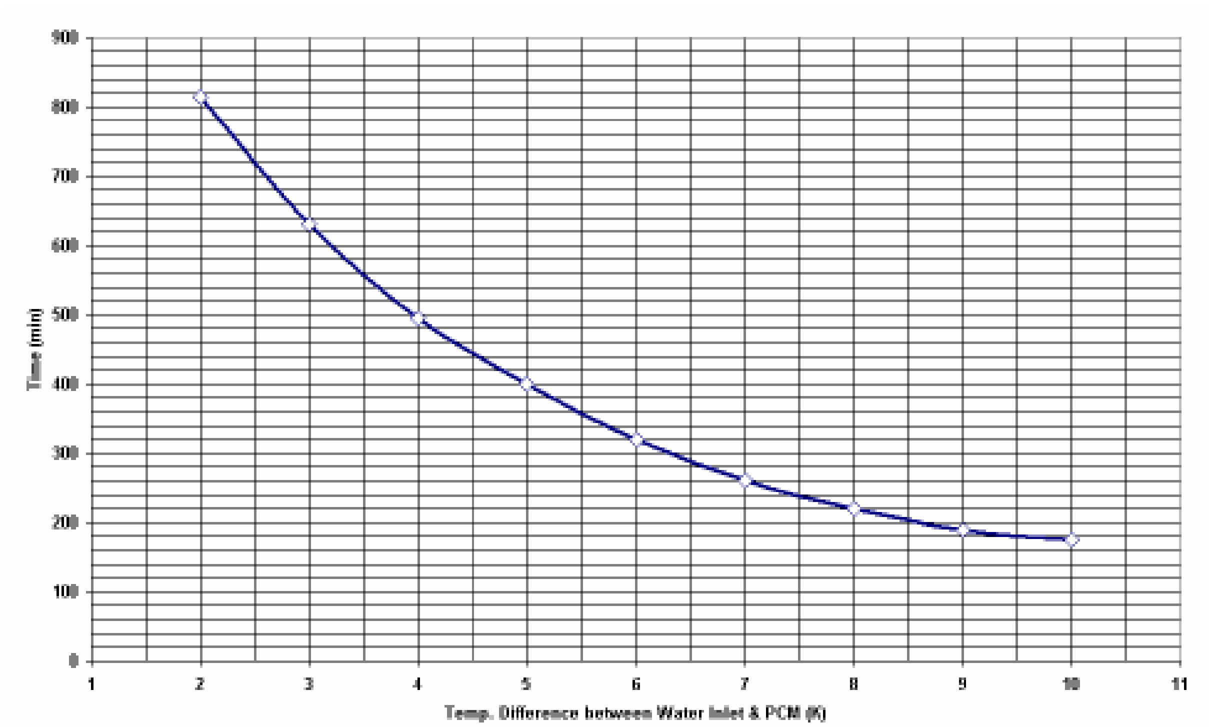


Figure 3.4.3.2 - FlatICE Freezing Performance

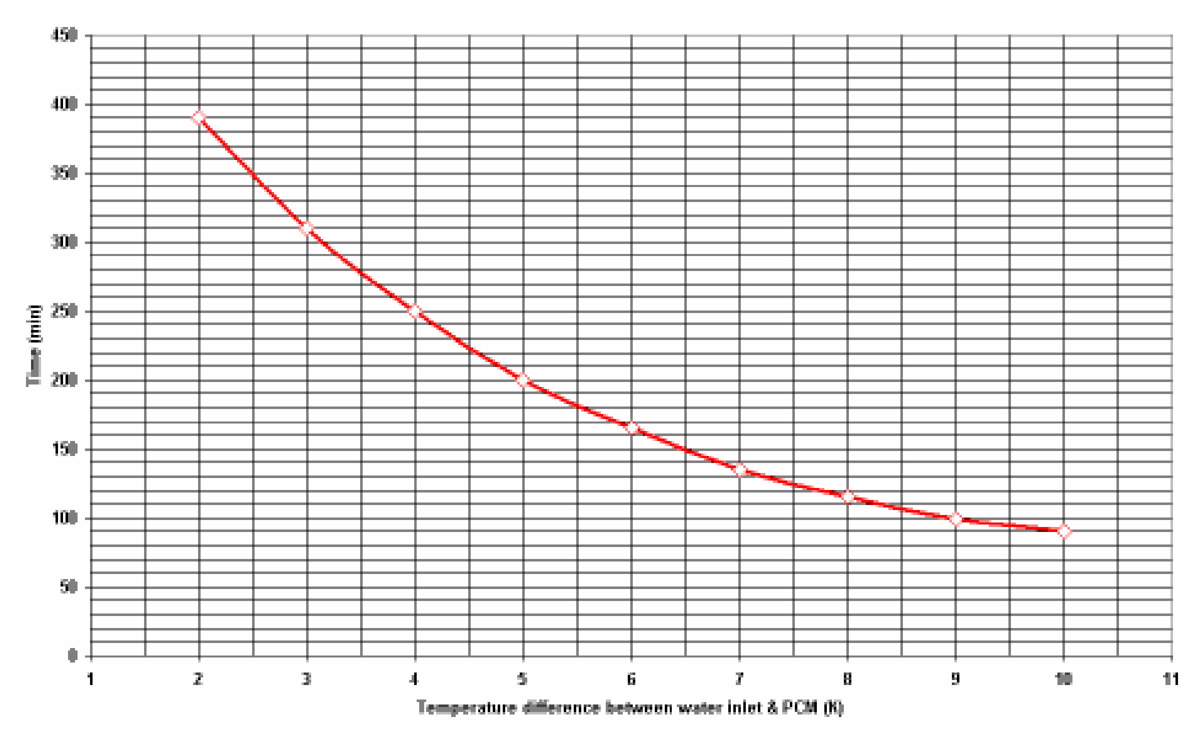


Figure 3.4.3.3 - FlatICE Melting Performance

The PlusICE phase change material is permanently sealed inside the flat plastic containers which can be placed in any shape tank to enable the water or air to pass around them in order to provide heat exchange capability.

The standard FlatICE containers are manufactured in 500 mm (19.6") x 250 mm (10") x 32mm (1.25") forms, but the standard PCM FlatICE containers can be manufactured in any other diameters to suit specific applications.

The FlatICE plastic containers can be stacked on top of each other within the tank in order to provide a centralised thermal energy storage concept and a typical layout of a PlusICE tank can be seen in Figure 3.4.3.4.

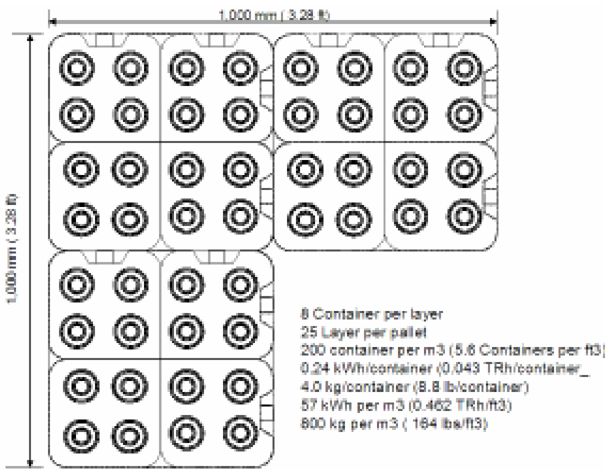


Figure3.4.3.4- FlatICE Tank Sizing

The unique self-locking circles of the FlatICE plastic containers with extended rings are designed to provide maximum linkage between the containers and maintain a uniform gap between the containers for an equal flow passages across the tank. These external surfaces are also designed to provide extra area as well as creating change in flow direction for maximum heat transfer efficiency across the tank.

The FlatICE plastic containers design offers a very flexible design providing by simply designing a larger tanks and adding more containers whenever required in the future.

A typical combination of centralised FlatICE plastic containers chilled water thermal energy storage application is illustrated in Figure 3.4.3.5 and Figure 3.4.3.6 for water and air TES applications.

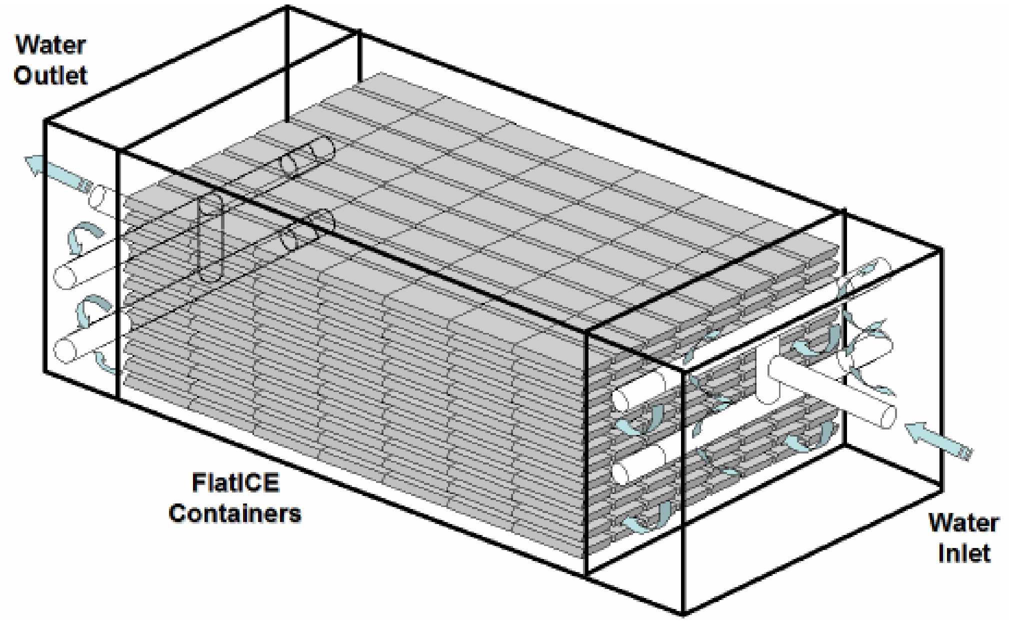


Figure 3.4.3.5 - A typical FlatICE plastic containers Water TES application

At night the chillers produce conventional 5ºC (41ºF) chilled water which passes through the PlusICE TES tank in order to charge the system. The cooling effect from the chilled water circuit is absorbed by the phase change material thereby freezing the eutectic solution at its phase change point. During the day, warm returned water from the building flows through the PlusICE TES tank to recover the stored latent heat capacity of the phase change materials before returning the chiller circuit.

