FITZER INCORPORATION

STRATIFIED CHILLED WATER THERMAL ENERGY STORAGE

FITZER
INCORPORATION

In the age of globalization the smarter and healthier buildings require high performance engineering solutions.

Today is the Need for Businesses to make a switch to best Engineering Practices & Promote Environmentally responsible products & Services.

Thermal Energy Storage (TES)

Thermal energy is stored by adding or removing heat from a substance. The change experienced by the substance helps define the type of storage system. Let us focus on the more conventional sensible and latent heat properties of materials.

Sensible Heat

Sensible heat is heat exchanged by a thermodynamic system that changes the temperature of the system without changing volume or pressure. The sensible heat possessed by an object is evidenced by its temperature. As temperature increases, the sensible heat content also increases. However, for a given change in sensible heat content, all objects do not change temperature by the same amount. Each substance has its own characteristics relationship between heat content and temperature. The proportionality constant between temperature rise and change in heat content is called the specific heat, measured in calories per gram per degree celsius or joules per kilogram per kelvin. Water for example has a specific heat of 1Cal/g/°C. In general, the gain in heat is accompanied by either a change in volume or a change in pressure (e.g. the water in the pot swells somewhat as you heat it; if you heat gas in a fixed volume, its pressure goes up).

Latent Heat

This is the energy absorbed or released by a thermodynamic system during a constant temperature process. Examples include ice melting or water boiling. When a solid turns into a liquid (melts) or a liquid turns into a gas (evaporates), the loosening of attraction among the molecules requires energy. If you raise ice from -20°C to 0°C, you put in sensible heat. If you keep adding heat to the ice, it melts but its temperature is constant, the sensible heat of ice/water system is not increasing but you continue to add heat energy to it. Energy is conserved, such that the extra heat tears apart the frozen ice molecules and sets them loose as a liquid. The liquid is therefore storing this energy in a form that you cannot sense. This energy is called latent heat.

Materials employed for thermal storage in this manner are often referred to as phase change materials (PCMs).

Potential Benefits

Thermal storage systems offer building owners the potential for substantial operating cost savings by using off-peak electricity to produce chilled water or ice for use in air-conditioning during peak hours. The storage systems are cost-effective in situations where

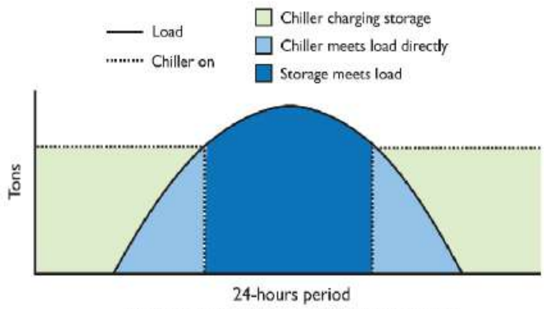
- A facility's maximum cooling load is much greater than the average load;
- The utility rate structure has high demand charges, or there is a differential between on- and off-peak energy rates;
- An existing cooling system is being expanded;
- Limited electric power is available at the site; or
- Backup cooling capacity is desirable.

It's difficult to generalize when a thermal storage systems will be cost-effective, but if you meet one or more of the above criteria, it may be worth doing a detailed analysis.

Cooling Demand Strategies

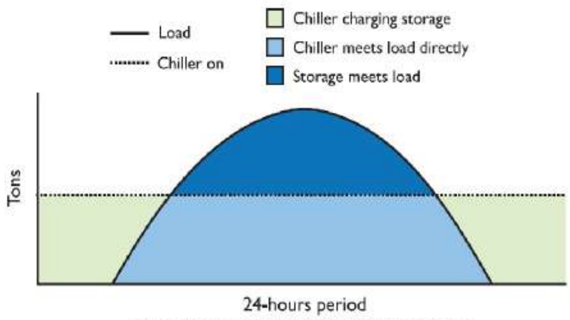
Several strategies are available for charging and discharging storage to meet cooling demand during peak hours. These are:

Full Storage - A full-storage strategy shifts the entire on-peak cooling load to off-peak hours (see Figure1). The system is designed to operate at full capacity during all non-peak hours to charge storage. This strategy is most attractive where on-peak demand charges are high or the on-peak period is short.