The circulation water flows within the tank between the containers during both freezing and melting cycles. A PlusICE system is easy to operate and control due to its static nature of the design and it is considered to be practicality maintenance-free.

The above heat transfer can also be organized for air circuits to store energy during off-peak periods or free over-night and the principal our heat transfer is identical to water circuits and a typical air TES using FlatICE containers are illustrated in Figure 3.2.3.6.

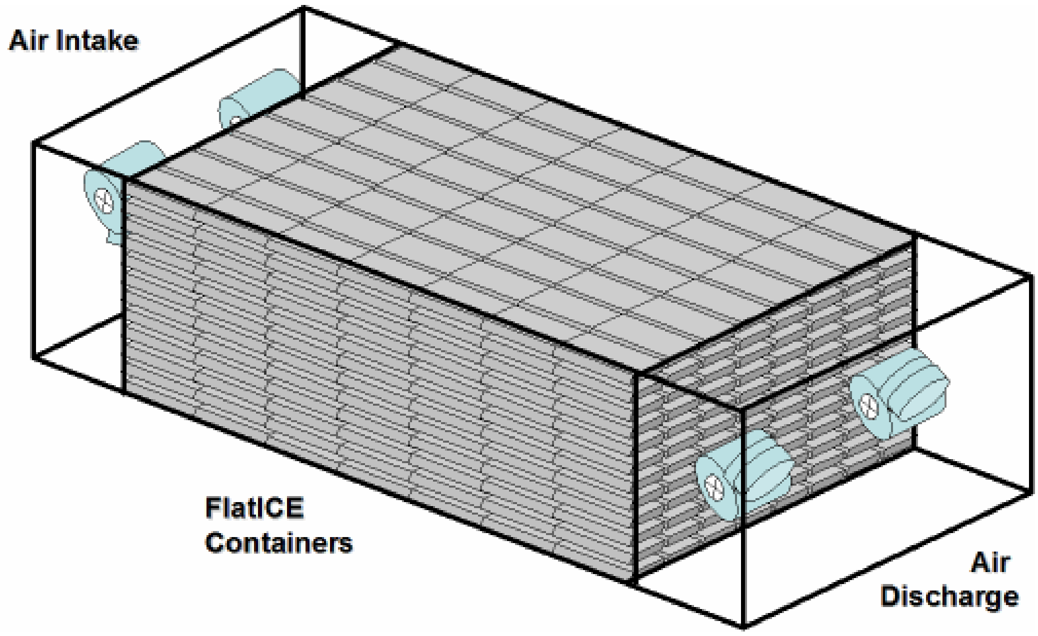


Figure 3.4.3.6 - A typical FlatICE plastic containers Air TES application

As a rule of thumb, 200 number of our standard FlatICE containers occupy 1 m3 tank volume and based on this capacity range the size of the tank volume as well as the number of containers can be selected to satisfy the operational temperature range. A simple table indicating the average capacity of the FlatICE plastic containers using our standard PlusICE solution is incorporated in Table 3.4.3.1.

Type	Temperature (C) (C)	Temperature (F) (F)	(kWh/Container)	Capacity (kWh/m3)	(Ton-hr/Cont.)	Capacity (Ton-hr/US Gallon)	Container Weight (kg)	Container Weight (lbs)
S46	46	115	0.318	64	0.090	0.063	6.03	13.30
S32	32	90	0.287	57	0.082	0.062	5.55	12.23
S30	30	86	0.277	55	0.079	0.060	4.96	10.93
S27	27	81	0.310	62	0.088	0.067	5.81	12.82
S25	25	77	0.248	50	0.070	0.053	5.76	12.69
S23	23	73	0.241	48	0.068	0.052	5.78	12.74
S21	21	70	0.234	47	0.067	0.050	5.78	12.74
S19	19	66	0.230	46	0.065	0.050	5.77	12.73
S17	17	63	0.230	46	0.065	0.050	5.80	12.78
S15	15	59	0.224	45	0.064	0.048	5.74	12.65
S13	13	55	0.224	45	0.064	0.048	5.76	12.69
S10	10	50	0.220	44	0.062	0.047	5.59	12.32
S8	8	46	0.219	44	0.062	0.047	5.61	12.36

Table 3.4.3.1 – FlatICE plastic containers Capacity Tables

FlatICE containers can only be stacked up to 2.6 m (8 ½ ft) level and therefore the height of the tank is restricted around 3m (10 ft) and the size of the tank can be adjusted within this limit. In principal, the longer the tank the larger the temperature difference one can achieve across the tank and the width / length ratios can be adjusted to suit the site requirements.

Furthermore, if the storage capacity too large and the design require multiple tanks, they can be arranged either in parallel or series format to suit the application and available space. Typically the depth of the tank will be 2.6 m (81/2 ft) inside dimension which corresponded to approx. 65 FlatICE containers high and 150mm (6") of head room above the containers. Therefore, to estimate the approximate tank size and shape one can use the following formula inline with Table 3.4.3.1 FlatICE capacity values.

SI Units;

$$\frac{\text{Load (kWh)}}{\text{FlatICE Capacity (kWh / m3)}} = \text{Tank Volume (m3)}$$

No of FlatICE = 200 x Tank Volume (m3)

Using the ideal aspect ratios of between 1:4~1:6, tank length can be calculated.

IP Units;

$$\frac{\text{Load (Ton-hr)}}{\text{FlatICE Capacity (Ton-hr / USG)}} = \text{Tank Volume (USG)}$$

No of FlatICE = 0.75 x Tank Volume (USG)

Using the ideal aspect ratios of between 1:4~1:6, tank length can be calculated.

Where the Width is divisible by 250mm (9.842") and the Length is rounded to the nearest even number. The inside length and width dimensions of the tank are derived from the nominal size of FlatICE container 250mm (10") x 500 mm (20") shape. It is vital to ensure the exact construction drawings are produced using this dimensional limits in particular the width has a critical tolerance as it must avoid by-pass of any flow which will have a detrimental affect on the operation of the tank.

The length has more tolerance and less critical from the operational point of view. Typically, it is recommended to include 1m (3.28 ft) of tolerance of clear space in each end to accommodate the entrance and exit headers.

3.4.4 Storage Tanks Options;

The flexible characteristic and extensive temperature range of FlatICE plastic containers offer the designers the flexibility of shape, size and location for the ice storage tank. Tanks can be divided into two groups namely factory or sire built units and generally factory built units remains within the limits of Glass Reinforced Polyester (GRP) or Steel Tanks.

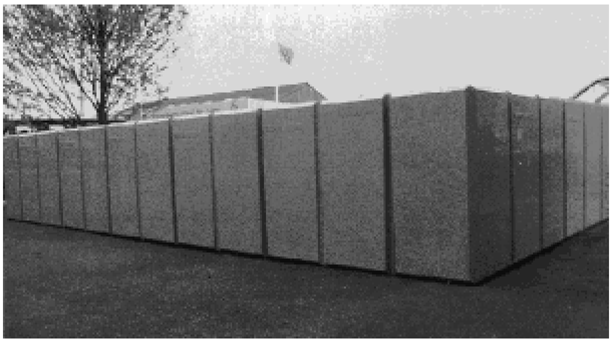
For smaller capacities our standard CFC-free pre-insulated Glass Reinforced Polyester (GRP) sectional rectangular and cylindrical tank concept can be utilised to accommodate the FlatICE plastic containers with slight different header arrangement in comparison with BallICE application.

However, the nature of the FlatICE results in the application of large capacity TES applications and the operating temperature of the PlusICE solutions applied for the FlatICE makes concrete tanks as the most economical and practical installation. It is vital to provide a suitable tank pipe sealing system, water flow and return headers for trouble free operation.

FACTORY BUILT TANKS

Glass Reinforced Polyester (GRP) sectional tanks can be designed for site assembly for application flexibility and all storage tanks ***MUST COMPLY*** with all local Water Bylaws.

It is recommended that a CFC-free pre-Insulated GRP tank complete with Totally Internal Flange (TIF) construction concept is implemented in order to achieve tight space application and sweat-free operation.



PlusICE ice storage vessels must be supplied complete with Manway Access, Safety Relief Vent, Overflow and Screen and the essential system inlet and outlet header arrangement to suit the application.

PCM Products Ltd. has a range of standard cylindrical and sectional rectangular tanks to suit any application as part of our FlatICE range. The relevant dimensional details are incorporated in Table 3.4.4.1 and Table 3.4.4.2 for rectangular and cylindrical tanks respectively.

Model		H5	H10	H25	H50	H75	H100
Volume	m3	5	10	25	50	75	100
	ft3	177	353	883	1766	2649	3532
Diameter	m	1.25	1.6	2	2.5	3	3
	ft	4.1	5.248	6.56	8.2	9.84	9.84
Height	m	3.75	4.5	8	10	10.6	11.1
	ft	12.3	14.76	26.24	32.8	34.768	36.408
Water Inlet	m	50	80	125	150	200	250
		2"	2"	2"	2"	2"	2"
Water Outlet	m	50	80	125	150	200	250
		2"	2"	2"	2"	2"	2"
Drain	m	50	50	50	50	50	50
		2"	2"	2"	2"	2"	2"
Vent	m	50	50	50	50	50	50
		2"	2"	2"	2"	2"	2"
Man Hole	m	400	400	400	400	400	400
Man Hole		16"	16"	16"	16"	16"	16"

Table 3.4.4.1 Rectangular Standard Tank Dimensional Details

		Tank Length (m)																
Dia. (m)	Type	4	4.5	5	5.5	6	6.5	7	7.5	8	8.5	9	9.5	10	10.5	11	11.5	12
1.00	C-**-**	130	151	173	195	216	238	260	281	303	324	346	368	389	411	433	454	476
1.25	C-**-**	149	173	198	223	248	272	297	322	347	371	396	421	446	470	495	520	545
1.50	C-**-**	197	229	262	295	328	360	393	426	459	491	524	557	590	622	655	688	721
1.75	C-**-**	279	326	372	419	465	512	558	605	651	698	744	791	837	884	930	977	1,023
2.00	C-**-**	375	438	500	563	625	688	750	813	875	938	1,000	1,063	1,125	1,188	1,250	1,313	1,375
2.25	C-**-**	485	565	646	727	808	888	969	1,050	1,131	1,211	1,292	1,373	1,454	1,534	1,615	1,696	1,777
2.50	C-**-**	600	700	800	900	1,000	1,100	1,200	1,300	1,400	1,500	1,600	1,700	1,800	1,900	2,000	2,100	2,200
2.75	C-**-**	746	870	994	1,118	1,243	1,367	1,491	1,615	1,740	1,864	1,988	2,112	2,237	2,361	2,485	2,609	2,734
3.00	C-**-**	891	1,040	1,188	1,337	1,485	1,634	1,782	1,931	2,079	2,228	2,376	2,525	2,673	2,822	2,970	3,119	3,267
3.50	C-**-**	1,142	1,332	1,522	1,712	1,903	2,093	2,283	2,473	2,664	2,854	3,044	3,234	3,425	3,615	3,805	3,995	4,186

Table 3.4.4.2 Cylindrical Standard Tank Dimensional Details

The headers for the fluid inlet and outlet are positioned at high and low levels to suit the application. Typical application examples of Horizontal Cylindrical and Concrete / Rectangular tank arrangements are highlighted in Figure 3.4.2.1 and Figure 3.4.2.2respectively.

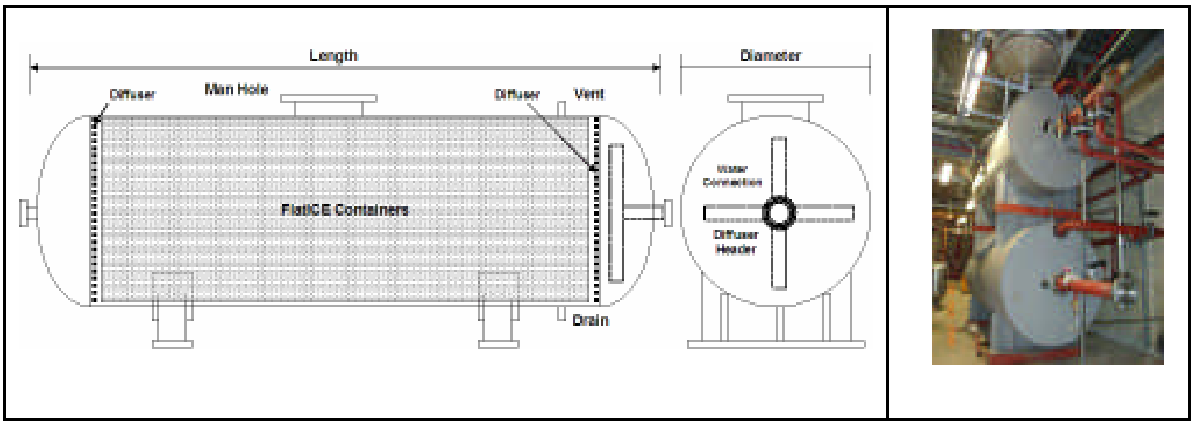


Figure 3.4.3.1- Typical Cylindrical FlatICE plastic containers TES Tank Design

SITE BUILT TANKS

Concrete tank applications require careful consideration regarding the contraction ratios of various tank materials. In particular, the pipe sealing system must be capable of providing leak free operation for varying solution temperatures. A suitable pipe sealing system must be installed for either the conversion of an existing or alternatively a site-built customised concrete tank installation.
The major technical challenge is to keep the internal tank water flow uniform throughout the tank section. In order to achieve this uniform flow so that the every single container is utilised it is recommend that carefully designed inlet and outlet diffusers are installed before and after the FlatICE stacks retaining sections.
A typical concrete tank using FlatICE containers are illustrated in Figure 3.4.2.3.

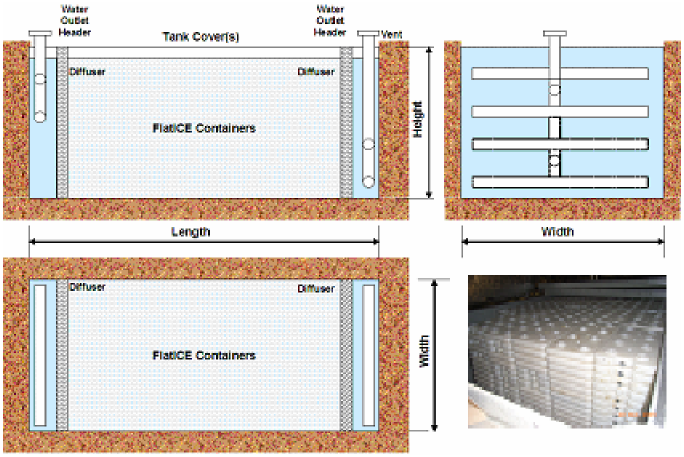


Figure 3.4.2.3- Typical Concrete FlatICE plastic containers TES Tank Design

However, the larger loads requires custom-made tanks and generally the lowest cost of tanks can be provided using concrete tanks which can be either above surface or underground.

In particular, the underground tanks offer the most cost effective solutions not only in terms of support and insulation but also it eliminates the need for large tank space as the surface of the TES tanks can be used either as a car park or alternative landscaped to suit the local architectural requirement.

3.5– Tank Installation & Operation

3.5.1- **Operational Modes;**

As the concrete tanks are designed for atmospheric pressure and therefore it requires a different piping in comparison with pressurised tanks and the operational modes of the atmospheric tank PlusICE TES are illustrated in Figure 3.5.1.1 and Figure 3.5.1.2 for Full Storage charging and discharging modes respectively.

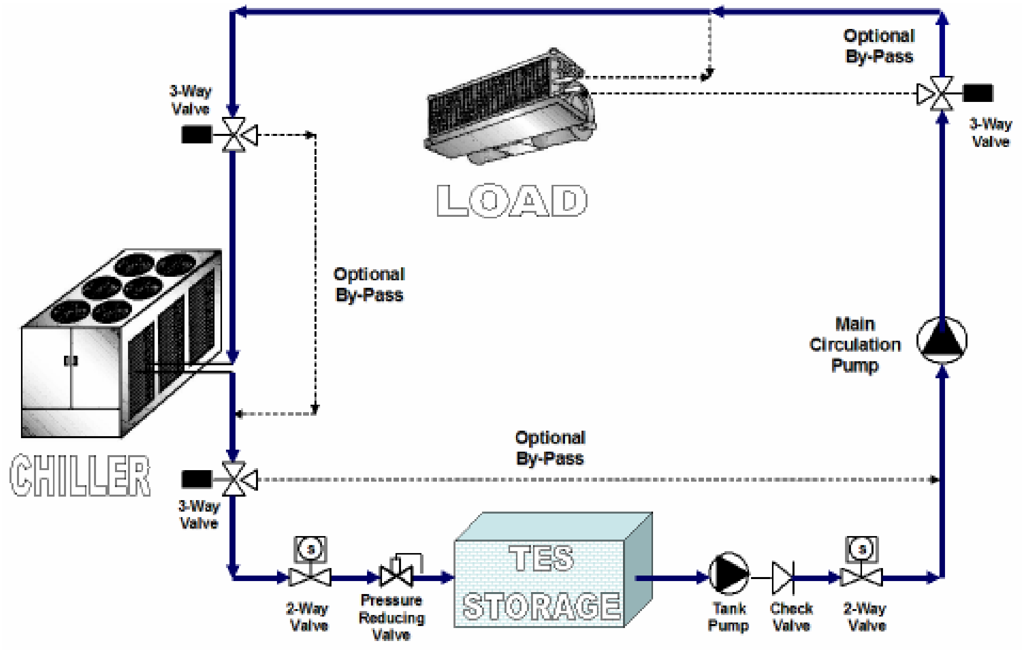


Figure 3.5.1.1- Full Storage Charging Mode

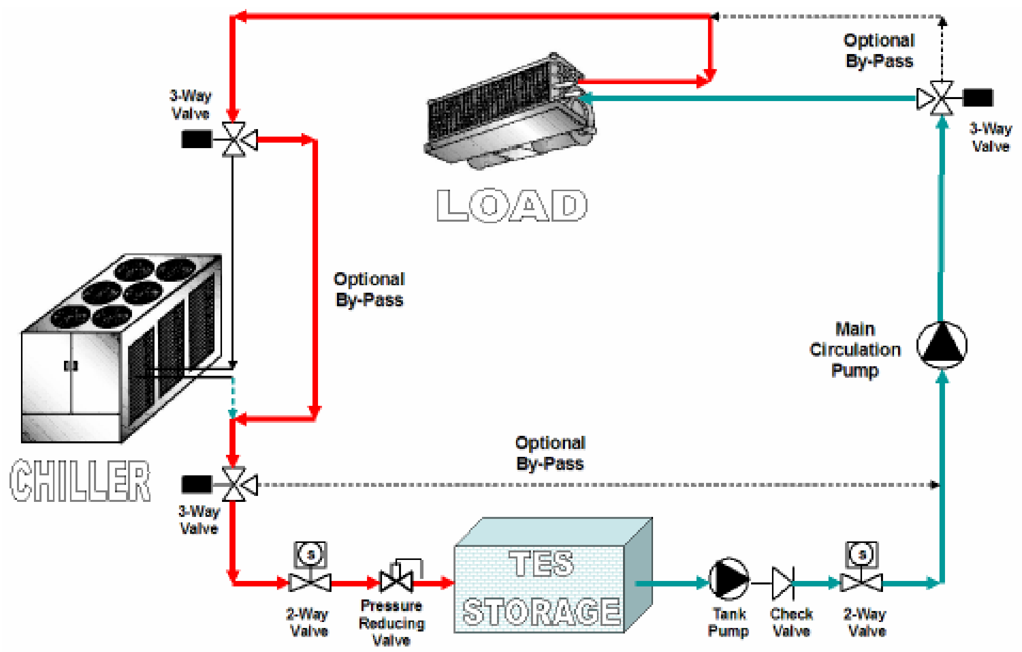


Figure 3.5.1.2- Full Storage Discharging Mode

The operational modes of the atmospheric tank PlusICE TES for Partial storage operation are illustrated in Figure 3.5.1.3 and Figure 3.5.1.4 for charging and discharging modes respectively.