Source: *ASHRAE Design Guide for Cool Thermal Storage*
Figure 1: Full-Storage Operating Strategy

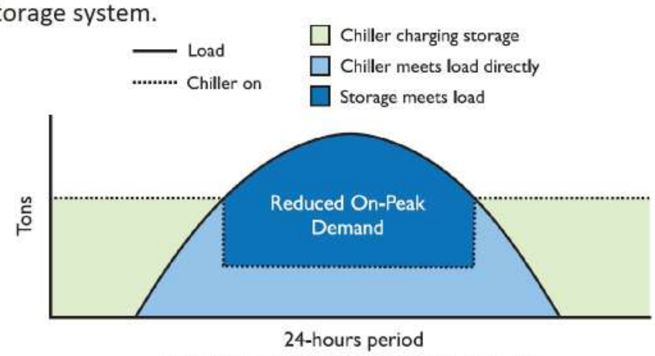
Partial Storage - In the partial-storage approach, the chiller runs to meet part of the peak period cooling load, and the remainder is met by drawing from storage. The chiller is sized at a smaller capacity than the design load. Partial storage systems may be run as load-levelling or demand-limiting operations.



Source: *ASHRAE Design Guide for Cool Thermal Storage*
Figure 2: Partial-Storage Load-Levelling Operating Strategy

In a load-levelling system (see Figure 2), the chiller is sized to run at its full capacity for 24 hours on the hottest days. The strategy is most effective where the peak cooling load is much higher than the average load.

Demand-Limiting System - In a demand-limiting system, the chiller runs at reduced capacity during on-peak hours and is often controlled to limit the facility's peak demand charge (see Figure 3). Demand savings and equipment costs are higher than they would be for a load-levelling system and lower than for a full-storage system.



Source: ASHRAE Design Guide for Cool Thermal Storage

Figure 3: Partial-Storage Demand-Limiting Operating Strategy

TES Technologies

If you're considering a thermal storage system, you'll need to select: which medium and tank you'll use for storage and what strategy you'll use to deliver the stored chilled water to the system.

Storage Medium

The storage medium determines how large the storage tank will be and the size and configuration of the HVAC system and components. The options include chilled water, ice, and eutectic salts.

Chilled-water systems require the largest tanks, but they can interface with most existing chiller systems. Ice systems use smaller tanks but they require more complex and typically less efficient chillers that are designed for low-temperature operation.

Chilled water. Chilled-water storage systems use the sensible heat capacity of water – 1 kcal per kg per degree centigrade - to store cooling capacity. They operate at temperature ranges compatible with standard chiller systems and are most economical. The capacity of a chilled-water thermal energy storage (TES) system is increased by storing the coldest water possible and by extracting as much heat from the chilled water as practical (thus raising the temperature of the return water). For a given tank volume, increasing the temperature differential from 10° to 20°F will double the cooling capacity.

Eutectic Salts. Eutectic salts, also known as phase-change materials, use a combination of inorganic salts, water, and other elements to create a mixture that freezes at a desired temperature. The material is encapsulated in metal/plastic containers that are stacked in a storage tank through which water is circulated. The most commonly used mixture for thermal storage freezes at 8°C, which allows the use of standard chilling equipment to charge storage, but leads to higher discharge temperatures. That in turn limits the operating strategies that may be applied. For example, eutectic salts may only be used in full storage operation if dehumidification requirements are low.

Ice. Ice thermal storage systems use the latent heat of fusion of water - 80 kcal/kg - to store cooling capacity. Storing energy at the temperature of ice requires refrigeration equipment that can cool the charging fluid (typically, a water/glycol mixture) to temperatures below the normal operating range of conventional air-conditioning equipment. Special ice-making equipment or standard chillers modified for low-temperature service (brine chillers) are used.