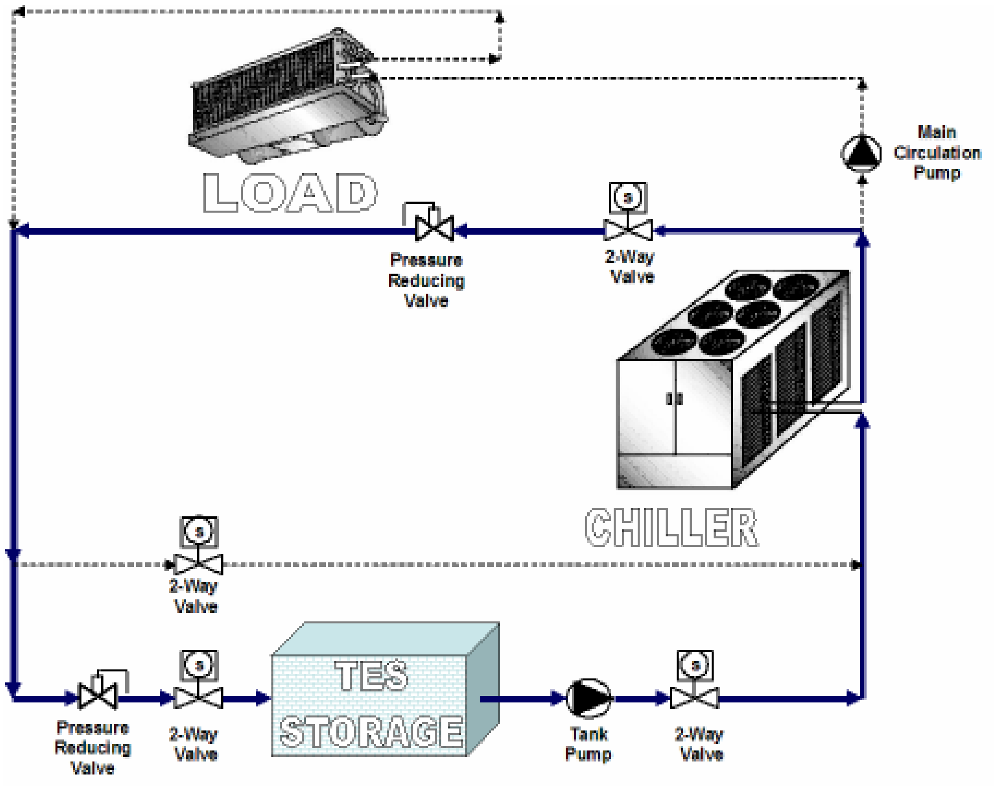


Figure 3.5.1.3- Partial Storage Charging Mode

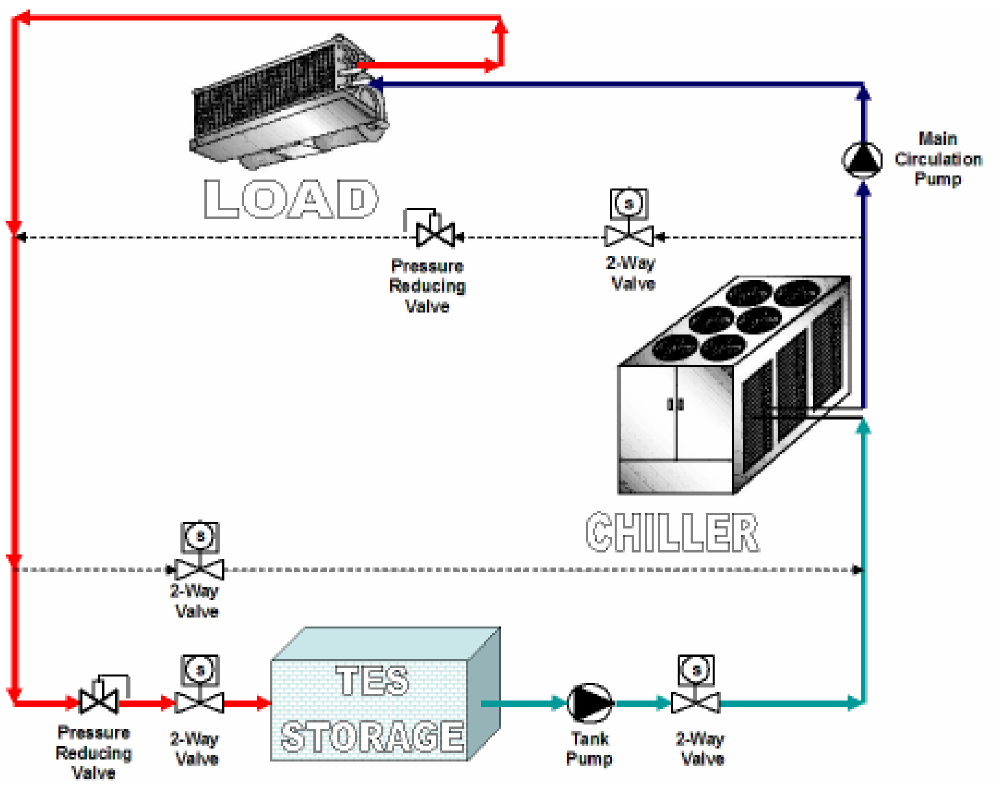


Figure 3.5.1.4- Partial Storage Discharging Mode

3.5.2- Tank Location

Generally concrete tanks are either built below ground level and the top of the tank used as a parking or landscape areas or alternatively within the basement area as part of the foundations. Tanks ideally should be construction as close as possible to the chiller and load to minimise the pipework and pumping energy penalties.

3.5.3- Tank Construction

Concrete tanks for energy storage generally constructed of reinforced concrete. Gunite, concrete block, tilt-up, pre-cast or site cast concrete can be considered as an option for the tank construction. If it required tank can in either cylindrical or rectangular shapes.

However, pneumatically applied concrete is found to be most cost effective and effective form of construction method. It is extremely sound, economical, and can be used to achieve excellent tolerances and finish. Each tank must be considered its own merits to suit the site and application as well as exact dimensions, loading requirements, soil conditions and therefore the designer must treat each tank individually and come up with the design to take care of all of these issues.

3.5.4- Tank Waterproofing

The recommended waterproofing system is a multi-layer, roll-on polyurethane liner. The result is tough, elastic coating, approx. 3mm (1/8") think that is designed to stretch at least 3mm (1/8") without any damage. This allows the membrane the flexibility to accommodate small shrinkage and settlement cracks that may occur during the life of the tank.

3.5.5- Water Flow Pattern

It is vital to get the water flow right as the performance of the heat exchange entirely relies on providing equal amount of flow across the FlatICE containers so that the heat exchange surface of the containers are fully utilised.

Water is introduced from one end and taking away fro the opposite end on single pass mode. The design is based on 0.3 m/s ~ 0.6 m/s (1 ft/min ~ 2 ft/min) fluid velocity over the Flat ICE containers and it take approx. 25 ~ 35 minutes for one full fluid exchange. FlatICE containers approx. displace 2/3 of the tank volume to the water line.

3.5.6- Entrance Headers

The fluid entrance header is manufactured utilising any common pipe materials but the plastic pipes are found to be far more practical due to light weight which spans the tank across the width parallel to the floor within the 1m (3.28ft) clear space before the FlatICE container packs.

The upper header is located just below the water level and the second header is positioned halfway between the water level and bottom of the tank. Both headers must be equally perforated on a regular pattern to provide an equally flow cross the width and height of the tank. Please consult our sales team for a proper header design.

3.5.7- Exit Headers

The fluid exit header is manufactured utilising any common pipe materials but the plastic pipes are found to be far more practical due to light weight which spans the tank across the width parallel to the floor within the 1m (3.28ft) clear space before the FlatICE container packs.
The bottom header is located 450mm (18") above the bottom of the tank and the second header is positioned halfway between the water level and top water level of the tank. Both headers must be equally perforated on a regular pattern to provide an equally flow cross the width and height of the tank. Please consult our sales team for a proper header design.

3.5.8- Tank Cover

The cover depends on the application and if it is for underground tank application it would be better to consider bowed, pre-stressed concrete planks across the width of the tank with full air tight sealing. If the tank is above ground either pre-stressed concrete or steel planks can be used.

It is vital to consult the structural engineer for the tank design as a whole and it is vital to ensure that the external contamination of the tank is avoided by design.

3.5.9- Tank Loading

It is vital to provide suitable inlet and outlet diffuser as well as headers to ensure as equal as uniform and water flow across the rectangular tank and more to the point the water flow between each and every FlatICE containers as equal as possible as this is vital to ensure that the whole tank PCM capacity can be charged and discharge.

Any atmospheric tank design should ensure that the tank would not have any stagnant section and water flow across the section of the tank remains uniform. Hence, a custom-made inlet and outlet diffuser to provide uniform water supply across the tank section. One side of the will be connected to the circulation pump which would generate negative pressure on the outlet section and equally it is vital to provide a positive pressure on the inlet diffuser side so that the pressure difference between the inlet and outlet sections force the water through the diffuser plates spreading the water equally like a shower head.

Although pressure drop across the FlatICE stack is very low but it is essential to allow at least 50 kPa (8 psig) avalaiable pressure for the tank as part of the pump design criteria so that this pressure will force the water through the diffuser plate on the inlet side and on the opposite end leaving water from the tank due to pump suction generates negative pressure to suck through the diffuser plates. Using this push and suck concept which should provide an equal flow across the tank section and also it should provide equal flow over each and every FlatICE containers so that the full heat transfer surface is utilised and effectively getting the full tank energy storage capacity.