Thermal Energy Storage Technologies

	Stratified Water	Ice Harvesting	Encapsulated ice	External Melt Ice-on-Coil	Internal Melt Ice-on-Coil
Chiller Efficiency	High	Low	Medium	Medium	Medium
Tank Volume	Medium	Small	Small Shape-adaptable	Small	Small
Discharge Fluid	Water	Water	Glycol	Water	Second Coolant
Tank Interface	Closed or Open Tank	Open Tank	Closed or Open Tank	Open Tank	Closed Circuit
Chiller Cost	Low	High	Medium	Medium	Medium
Tank Cost	High	Low	Low-Medium	Medium	Medium
Temperature Quality	High	High	Low	Low	Low

Stratified Chilled Water Thermal Energy Storage System (TES)

Stratified Chilled water storage tanks employed in the Chilled Water systems operate on the principle of thermal stratification to maintain the separation between the cold and warm water during the charging and discharging operation.

The two physical properties of water that are of special interest to the TES Design Engineer are:

★ The Density as it varies with Temperature.

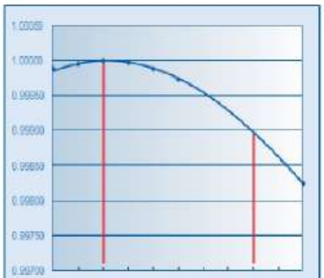
★ The Kinematic Viscosity as it varies with Temperature.

These two properties provide the basic mechanism for successfully stratifying water of different temperature within a single vessel.

The density difference between two liquids at different temperature creates buoyancy forces where the warm liquid is literally floated on top of the cool liquid.

The relatively large difference in Kinematic Viscosity of liquids separated only by a few degrees in temperature suppresses any mixing of the two fluids, due to flow disturbances and free convection at the vessel walls.

The stratification of CHW TES can be achieved by utilization of the water density difference according to the water temperature. The density of water is heaviest at 4.0 °C.

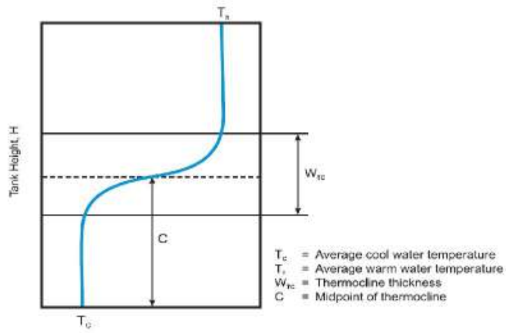


The performance of the chilled water tanks depends on the charge and discharge water flow rates, temperature difference (DT) between the cold and warm water streams, aspect ratio of the tank, and the design of the supply and return diffusers. The goal of the TES tank design is to maximize the performance by keeping the thickness of the thermocline as small as possible during the charging and discharging operation.

In a water stratified tank, warmer, less dense return water is stored at the top of the tank, and cooler, denser supply water is stored at the bottom. Water enters and leaves a stratified tank through the diffusers, designed to minimize thermal blending.

To minimize the volume and optimize the storage capacity of the tank, mixing and heat transfer between the warmer and cooler water must be minimized. The most effective method to minimize mixing and heat transfer is to use appropriate diffusers to achieve natural stratification by taking advantage of buoyancy forces.

Heat is transferred between the warm and cool water via mixing and conduction. This heat transfer increases the thermal losses and reduces the available cooling capacity of the tank. The relatively steep temperature gradient region between the cool and warm water is called thermocline (see fig). The thermocline is essentially a region of large vertical temperature and density gradients between the warmer and cooler water. The thermocline moves vertically through the tank during charging and discharging cycles.



The mixing and conduction processes that form the thermocline reduce the usable capacity of storage and increase the thermal losses. Mixing is the most important cause of capacity loss in stratified tanks. Heat gain from the environment through tank walls is reduced to negligible levels by insulation. Moreover, conductive heat transfer between warm and cool water within the tank is also quite small over the course of an operating cycle.

Therefore, it is important to control mixing phenomenon in the tank, which is related to two key dimensionless parameters: the Reynolds number and the Froude number.

The physical significance of the Reynolds number is the ratio between inertia and viscous forces. As the inlet Reynolds number increases, the inertia of the incoming fluid increases, and greater mixing is induced around the thermocline.

The Froude number is the ratio between inertia and buoyancy forces. As the inertia of the incoming flow increases relative to the buoyancy force, more mixing occurs. To minimize mixing, the fluid must be carefully introduced. Natural stratification involves formation of a thermocline by introduction of water at suitable values of these parameters. For this reason, in order to achieve the best stratification possible, diffusers design shall be based on proven flow distribution calculations to maintain the operating thermocline between the chilled and warm water, over the full range of flows and operation of the TES tank. Performance of the diffusers shall meet a maximum inlet Froude number (Fr) of one. Diffusers are designed to satisfy the above requirements and to obtain the best performance in the TES tank operation.

Water diffusers can have two typical different configurations: radial disk diffuser and octagonal slotted-pipe diffuser. Radial disc diffusers are simple to install and have a strong structure, it can withstand the shocks of the water hammering and surging and requires zero maintenance. While the octagonal pipe diffusers are weak to handle the shocks of the water hammering and surging, have a higher pressure drop, difficult to install and takes long time to install, also requires regular maintenance.

Chilled water storage systems become an economically attractive alternative if one or more of the following conditions exist:

★ Short period of cooling demand;
★ Frequently varying cooling loads;
★ Infrequent or cyclical loads;
★ Cooling demand and supply do not match;
★ Economic incentives are provided to use off-peak energy
★ Energy supply is limited by the utility company, thus making it impossible to satisfy the maximum load directly;
★ The capacity of an existing chiller is too low to provide peak load.

Applications

Demand Supply Management – Load Shifting

Load shifting is typically the main reason to install a chilled water storage system. And some key benefits of such load shifting are summarized as below:

Reduced Capital Cost Savings.

Traditional air-conditioning systems operate during the day to meet the cooling demands and remain idle at night. High capital cost and high capacity chillers are then selected to satisfy the maximum demand, which occurs only for a few hours per year, and thus spend the majority of their operational life at reduced capacity and low efficiency. Using stored energy, the TES supports the peak cooling demand, enabling a significant reduction in installed chiller capacity (up to 70%), and thus allowing the usage of lower cost and capacity chillers.

Also, smaller auxiliary equipment (e.g., cooling tower, pumps and fans), as well as piping and ductwork. Often, the electrical distribution system that supplies power for cooling and back-up generators can also be made smaller.

Energy Savings. Chilled water storage systems permit chillers to operate more at night when lower condensing temperatures improve equipment efficiency; furthermore, it increases the fraction of on-design load operation, minimising inefficient part-load performance.

Increased Flexibility. With a chilled water storage system, cooling can be available on any desired schedule, independently of the operation of the chillers (within limits). The chilled water storage unit may be able to deliver cooling at a higher rate than the chillers, or to supplement the chillers.

Extend the capacity of an existing system.

Zero Downtime of Chilled Water Supply for Mission Critical Facilities

High Tech Manufacturing
Data Centers

Most critical application air-conditioning systems require some form of standby or backup facility to protect against system failures, which can prove to be extremely costly. The TES is an ideal and efficient solution for these applications. The TES offers rapid response backup in the form of an independent, static technology solution which ensures the highest degree of reliability. In times of uncertain power availability, the TES system can provide non-stop cooling, even without grid power.

How a TES System Works?

The system allows the TES tank to be "charged" and "discharged" of chilled water on a continuous basis, see the schematic representation of Charging and Discharging Cycles.

Charge Cycle

The chilled water at a desired temperature is charged through the bottom diffuser into the tank at the same rate as the warm water is displaced through the top of the storage tank. The thermocline forms at the bottom and slowly moves up to the top as charging takes place. During charging, the available cooling capacity of the charged water degrades due to mixing of the charge with the stored water. This is in addition to the thermal diffusion, axial wall conduction and heat gains from the ambient. The thermal degradation due to mixing reduces with decreasing charge flow rate. Therefore, at very low charge flow rates, the thermal degradation is mainly a result of a combination of heat gain from ambient, thermal diffusion and axial wall conduction.

Discharge Cycle

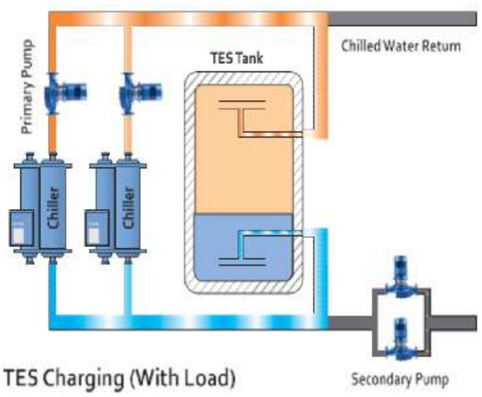
In a discharge cycle, the storage tank initially filled with chilled water is discharged through the bottom diffuser and returned to the tank through the diffuser at the top, after it is passed through the load. The thermocline forms at the top initially and slowly moves down to the bottom at the end of a discharge cycle.