A typical rectangular tank design is illustrated in Figure 3.5.9.1

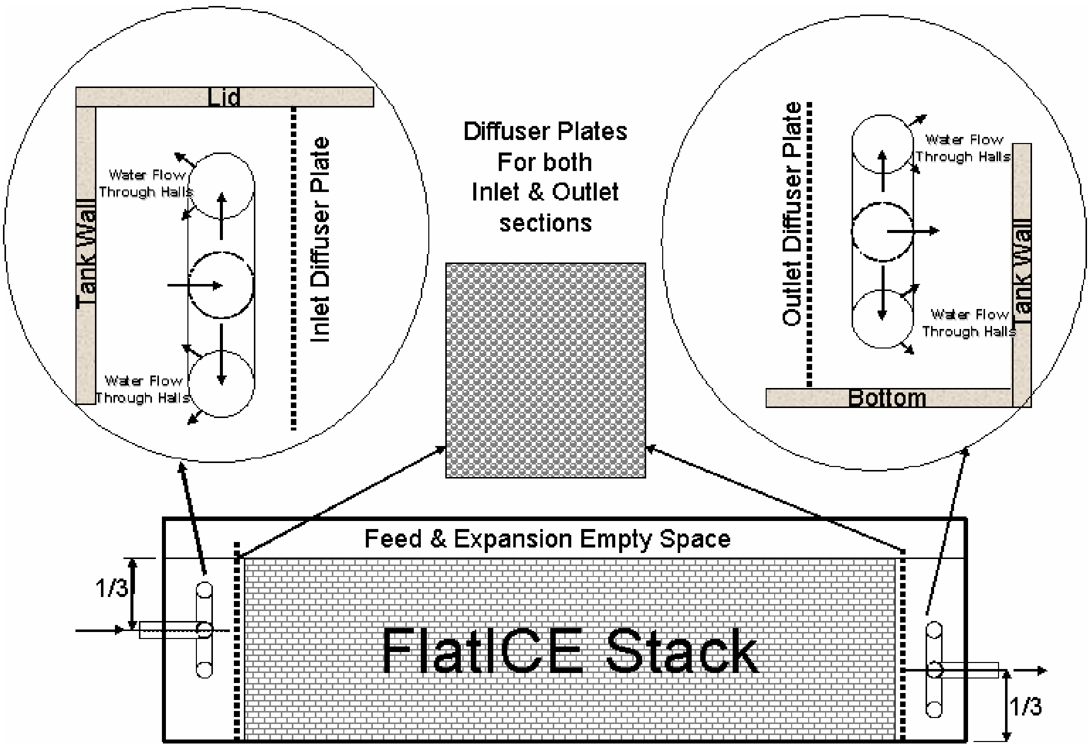


Figure 3.5.9.1- Typical Rectangular Tank Design

If the system requires pressurised tank it is far more practical to use cylindrical tanks and like atmospheric rectangular tank, it is vital to provide suitable inlet and outlet diffuser as well as headers to ensure as equal as uniform and water flow across the rectangular tank and more to as well as steps to ensure that circular edge do not crash the containers and keep than flat.

Like rectangular tank a custom-made inlet and outlet diffuser is required to provide uniform water supply across the tank section. One side of the will be connected to the circulation pump which would generate negative pressure on the outlet section and equally it is vital to provide a positive pressure on the inlet diffuser side so that the pressure difference between the inlet and outlet sections force the water through the diffuser plates spreading the water equally like a shower head.

Although pressure drop across the FlatICE stack is very low but it is essential to allow at least 50 kPa (8 psig) available pressure for the tank as part of the pump design criteria so that this pressure will force the water through the diffuser plate on the inlet side and on the opposite end leaving water from the tank due to pump suction generates negative pressure to suck through the diffuser plates. Using this push and suck concept which should provide an equal flow across the tank section and also it should provide equal flow over each and every FlatICE containers so that the full heat transfer surface is utilised and effectively getting the full tank energy storage capacity.

A typical rectangular tank design is illustrated in Figure 3.5.9.2

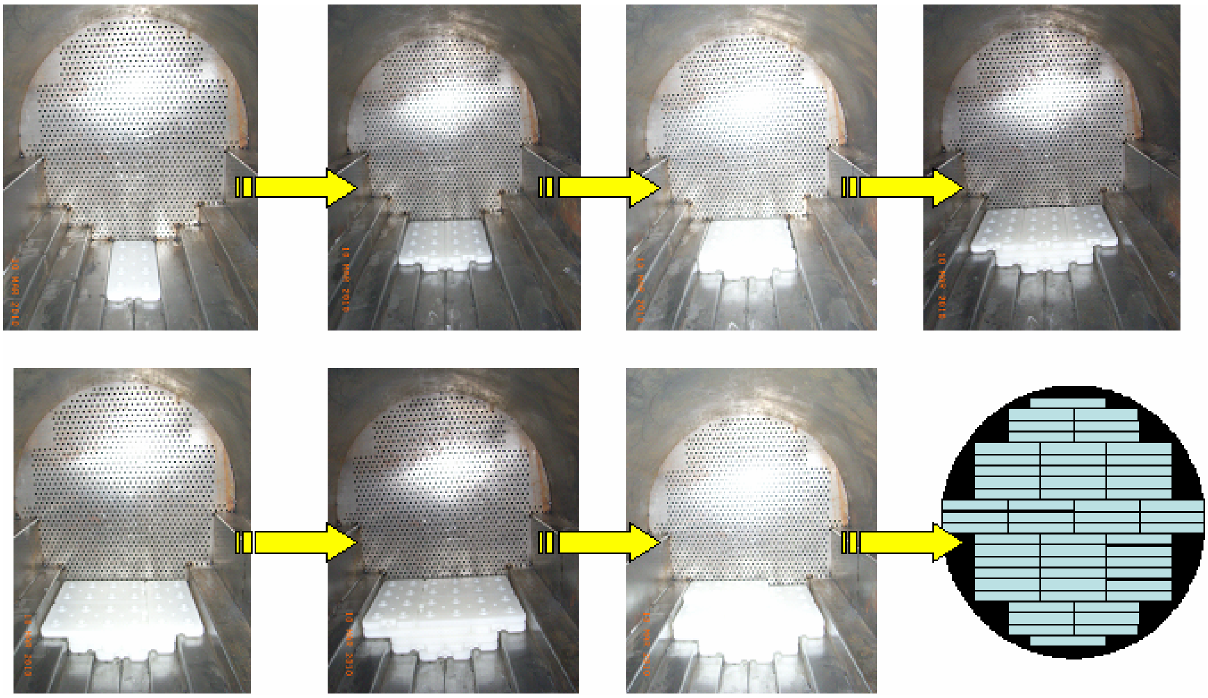


Figure 3.5.9.2- Typical Cylindrical Tank Design

3.5.10- Water Treatment

Depending on the operational pattern of the system whereby there may be occasions a large tank full of water can be left with stagnant water and therefore it is vital to apply a suitable form of Biocides control. PCM will be happy to recommend / supply this solution as part of our customer commitment.

Furthermore, majority of the PlusICE applications uses water only and therefore the hydraulic system must be protected against any corrosion related to the water circuit. In particular, the corrosion rates grow exponentially with temperature and therefore it is vital to introduce a suitable form of inhibitor package to provide the essential corrosion protection. PCM design team would bee happy to recommend / supply you with a suitable corrosion inhibitor package to suit the application.

3.5.11- Tank Loading & Commissioning

Tanks should be loaded equal distance from the diffuser plates on both sections as well as equal distance from the edges. In the case of FlatICE it is best to stack them in CRISS CROSS pattern i.e. one row length wise and the next row width wise stacked so that the whole stack within the tank will be stable.

Tanks should be stacked from bottom row up until reaching the last row. Once the containers are placed inside the tank and ready to charge the system it is VITAL to follow the next steps;

a) Take a sample of the water going to the tank (pure water or water with anti-freeze solution) and measure the electrical conductivity and record as part of the commissioning.

b) Fill the tank with water and apply the design pressure ideally using an external pressure i.e. without circulating through out the system and ensure that no leakage especially from man holes. After circulating the solution within the tank take another fluid sample and compare the circulated fluid sample with the original virgin fluid and ensure that conductivity is not changed. If it increases that means some of the PCM containers might have been damaged during loading. If so drain the system and replace the damaged containers and carry this step to ensure that tank have no leaking containers.

c) Full charge the whole system and run inline with the design and take another water sample from the system common location and compare the electrical conductivity reading with the main water i.e. virgin fluid used to charge the system and record the reading as part of commissioning.

d) If Item c is inline with Item a readings circulate the water as part of the design. If not and Item c reading is far higher than Item a some of the FlatICE containers might have been damaged during loading and depending on the difference either drain the water and carry out the same until the readings get closer before circulating the water trough out the system. Record all readings as part of the commissioning records.

e) After a few days operation i.e. complete freezing and melting cycles take another fluid sample from the system circulation and compare with the original electrical conductivity readings and record the data as part of the commissioning records.

f) Before handover it is vital to have at least three electrical conductivity readings namely virgin, commissioning and handover fluid conditions and this is vital for the long term safety and reliability of the system. Virgin fluid reading will be used as a bench mark, commissioning reading would be a proof of no damaged containers placed inside the tank and the final handover i.e. after a few days of design conditions i.e. a couple of freeze and melt cycles will be used as the system performance records.

Finally, we strongly recommend incorporating the above loading and commissioning guide as part of the any design and tender documentation so that installers would be fully aware how to install the system.

4.0. PlusICE APPLICATIONS:

When faced with the need to increase the system capacity for any of the following reasons;

- new project.
- the facility is being expanded.
- the internal hearing/cooling/process loads have been increased.
- standby or emergency cooling capacity is required.
- the existing chiller/refrigeration machinery replacement at the end of its useful life.
- the existing hearing machinery replacement at the end of its useful life.