Computational Fluid Dynamics (CFD) Model

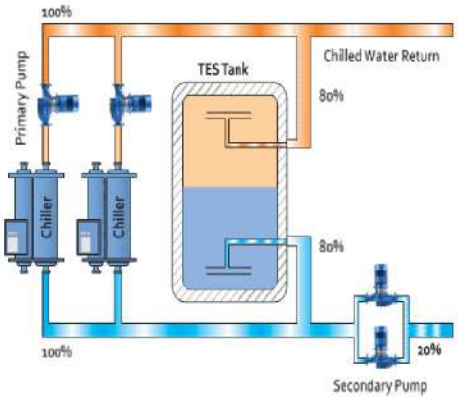
CFD analysis provide insights into:

★Prediction of the discharge water temperature with time.
★Prediction and optimization of thermocline thickness.
★Analysis of diffuser design on the performance of the tank.
★Design and optimization of supply and return diffusers.
★Three dimensional visualization of water flow patterns in the tank.
★Visualization location and thickness of thermocline with time.

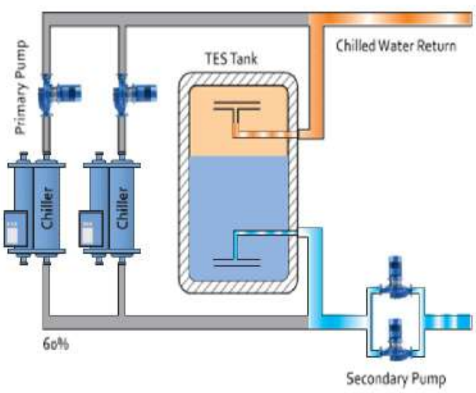
TES Charging (Without Load)



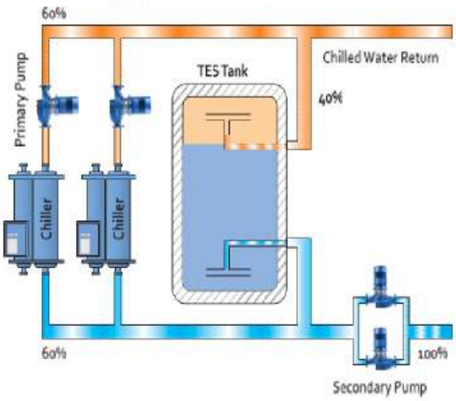
TES Charging (With Load)

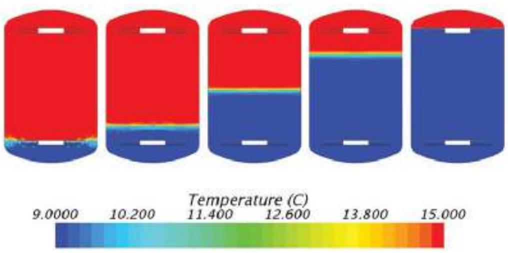


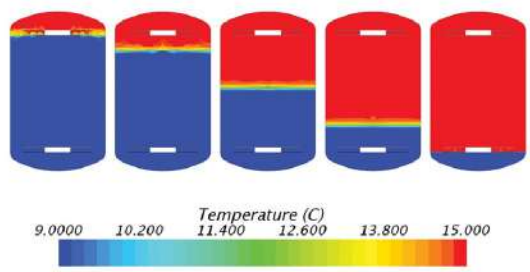
TES Discharging (Without Chiller)



TES Discharging (With Chiller)





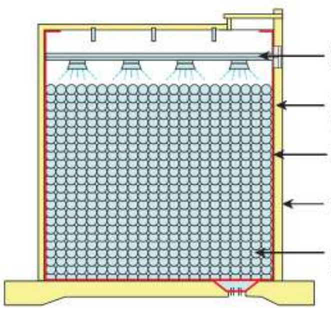


OTHER TECHNOLOGIES

Phase Change Materials

Phase Change Materials (PCMs) can be described as mixtures of chemicals having freezing and melting points above or below the water freezing temperature of 0°C. They are ideal products for thermal management solutions as they store and release thermal energy during the process of melting and freezing (changing from one phase to another).