Depending on the client's needs, PlusICE concept can be designed to provide full or partial thermal storage. In either case, the PlusICE system is a relatively simple addition to conventional chilled / hot / hearing water loops. In particular for a retrofit application whereby the existing chiller / boiler equipment can be used with minimal pipework modification and auxiliary equipment. Hence, the PlusICE System will be an extremely cost effective design solution with favourable payback periods.

Eutectic salt thermal storage offers dual benefits for retrofit applications by the reduction of capital cost for the chiller equipment and the continued savings which are generated by the use of off-peak electricity rates and even free cooling during the winter season.

The common problem and limitation for a system load expansion would be additional power intake requirements from the Electricity Board and, in some cases, this additional supply cannot be provided or requires expensive alterations and results in increased maximum demand charges which will directly affect the overall electricity rate structure and, consequently, higher energy bills. The PlusICE System eliminates these problems in such a way:

First of all, if the existing chiller is retained, the capacity of the system will increase as much as 30% of its normal design duty due to the lower night-time ambient and, consequently, less running time to charge the thermal storage thus further energy saving. The PlusICE Storage System can be also applied to hearing circuit and the heat rejection side of the system for additional savings.

Secondly, if the existing chiller has to be replaced, the original chiller can be replaced with a smaller chiller which will absorb less power and provide further energy saving, availability and maximum demand charges.

4.1 NEW CONSTRUCTION;

First Cost Advantages;

The initial refrigeration equipment can be further reduced in comparison with an ice storage systems to achieve the maximum reduction in the initial cost. The combination of smaller chiller equipment, higher chilled water temperature off-peak operation and the lower night-time ambient operation leads to considerable energy saving and consequently the overall system would give a very favourable return on the investment for a PlusICE thermal energy storage system.

Energy Efficiency;

In new construction, PlusICE balls offer an excellent operational efficiency obtained by operating a conventional chiller in a +5ºC (+41 ºF) chilled water leaving temperature. The thermal energy storage requirement can either be built as a module, similar to a conventional ice bank centralised system.

Simple to Operate, Control and Maintain;

A PlusICE system is very simple in design, operation and maintenance. The system has no moving parts, no ice thickness instrumentation, no level control system and refrigerant piping. The PlusICE system is virtually a maintenance-free concept and the control of a PlusICE system may be as simple as having a time clock and associated operating valves to turn the chillers on and off. A PlusICE system can also be supplied with a BMS compatible inventory and monitoring control system.

4.2 RETROFIT APPLICATIONS;

Easily Retrofitted;
The PlusICE system is ideal for building services, heating, heat recovery, solar, refrigeration and process retrofit applications. Any chiller, centrifugal, reciprocating or screw compressor type system can operate within their conventional operating temperature range of 5ºC, leaving chilled water to freeze the phase change materials.

Therefore, unlike an ice storage system, a PlusICE system can be implemented without any additional chiller or refrigeration equipment modifications in order to lower the operation temperature to produce minus temperature glycol solutions.

In retrofit applications, PlusICE concept overcomes the disadvantages of glycol chiller systems which will be not only operating at reduced design day duties in comparison with a 5ºC chilled water operation but also the glycol causes great pressure drops throughout the system which will be subjected to additional pumping requirement.

The constant high head pump circulation due to the Glycol addition will inevitably lead to higher electrical consumption for the circulation pump in comparison with a water pump for the same cooling duty. Furthermore, some of the ice storage systems also require a heat exchanger between the system and the ice circuit. This approach will lead additional pumps for the heat exchanger and consequently additional running and installation cost penalties.

Coincidentally, the reduction in the operation efficiency of a conventional ice TES due to lower evaporating temperatures will also result in longer operating hours which will cause significant additional energy costs. The conventional operating temperatures associated with the PlusICE thermal energy storage systems eliminate this issue.

No need for Glycol Low Temperature Chillers;

PlusICE Beams can be charged utilising the conventional chilled water temperatures and therefore it can be cost effectively and easily applied for an existing chilled water system without any major modification to existing chillers, air handling units, or piping.

The efficiency effect by means of higher leaving temperatures is illustrated in Figure 4.2.1 and Figure 4.2.2 for water and air cooled chiller operation for a conventional chiller during overnight charging and day operations compared with a PlusICE TES system.

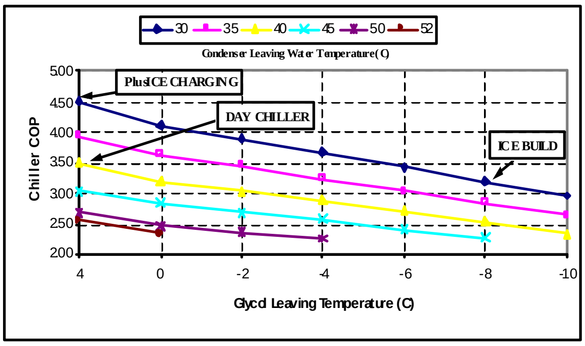


Figure 4.2.1. PlusICE Vs Conventional Ice TES Water Cooled Chiller Operation Comparison

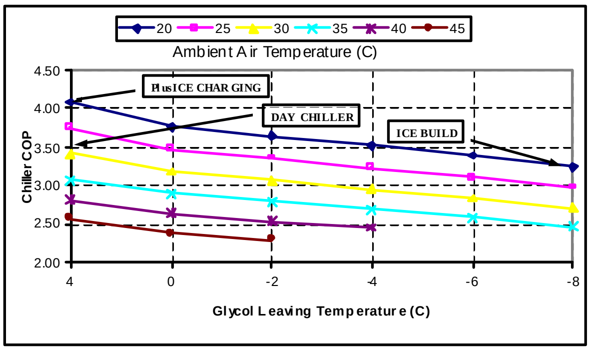


Figure 4.2.1. PlusICE Vs Conventional Ice TES Water Cooled Chiller Operation Comparison

Space Consideration;

As noted previously, the PlusICE ball TES tanks can be built as a central thermal energy storage concept as well as the possibility of utilising individually localised tanks as part of the pipe network. The location of the centralised storage tank can be under, beside, inside or on top of the building or, alternatively, it can be buried as part of the landscape.

4.3 REFRIGERATION SYSTEMS;

The efficiency of a refrigeration cycle can be improved by utilising a different type of refrigerant, compressor, condensing, evaporating and expansion devices but the cardinal rule of energy efficiency states that **"lower condensing pressures and high evaporating temperatures, larger sub-cooling and controlled suction superheat lead to less energy consumption for a given refrigeration duty and, therefore, designers should aim to achieve the above requirement design limits for a given system"**.

The temperature ranges offered by the PlusICE technology enables the designers to apply PlusICE balls as part of the secondary refrigeration systems as illustrated in Figure 4.3.1 in order to achieve the maximum operational efficiency for the refrigeration circuit by simply running the exiting machinery during low load conditions and later release this energy during peak hours to top up the refrigeration machinery.

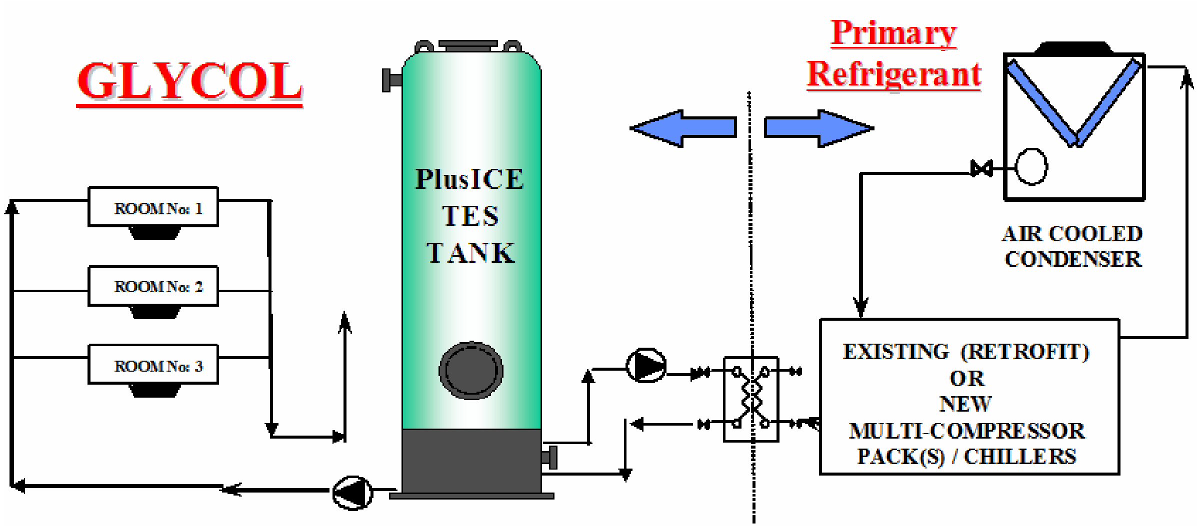


Figure 4.3.1. PlusICE Refrigeration Applications

The combination of PlusICE TES enables the designer to maintain a steady refrigeration envelope which results in improved efficiency, less running costs, and improved reliability for the system. It is an additional benefit for the PlusICE thermal energy storage systems to utilise the night-time low ambient condition to achieve a high overall COP.

4.4 FREE COOLING APPLICATIONS;

In a climate where the night-time temperatures drop below the freezing point of the PlusICE eutectic solution, the system may be charged without running a chiller by simply operating the heat rejection system, namely, cooling tower, evaporative cooler or alternatively dry cooler circuit.
A simple pipework and control modification can easily provide free cooling circuit which utilises the lower night-time ambient temperature by means of only running the circulation pumps and the heat rejection equipment in order to charge the PlusICE thermal energy storage systems.

The same application can also be applied to the heat rejection side of the system to be supplemented by a thermal energy storage system in order to overcome the daytime peaks condensing pressures, hence the reduction in electricity consumption.

A free cooling TES charging application becomes extremely beneficial for many buildings' refrigeration and process applications which have high winter day cooling loads and a free cooling technique will provide cooling with a little or no chiller operation and consequently significant energy saving and a typical layout of a free cooling circuit is illustrated in Figure 4.4.1.