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



To qualify as a useful PCM, the material has to meet several criteria:

Release and absorb large amounts of energy when freezing and melting; This requires the PCM to have a large latent heat of fusion and to be as dense as possible.

Have a fixed and clearly determined phase change temperature (freeze/melt point); The PCM needs to freeze and melt cleanly over as small a temperature range as possible. Water is ideal in this respect, since it freezes and melts at exactly 0°C. However, many PCMs freeze or melt over a range of several degrees and will often have a melting point that is slightly higher or lower than the freezing point.

Avoid excessive supercooling; Supercooling is observed with many eutectic solutions and salt hydrates. The PCM in its liquid state can be cooled below its freezing point whilst remaining a liquid. Some salt hydrates can be cooled to +50°C below their freezing point without crystallisation occurring. This can be beneficial, for example in hot packs where a +48°C PCM is kept as a supercooled liquid at room temperature until the hot pack is required and supercooling is broken by mechanical or chemical nucleation. However, for most applications, supercooling must be kept to a minimum by the addition of suitable nucleating agents to the PCM.

Remain stable and unchanged over many freeze/melt cycles; PCMs are usually used many times over, and often have an operational lifespan of many years in which they will be subjected to thousands of freeze/melt cycles. It is very important that the PCM is not prone to chemical or physical degradation over time which will affect the energy storage capability of the PCM. Some eutectic solutions may be susceptible to microbiological attack, so must be protected with biocides. Long term stability can be a problem in some salt hydrate PCMs, unless they are modified to prevent separation of the component materials over successive freeze/melt cycles.

Non-hazardous; PCMs are often used in applications whereby they could come in contact with people, for example in food cooling or heating applications, or in building temperature maintenance. For this reason, they should be safe. Ideally a PCM should be non-toxic, non-corrosive, non-hazardous and non-flammable. There are many substances that behave excellently as PCMs but cannot be used due to issues over safety.

Economical; It doesn't matter how well a substance can perform as a PCM if it is prohibitively expensive. PCMs can range in price from very cheap (e.g. water) to very expensive (e.g. pure linear hydrocarbons). If cost outweighs the benefits obtained using the PCM, its use will be very limited.

PCMs can broadly be arranged into five categories: eutectics, salt hydrates, organic, solid-solid and molten salt materials.

Eutectics are a homogeneous mixture of substances that melts or solidifies at a single temperature that is lower than the melting point of either of the constituents. Solutions of salts dissolved in water that have a phase change temperature below 0°C.

Salt hydrates are specific salts that use the reaction energy created when salts are hydrated or dehydrated. are able to incorporate water of crystallisation during their freezing process and tend to change phase above 0°C.

Organic materials used as PCMs are polymers with long chain molecules composed primarily of carbon and hydrogen. They tend to exhibit high orders of crystallinity when freezing and mostly change phase above or below 0°C. Examples of materials used as positive temperature organic PCMs include alcohols, waxes, oils, fatty acids and polyglycols.

Solid-Solid PCMs that undergo a solid-solid phase transition with the associated absorption and release of large amounts of heat. These materials change their crystalline structure from one lattice configuration to another at a fixed and well-defined temperature, and the transformation can involve latent heats comparable to the most effective solid-liquid PCMs.

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 slight expansion/contraction), and there are no problems associated like in handling liquids, i.e. containment, potential leakage, etc.