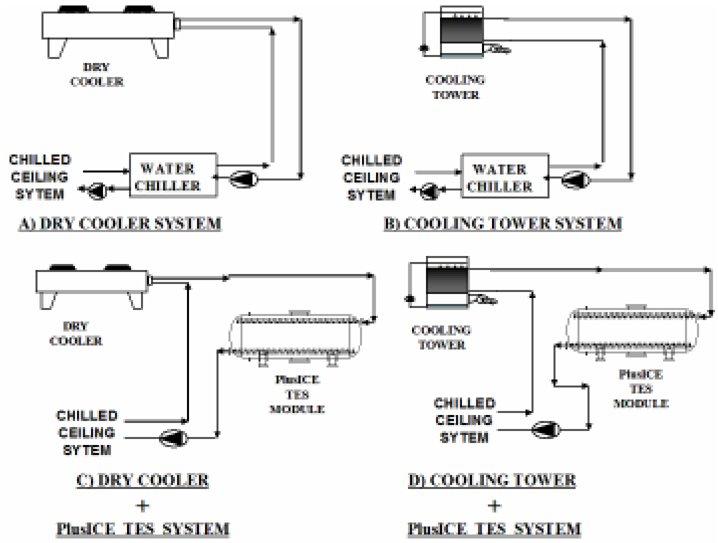


Figure 4.4.1 - A Typical Free Cooling Concept

A free cooling TES charging system may operate at a reasonable period without the need for a chiller operation depending on location and daily/seasonal ambient profiles and the potential for applications such as large banks, office blocks, dealer rooms, computer, industrial and process installations are vast compared with conventional chiller, chilled water and ice TES systems.

4.5 Heat Rejection Thermal Energy Storage Applications

The temperature range offered by the PlusICE TES provides a wide range of heat rejection, heat recovery TES applications for the medium and high temperature applications. A typical heat rejection TES application is illustrated in Figure 4.5.1.

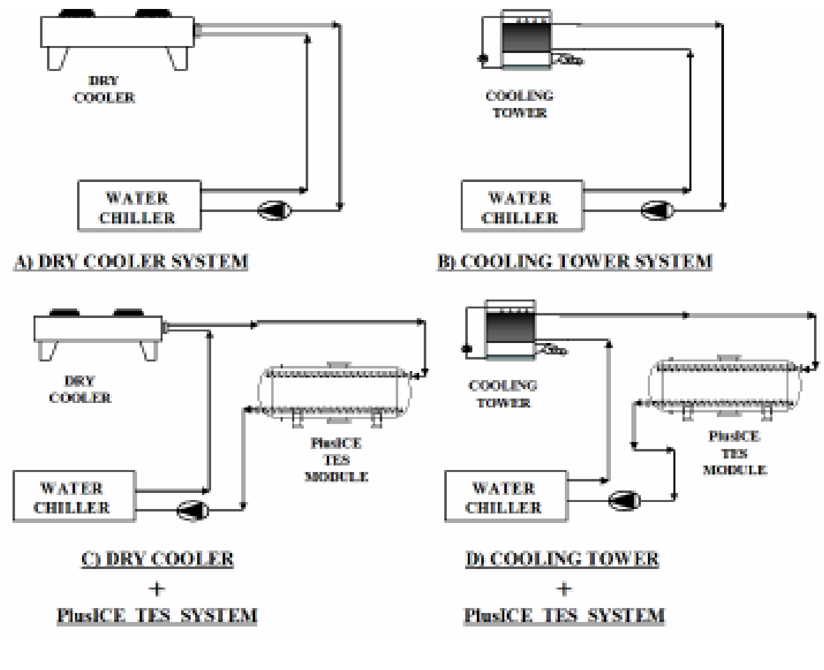
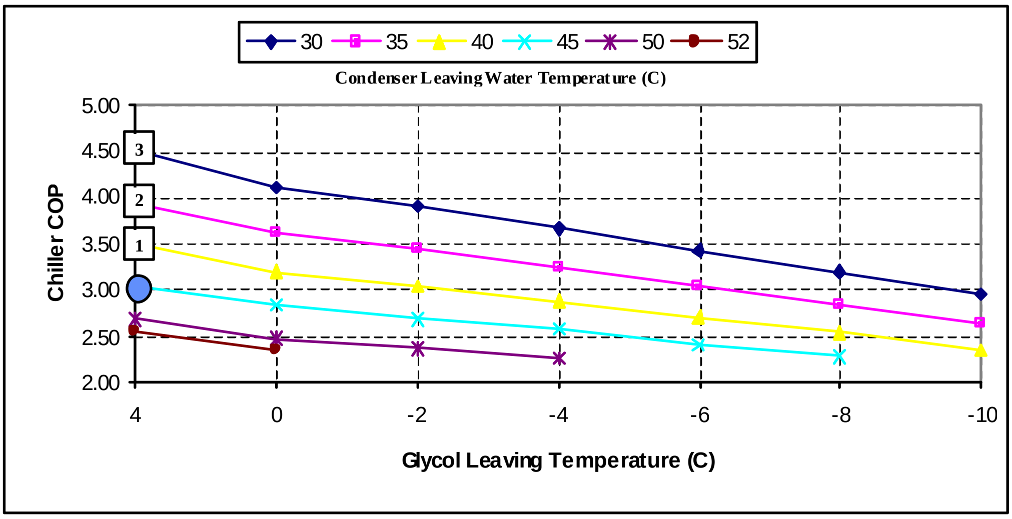


Figure 4.5.1. PlusICE Heat Rejection Applications

Heat rejection from a conventional water chiller as well as a refrigeration plant can be stored in the form of PlusICE TES systems during the off-peak period and the stored energy can later be used to control the heat rejection side of the circuits in order to improve the efficiency of the system as a whole.

Furthermore, the domestic as well as the central heating systems can be supplemented using PlusICE beams to overcome peak demand operations.

If the stored energy in terms of PlusICE TES balls is released back to the heat rejection circuit during peak ambient periods, this additional capacity will result in reduction in flow temperatures and the energy saving related to this additional cooling is highlighted in Figure 4.5.2 for a water cooled chiller application.



1)	5 °C REDUCTION	13 % COP IMPROVEMENT
2)	10 °C REDUCTION	23 % COP IMPROVEMENT
3)	15 °C REDUCTION	33 % COP IMPROVEMENT

Figure 4.5.2 - Heat Rejection TES Impact on COP

4.6 OTHER APPLICATIONS;

Co-generation and Waste Heat Utilisation;
It is widely felt that the PlusICE System can be very valuable when used with a co-generation plant, solar heating or industrial waste heat applications. If the co-generator requires a stable thermal storage load during the night to obtain sound economies or if the industrial process system is continuous to generate waste heat such as steam over night to satisfy the main steam circuit, then absorption chillers can be operated at night from the waste heat.
The absorption chillers can store their cooling capacity in the eutectic salts. The thermal storage can provide cooling for the building/process during the next day. Since the most commonly used Li-Br or NH3-water absorption chiller plants are rated to produce 5.5ºC (42ºF) chilled water, there is a natural match with charging temperature recommended for the PlusICE System.

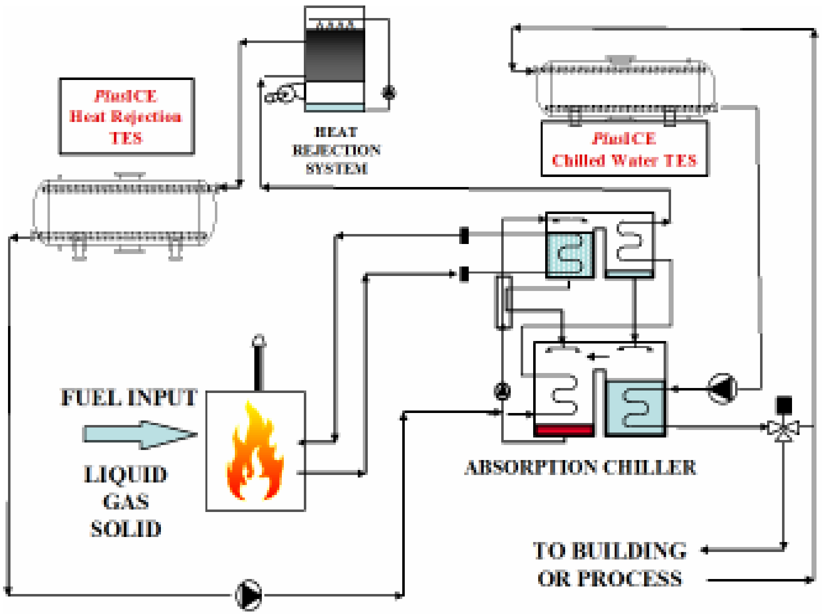


Figure 4.6.1. A Typical Absorption PlusICE TES Application

This approach can certainly permit the downsizing of the absorption chiller. It may also allow downsizing the entire co-generation package, making the entire project more cost effective.

Furthermore, if the system is designed for partial storage, the existing co-generation/waste heat drive adsorption chiller can be operated during the peak electricity period for further energy savings and attractive payback periods.

PCM will be happy to assist you for any feasibility or thermal storage energy management studies and engineering design such systems by using the computer based selections in order to reduce the time spent manually for "what if" capabilities to achieve the optimum and most attractive balance point for the thermal storage and absorption chiller system.

Solar Heating;

PlusICE beams are particularly beneficial for large scale solar heating applications in order to store the energy during the peak midday period which is the lowest demand for the hot water period.

The situation changes somewhat during the early hours as well as the late evening periods in particular for hotels. The demand and supply side of the hot water requirement can be balanced by means of applying PlusICE beams to offset the peak periods simply charging the thermal energy storage system during the peak daytime period.

When the maximum solar energy is available unfortunately the hot water requirement is the lowest for majority of the domestic and commercial applications. The time gap between the energy availability and energy use can be filled by using PlusICE TES to store the energy during day time and release this stored energy during early mornings and evening periods.

This heat can be stored for both heating and hot water production side of the system and a typical solar heating PlusICE TES application is illustrated in Figure 4.6.2.

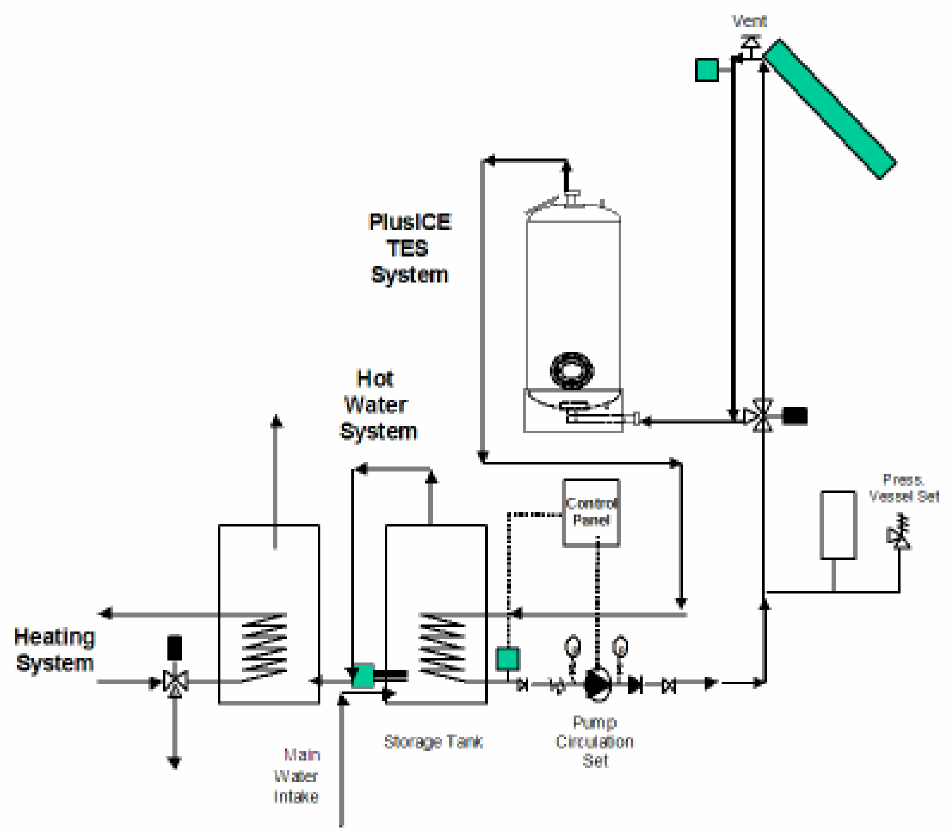


Figure 4.6.2. PlusICE Integrated Solar Heating Design Concept

Although conventional solar collector may not provide enough heat for hot water requiremenst but PCM energy storage using 27 °C (°F) in combination with either internal such as under-floor heating or external using a water storage tank is ideal to capture the day-time solar heat even during winter periods utilising conventional sealed hot water solar system and a typical application examples is illustrated in Figure 4.6.3.

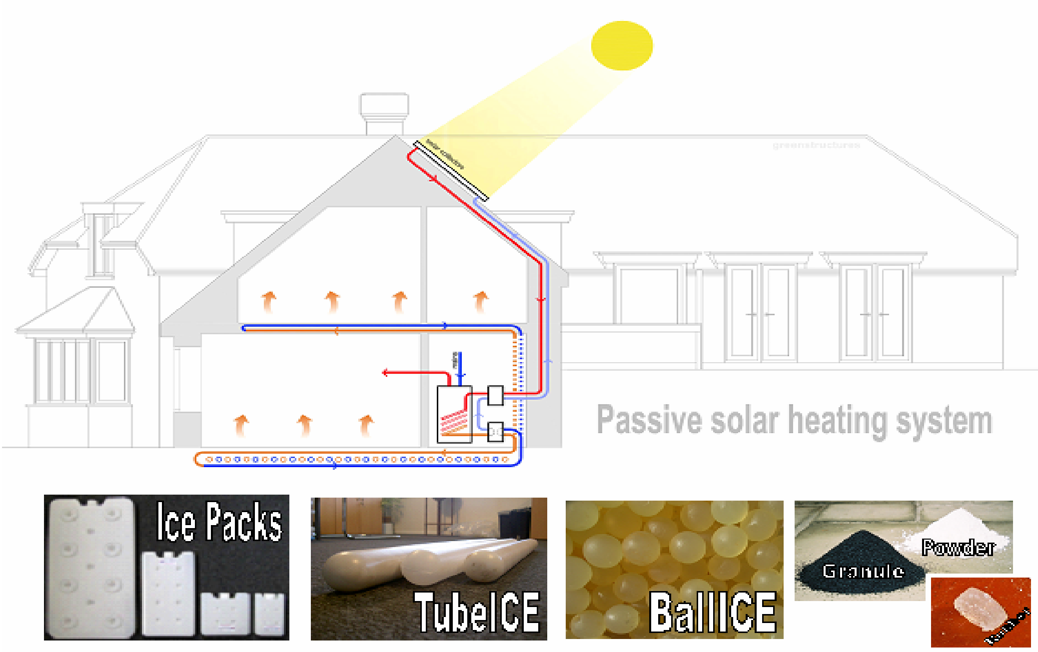


Figure 4.6.3- PCM Based Solar Heating Application.

Integrated HVAC&R Services;
PlusICE phase change temperature range between +4°C (+39ºF) and 89 °C (+192ºF) opens a new way of thinking regarding the load shifting for a given cooling and heating application. The combination of both chilled water and heat rejection TES reduces the machinery size and effectively electrical intake further in comparison with a conventional TES concept. A carefully balanced integrated TES not only provides a considerable initial installation cost saving but the overall running cost of the system can also be reduced significantly.
A typical HVAC&R integrated PlusICE Thermal Energy Storage concept is illustrated in Figure 4.6.4 for a typical supermarket application. However, the possibility of alternative combinations is endless and PCM will be happy to explore the suitability of PlusICE ball application for any specific and special applications not covered in this manual.

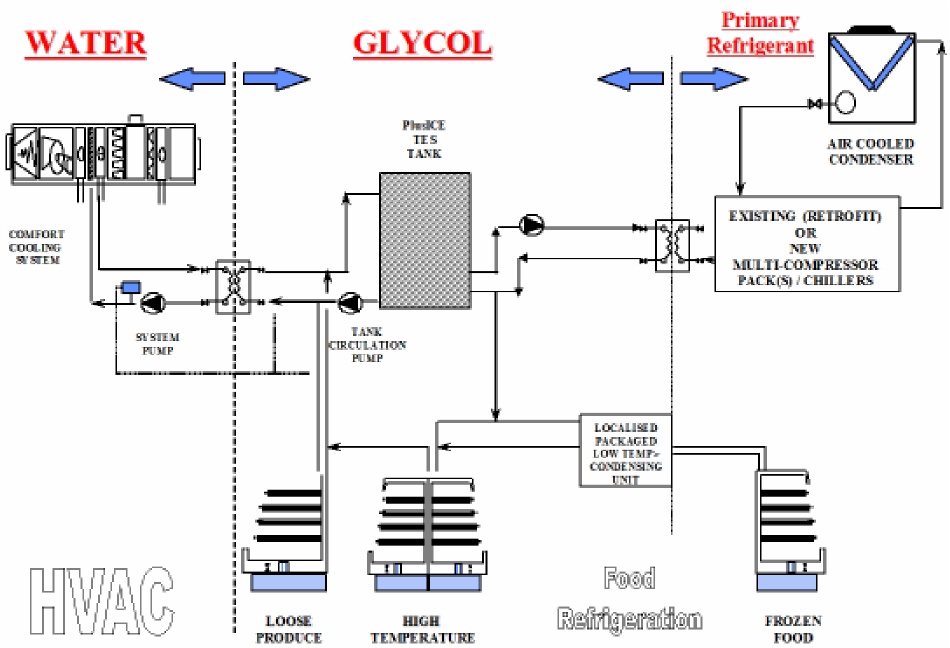


Figure 4.6.4 Integrated PlusICE TES Ball Application

5.0 - CONTROL SYSTEMS

5.1 Monitoring & Control;

The cardinal rule for a satisfactory TES control system is as follows;

"STORE THE MAXIMUM ENERGY DURING THE OFF-PEAK PERIOD AND USE THE COOLING/HEATING SOURCE MINIMUM DURING THE PEAK HOURS AND EXHAUST THE STORED ENERGY AT THE END OF THE COOLING/HEATING PERIOD".

TES system applications can be controlled up to a certain extend using conventional electromechanical controls within set time limits without any monitoring facility.

However the recent developments in Electronic Industry mainly microprocessor control systems have provided the missing link for the essential requirement of monitoring and self learning patterns to adjust the system (i.e. cooling/heating source) to match the storage and demand ratio according the changing weather and building load profiles.

As most of the PCM solutions are salt based and it is **VITAL** to monitor the condition of the circulation fluid on an ongoing basis by means of installing an **electrical conductivity transducer** as part of the BMS system. We strongly recommend to fit this ongoing and continues electrical conductivity reading so that any circulation water contamination in case of the PCM containers fails, this contamination can be picked up quickly and the sooner any leak and salt contamination is detected it would be safer and easier to handle any corrosion issues.

Using a continues electrical conductivity input as part of the BMS enables the system to set up a pre-alarm as well as full alarm signals so that any circulation fluid contamination can be picked up before it becomes a corrosion related problem.

The most common inputs for a TES system are as follows;

- **Load Pattern.**
- **Water Flow Rates.**
- **Water Inlet/Outlet Temperatures.**
- **Ambient Pattern/Temperature.**
- **Cooling/Heating Equipment Status.**
- **Storage Media Status.**
- **Electrical Conductivity Reading.**

Based on the above input, the control system must provide the following functions.

- **Control over Cooling/Heating source and all the associated equipment.**
- **Pumps and control valves.**
- **Storage System.**
- **Time function.**
- **Equipment status/alarm.**

A conventional TES control system can be a simple timer or alternatively the state of the art Building Management Systems (BMS) can be used for their flexibility and accuracy. With this mind, PCM developed a PlusICE control concept to satisfy both a simple control/monitoring or with optional additional functions as part of a common integrated BMS control system.