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

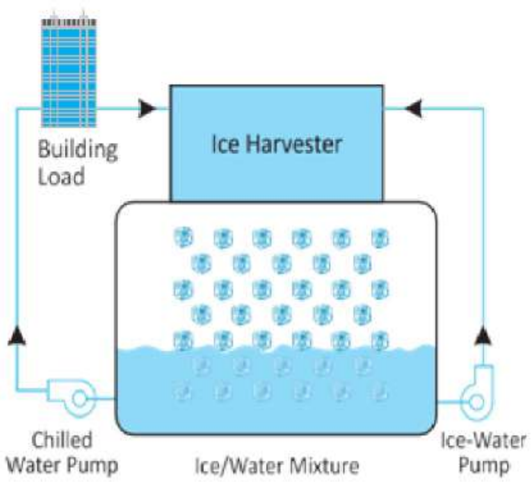
ICE Thermal Storage

Ice thermal storage tanks uses the latent heat of fusion of water to store cooling. Thermal energy is stored in ice at the freezing point of water (0° C), via a heat transfer fluid at temperatures of -9 to -3°C. Depending on the ice thermal storage technology selected, chillers are selected for low-temperature service or special ice making equipment is used.

The heat transfer fluid for ice making may be a refrigerant or a secondary anti-freeze coolant, such as glycol. The low storage temperature of ice also provides the ability to produce lower temperature air for cooling.

ICE Harvester

Ice harvesters are installed above an atmospheric tank that stores a combination of water and sheets of ice. The ice generator accumulates energy by generating ice. The evaporator is located in the upper position, and the storage tank in the lower position. There are also two pumps, the recirculation pump for the charging period of the tank, and the chilled water pump for the discharging period.

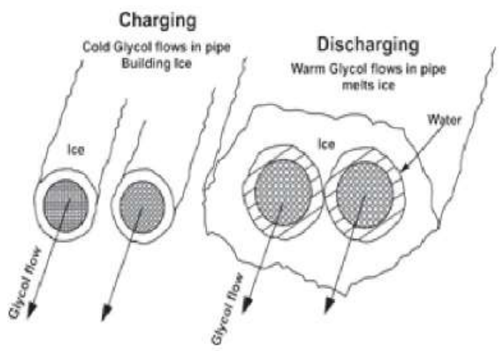


In the charging period, the recirculation pump sends water from the tank to the cooling coils of the ice generator, where the water freezes forming a layer of ice. Some of this water drops into the tank still in liquid phase. Once the ice thickness is appropriate, the refrigeration cycle is inverted temporally making the cooling coils work as condensers. By this way, generated pieces of ice drop into the tank.

In the discharging period, the recirculation pump stops and chilled water pump starts pumping the cold water from the bottom of the tank to the consumers. The discharge temperature remains relatively constant throughout the discharging period and rises when the last ice sheet is melted. Warm water from the consumers will pass back through the cooling coils of the ice generator once again. With this temperature, the ice generator is not able to deliver the water as ice to the tank, so it will do it as cold water, starting the charging period again.

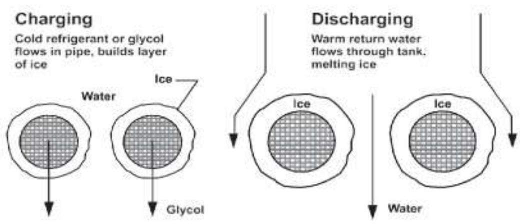
Internal Melt-on-Coil

In an internal melt system, there is a coil submerged in a closed water-filled tank. During storage, the cold glycol flows through the coil tubes, freezing the surrounding water. During discharging, the glycol that cools the load circulates back through the coils at higher temperature melting the ice that was stored from the inside out, hence the name internal melt-on-coil. The glycol system is a closed loop with a very simple control system, while the water does not circulate through the system. The water remains inside the tank and never leaves the container, experiencing only a phase change from liquid to solid and vice versa.



External Melt-on-Coil

In an external melt system, there is a heat exchanging coil inside a non-pressurized water tank. During storage, the cold glycol flows through the coil freezing the surrounding water. As the tank chilled water provides the required cooling to the load, warm water returns from the load. During discharging, the warm water is circulated back through the heat exchanging coil melting a portion of the stored ice from the outside in, hence the name external melt-on-coil.



OUR SERVICES:

- Design calculations and engineering for custom-made thermal energy storage systems
- Installation of the storage tanks and the charging and discharging arrays
- Design and installation of the stratification and storage management
- Turnkey solutions

FITZER INCORPORATION

Add : S/F-16,OMKAR COMPLEX, VALIA CHOKDI, GIDC, ANKLESHWAR, GUJARAT - 393002, INDIA
Email : fitzerincorporation@gmail.com Website : www.fitzerincorporation.com
Contact: +91 9137077904